FORSCHUNGSBERICHT AGRARTECHNIK
des Fachausschusses Forschung und Lehre der
Max-Eyth-Gesellschaft Agrartechnik im VDI (VDI-MEG) **616**

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Design of a decentralised camel milk processing plant with integration of renewable energy supply

Dissertation Witzenhausen, 2020

Universität Kassel
Fachbereich Ökologische Agrarwissenschaften,
Fachgebiet Agrartechnik
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Design of a decentralised camel milk processing plant with integration of renewable energy supply

Dissertation zur Erlangung des akademischen Grades Doktor der Agrarwissenschaften (Dr. agr.)

von

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aus Kericho district, Kenya

2020

Die vorliegende Arbeit wurde vom Fachbereich Ökologische Agrarwissenschaften der Universität Kassel als Dissertation zur Erlangung des akademischen Grades „Doktorin der Agrarwissenschaften" angenommen.

Tag der mündlichen Prüfung**: 11.08.2020**

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Gedruckt mit Unterstützung des Katholische Akademischer Ausländer-Dienst.

Im Selbstverlag: Jackline Akinyi Ogolla

Bezugsquelle: Universität Kassel,
FB Ökologische Agrarwissenschaften
Fachgebiet Agrartechnik
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‘I don’t know where the limits are, but I would like to go there.’

Eliud Kipchoge, 2019

Dedication

To the loving memories of my beloved Dad, Alex Obare Ogolla; my treasured Mum, Rose Adhiambo Ogolla; my gracious Aunt, Grace Anyango Mulase.

You were a light in our lives, inspiration in our educational quest and now a rainbow in the clouds. Thank you for the thirst you instilled in me and the clarity that knowledge quest should never be halted.

Ich liebe und vermisse euch, aber ich weiß, dass ihr alle vom Himmel herab lächelt.
DAS IST FÜR EUCH!!!

Acknowledgements

Alfred North Whitehead stated that, '*No one who achieves success does so without the help of others.'* Therefore, with humility, joy and confidence I would like to express my deepest and sincere gratitude to the team behind my successful completion of this work. The journey has been one that has shaped my outlook, sharpened my research skills and developed me holistically to approach all issues deeply and openly and rely on data-based evidence before any inferential remarks. This I am thankful.

First and foremost, to God, Your Grace and Mercy brought me through, and this moment is because of you!!!

Prof. Dr. Ing. Oliver Hensel, thank you for accepting me to your team, guiding me each step, giving me the opportunity to think and research without limitations. Thanks for the freedom you bestowed upon me throughout my study. Thanks for the trust you reposed in me and most importantly, thanks for your commitment to my work.

Prof. Dr. Habil. Barbara Sturm, words are inadequate to express my sincere gratitude for your contribution to the successful completion of this work. Your constant encouragement, your deep scientific insights, your deep interest, commitment to my work and your socio-mental support during some challenging moments of this journey. All these did ease the weight on my shoulders, and I am forever indebted to you. Your words, 'It will be fine' kept and still keeps me going. I would also like to extend my gratitude to Prof. Michael Wandayi Okoth, having mentored me from bachelor, through masters and now through PhD. Your insights Prof. Hensel, Dr Habil. Sturm and Prof. Okoth, encouragement and deep commitment in this journey has challenged me to pass on the baton to any individual that I will have an opportunity to journey with. I am looking forward to continuing collaborating with you all.

I would also like to thank Prof. Dr.- Ing. Werner Hofacker, Institute of Applied Thermo- and Fluid Dynamics, HTWG Konstanz, Germany for agreeing to assess this thesis, and Prof. Dr. Dirk Hinrichs and Dr Christian Hülsebusch for their participation as oral examiners.

I gratefully acknowledge Katholische Akademischer Ausländer-Dienst (KAAD), particularly the head of the African department, Dr. Marko Kuhn, for their financial support of my residence in Germany. I am also grateful to the German Federal Ministry of Education and Research (BMBF) which partially financed this PhD through the Global Food Supply (GlobE) project

RELOAD (FKZ 031A247 A). Many thanks to Michael Hesse, for your constant encouragement and always reminding me to take breaks. Your support in ensuring that when my scholarship ended, that I was financially catered for and my flights too, is highly appreciated.

I cannot proceed without acknowledging Prof Esper Günter & Julia Breitenbach of Fulda University of Applied Sciences, who allowed me access to their lab, provided me with training on spray drying and above all ensured that I obtained great results in my research, thank you. I also acknowledge the support of Dr. Christian Hülsebusch for resource materials on camel milk and also providing me with contacts in the field. In the field, I would like to thank the camel milk farmers, traders and my field assistants who were patient and answered my queries diligently, without them this work will not have been accomplished. Particular mention is Denis Ngala, who was instrumental in the field, thank you.

My special thanks go to my colleagues in the research group, 'Process and Systems Engineering in Agriculture': Dr. Abozar Nasirahmadi, Araba Aidoo, Bastian Lange, Emmanuel Miyingo, Gardis von Gersdorff, John Ndisya, Luna Shrestha, Phil Kirchoffer, Rhona Diaz, Rosalizan Saleh and Shavari Raut. More gratitude goes to the entire staff of the department of Agricultural and Biosystems Engineering for the great atmosphere you created during this journey: your hospitality, friendship and helpful assistance is deeply appreciated.

My Ph.D. journey would be dull without the company of Dr. Aditya Parmar, Dr. Dora Neina, Dr. Edmund Yamba, Dr. Guyo Roba. Dr. Ivan Adolwa, Dr Joseph Korese, Dr. Mwanaima Rajab, Dr. Katherine Tröeger, Dr. Margaret Lelea, Dr Nyasule Neke, Grace Mudombi-Rusinamhodzi and Jessica Amprako. Thanks for making my stay in Witzenhausen and Germany worthwhile. To my Kassel friends Isabella, Antje, Julia and Lisa thank you for some of the greatest moments in my doctoral journey, the laughter and the deep insights.

Finally, I am grateful to my siblings Seline, Charles, Fred, Peter, Evaline, and Beatrice. You are all incredible, you brought love, laughter, encouragement and resilience to this table of great achievement. I love you so much and I am grateful.

And thus, I reiterate, '*If I have seen further it is by standing on the shoulders of Giants*.' Thank you all and may the good Lord richly bless you.

Preface

This dissertation is comprised of manuscripts either published or prepared for publication in peer-reviewed journals and are referred to in the text by their chapter Arabic numbers as shown below.

Chapter 4[a]: **Jackline A. Ogolla,** Christian Dede, Michael W. Okoth, Oliver Hensel and Barbara Sturm (2017). Strategies and Technologies for Camel Milk Preservation and Utilization of Non-marketed Milk in Pastoral Regions. *East African Agricultural and Forestry Journal*. DOI: 10.1080/00128325.2017.1363686.

Chapter 5: **Jackline A. Ogolla,** Boris Kulig, Liliana Bădulescu, Michael W. Okoth, Günter Esper, Jutta Breitenbach, Oliver Hensel, and Barbara Sturm (2019). Influence of Inlet Drying Air Temperature and Milk Flow Rate on the Physical, Optical and Thermal Properties of Spray Dried Camel Milk Powders. *Food and Bioprocess Technology*

Chapter 6[b]: **Jackline A. Ogolla**, Michael W. Okoth, Oliver Hensel, and Barbara Sturm (manuscript submitted to journal of Thermal Science and Engineering). Development and Techno-economic feasibility analysis of a novel hybrid solar-powered process design for camel milk powder and butter processing plant for the ASALs.

[a] Parts of this chapter has been presented in the Tropentag 2016 annual conference as a poster and published in the book of abstracts (page 206).

[b] Parts of this chapter has been presented in the Tropentag 2017 annual conference as a poster and published in the book of abstracts.

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List of Abbreviations

Acronym	Meaning	Acronym	Meaning
AACE	Association for the Advancement of Cost Engineering	FGD	Focus group discussions
AC	Alternating current	FPC	Flat Plate Collectors
ALRMP	Arid Lands Resource Management Project	FSD	Flame spray drying
ANN	Artificial Neural Networks	GDP	Growth Domestic Product
ANOVA	Analysis of Variance	GHG	Greenhouse gas emissions
ASALs	Arid and Semi-Arid Lands	GJ	Gigajoules
ASDSP	Agricultural Sector Development Support Programme	GoK	Government of Kenya
B.C	Before Christ	GUI	Graphical user interface
BMBF	German Federal Ministry of Education and Research	GWh	Gigawatt hours
BMZ	German Federal Ministry for Economic Cooperation and Development	HepG2	Human hepatoma
$CaCl_3$	Calcium Chloride	HCT	Heat coagulation time
CBEs	Community Based Enterprises	HCV	Hepatitis C virus
CBOs	Community-based organizations	HEN	Heat exchanger network
CEPCI	Chemical engineering plant cost index	HEX	Heat exchanger
CI	Clearness index	HFO	Heavy fuel oil
CIP	Cleaning in Place	HTF	Heat transfer fluid
CPC	Compound Parabolic Concentrator	HTST	High Temperature Short Time
CM	Camel Milk	HVAC	Heating ventilation, and air conditioning
CMM	Commercial Camel Milk powder	Huh7.5	Hepatocyte-derived carcinoma
CN	Casein	IEA	International Energy Agency
CO_2	Carbon dioxide	IDHR	Indirect heat recovery
CO_2e	Carbon dioxide equivalent emissions	IPPs	Independent Power Producers
CSP	Concentrating solar power	IRENA	International Renewable Energy Agency
DC	Direct current	KAM	Kenya Association of Manufacturers
DHR	Direct heat recovery	KenGen	Kenya Electricity Generating Company
DNI	Direct normal irradiance	KII	Key informant interviews
DOs	Direct observations	KNBS	Kenya National Bureau of statistics
DSC	Differential Scanning Calorimetry	KPLC	Kenya Power & Lighting Company Limited
EPRA	Energy and Petroleum Regulatory Authority	kW	Kilowatts
EROP	Equipment repeated operation period	MACRS	Modified accelerated cost recovery system

ETC	Evacuated tube collectors	MAP	Mycobacterium avium – subspecies: paratuberculosis
FAO	Food and Agriculture Organization	MER	Maximum energy recovery
FAOSTAT	Food and Agriculture Organization Statistics	MoALFI	Ministry of Agriculture, Livestock, Fisheries and Irrigation
MOE&P	Ministry of Energy and Petroleum	SA	Serum albumin
MW	Megawatts	SAM	System analysis model
NGOs	Non-Governmental Organisations	SE4ALL	Sustainable Energy for All
NREL	National Renewable Energy Laboratory	SEM	Scanning electron microscopy
NPV	Net present value	SHC	Solar heating & cooling
OECD	Organization for Economic Cooperation and Development	SHIP	Solar heat industrial process
ORC	Organic Rankine Cycle	SNF	Solid Non-fat
PBD	Process block diagram	SSI	Semi-structured interviews
PFD	Process flow diagram	SWH	Solar water heating
PO	Personal observations	TAM	Time analysis model
PPP	Public private partnerships	TJ	terajoules
PRP	Peptidoglycan recognition protein	TS	Total solids
PV	Photovoltaic	TSM	Time slice model
REN21	Renewable Energy Policy Network for the 21st Century	UHT	Ultra-High Temperature
RES	Renewable energy sources	UO	Unit Operations
RELOAD	Reduction of Post-harvest Losses and Value Addition in East Africa Food Supply chains’	VAT	Value added tax
RH	Relative humidity	WMP	Whole milk powders
RQDA	R package for Qualitative Data Analysis	WPNI	Whey protein nitrogen index
RSM	Response surface methodology		

List of symbols

Symbols		units
α-CN	α-casein	-
α_E	Engineering factor	
α_{FIT}	Freight factor	-
α_L	Labour factor	-
α-la	α-lactalbumin	-
α_M	Material factor	-
α_O	Overhead factor	-
β-CN	β-casein	-
β-lg	β-lactoglobulin	-
ρ	Fluid density	kgm^{-3}
ρ_B	Bulk density	kgm^{-3}
ρ_T	Tapped density	kgm^{-3}
ĸ-CN	ĸ-casein	-
ΔE	colour difference	-
ΔT	Difference between inlet and target temperature	°C
n_{PV}	PV module efficiency	%
a*	redness coefficient	-
b*	yellowness coefficient	-
C	Chroma	-
C_{BM}	Bare module of each equipment cost	€
C_{DM}	Direct manufacturing costs	€
C_{FM}	Fixed manufacturing costs	€
C_{GR}	Green field costs	€
C_{OM}	Manufacturing costs	€
C_{OL}	Labour cost	€
C_{PO}	Purchased equipment cost at base	€
$c_{p,\,s}$	Specific heat capacity of milk or water	kj/kgK
C_{TM}	Total module costs	€
C_{UT}	Utility cost	€
C_{WT}	Waste treatment cost	€
CF	Cash flow	€
CFn	Cash flow in year n	€
C_{factor}	Conversion factor from energy to tons of carbon dioxide equivalent	-
$C_{factor\ th}$	The C_{factor} for fuel oil	-
$C_{factor\ el}$	The C_{factor} for electricity	-
c_{factor}	Capacity factor	%
CI	Carr's index	-
$Cost_{ST,\,PV}$	Solar pv/thermal project equity (initial investment)	€
d	Depreciation	€
D_{real}	Real discount rate	%

$D_{nominal}$	Nominal discount rate	%
DCFROR	Discounted Cash-flow Rate of Return	%
DI	dispersibility index	%
DR	Direct radiation	W/m^2
DNR	Diffuse normal radiation	W/m^2
E_{Aux}	Backup system energy for SWH system	W/m^2
E_{NR}	Annual total radiation (nominal)	W/m^2
E_{solar}	Energy supplied by solar system	kWh
F^o_{BM}	Module cost at base conditions	€
F_{BM}	Bare module cost factor	-
FCI	Fixed capital investment	€
FRta	Collector optical gain	
FRUL	Thermal loss coefficient	W/m^2 °C
$h_{evap/cond,\ s}$	Stream enthalpy evaporation/condensation	kW
H	Hue angle	-
HR	Hausner ratio (HR).	-
i	interest rate.	%
IA	Interstitial air (IA),	cm^3 /100 g of powder
IAM	Incident angle modifier	°
IFT	integration flow temperature	°C
IgG	immunoglobulins	-
IRT	integration return temperature	°C
L*	lightness coefficient	-
L	Analysis period	Years
LCOE	Levelized Cost of energy/electricity	€/kWh
Lf	Lactoferrin	-
$\dot{m}$	Mass flow rate	kg/s
NPV	Net present value	€
OM	Annual project costs	€
PR	Performance ratio	%
$\dot{Q}_{h/c}$	Heating and cooling demands	kW
$Q_{saved\ th}$	Thermal energy saved	kWh
$Q_{saved\ el}$	Electrical energy saved	kWh
$Q_{ST,PV}$	Energy generated by the SWH or PV system	kWh
R	Revenue	€
R^2	coefficient of determination	-
SF	Solar fraction	%
t	Taxation rate	%
$t_{CO_2e\ mitigated\ th}$	tonnes of CO_2 mitigated	tCO_2e
$t_{CO_2e\ mitigated\ el}$	tonnes of CO_2 mitigated	tCO_2e
T_g	Glass transition temperature	°C
TCI	Total capital investment	€
t_s	Time per individual stream	hours

U	Solar tank heat loss coefficient	$W/m^{2}\cdot{}^{\circ}C$
WC	Working capital	€
x_i	Mass fraction	%

1.0 General introduction

1.1 Introduction

Milk is often defined as the most complete food; though this is correct only for the young of the producing or closely related species, the milk of all species is a nutrient-rich and well-balanced food (du Puis 2002; Patton 2004). For humans, it is an important part of a balanced diet as it is rich in protein, fats and micro-nutrients. Nevertheless, fluid milk is very prone to microbial growth which will trigger spoilage if the milk is stored. To counter this, a range of products that are more stable than milk has been established; some of these date from 4000 BC and have developed desirable epicurean characteristics, in addition to their nutritional value. Currently, numerous food products are manufactured from milk: fluid milk, cheese, milk powders, concentrated milks, fermented milk products, butter, ice cream, infant formula, creams, protein-rich products and lactose(Fox, 2009).

There has been an increase in demand and consumption of milk and milk products due to the increase in human population and its high nutritional value. It has been projected that global milk consumption by 2025, is expected to increase to 177 Mt with an annual growth rate of 1.8%. About 73% of the 177 Mt is projected to come from developing countries in Africa and Asia (OECD/FAO 2016). In Kenya, milk production has continuously increased from 423 million litres in 2007 to 634.3 million litres in 2018 which is approximately an increase of 50% in the span of 11 years (KNBS 2019). The annual per capita milk consumption is significantly higher in urban areas with 125 litres compared to 19 litres in rural areas. Due to the strong tradition of including milk in diets, increase in middle class, rapid urbanization and increased export opportunities, there is an increase in demand of milk and milk products (Rademaker, Bebe, and Lee 2016). It is estimated that Kenya's annual milk consumption growth is 5.3%, the Kenya National Dairy Master Plan further aims to promote this annual per capita consumption to 220 litres by in 2025 (MoALF 2013; USAID 2018).

Although, much of the world milk production comes from bovines (81.6%), milk supply produced from non-bovine species such as goats, buffalo, sheep and camel has soared from 15.7% in 2001 to 18.4% in 2011 (FAOSTAT 2019). In countries in the global south, non-bovine species are increasingly being used for milk production accounting for one-third of milk produced (Minh, Bekhit, and McConnell 2014). Particularly in the ASALs, over the last decade camel husbandry has increased leading to increased camel milk (CM) production and commercialization. The shift from the traditional extensive systems in camel husbandry to the modern intensive system has been further driven by climatic changes (that has heightened environmental aridity leading to a shift from other dairy animals to camel and the increasing need for semi-zero grazing due to increases in ethnic clashes); globalization of the world economy (emergence of small or large camel dairy plants) and change in territorial distribution (due to expansion of traditional farming areas and by an increasing risk of emerging diseases) (Gossner et al. 2014; Faye, Madani, and El-Rouili 2014; Megersa et al. 2012).

Despite these significant contributions of CM to the ASALS, there have been limited strides in value addition and preservation technologies development of CM compared to milk from other animals. Currently, due to the changing dynamics in the desert, CM is processed into ghee, butter, cheese, yoghurt, ice cream, and fermented products (*gariss, Susaac, dhanaan*) among the pastoral communities (Seifu 2007; Wayua, Okoth, and Wangoh 2012; Mehaia 2006; El Zubeir and Jabreel 2008; Inayat et al. 2003).

In addition, to minimise milk spoilage through the value-added products, different preservation technologies and strategies that increase CM shelf life have been put in place to ensure reduced microbial contamination along the value chain. Interventions such as the use of commercial lactoperoxidase systems (LS) kits, cooling facilities, milk pasteurization, clean water provision and training on hygienic milk handling have been proposed in the pastoral regions of Kenya (Bornstein and Younan 2013; Adongo, Coppock, and Wayua 2013; Wayua, Okoth, and Wangoh 2013). Different studies have reported simple cooling technologies, fermentation, and smoking of camel milk in pastoral regions of Ethiopia and Kenya (Seifu 2007; Wayua, Okoth, and Wangoh 2012; Tabary 2018).

It is important to note that although CM processing into different value-added products, has increased over the last decades, these products have limited shelf life and, thus, require a constant cold chain along the entire value chain. Knowledge of the preservation technologies, strategies that ensure that the camel milk quality is maintained until the reception by the consumers is vital due to the high temperatures in these regions. Despite the significance of the camel milk, existing value-added products and the preservation technologies, the losses along the camel milk value chain have been approximated to be one third globally (Gustavsson et al. 2011). In addition, in documenting these losses, there has been limited information on the utilization of the non-marketed milk along the camel milk value chain and to what extent in the chain links they contribute to the losses. In Kenya, 55% of the total milk production is marketed of which 88% is sold informally as either chilled or un-chilled raw fresh milk directly to the consumers (Rademaker, Bebe, and Lee 2016).

It is well known that dehydration of milk results in products with less moisture content, easily transportable, easy to handle and store and with prolonged shelf life. There are two main dehydration technologies that have been utilised in the dairy industry for powder production: spray drying and drum drying. However, in obtaining the milk powder of high microbial, physical and chemical quality, spray drying is often the most preferred processing method (Mujumdar, Huang, and Chen 2010). This is because there is a reduction in the heat stress on the product sub-components (protein and free fat) achieved by the combination of the high temperature and short residence time. Severe heat treatment of milk, that is characteristic of drum drying, leads to thermal instability of the milk due to protein-protein interactions, degradation of lactose to isomerisation (e.g., to lactulose), and Maillard reactions (Fox and Kelly 2012). The final quality of milk powders for its application is dependent on the physical, thermal, functional, sensory and biochemical properties (Sharma, Jana, and Chavan 2012). These powder properties are directly influenced by the spray drying conditions and feed characteristics (Birchal et al. 2005; Koç et al. 2014).

Drying consumes large amount of energy approximately 10-20 % in industrialized nations, while in less industrialized nations such as Kenya is much lower, though, there has been documentation of increasing energy consumption in the food sector (Mujumdar 2013; KAM 2018). The specific energy for fluid milk processing has been established by different authors to be 0.47 GJ/m^3, 0.61 GJ/m^3, and 1.1 GJ/m^3 while for milk powder production 1.32GJ/m^3; 1,06 GJ/m^3 and 1.37 GJ/m^3 in Australia, Canada and Netherlands respectively (Prasad et al. 2004; Ramírez, Patel, and Blok 2006). Besides, drying of milk accounts for 51 %; concentration for 45 %; preheat treatment for 2.5 % and packing for 1.5 % of the overall energy demand. Of the total energy used in milk evaporation and drying stages acount for 75% and approximately 25% for cleaning (CIP) (Ramírez, Patel, and Blok 2006). In this regard, different studies have proposed a reduction of energy demand in the dairy processing industry put in place and also documented in the literature for reduction of energy consumption.

The utilization of emerging technologies such as radio frequency heating, membrane distillation, mono-disperse-droplet drying and air dehumidification by zeolites, and membrane contactor in skim milk powder production has been reviewed and an estimated savings in operational energy consumption of 60% were documented (Moejes and van Boxtel 2017). Energy recovery in milk powder manufacture through spray dryer exhaust air heat recovery has been documented (Atkins, Walmsley, and Neale 2011). An innovative large scale ultra-low energy milk powder plant design has been presented through a total site heat integration, process and utility model approach by which an estimated reduction of 51.5 %, 19.0 %, and 48.6% in thermal energy, electricity and emissions respectively in comparison to a modern milk powder plant (Walmsley et al. 2016).

Once the process has been optimized, solar thermal energy can thus be intergrated to reduce green house gases emission while promoting sustainable milk processing. A number of authors have proposed different integration strategies of solar themal in large scale industries after process optimization (Krummenacher and Muster 2015; Schmitt 2014; Sturm et al. 2015; Kulkarni, Kedare, and Bandyopadhyay 2008; Eiholzer et al. 2017). In integrating solar thermal energy at industrial level, this can be undertaken both at supply (total site analysis) and process (unit operation (UO)) levels (Schmitt 2014).

In the milk industry, most studies have focused on solar integration for low temperature processes such as pasteurization and the CIP water (Anderson and Duke 2008; Quijera, Alriols, and Labidi 2011). The potential of solar collector incorporation in the provision of thermal energy in processing of milk and milk products, and the subsequent reduction of the greenhouse gas emissions have been presented for India by Sharma et al. (2017). The viability of solar thermal system integration for low and middle temperature processes in a dairy plant in Spain using mathematical modelling and Pinch Analysis were evaluated (Quijera, Alriols, and Labidi 2011). The incorporation of solar heat into food processing is limited with the high solar capital installation costs (Quijera, Alriols, and Labidi 2011; Lauterbach, Schmitt, and Vajen 2014; Sturm et al. 2015).

Due to the high capital costs of integrating solar energy into food processing, techno-economic feasibility is vital in determining the possibility for self-financing or for applying for a bank loan. It is important to ensure that the margin between value added products produced and the raw material, cover the overhead costs while at the same time processors can meet the loan repayment within the stipulated time period. In locating a dairy plant, it is imperative to maximize profit, while minimizing losses, thus the location, energy, water supply, milk availability, market analysis, technical staff and the cost of raw milk are fundamental (Pisecky, 2012)

In conclusion, although, CM plays a significant role in the ASALS, and the increase in its commercialization, there is little information in literature that is significant in policy formulation regarding its powder processing into powder. A central theme of this thesis is that it is vital to understand the current uses, losses, preservation technologies and strategies available, powder production through spray drying pre-trials, technical and economic feasibility before the final design of a milk powder and butter processing plant for the ASALs can be realised. This thesis, therefore, presents a novel decentralized small-scale hybrid solar thermal-PV-fossil fuel-powered process design for camel milk powder and butter processing plant for the ASALs. This is to design an optimised small-scale decentralized processing line that limits the utilisation of fossil fuels while optimising the utilisation of water and energy before the incorporation of renewable energy. Moreover, economic and technical feasibility is presented that is critical for the ASALs that have high camel milk production but are limited in the knowledge and resources in establishing the processing industries.

1.2 Aims and Objectives

The overall aim of the dissertation is to design a decentralised camel milk processing plant with integration of renewable energy supply (RES). Particularly the dissertation aims to enhance the understanding of the camel milk value chain in the ASALs, camel milk powder production, design and present a techno-economic feasibility study of an ASAL decentralised small-scale hybrid (solar & fossil fuel) camel milk powder and butter processing plant. This is quite important in policy formulation as the Kenyan government has indicated food security as one of the big four agendas and value addition as one of its major components (KAM 2018). Further, there is a growing interest in the camel milk in Kenya due to its economic viability, food security, its medicinal value and because the camel milk value chain is mainly characterized by women (Republic of Kenya 2018). Thus, women will be empowered, increasing the household income and food security through increased sales of the value-added products (powder and butter), which attract higher market value than the liquid milk and are less prone to spoilage and spillage. Moreover, the ASALs of Kenya have higher concentration of camels and camel milk plays a significant role to the households' food basket and as source of income (Elhadi, Nyariki, and Wasonga 2012). However, there are limited information on the preservation technologies of camel milk and the technical and economic feasibility of a milk powder and butter processing plant that utilizes solar energy and reduced fossil fuel.

The increased need to reduce carbon emissions due to climate change while preserving forests that act as carbon sequestering calls for alternative energy sources to be utilised in food processing. In developing nations, steam for dairy industries is often generated from biomass and fuel oil but with depleting forest resources and need for greenhouse gases (GHG) emissions reductions, alternative energy sources are better to be utilised.

This study, therefore, aims to address the following **specific objectives**:

1. To examine the technologies and strategies used in camel milk preservation in the ASALs and the utilization of the non-marketed milk.
2. To determine the influence of inlet air drying temperature and milk flow rate on the thermal, physical and optical properties of spray dried camel milk.
3. To design a processing plant for a novel decentralised small-scale hybrid solar-fossil fuel powered camel milk powder and butter processing for the ASALs.
4. To determine the economic and technical feasibility of a novel decentralised small scale solar-fossil fuel hybrid camel milk powder and butter processing plant for the ASALs.
5. To assess the suitability of the designed processing plant to contribute to food and nutritional security of the populations in the ASALs.

To address these objectives the following **research questions** were formulated:

1. What are the strategies and technologies for camel milk preservation in the ASALs?
2. What percentage of the milk is not marketed and how is the non-marketed milk utilized?
3. How does the inlet air drying temperature and milk flow rate influence the thermal, physical and optical properties of spray dried camel milk powders?
4. Can a novel decentralised small-scale hybrid solar-fossil fuel powered process design for a camel milk powder and butter milk processing plant for the ASALs be developed?
5. Is it technically and economically feasible to build a decentralised small-scale hybrid solar fossil-fuel powered camel milk powder and butter processing plant in the ASALs?
6. Can the designed processing plant contribute to increasing food and nutritional security of the ASAL publics and empower women?

References

Adongo, A. O., Coppock, D. L., & Wayua, F. O. (2013). Simple evaporative cooling method reduces bacterial content of traditionally marketed camel milk in Isiolo county, Kenya. *African Journal of Food, Agriculture, Nutrition and Development*, *13*(1), 7213–7224. https://doi.org/10.4314/ajfand.v13i1.

Anderson, T. N., & Duke, M. (2008). Solar Energy Use for Energy Savings in Dairy Processing Plants. *IPENZ Engineering TreNz 2008-001*, 1–9.

Atkins, M. J., Walmsley, M. R. W., & Neale, J. R. (2011). Integrating heat recovery from milk powder spray dryer exhausts in the dairy industry. *Applied Thermal Engineering*, *31*(13), 2101–2106. https://doi.org/10.1016/j.applthermaleng.2011.03.006

Birchal, V. S., Passos, M. L., Wildhagen, G. R. S., & Mujumdar, A. S. (2005). Effect of Spray-Dryer Operating Variables on the Whole Milk Powder Quality. *Drying Technology*, *23*(3), 611–636. https://doi.org/10.1081/DRT-200054153

Bornstein, S., & Younan, M. (2013). Significant veterinary research on the dromedary camels of Kenya: past and present. *Journal of Camelid Science*, *6*, 1–48.

du Puis, E. M. (2002). *Nature's Perfect Food: How Milk Became America's Drink*. New York: New York University Press .

Eiholzer, T., Olsen, D., Hoffmann, S., Sturm, B., & Wellig, B. (2017). Integration of a solar thermal system in a medium-sized brewery using pinch analysis: Methodology and case study. *Applied Thermal Engineering*, *113*, 1558–1568. https://doi.org/10.1016/j.applthermaleng.2016.09.124

El Zubeir, I. E., & Jabreel, S. O. (2008). Fresh cheese from camel milk coagulated with Camifloc. *International Journal of Dairy Technology*, *61*(1), 90–95. https://doi.org/10.1111/j.1471-0307.2008.00360.x

Elhadi, Y. A. M., Nyariki, D. M., & Wasonga, V. O. (2012). Assessing the potential of camel milk as a livelihood option in the face of climatic and environmental changes in drylands of Kenya Résumé Literature Summary. *Third RUFORUM Biennial Meeting*, (September), 565–569.

FAOSTAT. (2019). FAOSTAT, FAO statistical databases, Livestock primary. Retrieved December 7, 2018, from FAO statistical databases website: http://www.fao.org/faostat/en/#data/QL

Faye, B., Madani, H., & El-Rouili, S. A. H. (2014). Camel milk value chain in Northern Saudi Arabia. *Emirates Journal of Food and Agriculture*, *26*(4), 359–365. https://doi.org/10.9755/ejfa.v26i4.17278

Fox, P.F., & Kelly, A. L. (2012). Biochemistry of Milk Processing. In B. K. Simpson, L. M. L. Nollet, F. Toldra, S. Benjakul, G. Paliyath, & Y. H. Hui (Eds.), *Food Biochemistry and Food Processing* (second, pp. 465–472). Iowa: JohnWiley & Sons, Inc.

Fox, Pat F. (2009). Milk:an overview. In *Milk Proteins* (pp. 1–54). https://doi.org/10.1016/B978-0-12-374039-7.00001-5

Gossner, C., Danielson, N., Gervelmeyer, A., Berthe, F., Faye, B., Aaslav, K. K., … Coulombier, D.

(2014). Human – Dromedary Camel Interactions and the Risk of Acquiring Zoonotic Middle East Respiratory Syndrome Coronavirus Infection. *Zoonoses and Public Health*, *63*, 1–9. https://doi.org/10.1111/zph.12171

Gustavsson, J., Cederberg, C., Sonesson, U., Otterdijk, R. van, & Meybeck, A. (2011). Global food losses and food waste - Extent, causes and prevention. In *Global Food Losses and Food Waste*. https://doi.org/10.1098/rstb.2010.0126

Inayat, S., Arain, M. A., Kahaskheli, M., & Malik, A. H. (2003). Study on the effect of processing onthe chemical quality of cheese made from Camel Milk. *Pakistan Journal of Nutrition*, *2*(2), 102–105.

KAM. (2018). *Manufacturing in Kenya Under the 'Big 4 Agenda.'*

KNBS. (2019). *Economic survey 2019*. Nairobi.

Koç, B., Sakin-YIlmazer, M., Kaymak-Ertekin, F., & BalkIr, P. (2014). Physical properties of yoghurt powder produced by spray drying. *Journal of Food Science and Technology*, *51*(7), 1377–1383. https://doi.org/10.1007/s13197-012-0653-8

Krummenacher, P., & Muster, B. (2015). Solar Process Heat for Production and Advanced Applications Methodologies and Software Tools for Integrating Solar Heat into Industrial Processes. In *IEA SHC Task 49*.

Kulkarni, G. N., Kedare, S. B., & Bandyopadhyay, S. (2008). Design of solar thermal systems utilizing pressurized hot water storage for industrial applications. *Solar Energy*, *82*(8), 686–699. https://doi.org/10.1016/j.solener.2008.02.011

Lauterbach, C., Schmitt, B., & Vajen, K. (2014). System analysis of a low-temperature solar process heat system. *Solar Energy*, *101*, 117–130.

Megersa, B., Biffa, D., Abunna, F., Regassa, A., Bohlin, J., & Skjerve, E. (2012). Epidemic characterization and modeling within herd transmission dynamics of an "emerging trans-boundary" camel disease epidemic in Ethiopia. *Tropical Animal Health and Production*, *44*(7), 1643–1651. https://doi.org/10.1007/s11250-012-0119-z

Mehaia, M. A. (2006). Manufacture of fresh soft white cheese (Domiati type) from dromedary camel's milk using ultrafiltration process. *Journal of Food Technology*, *4*(3), 206–212.

Minh, H., Bekhit, A. E.-D., & McConnell, M. (2014). Fractionation of whey proteins from red deer (Cervus elaphus) milk and comparison with whey proteins from cow, sheep and goat milks. *Small Ruminant Research*, *120*, 125–134.

MoALF. (2013). *Sesional paper no. 5 of 2013 on the National Dairy Development Policy*. Nairobi.

Moejes, S. N., & van Boxtel, A. J. B. (2017). Energy saving potential of emerging technologies in milk powder production. *Trends in Food Science & Technology*, *60*, 31–42. https://doi.org/10.1016/j.tifs.2016.10.023

Mujumdar, A. S. (2013). Editorial: Why Four Decades of R&D in Drying? *Drying Technology*, *31*(6), 617–618. https://doi.org/10.1080/07373937.2013.793129

Mujumdar, A. S., Huang, L.-X., & Chen, X. D. (2010). An overview of the recent advances in spray-drying. *Dairy Science &Technology*, *90*(2–3), 211–224. https://doi.org/10.1051/dst/2010015

OECD/FAO. (2016). OECD-FAO Agricultural Outlook 2016-2025. In *OECD Publishing*. https://doi.org/https://doi.org/10.1787/agr_outlook-2016-10-en

Patton, S. (2004). *Milk: Its Remarkable Contribution to Human Health and Well-being* . New Brunswick, New Jersey: Transaction Publishers.

Pisecky, J. (2012). Handbook of milk powder manufacture. In V. Westergaard & E. Refstrup (Eds.), *GEA Process Engineering A/S (GEA Niro)* (Second Edi). https://doi.org/10.1007/978-1-908517-43-2

Prasad, P., Pagan, R., Kauter, M., Price, N., & Crittenden, P. (2004). *Eco-efficiency for the Dairy Processing Industry The UNEP Working Group for Cleaner Production in the Food Industry*.

Quijera, J. A., Alriols, M. G., & Labidi, J. (2011). Integration of a solar thermal system in a dairy process. *Renewable Energy*, *36*(6), 1843–1853. https://doi.org/10.1016/j.renene.2010.11.029

Rademaker, C. J., Bebe, B. O., & Lee, J. Van Der. (2016). *Sustainable growth of the Kenyan dairy sector; A quick scan of robustness , reliability and resilience* (No. Report 3R Kenya). https://doi.org/10.13140/RG.2.2.26350.41285

Ramírez, C. A., Patel, M., & Blok, K. (2006). From fluid Milk to Milk Powder: Energy Use and Energy Efficiency in the European Dairy Industry. *Energy*, *31*(12), 1648–1668. https://doi.org/10.1016/j.energy.2005.10.014

Republic of Kenya. (2018). *Isiolo County Intergrated Development Plan (CDP)*. https://doi.org/10.1017/S0022278X00014853

Schmitt, B. (2014). *Integration thermischer Solaranlagen zur Bereit- stellung von Prozesswärme in Industriebetrieben* (Vol. 157). Shaker Verlag.

Seifu, E. (2007). Handling, preservation and utilization of camel milk and camel milk products in Shinile and Jijiga Zones, eastern Ethiopia. *Marketing*, *10*, 13–17.

Sharma, A., Jana, A. H., & Chavan, R. S. (2012). Functionality of Milk Powders and Milk-Based Powders for End Use Applications-A Review. *Comprehensive Reviews in Food Science and Food Safety*, *11*(5), 518–528. https://doi.org/10.1111/j.1541-4337.2012.00199.x

Sharma, A. K., Sharma, C., Mullick, S. C., & Kandpal, T. C. (2017). Potential of solar industrial process heating in dairy industry in India and consequent carbon mitigation. *Journal of Cleaner Production*, *140*, 714–724. https://doi.org/10.1016/j.jclepro.2016.07.157

Sturm, B., Meyers, S., Zhang, Y., Law, R., Siqueiros Valencia, E. J., Bao, H., … Chen, H. (2015). Process intensification and integration of solar heat generation in the Chinese condiment sector - A case study of a medium sized Beijing based factory. *Energy Conversion and Management*, *106*, 1295–1308. https://doi.org/10.1016/j.enconman.2015.10.045

Tabary, Z. (2018). With refrigerated ATMs, camel milk business thrives in Kenya. *Reuters*.

USAID. (2018). *Policy Brief Enhancing Investment Attractiveness in Kenya'S Dairy Sector*. Nairobi.

Walmsley, T. G., Atkins, M. J., Walmsley, M. R. W., Neale, J. R., M., P., & R.H. Peesel. (2016). Total

Site utility systems optimisation for milk powder production. *Chemical Engineering Transactions*, *52*, 235–240. https://doi.org/10.3303/CET1652040.

Wayua, F. O., Okoth, M. W., & Wangoh, J. (2012). Survey of postharvest handling, preservation and processing practices along the camel milk chain in Isiolo district, Kenya. *African Journal of Food, Agriculture, Nutrition and Development*, *12*(7), 6897–6912.

Wayua, F. O., Okoth, M. W., & Wangoh, J. (2013). Modelling of a locally fabricated flat-plate solar milk pasteuriser using artificial neural network. *African Journal of Agricultural Research*, *8*(9), 741–749. https://doi.org/10.5897/AJAR11.1256

2.0 State of the art

2.1 Camel's taxonomy, geographical distribution and physiological adaptation

2.1.1 Camel's taxonomy and origin

Camels belong to the family *Artiodactyla* (even-tooed, hoofed mammals), suborder *Tylopoda* (padded foot mammals) and old world-genus *Camelus.* The genus *Camelus* is comprised of two main species: *C. dromedarius* L., one-humped, that inhabit desert areas such as South West Asia, Africa, & Australia; *C. bactrianus* L., two-humped, which occupy cooler areas such as Northern China, Mongolia, Kazhakstan, & Russia (Farah 1986; Yagil 1982). The *Camelus* has two digits on the feet and walks on thick pads mainly consisting of fat. These features prevent them from sinking on the desert sand and heat from the land surface spreading into their legs (Werney 2006).

Camels originated in North America during the tertiary period 50 to 60 million years ago, (Zeuner 1963). These camels were the size of hares, where they evolved from upper Eocene, through the Tertiary period into the Late Miocene period, (approximately 40 million years). This evolution resulted in *camilinae* (camels with humps) and *laminae* (camels without humps). The *camelinae* then migrated eastwards across the Bering Straits to North East Asia and further to eastern Europe, North & East Africa and East Asia during the Pleistocene era. The environmental conditions that the camels have been exposed to have determined the different camel breeds. The Bactrian (Bactrian derived from an area "*Baktriana*" in North Afghanistan) are stockier and covered by thick wool, were then domesticated on the border of Iran and Turkmenistan where they spread to Crimea, Southern Siberia, Mongolia and China, throughout northern Africa to Asia (Farah and Fischer 2004).

The dromedary (derived from the Greek word *dromeus* which means *runner*) camels are slim, long-legged, and short-haired. They were first domesticated in the Arabian Peninsula (Currently Yemen and Oman) mainly for meat and milk (Epstein 1971). This is evidenced by the remains found in Palestine at the beginning of iron age about 1800 B.C (Bulliet 1975; G. G. Simpson 1945). They later migrated to the deserts and semi-deserts of North & East Africa, India and Persia (Schwartz and Dioli 1992). However, due to *Trypanosoma brucei* infection that evolved into the mechanically transmitted *T. evansi* throughout northern Africa into Asia, the camel spread was further inhibited (Field 1980). In Africa, the camels are mainly concentrated in the arid and semi-arid areas, basically Sudan, and the horn of Africa (Kenya, Ethiopia, Djibouti, and Somalia). Currently, the dromedary camels are classified depending on: names based on the tribes that raise them; riding or transport camels; colour; geographical origin; physical characteristics, and uses (milk, meat or racing) (Zeuner 1963).

2.1.2 Camel geographical distribution

The world camel population is estimated by FAO to be approximately 28.5 million heads, of which 84.6% are in Africa *(Dromedary),* 15.3% in Asia *(Bactrian & Dromedary)* and 0.1% in Europe *(Bactrian)* (FAOSTAT 2019). About 89.0% of the world camels are two-humped while 11% are single-humped. The number of nomads' population over the last five decades has decreased from 10% to 1.5% while the camels' population has steadily increased by 2% annually. This annual increment is like the buffalo growth rate and is second to the annual growth rate of goats while superseding others such as the cattle, lama, sheep and horse (figure 2.1& 2.2) (FAOSTAT 2019). The camels are more concentrated in North East Africa (Somalia, Sudan, Ethiopia, and Kenya) than in the West or North regions (El-Agamy 2008).

Kenya's 3.22 million dromedary camel population is estimated to be the second largest camel herd in the world after Somalia and mainly concentrated in the northern parts of the country (FAOSTAT 2019). They are majorly distributed in the former northern-eastern province (54%), eastern province (29%), rift valley (13%) and coast province (4%) (Elhadi 2014). In northern Kenya, among the Rendille and the Gabbra ethnicities, camels are the most significant livestock as they survive the extremely arid conditions while producing milk which is the staple diet of these communities (Farah, Streiff, & Bachmann, 1989; Sato, 1976; Torry, 1973). The main camel breeds domesticated by these ethnicities are the Somali, Rendille/ Gabbra, Turkana and the Pakistan (Farah & Fischer, 2004). In the past few years, other livestock rearing communities have adopted camels thus resulting in the shifting of the camel rearing zone further south. The camels have been effectively introduced to areas outside their traditional range that used to particularly keep cattle such as Samburu, Kilifi, Kajiado, Mwingi, Laikipia, Narok, West Pokot and Kitui (Kuria et al. 2011; Elhadi 2014; KNBS 2010).

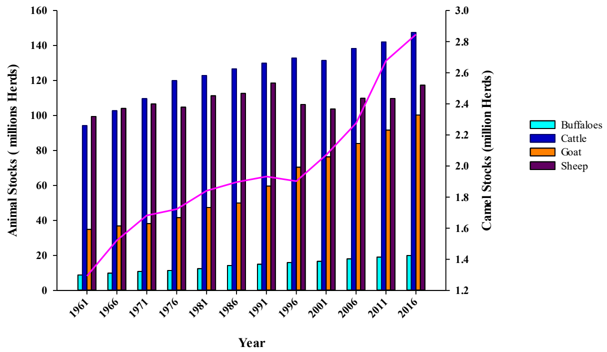


Figure 2. 1: Dairy animal stocks (FAOSTAT 2019)

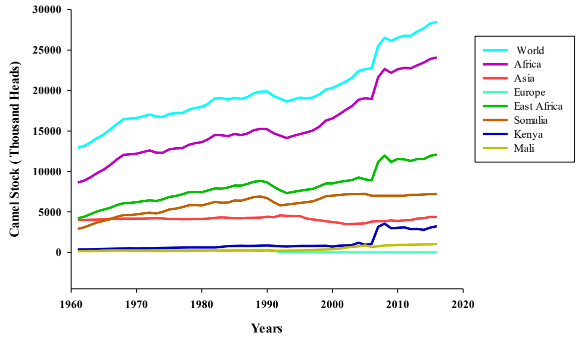


Figure 2. 2: Camel Stock (FAOSTAT 2019)

2.1.3 Significance of Camel

Domesticated camels are typically used as beasts of burden, mounts of riding, meat (less fat content but similar protein content to beef), wool (mainly from Bactrian and similar to cashmere both in fibre diameter and handle), hides (tensile strength five times that of cattle hide) and milk (Faye 2016; Farah and Fischer 2004). Besides, in the deserts, camels play a significant role in the social and cultural heritage, e.g. when a male child is born, he is gifted a female calf, while others use it for dowry or settling criminal offences (Hartley 1984). Camels have also been used in battle such as: early Islamic conquests, in Europe (French Napoleon, British in India & Afghanistan in 1881), Middle East, Asia, North Africa and the United Arabs Emirates.

2.1.4 Important physiological Characteristics of the camel

The *Camelus* has two digits on the feet and walks on thick pads mainly consisting of fat. These features prevent them from sinking on the desert sand and heat from the land surface spreading into their legs (Werney 2006). Among the domestic animals, camels have the lowest water turnover hence, can continue feeding even when deprived of water up to 54 days (Hassan 1971). During dry seasons, camels are watered once every 10-20 days while grazing and walking long distances but continually lactate and produce milk up to 90% water content (Knoess et al. 1986; Yagil and Etzion 1980). Moreover, harsh climatic conditions in the ASALs limit crop production and survival of other animals, but the Camels thrive. Consequently they are referred to as '*White gold of the desert*' (Bornstein and Younan 2013; Werney 2006). Furthermore, the browsing nature of camels in the ASALs facilitates the preservation of the habitats, while their long eyelashes and hair on the lips aid in pollination (Laudadio et al. 2009).

2.2 Camel Milk

2.2.1 Camel milk production

Milk is acknowledged as an important element of the pastoral civilisations in Africa. Indigenous groups in different parts of the world such as the *Maasai, Borani, Fulani* and *Tuareg* have a robust historical dairy tradition. They share many habits which include their regard of milk as a product of harmony that is freely offered to relatives, friends and visitors (Ndambi 2008). Milk is the main food obtained from a herd of camels (Dahl and Hjort 1990). In the horn of Africa, culturally, camels are milked by only unmarried women, boys or ritually clean men (Hartley 1984). However, among the pastoralists, the milking is mainly undertaken by men while standing with one knee raised to support the bowl due to the height of the udder (Farah and Fischer 2004). Camels are milked once to several times a day but habitually in the early morning and evening among the nomadic tribes (Nato et al. 2018). In arid areas CM production is higher than cattle, goats or sheep, for example in northern Kenya the Sakuye camels produce a mean of 4-12 kg per day compared to 0.5-1.5 kg of cattle (Farah 1982).

Depending on forage quantity and quality, water availability, climate, breeding age, parity, milking frequency, calf nursing, health, milking method (hand or machine), reproductive status, and individual merit; camel milk daily yield varies and ranges from 2 kg in Tunisia, 9.8 in Saudi Arabia to 50 litres in northern Kenya (Moslah 1994; Field 1980; Knoess et al. 1986; Ismail and Al-Mutairi 1994). In systems where camel production is dependent on natural pastures such as in Kenya, seasonal variation is the primary determinant of camel milk yield (Nicholson 1984).

The current world CM production is estimated to be 2.8 million tonnes with Africa contributing about 92.9% of the marketed milk (Fig 2.4). In Africa, most CM is from the horn of Africa with Somalia's 0.95 million tonnes of milk being the principal producer followed by Kenya's 0.85 million tonnes. Though, Kenya is classified as the second largest CM producing country in the world, it reports the highest yield per animal head in litres globally (Fig. 2.5). Over the last couple of years, CM production in Kenya has been increasing significantly (Fig. 2.6) due to its increased commercialization (Noor, Bebe, and Guliye 2012).

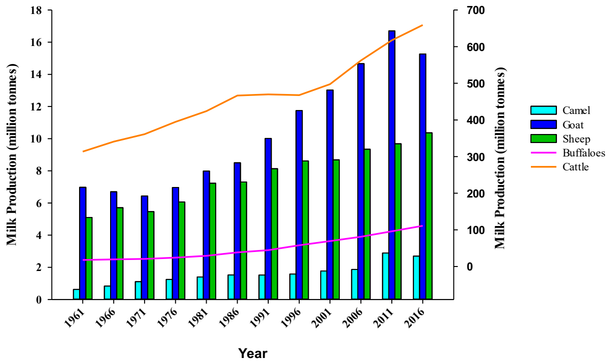


Figure 2. 3: Milk production among dairy animals (FAOSTAT 2019)

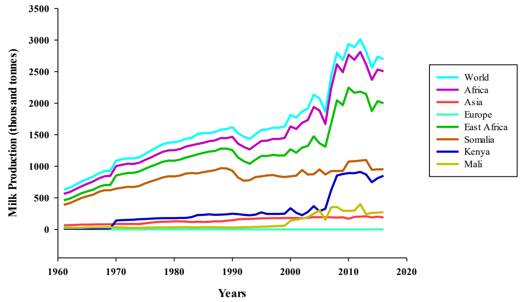


Figure 2. 4: Camel milk production (FAOSTAT 2019)

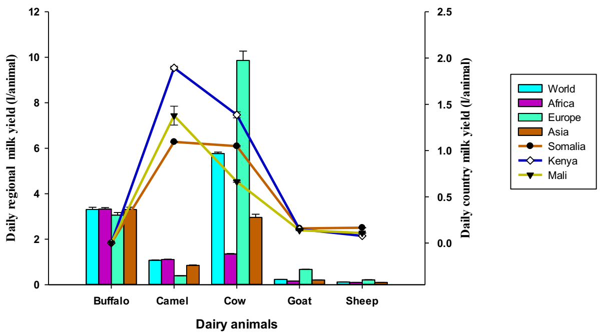


Figure 2. 5: Daily milk yield from dairy animals from different regions and countries (FAOSTAT 2019)

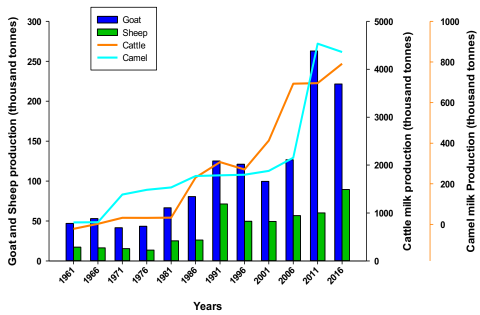


Figure 2. 6: Daily milk production from dairy animals in Kenya (FAOSTAT 2019)

2.2.2 Camel milk nutritional and physicochemical composition

2.2.2.1 The physical composition of camel milk

Compared to bactrian milk, the dromedary milk is foamy and opaque-white, due to the fine distribution of fat globules throughout the milk and lack of β-carotene (Jilo and Tegegne 2016; El-Agamy 1983; Al haj and Al Kanhal 2010). The taste of the CM varies from sweet when fed on green fodder and an unlimited supply of water to salty when fed on shrubs and herbs in the arid (El-Agamy 1994; Patel et al. 2016). The pH of CM ranges from 6.5-6.7 with an average of 6.6; while the density varies from 1025 to 1032 averaging at 1029 kgm^{-3} (Khaskheli et al. 2005) (Table. 2.1). In milk powder production, viscosity, density and heat stability play a significant role (Pisecky 2012).

2.2.2.2 The chemical composition of camel milk

The chemical composition of CM varies depending on the breed, feeding, age, geographical conditions, seasonal variations and lactation stage (Antunac et al. 2015; Al haj and Al Kanhal 2010). Amongst which, seasonal fluctuations and geographical conditions have a significant effect on its chemical composition (Konuspayeva, Faye, and Loiseau 2009). Table 2.1 provides the chemical and physical composition of dromedary CM as documented by different researchers across different regions.

Table 2. 1 Physicochemical Parameters of Dromedary Camel Milk from Different Countries

Percentage composition (wet weight basis (wwb))											
Country	**Water**	**Total Solid**	**Fat**	**SNF**	**Protein**	**CN**	**WPN**	**Lactose**	**Ash**	**pH**	**Reference**
Egypt	87.80	12.20	3.75	8.56	3.13	2.43	0.95	4.50	0.80	6.53	a, b, c, d, e
Libya	87.00	13.00	3.30	9.70	3.30	-	-	5.6	0.80	-	f
Saudi Arabia	87.70	12.30	3.49	8.87	3.26	1.90	0.90	-	0.83	6.50	g, h, i, j
Kenya	87.70	12.30	4.33	8.62	3.20	2.64	-	4.78	0.82	-	k, l, m
Somalia	86.90	13.10	4.60	8.50	3.00	-	-	4.34	0.60	6.50	n
Ethiopia	85.60	14.40	5.50	8.90	4.50	-	-	4.9	0.90	-	o
India	90.20	9.80	3.20	6.60	2.70	-	-	4.2	0.60	6.50	p
Tunisia	87.90	12.10	3.76	8.37	3.43	2.88	-	-	0.81	6.53	q
Pakistan	87.10	12.90	5.22	7.71	2.68	-	-	4.30	0.73	6.60	r

[a](Elagamy 2000a); [b] (El-Bahay 1962); [c] (Farag and Kebary 1992); [d] (Hamers-Casterman et al. 1993); [e] (Ripinsky 1983); [f] (Gnan and Sheriha 1986); [g,h] (I. H. Abu-Lehia 1987, 1989); [i] (Sawaya et al. 1984); [j] (Mehaia and Al-Kahnal 1989); [k] (Wangoh, Farah, and Puhan 1998); [l] (Karue 1998); [m] (Farah and Ruegg 1989); [n] (Mohamed 1985); [o] (Knoess 1977); [p] (Desai et al. 1982); [q] (Kamoun 1994); [r] (Zia-Ur-Rahman and Haq 1994).
The abbreviations : SNF: Solid Non Fat; WPN:Whey Protein ; CN: Casein

In addition, CM differs in composition from milk from other dairy species (Table 2.2) and this is significant for the nutritional composition of the communities that live in these regions who only have access to camel milk.

Table 2. 2 Physicochemical composition of camel milk compared to other dairy species

	Percentage composition (wwb)			Ratio	Percentage composition (wwb)			(kgm^{-3})	At 25°C
Species	Moisture	Fat	Protein	CN: Whey	Lactose	Ash	Acidity	Density	pH
Camel	86.0-91.0	2.9-5.4	2.8-3.9	1.68:1	3.3-5.4	0.6-1.0	3.3-5.4	1.01-1.02	6.57-6.97
Bovine	86.0-88.0	3.7-4.4	3.2-3.8	4.7:1	4.8-4.9	0.7-0.8	4.8-4.9	1.02-1.03	6.63-6.68
Goat	87.0-88.0	4.0-4.5	2.9-3.7	3.5:1	3.6-4.2	0.8-0.9	3.6-4.2	1.02-1.02	6.34-6.80
Sheep	79.0-82.0	6.9-8.6	5.6-6.7	3.1:1	4.3-4.8	0.9-1.0	4.3-4.8	1.02-1.03	6.40-6.80
Buffalo	82.0-84.0	7.0-11.5	3.3-3.6	4.6:1	4.5-5.0	0.8-0.9	4.5-5.0	1.02-1.02	6.60-6.90
Human	88.0-88.4	3.3-4.7	1.1-1.3	04:1	6.8-7.0	0.2-0.3	6.8-7.0	1.03-1.03	6.8-6.8

Modified from: (Fox et al. 2015; Fox and Mcsweeney 2015; Uniacke-Lowe 2011; Omar 2018)

a. Fat

CM fat contains lower amounts of short chain fatty acids and a higher proportion of long chain fatty acids compared to buffalo and bovine milk (Abbas et al. 2013), and cholesterol level of 34.5 mg/100 g is higher than that of bovine milk (25.63 mg/100 g) (Konuspayeva, Faye, and Loiseau 2009). The lower content of β-carotene coupled with the smaller fat globules (2.99 μm) characterises the white colour of CM (Al haj and Al Kanhal 2010).

b. Protein

The dromedary CM protein content ranges between 2.8 and 3.9% and is comprised majorly of whey and casein (CN) protein fractions (Table 2.2). The breed and seasonal variations influence the protein content of CM, with the highest content recorded in February (3.32%) and lowest content in October (2.76%) in the same breed in Saudi Arabia (Musaad, Faye, and Al-Mutairi 2013; Mehaia et al. 1995). The protein composition of the milk is low in high yielding and high in low yielding camels, while other milk compositions are not influenced by the yield (Zia-Ur-Rahman and Haq 1998).

Among different dairy species, CM protein has the highest concentration of whey protein (0.80%), followed by buffalo (0.68%), sheep (0.66%), goat (0.53%), and bovine milk (0.47%) (Rafiq et al. 2016). The CN protein fraction, consisting of β-casein ((β-CN) (65%)), α-casein ((α-CN) (31.5%)) and ϰ-casein ((ϰ-CN) (3.5%)) is the main protein in CM accounting for 52-87% of the total protein (Abbas et al. 2013; Al haj and Al Kanhal 2010; Antunac et al. 2015). The 3.5% ϰ-CN is approximately four times lower than the bovine ϰ-CN, which can be attributed to the larger casein micelles compared to the bovine casein micelles (Farah and Ruegg 1989; Gouda, El Zayat, and El Shabrawy 1984). Moreover, the CM stability is influenced by the additional proline residue in the ϰ-CN sequence which offers a different site for its hydrolysis by chymosin (Phe97-Ile98) compared to bovine ϰ-CN (Phe105-Met106) (Farah and Ruegg 1989; Hailu et al. 2016; Kappeler 1998). The amino acids content of CM is similar to that of bovine only differing slightly: While the casein of CM has higher proline, lysine and arginine bovine milk has been reported to contain higher levels of methionine, isoleucine, leucine, valine, phenylalanine, histidine, glycine, and serine (Elagamy 2009; Salmen et al. 2012).

Whey protein accounts for 20-25% of the CM protein fractions and it comprises of peptidoglycan recognition protein (PRP), immunoglobulins (lgG), α-lactalbumin (α-la), lactoferrin (Lf) and serum albumin (SA) (Hinz et al. 2012). In comparison to bovine milk, where β-lg (55%) is the main protein, in CM α- la (27%) is the main protein followed by SA (26%) (Laleye, Jobe, and Wasesa 2008; Hailu et al. 2016; Elagamy 2009). Both CM and bovine milk have equal number of amino acids residues (123) in α-la, however, the number of antioxidants amino acid residues (cysteine, tryptophan, and methionine) is higher in CM α-la (Salami et al., 2009). The number of amino acid residues in Camel lactoferrin (Lf) (137) is higher than that of bovine Lf (135) (Elagamy 2009).

c. Lactose

The lactose content in CM varies depending on water consumption and vegetation type that camels feed on and ranges from 3.3 to 5.4% averaging at 4.37% (Table 2.2) (Ismaili et al. 2016; Omar 2018). During seasons of water scarcity, the lactose content of CM decreases and the milk is less sweet (Al-Juboori et al. 2013). Camels often prefer halophilic plants such as Acacia, *Salosa,* and *Artiplex* to meet their physiological requirements of salts, which are responsible for the salty or bitter taste of CM (Jilo and Tegegne 2016; Al haj and Al Kanhal 2010). During the entire lactation period, the lactose content in CM remains constant (Haddadin, Gammoh, and Robinson 2008).

d. Ash/Minerals

The mineral content of CM varies from 0.6-1.0% (Table 2.2) and is influenced by water intake, breed, analytical procedures and feeding (Konuspayeva, Faye, and Loiseau 2009; Haddadin, Gammoh, and Robinson 2008). CM is a vital source of chloride, and has higher levels of Fe, Cu, Mn, Na and K compared to bovine milk (Antunac et al. 2015; Sawaya et al. 1984). In comparison to bovine and buffalo milk, the total mineral content of CM is significantly higher (Yoganandi et al. 2014).

e. Vitamins

Camel milk contains higher levels of niacin, vitamin C, folic acid, vitamin B1, B2 but lower levels of fat-soluble vitamins (A, E, B, and riboflavin) and β-carotene, than in bovine milk (Stahl et al. 2006). With a mean value of 34.16 mg/l, CM has higher vitamin C content 3-5 greater than bovine milk and 1.5 times that of human milk (Jilo and Tegegne 2016).

f. Water

The water content of CM varies throughout the year increasing to approximately 91% when water was limited at temperatures of 40-45°C and decreased to 86% when water was unlimited (Haddadin, Gammoh, and Robinson 2008). The higher water content in CM during the dry seasons is attributed to the natural adaptation where the lactating animals lose milk to water to provide the dehydrated calf with the milk of sufficient water content and nutritional value (Yadav et al. 2015).

2.2.3 Camel milk therapeutic properties

The therapeutic benefits of CM have been attributed to the several bioactive compounds therein which exist naturally in the CM or are derived using probiotic strains from CM proteins (Elagamy 2009; Quana, Tsuda, and Miyamoto 2008; Elayan, Sulieman, and Saleh 2010). CM has been documented to have significant nutritional properties and to have greater health benefits (hypo-cholesterolaemic, hypoglycemic, hypo-allergic, antimicrobial and a blood pressure regulator) compared to other types of milk, such that traditionally the Bedu and Arabia were able to survive mainly on camel milk and dates only (Benkerroum et al. 2004; El-Agamy 2007; Elayan, Sulieman, and Saleh 2010; Agrawal et al. 2007; Singh, Fotedar, and Lakshminarayana 2008; Quana, Tsuda, and Miyamoto 2008). However, these therapeutic properties have only been confirmed at laboratory levels and thus more studies need to be undertaken, to make concluding remarks.

2.2.3.1 Camel milk as an alternative for Cow Milk Protein Allergy (CMPA) and lactose intolerance

The absence of β-lg (a typical milk protein characteristic of ruminant milk) in CM makes it a good substitute for people and infants with CMPA (Konuspayeva, Faye, and Loiseau 2009; Laleye, Jobe, and Wasesa 2008). Furthermore, Infant milk powders are typically made from cow or soybean milk, however, approximately 7.5% of all babies experience CMPA (Solinas et al. 2010). Among infants and young children younger than 3 years, CMPA is the leading food allergy and can lead to anaphylactic shock and sometimes death in children while in all age groups CMPA with gastrointestinal tract manifestation can be diagnosed (Sicherer 2011; Rona et al. 2007; Spergel et al. 2002; R. G. Nielsen et al. 2004). These allergic reactions are associated with abnormal immunological responses to the casein; thus, CM is often recommended due to its lack of β-lg and the high ratio of whey protein to casein that results in a soft curd easy to digest (Kappeler 1998; El-Agamy 2008). Consequently, when 250 ml of CM was administered to 25 patients aged between 2 to 68 years diagnosed with lactose intolerance on an empty stomach for five consecutive days, 92% had no adverse effects while only 8% had mild reactions (Cardoso et al. 2010).

2.2.3.2 Hypoglycemic effect (antidiabetic effect)

Agrawal et al. (2005) and Singh, Fotedar, and Lakshminarayana (2008) documented that when CM was administered to diabetic patients in the Raica community in India, the diabetes prevalence decreased. Moreover, when 500 ml of fresh raw CM was administered daily to 24 type 1 diabetic patients, there was an improvement in long-term glycaemic control as indicated by the increase in blood glucose that resulted in a significant reduction in doses of insulin administered (Agrawal et al. 2011; Mohamad et al. 2009). The hypoglycaemic effect of CM can be ascribed to the following factors: the encapsulation of CM insulin in nanoparticles (lipid vesicles) enhancing its absorption and secure passage to the bloodstream without coagulation in the acidic conditions of the human stomach; CM small size immunoglobulin protect the pancreases' β cells from destruction; compared to milk from other dairy species, CM possess a higher concentration of Insulin-insulin like proteins such as half cysteine (Al haj and Al Kanhal 2010; Abdel Gader and Alhaider 2016).

2.2.3.3 Anti-microbial and antiviral properties of camel milk

CM contains protective proteins: lysozyme, lactoferrin (Lf), lactoperoxidase and immunoglobulins (IgG) at higher concentrations than bovine, human or buffalo milk

(Benkerroum et al. 2004; El agamy et al. 1992; Konuspayeva et al. 2007). These protective proteins are responsible for the antimicrobial and anti-viral properties of CM. Studies have indicated that Lf and Lactoperoxidase isolated from CM, possess in vitro inhibitory effects on hepatitis C virus (HCV) (genotype 4a) by preventing the entry and interaction of HCV, HepG2 (human hepatoma) and Huh7.5 (hepatocyte-derived carcinoma) cells (Redwan et al. 2015; El-Fakharany et al. 2013).

The antimicrobial effect of the CM is against both the gram-positive and gram-negative bacteria including *Listeria monocytogenes, Salmonella typhimurium Escherichia coli*, and *Staphylococcus aureus* (Elagamy 2000b; Benkerroum et al. 2004).

2.2.3.4 Treatment of Crohn's disease

Crohn's disease is a bacterial infection caused by *Mycobacterium avium* – subspecies: *paratuberculosis* (MAP), leading to the inflammation of the guts or digestive system. MAP is unaffected by pasteurisation temperatures thus can be spread through bovine milk. However, Shabo, Barzel, and Yagil (2008) reported that consumption of unpasteurized camel milk had a positive effect on Crohn diseases. This can be attributed to the presence of PRP protein, the bactericidal properties of CM and the restoration of the immune system through the action of immunoglobulins on the anti-DNA (Gizachew, Teha, and Birhanu 2014).

2.2.4 Camel milk post-harvest handling, value addition and constraints

2.2.4.1 Preservation technologies

To minimise CM spoilage through microbial contamination, different preservation technologies and strategies that increase its shelf life have been put in place along the camel milk value chain. Interventions such as the use of commercial lactoperoxidase systems (LPS) kits, evaporative cooling facilities, milk pasteurization, clean water provision and training on hygienic milk handling have been proposed in the pastoral regions of Kenya (Bornstein and Younan 2013; Adongo, Coppock, and Wayua 2013; Wayua, Okoth, and Wangoh 2013).

LPS entails the use of the lactoperoxidase enzyme to delay bacterial growth and thus preventing souring of milk for approximately 7-8 hours but does not improve the hygienic quality. It is often used within 30 minutes after milking and in areas where transportation from point of production to the cooling centres is far or where cooling facilities are absent (Moffat et al. 2016). The cost of applying the LPS system is about €0.001 per litre of milk.

Different studies have reported simple cooling technologies, fermentation, and smoking of camel milk in pastoral regions of Ethiopia and Kenya (Seifu 2007; Wayua, Okoth, and Wangoh 2012; Tabary 2018). In evaporative cooling systems, only a limited amount of milk can be handled and, is only suitable in regions with relative humidity (RH) less than 30%. This is because the cooling of milk is dependent on the difference between the wet- and dry-bulb temperatures of the surrounding air. And as the RH of the air increases, the evaporative cooling of the milk is limited (Adongo, Coppock, and Wayua 2013). Currently, plans are underway for the first camel milk processing plant in Isiolo.

2.2.4.2 Value-added Products

a. *Fermented milk*

Excess milk among the pastoral communities is usually fermented for medicinal and drinking purposes which are prepared following different methodologies that are specific to the communities. Further, targeted fermentation limits spontaneous natural fermentation that occurs in the ASALs and which is enhanced by the higher temperatures which can result in undesirable products that are risky or dangerous for human health (Farah et al. 2007). The fermented CM products as prepared across the globe are briefly described below:

- *Chal*: Traditionally sparkling white fermented camel milk prepared in Turkmenistan & Iran through addition of already fermented milk to the raw milk followed by incubated (Martinenko et al. 1977; Yam et al. 2014).
- *Kefir:* Prepared in USSR through flash pasteurisation and inoculation with Kefir culture (Rao, Gupta, and Dastur 1970).
- *Shubat:* Is a fermented milk product in Kazakhstan, north- and central-Asia prepared from raw CM with addition of *shubat* culture (lactic acid bacteria and yeast) resulting in an extremely sour taste (Chuvakova et al. 2000; Blok 2012; Lü et al. 2014).
- *Oggtt*: is obtained from dry fermented CM butter in Saudi Arabia (Al-Ruqaie, El-Nakhal, and Wahdan 1987).
- *Susaac (Susa):* is made through leaving raw milk to ferment for 1-2 days or through addition of mesophilic cultures and incubated for 24 hours (Farah, Streiff, and Bachmann 1990; Wayua, Okoth, and Wangoh 2012). It has a smoky aroma, stringent taste and low viscosity and has a shelf life of up to 20 days, due to the effect of the smoke used (Lore, Mbugua, and Wangoh 2005; Mwangi et al. 2013).

- *Gariss & Dhanaan:* It is characteristic of Somalia, and Ethiopia produced through semi-continuous fermentation of raw CM mixed with onion and black cumin *(Nigellica sativa)* that is placed in a goatskin bag and hung on the camel's saddle. The bag is then wrapped in moistened green or dry grass and enclosed in a palm leaves net. During this period, the milk is incubated within a day at the ambient temperatures (25-30 °C) (Biratu and Seifu 2016). Fermentation occurs through the continuous shaking by the bumpy camel walk and the effect of the microbes.

b. Cheese

Cheese manufacture from milk is through the enzymatic hydrolysis of κ-cN at the surface of casein micelles resulting in coagulation of milk. CM is characterised by a high ratio of whey protein to casein, and larger casein micelle size (average diameter 380 nm), which results in longer rennet coagulation time (2-3 fold) and a soft coagulum in comparison to bovine milk (Barlowska et al. 2011; Farah and Bachmann 1987). Moreover, the lower dry matter and lower κ-CN in CM lead to lower cheese yield (Bornaz et al. 2009). Due to these differences in protein composition in CM from cow, goat and sheep milk, cheese production from CM is limited. Therefore, addition of camel chymosin to the camel milk has been utilised in the production of different types of cheeses (Konuspayeva et al. 2014; Govindasamy-Lucey et al. 2010). These cheeses include: hard cheeses with a yield of 5%, soft cheeses with a yield of 4.5% for ripened and 12% for fresh cheeses (Kamoun 1994; Hailu, Seifu, and Yilma 2014), domiati cheese with a yield of between 10-12% and semi-hard cheese (Vikas and Farah 1991; Mehaia 1993). Other cheese varieties have also been manufactured from camel milk: fresh cheese, soft cheese, blue cheese, pressed cheese, Ricotta (from whey) and cottage cheese *(aarts)* (Indra and Erdenebaatar 1994; Ramet 2011, 1991; Hailu, Seifu, and Yilma 2014).

c. Butter

Production of CM butter is limited due to the creaming rate. CM fat has a higher melting point (40-41 °C) than bovine milk (8-14 °C), smaller fat globules, thicker fat globule membrane and a low amount of protein agglutinin limits faster creaming and churning in comparison to bovine milk (Farah, Streiff, and Bachmann 1989; Berhe, Seifu, and Kurtu 2013). CM has higher percentage of long chain fatty acid in their fatty acid profile, thus the higher melting point. Butter has been processed from CM, but the production process differs from bovine milk butter production due to the small fat globule sizes in CM. In Egypt, Pakistan and Sudan, camel butter has been obtained from fermented milk. However, among the nomads of northern Kenya and

Ethiopia, it is obtained from raw CM through heating in a container with several stones, cooling, beating with a whisk resulting in butter (Farah 1987; Abeiderrahmane 1994). The obtained butter is used for medicinal purposes and cooking (Mourad and Nour-Eddine 2006). Moreover, a controlled process has been developed for commercial butter processing from CM or CM mixed with other milk in northern Kenya and globally (Berhe, Seifu, and Kurtu 2013; Asresie, Seifu, and Kurtu 2013; Farah, Streiff, and Bachmann 1989).

d. Ice cream

Several authors have documented ice cream production from CM by addition of dates, vanilla and coconut to enhance sensory properties (Salem et al., 2017) Ahmed and El Zubeir (2015). In Kenya, ice cream known as *Cold Hump™* was manufactured and sold by Vital Camel Milk which was closed in 2018 (Vital Camel Milk n.d.).

e. Yoghurt

The presence of antibacterial proteins in CM that are heat stable such as lysozymes, Lf, IgG, impede the microbial starter used in yoghurt manufacture preventing acidification and curd formation (Attia, Kherouatou, and Dhouib 2001). Moreover, due to its low protein content, there is no influence on the viscosity of CM during gelation (Jumah, Shaker, and Abu-Jdayil 2001; Yoganandi et al. 2014; Omar, Harbourne, and Oruna-concha 2016). Due to these CM characteristics, production of yoghurt from CM is only possible through additives to enhance firmness and limit syneresis such as sodium alginate, Calcium Chloride ($CaCl_3$,) corn starch, and colloids (κ-carrageenan and xanthan gum) (Hashim, Khalil, and Habib 2009; Kavas 2015; Al haj and Al Kanhal 2010; Desouky, Shalaby, and Soryal 2013). Different varieties of CM yoghurt have been processed to enhance sensory value and improve consumer acceptability, this include: banana frozen yoghurt, bovine milk and CM yogurt, fermented yoghurt (*Yog'or*™) and spiced yoghurt (Attia, Kherouatou, and Dhouib 2001; Ahmadoon 2012; Ahmed, Haroun, and Eisa 2010; Shori et al. 2013; Vital Camel Milk n.d.).

f. Pasteurized and Ultra High-Temperature (UHT) treated camel milk products

Milk is heated to improve microbial safety for human consumption and prolong the shelf life. The current methods that are used in the heat treatment are pasteurisation (Low Temperature Long Time (LTLT) and High Temperature Short Time (HTST)), UHT (Ultra High Temperature) and Sterilization with UHT and HTST mainly used in the dairy industry (Benabdelkamel et al. 2017). Previous studies have indicated that at low heat treatment temperatures (<90 °C, 60 min), CM whey proteins are more stable compared to buffalo and bovine milk, but as the temperatures increase towards 98 °C for 60 min, higher levels of denaturation of whey protein occurs as indicated by the higher heat coagulation time (HCT) (Benabdelkamel et al. 2017; Sagar et al. 2016). The denaturation of whey protein during pasteurisation occurs in the following order: SA< β-lg < α- la (Farah 1986; Elagamy 2000b). However, experiments carried out on heating of CM at temperatures higher than 120 °C, reported that CM coagulated within 2-3 minutes at pH 6.5-7.1, indicating a lower heat stability at higher temperatures compared to other milk (Farah et al. 2004; O'Connell and Fox 2011; Al haj and Al Kanhal 2010). The lower heat stability at high temperatures in CM can be attributed to lower content of κ-CN and lack of β-lg which are essential for milk stabilization especially when the molar ratio between the two proteins is equal to 1 (Kappeler 1998; Barlowska et al. 2011); the low citrate level in CM influences the salt balance (the ratio of Ca & Mg to citrate & phosphate) (Farah and Ruegg 1989; El-Agamy 1983). To improve heat stability at 121 °C, it has been demonstrated that the pH of CM could be increased to 7.0–7.2 together with the addition of κ-CN, EDTA or sodium phosphate (Alhaj, Metwalli, and Ismail 2011). Both LTLT and HTST CM pasteurisation have been used to improve the microbial stability and extend the shelf life (Tay and Chua 2015; Mohamed and El-Zubeir 2014). Different studies have demonstrated that HTST, LTLT and sterilisation cause a decrease in pH, nitrogen distribution, protein and lactose content; increase in acidity and ash content while the (Solid Non-Fat) SNF, fat and milk density remained stable (Hattem et al. 2011; Elhasan et al. 2017).

Moreover heating the CM at temperatures of 50 °C negatively affected gelation properties of CM while preheating of the CM at 70 °C prevented rennet-induced gelation of CM (Kamal, Foukani, and Karoui 2017). CM has been continuously pasteurised in different countries, Mauritania, Kenya and Saudi Arabia using modern milk processing facilities, but the plants have limited capacities (3000l/day) compared to the bovine milk. In Kenya camel, milk processing plant was established in 2005, in Nanyuki, where fresh (*Vital camel Milk*^{TM}).

g. Camel Milk powder

Different studies have documented properties of spray dried cow, goat and donkey milk powders, but only a limited number of studies has focused on spray dried camel milk (Oldfield and Singh 2005; Reddy et al. 2014; Di Renzo, Altieri, and Genovese 2013). For instance, Rahman et al. (2012) studied the thermal characteristics of freeze-dried whole and skimmed CM powders through use of differential scanning calorimetry (DSC).

Sulieman et al. (2014) compared the influence of the direction of feed and concentration on the physicochemical properties of spray dried camel and cow milk powders using a pilot spray dryer. They concluded that the counter current feed direction had better influence on the yield, colour, water activity, flowability and the solubility of the powders.

2.3 Milk powder industrial production process

2.3.1 Milk powder production process

The milk for whole milk powder production should be of class A quality and is first clarified to remove dirt and any other suspended physical contaminants. The milk is then chilled at temperatures less than 5 °C and stored for less than 48 hours. The milk is then centrifuged to separate the cream, followed by cream and skim milk pasteurization (72 °C for 15 s). This is followed by standardization through addition of pasteurized cream to meet the desired fat content for whole milk powders (WMP). Homogenization follows where the fat globules sizes are decreased to diameters <1 μm, decreasing the viscosity of the milk, and further inhibiting the agglutination of the fat globules due to the denaturation of the cryoglobulins. The milk is subjected to the peroxidase test to ensure that the milk has been pasteurised appropriately, phosphatase and lipases inactivated before the evaporation process in the production of WMP. The fluid milk is channelled to the falling film evaporation where the total solids (TS) of the milk is increased to 45-55 % before spray drying through vacuum. The residence time is often less than one minute, and evaporation occurs under vacuum, to prevent deterioration of chemical compounds while also improving the heat economy of milk powder production. Evaporation of milk results in a decrease in pH, increase in viscosity, increase in lactose and salts, which enhances the partially irreversible release of soluble calcium phosphate to the colloidal form (Le Graet and Brule 1982; Oldfield 1996). The denaturation of whey protein results in an increase in viscosity as determined by the whey protein nitrogen index (WPNI). The viscosity of the concentrate is improved by heating the milk before spray drying and results in smaller droplets that decreases the outlet drying temperatures.

Spray drying can be single or multi-stage, and this is dependent on the desired final moisture of the product of approximately 2-5 % for WMP. In single stage processing, complete moisture removal occurs in the drying chamber before the powder particles are separated from the air. In two stage drying, the powders are initially dried to about 7 % moisture content in the drying chamber before final moisture removal by a fluidized bed. Compared to single stage drying, the temperature of the milk powder is about 15-25 °C lower, this results in 10 % lower energy consumption and limited heat damage to the powder. However, it is less economical in terms of investment due to increased plant capacity and powders are more prone to stickiness, thus only steep cone with separate outlet drying air are suitable for two stage drying.

The rapid removal of moisture from the concentrated milk during spray drying results in amorphous glassy state of lactose. This lactose is highly hygroscopic and readily absorbs moisture when the powder is exposed to high RH, resulting in crystallisation that leads to plasticization and caking of the milk powder (Kelly, O'Connell, and Fox 2003).

2.3.2 Spray drying process

Spray drying is the most commonly used dehydration technology for milk and its products (Mujumdar, Huang, and Chen 2010). It results in the stabilisation of milk constituents for storage and later uses through increased shelf life (Schuck 2011). Spray drying was first patented in 1882 by Samuel Percy, and its usage in the dairy industry began in 1920. Spray drying entails the atomization of a liquid containing dissolved or dispersed solids, into small droplets and exposing the droplets into a spray of microbiologically and chemically clean heated atmospheric air flowing concurrently with the droplets. The evaporation of moisture from the droplets is enhanced by the large surface area of the droplets resulting in dry powders. Moreover, there are higher rates of heat and mass transfer between the hot air and the milk droplets and thus drying take places within a short time (seconds).

In the dairy industry, concentrated milk (less than 0.06 Pa s for WMP) is atomised into droplets through either the rotary, pressure, sonic or nozzle atomisers. The atomised milk droplets come into contact concurrently with hot filtered drying air, where moisture is evaporated from the milk droplet until the droplets reach the speed of the drying air. This result in a reduction of temperature of air and an increase in the temperature of the milk droplets resulting in the production of powders. The smaller the droplets, the faster the moisture evaporation and often approximately 90% of small droplets moisture is lost within 0.1 m from the atomiser while larger particles are dried at up to 1.0 m down the drying chamber.

During the drying process, milk droplets initially undergo a constant rate drying period where moisture evaporates from the concentrate interior to the surface maintaining its saturation. During this period, the droplets follow the ideal weight-volume-diameter relationship closely and retain its spherical shape. Once the critical moisture content (15-30%) of the droplets is achieved, where the concentrate translates into a wet solid, the falling rate (second drying rate) begins. The falling rate drying is characterised by moisture diffusion through the wet particle. At this stage, the heat transfer is higher than the mass transfer and thus result in a faster increase in the particle temperature, characterised by both the moisture and temperature gradients, leading to crust formation on the particle surface.

2.3.3 Influence of spray drying on the physical-chemical and thermal properties of camel milk

In recent years, spray drying in the dairy industry has evolved both in intensification of scale and efficiency in the drying of milk products such as skim milk and whole milk powders and in the production of dairy ingredients in dried form (Schuck et al. 2016). The quality of these milk powders depends on their physical, functional, biochemical, microbiological, and sensory attributes all of which are correlated (Sharma, Jana, and Chavan 2012). These properties are in turn influenced by the feed characteristics, additives, type of dryer, preheating of the concentrate, evaporation temperature, inlet air drying temperature, outlet air drying temperature and the type of atomization (Tamime 2009; Nijdam and Langrish 2006; Pisecky 2012; Singh and Ye 2010). Figure 2. 7 indicates the influence of different spray drying parameters on the physical, chemical and thermal properties of milk. The feed viscosity depends on the total solids of the feed, homogenization degree, protein content, age thickening, temperature of the feed and the pasteurization conditions of the feed. This in turn influences the droplet size which significantly imparts the moisture content of the powders (Fig. 2.8).

Moreover, during spray drying, there are irreversible shifts in the calcium and phosphate, as indicated by lower levels of the compounds in reconstituted milk powders (Le Graet and Brule 1982). To ease the atomisation of the concentrated milk for spray drying and prevent adverse effect on the produced powder, the temperature of the concentrate must be maintained at temperatures lower than 60 °C.

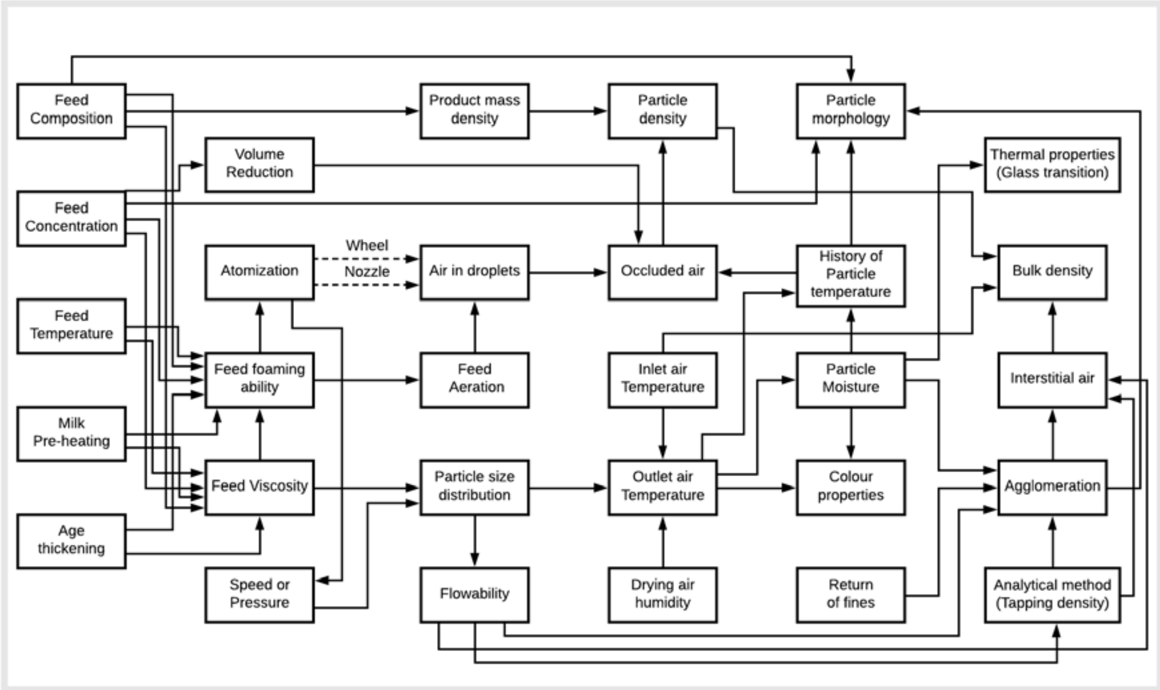


Figure 2. 7: Interrelationship of various drying parameters and feed properties on physico-chemical, colour and thermal characteristics of milk powders. Modified from (Pisecky, 2012; Schuck, 2011; Sharma et al., 2012)

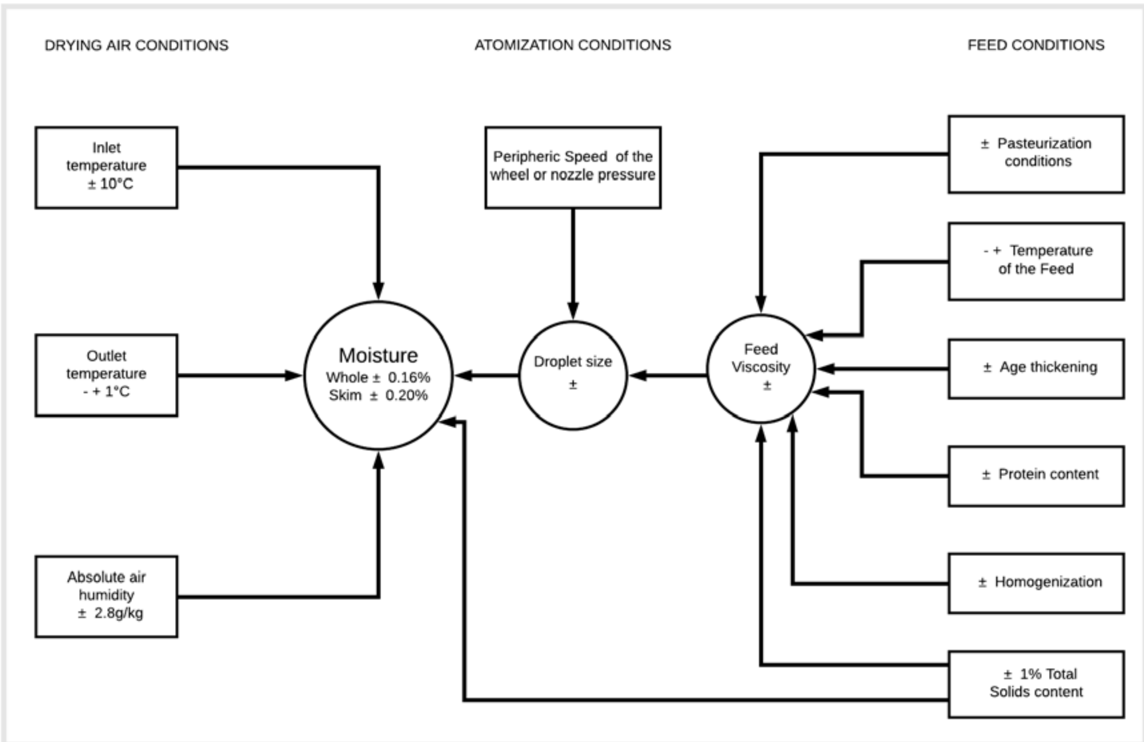


Figure 2. 8: Influence of drying air and feed conditions on powder moisture content. Adapted from (Pisecky, 2012)

2.4 Energy use in the food industry

2.4.1 Energy use in food processing

2.4.1.1 Global energy use in Food processing

Globally, the food sector accounts for about 30% of energy consumption contributing to approximately 20% of greenhouse gas emissions (GHG) due to use of fossil fuels (Gustavsson et al. 2011). In 2015, the heating sector accounted for over 50% of the total global final energy consumption, with greater than 70% of this energy originating from burning fossil fuels such as natural gas, oil or coal. Industrial heating accounts for approximately 25% of the global final energy consumption(Fig. 2.9), while cooling only for 2% (IRENA, IEA, and REN21 2018).

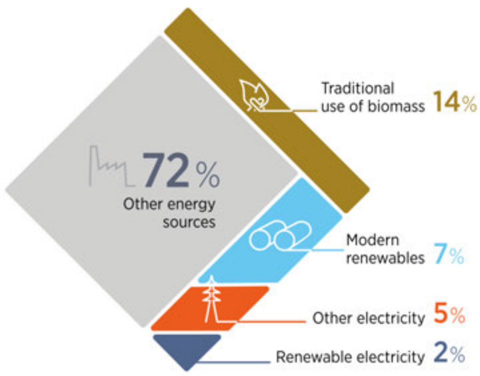


Figure 2. 9 Total global energy consumption for heat, 2015. Adapted from IRENA, IEA, and REN21 (2018). NB: Other major energy sources are gas, oil and coal.

Due to the surge in climate change and the appeal to decrease GHG emissions through use of renewable energy sources (RES) and sustainable energy usage, solar energy has been harnessed for use in the food industry either through solar photovoltaic or solar thermal technologies. While solar photovoltaic provides electrical energy, solar thermals provide energy for both heating and cooling demands (Allouhi et al. 2017; Quijera, Alriols, and Labidi 2011; Meyers et al. 2016; Sharma et al. 2017; Atkins, Walmsley, and Morrison 2010).

Industrial cooling is either through direct supply to the process such as use of refrigerant or an intermediate cooling medium such as glycol-water mixture which delivers cooling through a heat exchanger (Hassine et al. 2015). The most common cooling machine type in industry is the electrically driven compression chiller. Nevertheless, for solar cold supply absorption chillers are preferred where the electrical compressor is replaced by a thermal compressor. However, there is limited data globally on the use of renewables for cooling. Solar energy can be used to meet cooling demands through distributed solar PV generation, self-consumption, solar absorption chillers and ground source cooling (IRENA, IEA, and REN21 2018).

In a typical food industry, thermal processing contributes approximately 29-59 %, refrigeration 16 %, motor drive 12 %, HVAC and lighting 8 % and the remaining 8 % others of the total energy consumption (Okos et al. 1998; Wang 2008). The highest electrical consumption in the food industry are refrigeration (48 %) and motors 25 % (Wang 2014; Okos et al. 1998).

2.4.1.2 Integration of renewable energy in food processing industries

Most food processing industries are suited for solar heat integration as they operate at temperatures below 100 °C (Kulkarni, Kedare, and Bandyopadhyay 2008; Sturm et al. 2015; Mekhilef, Saidur, and Safari 2011). However, the feasibility of RES integration depends on the individual characteristics of the company such as the size, geographical location, thermal load, energy mix of a country, governmental programmes and thermal load profile (Sturm 2018). The methodology on the assessment of solar heat integration at process and system level in the brewery industry developed by Schmitt, (2014) has been adopted for use in the food sector due to its flexibility. The key challenges in RES integration are temporal variation of solar heat supply, complexity of heat supply and time required for optimal system design and management of heat storage (Hassine et al. 2015; Sturm 2018).

2.4.2 Energy in milk processing Industry

2.4.2.1 Energy in milk processing

Approximately, 70% of energy use in the milk processing industry is for process heating (50 °C to 220 °C) and majorly supplied in form of steam or pressurised hot water as a heat transfer medium (Kalogirou 2003). Though evaporation and spray drying are the most energy consuming processes (96% of total energy demand), in milk powder processing, they also offer an enormous potential for energy saving (Ramírez, Patel, & Blok, 2006; Wang, 2008; Westergaard, 2011). Fuels are often used in process and space heating, while electricity for refrigeration, automation, pumping, and motor drives (Wang 2014). Cooling demands along the entire milk processing chain are majorly met through indirect cooling (Hassine et al. 2015).

2.4.2.2 Energy efficiency in milk processing

In the food industry, increase in energy sustainability has been enabled through process intensification (Miah et al. 2014), process optimization (Pask et al. 2014), waste heat recovery, unit operation optimization and renewable energy integration (Krummenacher and Muster 2015). Over the past years, in the milk processing industry, these measures have seen the reduction of specific fuel consumptions from 12000 MJ_f/t_p to 5000-6000 MJ_f/t_p, and the specific electrical consumption varies between 150-400 kWh/t_p (Ramírez, Patel, and Blok 2006; Meyers et al. 2016). The fuel and electrical consumption are dependent on the scale of production, degree of heat integration and the efficiencies of the utility system (Walmsley et al. 2016).

The energy savings and use in fluid milk processing such as cheese, pasteurized milk and cream across the globe have been illustrated by a number of researchers (Xu and Flapper 2011, 2009; Ramírez, Patel, and Blok 2006; Xu, Flapper, and Kramer 2009); The utilization of emerging technologies such as radio frequency heating, membrane distillation, mono-disperse-droplet drying and air dehumidification by zeolites, and membrane contactor in skim milk powder production has been reviewed, and estimated savings in operational energy consumption of 60% has been documented (Moejes and van Boxtel 2017). Energy recovery in the milk powder manufacture through spray dryer exhaust air heat recovery has been documented by Atkins, Walmsley, & Neale, (2011). They concluded that selection of a suitable heat sink could supply about 21% of hot utility supply. Indirect heat transfer via a coupled loop between the spray dryer exhaust and various heat sinks were modelled, and the effective heat recovery potential was determined (Atkins, Walmsley, and Neale 2011).

Walmsley et al. (2016), developed an innovative ultra-low energy milk powder plant design through a total site heat integration, process and utility model approach by which an estimated reduction of 51.5%, 19.0%, and 48.6% in thermal energy, electricity and emissions respectively were realised in comparison to a modern milk powder plant. Piatkowski, Taradaichenko, and Zbicinski (2015) presented a novel spray-drying technique where maltodextrin was spray dried using flame spray drying (FSD) resulting in 5-30% lower energy consumption than the conventional spray dryers. Energy conservation in the processing of viscous dairy products at low concentration has been developed by use of a new thin film concentration device based on a spinning cone evaporator (Centritherm CT) (Tanguy et al. 2015). A reduction of energy costs by 5-30% and building costs of about 40% in production of permeate powders was documented by using vacuum concentration step of permeate from 6% to 60% TS and batch crystallisation (Schuck, Dolivet, and Méjean 2016).

2.4.2.3 Process integration for energy efficiency

This entails holistic analysis of all processes and supply equipment in a production system, insights into energy demand over time on different temperature levels, and displays optimization potential through technology enhancement, efficiency improvement and heat reocovery (Hassine et al. 2015). Several authors have presented different approaches, however optimal heat recovery through process intergration using Pinch Analysis has been documented to be the most practical in reducing energy demand in industrial processes (Kemp 2007). This is because it offers insight on the system and specific bottlenecks, solve energy and material efficiency, aid in planning process modifications, and an optimized design of a profitable energy mix for heat recovery and RES (Krummenacher and Muster 2015).

2.4.3 Renewable energy in the dairy industry

The dairy industry is the food sector with many heating and cooling processes and is approximately 15% of the of the total energy demand in the food sector in developed nations such as the Netherlands (Ramírez, Patel, and Blok 2006). In the dairy industry for production of milk powder both solar PV and solar thermal would thus play a significant role as electrical energy is demanded for mechanical and cooling purposes, while thermal demands for heating processes and utilities.

Different authors have proposed different methodologies in the integration of solar thermal in industries (Krummenacher and Muster 2015; Schmitt 2014; Sturm et al. 2015; Kulkarni, Kedare, and Bandyopadhyay 2008; Eiholzer et al. 2017). In integrating solar thermal at industrial level, this can be undertaken both at process level (total site analysis) and at unit operation (UO) levels (Schmitt 2014).

Nielsen and Pedersen (2001) utilised a solar photovoltaic system that supplied 12 DC through a control system of 10 kW to pasteurise 200 l/h of milk in Tanzania. Fresnel solar collectors have also been utilised in concentration and pasteurisation of 100 l/h of milk for cheese production with a repayment period of 8 years (Franco et al. 2008). Using flat plate collector, milk was batch pasteurised in Egypt with a pasteurisation time between 3-19 minutes depending on solar irradiation available. Minimum milk volume pasteurised was 37.3 l at 72 °C and 73.9 l at 63 °C (Atia 2008). Wayua, Okoth, and Wangoh (2013) fabricated a 40-l low-cost milk solar hot water bulk milk pasteurisation using Artificial Neural Networks (ANN) for the ASALs region of Kenya. The milk was pasteurised within 1.3 ± 0.5 h. Evacuated tube collectors were also utilised in solar pasteurisation of approximately 500 l of milk at 72 °C by Dobrowsky et al. (2015). Integration of solar in the milk pasteurization plant of 100 l/day resulted in a decrease in the amount of furnace oil used (28 l/day), increased amount of water, decreased conventional energy consumption (97.6 MWh per annum) and net annual solar savings of approximately 15,960 € (Pandagale, Gajabe, and Khambaklar 2016).

In the milk industry, most studies have focused on solar integration in the low-temperature processes such as pasteurisation and the CIP water (Anderson and Duke 2008; Quijera, Alriols, and Labidi 2011). The potential of solar collector incorporation in the provision of thermal energy in processing of milk and milk products, and the subsequent reduction of the greenhouse gas emissions have been presented for India by Sharma et al. (2017). The viability of solar thermal system integration for low and middle-temperature processes in a dairy plant in Spain using mathematical modelling and Pinch Analysis was evaluated by Quijera, Alriols, and Labidi, (2011). They concluded that incorporation of solar heat into food processing was limited due to high solar capital installation costs (Quijera, Alriols, and Labidi 2011). Walmsley et al. (2016) compared different geographical regions, different renewable energy technologies and process integration for sustainable milk powder production. They found that in California with high solar irradiation and intensive dairy production, by optimizing the process, and using biomethane from manure, 75% of themal energy above 80°C and 100% of the electrical demands could be met. The remaining 25% of thermal demands below 80°C could be met by solar thermal, but this was limited due to the large collector area and storage volumes to meet both the day and night variation. Therefore, improving manure collection by 50% was a better alternative to solar thermal usage.

Using F chart analysis, Anderson and Duke (2008) simulated the performance of four types of collectors for heating and cooling in the dairy industry. In conclusion, they documented that evacuated tubes with Compound Parabolic Concentrator (CPC) reflectors, flate plate and the building intergrated collectors could provide the heating and cooling loads to the New Zealand dairy processing industry. However, evacuated tubes without reflectors were unsuitable. Moreover, they also found that the collector area to storage volume ratio determined the solar fraction.

In milk powder production use of solar thermal processing heating systems (Benz et al., 1998 and Benz et al., 1999) and design of low-cost solar collectors for process industry applications in New Zealand has been documented (Anderson et al., 2007). In India, Arun solar concentrators have been used in steam and hot water generation for pasteurisation of milk.

Fossil fuels or waste heat often power thermal cooling systems. Through an hourly simulation model of the performance of solar process heating system, the effect of direct normal irradiance (DNI) on the annual performance of solar process heating system were studied in India. The authors estimated that the solar collector area of between 1.58-1.83*10^6 m^2 with an average solar fraction of 0.18-0.32, resulted in an annual carbon dioxide (CO_2) emission reduction of between 32-144 thousand tonnes, for energy demand of 6.40-4.50 million GJ/annum in the dairy industry (Sharma et al. 2017).

2.4.4 Solar thermal integration concepts

In solar thermal intergration (Schmitt 2014), documents the boundary conditions to be considered: what level (supply & process level); at supply level the heat transfer medium; at process level the category of heat consumer and the conventional way of heating. Table 2.3 summarizes the solar thermal integration concepts as given by (Schmitt 2014, 2016).

Table 2. 3 Solar integration Concepts (modified from (Schmitt 2014, 2016)**).**

Integration level	Heat transfer Medium	Conventional way of heating	Solar heat integration Concept	Integration Code
Supply Level	Steam (**S**)		Prallel integration (Direct or indirect) **(PD/PI)**	SL_S_PD SL_S_PI
			Heating of feed water (**FW)**	SL_S_FW
			Make-up water heating (MW)	SL_S_MW
	Liquid (**L**)		Parallel integration (direct or indirect) **(PD/PI)**	SL_L_PD SL_L_PI
			Return flow boost **(RF)**	SL_L_RF
			Heating of storage or cascades **(SC)**	SL_L_SC
Process Level		External HEX **(E)**	Heating of process medium (**PM)**	PL_E_PM
			Heating of intermediate hot water circuit (**IC)**	PL_E_IC
			Heating of bath, machinery or tank (**HB)**	PL_E_HB
			Heating of input sreams **(IS)**	PL_E_IS
		Internal HEX (**I)**		PL_I
		Steam supply **(S)**	Vacuum steam (**V)**	PL_S_V
			Low pressure steam (**LP)**	PL_S_LP

The goal is low solar heating costs thus solar heat industrial process (SHIP) systems should be designed for high system utilization. In these systems, two characteristic integration temperature levels are quite important. The integration return temperature (IRT) which is determined by the medium is the temperature from the integration point to the SHIP system. The lower the IRT the lower the mean collector temperatures, higher collector & system efficiencies thus higher system gains. The integration flow temperature (IFT) is determined by the final temperature of the medium to be heated and is the solar feed temperature. IFT can either be maximum, set or minimum, but often in the control settings a set IFT with a range of temperature tolerance is specified to maintain the process medium temperature (Hassine et al. 2015). The annual heat demand ought to be determined before the integration of solar energy as it determines the solar yield.

2.5 Energy in Kenya

2.5.1 Energy mix in Kenya

The Ministry of Energy and Petroleum (MoEP) is the Governments' apex institution in the energy sector. MoEP's directorates encompass Petroleum, Electrical Power, Renewable Energy and Geo-explorations (SE4ALL 2016). Kenya's energy mix in 2018 totalled to 284.407 thousand terajoules (TJ), with biomass accounting for 73.6% of the total energy supply (KNBS 2019). In 2018, households demanded 88.3% of non-renewable forest stocks forcing the government put a ban on logging of government forests.

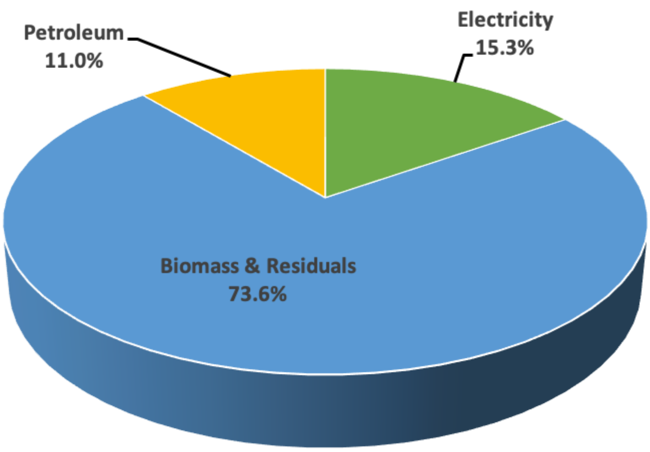


Figure 2. 10 Physical energy supply in Kenya in 2018 (KNBS 2019)**.**

2.5.2 Electricity Mix in Kenya

The installed and effective electricity capacity in Kenya in 2018 was 2711.7MW and 2253MW respectively (Fig. 2.11 a & b) (KNBS 2019). Hydropower is the largest contributor to Kenya's electrical mix, but it is dependent on the unpredictable weather conditions thus there are frequent power outages. For instance, Kenya's average power outages are at 33% compared to an average of 1% in China, South Africa and Mexico. Moreover, the energy cost of US$0.150 per kWh is about 4 times the energy cost in South Africa of US$0.040. Kenya is the 8th largest geothermal electricity produced in the world. High investment costs limit the potential of geothermal energy in Kenya, high resource exploration and development risks, land use conflicts, inadequate expertise, and high investment in infrastructure due to long distances from geothermal sites to existing load centres (MoEP 2015). However, there has been a strong focus on expanding geothermal power, which is considered a key enabler for Kenya's economic growth. Although geothermal is the most promising renewable energy source, Kenya also has excellent bioenergy, solar, wind and hydro resources for the supply of electricity.

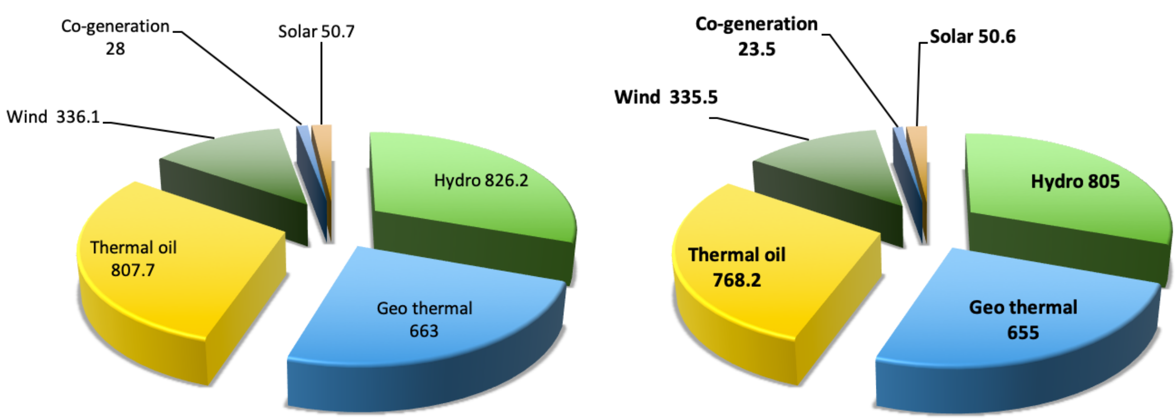


Figure 2. 11 a & b Installed and effective electricity reserves in MW in Kenya in 2018 (KNBS 2019)**.**

The Kenya Electricity Generating Company (KenGen) generates about 68% while Independent Power Producers (IPPs) about 30%. Total electricity generated in Kenya in 2018 was 11182 GWh. Generation was dominated by hydroelectricity, geothermal power and thermal oil (medium-speed diesel), which accounted for 35.6, 45.9 and 13.8 per cent of electricity supplied to the national grid (Fig. 2.12) respectively. Lake Turkana Wind Power resulted in an increase on the electricity generated from electricity from 61.3 in 2017 to 375.6 GWh in 2018. In addition, Garissa Solar power plant increase the amount of solar power generated to 13.7 GWh (KNBS 2019).

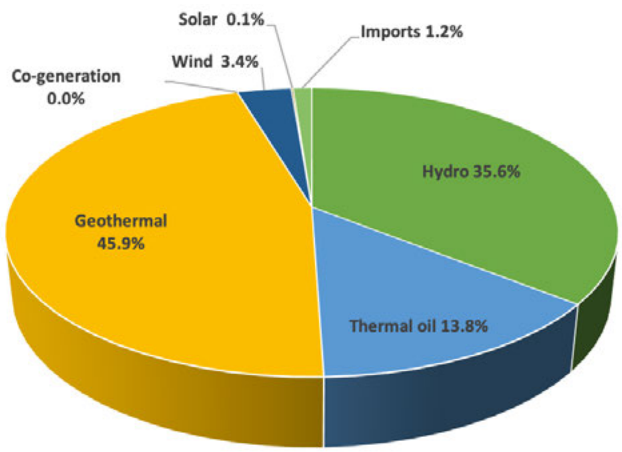


Figure 2. 12 Electricity Generation in Kenya by Energy Sources (KNBS 2019)

Kenya has great potential for the use of solar energy throughout the year because of its strategic location near the equator with 4-6 kWh/m^2/day levels of insolation. It is estimated that 200,000 photovoltaic solar home systems, most of which are rated between 10 W_e and 20 W_e estimated at a cost of Kshs 1,000/W_e, are currently in use in Kenya and generate 9 GWh of electricity annually, primarily for lighting and powering television sets. However, this is only about 1.2% of households in Kenya (KCIC 2018). Rapidly increasing demand for electricity and fluctuating hydroelectric output have led to an increase in diesel-based generation in recent years.

2.5.3 Energy in food processing in Kenya/ Process Heat Sector

The manufacturing sector contributes to 9.2% of the Kenya GDP and is the largest sub sector is the food industry. The food sub sector accounts for 43% of the total manufacturing sector therefore contributes to 3.96% of the country's GDP (KNBS 2019). With the annual thermal energy consumption in the manufacturing sector being 6394.5 GWh of which 97.9% is Biomass and the remaining 2.1% petroleum.

Industrial processes require thermal energy to produce the basic commodities and materials. The increasing cost in fuel oil has led to industries particularly the food processing industries to switch to biomass or briquettes as alternative energy sources (KAM 2018). The highest consumer of wood fuel is the tea industry followed by cottage industries (brick making, fish smoking, tobacco curing, bakeries and jaggeries). Moreover, over 80% of Kenyans are dependent on biomass as the primary energy source with charcoal contributing 13.3% and firewood 68.7% (GLGP 2013). About 82% of the urban and 87% rural population use charcoal and firewood respectively for cooking (GoK 2013). Destruction of major water catchment areas and carbon sinks, land degradation and unsustainable logging for charcoal production has led to deforestation. This has resulted in unsustainability of woody biomass and reduction of carbon sequestering provided by the trees (Government of Kenya 2018).

2.5.4 Renewable energy in dairy industry in Kenya

As can be observed from figure 2.12, renewable energy constitutes the highest percentage of the electricity mix in Kenya. In the dairy industry, electricity generated from the RES is mainly used for mechanical and electrical processes. For thermal demands, wood fuel and fuel oil are majorly used to provide thermal energy for steam and hot water generation. Milk bulking and chilling centres and processing plants need electricity to prevent deterioration of milk quality, especially the evening milk in areas where milk is only collected in the morning (ACET 2015). Before rural electrification reached many villages, CBEs and processors invested in diesel generators, also to manage the frequent interrupted supply, which drive up operational costs. Electricity costs of approximately € 0.11 (KPLC 2018) are prohibitive with constant tariff fluctuations for small cooperatives (Makoni et al. 2014; PPD Consultants 2013; MoALF 2013). Thus, providing cheaper electricity and solar power, are investment opportunities for the public and private sectors, to foster the development of the dairy sector. There are isolated attempts to adopt renewable energy technologies, such as solar panels, to power cooling systems of chilling tanks to reduce costs (Rademaker, Bebe, and Lee 2016).

2.6 Technical and socio-economic feasibility studies for a new food processing plant

2.6. 1. Food process and plant design

There is a limited source of literature on food plant design, based on the principles and technology of food science and engineering. Saravacos & Kostaropoulos (2012) recommend the adoption of chemical plant design by considering the complexity of food materials and their sensitivity to processing conditions. While process blocks diagram (PBD) are important for preliminary material and energy balances, process flow diagrams (PFD) are more detailed utilizing specific equipment, piping and utilities. Material flow rates (kg/h), temperatures (°C), pressure (bars) and energy flows (kW) can be shown in both PFD and PBD. When designing a preliminary design and sizing equipment, only the heat energy and heat balances are considered. However, in detailed process design, both electrical and mechanical demands for refrigeration, transportation, process and utility equipment are also considered.

2.6.2 Economic Analysis in food process plant design

Techno-economic feasibility is vital in determining the possibility for self-financing or for applying for a bank loan. It is important to ensure that the margin between value added products produced and the raw material, cover the overhead costs while at the same time able to meet the loan repayment within the stipulated time period (Pisecky 2012).

In locating a dairy plant, it is imperative to maximize profit, while minimizing losses, thus the location, energy, water supply, milk availability, market analysis, technical staff and the cost of raw milk are fundamental (Pisecky, 2012). Further, to undertake an economic analysis of a process, use of PFD, analytical tables of materials, labour requirements and energy at each stage is essential. In solving the complex flow sheet problems, numerical solutions, and computer techniques have been used such as CAPCOST, ASPEN PLUS (Al-Malah 2016). The annual cash flows which comprise of capital investment, annual expenses and revenue are the major building blocks of the financial economic analysis of a plant (Sanne Lemmens 2016). For solar integration in an industrial process feasibility assessment is carried out through the identification of the temperatures and load profile (Schmitt 2016).

2.6.3 Capital estimation methods

Investment cost estimation of a new plant is a challenging task, iterating as the design evolves to increased detail. Based on their level of detail and accuracy, plant cost estimates are classified into five classes (Table 2.4) and are applicable to all process industries. The accuracy ranges in each estimate, depending on technological complexity, project contingencies determination, and suitable reference information (AACE International 2016). The more details on equipment and process, the smaller the range of accuracy, thus improved estimation of the capital costs (Turton et al. 2018). Fixed capital is used in estimating the operating expenses, calculation of depreciation, cash flow and profitability of the project, thus is significant in developing the process economics.

Table 2. 4 Capital cost estimation classification matrix for process industries

No	Estimate type	Project definition level	Description	Cost estimation Methods	Accuracy range
Class 5	Order-of-magnitude/ (Ratio estimate)	0% to 2%	▪ No design information ▪ Cost data based on similar-type plants. ▪ Concept screening ▪ Utilizes PBD diagrams	▪ Stochastic ▪ *Judgement, Analogy, Capacity factored, parametric models* ▪ (Seven-tenths rule, Turnover ratio; Fixed investment/ ton capacity)	Low: -20% to -50% High: +30% to +100%
Class 4	Study / factored estimate	1% to 5%	▪ Feasibility studies ▪ Concept evaluation ▪ Project screening ▪ Preliminary budget approval ▪ Major equipment sizes basis ▪ Utilizes PFD diagrams	▪ Primarily stochastic ▪ *Equipment factored,* ▪ *Parametric models* ▪ (Lang, Hand, Wroth, Brown)	Low: -15% to -30% High: +20% to +50%
Class 3	Preliminary design/Scope /budget authorization	10% to 40%	▪ Budget authorization, funding & appropriation ▪ Detailed equipment sizing. ▪ Based on PFD diagrams	▪ Mixed but mainly stochastic ▪ *Semi-detailed unit costs & assembly level line items*	Low: -10% to -20% High: +10% to +30%
Class 2	Definitive/quotation/ Project Control estimates	30 to 70%	▪ Completed front-& engineering design (FEED) ▪ Control or Bid for contractors.	▪ Primarily Deterministic ▪ *Detailed unit cost & forced* ▪ *Detailed take-off* ▪ (Hirsh & Glazier; Guthrie)	Low: -5% to -15% High: +5% to +20%
Class 1	Detailed/ Check/ as-bid/ estimates	65% to 100%	▪ Completed design & negotiations on equipment. ▪ Vendor quotes	▪ Deterministic ▪ *Detailed unit cost with* ▪ *detailed take-off* ▪ (Richardson rapid method; code of accounts)	Low: -3% to -10% High: +3% to +15%

Source: Humphreys 2013; AACE International 2016; Perry and Green 2008; Turton et al. 2018; Couper 2003

2.6.4 Profitability analysis

Before the economic feasibility of a food processing plant, the manufacturing costs expressed as unit dollars/ time, ought to be estimated. Manufacturing costs (C_{OM}) is based on process information from the PFD, fixed capital investment (FCI), and number of plant operators. C_{OM} is the sum of general expenses (GE), direct (C_{DM}) and fixed (C_{FM}) manufacturing costs (Ulrich 1984; Peters et al. 2003; Valle-Riestra 1983). The after-tax cash flow, payback time and

DCFROR are crucial in the determination of the profitability of a plant. The taxation rate, interest rate and time the discounted rate criterion is used in the determination of Net present value (NPV).

2.6.5 Sensitivity analysis

To ascertain the effect of uncertainties in the viability of the designed process, a sensitivity analysis is undertaken by varying the costs of various variables. In food industry, the costs of raw material, manufacturing, Fixed capital, revenue, interest rate and taxation rate are often varied (Saravacos and Kostaropoulos 2012). A tornado plot using Excel^{TM} is plotted to identify the critical factors influencing the profitability.

2.7 Gaps in knowledge and necessary key advances in the state of art

While a great number of studies have been undertaken on the dairy industry particularly camel milk in Kenya, in assessing the losses and understanding the value chain, there still exists a gap in documentation of strategies and technologies for camel milk preservation in the ASALs. Moreover, limited information is available on the milk that is non utilized with assumption that they are always discarded. To address the losses and develop new products that can be kept for longer duration of time, it is imperative to assess the situation through detailed studies.

Milk powder is one of the value-added milk products that have longer shelf life of up to eighteen months and thus is one of the technologies that can utilised to limit milk losses in the ASALs. Whilst there exists literature on milk powder production through spray drying from different animals such as bovine, goat and donkey, there is limited information on CM powder. Literature on CM powder production has been limited on its thermal properties when freeze-dried and how feed direction and concentration of the feed influence its physicochemical. A gap in knowledge exists on how different processing parameters influence the CM powder properties. Particularly, the effect of the inlet drying air temperature and milk flow rate on the physical, optical and thermal characteristics of laboratory dried camel milk powders has not been documented. Besides, there is no information on the comparison of the laboratory spray dried camel milk and commercial milk powders.

Large scale industrial fuel oil and biomass plants for milk powder processing exists across different parts of the globe and in Kenya where spray drying of milk powder from different animals is undertaken. In Kenya, despite the large volume of camel milk available, the milk processing plants established only process bovine milk into milk powder utilizing biomass as source of fuel for heating whilst electricity is utilised for cooling and mechanical processes. The ASALs of Kenya is characterized by high CM production, high solar irradiation, less biofuels due to deforestation, less water supply, high poverty levels and low literacy rates. Hence, designing a milk powder processing plant ought to take into consideration the socio-economic and technical feasibility of these areas. Thus, a different approach must be explored that: limits fossil fuel and biofuels utilization, technically feasible for the ASALs and utilises the high solar irradiation characteristic of the region to limit the CM physical and economic losses. In this regard, there is need to explore the development and design of a decentralized small-scale hybrid solar-fossil fuel powered decentralized process design for a CM powder and butter processing plant for the ASALs.

References

AACE International. 2016. “Recommended Practice No. 18R-97: Cost Estimate Classification System, Rev March 1, 2016.” https://doi.org/Recommended Practice No. 18R-97.

Abbas, S, A Hifsa, N Aalia, and S Lubna. 2013. “Physico-Chemical Analysis and Composition of Camel Milk.” *International Researchers* 2 (2): 82–98.

Abdel Gader, Abdel Galil M., and Abdulqader A. Alhaider. 2016. “The Unique Medicinal Properties of Camel Products: A Review of the Scientific Evidence.” *Journal of Taibah University Medical Sciences* 11 (2): 98–103. https://doi.org/10.1016/j.jtumed.2015.12.007.

Abeiderrahmane, N. 1994. “Pasteurization of Camel’s Milk in Experiments in Mauritania.” In *Workshop Dromedaries and Camels as Milking Animals, Nouakchott, Mauritania, 24–26 October*, edited by P. Bonnet, 213–19.

Abu-Lehia, I. H. 1987. “Composition of Camel Milk.” *Milchwissenschaft* 42: 368–71. https://doi.org/10.1111/j.1471-0307.2010.00575.x.

Abu-Lehia, I. H. 1989. “Physical and Chemical Characteristics of Camel’s Colostrum.” *Australian Journal of Dairy Technology* 44: 34–36. https://doi.org/10.1533/9781845693398.10.

ACET. 2015. “Promoting Sustainable Rural Development and Transformation in Africa – Kenya Country Report.” Accra.

Adongo, A. O., D. L. Coppock, and F. O. Wayua. 2013. “Simple Evaporative Cooling Method Reduces Bacterial Content of Traditionally Marketed Camel Milk in Isiolo County, Kenya.” *African Journal of Food, Agriculture, Nutrition and Development* 13 (1): 7213–24. https://doi.org/10.4314/ajfand.v13i1.

Agrawal, R. P., S Budania, P Sharma, Rajeev Gupta, D. K. Kochar, R. B. Panwar, and M. S. Sahani. 2007. “Zero Prevalence of Diabetes in Camel Milk Consuming Raica Community of North-West Rajasthan, India.” *Diabetes Research and Clinical Practice* 76 (2): 290–96. https://doi.org/10.1016/j.diabres.2006.09.036.

Agrawal, R. P., S Jain, S Shah, A Chopra, and V Agarwal. 2011. “Effect of Camel Milk on Glycemic Control and Insulin Requirement in Patients with Type 1 Diabetes: 2-Years Randomized Controlled Trial.” *European Journal of Clinical Nutrition* 65 (10): 1048–52. https://doi.org/10.1038/ejcn.2011.98.

Agrawal, R P, R Beniwal, S Sharma, D K Kochar, and F C Tuteja. 2005. “Effect of Raw Camel Milk in Type 1 Diabetic Patients : 1 Year Randomised Study.” *Journal Of Camel Practice And Research* 12 (1): 27–35.

Ahmadoon, Hala Gindeel Abubaker. 2012. “Quality Changes in Yoghurt Made from Camel Milk and Mixed Camel Milk with Cow Milk during Preservation.” *Red Sea University Journal* 2: 27–37.

Ahmed, Salma Kh, Rea Haroun, and Mohamed O. Eisa. 2010. “Banana Frozen Yoghurt from Camel Milk.” *Pakistan Journal of Nutrition* 9 (10): 955–56. https://doi.org/10.3923/pjn.2010.955.956.

Al-Juboori, A. T., M. Mohammed, J. Rashid, J. Kurian, and S. El Refaey. 2013. “Nutritional and Medicinal Value of Camel (Camelus Dromedarius) Milk.” *WIT Transactions on Ecology and the Environment* 170: 221–32. https://doi.org/10.2495/FENV130201.

Al-Malah, K. I.M. 2016. *Aspen Plus: Chemical Engineering Applications.*

Al-Ruqaie, Ibrahim M., Hamza M. El-Nakhal, and Ahmed N. Wahdan. 1987. “Improvement in the Quality of the Dried Fermented Milk Product, Oggtt.” *Journal of Dairy Research* 54 (3): 429–35. https://doi.org/10.1017/S0022029900025619.

Alhaj, Omar A., Ali A. M. Metwalli, and Elsayed A. Ismail. 2011. “Heat Stability of Camel Milk Proteins after Sterilisation Process.” *Journal of Camel Practice and Research* 18 (2): 277–82.

Allouhi, A, Y Agrouaz, Mohammed Benzakour Amine, S Rehman, M. S. Buker, T Kousksou, A Jamil, and A Benbassou. 2017. “Design Optimization of a Multi-Temperature Solar Thermal Heating System for an Industrial Process.” *Applied Energy* 206: 382–92. https://doi.org/10.1016/j.apenergy.2017.08.196.

Anderson, Timothy Nicholas, and Mike Duke. 2008. “Solar Energy Use for Energy Savings in Dairy Processing Plants.” In *IPENZ Engineering TreNz 2008-001*, 1–9.

Antunac, Neven, Andreja Brezovečki, Mateja Čagalj, Zrinka Filipović Dermit, Nataša Mikulec, Darija Bendelja Ljoljić, and Neven Antunac. 2015. “Camel Milk and Milk Products.” *Mljekarstvo* 65 (2): 81–90. https://doi.org/10.15567/mljekarstvo.2015.0202.

Asresie, Aleme, Eyassu Seifu, and Mohammed Yusuf Kurtu. 2013. “Churning Efficiency and Microbial Quality of Butter Made from Camel Milk Alone and Blending It with Goat Milk.” *Net Journal of Agricultural Science* 1: 75–80.

Atia, M.F. 2008. “Solar Energy Utilization for Milk Pasteurization in Egypt.” Ain Shams Univeristy.

Atkins, Martin J, Michael R W Walmsley, and Andrew S Morrison. 2010. “Integration of Solar Thermal for Improved Energy Efficiency in Low-Temperature-Pinch Industrial Processes.” *Energy* 35: 1867–73. https://doi.org/10.1016/j.energy.2009.06.039.

Atkins, Martin J, Michael R W Walmsley, and James R Neale. 2011. “Integrating Heat Recovery from

Milk Powder Spray Dryer Exhausts in the Dairy Industry.” *Applied Thermal Engineering* 31 (13): 2101–6. https://doi.org/10.1016/j.applthermaleng.2011.03.006.

Attia, H, N Kherouatou, and A Dhouib. 2001. “Dromedary Milk Lactic Acid Fermentation: Microbiological and Rheological Characteristics.” *Journal of Industrial Microbiology and Biotechnology* 26 (5): 263–70. https://doi.org/10.1038/sj.jim.7000111.

Barlowska, J., M. Szwajkowska, Z. Litwi´nczuk, J. Kr´ol, Z. Litwi??czuk, and J. Kr??l. 2011. “Nutritional Value and Technological Suitability of Milk from Various Animal Species Used for Dairy Production.” *Comprehensive Reviews in Food Science and Food Safety* 10 (6): 291–302. https://doi.org/10.1111/j.1541-4337.2011.00163.x.

Benabdelkamel, Hicham, Afshan Masood, Ibrahim O. Alanazi, Dunia A. Alzahrani, Deema K. Alrabiah, Sami A. Alyahya, and Assim A. Alfadda. 2017. “Proteomic Profiling Comparing the Effects of Different Heat Treatments on Camel (Camelus Dromedarius) Milk Whey Proteins.” *International Journal of Molecular Sciences* 18 (4): 1–15. https://doi.org/10.3390/ijms18040721.

Benkerroum, Noreddine, Majda Mekkaoui, Nargisse Bennani, and Kamal Hidane. 2004. “Antimicrobial Activity of Camel’s Milk against Pathogenic Strains of Escherichia Coli and Listeria Monocytogenes.” *International Journal of Dairy Technology* 57 (1): 39–43. https://doi.org/10.1111/j.1471-0307.2004.00127.x.

Berhe, Tesfamariam, Eyassu Seifu, and Mohammed Y. Kurtu. 2013. “Physicochemical Properties of Butter Made from Camel Milk.” *International Dairy Journal* 31 (2): 51–54. https://doi.org/10.1016/j.idairyj.2013.02.008.

Biratu, K, and E Seifu. 2016. “Chemical Composition and Microbiological Quality of Dhanaan: Traditional Fermented Camel Milk Produced in Eastern Ethiopia.” *International Food Research Journal* 23 (5): 2223–28.

Blok, Kim. 2012. “Microbiological and Biochemical Characterization of Kombucha.” In *2nd International Camelid Conference: Agroeconomics of Camelid Farming, Almaty, Kazakhstan. 2000.*, 75. Almaty, Kazakhstan.

Bornaz, Salwa, Ali Sahli, Amira Attalah, and Hamadi Attia. 2009. “Physicochemical Characteristics and Renneting Properties of Camels’ Milk: A Comparison with Goats’, Ewes’ and Cows’ Milks.” *International Journal of Dairy Technology* 62 (4): 505–13. https://doi.org/10.1111/j.1471-0307.2009.00535.x.

Bornstein, S, and M Younan. 2013. “Significant Veterinary Research on the Dromedary Camels of Kenya: Past and Present.” *Journal of Camelid Science* 6: 1–48.

Bulliet, Richard. 1975. “The Camel and the Wheel.” *Cambridge, MA: Harvard University Press* 56: 340.

Cardoso, Ronald R.A., R. M.D.B. Santos, C. R.A. Cardoso, and M. O. Carvalho. 2010. “Consumption of Camel’s Milk by Patients Intolerant to Lactose. A Preliminary Study.” *Revista Alergia Mexico* 57 (1): 26–32.

Chuvakova, Z.K., R.U. Beisembayeva, O.M. Puzyrevskaya, M.G. Saubenouva, M.G. Shamenova, T.I. Glebova, E.I. Popova, M.M. Baizhomartova, and E.K. Baimenov. 2000. "Chemical Composition, Microbial Control and Antiviral Properties of Freshly Made and Conserved Shubat 'Bota.'" In *Proc. 2nd Int. Caroc. 2nd International Camelid Conference Agroeconomics of Camelid Farming, Almaty, Kazakhstan, 8–12 September*, 8–12. Almaty, Kazakhstan.

Couper, James R. 2003. *Process Engineering Economics*. New York: Mercel Dekker, Inc.

Dahl, G, and A Hjort. 1990. "Dromedary Pastoralism in Africa and Arabia." *Improvement of Tropical and Subtropical*, 144–60.

Desai, H.K., J.N. Patel, A.J. Pandya, K.G. Upadhyay, and S.H. Vyas. 1982. "Composition of Camels' Milk." *Gujarat Agricultural University Research Journal* 7 (2): 131–32.

Desouky, Marwa M., Samah M. Shalaby, and K.A. Soryal. 2013. "Compositional, Rheological and Organoleptic Qualities of Camel Milk Labneh as Affected by Some Milk Heat Treatments." *World Journal of Dairy & Food Sciences* 8 (2): 118–30. https://doi.org/10.5829/idosi.wjdfs.2013.8.2.1124.

Dobrowsky, P.H., M. Cartens, J. De Villiers, T. E. Cloete, and W. Khan. 2015. "Efficiency of a Closed Coupled Solar Milk Pasteurizer System in Treating Roof Harvested Rainwater." *Sci Total Environ* 536: 206–2014.

Eiholzer, Tobias, Donald Olsen, Sebastian Hoffmann, Barbara Sturm, and Beat Wellig. 2017. "Integration of a Solar Thermal System in a Medium-Sized Brewery Using Pinch Analysis: Methodology and Case Study." *Applied Thermal Engineering* 113 (February): 1558–68. https://doi.org/10.1016/j.applthermaleng.2016.09.124.

El-Agamy, E.I. 1983. "Studies on Camel's Milk." Alexandria University, Egypt.

El-Agamy, E.I. 1994. "Camel Colostrum. I. Physicochemical and Microbiological Study." *Alexandria Science Exchange* 15: 209–17.

El-Agamy, E.I. 2007. "The Challenge of Cow Milk Protein Allergy." *Small Ruminant Research* 68 (1): 64–72. https://doi.org/10.1016/j.smallrumres.2006.09.016.

El-Agamy, E.I. 2008. "Camel Milk." In *Handbook of Milk of Non-Bovine Mammals*, edited by Young W. Park and George F W Haenlein, 1–449. https://doi.org/10.1002/9780470999738.

El-Agamy, El Sayed I., Roger Ruppanner, Amin Ismail, and Claude P. Champagne. 1992. "Antibacterial and Antiviral Activity of Camel Milk Protective Proteins." *Journal of Dairy Research* 59 (2): 169–75. https://doi.org/10.1017/S0022029900030417.

El-Bahay, G.M. 1962. "Normal Contents of Egyptian Camel Milk." *Vet. Med. J.* 8 (9): 7–18.

El-Fakharany, Esmail M, Lourdes Sánchez, Hussein A Al-Mehdar, and Elrashdy M Redwan. 2013. "Effectiveness of Human, Camel, Bovine and Sheep Lactoferrin on the Hepatitis C Virus Cellular Infectivity: Comparison Study." *Virology Journal* 10: 1–10. https://doi.org/10.1186/1743-422X-10-199.

Elagamy, E. I. 2009. "Bioactive Components in Camel Milk." In *Bioactive Components in Milk and*

Dairy Products, edited by Y. W. Park (Ed.), 107:159–185. Wiley-Blackwell.

Elagamy, E.I. 2000a. "Physicochemical, Molecular and Immunological Characterization of Camel Calf Rennet: A Comparison with Buffalo Rennet." *Journal of Dairy Research* 67 (1): 73–81. https://doi.org/10.1017/S0022029999003957.

Elagamy, E.I. 2000b. "Effect of Heat Treatment on Camel Milk Proteins with Respect to Antimicrobial Factors: A Comparison with Cows' and Buffalo Milk Proteins." *Food Chemistry* 68 (2): 227–32. https://doi.org/10.1016/S0308-8146(99)00199-5.

Elayan, Abdallah A., Abdel Moneim E Sulieman, and F. A. Saleh. 2010. "The Hypocholesterolemic Effect of Gariss and Gariss Containing Bifidobacteria in Rats Fed on a Cholesterol-Enriched Diet." *Asian Journal of Biochemistry* 5 (1): 43–47. https://doi.org/10.3923/ajb.2008.43.47.

Elhadi, Yazan Ahmed Mohamed. 2014. "Assessing the Contribution of Camel Milk As a Livelihood Strategy for Building Pastoral Household Resilience in the Drylands of Kenya." University of Nairobi, Kenya.

Elhasan, Sawsan M.O., Amir M.M. Bushara, Hamid A. Elfaki Khadir E.K. Abdelhakam, Ahmed I.A. Eibaid, Fatin H. Farahat, Ezzeldein M.Y. Ali, and Awad M.A. Sukrab. 2017. "Effect of Heat Treatments on Physico-Chemical Properties of Milk Samples." *Journal of Academia and Industrial Research (JAIR)* 6 (3): 40–46.

Epstein, Hellmut. 1971. *The Origins of the Domestic Animals of Africa*. Vol. 2. Africana Publishing Corporation.

FAOSTAT. 2019. "FAOSTAT, FAO Statistical Databases, Livestock Primary." FAO Statistical Databases. 2019. http://www.fao.org/faostat/en/#data/QL.

Farag, S I, and K M K Kebary. 1992. "Chemical Composition and Physical Properties of Camel's Milk and Milk Fat." In *Proceedings: 5th Egyptian Conference for Dairy Science and Technology. Egyptian Society of Dairy Science, Cairo, Egypt*, 57–67. Cairo, Egypt.

Farah, Z., and A. Fischer. 2004. *Milk and Meat from the Camel - Handbook on Products and Processing*. vdf Hochschulverlag.

Farah, Z., and M. W Ruegg. 1989. "The Size Distribution of Casein Micelles in Camel Milk." *Food Microstructure* 8 (2): 211–16.

Farah, Z., T. Streiff, and M.R. Bachmann. 1989. "Manufacture and Characterization of Camel Milk Butter." *Milchwissenschaft* 44 (7): 412–14.

Farah, Z., Thomas Streiff, and Marc R. Bachmann. 1990. "Short Communication: Preparation and Consumer Acceptability Tests of Fermented Camel Milk in Kenya." *Journal of Dairy Research* 57 (2): 281–83. https://doi.org/10.1017/S002202990002690X.

Farah, Zakaria. 1986. "Effect of Heat Treatment on Whey Proteins of Camel Milk." *Milchwissenschaft* 41 (12): 763–65.

Farah, Zakaria. 1987. "Production of Cultured Milk and Butter from Camel Milk." *Report on Field Studies in Kenya, ETH Zurich*.

Farah, Zakaria, and Marc R. Bachmann. 1987. “Rennet Coagulation Properties of Camel Milk.” *Milchwissenschaft* 42 (10): 689.

Farah, Zakaria, P. Eberhard, J. Meyer, B. Rehberger, A. Thomet, and P.U. Gallmann. 2004. “UHT Processing of Camel Milk.” Zurich.

Farah, Zakaria, Matthias Mollet, Mario Younan, and Ragge Dahir. 2007. “Camel Dairy in Somalia: Limiting Factors and Development Potential.” *Livestock Science* 110 (1–2): 187–91. https://doi.org/10.1016/j.livsci.2006.12.010.

Farah, Zakaria, Thomas Streiff, and M.R. Marc R Bachmann. 1989. “Manufacture and Characterization of Camel Milk Butter.” *Milchwissenschaft* 44 (7): 412–14.

Faye, Bernard. 2016. “The Camel, New Challenges for a Sustainable Development.” *Tropical Animal Health and Production* 48 (4): 689–92. https://doi.org/10.1007/s11250-016-0995-8.

Field, C. R. 1980. “Camel Milk Production in Marsabit District, Northern Kenya.” In *6th Workshop on Camels, Khartoum, Sudan, 18-20 December 1979.*, 21–24. Khartoum, Sudan: International Foundation for Science.

Fox, P.F., T. Uniacke-Lowe, P.L.H. McSweeney, and J.A. O’Mahony. 2015. “Production and Utilization of Milk.” In *Dairy Chemistry and Biochemistry*, Second, 1–19. Cham: Springer.

Fox, P F, and P L H Mcsweeney. 2015. *Dairy Chemistry and Biochemistry*. *Dairy Chemistry and Biochemistry*. 2nd ed. Cham: Springer. https://doi.org/10.1007/978-3-319-14892-2.

Franco, Judith, Luis Saravia, Veronica Javi, Ricardo Caso, and Carlos Fernandez. 2008. “Pasteurization of Goat Milk Using a Low Cost Solar Concentrator.” *Solar Energy* 82: 1088–94.

Gizachew, Ayele, Jabir Teha, and Tadesse Birhanu. 2014. “Review on Medicinal and Nutritional Values of Camel Milk.” *Nature and Science* 12 (12): 35–40. https://doi.org/10.5829/idosi.ajn.2014.3.3.93210.

GLGP. 2013. “Kenya Market Assessment.”

Gnan, S.O., and A.M. Sheriha. 1986. “Composition of Libyan Camel’s Milk.” *Australian Journal of Dairy Technology* 41 (1): 33–35.

GoK. 2013. “ANALYSIS OF DEMAND AND SUPPLY OF WOOD PRODUCTS IN KENYA.”

Gouda, A, A El Zayat, and SA El Shabrawy. 1984. “Electron Microscopy Study on the Size Distribution of Casein Micelles, Fat Globules and Fat Globule Membrane of Camel Milk.” *Annals of Agricultural Science, Ain Shams University* 20 (2): 755–62.

Government of Kenya. 2018. “National Climate Change Action Plan (Kenya) 2018-2022.” Vol. I. Nairobi, Kenya.

Govindasamy-Lucey, Selvarani, Yanjie Lu, John J. Jaeggi, Mark E. Johnson, and John A. Lucey. 2010. “Impact of Camel Chymosin on the Texture and Sensory Properties of Low-Fat Cheddar Cheese.” *Australian Journal of Dairy Technology* 65 (3): 139–42.

Graet, Y Le, and G Brule. 1982. “Effect of Concentration and Drying on Mineral Equilibria of Skim Milk and Retentates.” *Lait* , 113–25.

Gustavsson, Jenny, Christel Cederberg, Ulf Sonesson, Robert van Otterdijk, and Alexandre Meybeck. 2011. "Global Food Losses and Food Waste - Extent, Causes and Prevention." *Global Food Losses and Food Waste*. https://doi.org/10.1098/rstb.2010.0126.

Haddadin, Malik SY, Sana I Gammoh, and Richard K Robinson. 2008. "Seasonal Variations in the Chemical Composition of Camel Milk in Jordan." *Journal of Dairy Research* 75 (01): 8–12. https://doi.org/10.1017/S0022029907002750.

Hailu, Yonas, Egon Bech Hansen, Eyassu Seifu, Mitiku Eshetu, Richard Ipsen, and Stefan Kappeler. 2016. "Functional and Technological Properties of Camel Milk Proteins: A Review." *Journal of Dairy Research* 83 (4): 422–29. https://doi.org/10.1017/S0022029916000686.

Hailu, Yonas, Eyassu Seifu, and Zelalem Yilma. 2014. "Physicochemical Properties and Consumer Acceptability of Soft Unripened Cheese Made from Camel Milk Using Crude Extract of Ginger (Zingiber Officinale) as Coagulant." *African Journal of Food Science* 8 (2): 87–91. https://doi.org/10.5897/AJFS2013.1102.

haj, Omar A. Al, and Hamad A. Al Kanhal. 2010. "Compositional, Technological and Nutritional Aspects of Dromedary Camel Milk." *International Dairy Journal* 20 (12): 811–21. https://doi.org/10.1016/j.idairyj.2010.04.003.

Hamers-Casterman, C., T. Atarhouch, S. Muyldermans, G. Robinson, C. Hammers, E. Bajyana Songa, N. Bendahman, and R. Hammers. 1993. "Naturally Occurring Antibodies Devoid of Light Chains." *Nature* 363 (6428): 446–48. https://doi.org/10.1038/363446a0.

Hartley, B.J J. 1984. "The Dromedary of the Horn of Africa." In *The Camelid: An All Purpose Animal. Proc.Workshop Camels, Khartoum, Sudan, 18–20 December, 1979*, edited by W.R. Cockrill, 1st ed., 77–97. Scandinavian Institute of African studies.

Hashim, I B, A H Khalil, and H Habib. 2009. "Quality and Acceptability of a Set-Type Yogurt Made from Camel Milk." *Journal of Dairy Science* 92 (3): 857–62. https://doi.org/doi.org/10.3168/jds.2008-1408.

Hassan, Y.M. 1971. "A Note on the Effect of Dehydration on a Camel." *Sudan Journal of Veterinary Science and Animal Husbandry* 12: 111–12.

Hassine, Ilyes Ben, Annabell Helmke, Stefan Heß, Pierre Krummenacher, Bettina Muster, Bastian Schmitt, and Hans Schnitzer. 2015. "Solar Process Heat for Production and Advanced Applications: Integration Guideline." *IEA SHC Task 49*.

Hattem, HE, MA Naeim, HS Sakr, and EH Abouel-Einin. 2011. "A Study on the Effect of Thermal Treatments on Composition and Some Properties of Camel Milk." *Slovakia Journal of Animal Science* 44 (3): 97–102.

Hinz, Katharina, Paula M. O'Connor, Thom Huppertz, R Paul Ross, and Alan L Kelly. 2012. "Comparison of the Principal Proteins in Bovine, Caprine, Buffalo, Equine and Camel Milk." *Journal of Dairy Research* 79 (2): 185–91. https://doi.org/10.1017/S0022029912000015.

Humphreys, Kenneth K. 2013. *Project and Cost Engineers's Handbook*. Vol. 53.

https://doi.org/10.1017/CBO9781107415324.004.

Indra, R., and B. Erdenebaatar. 1994. "Camel's Milk Processing and Its Consumption Patterns in Mongolia." In *Workshop Dromedaries and Camels as Milking Animals, Nouakchott, Mauritania, 24–26 October*, edited by P. Bonnet (ed.), 257–61.

IRENA, IEA, and REN21. 2018. "Renewable Energy Policies in a Time of Transition."

Ismail, M.D., and S.E. Al-Mutairi. 1994. "Milk Production Potential of Dairy Camels in Northern Saudi Arabia." In *In: Proc. Workshop Dromedaries and Camels as Milking Animals, Nouakchott, Mauritania, 24–26 October*, edited by P. Bonnet (ed.)., 35–40.

Ismaili, Maha Alaoui, Bouchta Saidi, Mohamed Zahar, Abed Hamama, and Raghia Ezzaier. 2016. "Composition and Microbial Quality of Raw Camel Milk Produced in Morocco." *Journal of the Saudi Society of Agricultural Sciences*. https://doi.org/10.1016/j.jssas.2016.12.001.

Jilo, Kula, and Dechasa Tegegne. 2016. "Chemical Composition and Medicinal Values of Camel Milk." *International Journal of Research Studies in Biosciences* 4 (4): 13–25. https://doi.org/10.20431/2349-0365.0404002.

Jumah, R Y, R R Shaker, and B Abu-Jdayil. 2001. "Effect of Milk Source on the Rheological Properties of Yogurt during the Gelation Process." *International Journal of Dairy Technology* 54 (3): 89–93. https://doi.org/10.1046/j.1364-727x.2001.00012.x.

Kalogirou, Soteris. 2003. "The Potential of Solar Industrial Process Heat Applications." *Applied Energy* 76 (4): 337–61. https://doi.org/10.1016/S0306-2619(02)00176-9.

KAM. 2018. "Manufacturing in Kenya Under the 'Big 4 Agenda.'"

Kamal, Mohammad, Mohammed Foukani, and Romdhane Karoui. 2017. "Effects of Heating and Calcium and Phosphate Mineral Supplementation on the Physical Properties of Rennet-Induced Coagulation of Camel and Cow Milk Gels." *Journal of Dairy Research* 84 (2): 220–28. https://doi.org/10.1017/S0022029917000152.

Kamoun, M. 1994. "Evaluation de La Composition Du Lait de Dromadaire Durant La Lactation: Consequences Technologiques." In *Roc. Workshop Dromedaries and Camels as Milking Animals, Nouakchott, Mauritania, 24–26 October*, edited by P. Bonnet (ed.), 167–71.

Kappeler, Stefan. 1998. "Compositional and Structural Analysis of Camel Milk Proteins with Emphasis on Protective Proteins." SWISS FEDERAL INSTITUTE OF TECHNOLOGY Zurich. https://doi.org/https://doi.org/10.3929/ethz-a-010180262 Rights.

Karue, C. N. 1998. "T He Dairy Characteristics of the Kenyan Camel." In *Proc. Workshop Dromedaries and Camels as Milking Animals, Nouakohott, Mauritania, 24–26 October*, 55–60.

Kavas, G. 2015. "KEFIRS MANUFACTURED FROM CAMEL (Camelus Dramedarius) MILK and COW MILK : Comparison of Some Chemical and Microbial Properties." *Italian Journal of Food Science and Technology* 27: 357–65.

KCIC. 2018. "Kenya Solar Pv Market Assesment." Nairobi; Kenya.

Kelly, A. L. L., J. E. E O'Connell, and P. F. F. Fox. 2003. "Manufacture and Properties of Milk

Powders." In *Advanced Dairy Chemistry: Vol. 1. Proteins*, 1:1027–62. Boston, MA: Springer US. https://doi.org/10.1007/978-1-4419-8602-3_29.

Kemp, Ian C. 2007. *Pinch Analysis and Process Integration: A User Guide on Process Integration for the Efficient Use of Energy*. *Pinch Analysis and Process Integration*. Second edi. Elsevier Ltd. https://doi.org/http://dx.doi.org/10.1016/B978-075068260-2.50003-1.

Khaskheli, M., M.A. Arain, S. Chaudhry, A.H. Soomro, and T.A. Qureshi. 2005. "Physico-Chemical Quality of Camel Milk." *Journal of Agriculture & Social Sciences* 1 (2): 164–66.

KNBS. 2010. "KENYA DEMOGRAPHIC AND HEALTH SURVEY 2008-09." Nairobi.

KNBS. 2019. "Economic Survey 2019." Nairobi.

Knoess K. H. 1977. "The Camel as Meat and Milk Animal." *World Animal Review* 22: 39–44.

Knoess, K H, A J Makhudum, M. Rafiq, and M. Hafeez. 1986. "Milk Production Potential of the Dromedary, with Special Reference to the Province of Punjab, Pakistan." *World Animal Review* No. 57: 11–21.

Konuspayeva, G., B. Faye, and G. Loiseau. 2009. "The Composition of Camel Milk: A Meta-Analysis of the Literature Data." *Journal of Food Composition and Analysis* 22 (2): 95–101. https://doi.org/10.1016/j.jfca.2008.09.008.

Konuspayeva, G., B. Faye, G. Loiseau, and D. Levieux. 2007. "Lactoferrin and Immunoglobulin Contents in Camel's Milk (Camelus Bactrianus, Camelus Dromedarius, and Hybrids) from Kazakhstan." *Journal of Dairy Science* 90 (1): 38–46. https://doi.org/10.3168/jds.S0022-0302(07)72606-1.

Konuspayeva, Gaukhar, Benedicte Camier, Frederic Gaucheron, and Bernard Faye. 2014. "Some Parameters to Process Camel Milk into Cheese." *Emirates Journal of Food and Agriculture* 26 (4): 354–58. https://doi.org/10.9755/ejfa.v26i4.17277.

KPLC. 2018. "Electricity Cost Tariffs & Schedule of Tariffs 2018." Nairobi, Kenya.

Krummenacher, Pierre, and Bettina Muster. 2015. "Solar Process Heat for Production and Advanced Applications Methodologies and Software Tools for Integrating Solar Heat into Industrial Processes." *IEA SHC Task 49*.

Kulkarni, Govind N., Shireesh B. Kedare, and Santanu Bandyopadhyay. 2008. "Design of Solar Thermal Systems Utilizing Pressurized Hot Water Storage for Industrial Applications." *Solar Energy* 82 (8): 686–99. https://doi.org/10.1016/j.solener.2008.02.011.

Kuria, S G, A Omore, I N Thendiu, D M Mwangi, A B Nga, and S Kaitibie. 2011. "Constraints on Camel Meat and Milk Marketing and Strategies for Its Improvement in Northern Kenya." *Journal of Agricultural Science and Technology* 1: 703–12.

Laleye, L. C., B. Jobe, and A. A. H. Wasesa. 2008. "Comparative Study on Heat Stability and Functionality of Camel and Bovine Milk Whey Proteins." *Journal of Dairy Science* 91 (12): 4527–34. https://doi.org/10.3168/jds.2008-1446.

Laudadio, Vito, Vincenzo Tufarelli, Marco Dario, Mohamed Hammadi, Mabrouk Mouldi Seddik, Giovanni Michele Lacalandra, and Cataldo Dario. 2009. "A Survey of Chemical and Nutritional Characteristics of Halophytes Plants Used by Camels in Southern Tunisia." *Tropical Animal Health and Production* 41 (2): 209–15. https://doi.org/10.1007/s11250-008-9177-7.

Lore, Tezira A., Samuel K. Mbugua, and John Wangoh. 2005. "Enumeration and Identification of Microflora in Suusac, a Kenyan Traditional Fermented Camel Milk Product." *LWT - Food Science and Technology* 38 (2): 125–30. https://doi.org/10.1016/j.lwt.2004.05.008.

Lü, Xin, Pan Hu, Ying Dang, and Bianfang Liu. 2014. "Purification and Partial Characterization of a Novel Bacteriocin Produced by Lactobacillus Casei TN-2 Isolated from Fermented Camel Milk (Shubat) of Xinjiang Uygur Autonomous Region, China." *Food Control* 43: 276–83. https://doi.org/10.1016/j.foodcont.2014.03.020.

Makoni, N.F., R. Mwai, T. Redda, A. van der Zijpp, and J. van der Lee. 2014. "White Gold: Opportunities for Dairy Sector Development Collaboration in East Africa." Wageningen.

Martinenko, N.I., S.G. Yagodinskaya, A.A. Adhundov, K.C. Charyev, and O. Khumedov. 1977. "Content of Trace Elements, Copper, Manganese, Molybdenum in Culture of Chal and Camel's Milk and Their Clinical Significance." *Dairy Sci. Abst.* 40: 7802.

Mehaia, M.A., and M.A. Al-Kahnal. 1989. "Studies on Camel and Goat Milk Proteins: Nitrogen Distribution and Amino Acid Composition." *Nutrition Report Intern* 39 (2): 351–57.

Mehaia, Mohamed A., Mohamed A. Hablas, Kamal M. Abdel-Rahman, and Samy A. El-Mougy. 1995. "Milk Composition of Majaheim, Wadah and Hamra Camels in Saudi Arabia." *Food Chemistry* 52 (2): 115–22. https://doi.org/10.1016/0308-8146(94)P4189-M.

Mehaia, Mohammed. A. 1993. "Fresh Soft White Cheese (Domiati-Type) from Camel Milk: Composition, Yield, and Sensory Evaluation." *Journal of Dairy Science* 76 (10): 2845–55. https://doi.org/10.3168/jds.S0022-0302(93)77623-7.

Mekhilef, S., R. Saidur, and A. Safari. 2011. "A Review on Solar Energy Use in Industries." *Renewable and Sustainable Energy Reviews* 15 (4): 1777–90. https://doi.org/10.1016/j.rser.2010.12.018.

Meyers, Steven, Bastian Schmitt, Mae Chester-Jones, and Barbara Sturm. 2016. "Energy Efficiency, Carbon Emissions, and Measures towards Their Improvement in the Food and Beverage Sector for Six European Countries." *Energy* 104: 266–83. https://doi.org/10.1016/j.energy.2016.03.117.

Miah, J H, A Griffiths, R Mcneill, I Poonaji, R Martin, A Yang, and S Morse. 2014. "Heat Integration in Processes with Diverse Production Lines : A Comprehensive Framework and an Application in Food Industry." *APPLIED ENERGY* 132: 452–64. https://doi.org/10.1016/j.apenergy.2014.07.027.

MoALF. 2013. "Sesional Paper No. 5 of 2013 on the National Dairy Development Policy." Nairobi.

Moejes, S.N., and A.J.B. van Boxtel. 2017. "Energy Saving Potential of Emerging Technologies in Milk Powder Production." *Trends in Food Science & Technology* 60: 31–42. https://doi.org/10.1016/j.tifs.2016.10.023.

MoEP. 2015. "Ministry of Energy and Petroleum DRAFT NATIONAL ENERGY AND PETROLEUM

POLICY." Nairobi.

Moffat, Frazer, Sam Khanal, Antony Bennett, Tek Thapa, and Sonnet George. 2016. *Technical and Investment Guidelines for Milk Cooling Centres*. *Food and Agriculture Organization of the United Nations*.

Mohamad, Ragaa Hosny, Zekry Khalid Zekry, Hussain A. Al-Mehdar, Omar Salama, Siad Ebrahim El-Shaieb, Amany A. El-Basmy, Mohamad Gamil Abdel Monem Al-said, and Sabry Mohamed Sharawy. 2009. "Camel Milk as an Adjuvant Therapy for the Treatment of Type 1 Diabetes: Verification of a Traditional Ethnomedical Practice." *Journal of Medicinal Food* 12 (2): 461–65. https://doi.org/10.1089/jmf.2008.0009.

Mohamed, Ismail Mohamed Abdella, and Ibtisam El Yas Mohamed El-Zubeir. 2014. "Effect of Heat Treatment on Keeping Quality of Camel Milk." *Annals. Food Science and Technology* 15 (2): 239–45.

Mohamed, M.A. 1985. "A Study of Camel Milk Composition, Mogadishu, Somalia." 8. *Camel Forum (Sweden)*. Uppsala, Sweden: Somali Academy of Sciences and Arts/ SIAS.

Moslah, M. 1994. "La Production Laitiere Du Dromadaire En Tunisie." In *Workshop Dromedaries and Camels as Milking Animals, Nouakchott, Mauritania, 24– 26 October*, edited by P. Bonnet (ed.), 61–65.

Mourad, Kacem, and Karam Nour-Eddine. 2006. "Physicochemical and Microbiological Study of 'Shmen', a Traditional Butter Made from Camel Milk in the Sahara (Algeria): Isolation and Identification of Lactic Acid Bacteria and Yeasts." *Grasas y Aceites* 57 (2): 198–204. https://doi.org/10.3989/gya.2006.v57.i2.37.

Mujumdar, Arun S., Li-Xin Huang, and Xiao Dong Chen. 2010. "An Overview of the Recent Advances in Spray-Drying." *Dairy Science &Technology* 90 (2–3): 211–24. https://doi.org/10.1051/dst/2010015.

Musaad, Abdelgadir M., Bernard Faye, and Sallal E. Al-Mutairi. 2013. "Seasonal and Physiological Variation of Gross Composition of Camel Milk in Saudi Arabia." *Emirates Journal of Food and Agriculture* 25 (8): 618–24. https://doi.org/10.9755/ejfa.v25i8.16095.

Mwangi, L.W., J.W. Matofari, P.S. Muliro, and B.O. Bebe. 2013. "Handling Practices and Microbiological Quality Characteristics of Traditional Pastoral Fermented Milk (SUUSA)." In *African Crop Science Conference Proceedings, Vol.*, 427–30.

Nato, Samuel Muyoma, Joseph Wafula Matofari, Bockline Omedo Bebe, and Christian Huelsebusch. 2018. "Effect of Predisposing Factors on Microbial Loads in Camel Milk along the Pastoral Dairy Value Chain in Kenya." *Pastoralism* 8 (1). https://doi.org/10.1186/s13570-018-0123-7.

Ndambi, Oghaiki Asaah. 2008. "Milk Production Systems in Central Uganda: A Farm Economic Analysis." Christian-Albrechts-Universität zu Kiel. https://doi.org/10.1007/s11250-007-9091-4.

Nielsen, K. M., and T. S. Pedersen. 2001. "Solar Panel Based Milk Pasteurization. Denmark." Aalborg.

Nielsen, R G, Bindslev-Jensen, Kruse-Andersen, and S. Husby. 2004. "Severe Gastroesophageal Reflux

Disease and Cow Milk Hypersensitivity in Infants and Children: Disease Association and Evaluation of a New Challenge Procedure.” *Journal of Pediatric Gastroenterology and Nutrition* 39 (4): 383–91. https://doi.org/10.1097/00005176-200410000-00015.

Nijdam, J.J., and T.A.G. Langrish. 2006. “The Effect of Surface Composition on the Functional Properties of Milk Powders.” *Journal of Food Engineering* 77 (4): 919–25. https://doi.org/10.1016/j.jfoodeng.2005.08.020.

Noor, Issack Mohamed, Bockline Omedo Bebe, and Abdi Yakub Guliye. 2012. “Analysis of an Emerging Peri-Urban Camel Production in Isiolo County, Northern Kenya.” *Journal of Camelid Science* 5: 41–61.

O’Connell, J.E., and P.F. Fox. 2011. “Heat Treatment of Milk | Heat Stability of Milk.” *Encyclopedia of Dairy Sciences* 57 (2): 744–49. https://doi.org/10.1016/B978-0-12-374407-4.00222-3.

Okos, Martin, Nishant Rao, Sara Drecher, Mary Rode, and Jeannie Kozak. 1998. “Energy Usage in the Food Industry: A Study.” Washington, DC (United States).

Oldfield, D.J. 1996. “Heat -Induced Whey Protein Reactions in Milk.” Massey University Plamerston North.

Oldfield, David, and Harjinder Singh. 2005. “Functional Properties of Milk Powders.” In *Food Science and Technology*, 146:365. New York-Marcel Dekker.

Omar, Adel. 2018. “Effects of Industrial Processing Methods on Camel Skimmed Milk Properties.” *International Dairy Journal*. University of Reading. https://doi.org/10.1016/j.idairyj.2018.03.011.

Omar, Adel, Niamh Harbourne, and Maria Jose Oruna-concha. 2016. “Quantification of Major Camel Milk Proteins by Capillary Electrophoresis.” *International Dairy Journal* 58: 1–5. https://doi.org/10.1016/j.idairyj.2016.01.015.

Pandagale, V.P., Madhuri Gajabe, and V. P. Khambaklar. 2016. “Integration of Solar Thermal Energy in Milk Processing Plant.” *Itenational Journal of Research Engineering, Science and Technology* 1 (6): 1–5.

Pask, F, J Sadhukhan, P Lake, S Mckenna, E B Perez, and A Yang. 2014. “Systematic Approach to Industrial Oven Optimisation for Energy Saving.” *Applied Thermal Engineering* 71 (1): 72–77. https://doi.org/10.1016/j.applthermaleng.2014.06.013.

Patel, A.S., S. J. Patel, N. R. Patel1, and G.V. Chaudhary. 2016. “Importance of Camel Milk - An Alternative Dairy Food.” *Journal of Livestock Science* 7: 19–25.

Perry, Robert H., and Don W. Green. 2008. *Perry’s Chemical Engineers’ Handbook*. Eighth. Vol. 1. The McGraw-Hill Companies, Inc. https://doi.org/10.1036/0071422943.

Peters, Max, Klaus Timmerhaus, Ronald West, and Max Peters. 2003. *Plant Design and Economics for Chemical Engineers*.

Piatkowski, M., M. Taradaichenko, and I. Zbicinski. 2015. “Energy Consumption and Product Quality Interactions in Flame Spray Drying.” *Drying Technology* 33 (9): 1022–28. https://doi.org/10.1080/07373937.2014.924137.

Pisecky, Jan. 2012. *Handbook of Milk Powder Manufacture*. Edited by Vagn Westergaard and Ejnar Refstrup. *GEA Process Engineering A/S (GEA Niro)*. Second Edi. https://doi.org/10.1007/978-1-908517-43-2.

PPD Consultants. 2013. "Dairy Sector Policy Study and Capacity Needs Assessment of Stakeholder Associations. Final Report." Nairobi.

Quana, Shuang, Harutoshi Tsuda, and Taku Miyamoto. 2008. "Angiotensin I-Converting Enzyme Inhibitory Peptides in Skim Milk Fermented with Lactobacillus Helveticus 130B4 from Camel Milk in Inner Mongolia, China." *Journal of the Science of Food and Agriculture* 88 (15): 2688–92. https://doi.org/10.1002/jsfa.3394.

Quijera, José Antonio, María González Alriols, and Jalel Labidi. 2011. "Integration of a Solar Thermal System in a Dairy Process." *Renewable Energy* 36 (6): 1843–53. https://doi.org/10.1016/j.renene.2010.11.029.

Rademaker, Corné J, Bockline Omedo Bebe, and Jan Van Der Lee. 2016. "Sustainable Growth of the Kenyan Dairy Sector; A Quick Scan of Robustness , Reliability and Resilience." Report 3R Kenya. WLR 979. Wageningen. https://doi.org/10.13140/RG.2.2.26350.41285.

Rafiq, Saima, Nuzhat Huma, Imran Pasha, Aysha Sameen, Omer Mukhtar, and Muhammad Issa Khan. 2016. "Chemical Composition, Nitrogen Fractions and Amino Acids Profile of Milk from Different Animal Species." *Asian-Australasian Journal of Animal Sciences* 29 (7): 1022–28. https://doi.org/10.5713/ajas.15.0452.

Rahman, Mohammad Shafiur, Halaa Al-Hakmani, Ahmed Al-Alawi, and Insaaf Al-Marhubi. 2012. "Thermal Characteristics of Freeze-Dried Camel Milk and Its Major Components." *Thermochimica Acta* 549: 116–23. https://doi.org/10.1016/j.tca.2012.09.005.

Ramet, J.P. 1991. "Processing Camel Milk into Cheese." *Revue Mondiale de Zootechnique* 61: 21–28.

Ramet, J.P. 2011. *The Technology of Making Cheese from Camel Milk (Camelus Dromedarius)*. *Food and Agriculture Organization of the United Nations*. Rome.

Ramírez, C. A., M. Patel, and K. Blok. 2006. "From Fluid Milk to Milk Powder: Energy Use and Energy Efficiency in the European Dairy Industry." *Energy* 31 (12): 1648–68. https://doi.org/10.1016/j.energy.2005.10.014.

Rao, M.B., R. C. Gupta, and N. N. Dastur. 1970. "Camels' Milk and Milk Products." *Indian Journal of Dairy Science* 23 (2): 71–78.

Reddy, Ravula Sudharshan, C T Ramachandra, Sharanagouda Hiregoudar, Udaykumar Nidoni, Jagjiwan Ram, and Mouneshwari Kammar. 2014. "Influence of Processing Conditions on Functional and Reconstitution Properties of Milk Powder Made from Osmanabadi Goat Milk by Spray Drying." *Small Ruminant Research* 119 (1–3): 130–37. https://doi.org/10.1016/j.smallrumres.2014.01.013.

Redwan, El-Rashdy M, Hussein A Almehdar, Esmail M. EL-Fakharany, Abdul-Wahab K Baig, and Vladimir N Uversky. 2015. "Potential Antiviral Activities of Camel, Bovine, and Human

Lactoperoxidases against Hepatitis C Virus Genotype 4.” *RSC Advances* 5 (74): 60441–52. https://doi.org/10.1039/C5RA11768B.

Renzo, Giovanni Carlo Di, Giuseppe Altieri, and Francesco Genovese. 2013. “Donkey Milk Powder Production and Properties Compared to Other Milk Powders.” *Dairy Science & Technology* 93: 551–64. https://doi.org/10.1007/s13594-013-0108-7.

Ripinsky, Michael. 1983. “Camel Ancestry and Domestication in Egypt and the Sahara.” *Archaeology* 36 (3): 21–27.

Rona, Roberto J, Thomas Keil, Colin Summers, David Gislason, Laurian Zuidmeer, Eva Sodergren, Sigurveig T Sigurdardottir, et al. 2007. “The Prevalence of Food Allergy: A Meta-Analysis.” *Journal of Allergy and Clinical Immunology* 120 (3): 638–46. https://doi.org/10.1016/j.jaci.2007.05.026.

Sagar, Shyam P., Bhavbhuti M. Mehta, K.N. Wadhwani, V. B. Darji, and K.D. Aparnathi. 2016. “Evaluation of Camel Milk for Selected Processing Related Parameters and Comparisons with Cow and Buffalo Milk.” *International Journal of Health, Animal Science and Food Safety* 3 (1): 27–37.

Salmen, Saleh H, Hamza M Abu-Tarboush, Abdulrahman A Al-Saleh, and Ali A Metwalli. 2012. “Amino Acids Content and Electrophoretic Profile of Camel Milk Casein from Different Camel Breeds in Saudi Arabia.” *Saudi Journal of Biological Sciences* 19 (2): 177–83. https://doi.org/10.1016/j.sjbs.2011.12.002.

Sanne Lemmens. 2016. “Cost Engineering Techniques and Their Applicability for Cost Estimation of Organic Rankine Cycle Systems.” *Energies* 9 (485): 2–18. https://doi.org/10.3390/en9070485.

Saravacos, George, and Athanasios E. Kostaropoulos. 2012. *Handbook of Food Processing Equipment*. Second. Springer. https://doi.org/10.1007/978-3-319-25020-5_4.

Sato, Shun. 1976. “Preliminary Report of Camel Ecology among the Rendille in Northern Kenya.”

Sawaya, W. N., J. K. Khalil, A. AL-Shalhat, and H. AL-Mohammad. 1984. “Chemical Composition and Nutritional Quality of Camel Milk.” *Journal of Food Science* 49 (3): 744–47. https://doi.org/10.1111/j.1365-2621.1984.tb13200.x.

Schmitt, Bastian. 2014. “Integration Thermischer Solaranlagen Zur Bereit- Stellung von Prozesswärme in Industriebetrieben.” Shaker Verlag.

Schmitt, Bastian. 2016. “Classification of Industrial Heat Consumers for Integration of Solar Heat.” In *Energy Procedia*, 91:650–60. https://doi.org/10.1016/j.egypro.2016.06.225.

Schuck, Pierre. 2011. “Dehydrated Dairy Products | Milk Powder: Physical and Functional Properties of Milk Powders.” In *Encyclopedia of Dairy Sciences*, 117–24. Elsevier. https://doi.org/10.1016/B978-0-12-374407-4.00122-9.

Schuck, Pierre, Anne Dolivet, and Serge Méjean. 2016. “Technological Breakthrough and Innovation in the Production of Whey Powders , with 30-40 % Reduction in Energy Costs.” In *5th International Congress on Green Procee Engineering (GPE 2016)*, 6–22. ECI.

Schuck, Pierre, Romain Jeantet, Bhesh Bhandari, Xiao Dong Chen, Ítalo Tuler Perrone, Antônio Fernandes de Carvalho, Mark Fenelon, and Phil Kelly. 2016. "Recent Advances in Spray Drying Relevant to the Dairy Industry: A Comprehensive Critical Review." *Drying Technology* 34 (15): 1773–90. https://doi.org/10.1080/07373937.2016.1233114.

Schwartz, H. J., and M. Dioli. 1992. *The One-Humped Camel (Camelus Dromedarius) in Eastern Africa : A Pictorial Guide to Diseases, Health Care and Management*. Weikersheim; Germany: Verlag Josef Margraf.

SE4ALL. 2016. "Kenya Action Agenda."

Seifu, Eyassu. 2007. "Handling, Preservation and Utilization of Camel Milk and Camel Milk Products in Shinile and Jijiga Zones, Eastern Ethiopia." *Marketing* 10: 13–17.

Shabo, Y., R. Barzel, and R Yagil. 2008. "ETIOLOGY OF CROHN ' S DISEASE AND CAMEL MILK TREATMENT." *Journal of Camel Practice and Research* 15: 55–59.

Sharma, Anup, Atanu H. Jana, and Rupesh Shrikant Chavan. 2012. "Functionality of Milk Powders and Milk-Based Powders for End Use Applications-A Review." *Comprehensive Reviews in Food Science and Food Safety* 11 (5): 518–28. https://doi.org/10.1111/j.1541-4337.2012.00199.x.

Sharma, Ashish K., Chandan Sharma, Subhash C. Mullick, and Tara C. Kandpal. 2017. "Potential of Solar Industrial Process Heating in Dairy Industry in India and Consequent Carbon Mitigation." *Journal of Cleaner Production* 140: 714–24. https://doi.org/10.1016/j.jclepro.2016.07.157.

Shori, A.B., A.S. Baba, M. Misran, and H.W. Tan. 2013. "Enrichment of Yogurt Made from Camel Milk with Allium Sativum and Cinnamomum Verum : Influence on Syneresis , Water Holding Capacity , Exopolysaccharides and Rheological Properties." *International Journal of Veterinary Science* 1 (1): 51–63.

Sicherer, Scott H. 2011. "Epidemiology of Food Allergy." *Journal of Allergy and Clinical Immunology* 127 (3): 594–602. https://doi.org/10.1016/j.iac.2017.09.002.

Simpson, Gilford George. 1945. "The Principles of Classification and a Classification of Mammals." *Bulletin of the American Museum of Natural History* 85: 1–350. https://doi.org/10.1007/s13398-014-0173-7.2.

Singh, Harjinder, and Aiqian Ye. 2010. "Controlling Milk Protein Interactions to Enhance the Reconstitution Properties of Whole Milk Powders – A Minireview." *Dairy Science & Technology* 90 (2–3): 123–36. https://doi.org/10.1051/dst/2009038.

Singh, Madhu B., Ranjana Fotedar, and J. Lakshminarayana. 2008. "Camel Milk Consumption Pattern and Its Association with Diabetes among Raika Community of Jodhpur District of Rajasthan." *Ethno-Medicine* 2 (2): 103–5.

Solinas, C., M. Corpino, R. MacCioni, and U. Pelosi. 2010. "Cow's Milk Protein Allergy." *Journal of Maternal-Fetal and Neonatal Medicine* 23 (3): 76–79. https://doi.org/10.3109/14767058.2010.512103.

Spergel, Jonathan M., Janet L. Beausoleil, Maria Mascarenhas, and Chris A. Liacouras. 2002. "The Use of Skin Prick Tests and Patch Tests to Identify Causative Foods in Eosinophilic Esophagitis." *Journal of Allergy and Clinical Immunology* 109 (2): 363–68. https://doi.org/10.1067/mai.2002.121458.

Stahl, T., H. P. Sallmann, R. Duehlmeier, and U. Wernery. 2006. "Selected Vitamins and Fatty Acid Patterns in Dromedary Milk and Colostrum." *Journal of Camel Practice and Research* 13 (1): 53–57.

Sturm, Barbara. 2018. "Vorgelegt von: Dr. Agr. Barbara Sturm Witzenhausen, Januar 2018." Universität Kassel.

Sturm, Barbara, Steven Meyers, Yongjie Zhang, Richard Law, Eric J. Siqueiros Valencia, Huashan Bao, Yaodong Wang, and Haisheng Chen. 2015. "Process Intensification and Integration of Solar Heat Generation in the Chinese Condiment Sector - A Case Study of a Medium Sized Beijing Based Factory." *Energy Conversion and Management* 106: 1295–1308. https://doi.org/10.1016/j.enconman.2015.10.045.

Sulieman, Abdel Moneim E., Osama M. Elamin, Elamin A. Elkhalifa, and Loouis Laleye. 2014. "Comparison of Physicochemical Properties of Spray-Dried Camel's Milk and Cow's Milk Powder." *International Journal of Food Science and Nutrition Engineering* 4 (1): 15–19. https://doi.org/10.5923/j.food.20140401.03.

Tabary, Zoe. 2018. "With Refrigerated ATMs, Camel Milk Business Thrives in Kenya." *Reuters*, 2018.

Tamime, Adnan Y. 2009. *Milk Processing and Quality Management*. https://doi.org/10.1002/9781444301649.

Tanguy, Gaëlle, Anne Dolivet, Fabienne Garnier-Lambrouin, Serge Méjean, Diarmuid Coffey, Tim Birks, Romain Jeantet, and Pierre Schuck. 2015. "Concentration of Dairy Products Using a Thin Film Spinning Cone Evaporator." *Journal of Food Engineering* 166: 356–63. https://doi.org/10.1016/j.jfoodeng.2015.07.001.

Tay, T T, and Y L Chua. 2015. "High Temperature Short Time (HTST) Camel Milk Pasteurization Plant." *ARPN Journal of Engineering and Applied Sciences* 10 (15): 6241–45.

Torry, William I. 1973. "Subsistence Ecology Among the Gabra: Nomads of the Kenya/Ethiopia Frontier." Columbia University, New York.

Turton, Richard, Joseph A. Shaeiwitz, Debangsu Bhattacharyya, and Wallace B. Whiting. 2018. *Analysis, Synthesis, and Design of Chemical Processes*. 5th editio. Upper Saddle River, NJ, USA: Pearson Education International.

Ulrich, Gail D. 1984. *A Guide to Chemical Engineering Process Design and Economics*. New York: John Wiley & Sons. https://doi.org/10.1002/aic.690300636.

Uniacke-Lowe, Therese. 2011. "Studies on Equine Milk and Comparative Studies on Equine and Bovine Milk Systems." University College Cork.

Valle-Riestra, J Frank. 1983. *Project Evaluation in the Chemical Process Industries*. New York: McGraw-Hill .

Vikas, M., and Z. Farah. 1991. “Manufacture of Cheese from Camel Milk. Report on Field Studies in Kenya,.”

Vital Camel Milk. n.d. “VITAL CAMEL MILK LTD_® - VITAL CAMEL MILK - Pasteurized Camel Milk - Natural Camel Milk.” Accessed September 20, 2018. http://www.vitalcamelmilk.com/index.html.

Walmsley, Michael R.W., Timothy G. Walmsley, Martin J. Atkins, and James R. Neale. 2016. “Sustainable Milk Powder Production Using Enhanced Process Integration and 100 % Renewable Energy.” *Chemical Engineering Transactions* 52: 559–64. https://doi.org/10.3303/CET1652094.

Walmsley, Timothy G., Martin J. Atkins, Michael R.W. Walmsley, Matthias Philipp, and Ron-Hendrik Peesel. 2016. “Process and Utility Systems Integration and Optimisation for Ultra-Low Energy Milk Powder Production.” *Energy*, 1–15. https://doi.org/10.1016/j.energy.2017.04.142.

Wang, L. 2008. *Energy Efficiency and Management in Food Processing Facilities*.

Wang, Lijun. 2014. “Energy Efficiency Technologies for Sustainable Food Processing.” *Energy Efficiency* 7 (5): 791–810. https://doi.org/10.1007/s12053-014-9256-8.

Wangoh, J., Z. Farah, and Z. Puhan. 1998. “Composition of Milk from Three Camel (Camelus Dromedarius) Breeds in Kenya during Lactation.” *Milchwissenschaft* 53 (3): 136–39.

Wayua, Francis O., Michael W Okoth, and John Wangoh. 2013. “Modelling of a Locally Fabricated Flat-Plate Solar Milk Pasteuriser Using Artificial Neural Network.” *African Journal of Agricultural Research* 8 (9): 741–49. https://doi.org/10.5897/AJAR11.1256.

Wayua, Francis O., Michael Wandayi Okoth, and John Wangoh. 2012. “Survey of Postharvest Handling, Preservation and Processing Practices along the Camel Milk Chain in Isiolo District, Kenya.” *African Journal of Food, Agriculture, Nutrition and Development* 12 (7): 6897–6912.

Werney, Ulrich. 2006. “Camel Milk the White Gold of the Desert.” *Journal of Camel Practice and Research* 13 (1): 15–26.

Westergaard, Vagn. 2011. “Milk Powder Technology Evaporation and Spray Drying.”

Xu, Tengfang, and Joris Flapper. 2009. “Energy Use and Implications for Efficiency Strategies in Global Fluid-Milk Processing Industry.” *Energy Policy* 37 (12): 5334–41. https://doi.org/10.1016/j.enpol.2009.07.056.

Xu, Tengfang, and Joris Flapper. 2011. “Reduce Energy Use and Greenhouse Gas Emissions from Global Dairy Processing Facilities.” *Energy Policy* 39 (1): 234–47. https://doi.org/10.1016/j.enpol.2010.09.037.

Xu, Tengfang, Joris Flapper, and Klaas Jan Kramer. 2009. “Characterization of Energy Use and Performance of Global Cheese Processing.” *Energy* 34 (11): 1993–2000. https://doi.org/10.1016/j.energy.2009.08.014.

Yadav, Alok Kumar, Rakesh Kumar, Lakshmi Priyadarshini, and Jitendra Singh. 2015. “Composition and Medicinal Properties of Camel Milk: A Review.” *Asian Journal of Dairy and Food Research* 34 (2): 83. https://doi.org/10.5958/0976-0563.2015.00018.4.

Yagil, R. 1982. "Camels and Camel Milk." 26. Publications Division, Food and Agriculture Organization of the United Nations. Rome.

Yagil, R, and Z Etzion. 1980. "Milk Yield of Camels (Camelus Dromedarius) in Drought Areas." *Comparative Biochemistry and Physiology* 67 (A): 207–9. https://doi.org/10.1016/0300-9629(80)90433-8.

Yam, B. A. Z., M. Khomeiri, A. S. Mahounak, and S. M. Jafari. 2014. "Hygienic Quality of Camel Milk and Fermented Camel Milk (Chal) in Golestan Province , Iran." *Journal of Microbiology Research* 4 (2): 98–103. https://doi.org/10.5923/j.microbiology.20140402.09.

Yoganandi, Jaydeep, Bhavbhuti M Mehta, K.N. Wadhwani, V.B. Darji, and K.D. Aparnathi. 2014. "Comparison of Physico-Chemical Properties of Camel Milk with Cow Milk and Buffalo Milk." *Journal of Camel Practice and Research* 21 (2): 253. https://doi.org/10.5958/2277-8934.2014.00045.9.

Zeuner, F.E. 1963. *A History of Domesticated Animals*. Hutchinson, London: London: Hutchinson & Co. (Publishers) Ltd. https://doi.org/10.1525/aa.1964.66.1.02a00560.

Zia-Ur-Rahman, N., and Haq, I.U. 1998. "B Lood Biochemical , Hormonal Profiles and Milk Composition of Low and High Yielding Camel." In *Dromedaries and Camels as Milking Animals, Nouakchott, Mauritania, 24–26 October,* edited by P. Bonnet (ed.), 24–26. Mauritania.

Zia-Ur-Rahman, N., and I.U. Haq. 1994. "Milk Production Potential of Camels in Punjab." In *Proc. Workshop Dromedaries and Camels as Milking Animals, Nouakchott, Mauritania, 24–26 October,* edited by P. Bonnet (ed.), 107–9.

3.0 Methodology and Statistical Analysis

3.1 Study area

3.1.1 Geographical Location & Topography

Isiolo County is located in Northern Kenya at a latitude of 0° 21’ 0 °N and a longitude of 37° 35’ 0 °E, with an area of approximately 25,700 km² (KNBS 2019). The county borders: Marsabit county to the north; Wajir & Garissa counties to the east; Tana River & Meru Counties to the south; and Samburu & Laikipia counties to the west (see Fig. 3.1). Administratively; the county is divided into three sub-counties: Isiolo central (3,269 km^2), Garbatulla (9,819 km^2) and Merti (12,612 km^2) (KNBS 2019). Isiolo County is further sub-divided into ten administrative wards, namely: Ol-donyiro, Burat, Bulapesa, Isiolo East, Ngaremara, Kinna, Sericho, Garbatula, Chari and Cherab (Republic of Kenya 2018).

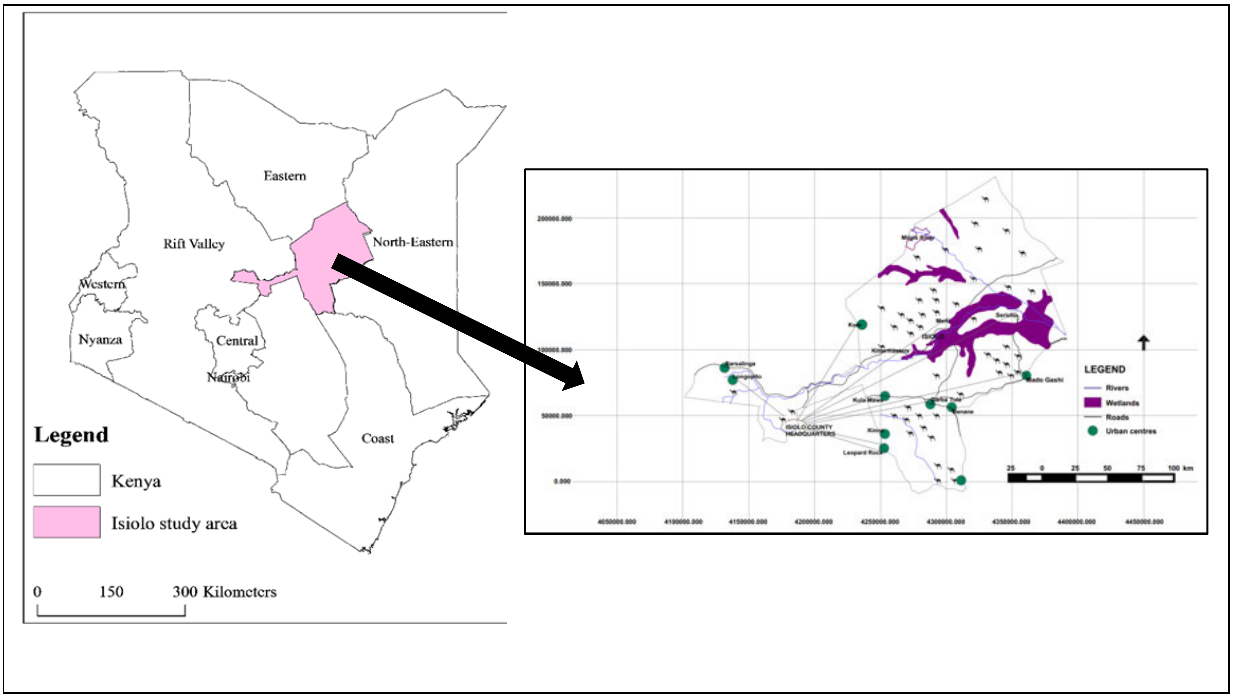


Figure 3. 1 Study area location and camel distribution within the county (author’s own)

Ecologically, the County is characterised by variability in rainfall and vegetation types and classified into three agro-climatic zones: the semi-arid (5%), arid (30%) and very arid zones (65%) (Republic of Kenya 2018). The vegetation types in the county is presented in figure 3.2.

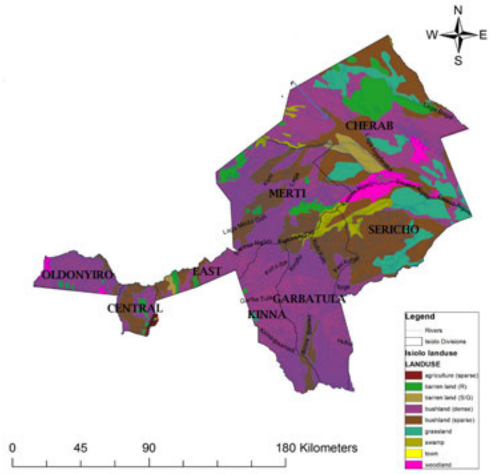


Figure 3. 2 Vegetation type in Isiolo County
Source: (ECARRP 2013)

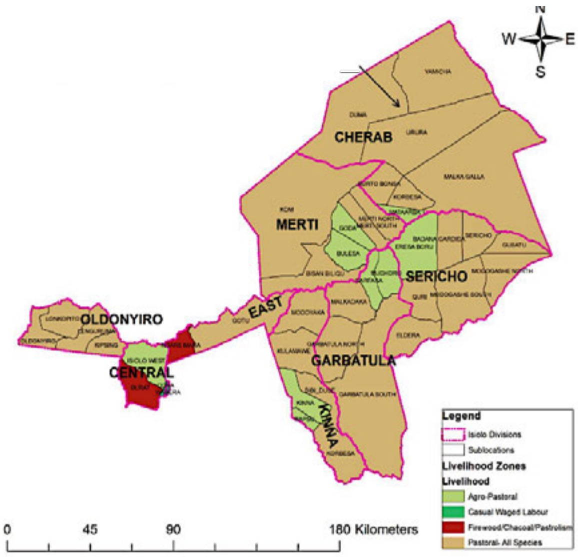


Figure 3. 3 Livelihood zones in Isiolo County.
Source: (ECARRP 2013)

The altitude ranges between 200 m to 300 m above sea level. The county has flat low lying plain rising gradually from an altitude of about 180 m (Lorian swamp (Habaswein) to approximately 1000 m (Merti Plateau) above the sea level) (Noor, Bebe, and Guliye 2012).

The study was undertaken in Isiolo and Garbatulla sub-counties. This is because the two sub-counties account for more than 90% of the camel population in the county (Muli, Kimenya, and Kivolonzi 2008).

3.1.2 Population

The county's estimated population in 2019 was 268, 002 persons of which 52% were male and 48% female (KNBS, 2019). Across the county, the population density was 11 persons per square kilometre in 2019 with a population growth rate of 1.45% (KNBS, 2019; Republic of Kenya, 2018). The population comprises of mostly Cushite communities (Oromo- speaking Boran and Sakuye) and Turkana, Samburu, Meru, Somali and other immigrant communities from other parts of the country (Stoker, 2000).

3.1.3 Livelihood

According to Kamunyan et al., (2013), approximately 70% of the total population in Isiolo county live below the poverty line of € 0.57 per day. Pastoralism, charcoal/firewood burning and casual wages are the main livelihood activities in the study area (Fig. 3.3). Due to the erratic rainfall experienced in the area, that limits crop production, livestock production is thus the backbone of the County's economy with over 80 % of the population relying on it for livelihood (Republic of Kenya 2018). The main livestock species kept in the study area are cattle, sheep, goats, camels, donkeys, rabbits and chicken. Livestock production is characterised by pastoral systems that comprise of sedentary, migratory and transhumant (Elhadi 2014). However, most of the inhabitants are migratory and transhumant, and these has contributed to environmental degradation due to overgrazing caused by overstocking. The Borana and Somali pastoralists living in Isiolo predominantly keep a mix of livestock species with an estimated population of 40,300 camels (Stoker 2000). Camels are primarily kept for milk production both for household consumptions and commercial purposes (Noor, Bebe, and Guliye 2012). However, there is no value addition agro-based industries that can increase the value of the CM thus increasing the price of the CM. Therefore, contributing to the high food poverty index of 77% resulting in dependence on relief food which is further enhanced by the low level of farm produce harvested (FAO et al. 2018).

3.1.4 Water resources

Poor accessibility to water resources characterizes the County with an average distance of 3 km to the nearest water sources for most households. Approximately 6% and 35% of the households in the county have access to piped and potable water respectively. Although, 59% of the residents use improved water sources, only 7% have access to clean and safe water within 5 km reach. Furthermore, 58% of the total water in the county is saline, limiting the water available for human usage. The four significant sources of water supply in Isiolo county are natural water sources (rivers, streams and springs); developed surface water (earth dams, sand/subsurface dams, tanks and pans); developed groundwater (wells, shallow wells, boreholes); Emergency water supply (government tankers). The main water supply schemes in the county are Isiolo Water and Sewerage Company, Merti Water Supply and Garbatulla (Republic of Kenya 2018). There are three perennial rivers in Isiolo County namely: Ewaso Nyiro, Kinna and Bisanadi.

3.1.5 Energy resources

The primary energy source in the county is wood fuel with about 70% of the household dependent on it as the primary source of power. This has led to land degradation due to depletion of forests for charcoal production. Only 2500 of the 31,326 households and 15% of trading centres, with fewer schools and health facilities, are connected to electricity (Republic of Kenya 2018).

3.1.6 Climatic Conditions of the study area

3.1.6.1 Rainfall pattern

Isiolo County lies in the ASALs which are characterized by low, unpredictable and erratic rainfall patterns (Ngaira 2009). The typical annual rainfall variation in Isiolo County follows the passage of the Inter-Tropical Convergence Zone (ITCZ) and the changes in wind directions, which are accompanied by dramatic shifts in precipitation regimes between very dry and very rainy. The rainfall regime is dominated by two dry and two rainy seasons. The rainy seasons are known as the "long rains" which last for three months from around mid-March and contribute about 40% of the total precipitation. The short rains last for two to three months, usually starting in October, and contribute 60% of the total precipitation (KMD 2018).

The monthly rainfall distribution in the study area mainly follows the typical bimodal pattern. Isiolo County experiences bimodal rainfall pattern an annual range between 600 mm and 350 mm (Herlocker, Shaaban, and Wilkes 1993; Fu et al. 2014; KMD 2018). The rainfall pattern follows the monsoon and therefore highly seasonal (Francine and Hughes 1984). Due to the high temporal and spatial variations and erratic nature of the precipitation, the study area experiences drought almost every year resulting in loss of livestock and human lives (GoK 1997).

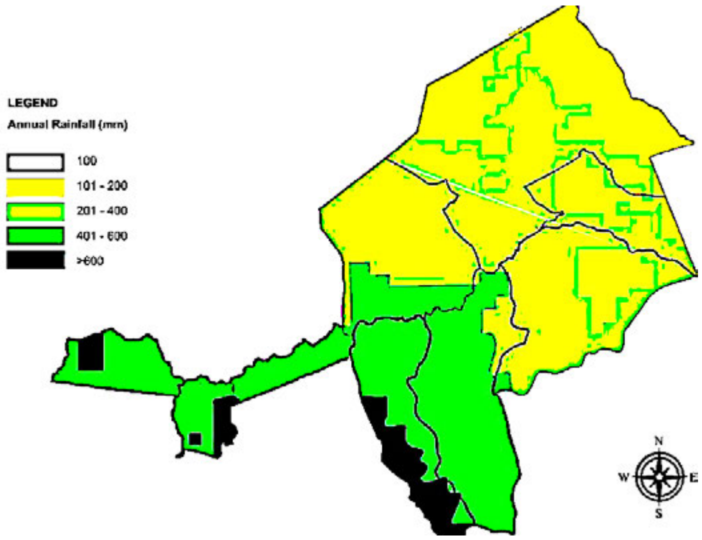


Figure 3. 4 Annual Rainfall distribution in Isiolo County. Source (KMD 2018)

3.1.6.2 Temperature

The temperature in Isiolo County is hot and dry most of the year, with a maximum daily average of about 36.1 °C usually experienced in February and a minimum of 21.8 °C in December every year (Herlocker, Shaaban, and Wilkes 1993; KMD 2018). The mean average temperatures are usually above 26 °C. Figure 3.5 provides a summary of the maximum, minimum and mean temperatures from 1979 to 2010 in Isiolo County.

On average, the county experience nine hours of sunshine per day and strong winds all year round with a peak in July and August. These, therefore, depicts a vast potential for both solar and wind energy. Direct Normal (DNI) and Global horizontal irradiation (GHI) are given in figures 3.5 & 3.6.

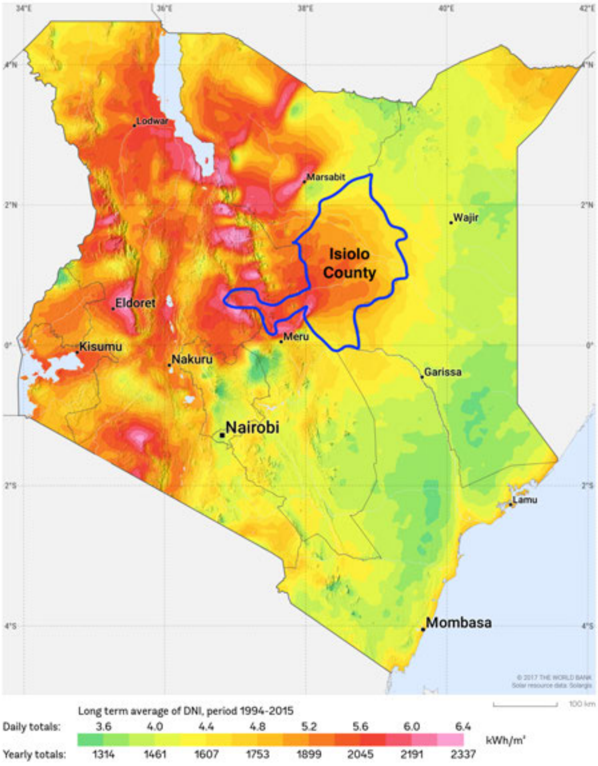


Figure 3. 5 Direct Normal Irradiation. Adapted from Solargis (2019)

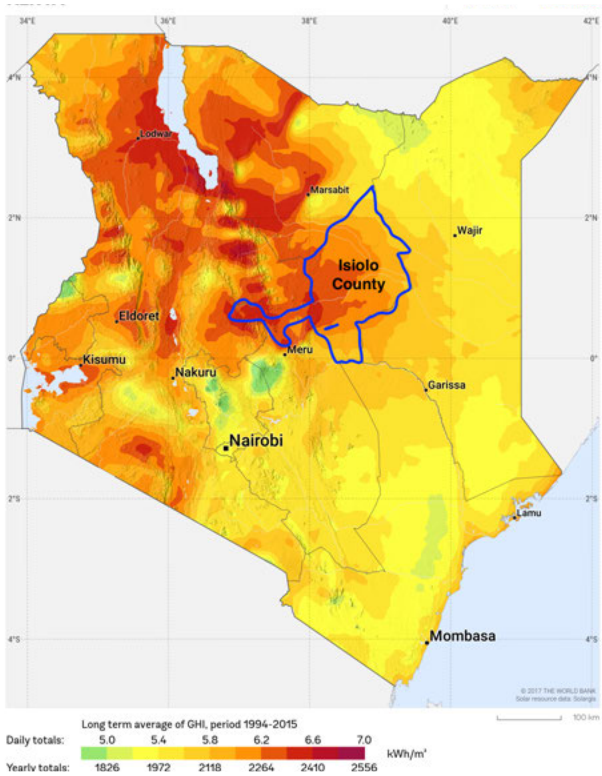


Figure 3. 6 Global Horizontal Irradiation. Adapted from Solargis (2019)

3.2 Data Collection and Statistical analysis

In this dissertation, each study utilized different type of data collection methods and analysis. These entailed mixed methods (quantitative and qualitative) that were utilized in Study 1. Study 2 involved laboratory experiments that employed a three by two factorial design in the milk powder production. Finally, Study 3 was carried out through an excel simulation, SAM simulation, technical and economic feasibility of an arid solar fossil fuel powered plant. Table 3.1 presents the research purposes, questions, data collection and data analysis used in the three articles. Further, a tabular overview of the methods and materials used in this thesis and the factors investigated are presented in table 3.2.

Table 3. 1 Research Purpose, questions, data collection tools and analysis of the Study

Research Purpose	Research questions	Data collection	Data analysis
Article 1: Strategies and Technologies for Camel Milk Preservation and Utilization of Non-Marketed Milk in Arid and Semi-Arid Areas			
To identify and document the strategies and technologies used in CM preservation and how the non-marketed milk is used in Isiolo County.	1. How is the CM supply chain characterized? 2. What are the strategies and technologies available in Isiolo for CM preservation? 3. How is the non-marketed milk utilized in the region? 4. How is the CM consumed and how feasible is camel milk powder?	▪ Key informant interviews (KII). ▪ Focus group discussions (FGD) ▪ Personal observation (PO) ▪ Semi-structured interviews (SSI)	▪ Thematic Coding using RQDA analysis ▪ Descriptive statistics & ▪ Inferential statistics using IBM SPSS.
Article 2: Influence of inlet drying air temperature and milk flow rate on the physical, optical and thermal properties of spray dried camel milk powders			
To assess how inlet air drying temperature and milk flow rate influence the optical, thermal and physical properties of spray dried CM powder.	1. Do laboratory and industrial spray dried CM powders differ in thermal, optical and physical properties? 2. Are there variations in thermal, colour and optical properties of the laboratory spray dried CM powder? 3. What is the optimal spray drying conditions for laboratory scale CM powder production?	▪ Three by two factorial experimental design ▪ Thermal properties ▪ Optical properties ▪ Physical properties (particle morphology, size; bulk & rehydration)	▪ Design of experiments ▪ Multifactorial ANOVA ▪ Fisher F-test ▪ Predicted ▪ Adjusted R^2 ▪ Response surface methodology (RSM) ▪ Numerical optimization

Article 3: Development and Techno-economic feasibility analysis of a novel solar-powered process design for camel milk powder and butter processing plant for the ASALs			
To develop a novel decentralized small-scale hybrid solar-fossil fuel powered process design for CM powder and butter processing plant for the ASALs	1. How much thermal energy and electricity is required to process 3135 litres of camel milk to milk powder and butter? 2. Is it possible to design an optimised processing line that limits the utilisation of fossil fuels while optimising the utilisation of water and energy? 3. How much energy and water are saved from the optimized processing plant? 4. What are the best points of integration of solar thermal? 5. How technical and economical feasible is the processing plant designed? 6. Can the designed plant contribute to food and nutritional security of the publics in the ASALs and empower women?	▪ Structured questionnaire for milk volumes. ▪ Mass and energy balances ▪ Secondary data: Energy, Water, thermodynamics, costings.	▪ Numerical modelling of mass and energy balances in Excel™. ▪ PinCH analysis ▪ Simulation for RES integration (System Analysis Model (SAM)) ▪ Sankey diagrams ▪ Sensitivity analysis ▪ Levelized cost of energy (LCOE) ▪ Economic analysis

Further specific methodologies, variables, data analysis and materials for each study are presented in table 3.2

Table 3. 2 Specific methodologies, variables, data analysis and materials for each study

Methods (i)/ Materials (ii); Investigated factors (variables) (iii); Data analysis tool (iv)	**Study**
ANOVA (i)	Study 2
Adjusted R^2 (i)	Study 2
Bulk milk (i)	Study 3
Butter (ii)	Study 3,
Camel milk (ii)	Study 1, 2
Camel milk supply chain (iii)	Study 1
Capital cost estimation (i)	Study 3
CO_2 emission analysis (i)	Study 3
Coefficient of determination (i)	Study 2
Colour Measurements (i)	Study 2
Consumption and feasibility of milk powder (iii)	Study 1
Cross sectional survey(i)	Study 1
Cost of manufacturing (i)	Study 3
Cow milk (i)	Study 3
Descriptive statistics (i)	Study 1
Density (iii)	Study 2, 3
Derringer's desirability function (i)	Study 2
Dispersibility in water (DI) (iii)	Study 2
Energy and mass balances (i)	Study 3
Experimental design	Study 2
Feed flow rate (iii)	Study 2
Fisher F-test (i)	Study 2
Flowability (Carr's index) (iii)	Study 2
Fluid milk (ii)	Study 3,
Focus group discussions (FGDs) (i)	Study 1
Financial analysis (i)	Study 3
Hausner ratio (Cohesiveness) (iii)	Study 2
Heat and mass transfer modelling and simulation (i)	Study 3
Heat integration and recovery (i)	Study 3
Inlet drying air temperatures (iii)	Study 2

Methods (i)/ Materials (ii); Investigated factors (variables) (iii); Data analysis tool (iv)	**Study**
Interstitial air (IA) (iii)	Study 2
Key informant interviews (KIIs) (i)	Study 1
Levelized cost of energy (LCOE) (i)	Study 3
Loose bulk density (ρ_B) determination (i)	Study 2
Non-marketed milk utilization (seasonal variation) (iii)	Study 1
Numerical optimization (i)	Study 2
Mixed methods (i)	Study 1
Milk powder (ii)	Study 1, 2, 3,
Moisture content determination (i)	Study 2
Multifactorial ANOVA (i)	Study 2
Net present Value (iii)	Study 3
pH (iii)	Study 2
Particle morphology (iii)	Study 2
Particle size (iii)	Study 2
Personal observations (PO) (i)	Study 1
Physical properties (iii)	Study 2
Predicted R^2 (i)	Study 2
Preservation technologies (iii)	Study 1
Process integration (iii)	Study 3
Process simulation (i)	Study 3
Process optimisation (iii)	Study 3
Pinch analysis (i)	Study 3,
Qualitative data (i)	Study 1
Quantitative data (i)	Study 1
Renewable Energy Integration (iii)	Study 3
Response surface methodology (RSM) (i)	Study 2
Seasonal variation at production level (iii)	Study 1
Seasonal variation at marketing level (iii)	Study 1
Semi-structured interviews: producers, traders (i)	Study 1
Sensitivity analysis (i)	Study 3
Simulation RES integration (i)	Study 3

Methods (i)/ Materials (ii); Investigated factors (variables) (iii); Data analysis tool (iv)	Study
Solar thermal energy integration (iii)	Study 3
Spray drying (iii)	Study 2, 3,
System advisor model (iv)	Study 3
Tapped bulk density (ρ_T) determination (i)	Study 2
T tests (i)	Study 1
Thematic coding (i)	Study 1
Thermal analysis (i)	Study 2
Unit operation optimisation (iii)	Study 3,
Viscosity (iii)	Study 2
Volumetric flow rate of camel milk (i)	Study 2
Wettability (iii)	Study 2

Study 1

The data for this study were collected between June and August 2015. A mixed method) quantitative and qualitative) data collection were utilized (Creswell and Clark 2011). Key actors in the camel milk chain were identified through snowballing for the KIIs. A cross sectional survey among the producers was undertaken through semi-structured interviews in two sub-counties (Garba Tula and Isiolo Central) based on the contribution of the camel milk to the total volume sold in Isiolo and Nairobi Counties. Personal observations were also carried out at the production, market and bulking centres.

The data collected comprised of:

1. Through semi-structured interviews with Producers (145) and traders (50), FGDs (6), KIIs (12), Milk transporters (20) and POs,
    a. Camel milk supply chains were characterized.
    b. The seasonal variation of camel milk at production and marketing level and utilization of non-marketed milk were investigated
    c. The strategies and technologies of milk preservation available in Isiolo County were identified

2. Consumption and feasibility of camel milk powder in the study area through semi-structured interviews with Producers (145) and traders (50), FGDs (6), and KIIs (12).

For qualitative data, RQDA qualitative analysis software was used for the thematic coding of the transcripts (Huang 2014). Quantitative data analysis was undertaken using IBM SPSS software version 22 while the graphical presentation was undertaken using sigma plots (IBM Corp. 2015; Systat Software Inc. 2012).

Study 2

The data for the second objective was obtained from a laboratory experiment carried out at Fulda University of Applied sciences and University of Kassel, department of Agriculture and Biosystems engineering between the months of August 2016 to November 2016. A two by three factorial experimental design which entailed of two milk flow rates (166 & 248 cm^3/h) and three inlet air drying temperatures (110,120,130°C) aided in understanding their influence on the optical, physical and thermal properties of spray dried camel milk powders. The data were analysed through design of experiments (DOE) and numerical optimization was undertaken through the derringer desirability function to determine the optimal conditions (Hu, Cai, and Liang 2008).

Study 3

The methodology adopted in study 3 for the design of the butter and milk processing plant was similar to that proposed by Quijera & Labidi, (2013) and two stages of the methodology 455 presented in the IEA SHC Task 49 Guidelines (Krummenacher and Muster 2015). Initially, the current situation was described based on findings in study 1; the process then characterized through excel simulation based on findings in study 2; energy optimisation of the process and redefinition of the energy targets through PinCH analysis (HSLU 2012). Solar thermal and PV integrated into the processing design was based on modification of Schmitt, (2014) methodology. Solar thermal and PV was determined using the solar water heating (SWH) component and detailed PV model of the systems advisor model (SAM) respectively (Blair et al. 2018). Since this is a feasibility project, the financial viability of the solar PV and heat integration was determined based on the SAM fixed charge rate (FCR) method through the Levelized cost of energy (LCOE) expressed as €/kWh. Performance analysis of the SWH was based on capacity factor (c_{factor}), solar fraction (SF) and annual solar energy provided by the system. Whilst for solar PV system, the system performance metrics were capacity factor, performance ratio (PR) and annual energy yield by the system.

The economic feasibility of establishing the milk butter and powder processing plant was assessed through the modular method for capital estimation as proposed by Perry & Green, (2008); Saravacos & Kostaropoulos, (2012); Towler & Sinnott, (2013). Profitability of the enterprises was determined by the Net present value (NPV), payback period and DCFROR. Sensitivity analysis of the designed processing plant was utilized to assess how NPV is influenced by variations in selected parameters (Turton et al. 2018). To cater for cost escalations over the years and inflation over the years, Chemical Engineering Plant Cost Indices (CEPCI) of August 2018 was used and a factor of two for modular cost of steel was used for equipment when unavailable since this was a food processing plant (Chemical engineering n.d.; Saravacos and Kostaropoulos 2012). To determine the tonnes of CO_2 savings, methodologies utilized by (Meyers et al. 2016), taking into consideration the conversion factors for fuel oil and electricity that were Kenya specific were employed (Government of Kenya 2018).

3.3 Dissertation outline

The first three chapters of this dissertation introduces the study, by providing background information, research gaps, aim, study objectives, literature review, study methodology and statistical analysis. The subsequent part of the dissertation is structured as follows: in Chapter 4-6 results of the study are elaborated with each chapter addressing a specific objective of the study.

Chapter 4: Explores the strategies and technologies used in the camel milk preservation: In addition, the utilization of non-marketed camel milk is also presented.

Chapter 5: Assess the influence of feed flow rate and inlet air temperatures as it influences the physical, thermal and optical properties of spray dried camel milk.

Chapter 6: Process design and technical and economic feasibility of an optimized novel hybrid decentralised small-scale solar fossil-fuel powered camel milk powder and butter processing plant for the ASALs.

Chapter 7: Presents a general discussion of the results of each study as a holistic approach.

Chapter 8: Presents the reflection on methodologies, policy implications, outlook and conclusion of the dissertation.

References

Blair, Nate, Nicholas Diorio, Janine Freeman, Paul Gilman, Steven Janzou, Ty W. Neises, and Michael J. Wagner. 2018. "System Advisor Model (SAM) General Description." Oak ridge.

Chemical engineering. n.d. "Economic Indicators." 2018. Accessed November 13, 2018. https://www.chemengonline.com/site/plant-cost-index/.

Creswell, John W, and Vicki L Plano Clark. 2011. *Designing and Conducting Mixed Methods*. *Applied Linguistics*. 2nd ed. Vol. 2nd. Thousand Oaks, California, USA.: Sage publications. https://doi.org/10.1111/j.1753-6405.2007.00096.x.

ECARRP. 2013. "Location, Livelihood and Administrative Layers of Kenyan Districts." Nairobi.

Elhadi, Yazan Ahmed Mohamed. 2014. "Assessing the Contribution of Camel Milk As a Livelihood Strategy for Building Pastoral Household Resilience in the Drylands of Kenya." University of Nairobi, Kenya.

FAO, IFAD, UNICEF, WFP, and WHO. 2018. "Food Security and Nutrition in the World. The State of Building Climate Resilience for Food Security and Nutrition." Rome.

Francine, M., and R. Hughes. 1984. "A Comment on the Impact of Development Schemes on the Floodplain Forests of the Tana River of Kenya." *The Geographical Journal* 150 (2): 230. https://doi.org/10.2307/635001.

Fu, Xiaping, Moon S. Kim, Kuanglin Chao, Jianwei Qin, Jongguk Lim, Hoyoung Lee, Ana Garrido-Varo, Dolores Pérez-Marín, and Yibin Ying. 2014. "Detection of Melamine in Milk Powders Based on NIR Hyperspectral Imaging and Spectral Similarity Analyses." *Journal of Food Engineering* 124: 97–104. https://doi.org/10.1016/j.jfoodeng.2013.09.023.

GoK. 1997. "Isiolo District Development Plan 1997-2001." Nairobi: Government Printers.

Government of Kenya. 2018. "National Climate Change Action Plan (Kenya) 2018-2022." Vol. I. Nairobi, Kenya.

Herlocker, DJ, SB Shaaban, and S Wilkes. 1993. *Range Management Handbook of Kenya*. Volume II,. Nairobi: Ministry of Agriculture, Livestock Development and Marketing.

HSLU. 2012. "PinCH - An Analysis and Design Tool for Process Integration."

Hu, Zhuoyan, Ming Cai, and Han Hua Liang. 2008. "Desirability Function Approach for the Optimization of Microwave-Assisted Extraction of Saikosaponins from Radix Bupleuri." *Separation and Purification Technology* 61 (3): 266–75. https://doi.org/10.1016/j.seppur.2007.10.016.

Huang, Ronggui. 2014. "RQDA: R-Based Qualitative Data Analysis."

IBM Corp. 2015. "IBM SPSS Statistics for Windows, Version 22.0." Armonk, NY: IBM Corp.

KMD. 2018. "Isiolo County Climate Information Services Plan." Nairobi. https://doi.org/10.1016/b978-

008044109-2/50026-4.

KNBS. 2018. "Kenya Integrated Household Budget Survey 2015-2016." Nairobi, Kenya.

KNBS 2019. *2019 KENYA POPULATION AND HOUSING CENSUS VOLUME I : POPULATION BY COUNTY AND SUB-COUNTY*. Vol. I. Nairobi, Kenya: Government Printers.

Krummenacher, Pierre, and Bettina Muster. 2015. "Solar Process Heat for Production and Advanced Applications Methodologies and Software Tools for Integrating Solar Heat into Industrial Processes." *IEA SHC Task 49*.

Meyers, Steven, Bastian Schmitt, Mae Chester-Jones, and Barbara Sturm. 2016. "Energy Efficiency, Carbon Emissions, and Measures towards Their Improvement in the Food and Beverage Sector for Six European Countries." *Energy* 104: 266–83. https://doi.org/10.1016/j.energy.2016.03.117.

Muli, Masinga, David Kimenya, and Peter Kivolonzi. 2008. "The Camel Milk Industry in Kenya."

Ngaira, Josephine Khaoma. 2009. "Challenges of Water Resource Management and Food Production in a Changing Climate in Kenya." *Journal of Geography and Regional Planning* 2 (4): 97–103.

Noor, Issack Mohamed, Bockline Omedo Bebe, and Abdi Yakub Guliye. 2012. "Analysis of an Emerging Peri-Urban Camel Production in Isiolo County, Northern Kenya." *Journal of Camelid Science* 5: 41–61.

Perry, Robert H., and Don W. Green. 2008. *Perry's Chemical Engineers' Handbook*. Eighth. Vol. 1. The McGraw-Hill Companies, Inc. https://doi.org/10.1036/0071422943.

Quijera, José Antonio, and Jalel Labidi. 2013. "Pinch and Exergy Based Thermosolar Integration in a Dairy Process." *Applied Thermal Engineering* 50 (1): 464–74. https://doi.org/10.1016/j.applthermaleng.2012.06.044.

Republic of Kenya. 2018. "Isiolo County Intergrated Development Plan (CDP)." Isiolo. https://doi.org/10.1017/S0022278X00014853.

Saravacos, George, and Athanasios E. Kostaropoulos. 2012. *Handbook of Food Processing Equipment*. Second. Springer. https://doi.org/10.1007/978-3-319-25020-5_4.

Schmitt, Bastian. 2014. "Integration Thermischer Solaranlagen Zur Bereit- Stellung von Prozesswärme in Industriebetrieben." Shaker Verlag.

Solargis. 2019. "Solar Resource Maps of Kenya." 2019. https://solargis.com/maps-and-gis-data/download/kenya.

Stoker, Jeanie. 2000. "Keeping You Informed." *Home Healthcare Nurse* 18 (6): 371–72. https://doi.org/10.1097/00004045-200006000-00012.

Systat Software Inc. 2012. "Sigmaplots." San Jose California USA.

Towler, Gavin, and Ray Sinnott. 2013. *Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design*. *Chemical Engineering Design*. Second Edi. Elsevier.

https://doi.org/10.1016/B978-0-08-096659-5.00022-5.

Turton, Richard, Joseph A. Shaeiwitz, Debangsu Bhattacharyya, and Wallace B. Whiting. 2018. *Analysis, Synthesis, and Design of Chemical Processes*. 5th editio. Upper Saddle River, NJ, USA: Pearson Education International.

4.0 Strategies and Technologies for Camel Milk Preservation and Utilization of Non-Marketed Milk in Arid and Semi-Arid Areas[2]

[2] The content of the chapter has been published as a journal paper

Ogolla et al., 2017. Strategies and Technologies for Camel Milk Preservation and Utilization of Non-Marketed Milk in Arid and Semi-Arid Areas. East African Agricultural and Forestry Journal. DOI:10.1080/00128325.2017.1363686

Abstract

This study determined the seasonal fluctuations in camel milk yield, consumption, spoilage and spillages, and explored its forms of consumption and the acceptability of camel milk powder in Isiolo County, Kenya. In addition, the utilization of non-marketed milk, preservation technologies, and strategies for milk loss reduction employed along the camel milk supply chain were examined. Quantitative data was collected from 216 respondents (producers, traders and transporters) using a semi-structured questionnaire while qualitative data was collected through participant observations, key informant interviews and focus group discussions involving the camel milk supply chain participants. For quantitative data, descriptive and inferential analyses were conducted whereas for qualitative data thematic analyses were utilized.

Camel milk yield, consumption, spoilages and spillages increased by 45.5%, 40%, 81.0% and 79.1% respectively in the wet season. Camel milk was often consumed in smoked and boiled forms or as tea but never in pasteurized or powder form. Transportability, affordability and shelf life were mentioned as important attributes for camel milk powder acceptability. For non-marketed milk, 28.8% and 9.0% was discarded in the wet and dry seasons respectively while 11.2% and 22.4% was processed.

The main strategies employed for milk loss reduction were maintenance of hygienic practices (88% producers, 61% traders), smoking of the milk handling equipment (68% producers, 10% traders), and simple cooling (13% producers). High cost and limited technical feasibility restricted the utilization of preservation technologies (chilling and refrigeration). These findings show the need for appropriate milk preservation technologies for longer shelf life of milk products in arid and semi-arid areas.

Keywords: Isiolo; loss reduction; strategies; non-marketed camel milk; preservation technologies; seasonal dependency

4.1 Introduction

The world camel population is estimated to be approximately 27 million head, of which 85.2% are in Africa, 14.7% in Asia and 0.1% in Europe. Kenya's 3.1 million dromedary camel population is estimated to be the third largest camel herd in the world after Somalia and the Republic of Sudan (FAO 2014b) . Camels belong to the family *Artiodactyla*, suborder *Tylopoda* and genus *Camelus* which has two main species: *C. dromedarius* L., one humped, that live in desert areas such as South West Asia, Africa, & Australia and *C. bactrianus* L., two-humped, which occupy cooler areas such as Northern China, Mongolia, Kazhakstan, & Russia (Farah 1986; Yagil 1982). Camels are often referred to as the 'White gold of the desert' as they can thrive in areas where crop production is limited and other animals cannot withstand the harsh climatic conditions (Bornstein and Younan 2013; Werney 2006).

Camels are kept for milk, meat, transportation, traction, hide and tourism. Camel milk has significant nutritional properties and more health benefits compared to other types of milk (Benkerroum et al. 2004; El-Agamy 2007; Agrawal et al. 2007; Singh, Fotedar, and Lakshminarayana 2008; Elayan, Sulieman, and Saleh 2008). Moreover, in pastoral regions where fruits and vegetables are scarce, camel milk is often the main source of vitamin C as it contains 30 times more than bovine milk and six times more than human milk (Haddadin, Gammoh, and Robinson 2008). The great contribution of camel milk to the nutrient requirements of pastoral groups has led to its acknowledgement as an important component of pastoralists' diets across the world (Fratkin, Roth, and Nathan 2004; Sadler et al. 2009). In Kenya, camel milk accounts for 60% of the total nutrient intake of the pastoral communities inhabiting the Arid and Semi-Arid Lands (ASALs) (Kaufmann 2003; Simpkins et al. 1997). Camel milk is often consumed raw or naturally fermented (Yagil 1982; Agrawal et al. 2005). However, the acceptability and consumption of milk products with a longer shelf life have not been explored in Isiolo, County Kenya.

Estimated daily average camel milk yield is between 3 and 10 litres during a lactation period of 12–18 months (Farah et al. 2007). Some factors have been reported to increase camel milk yield, including feeding, seasonal variation, husbandry, watering, and veterinary services (Cardellino, Rosati, and Moscom 2004). Of these, in systems where camel production is dependent on natural pastures such as in Kenya, seasonal variation is the major determinant of camel milk yield in tropical and sub-tropical regions (Nicholson 1984). In these systems, the scarcity of water for camel consumption in the dry season results in decreased camel milk yield (Haddadin, Gammoh, and Robinson 2008) However, in areas such as the Gulf, modernised units have facilitated the intensification of camel milk production, thus less seasonal variation in milk yield occurs (Bernard Faye 2005). There is limited information available in Kenya on camel milk yield as influenced by seasons.

Traditionally, camel milk marketing was viewed as taboo amongst pastoral communities. In addition, camel herds are located in the arid and desert areas which are far from the commercial markets (Konuspayeva and Faye 2004). This limited the use of camel milk to subsistence and raising of calves, with only a small percentage reaching the markets (Al haj and Al Kanhal 2010). However, in recent years, there has been a shift in camel milk utilisation from subsistence to commercial in different parts of the globe, indicating the significant role of the camel in a household's food basket (Adongo, Coppock, and Wayua 2013; Nori 2010; Anderson et al. 2016). In both dry and wet seasons, pastoral households in Kenya are dependent on camel milk sales as their main income source and the volume sold is dependent on the economic and social needs of the household (Nori 2010). For example, in 2013, Africa contributed 32% of the world's 2.9 million tonnes of camel milk marketed. Kenya's 937 000 tonnes ranked second after Somalia (FAO 2014a). However, studies have shown that 50% of the total Kenyan camel milk produced does not reach consumers and 30% of the marketed milk is sold in sour form (Kuria et al. 2011). Therefore, to increase the amount of milk marketed, it is vital to understand the factors contributing to the quantities reaching the consumers and to estimate the volumes and forms of milk marketed. Information on the milk losses along the camel milk supply chain and how the non-marketed milk is utilised among the pastoral communities has not yet been fully acquired.

To minimise milk spoilage, different preservation technologies and strategies that increase its shelf life have been put in place to ensure limited microbial contamination along the value chain. Interventions such as the use of commercial lactoperoxidase systems (LS) kits, cooling facilities, milk pasteurization, clean water provision and training on hygienic milk handling have been proposed in the pastoral regions of Kenya (Bornstein and Younan 2013; Wayua, Okoth, and Wangoh 2013; Adongo, Coppock, and Wayua 2013). Different studies have reported simple cooling technologies, fermentation, and smoking of camel milk in pastoral regions of Ethiopia and Kenya (Seifu 2007; Wayua, Okoth, and Wangoh 2012). However, with the ever-evolving camel milk trade in Kenya, there is a need to document both the traditional and modern milk preservation technologies and the energy they utilise.

Preservation of camel milk has also been enhanced through processing it into value added products. Among the pastoral communities in Ethiopia, Kenya, and Somalia, camel milk has been processed into ghee, fermented milk (*gariss, dhanaan, susaac*), yoghurt, cheeses, and butter (Seifu 2007; Wayua, Okoth, and Wangoh 2012). These products have enabled the availability of valuable milk nutrients during seasons of scarcity, income generation for households, and also limited the losses attributed to milk glut (El Zubeir and Jabreel 2008; Elayan, Sulieman, and Saleh 2008). However, information on the amount of milk that is not marketed but is processed into these products, variation according to the seasons, and at what point in the value chain processing occurs have not been explored.

The objectives of the present study were therefore: (1) To determine the seasonal fluctuations in camel milk yield, consumption, spoilage and spillages; (2) To determine how non-marketed milk is utilized; (3) To identify the strategies and preservation technologies for milk loss reduction employed in Isiolo County, Kenya; (4) To explore the forms of camel milk consumption and the acceptability of camel milk powder.

4.2 Methodology

4.2.1 Study area

Isiolo County is situated in the dry lands of Northern Kenya, at a latitude of 0°21′0″ N and a longitude of 37°35′0″ E. The study area lies at an altitude of 200–300 metres above sea level and experiences an annual mean temperature of 23.3 °C and bimodal rainfall with an annual average of 580 mm. The County covers an estimated area of 25 605 km² (Arid Lands Resource Management Project (ALRMP) 2009) with a projected population of 143, 294 (KNBS, 2019).. Administratively, the County is divided into three main sub-counties: Isiolo central, Garba Tula, and Merti. Ecologically, the area consists of three zones: the semi-arid (5%), arid (30%) and very arid zones (65%), characterised by variability in rainfall and vegetation types. Livestock production is the main livelihood strategy with over 80% of the population relying on the livestock Agricultural Sector Development Support Programme (ASDSP). The Borana and Somali pastoralists living in Isiolo predominantly keep a mix of livestock species with an estimated population of 40 300 camels (KNBS, 2019). Camels are mainly kept for milk production both for household consumption and commercial purposes (Noor, Bebe, and Guliye 2012). The maps of the study site and climatic conditions are presented in figures 4.1 and 4.2 respectively.

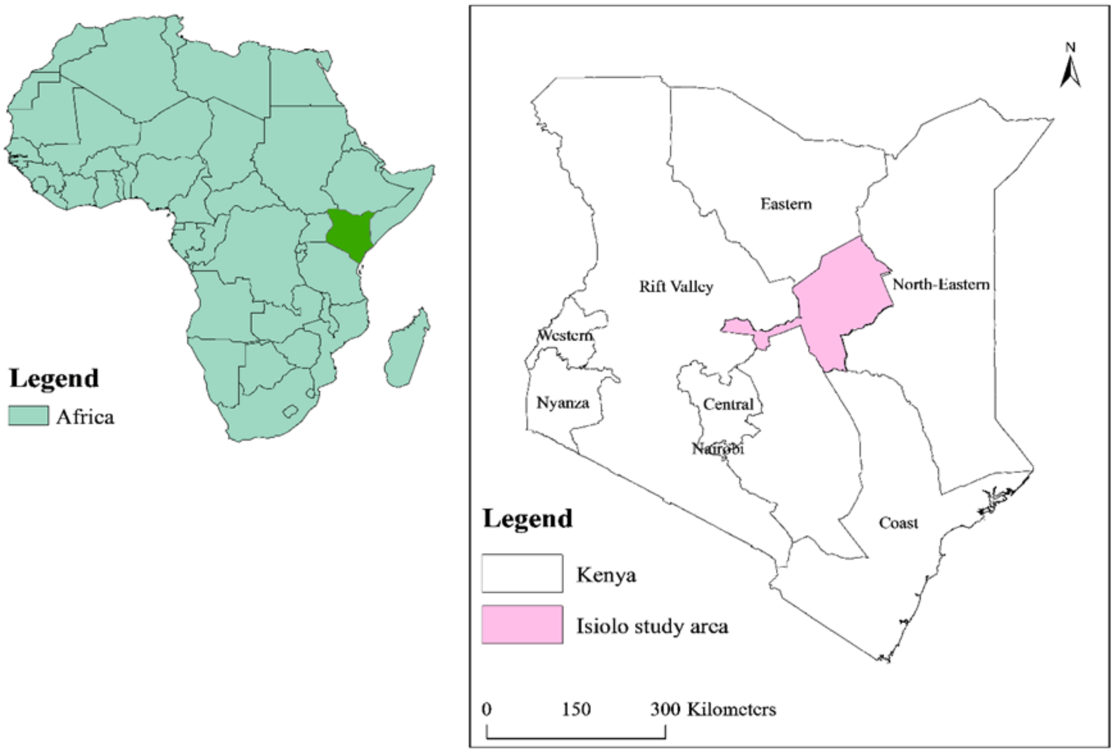


Figure 4. 1:Map of the study area. Source: Author's own

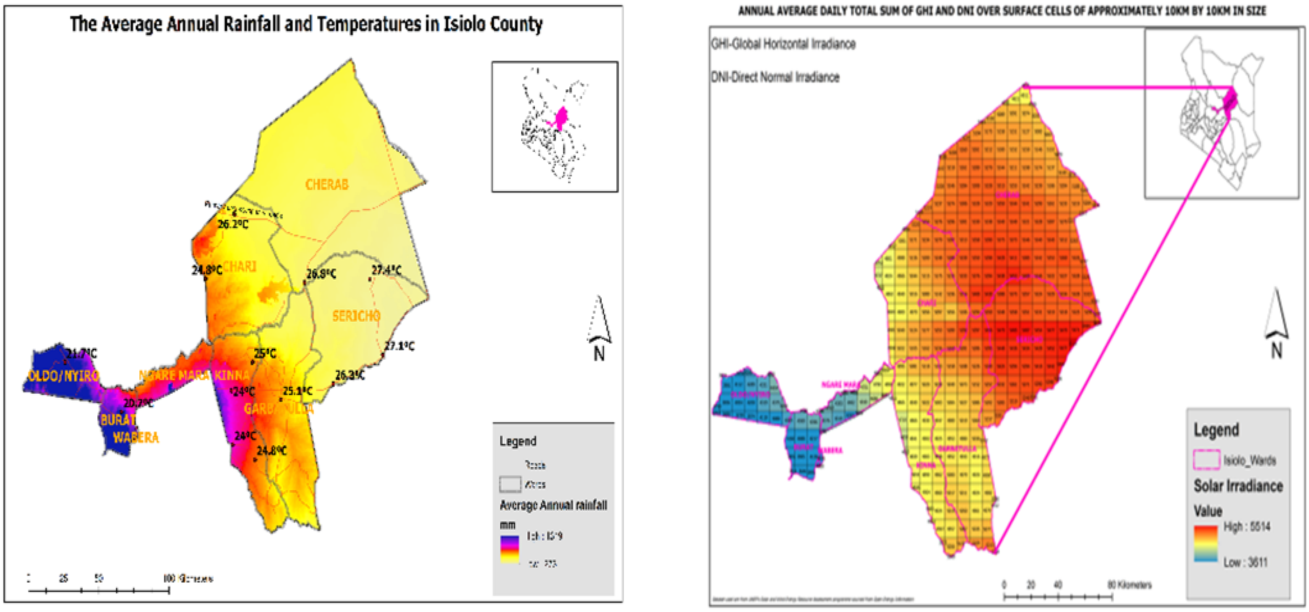


Figure 4. 2: Climatic conditions of the Study Area: credit: kipsongokkibet@gmail.com

4.2.2 Sampling procedures and sample

This study employed a cross-sectional design (specific point in time of data collection and analysis) concurrent with a mixed methods design (combination of both qualitative and quantitative methods of data collection and analysis) (Creswell and Clark 2011).

4.2.2.1 Quantitative sampling procedure

A cross-sectional survey using structured and semi-structured interviews was carried out in Isiolo County, Kenya between August and September 2015. The study employed purposive and multistage sampling techniques in Garba Tula and Isiolo Central because of their higher contribution to the marketed camel milk in the County. The sampling unit consisted mainly of supply chain players comprising commercial camel milk producers, traders, consumers, transporters, Non-Governmental Organisations (NGOs), cooling hub managers, and County government members who were available and willing to participate in the study.

Sampling of producers (N = 145) was limited to the accessibility of herd owners who were involved in the commercial camel milk business, and 15 villages were sampled. In each village, a landmark was identified from which a transect was drawn, and in every fifth household involved in a commercial camel milk business, the household head who consented was interviewed. If the herd owner was absent or unwilling to participate in the study, the next household was chosen, and the interview carried out.

The milk transporters were purposively sampled. These included transporters from the production sites to cooling hubs (7 motorcycle operators), from the primary collection centres to the cooling hubs (6 motorcycle operators and 3 land cruiser owners), and from the cooling hubs to the main market in Nairobi (4 buses).

4.2.2.2. Qualitative sampling procedure

A total of 6 focus group discussions (FGDs) that comprised 6–8 participants were held, with four FGDs conducted separately with consumers, producers, traders and transporters and two FGDs carried out with mix of players in the supply chain. A total of 12 key informant interviews (KIIs) were held with representatives from non-governmental organizations (NGOs) (2), government representatives (4), community-based organizations (2), herders (2), local leaders (1) and a cooling hub manager (1).

4.2.3 Data collection tools and procedures

The interviews were conducted orally in a face-to-face manner by four trained enumerators who were conversant with the local dialect. The semi-structured questionnaires were first pre-tested for clarity of questions with a group of 10 producers and five traders who were then excluded from the study. Data collected through the structured questionnaire administered to the producers and transporters was based on their past sales records for the month of June (wet season) and the actual volumes of milk in the month of August (dry season). Data on production, consumption, sales, spoilage, spillages, preservation techniques and loss reduction, and acceptability of milk powder were collected through a semi-structured questionnaire administered to the producers and traders. Simultaneously, data on purchases, sales & spoilage were obtained from the main cooling hub (Anolei) for the months of January to August 2015.

To understand the supply chain, a checklist was used to collect secondary data from the Ministry of Agriculture, Livestock & Fisheries at the county level and the cooling hubs. This was complemented by participant observations at marketplace and collection centres to understand both preservation technologies and energy sources used in the camel milk supply chain.

4.2.4 Data analyses

Descriptive and inferential statistics for quantitative data from both the traders and producers were generated using the IBM SPSS software version 22 (IBM Corp. 2015). The plotting was conducted using the Sigma plots software version 13 (Systat Software Inc. 2012).

Qualitative data recorded from the FGDs and KIIs were transcribed by the first author verbatim from Swahili to English. Recorded interviews carried out in English and field notes from direct observations (DOs) were also compiled. These were later coded into thematic topics using R-based Qualitative Data Analysis version 0.2-7 (Huang 2014).

4.2.5 Data quality control

The administration of questionnaires was carried out by enumerators who spoke the local dialect and were chosen based on the minimum requirement of a university degree. They were then trained and closely supervised by the researcher in the field. Daily meetings were held in the evening for clarification on any matter that arose throughout the course of the day. The variables measured, and the data analyses carried out are presented in Table 4.1

Table 4. 1: Variables measured and data analyses

Variable	Measurements	Source of data	Analyses
Camel milk supply chain	▪ Key actors & their activities ▪ Production functions ▪ Factors contributing to losses	▪ Producer questionnaire ▪ Traders questionnaire ▪ FGDs, KIIs, POs	▪ Thematic coding
Seasonal variation at production level	▪ Monthly yield in liters ▪ Monthly sales in liters ▪ Monthly spoilages in liters ▪ Monthly consumption in liters ▪ Volume fed to calf ▪ Prices in Kes/liter	▪ Producer questionnaire Traders questionnaire ▪ FGDs, KIIs	▪ Descriptive statistics ▪ T-tests ▪ Thematic coding
Seasonal variation at marketing level	▪ Monthly sales in liters ▪ Monthly spoilages in liters ▪ Monthly Purchases in liters	▪ Traders questionnaire ▪ FGDs, ▪ Document reviews	▪ Descriptive statistics ▪ Thematic coding
Non-marketed milk utilization (seasonal variation)	▪ Percentage fed to calf ▪ Percentage for home consumption ▪ Percentage discarded ▪ Percentage processed into other products ▪ Percentage given to neighbours	▪ Producer questionnaire Traders questionnaire ▪ FGDs, KIIs	▪ Descriptive statistics ▪ Thematic coding
Preservation technologies	▪ Capacity of the technologies available ▪ Energy sources used ▪ Shelf life of milk stored ▪ Pictorial representation ▪ Challenges in technology uptake	▪ Producer questionnaire Traders questionnaire ▪ FGDs, KIIs, POs,	▪ Thematic coding
Consumption and feasibility of milk powder	▪ Important attributes: Transportability, storability, affordability, taste, colour ▪ Mode of consumption of milk	▪ Producer questionnaire Traders questionnaire ▪ FGDs, KIIs, POs	▪ Descriptive statistics

FGD: focus group discussion, KII: key informant interviews, PO: participant observation

4.3 Results

This section is divided into eight subsections including: characterization of the respondents; the camel milk supply chain; camel milk yield, sales, consumption and losses at production and marketing level; utilization of non-marketed camel milk; strategies employed for milk spoilage reduction; preservation techniques along the camel milk supply chain; energy sources in camel milk preservation, and camel milk consumption forms and milk powder acceptability.

4.3.1. Characterization of the respondents

Table 4.2 indicates the socio-demographic characteristics of the respondents in the study area.

Table 4. 2: Socio-demographic characteristics of the respondents in the study area

Socio-Demographic indicators		Producers (N=145)	Traders (N=50)
Gender	Male	40.0%	4.6%
	Female	60.0%	95.4%
Head of household	Male	86.2%	_
	Female	13.8%	_
Household size		9.1±2.9	_
Age in years		49. 1±11.2	34.2±7.4
Educational level	None	84.1%	63%
	Primary	13.1%	33%
	Secondary	0.7%	4%
	Tertiary	2.1%	0%
Occupation	None	2.1%	0%
	Livestock keeping	92.4%	11.8%
	Business	4.1%	87.2%
	Crop farming	0.7%	0%
	Wage employment	0.7%	0%
Years in commercial milk business		10.5±5.8	5.8±2.5
Number of Lactating camels		14.6±0.8	-
Number of Customers		-	3.5±5.04
Number of Suppliers		-	4.9±2.0

Though many respondents were female (60.0%), they indicated that the household heads were mainly male (86.2%). The producers largely (92.4%) depended on livestock as a source of livelihood compared to 84.1% of the traders who depended on business (marketing of the camel milk) as their source of livelihood. Milk pooling among the traders was common as an average of 3.5±1.0 producers supplied a single trader who in turn sold to 4.9±2.0 retailers.

4.3.2 Camel milk supply chain

The camel milk supply chain in Isiolo County was characterised by actors who performed five main chain functions: production, primary transportation, collection, secondary transportation and retail (Table 4.3). Table 4.3 indicates the camel milk supply chain in Isiolo County, Kenya. Analysis of FGDs, KIIs, and POs indicated that camel milk losses varied along the supply chain. Non-hygienic milk handling practices and lack of preservation technologies characterised milk spoilage at production and marketing levels. Economic losses during the dry season as mentioned by the respondents were due to the migration of camels in search of pasture and water, and as the calves could feed on the dam, no milk was sold. Participants in the traders FGD reported that the primary milk transporters covered vast distances between milk collection centres during the dry seasons as the camels were further apart, thus delaying milk delivery at the marketing level. The exposure of the milk to high temperatures while awaiting transportation and during transit, coupled with the rough terrain, resulted in the churning of milk. During the wet season, economic losses attributed to low milk prices and fewer camels milked resulted in more milk consumption by the calf. Spillages during transportation were due to overloading of motorcycles or loosely tied jerry cans on land cruisers that burst or fell off during transportation.

Table 4. 3: Camel milk supply chain, actors and factors contributing to losses

Milk flow ↑

Chain functions	Actors	Activities	Type of loss	Factors mentioned as contributing to losses
Retail	Retailers	Selling to consumers, milk bars, and restaurants	Spoilage	▪ Unhygienic milk handling practices ▪ Delay in milk delivery
Transport	Cart and Bus drivers	Transport from cooling hubs to bus stops to urban retailers	Spoilages	▪ Mechanical problems thus delay in milk delivery
Collection	Bulking traders	Bulk, test, preserve and pack milk	Spillages Spoilages	▪ Unhygienic milk handling practices ▪ Delay in milk delivery ▪ Lack of milk preservation technologies ▪ Chemical and physical contamination
	Non-Bulking traders	Test, preserve and pack milk	Spillages Spoilages	▪ Unhygienic milk handling practices ▪ Delay in milk delivery ▪ Lack of preservation technologies ▪ Chemical and physical contamination
Transport	Motorcycles	Transport from producers to traders and local retailers	Spillages	▪ Poor terrains ▪ Loosely tied containers ▪ Overloading
	Land Cruisers	Transport from producers to traders and local retailers	Spillages	▪ Poor terrains ▪ Unreliable transportation
Production	Producers	Livestock husbandry, milking, packaging, transportation to the traders and retailers	Spoilages Spillages Economic losses	▪ Unhygienic milk handling practices ▪ Lack of milk preservation technologies ▪ Migration of camels during the dry season. ▪ Sickness of camels ▪ Insecurity ▪ Mixing of milk ▪ Lack of market in wet season

4.3.3 Camel Milk Yield, Sales, Consumption and Losses

4.3.3.1 Variation in camel milk yield, sales and losses at production level

During the dry seasons 26.2%, 58.6%, and 15.2% of the producers (N = 145) reported that they milked their camels once, twice and three times daily respectively compared to 6.9%, 29.0%, and 64.1% during the wet season. When the milking was conducted three times a day, this was carried out twice in the morning (0600 h & 0900–1000 h) and once in the evening (1800–2000 h). The morning milk was both for household consumption and marketing while the evening milk was mainly for the herders. During the dry season, which was characterised by limited forage and water, the milk yield decreased (815.2±53.4 L) while the marketing price per litre of milk increased ($0.69±0.01). This resulted in a percentage of marketed milk increasing in relation to the yield. During the wet season, characterised by the availability of forage and water, the milk yield increased (1496.1±82.2 L), prices decreased ($0.39 ±0.01), and thus the percentage of the marketed milk also decreased by about 79.5% in relation to the yield. The volumes of milk spilt increased in the wet season from 0.6% to 1.4% in the dry season and the amount of milk rejected increased from 2.1% in the dry season to about 7.5% in the wet season (Table 4.4).

Table 4. 4: Variations in yield, spillages, rejects, consumption, sales and prices with the season at production level (N=145)

Monthly	Dry season	Percent of production	Wet season	Percent of production	Percentage Change (%)	t-test	p values
Production (L)	815.2±53.4	100	1496.1±82.2	100	45.5	17.4	<0.01
Spillages (L)	4.5±1.1	0.6	21.5±4.2	1.4	79.1	4.5	<0.01
Rejects (L)	17.6±3.9	2.1	111.6±12.6	7.5	81.0	8.4	<0.01
Consumed (L)	104.1±5.6	12.8	173.4±7.1	11.6	40.0	8.5	<0.01
Sales (L)	689.0±50.6	84.5	1190.1±78.5	79.5	42.1	15.0	<0.01
Price (€)	0.61±0.01		0.35±0.01		-75.3	-38.8	<0.01

4.3.3.2 Variation in camel milk purchases, sales and spoilages at marketing level

The volumes of milk traded and spoilt during the wet and dry season varied throughout the year (Fig. 4.3).

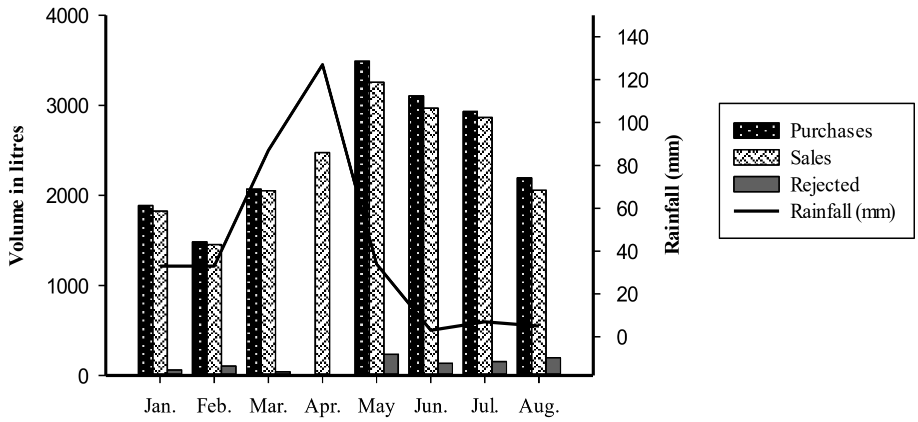


Figure 4. 3: Monthly variation in daily milk purchases, sales and spoilages & monthly rainfall in millimetres in Isiolo County.

These results were supported by qualitative data from KIIs which denoted that less milk spoilage occurred during the dry season. As one of the respondents indicated:

> *"Now we receive 2000–2200 litres per day and the milk spoilt will not reach 5%. It is approximately 2–3%. For example, today 20–30 litres are spoilt. However, during the rainy season… there is much spoilage. For 3000–3500 litres that we receive, we can get up to 200 litres of milk which are spoilt.*

KII 30 years Male.

In times of milk scarcity, the fermented milk was bought by the retailers and marketed at the same price as fresh milk, contrary to the wet seasons where a slight sign of natural fermentation resulted in milk rejection as explained by one key informant:

> *"You know like now the season is the peak, the milk has great demand. Now even the milk that is fermented is still being sold in Nairobi at the same price. However, during the rainy season, when the milk is plenty, any slight fermentation of milk, the milk is returned to them. During that season, they do not send the fermented milk to the retailers."*

KII Male 43 years.

4.3.4 Utilisation of non-marketed camel milk

The non-marketed milk comprised of the milk that was not sold due to spillage, market glut, or spoilages. Before accepting the milk from the producers, the traders determined the quality of the milk by carrying out either chemical tests (alcohol test) (13.7%), combined chemical and organoleptic tests (9.8%) at the main cooling hub or organoleptic tests (76.5%) (Sight, taste and smell) at the primary collection points. Milk was rejected when naturally fermented and returned to the producers by the traders. Upon the addition of sugar, the returned milk was either sold at a lower price (48%) or consumed (52%) at the household level depending on the season. The monthly non-marketed camel milk volume accounted for 8.1% (122.1±165.0 litres) and 2.4% (20.3±45.2 l) in the wet and dry season respectively per household. Based on the prices fetched in the dry and wet season (Table 5.3), the monthly non-marketed milk valuation per household ranged between €12.67–-€ 28.21 in the dry season and €43.4–€ 58.60 in the wet season. If the non-marketed portion in the wet season is valued similarly to the costs in the dry season, the household loses approximately €76.05–€102.81 on a monthly level. Approximately 22.4% of this milk was processed (*Suusac* – naturally fermented milk with added sugar) during the dry season compared to 11.2% during the wet season. Similarly, 28.8% of the milk was discarded during the wet season compared to only 9% in the dry season (Fig. 4.4).

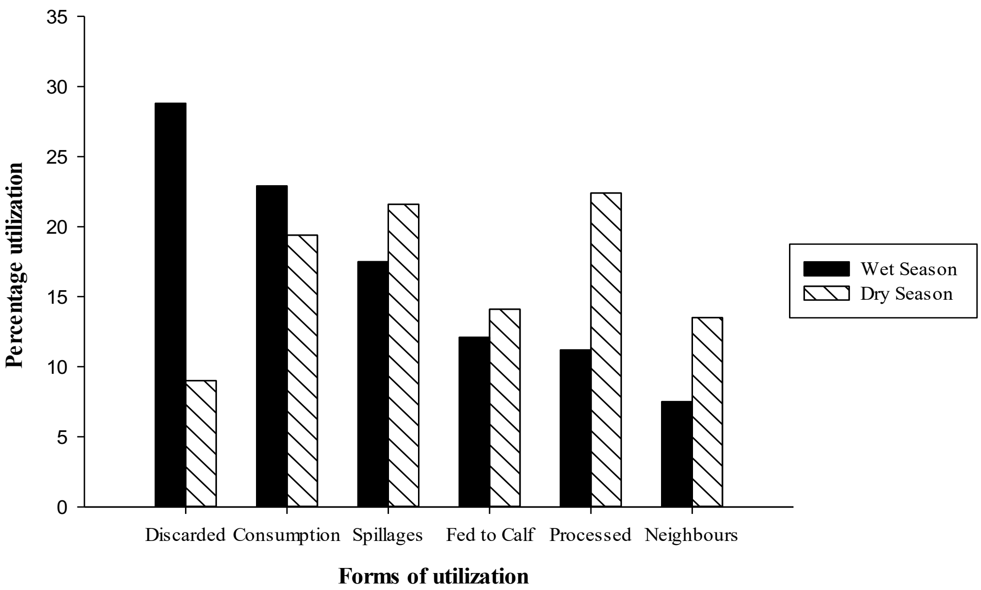


Figure 4. 4: Utilisation of non-marketed milk during the dry and wet season at production level

4.3.5 Strategies employed for milk spoilage reduction

Strategies to limit camel milk losses along the supply chain in the study area included techniques to limit contamination and spoilage, thus prolonging the shelf life of milk. Strategies to limit contamination were the responsibility of both the producers and traders and the most important was hygienic handling from milking (88%) to bulking (61%) (Table 4.5). These comprised of milking with clean hands, and cleaning of the camel udder and milk handling equipment. The producers further ensured that during milking contamination with camel urine, calf saliva and insects was prevented. Traders filtered milk at the cooling hubs to remove particles and dust. Moreover, the spoilt and non-spoilt milk were not mixed during bulking as indicated by 35% of the traders. Both traditional and modern strategies were utilised at both production and marketing levels to increase the shelf life of the milk. These included smoking of the milking and storage containers, as well as boiling and cooling of the milk.

Table 4. 5: Strategies employed for milk loss reduction at production and marketing level

Strategies employed	Percentage producers' respondents (N=145)	Percentage traders' respondents (N=51)
Hygienic practices	88%	61%
Smoking the jerry cans	68%	10%
No mixing of spoilt and non-spoilt milk spoilt milk	-	35%
Simple cooling technologies	13%	2%
Boiling of milk	8%	2%
Treatment of sick camels	4%	8%
Sieving of Milk	-	10%
Timely delivery of milk	5%	-

Percentages are greater than 100% since the questions were multiple answers.

4.3.6 Preservation techniques along the camel milk supply chain

Preservation technologies along the Isiolo camel milk supply chain were determined from the analysis of both the traders' and producers' interviews coupled with the information from key informants and FGDs. Preservation of milk along the camel milk value chain varied from production to consumption (Fig. 4.5). Approximately 95% of the total camel milk produced was smoked while 5% was refrigerated during transit. The non-smoked camel milk was pre-ordered for the processing of value-added camel milk products such as pasteurised milk, yoghurt and fermented milk in urban areas.

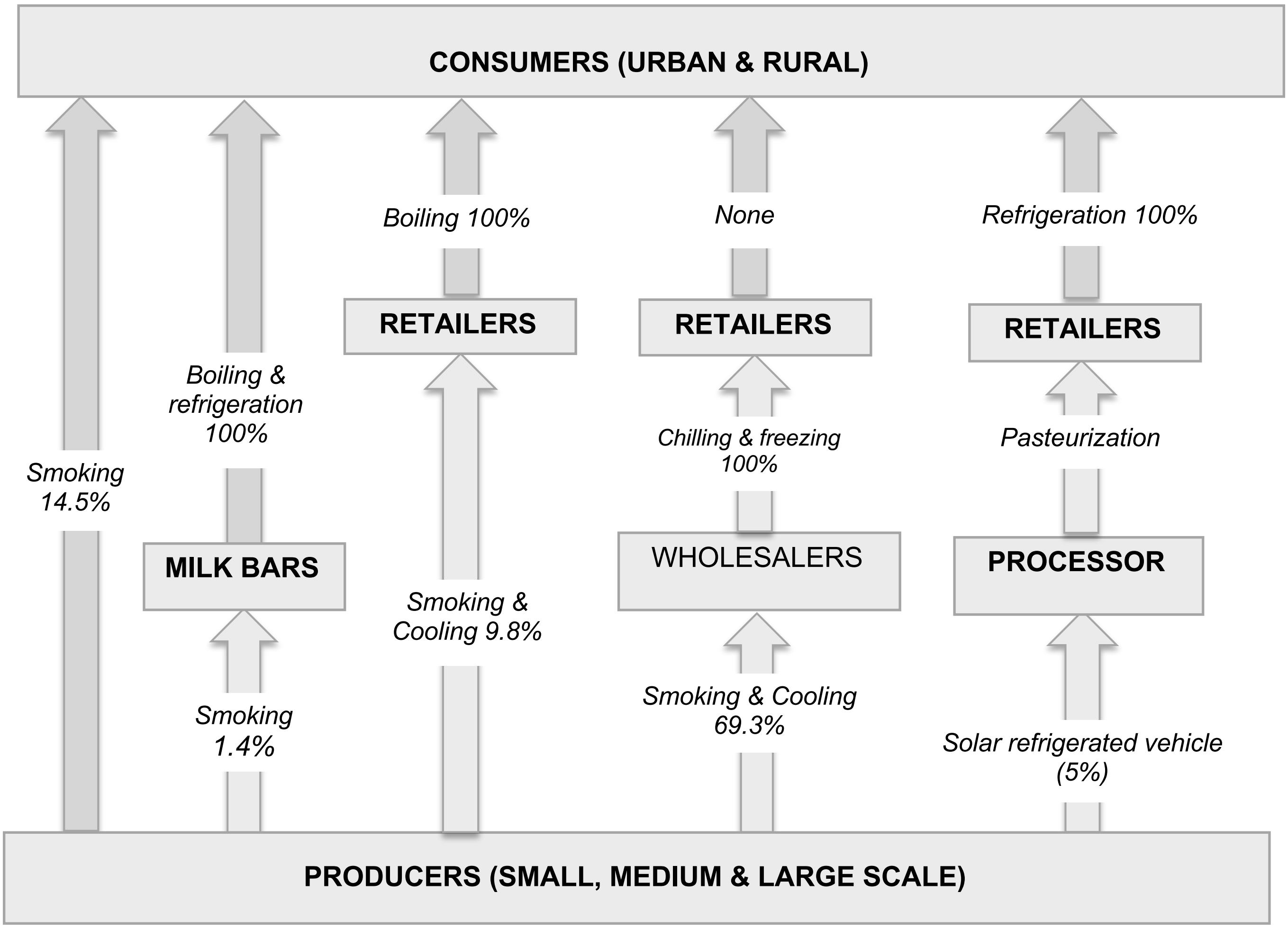


Figure 4. 5: Preservation techniques along the camel milk value chain

The camel milk preservation technologies indicated in figure 4.5 are discussed below.

4.3.6.1 Smoking (Fumigation) of the jerry cans and milking cans

Fumigation of milk was carried out by the respondents to impart flavour and increase the keeping quality of milk left for 12–24 hours without refrigeration. This entailed first, the cleaning of the plastic milk jerrycans (1–20 litres) or the *Damela* used in the milking of the camel. The selected shrubs were lighted, and then extinguished before being introduced into the cleaned containers. The containers were closed and shaken, with duration of smoking time being dependent on the volume of the container. The burnt particles were then either removed or left in the containers, after which they were sieved off at the cooling hubs or the refrigeration centres. Fumigation of the jerrycans was carried out at the household level, by herders, or in Isiolo town by the traders. The main tree species utilised by the respondents were community specific and included: *Vachellia nilotica* (L.) *(Sabans)*, *Cardia quercifolia* (L.) J. Sm. (*Madeer*), *Balanites pedicellaris* Milbr. & Schlecht, *Acacia zanzibarica* (S.Moore) Taub, *Cordia sinensis* Lam. and *Terminalia kilimandscharica* Engl.

4.3.6.2 Boiling

Milk was boiled to a temperature of approximately 60° C and then cooled. This was mainly carried out in areas such as the Kulamawe region where traders and producers had limited access to cooling facilities and unreliable transport services. In Isiolo town, the small-scale retailers handling 10–20 litres per day boiled and sold their milk to the final consumers in this form. The bulkers rarely purchased boiled milk. One respondent explains,

> *"We used to boil our milk and send it to Nairobi, but every time the person whom we used to send the milk to would complain that the milk is spoilt. This continued for quite a period until it reached a point that we stopped sending the milk to him and resorted to selling the fermented (Suusac) milk."*

Large scale Camel milk producer, Male 51 years of age.

4.3.6.3 Cooling Technologies

4.3.6.3.1 Use of 'Qoodha.'

We identified a special traditional container (Qoodha) that could store milk for up to 72 hours. The Qoodha is an oval-shaped container specially woven from the roots of the Ergemis sp tree and decorated with cowrie shells (Fig. 4.6 a). The top part of the Qoodha is made from fibres obtained from the stem of *Adansonia digitata* L. Using a metal needle, the two fibres are woven and interwoven into a pot like a basket. The inside is later smoked with branches from *Cordia monoica* (*Mader* in Borana) until the inside of the pot becomes compact due to the layers formed. The Qoodha is then filled with milk and tied onto the roof of the grass-thatched house, supported by a casing made from dried camel or cow hide. The preservation technique is dependent on both the cooling and antimicrobial properties of the smoked container. According to the FGD findings, the utilisation of this technology was reported to be fast becoming extinct among the commercial camel milk producers, but it is still optimally used in isolated rural communities away from commercial centres.

Figure 4.6 a: Qoodha

Figure 4.6 b: Hemp bag

Figure 4.6 c: Charcoal evaporative cooler

Figure 4.6 d: Chillers

Figure 4.6 e: Freezer

Figure 4.6 f: Butter making

Figure 4. 6:Pictorial representation of the different preservation technologies in Isiolo, County

4.3.6.3.2 Simple evaporative cooling

Simple cooling technologies that entailed the use of gunny or hemp bags soaked in water wrapped around 20-litre milk jerrycans were practised in the study area (Fig. 4.6 b). This was utilised during the transportation of the milk from the milking point to, and at, the primary collection centre, where the jerrycans were placed in the shade of a tree while awaiting transportation to the cooling hubs. Prolonged delays in the collection of milk from the primary collection centres also enhanced the utilisation of this simple cooling technology. A simple charcoal evaporative cooler (Fig. 4.6 c) was identified in Kulamawe but was not utilised by the local communities due to the high cost of charcoal and inadequate water supply as indicated by the FGD participants.

4.3.6.3.3 Chilling

Freezing and chilling of the camel milk were extensively carried out in Isiolo town by traders either individually or as groups on milk destined for the urban markets. Frozen and chilled milk accounted for the greatest percentage of all the marketed camel milk not only in Isiolo County but also in the country. This milk was sold as fresh to the final consumers, hotels, and milk bars and some of it was pasteurised at the marketing level in the urban centres. The pasteurised milk was sold at €2.26 per litre at the main retail outlets in Nairobi, Kenya compared to €0.27 and €0.62 obtained by the producers during the wet and dry season respectively. Chillers with capacities of 3000 and 550 litres (Fig. 4.6 d) were available for cooling in Isiolo County. The capacity of the chillers was limited since the camel milk had to be sold the next morning to create space for the next quantity of milk. During the rainy season, the capacity of the chillers was exceeded, and the excess milk stored in freezers. Approximately 3500 litres of milk were received daily during the wet season compared to between 2000 and 2200 litres during the dry season. It took between 4–5 hours for the milk temperature to drop to 5 °C from about 30 °C and this varied depending on the time of the last milk delivery, which influenced the quality of the chilled milk. Rejection of the milk at the chiller was based on adulteration that was determined through an alcohol test and was higher during the wet season (Fig. 4.3). The monthly charges for using the chiller depended on utility charges (electricity bill, rent, water bills, employees, and permits) incurred during the month and ranged between €27.13 and €31.65 per individual.

4.3.6.3.4 Freezing

Most of the milk at marketing level was stored in individual freezers either owned or rented by individuals. During the rainy season, the freezers operated at full capacity with an average of 200 to 220 litres compared to 140–160 litres per day during the dry season. The cost of renting a freezer was dependent on the season, with monthly charges of approximately €45.21 during the rainy season and €27.13 during the dry season. There were milk residues on the walls of the freezers due to spillages when milk was transferred from the transportation containers to the containers in the freezers for storage. The milk was kept in the freezers in aluminium cans (10 and 20 litres), polythene bags (2 litres), plastic jerrycans (capacities 20, 10, 5, and 3 litres), or plastic buckets (10 litres) (Fig. 4.6 e). The aluminium cans were provided by the camel milk supply chain supporters such as the non-governmental bodies. According to the respondents, they were expensive to purchase and not easily portable and hence had limited usage in the storage of milk in the freezers and transportation. Some freezing and chilling facilities are shown in figures 4.6 d and 4.6 e.

4.3.6.4 Value added products

According to the participants in the producer and trader FGDs, the milk glut during the wet season enabled the processing of camel milk into value-added products such as butter (Fig. 4.6 f), cheese and yoghurt. Most of the traders and some of the producers had been trained in milk pasteurisation though no pasteurisation of milk took place in Isiolo. This they attributed to the consideration that it was meant for the high-end market. Consumption of the naturally fermented milk known as *Susaac* which was prepared through spontaneous fermentation of fresh camel milk was common.

4.3.7 Energy sources in camel milk preservation

The main energy sources that were utilised in milk preservation among the traders in Isiolo County were electricity (62.7%), firewood (27.5%) and charcoal (7.8%). On-grid electricity was utilised mainly for camel milk cooling in the freezers and the chillers in Isiolo central sub-county while charcoal and firewood were used for the boiling of milk both at Kulamawe and Isiolo town by the retailers and the milk bars. According to the participants in the traders FGD, the main challenges in utilising on-grid electricity were high cost of installation, high monthly electricity bills and termination of an electrical connection when payments were delayed. Only 11.8% of the traders who used electricity used a diesel driven generator during power outages while the rest depended on the ice that was frozen in the refrigerators for cooling, discarded the milk or allowed the milk to ferment naturally.

Waterlogging and inaccessibility of firewood in the wet season led to increased utilisation of charcoal by 13.7% for camel milk boiling according to the respondents. From the traders FGD, they reported that the main challenges in using wood fuels in milk boiling were government policies that limit the burning of charcoal and the woody flavour of the camel milk. The residents of Kulamawe had to travel for approximately 2 km to obtain firewood. The boiling of milk by retailers took place in their households before transportation to the market. Approximately 10 kg of charcoal during the dry season cost €2.26 compared to €3.62 during the wet season and could be used to boil approximately 100 litres of milk, resulting in an average cost of €$0.023 per litre of milk. Firewood was measured in terms of a cartload drawn by a donkey and traded at €23.

4.3.8 Camel Milk Consumption Forms and Feasibility of Milk powder Acceptability.

4.3.8.1: Forms of camel milk Consumption

Camel milk was often consumed in raw, boiled or smoked but rarely fermented forms (Fig. 4.7). Neither pasteurised milk nor milk powder had been consumed by the respondents interviewed (Fig. 4.7).

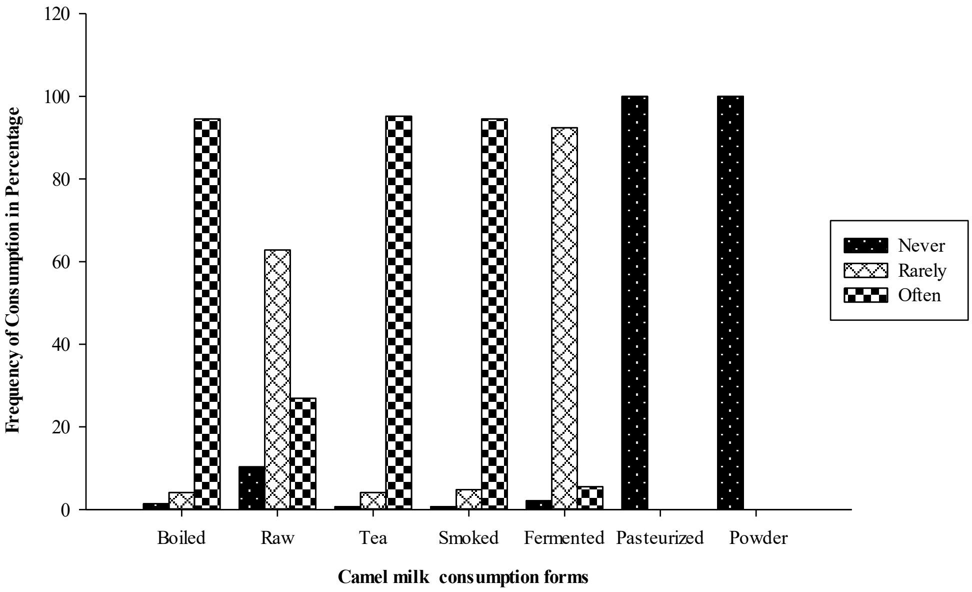


Figure 4. 7: Form of camel milk consumption among the producers (N=145)

In the milk bars surveyed, the milk was either sold fresh or as tea whereby a cup (200 ml) was sold at €0.45 compared to the bovine milk tea that was sold at €0.27. Most participants in the consumer FGD reported that they preferred consuming camel milk to other milk due to the long shelf life, low-fat content and the medicinal values associated with the camel milk. From the FGDs with the producers and consumers, it was concluded that camel milk scarcity during the dry season led to high prices, which resulted in the purchase of cow or goat milk, reduced intake of camel milk, or non-consumption of any form of milk at all. Those who maintained their usual consumption volume were prone to credit as explained below:

> *"When the prices of the camel milk are high during the dry season, we are forced to buy a half litre of milk compared to the 1 litre that we consume. Sometimes we obtain milk on credit, and it takes us up to two weeks to pay."*

Consumer FGD

4.3.8.2: Feasibility of camel milk powder acceptability

While the respondents' acknowledged the use of cow milk powder, none had consumed camel milk powder. Among the producers (N = 145), 51.7% had consumed cow milk powder. The likelihood of purchasing camel milk powder was higher (86.7%; N = 145) among those who had consumed cow milk powder as opposed to those who had never consumed it (32.9%; N = 145). About 47.1% of the respondents who had consumed cow milk powder were neither likely nor unlikely to purchase camel milk powder. About 70% of the respondents (N = 145) ranked the milk powder attributes tested as important (Fig. 4.8). The participants of the FGD with all players acknowledged the need for a product with a stable long shelf-life like that of cow milk powder.

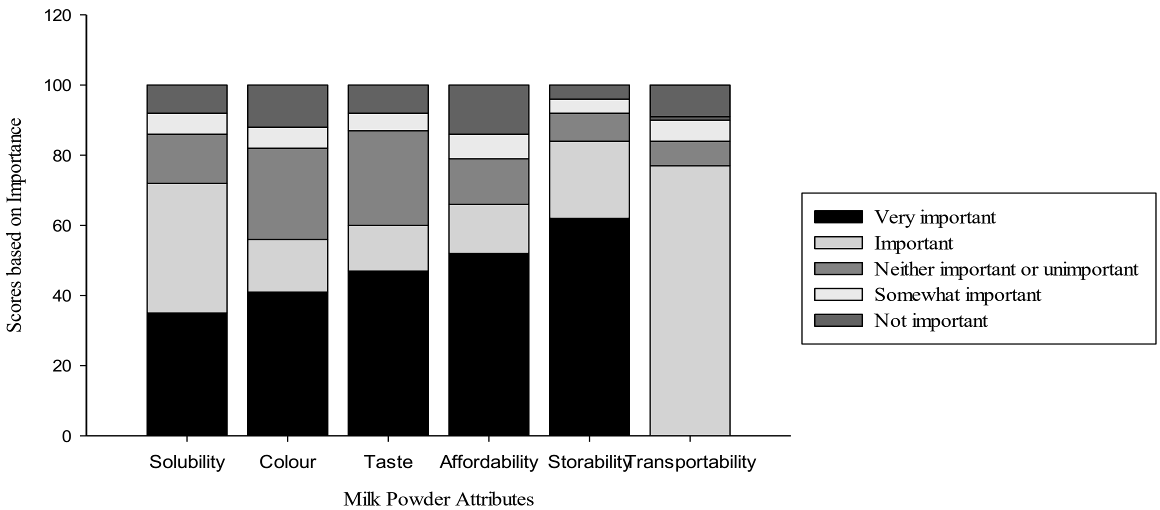


Figure 4. 8: Important milk powder attributes (N=145)

4.4 Discussion

The camel milk supply chain in Isiolo comprised five main production functions with limited post-harvest handling technologies. Men were the main role-players in husbandry and milking while milk handling, preservation and marketing were entirely the women's responsibility. In pastoral households with camels, the camel belongs to the man, but the milk is the property of the woman who uses it to meet the subsistence needs of the household (Anderson et al. 2012). The increased commercialization of large volumes of camel milk characterised by greater returns has encouraged pooling of milk from different suppliers to be able to meet the wholesalers' demands (Anderson et al. 2012; Nori 2010).

From our findings, milk yield, consumption and utilisation varied between the two seasons. Similar studies undertaken in Jordan have recorded a decrease in the volume of camel milk during the dry season due to the decline of forage and water available to the camels (Haddadin, Gammoh, and Robinson 2008). The decreased volume of milk results in increased demand for the available milk, thus leading to higher sales and higher market prices. This can be attributed to the need to purchase cereals and proteins for the households or as payback for outstanding arrears (Elhadi, Nyariki, and Wasonga 2015). In Ogaden region in Somalia, the sale of livestock milk products during the dry season contributed to more than 80% of the pastoral households' income compared to about 40% in the wet season (Hussein 1999).

Lack of preservation technologies and the unwillingness of the producers to sell their milk at prices (75.3%) lower than the market price fetched during the dry season contributed to a lower volume (79.5%) of milk sold during the wet season among the producers. The low market prices and high supply of the camel milk in the wet season also encouraged processing of camel cheese and yoghurt. This not only diversified the consumption of camel milk but also increased the milk shelf life and improved the nutritional content of the milk. Similar findings have been reported on value addition on cow and camel milk during milk gluts by pastoral communities in Somalia and Ethiopia (Nori et al. 2006; Sadler et al. 2009).

Acceptability of milk by the traders was based on quality, determined through chemical testing at the main cooling hub and organoleptic tests by sight, taste and smell by other bulkers. Milk that failed these tests, depending on the season, was returned to the producers to minimise economic losses among the traders. The returned milk was processed, consumed at household level, or given to neighbours, similar to findings in Somalia on the utilisation of rejected milk (Nori 2010). Processing was through natural fermentation into *Suusac* which was either sold at a lower price (48%) or consumed (52%) at the household level after addition of sugar (Noor et al., 2012). This represents a significant economic loss as the producers were forced to consume the milk instead of selling it to gain income for their households. Though there was no significant variation in the percentage of the non-marketed milk consumed in the wet and the dry season, the nature of the milk consumed differed. In the rainy season, mainly fresh smoked milk was consumed while in the dry season it was naturally fermented milk. This was because of the decreased availability of milk in the dry season that limited consumption of camel milk to the rejected fermented milk. Different authors also documented that camel milk was offered as a gift to strengthen the social ties among the rural households and also as a sign of seeking help from wealthy households (Bush 1995; Sikana, Kerven, and Benkhe 1993). This is similar to our findings, where the nonmarketed milk was given to neighbours to enhance social relationships. Allowing the calves to feed on the dam during both the dry and wet seasons is in agreement with the importance that pastoral communities attach to herd replacement and growth as opposed to immediate economic benefit (Western and Finch 1986; Holden, Coppock, and Assefa 1991).

Knowledge of factors that contributed to the non-marketing of milk, due to spoilages or spillages by both the traders and producers, enabled them to apply strategies that counteracted these factors. This resulted in a reduced volume of non-marketed milk, thus indicating the importance of knowledge accessibility for pastoral communities. At marketing level, qualitative milk losses were characterised by milk spoilage. This encouraged the use of milk preservation technologies such as chilling and freezing. Physical contaminants that were present in the milk were reduced through sieving of the milk at the cooling hub. Milk received by the traders when spoilt due to unhygienic milk handling at production level was returned to the producers. This in turn influenced the producers to observe hygienic milk handling practices at milking level.

Delay in milk delivery due to unreliable milk transportation services increased the utilisation of simple milk preservation technologies such as the use of hemp bags soaked in water and boiling of milk at production and collection centres. Moreover, duration of milk exposure to the ambient temperatures and the degree of wetness of the gunny bags determined the extent to which the milk was cooled (Adongo, Coppock, and Wayua 2013). Evaporation of water from the gunny or hemp bags resulted in the cooling of milk through the extraction of latent heat of vaporisation from the milk. This temperature drop aided in inhibiting the multiplication of the psychotropic microorganisms, thus delaying milk spoilage during transportation (Adongo, Coppock, and Wayua 2013). Lack of storage or cooling facilities at production and distribution levels compelled the primary retailers to boil the milk so as to improve the keeping quality although it has been reported to negatively influence the vitamin C and Riboflavin contents of the milk (Mehaia 1994). When spoilt, boiled camel milk was discarded since it could neither be processed into any other product nor consumed. This is because fermented boiled camel milk results in poor curding as opposed to fresh milk. Disposal of milk has a negative environmental impact as land, water and energy are utilised in the production and processing of this milk (Gustavsson et al. 2011).

Smoking (fumigation) of the milk containers was reported as the main milk preservation technology among the producers as milk could then be transported over longer distances while exposed to high temperatures without spoilage. Moreover, lack of alternative milk preservation technologies at the production level encouraged its utilisation. Fumigation is a chemical preservation technique that prevents food spoilage through altering the chemical composition of the food (Ogbadu 2014). In the pastoral regions, fumigation of milk containers using *Olea africana* Mill. and *Balanities aegyptica* (L.) Delile branches is a common practice that imparts flavour and inhibits microbial growth (Wayua, Okoth, and Wangoh 2012). Approximately 95% of the total camel milk produced was smoked while 5% was subjected to refrigeration during transit. This contrasts Blench's (2001) review that few African pastoralists are involved in milk preservation. However, the smoked milk could only be kept for a short length of time, thus the willingness of the respondents to purchase the camel milk powders was so high. The 5% of non-smoked camel milk was pre-ordered for the processing of value-added camel milk products including pasteurized milk, yoghurt and fermented milk to meet the requirements of the non-Cushitic population who live in the urban areas and do not appreciate the flavor imparted by smoking the camel milk (Muli, Kimenya, and Kivolonzi 2008). Smoking of the milk was undertaken in plastic containers which were the main transportation and storage vessels along the camel milk supply chain. Plastic containers are known to be prone to migration phenomena and also flavor scalping thus they may inversely affect the sensory properties of the camel milk (Kontominas 2010).

Chilling and freezing are low temperature treatments that prevent quality deterioration by inhibiting physiological, biochemical and microbial activities (Berk 2013a). Low temperature milk storage does not destroy microorganisms but merely retards their growth. Thus, it is necessary to cool milk within 4 hours of milking to prevent the multiplication of microorganisms. However, in the study area the milk took approximately 8 hours to reach the cooling plants and studies have deduced that transportation time positively correlates with the milk spoilage (Odongo et al. 2016). Depending on the time of the last milk delivery, it took approximately 4–5 hours for the milk temperature to drop to 5 °C from about 30 °C at the chiller. Moreover, during the wet season, the capacity of the cooling facilities available was limited. Thus, the producers mentioned a lack of demand for their milk as the bulkers could not purchase higher volumes. This consequently led to milk being sold at lower prices resulting in economic losses among the producers. In addition, some producers allowed the calves to feed on the dam during this season thus compounding the economic loss. These findings are similar to the findings by Gustavsson et al. (2011) in the horticultural industry where farmers either left excess produce unharvested or sold the produce to the feed industries and processors at a lower price.

The utilization of firewood in camel milk processing is related to its' being the main energy source used by Kenyan households for cooking (Gathui and Ngugi 2010). The use of firewood and charcoal contributes to environmental degradation due to the emission of carbon dioxide and carbon monoxide. Moreover, their indoor use contributes to household pollution and influences the taste and colour of the camel milk. The incomplete combustion of charcoal and firewood and inhalation of the smoke by the members of the household can be detrimental due to its association with respiratory diseases. In developing countries, bio-fuels have been ranked as the second highest risk factor for ill-health (Lim et al. 2012). Chilling and freezing of milk are highly energy intensive, costly and depend on conventional energy sources

In times of milk scarcity in pastoral regions, bovine milk powder and condensed camel milk are the main sources of protein for the pastoral households (UNA 1998). It is therefore reasonable to infer that the pastoralists would be willing to purchase and consume camel milk powder if it were available. Transportability, storability and affordability of the camel milk powder were its most important attributes. Its attractiveness is due to the ease of transportation caused by reduced volume and weight, long shelf life of up to 18 months and low price compared to the fresh milk that is available in the region (Kalyankar et al. 2016). These attributes differ from those reported in Northern Kenya on acceptability of camel milk products (Akweya, Gitao, and Okoth 2012). This is because the findings were based on liquid milk products where colour, taste, packaging, aroma and thickness were considered vital. Consumption of the camel milk in Isiolo County was limited to smoked, boiled or as tea both at household level and at the milk bars. From our findings, camel milk tea fetched higher prices than bovine milk, an indication of the great value that is associated with camel milk. Similar findings are reported by the (FAO 2014b).

4.5 Conclusions and Recommendations

In a nutshell, the camel milk yield, consumption, losses, marketed volume and utilization of non-marketed milk were all season dependent. The milk consumption was limited to fresh, smoked and boiled forms but longer shelf-life products such as milk powders were highly acceptable. The limited value addition was due to inadequate milk preservation technologies, high investment costs and low technical feasibility of modern technologies.

Moreover, these preservation technologies were dependent on charcoal, firewood, diesel and on-grid electricity which were unreliable. Therefore, availability of high solar irradiance and nominal radiation coupled with the long sunshine hours in Isiolo County provide a good source of energy that may be harnessed through conversion into either electrical energy or thermal energy for producing longer shelf-life milk products such as milk powder. The use of Mazzi cans could be explored to limit the use of plastic containers and heavy aluminium cans.

This study entailed the use of mixed methods for data gathering, therefore different perspectives from both the qualitative and quantitative point of view were employed. Data was collected along the camel supply chain, and the various players and chain supports were involved.

This study utilised questionnaires and key informants who were susceptible to recall bias as it was based on reported information. Secondary documents used are susceptible to having incomplete information. Therefore, the authors recommend longitudinal research in the long term. This study also provides an opportunity for further research on nutritional analysis of the spoilt camel milk for quantification of nutritional losses associated with milk spoilage and the determination of willingness to pay for the long shelf life value-added camel milk products and possible technologies.

Acknowledgement

The authors are appreciative of the financial support of the KAAD (Katholische Akademischer Ausländer Dienst), RE4Food and the RELOAD (Reducing Losses Adding Value) project sponsored by the Federal Ministry of Education and Research (BMBF) Grant Number: 031A247A-D. We also appreciate the support of the Isiolo County government, Mr Khalif Abey of the Kenya Camel Milk Association and Mr Paul of SNV, Isiolo. We are also highly indebted to the key respondents, camel milk producers, traders, research assistants and Katherine Troger.

References

Adongo, A. O., Coppock, D. L., & Wayua, F. O. (2013). Simple evaporative cooling method reduces bacterial content of traditionally marketed camel milk in Isiolo county, Kenya. *African Journal of Food, Agriculture, Nutrition and Development*, *13*(1), 7213–7224. https://doi.org/10.4314/ajfand.v13i1.

Agrawal, R. P., Beniwal, R., Sharma, S., Kochar, D. K., & Tuteja, F. C. (2005). Effect of Raw Camel Milk in Type 1 Diabetic Patients : 1 Year Randomised Study. *Journal Of Camel Practice And Research*, *12*(1), 27–35.

Agrawal, R. P., Budania, S., Sharma, P., Gupta, R., Kochar, D. K., Panwar, R. B., & Sahani, M. S. (2007). Zero prevalence of diabetes in camel milk consuming Raica community of north-west Rajasthan, India. *Diabetes Research and Clinical Practice*, *76*(2), 290–296. https://doi.org/10.1016/j.diabres.2006.09.036

Akweya, B. A., Gitao, C. G., & Okoth, M. W. (2012). The acceptability of camel milk and milk products from north eastern province in some urban areas of Kenya. *African Journal of Food Science*, *6*(19), 465–473. https://doi.org/10.5897/AJFS10.061

Al haj, O. A., & Al Kanhal, H. A. (2010). Compositional, technological and nutritional aspects of dromedary camel milk. *International Dairy Journal*, *20*(12), 811–821. https://doi.org/10.1016/j.idairyj.2010.04.003

Anderson, D. M., Eliott, H., Kochore, H. H., & Lochery, E. (2016). *Camel milk, Capital, and Gender: The changing dynamics of pastoralist dairy markets in Kenya*.

Anderson, D. M., Elliott, H., Kochore, H. H., & Lochery, E. (2012). Camel herders, middlewomen, and urban milk bars: The commodification of camel milk in Kenya. *Journal of Eastern African Studies*, *6*(3), 383–404. https://doi.org/10.1080/17531055.2012.696886

Arid Lands Resource Management Project (ALRMP). (2009). *Vision 2030 Development Strategy for Northern Kenya and other Arid Lands*. Nairobi.

Benkerroum, N., Mekkaoui, M., Bennani, N., & Hidane, K. (2004). Antimicrobial activity of camel's milk against pathogenic strains of Escherichia coli and Listeria monocytogenes. *International Journal of Dairy Technology*, *57*(1), 39–43. https://doi.org/10.1111/j.1471-0307.2004.00127.x

Berk, Z. (2013). Chapter 27 - Food Packaging. In Z. Berk (Ed.), *Food Process Engineering and Technology (Second Edition)* (pp. 621–636). San Diego: Academic Press.

Blench, R. M. (2001). *Pastoralism in the new millennium. FAO animal health and production series no. 150*. Rome, Italy.

Bornstein, S., & Younan, M. (2013). Significant veterinary research on the dromedary camels of Kenya: past and present. *Journal of Camelid Science*, *6*, 1–48.

Bush, J. (1995). The Role of Food Aid in Drought and Recovery: Oxfam's North Turkana (Kenya) Drought Relief Programme, 1992-94. *Disasters*, *19*(3), 247–259. https://doi.org/10.1111/j.1467-7717.1995.tb00343.x

Cardellino, R., Rosati, A., & Moscom, C. (2004). Current status of genetic resources, recording and production systems in Africa, Asia and America camelids FAOICAR seminar on camelids. *Sousse, Tunisia: Food and Agriculture Organization of the United Nations and International Committee for Animal Recording*.

Creswell, J. W., & Clark, V. L. P. (2011). Designing and conducting mixed methods. In *Applied Linguistics* (2nd ed., Vol. 2nd). https://doi.org/10.1111/j.1753-6405.2007.00096.x

El-Agamy, E. I. (2007). The challenge of cow milk protein allergy. *Small Ruminant Research*, *68*(1), 64–72. https://doi.org/10.1016/j.smallrumres.2006.09.016

El Zubeir, I. E., & Jabreel, S. O. (2008). Fresh cheese from camel milk coagulated with Camifloc. *International Journal of Dairy Technology*, *61*(1), 90–95. https://doi.org/10.1111/j.1471-0307.2008.00360.x

Elayan, A. A., Sulieman, A. M. E., & Saleh, F. A. (2008). The hypocholesterolemic effect of Gariss and gariss containing bifidobacteria in rats fed on a Cholesterol-Enriched Diet. *Asian Journal of Biochemistry*, *3*(1), 43–47. https://doi.org/10.3923/ajb.2008.43.47

Elhadi, Y. A., Nyariki, D. M., & Wasonga, O. V. (2015). Role of camel milk in pastoral livelihoods in Kenya: contribution to household diet and income. *Pastoralism*, *5*(1), 8. https://doi.org/10.1186/s13570-015-0028-7

FAO. (2014a). *FAO statistical pocket book 2014*.

FAO. (2014b). *FAO Statistical Yearbook 2014*. https://doi.org/10.1007/978-94-007-0929-4_486

Farah, Z. (1986). Effect of heat treatment on whey proteins of camel milk. *Milchwissenschaft*, *41*(12), 763–765.

Farah, Z., Mollet, M., Younan, M., & Dahir, R. (2007). Camel dairy in Somalia: Limiting factors and development potential. *Livestock Science*, *110*(1–2), 187–191. https://doi.org/10.1016/j.livsci.2006.12.010

Faye, B. (2005). Productivity Potential of Camels. In P. (Eds. . Faye, B., Esenov (Ed.), *Proc. of. Intern. Workshop, Desertification Combat and Food Safety: the Added Value of Camel Producers, Vol. 362 NATO Sciences Series, Life and Behavioural Sciences, Ashkabad, Turkménistan, April 19–22, 2004.* (pp. 127–134). Ashkabad, Turkménistan: IOS Press Publ., Amsterdam, The Netherlands.

Fratkin, E., Roth, E. A., & Nathan, M. A. (2004). Pastoral sedentarization and its effects on children's diet, health, and growth among Rendille of Northern Kenya. *Human Ecology*, *32*(5), 531–559. https://doi.org/10.1007/s10745-004-6096-8

Gathui, T. W., & Ngugi, W. (2010). Bioenergy and Poverty in Kenya : Attitudes , Actors and Activities. In *Policy Innovation Systems for Clean Energy Security (PISCES)*.

Gustavsson, J., Cederberg, C., Sonesson, U., Otterdijk, R. van, & Meybeck, A. (2011). Global food losses and food waste - Extent, causes and prevention. In *Global Food Losses and Food Waste*. https://doi.org/10.1098/rstb.2010.0126

Haddadin, M. S., Gammoh, S. I., & Robinson, R. K. (2008). Seasonal variations in the chemical composition of camel milk in Jordan. *Journal of Dairy Research*, *75*(01), 8–12. https://doi.org/10.1017/S0022029907002750

Holden, S. J., Coppock, D. L., & Assefa, M. (1991). Pastoral Dairy Marketing and Household Wealth Interactions and Their Implications for Calves and Humans in Ethiopia. *Human Ecology*, *19*(1). https://doi.org/10.1007/BF00888976

Huang, R. (2014). *RQDA: R-based Qualitative Data Analysis.*

Hussein, A. A. (1999). The role of pastoralism in ensuring food security in the Horn of Africa. A case study on Somali National regional State of Ethiopia. *Proceedings of a Workshop Sponsored by Pastoral and Environmental Network in the Horn of Africa. Kampala, Uganda*. Kampala, Uganda.

IBM Corp. (2015). *IBM SPSS Statistics for Windows, Version 22.0.* Armonk, NY: IBM Corp.

Kalyankar, S. D., Deshmukh, M. A., Chopde, S. S., Khedkar, C. D., Lule, V. K., & Deosarkar, S. S. (2016). Milk Powder. In (eds). B. Caballero, P.M. Finglas, and F. Toldrá (Ed.), *Encyclopedia of Food and Health* (pp. 724–728). Oxford: Academic Press.

Kaufmann, B. A. (2003). Differences in perception of causes of camel calf losses between pastoralists and scientists. *Experimental Agriculture*, *39*(4), S0014479703001352–S0014479703001352. https://doi.org/10.1017/S0014479703001352

KNBS. (2010). *KENYA DEMOGRAPHIC AND HEALTH SURVEY 2008-09*. Nairobi.

KNBS. (2019). *2019 KENYA POPULATION AND HOUSING CENSUS VOLUME I : POPULATION BY COUNTY AND SUB-COUNTY*. Nairobi, Kenya: Government Printers.

Kontominas, M. (2010). 5 – Effects of packaging on milk quality and safety. In M. W. Griffiths (Ed.), *Improving the Safety and Quality of Milk* (pp. 136–158). https://doi.org/10.1533/9781845699437.2.136

Konuspayeva, G., & Faye, B. (2004). Chemical and physico-chemical properties of camel milk at different stages of lactation. *Proceedings of International. Conference. "Saving the Camel and Peoples' Livelihoods," Sadri, Rajasthan, India November, 2004.*, 28–36. India.

Kuria, S. G., Omore, A., Thendiu, I. N., Mwangi, D. M., Nga, A. B., & Kaitibie, S. (2011). Constraints on Camel Meat and Milk Marketing and Strategies for Its Improvement in Northern Kenya. *Journal of Agricultural Science and Technology*, *1*, 703–712.

Lim, S. S., Vos, T., Flaxman, A. D., Danaei, G., Shibuya, K., Adair-Rohani, H., … Ezzati, M. (2012). A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990-2010: A systematic analysis for the Global Burden of Disease Study 2010. *The Lancet*, *380*(9859), 2224–2260. https://doi.org/10.1016/S0140-6736(12)61766-8

Mehaia, M. A. (1994). Vitamin C and riboflavin content in camels milk: effects of heat treatments. *Food Chemistry*, *50*(2), 153–155. https://doi.org/10.1016/0308-8146(94)90113-9

Muli, M., Kimenya, D., & Kivolonzi, P. (2008). *The Camel Milk Industry in Kenya*.

Nicholson, M. J. L. (1984). Pastoralism and milk production. *ILCA Bulletin*, *20*, 23–28.

Noor, I. M., Bebe, B. O., & Guliye, A. Y. (2012). Analysis of an emerging peri-urban camel production in Isiolo County, Northern Kenya. *Journal of Camelid Science*, *5*, 41–61.

Nori, M. (2010). Along the milky way: Marketing camel milk in puntland, Somalia. *European Journal of Development Research*, *22*(5), 696–714. https://doi.org/10.1057/ejdr.2010.40

Nori, M., Kenyanjui, M. B., Yusuf, M. A., & Mohammed, F. H. (2006). Milking Drylands: The Marketing of Camel Milk in North-east Somalia. *Nomadic Peoples*, *10*(1), 9–28. https://doi.org/10.3167/082279406781020392

Odongo, N. O., Lamuka, P. O., Matofari, J. W., & Abong, G. O. (2016). Risk factors associated with the post-harvest loss of milk along camel milk value chain in Isiolo County, Kenya. *African Journal of Agricultural Research*, *11*(8), 674–682. https://doi.org/10.5897/AJAR2015.9988

Ogbadu, L. J. (2014). Preservatives: Traditional Preservatives - Wood Smoke. In C. A. B. Lou Tortorello (Ed.), *Encyclopedia of Food Microbiology: Second Edition* (pp. 141–148). https://doi.org/10.1016/B978-0-12-384730-0.00261-5

Sadler, K., Kerven, C., Calo, M., Manske, M., & Catley, A. (2009). *Milk Matters: A Literature Review of*

Pastoralist Nutrition and Programming Responses.

Seifu, E. (2007). Handling, preservation and utilization of camel milk and camel milk products in Shinile and Jijiga Zones, eastern Ethiopia. *Marketing*, *10*, 13–17.

Sikana, P. M., Kerven, C. K., & Benkhe, R. H. (1993). *From subsistence to specialised commodity production: commercialisation and pastoral dairying in Africa*. Pastoral Development Network, ODI.

Simpkins, J. W., Rajakumar, G., Zhang, Y.-Q., Simpkins, C. E., Greenwald, D., Yu, C. J., … Day, A. L. (1997). Estrogens may reduce mortality and ischemic damage caused by middle cerebral artery occlusion in the female rat. *Journal of Neurosurgery*, *87*(5), 724–730. https://doi.org/10.3171/jns.1997.87.5.0724

Singh, M. B., Fotedar, R., & Lakshminarayana, J. (2008). Camel Milk Consumption Pattern and Its Association with Diabetes among Raika Community of Jodhpur District of Rajasthan. *Ethno-Medicine*, *2*(2), 103–105.

Systat Software Inc. (2012). *Sigmaplots*. San Jose California USA.

UNA. (1998). *Milk marketing study in North East Somalia.* Nairobi.

Wayua, F. O., Okoth, M. W., & Wangoh, J. (2012). Survey of postharvest handling, preservation and processing practices along the camel milk chain in Isiolo district, Kenya. *African Journal of Food, Agriculture, Nutrition and Development*, *12*(7), 6897–6912.

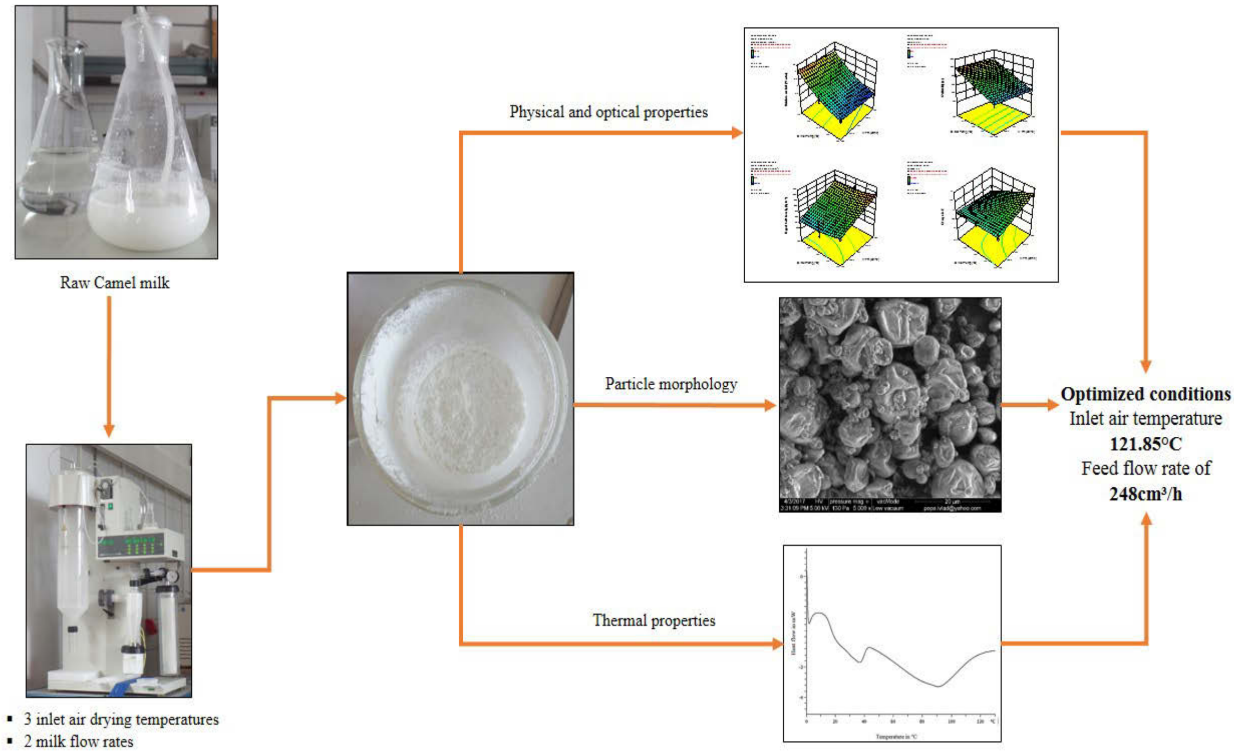
Wayua, F. O., Okoth, M. W., & Wangoh, J. (2013). Modelling of a locally fabricated flat-plate solar milk pasteuriser using artificial neural network. *African Journal of Agricultural Research*, *8*(9), 741–749. https://doi.org/10.5897/AJAR11.1256

Werney, U. (2006). Camel milk the white gold of the desert. *Journal of Camel Practice and Research*, *13*(1), 15–26.

Western, D., & Finch, V. (1986). Cattle and Pastoralism: Survival and Production in Arid Lands. *Human Ecology*, *14*(1). https://doi.org/10.1007/BF00889211

Yagil, R. (1982). *Camels and Camel Milk* (No. 26). Rome.

5.0 Influence of inlet drying air temperature and milk flow rate on the physical, optical and thermal properties of spray dried camel milk powders[3]



[3] The content of the chapter has been published as a journal paper

Ogolla et al., 2019. Influence of Inlet Drying Air Temperature and Milk Flow Rate on the Physical, Optical and Thermal Properties of Spray-Dried Camel Milk Powders. *Food and Bioprocess Technology*. https://doi.org/10.1007/s11947-019-2243-5

Abstract

The influence of milk flow rate and inlet drying air temperature on the physical, optical and thermal properties of laboratory spray dried camel milk powders is investigated. The physical, thermal and optical properties of laboratory spray dried camel milk powders at three inlet drying air temperatures (110, 120 & 130 °C) and two milk flow rates (166 & 248 cm^3/h) were evaluated. These properties are fundamental to understanding the quality, stability, final application and portability of the milk powders. Following this, the results were compared to commercial milk powder (CMM). Specifically, we evaluated the influence of the inlet drying air temperatures and feed rates on the reconstitution properties, particle properties, bulk, colour, and thermal properties. Using Response Surface Methodology (RSM), the findings indicated that the inlet drying air temperatures significantly influenced moisture content, and the L* a* b* colour properties ($p<0.0001$) of the powders. However, the bulk and reconstitution properties were significantly influenced by the milk flow rate ($p<0.0001$).

The thermograms of all the milk powders had three endothermic peaks and two shifts. The onset of the glass transition increased in temperature with decreasing moisture content of the powders varying from 37.49 °C to 44.21 °C. Scanning electron microscopy (SEM) images of the laboratory spray dried powders were hollow and collapsed compared to the commercial samples which were spherical and rough with small cracks, dents and pores.

The results demonstrated that both the inlet drying air temperature and the milk flow rate influenced the thermal, optical and physical properties of laboratory spray-dried powders.

Keywords: Camel milk powder, spray drying, physical properties, colour properties, thermal properties, SEM.

5.1 Introduction

Camels *(Camelus dromedaries)* occupy the enormous pastoral areas in Africa and Asia and are mainly kept for milk, meat, transportation, traction, hide and tourism. The high nutritional properties and health benefits of camel milk, compared to milk from other animals, signifies its importance. For instance, camel milk is reported to exert hypo-cholesterolaemic (Elayan, Sulieman, and Saleh 2008), hypoglycaemic (Agrawal et al. 2011; Singh, Fotedar, and Lakshminarayana 2008), hypo-allergic (El-Agamy 2007), antimicrobial (Benkerroum et al. 2004) and blood pressure regulator (Quana, Tsuda, and Miyamoto 2008) effects. Camel milk is the main source of protein and vitamin C in pastoral regions due to its high vitamin C content (approximately six times) compared to bovine and human milk (Haddadin, Gammoh, and Robinson 2008). Camel milk does not contain β-lactoglobulin, a typical milk protein characteristic of ruminant milk; hence it is a good substitute for people with cow milk protein allergy (CMPA) (Konuspayeva, Faye, and Loiseau 2009; Laleye, Jobe, and Wasesa 2008).

Traditionally, camel milk was considered to be suitable only for drinking (Yagil, Saran, and Etzion 1984). Currently, the dromedary camel milk is processed into different dairy products. These products include soft cheese (El Zubeir and Jabreel 2008; Inayat et al. 2003; Mehaia 2006; Ogolla et al. 2017), fermented milk (Elayan, Sulieman, and Saleh 2008; Farah, Streiff, and Bachmann 1990), yoghurt (Hashim, Khalil, and Habib 2009), ice cream (Abu-Lehia, Al-Mohizea, and El-Behry 1989) and butter (Farah, Streiff, and Bachmann 1989; Rüegg and Farah 1991). Camel milk powder has been given little attention compared to the aforementioned products (Ogolla et al. 2017). However, milk powder is the product with the most extended shelf life and the easiest to store (Pisecky 2012). Thus, there is a growing demand for camel milk powder in the arid regions, which calls for an increased focus on the production and more in-depth understanding of characteristics of camel milk powder (Ogolla et al. 2017).

Spray drying is the most commonly used dehydration technology for milk and its products (Mujumdar, Huang, and Chen 2010). It results in the stabilisation of milk constituents for storage and later uses through increased shelf life (Schuck 2011). The overall objective of optimisation of spray drying is to reduce the heat stress on the product sub-components (protein and free fat) achieved by the combination of the high temperature and short residence time. Severe heat treatment of milk leads to thermal instability of the milk due to protein-protein interactions, degradation of lactose through isomerisation (e.g., to lactulose), and Maillard reactions (Fox and Kelly 2012). Spray drying, therefore, results in powders that are portable, easy to handle and easy to store. The quality of these milk powders depends on their physical, functional, biochemical, microbiological, and sensory attributes all of which are correlated (Sharma, Jana, and Chavan 2012).

The physical and functional properties of milk powders are essential for recombination and use in the manufacture of other food products. Bulk properties influence the packaging type, handling and size of packaging (Barbosa-Cánovas et al. 2005). The reconstitution properties (sinkability, dispersibility, wettability and solubility) determine the instantization of the powders which are dependent on the particle size, density, porosity, surface area, surface charged, surface activity and presence of amphipathic substances in the final product (Kim, Chen, and Pearce 2002; Westergaard 2004). However, all these powder properties are directly influenced by the spray drying conditions and feed characteristics (Birchal et al. 2005; Koç et al. 2014). The drying parameters include spray dryer type, atomiser type, pressure, agglomeration, and the drying air parameters, i.e. relative humidity, velocity, and temperature. The relevant feed characteristics are composition, viscosity and thermosensitivity (Oldfield and Singh 2005).

The glassy nature of freeze-dried and spray-dried materials is significant in determining food stability regarding caking, the collapse of the food structure, crystallisation, agglomeration and oxidative reactions. These changes are due to an increase in the diffusion of molecules that results from an increase in the mobility of the molecules around the glass transition temperature (T_g) (Roos 2010). Anglea, Karathanos, and Karel (1993) suggested that, by keeping the material temperature close to the T_g, structural and other quality changes during dehydration could be avoided, thus improving the quality of dehydrated foods. The T_g of freeze-dried camel milk powders has been determined (Rahman et al. 2012). However, to date, there is limited information on the T_g of spray dried camel milk powders.

Different studies have documented properties of spray dried cow, goat and donkey milk powders, but only a limited number of studies has focused on spray dried camel milk (Oldfield and Singh 2005; Reddy et al. 2014; Di Renzo, Altieri, and Genovese 2013). For instance, Rahman et al.

(2012) studied the thermal characteristics of freeze-dried camel milk powders while Sulieman et al. (2014) presented the influence of the direction of feed and concentration on the physicochemical properties of spray dried camel milk powder. Therefore, to our knowledge, there has been no study undertaken to determine the effect of the inlet drying air temperature and milk flow rate on the physical, optical and thermal characteristics of laboratory dried camel milk powders. Moreover, there is no information on the comparison of the laboratory spray dried camel milk and commercial milk powders.

The primary goal of this study was, therefore, to assess the influence of different processing temperatures and feed rates on the physical (bulk properties, wettability, dispersibility, and particle size & morphology), thermal (glass transition) and optical properties of spray dried camel milk powders. Firstly, we evaluated the physical, thermal and optical properties of laboratory spray dried non-pasteurized camel milk powders. Secondly, we compared laboratory spray dried milk powders with the commercially available ones. These physical, thermal and optical properties are important in understanding the quality, stability, final application and portability of the camel milk powders which are influenced by processing parameters.

5.2 Materials, Methods and Statistics

5.2.1 Camel milk properties

5. 2.1.1 Sample

Camel milk was obtained from a farm in the Netherlands. The milk was from dromedary camels that had controlled feeding and watering. The non-pasteurised milk packaged in 500 ml plastic containers was transported in frozen cool boxes. The samples were received in three batches of seven 500 ml bottles milked in three different weeks (15.08; 24.08 and 05.09.2016). The samples were then frozen at -21 °C ± 2 °C prior to the determination of the physical properties and spray drying. The temperature was controlled to ensure that the storage temperatures did not go below -23 °C which could lead to a decrease in pH, salting out resulting in casein micelles aggregation, and clumping of fat globules (Fox and Kelly 2012). The frozen camel milk was first thawed in a cold room at 10.0 ±1.0 °C for approximately 24 hours before spray drying and the determination of other physical properties. This was to prevent casein micelles aggregation due to salting out and fat clumping that occurs from a sudden increase in temperature (Fox and Kelly 2012). The camel milk powder packaged in a 420 g plastic container obtained through spray drying was also sourced from the same farm, Kamelenmelkerij Smits, The Netherlands.

5.2.1.2 Density of camel milk

The density of the milk was measured at 20 °C using the Anton Paar DSA-48 Density and Sound Analyzer, (Ostfildern-Scharnhausen, Deutschland). Before measurement, the equipment was first calibrated by pumping dry air to dry the measuring cell. Afterwards, distilled water was passed through the measuring cell to ensure that there was no air bubble in the system. Approximately 5 ml of milk was fed into the density analyser using a syringe and measurements were conducted in triplicates for the three milk batches and results expressed as kgm^{-3}.

5.2.1.3 pH of the Milk

For the determination of the pH, a PT-10P pH meter (Sartorius AG Göttingen, Germany) was used, which was first calibrated using buffer solutions of pH 4 and pH 7, at a temperature of 22°C (standard room temperature). Thereafter, the pH of distilled water, tap water and camel milk were measured. Measurements were conducted in triplicates.

5.2.1.4 Viscosity of the milk and water

The viscosity of the camel milk was determined in the temperature ranges between 20 to 60 °C (±2 °C) using the Thermo Scientific HAAKE Falling Ball Viscometer Type C. The heating medium for the milk was hot water using a Lauda CS-C20 Circulating Bath and equation 5.1 was used to calculate the viscosity.

$$n = t(\rho_1 - \rho_2)k \qquad \text{Eq. 5.1}$$

Where n *is the viscosity in mPa s;* t *is the time in seconds for the pebble to reach the bottom of the tube;* ρ_1 *&* ρ_2 *are the density of the pebble and milk in g/cm³ respectively while* k *(0.09047) is a constant.*

5.2.2 Spray drying

5. 2.2.1 Sample for spray drying

Before spray drying the milk was warmed in a hot water bath to a temperature of approximately 25.0 ±1.0 °C using a GTH175/MO Digital Thermometer (GREISINGER electric, Germany) to disperse the fat globules that had coalesced.

5.2.2.2 Spray drying settings

Spray drying was carried out with the Buchi B-290 (Büchi, Switzerland) spray dryer at Fulda University of Applied Sciences, Germany. The milk was pumped through a peristaltic pump and atomised through a two-fluid atomiser of an inside diameter of 0.70 mm at a pressure of 2.94 bars. The compressed air flow rate for atomization was 160.88 l/h (0.04 l/s) with a pressure drop of 0.41 bars resulting in an actual volume flow of 226.85 l/h (0.06 l/s). The heated air used for drying flowed co-currently with the atomised milk droplets in the drying chamber. The minimum mean residence time of the particles in the chamber was approximately 1.0-1.5 seconds. The drying air flow rate was at 25 m^3/h in the cyclone where the less dense particles and the air separated from the powder. The powder was collected at the base of the cyclone and packed in glass containers for further analysis.

5.2.2.3 Spray drying of camel milk

The milk was spray dried at three different inlet air temperatures (110 °C, 120 °C and 130 °C ± 1 °C) and feed flow rates of 166 cm^3/h and 248 cm^3/h respectively. The corresponding outlet air temperatures were recorded. The spray drying was done in triplicates resulting in a total of 18 experiments. Table 1 gives the different spray drying conditions used in this study. The ambient air temperature and humidity of the spray drying environment were recorded using Testo 451 combined temperature and humidity probes (Testo GmbH, Germany).

Table 5. 1 Laboratory Spray drying Conditions

Sample	Inlet Temperature (°C)	Milk Flow rate (cm³/h)	Outlet Temperature (°C)
CM1158	110.0±1.0	166	58.0±1.0
CM1160	110.0±1.0	248	60.0±1.0
CM1265	120.0±1.0	166	65.0±1.0
CM1270	120.0±1.0	248	70.0±1.0
CM1375	130.0±1.0	166	75.0±1.0
CM1380	130.0±1.0	248	80.0±1.0

5.2.2.4 Volumetric flow rate of camel milk

The volumetric flow rate of the camel milk was determined by filling the milk into a 300 ml conical flask and recording the mass (g). The milk was pumped into the spray dryer at six different pumping rates ranging from 5 % to 30 % arbitrary units of the pump for 5 minutes each. The change in the mass of the milk in grams divided by its density (1.024 g/cm^3) was the volumetric flow rate in cm^3/h as indicated in equation 5.2.

$$\dot{v} = \frac{\dot{m}}{\rho} \text{ with } \dot{m} = \frac{m}{t_m} \times T \qquad \text{Eq. 5. 2}$$

Where $\dot{m}$ is the mass flow rate (g/h) of the powder, $\dot{v}$ is the volumetric flow rate (cm^3/h) and ρ density in g/cm^3, m is the measured mass (g), t_m is the measured time (h), and T is the number of minutes per hour.

5.2.3 Physical properties

5.2.3.1 Moisture content determination

The moisture content was determined using the gravimetrical method of conventional oven drying at 105 °C in a Memmert typ ULM 500 oven (Schwabach, Germany) for 24 hours until the final weight was constant (Westergaard 2004). The moisture content obtained was expressed as a percentage on wet weight basis.

5.2.3.2 Loose (ρ_B) & Tapped (ρ_T) bulk density determination

The ρ_B of the powders was determined by measuring the mass of the powder using a Sartorius excellence E2000D weighing scale (Gottingen, Germany) and the corresponding volume from the measuring cylinder according to the IDF methodology (Westergaard 2004; Schuck, Dolivet, and Jeantet 2012; Jinapong, Suphantharika, and Jamnong 2008). After the estimation of the loose bulk density, the powder was tapped approximately 100 times until no change in volume could be detected upon which the final volume of the powder was recorded. The ρ_B & ρ_T in kgm^{-3} were calculated using equations 5.3 & 5.4 respectively

$$\rho_B = \frac{m_1}{v_1} \qquad \text{Eq. 5. 3}$$

$$\rho_T = \frac{m_1}{v_2} \qquad \text{Eq. 5. 4}$$

Where m_1 is the mass (kg) of the powder and, v_1 is the volume (m³) read directly from the cylinder and, v_2 is the tapped volume (m³) read directly from the cylinder.

5.2.3.3 Flowability, Cohesiveness and Interstitial air (IA)

The flowability of the powders was evaluated by applying the Carr's index (CI) (%), while cohesiveness of the powders was assessed using the Hausner ratio (HR). The Hausner ratio is correlated to the flowability of spray dried powders. Interstitial air is the difference between the volume of a given weight of powder and the volume of the same weight of powder after compaction. Carr's chart was used to interpret the CI and estimate the Hausner ratio. The Carr's index (CI), Hausner ratio, and Interstitial air (IA), were calculated by Equations 5.5-5.7.

$$CI = \frac{\rho_T - \rho_B}{\rho_T} \times 100 \qquad \text{Eq. 5. 5}$$

$$Hausner\ ratio = \frac{\rho_T}{\rho_B} \qquad \text{Eq. 5. 6}$$

$$IA = \left(\frac{1}{\rho_T} - \frac{1}{\rho_B}\right) \times 1000000 \qquad \text{Eq. 5. 7}$$

Where IA is the interstitial air content in cm^3 /100 g of powder, ρ_T and ρ_B are the tapped and loose bulk density in kgm^{-3} respectively.

5.2.3.4 Particle morphology

We examined the appearance, shape and size of the camel milk powder samples by attaching them to a double-sided adhesive carbon tab mounted on Scanning electron microscopy (SEM) stubs. Excessive powder at the surface of the stub was removed by directing dry air. The samples were then coated with gold=palladium and examined with a Phillips xT microscope (Philips Export BV, the Netherlands) operating at a low vacuum, an accelerating voltage of 5 kV, a pressure of 130 Pa and enlargement of 1000x and 5000x.

5.2.3.5 Particle size

The powders were placed on a slide and observed under a Keyence digital microscope VHX-2000 (Osaka, Japan) at a magnification of X500. The diameters of particles per sample were measured in triplicates selected randomly. The median diameter of the measurements was used to estimate the particle sizes of the camel milk powders.

5.2.3.6 Wettability

The wettability of the camel milk powders was determined using the IDF methodology introduced by Westergaard (2004) and Jinapong, Suphantharika, and Jamnong (2008) with some slight modifications. Approximately 10 ml of distilled water was poured into a 50 ml beaker, at 25 °C. On a ring stand, a glass funnel was set over the beaker with a distance between the water surface and the funnel bottom of 10 cm. A test tube was used to block the lower opening of the funnel. Approximately 0.130 ± 0.001 g of the powder was spread around the test tube, the test tube was then lifted, and the stopwatch started. The time in seconds for the whole powder to be completely wetted was recorded.

5.2.3.7 Dispersibility in water (DI)

The dispersibility of the milk powders was determined using a slight modification of the IDF standard 87:1979 (Schuck, Dolivet, and Jeantet 2012; Westergaard 2004). Approximately, 1.300±0.001 g of the powdered milk was dissolved in 10 ml of distilled water at 25 °C in a beaker. The mixture was vigorously stirred for 15 seconds and then sieved through a 150 µm sieve. The reconstituted milk was dried in a conventional Memmert typ ULM 500 oven (Schwabach, Germany) at 105 °C for 7 hours. The dispersibility index was calculated using equation 5.8:

$$DI = \frac{(10+a)\times(x_{dm})}{a(\frac{100-(x_{rw})}{100}} \quad \text{Eq. 5. 8}$$

Where a *is the weight of the powder used,* x_{dm} *is the dry matter of the filtrate after sieving (% w/w);* x_{rw} *is the residual free water content of the powder (% w/w).*

5.2.4 Colour Measurements

Chromatic measurements were carried out on the milk and milk powders. The mean CIELAB values recorded at six points for each sample were calculated after measurement with a Konica-Minolta CR-100 (Konica-Minolta, Marunouchi, Japan) (Al-Saadi and Deeth 2008).

The results were expressed in the three-dimensional CIE L*, a*, b* scale. L* represents the lightness coefficient, (0 black to 100 white); a* is the redness coefficient (-80 green to +100 red) while b* the yellowness coefficient (-80 blue to +70 yellow) characteristics respectively of the various milk powder samples. The colorimeter was calibrated against a black tile and by a white plate standard (L* 96.93; a*-0.02; b* 1.93). The hue angle (H), chroma (C), and colour difference (ΔE), were calculated using Equations 5.9-5.11.

$$H = tan^{-1}\frac{b^*}{a^*} \quad \text{Eq. 5. 9}$$

$$C = \sqrt{a^{*2} + \quad b^{*2}} \quad \text{Eq. 5. 10}$$

$$\Delta E = \sqrt{(a^* - a^*{}_0)^2 + (b^* - b^*{}_0)^2 + (L^* - L^*{}_0)^2} \quad \text{Eq. 5. 11}$$

Where L^*, a^* *and* b^* *are powder values and* $L^*{}_0$, $a^*{}_0$ *and* $b^*{}_0$ *are reference sample (milk) values. The Hue angle describes the colour perception and chroma defines the saturation of colour.*

5.2.5 Thermal analysis

The dried milk samples were immediately subjected to Differential Scanning Calorimetry (DSC 1 Mettler Toledo, Schwerzenbach, Switzerland). Aluminum sample pans, which were hermetically sealable, were used in all measurements with an empty pan as the reference. The DSC pans were tared, approximately 8.00±0.05 mg of camel milk powder transferred into the aluminium pan, which was then hermetically sealed and reweighed. The powders were scanned from 0 to 130 °C at a heating rate of 5 °C/min and the STAR^e Software version 9.10 was used for the analysis of the DSC thermograms. The glass transition point, characterised by a shift in the thermogram line, and the fat melting points, which were characterised by the endothermic peaks, were identified. The glass transition point is indicated by a change in the specific heat capacity of the initial, middle and end points. The endothermic peaks characterised the initial, maximum slope, peak points and enthalpy involved in the transition. The measurements were conducted in triplicates, and the mean and standard deviations were obtained.

5.2.6 Statistical Data analysis

A general factorial experimental design with two independent and a dependent co-factor was employed. The experimental data was fed into the Design-Expert® Software Version 10 (DX10) (Stat-Ease, Inc., Minneapolis, USA) and analysed using the response surface methodology (RSM). The effect of the two independent variables (flow rate and inlet temperature) on the physical, colour and reconstitution properties of the spray dried camel milk powders were investigated to determine the optimal conditions by employing a randomised two by three factorial design. The RSM was chosen due to its ability to detect the interactions between the inlet temperature and flow rate, and a possible quadratic term of inlet temperature and the flow rate (Ferreira et al. 2007). To obtain the regression coefficients, the experimental data were fitted to a second-order polynomial model indicated by equation 5.12 with the general linear model approach.

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i \neq j=1}^{k} \beta_{ij} X_i X_j \qquad \text{Eq. 5. 12}$$

Where β_0, β_i, β_{ii} and β_{ij} are the regression coefficients for model constant, linear, quadratic and interaction terms, respectively. While Y is the predicted response, X_i and X_j are the independent variables and k is the number of tested variables (Bruns, Scarminio, and Barros Neto 2006).

The coefficient of determination (R^2) characterises the fit of the polynomial equation. The robustness of the fitted equation is obtained by controlling the difference between adjusted R^2 and prediction R^2 (desirable diff < 0.2) via iterative model selection. The final model contains only significant terms considering the hierarchy of the model. The significance of the regression coefficients was confirmed by multifactorial ANOVA and Fisher F-test at a probability of? 95% confidence level (Yolmeh, Habibi Najafi, and Farhoosh 2014). The coefficient estimates are shown for coded factors; the actual factor levels are standardized on a range from -1 for the lowest actual level to +1 for the highest actual level of a certain factor. The given coefficient estimates can be directly interpreted as leverage of a factor in the same unit as the response variable. The interactive effects of the inlet drying air temperatures, milk flow rate and the responses are visualised using the 3D response surface plots derived from the regression models. For every quality parameter (response variable) the best possible model was applied independently. As a second step the multi response goal conflict was optimized using Derringer's desirability function. The optimal inlet drying air temperatures and flow rate of the response from physical, colour and reconstitution properties of camel milk powder were obtained. The response was optimised to the same weight (w=1), and the desirability values of the responses ranging from 0 to 1 determined the credibility of the numerically optimised conditions (Hu, Cai, and Liang 2008; Islam, Alam, and Hannan 2012).

5.3 Results and Discussion

5.3.1 Physical and colour properties of camel milk and commercial milk powder

Table 2 gives the different physical properties of the camel milk and the commercial camel milk powder (CMM). The average density of camel milk was established to be 1024.5 kgm^{-3} which is almost identical to that reported by Farah (1996) of 1029 kgm^{-3} (Table 5.2). The pH of the milk of 6.5 corroborates to the values reported from other studies which ranged from 6.0 to 6.7 (Khaskheli et al. 2005; El-Hadi Sulieman, Ilayan, and El-Awad El Faki 2006).

Table 5. 2: Physical and colour properties of camel milk and commercial camel milk powder

Parameters	Camel milk	CMM
L	88.20±0.65	97.67±0.37
a*	-1.36±0.21	-1.71±0.01
b*	0.22±0.27	7.00±0.06
Chroma (C)	1.41±0.16	7.20±0.06
Hue angle (H)	0.18±0.02	-1.33±0.02
Colour difference (ΔE)	-	13.64±0.30
Density kgm^{-3}	1024.50±1.73	-
Loose density kgm^{-3}	-	360.36±6.14
Tapped density kgm^{-3}	-	518.82±14.67
Compressibility (%)	-	30.74±0.86
Hausner ratio	-	1.44±0.02
Interstitial air	-	8.49±0.14
Dispersibility (%)	-	76.93±0.39
Wettability (s)	-	734.25±23.06
Moisture content (%)	91.06±0.06	3.26±0.09
pH	6.50±0.20	-

The average density of camel milk was established to be 1024.5 kgm^{-3} which is almost identical to that reported by Farah (1996) of 1029 kgm^{-3} (Table 5.2). The pH of the milk of 6.5 corroborates to the values reported from other studies which ranged from 6.0 to 6.7 (Khaskheli et al. 2005; El-Hadi Sulieman, Ilayan, and El-Awad El Faki 2006).

The viscosity of the camel milk varied from 2.87 at 20 °C to 0.97 mPa s at 60 °C (Fig. 5.1) which was slightly higher than the values reported in the literature of both the camel (1.72 mPa s) and cow milk (2.04 mPa s) at 20 °C (Kherouatou et al. 2003).

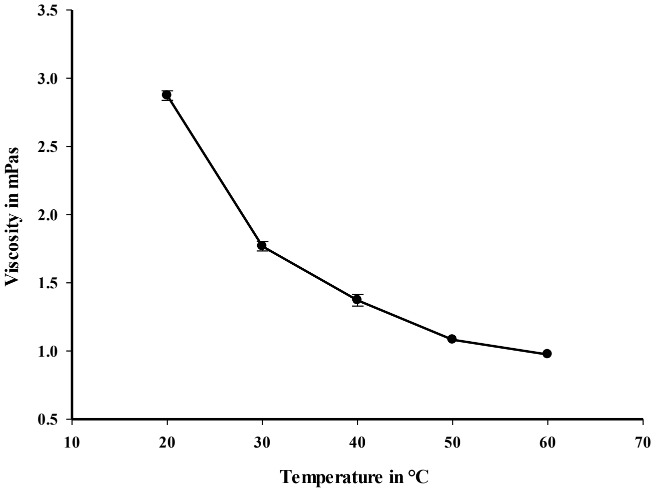


Figure 5. 1: Viscosity of camel milk at different temperatures

The difference in the physical properties of the camel milk values stated in this study and those reported in the literature could be due to diet of the camels, location, number of milkings per day or lactation period. Moreover, camel milk used in this study was obtained from dromedary camels that had defined feed composition and easily accessible water sources in North Western Europe. Besides, the total solids of the camel milk used in the study were lower (8.94 %) than those reported in the literature (12.39 %) (Konuspayeva, Faye, and Loiseau 2009). The slight differentiation of the camel milk properties in this study from the reported ones, thus imply that the location and feeding of the camel influences the camel milk composition.

The milk utilised in the present study was non-pasteurized, therefore, the protein constituents of the milk were not affected by pasteurisation before spray drying. However, the high values of wettability and low dispersibility observed in the CMM (Table 5.2) can be attributed to the changes that occur to milk components, such as protein denaturation during pasteurisation and concentration before the final spray drying, that influence the rehydration properties (Elagamy 2000b). In addition, these high values can be due to prolonged storage and fluctuations in spray drying conditions. The high b* values in the CMM (Table 5.2) can be attributed to the presence of free fats on the surfaces of the powder particles, as influenced by pasteurisation and concentration processes, that are prone to oxidation (Fox and Kelly 2012; Kim, Chen, and Pearce 2009). The moisture content of the CMM powder was approximately 3.26 % while the tapped bulk density was approximately 520 kgm^{-3} (Table 5.2).

5.3.2 Effect of inlet drying air temperatures and milk flow rate on the moisture content of spray dried camel milk powders

The moisture content of camel milk powders varied from 3.31 to 5.05 %, decreasing with an increase in inlet drying air temperatures and a decrease of milk flow rate (Fig. 5.2).

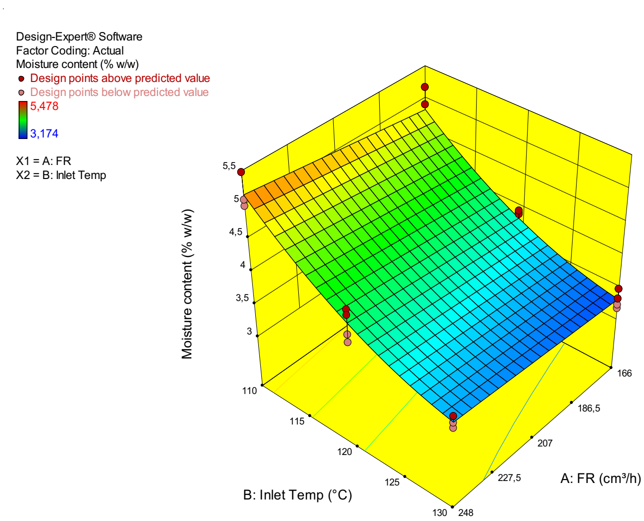


Figure 5. 2: Response surface 3D plots of combined effects of temperature and flow rate on moisture content

Although the CMM had a higher moisture content (Table 5.2), both the laboratory and the commercial powders' values are above the desired value of less than 2.5% for whole milk powders (Westergaard 2004). Indicating that they are less shelf stable, this can be attributed to the single stage drying applied. The effect of different inlet drying air temperatures and milk flow rate on the physical and optical properties are presented in Table 5.3.

Table 5. 3 Fitted second order polynomial and linear equations; effect of milk flow rate and inlet air drying air temperatures for the different measured milk powder properties

Response	Model	R^2	F value (model)	F value (lack of fit)
$Outlet\ Temperature\ (°C)$	$= 67.50 - 2.00A + 9.25B + 0.75B^2$			
$Moisture\ content$ (%)	$= 3.96 + 0.13A - 0.79B + 0.25B^2$	0.934	63.75***	0.49
$Dispersibility$ (%)	$= 81.23 + 0.12A - 0.50B + 0.64AB - 1.03B^2$	0.530	5.07*	2.28
$Wettability\ (s)$	$= 336.6 - 5.51A + 58.50B$	0.815	39.56***	0.14
$Loose\ Density\ (kgm^{-3})$	$= 0.29 + 0.020A$	0.626	7.52**	0.37
$Tapped\ Density(kgm^{-3})$	$= 0.43 + 0.032A$	0.832	19.84***	1.67
$Compressibility$ (%)	$= 31.52 - 1.22A - 0.65B - 2.51AB + 7.60B^2$	0.785	17.30***	0.022
$Hausner\ ratio$	$= 1.46 - 0.024A - .0055B - 0.058AB + 0.19B^2$	0.821	20.67***	59.71
$Interstitial\ air$ (IA)	$= 111.24 - 15.08A - 4.19B - 13.95AB + 33.69B^2$	0.839	22.09***	1.76
$Lightness\ parameter\ (L$	$= 98.44 + 0.2A - 0.48B$	0.816	29.63***	2.03
$Redness\ parameter\ (a*)$	$= -0.63 - 0.019A + 0.061B$	0.936	162.13***	2.29
$Yellowness\ parameter\ (b)$	$= 3.11 - 0.065A + 0.34B - 0.18B^2$	0.961	110.75***	0.64
$Chroma\ (C)$	$= 3.17 - 0.059A + 0.32B - 0.17B^2$	0.956	106.60***	0.73
$Hue\ angle\ (H)$	$= -1.38 + 0.005A - 0.019B - 0.010AB$	0.947	84.91***	0.25
$Colour\ difference\ (\Delta E)$	$= 11.10 + 0.13A - 0.28B - 0.24AB$	0.852	32.62***	2.03
$Particle\ size\ (PS)\ (\mu m)$	$= 12.29 + 1.30A - 0.85B - 0.13AB - 0.52B^2$	0.685	9.24**	0.5

Where A is the flow rate in (m^3/h), B is the inlet air temperature (°C), Interaction between flow rate and inlet drying air temperatures (AB). Level of significance: * p<0.05, **p<0.001, ***p<0.0001

Furthermore, for the moisture content, the model fitted with good prediction (R^2=0.934), as indicated by the non-significant lack of fit (F =63.75) indicating that the model could not explain only 0.07 % of the variation, thus a perfect fit (Table 5.3). The accuracy of the model was further indicated by the non-significant lack of fit (F=0.49) and the ultimate equation for moisture content, with only significant factors considered, is given in Table 3. Further, analysis of variance (ANOVA) showed significantly (p < 0.0001) negative linear to inlet drying air temperature, whereas both the milk flow rate and the quadratic value of the inlet drying air temperatures were positively significant for the moisture content ($p<0.05$). These findings imply that the inlet temperature influences the milk powder moisture content approximately six times more than the inlet milk flow rate.

5.3.3 Effect of inlet drying air temperatures and milk flow rate on reconstitution properties of spray dried camel milk powders

The dispersibility of the spray dried camel milk powders in water ranged from 78.74-81.48 % (Fig. 3a) which is lower than that of cow milk powders (85 %) as reported by Tamine (2009). However, the CMM had the lowest dispersibility values of 76.93 % (Table 5.2). The variation could be due to the type of atomiser, drying method, or the nature and concentration of the spray dried milk (Reddy et al. 2014; Zbikowska and Zbikowski 2006). Fig. 3 indicates the three-dimensional plots for dispersibility and wettability of the spray dried camel milk powder.

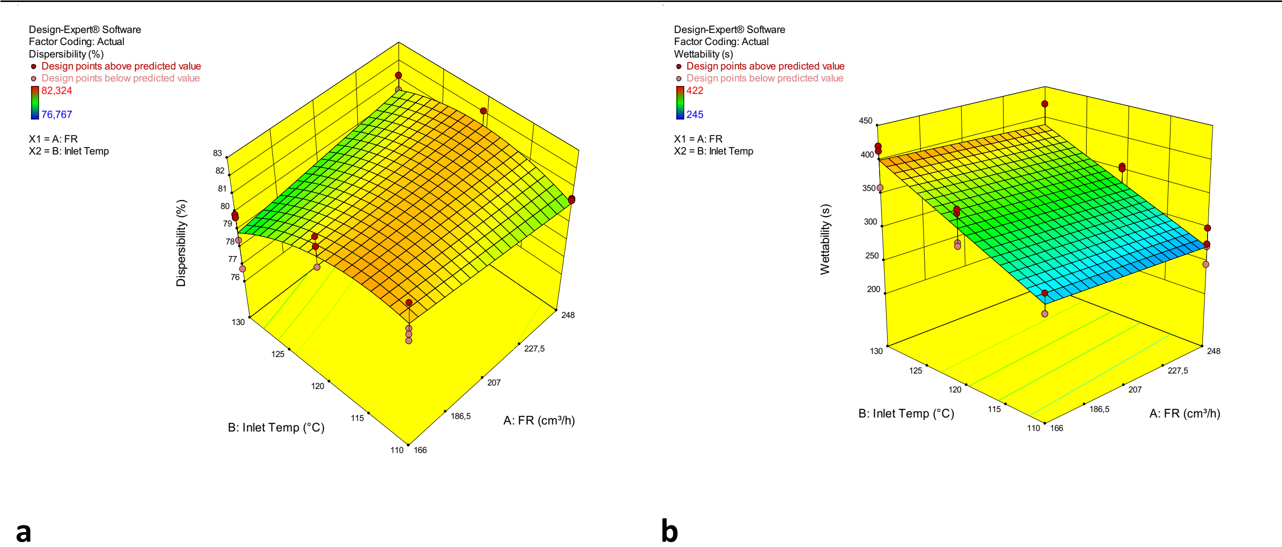


Figure 5. 3: Response surface 3D plots of combined effects of temperature and flow rate on (a) dispersibility (b) wettability

The non-significant lack of fit (F= 2.28) for dispersibility indicated that the model fitted to the spatial influence of both the inlet air temperature and milk flow rate with a reasonable prediction (R^2=0.530) (Table 5.3). The p-value lower than 0.05 for dispersibility demonstrated that the regression model was significant (Table 5.3). Considering the linear effect, both the milk flow rate

($p<0.0001$) and inlet air drying temperature were significant ($p<0.05$). Higher inlet drying air temperatures lead to faster surface hardening, thus, decreasing the dispersibility of the powders (Fig 5.3 a). Lower inlet drying temperatures are preferable as samples produced at low inlet drying air temperatures had a greater dispersibility, which has also been reported for goat milk powder (Reddy et al. 2014). Thus, to ensure an excellent dispersible product, lower inlet drying temperatures are recommended. Moreover, use of amphiphilic agents, such as lecithin, has been reported to improve the dispersibility of whole milk powders (Fox and Kelly 2012).

The model for wettability fitted with good prediction (R^2=0.815), as indicated by the non-significant lack of fit (F =39.56) (Table 5.3). The wettability was higher than 120 seconds in all samples and increased with an increase in inlet drying air temperatures (Fig. 5.3 b). These findings are similar to those reported by other studies, where the wettability values of whole cow and goat milk powders were higher than 120 s and increased with increase in inlet drying air temperature (Westergaard 2004; Schuck, Dolivet, and Jeantet 2012; Reddy et al. 2014). The high wettability values could be due to the presence of fat molecules on the surface of the powders which offer lipophilic properties, leading to an increase in time for the powder particles to be wetted (Zbikowska and Zbikowski 2006; Kim, Chen, and Pearce 2002). The inability of powder particles to be wetted in less than 60 seconds indicates that the powders were not instant (Kelly, O'Connell, and Fox 2003). This implies that the powders are not readily dispersible in cold and warm water, thus, undesirable for applications requiring reconstitution at home. It was further observed from the model equations that the linear and quadratic drying air inlet temperature terms most significantly affected the dispersibility and wettability of the powders respectively (Table 3). The more dispersible the powder, the less time was needed to wet the powders. Further, a decrease in the residual moisture content of the powder particles with an increase in inlet drying air temperatures has been indicated to increase the wettability time in milk powders (Chegini and Taheri 2013). The dispersibility and wettability values are within the expected values for a laboratory scale spray dryer but less than the desired industrial values of >85 % and 60 s respectively (Schuck, Dolivet, and Jeantet 2012). Therefore, for industrial purposes, addition of surface-active agents of particles is often used in enhancing the rehydration of the powders. Moreover, multi-stage spray drying also enhances agglomeration of particles that improve further dispersibility and wettability properties of the powders (Westergaard 2004).

The CMM powders were produced from pasteurised and concentrated milk, while the laboratory samples were obtained from non-pasteurized milk, resulting in lower dispersibility and higher wettability values of the laboratory spray dried powder. During spray drying, there is a limited influence on the protein content of the milk compared to the heat treatments (pasteurisation and evaporation) which are vital in ensuring the safety of the milk, as well as thermal efficiency. Both pasteurisation and evaporation lead to protein denaturation that adversely affects rehydration properties (Fox and Kelly 2012). Further, homogenization, and preheating, increase the viscosity of the milk resulting in larger droplets upon atomization. The larger droplets results in intense heat treatment during spray drying which lowers the dispersibility of the powders (Walstra, Wouters, and Geurts 2006).

5.3.4 Effect of inlet drying air temperatures and milk flow rate on bulk properties of spray dried camel milk powders

According to Barbosa-Cánovas et al. (2005) and Schuck, Dolivet, and Jeantet (2012), whole milk powders have bulk densities between 400-630 kgm^{-3}. In our study, the bulk densities of the camel milk powders ranged from 390 kgm^{-3} to 480 kgm^{-3} (Fig. 5.4 a & b) which were lower than the commercial ones of 520 kgm^{-3} (Table 5.2). It has been reported that increasing the dry matter content increases the bulk density; this explains the high bulk density in CMM which, at industrial level, are concentrated before spray drying as opposed to the laboratory produced powders from low dry matter content milk (Schuck, Dolivet, and Jeantet 2012). Also, from our findings, the ρ_B was approximately 2/3 of the ρ_T, which corresponds with the observations of Tuohy (1989).

The regression models of tapped bulk density, Hausner ratio and interstitial air fitted with good prediction (R^2=0.832, 0.821, and 0.839 respectively) as indicated by the non-significant lack of fit (F=1.67, 59.71 and 1.76 respectively) (Table 5.3). However, the regression models for loose bulk density and compressibility fitted with a lower prediction (R^2= 0.626 and 0.785 respectively) but the lack of fit was non-significant with F values of 0.037 and 0.022 respectively. The p-values of lower than 0.0001 for all the bulk properties excluding the loose density ($p<0.001$) allow the conclusion that the model was highly significant (Table 5.3).

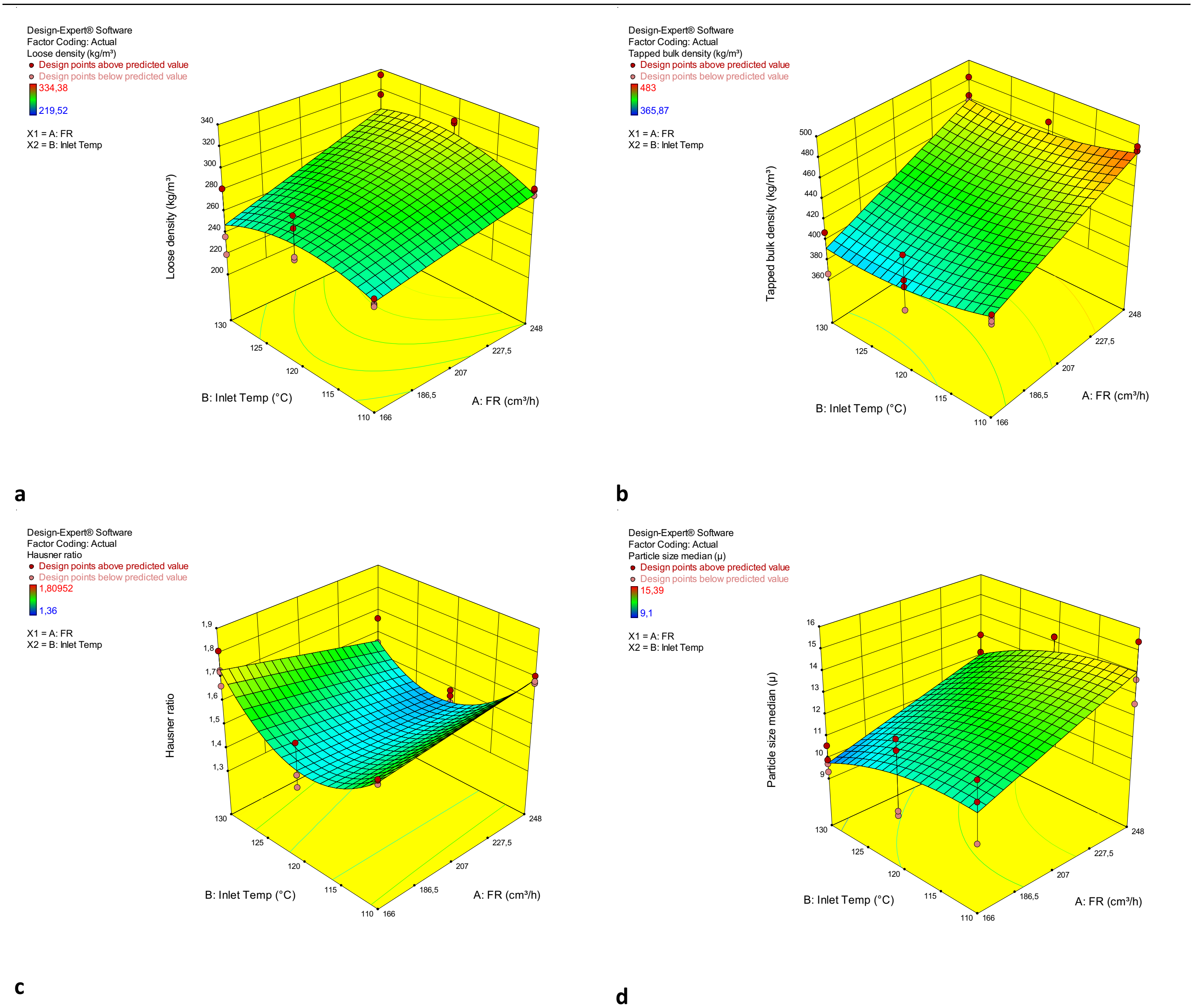


Figure 5. 4: Response surface 3D plots of combined effects of temperature and flow rate on bulk properties (a: Loose density; b: Tapped bulk density; c: Hausner ratio[4]. and particle size (d)

[4] **Specifications for Carr's index (%) and Hausner ratio**

Flowability	Carr's index (%)	Hausner ratio
Excellent	0–10	1.00–1.11
Good	10–15	1.12–1.18
Fair	16–20	1.19–1.25
Possible	21–25	1.26–1.34
Poor	26–31	1.35–1.45

The ANOVA on the fitted models showed that tapped density and loose bulk density had a highly significant ($p<0.0001$) positive linear effect on milk flow rate and a negative linear effect on compressibility, Hausner ratio and interstitial air (Table 5.3). However, the quadratic effect of the inlet drying air temperatures showed significant influence on both compressibility and Hausner ratio ($p<0.0001$). The interactive effect of milk flow rate and the inlet drying air temperatures also influenced the compressibility, Hausner ratio and the interstitial air ($p<0.001$) but had no significant influence on both the loose and tapped densities (Table 5.3).

Different studies on the effect of inlet drying air temperatures on the density of spray dried products indicated a decrease in the bulk density with increased inlet drying air temperatures (Tonon, Brabet, and Hubinger 2008; Bansal, Sharma, and Nanda 2014). The particles produced by the laboratory spray dryer at low temperatures were shrivelled and less porous resulting in high bulk densities. Lower bulk densities are undesirable due to an increase in occluded air and, thus, produce a product more prone to oxidation which reduces the shelf life of the powders during storage. Moreover, this enhances the volume of the packages that are required for storage of products (Goula and Adamopoulos 2008; Kurozawa, Park, and Hubinger 2009).

In this study, whole milk powders were used which resulted in the fat on the surfaces of the particles influencing the powder flow (Kim, Chen, and Pearce 2005). This is because, at high temperatures, the fat melts which results in an adhesive, rubbery and viscous liquid increasing the stickiness of the particles to each other and consequently lowering the flowability of the milk powders (Fitzpatrick et al. 2004). The powders were highly cohesive as indicated by the Hausner ratio values which were between 1.40 and 1.73 (Fig. 5.4 c). These high values are in line with their high Carr index (30.40 % - 42.20 %) indicating poor flowability. These values suggest that the compressibility ranged from poor to extremely poor. The low bulk densities, poor compressibility, high Carr index and Hausner ratio of the laboratory produced powders, implies that the powders would be difficult to measure, handle and package.

Very poor	32–37	1.46–1.59
Very, very poor	>38	>1.60

5.3.5 Effect of inlet drying air temperatures and milk flow rate on colour parameters of spray dried camel milk powders

The linear effect of milk flow rate and inlet drying air temperatures had a significant positive effect on all colour parameters while the milk flow rate significantly influenced, a* and hue angle (H) of the powders (Table 5.3). The colour difference depended heavily on the interaction between the flow rate and the inlet drying air temperatures ($p<0.0001$) (Table 5.3) The regression models of the colour parameters fitted with good prediction (R^2=0.816, 0.936, 0.961, 0.960, 0.947, and 0.852 for L*, a*, b*, C, H, and ΔE respectively) as indicated by the non-significant lack of fit (F=2.03, 2.29, 0.64, 0.73, 0.25 and 2.03 for L*, a*, b*, C, H, and ΔE respectively). Effects that were not significant ($p > 0.05$) were excluded from models without damaging the hierarchy (Table 5.3).

Lower inlet drying air temperatures and higher milk flow rates result in increased L* and ΔE values as well as Hue angles while lowering the a*, b* and chroma values (Fig. 5.5 a, b, c; Table 5.3). Both the flow rate and inlet drying air temperatures influenced the lightness parameter for the laboratory spray-dried powders (Table 5.3). With the increase in inlet drying air temperatures and a decrease in flow rate the L* values decreased. The lowest values were observed at an inlet drying air temperatures of 130 °C and flow rate 166 cm^3/h (Fig. 5.5 a). These findings can be due to the lower moisture content of the samples at higher temperatures and lower milk flow rate; thus, more particles were exposed to higher temperatures. Additionally, the powders are prone to biochemical changes such as Maillard reactions or caramelisation of the sugars at higher temperatures (Schuck, Dolivet, and Jeantet 2012; Daza et al. 2016). The effect of different inlet air temperatures on the colour of spray-dried milk powders previously assessed, and a reduction in the value of L* with an increase in inlet air temperature was observed in this study (Sulieman et al. 2014).

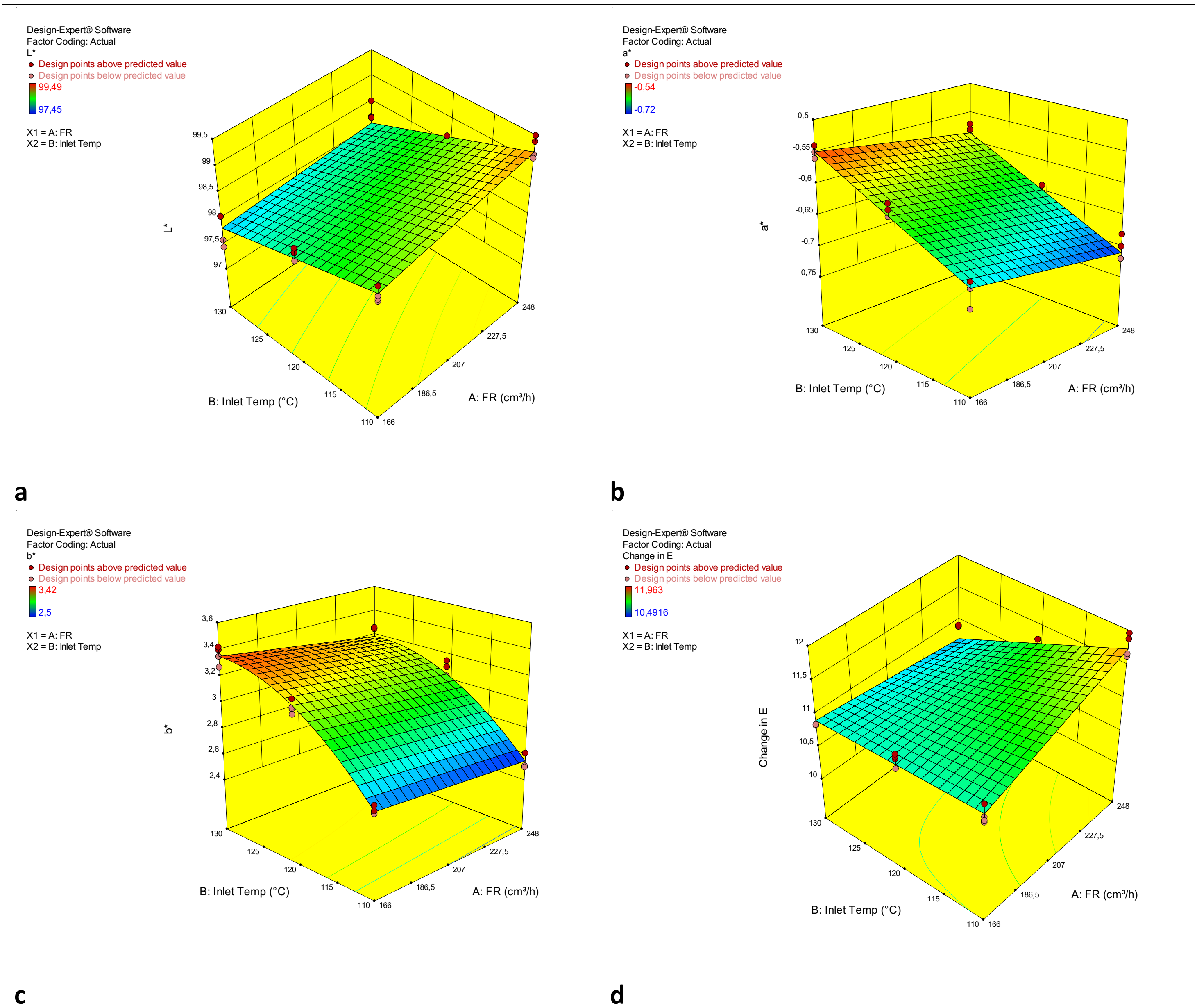


Figure 5. 5: Response surface 3D plots of combined effects of temperature and flow rate on colour properties

The a* values of all samples were negative and tended to the positive with increasing inlet drying air temperatures and decreasing flow rates (Fig. 5.5 b), indicating a tendency towards the reddish colour which could be an indicator for enzymatic and non-enzymatic browning (Reddy et al. 2014; Sturm, Hofacker, and Hensel 2012). These findings are in agreement with those of spray dried camel milk powders (Sulieman et al. 2014).

Both the inlet drying air temperature ($p<0.0001$) and flow rate ($p<0.001$) significantly influenced the yellowness index. All the b* values of the samples displayed positive values indicating a tendency towards the yellow colour (Fig. 5.5 c). Similar results were reported with a decrease in flow rate, as more yellowing of the powder was observed (Sulieman et al. 2014). Regarding the colour difference (ΔE), all the sample values were higher than 3.8 (Fig. 5.5 d), indicating that it was possible to perceive the colour change visually (Nollet, Toldrá, and Group 2010). Moreover, the ΔE increased with a decrease in milk flow rate, indicating that thermal damage due to Maillard reactions and melanoidin formation increased with exposure to higher drying temperatures. Similar results have been documented by other studies in apples and powders (Sturm, Hofacker, and Hensel 2012). Moreover, the CMM samples had a greater ΔE compared to the laboratory spray-dried powders. This can be attributed to the pasteurisation and concentration of milk, high spray drying temperatures and the prolonged storage before usage of industrially produced powders. The colour change is due to melanoidin formation that is a characteristic of Maillard reaction. Thus, at industrial level, care should be taken to minimise colour change while increasing the L* and decreasing a* and b* values to obtain the desired colour properties similar to those produced at the laboratory scale dryer.

5.3.6 Particle size

The quadratic regression model of the particle size fitted with reasonable prediction ($R^2=0.6848$). The non-significant lack of fit of the model ($F=9.24$) indicated that the model fits with the data. The p-value lower than 0.001 for the model demonstrated that the regression model was significant (Table 5.3). Moreover, the lack of fit was non-significant with an F value of 0.5. The particle size of the powders was significantly affected by the linear effect of the milk flow rate, and the interaction ($p<0.0001$) between the inlet air temperature and milk flow rate (Table 5.3). From figure 5.4 d and table 5.3, it can be observed that an increase in inlet air temperature and a decrease in milk flow rate cause the formation of smaller particles. Other studies have reported similar findings for cow milk powders. The two-fluid nozzle used in the production of the milk powders and, thus, the particle size of the powders in this study do not differ significantly at the different processing temperatures and flow rates (Nijdam and Langrish 2006). Although particle agglomeration affects the particle size, this could not be observed in the laboratory spray dried particles due to the lower number of particle collisions in the drying chamber compared to the higher collisions at industrial level (Westergaard 2004).

5.3.7 Optimization

The optimum conditions for spray drying of camel milk were determined to define the minimum optimal rehydration properties, bulk density and minimum moisture content. In optimising the bulk density, colour change (ΔE), moisture content, dispersibility, wettability and particle size were selected. These target variables were weighted based on their importance (Table 5.4).

Table 5. 4 Conditions and outputs of the numerical optimization of the responses for camel milk powder

Factor/ Parameter	Goal	Lower Limit	Upper Limit	Lower weight	Upper weight	Importance
Flow rate (kgm^{-3})	is in range	166.00	248.00	1	1	3
Inlet air Temperature (°C)	is in range	110.00	130.00	1	1	3
Moisture content (%)	minimize	3.17	5.48	1	1	5
Particle size (μm)	maximize	9.10	15.39	1	1	5
Wettability (s)	minimize	365.87	483.00	1	1	5
Dispersibility (%)	maximize	76.77	82.32	1	1	5
ρ_T (kgm^{-3})	maximize	245.00	422.00	1	1	5
ΔE	minimize	10.49	11.96	1	1	5

The optimisation results are indicated in Table 5.5. In optimising an individual target, the dependent variable was categorised as importance 5 while the others were set as 1. If all targets were regarded as equally important, all of them were assigned an importance of 5.

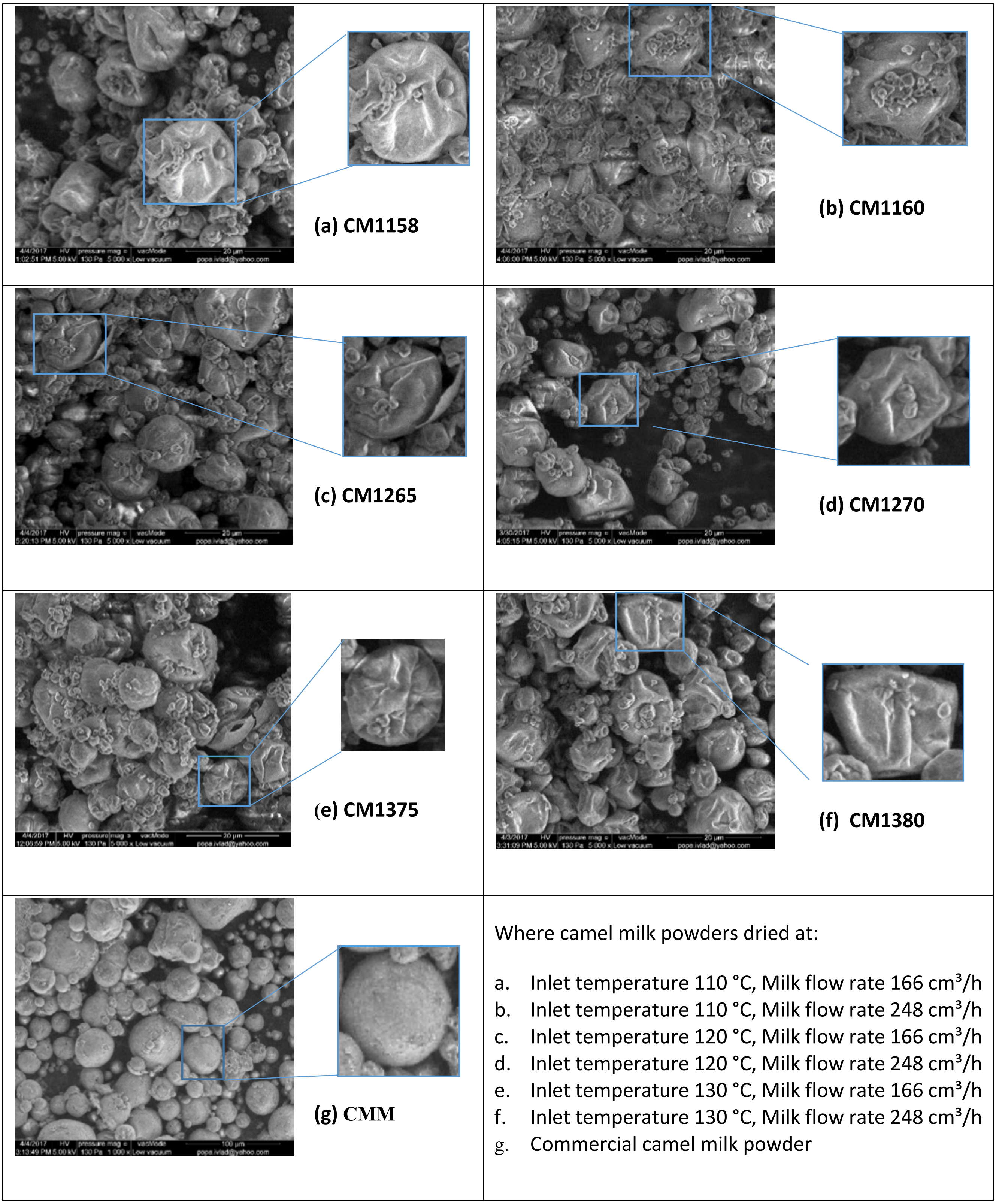
Table 5. 5: Desirable solutions for the optimization of spray drying camel milk powder

Factors	Flow rate (kgm^{-3})	Inlet air temperature (°C)	Moisture content (%)	Particle size (µm)	Dispersibility (%)	Wettability (s)	ρ_T (kgm^{-3})	ΔE	Desirability
Moisture content (%)	248	123.15	3.87	13.23	81.29	349.20	457.64	11.07	0.65
Particle size (µm)	248	121.04	4.01	13.48	81.36	336.85	458.27	11.18	0.65
Wettability (s)	248	119.83	4.11	13.60	81.35	329.77	458.98	11.24	0.63
Dispersibility (%)	248	121.69	3.97	13.41	81.35	340.65	458.00	11.14	0.67
ρ_T (kgm^{-3})	248	121.72	3.96	13.40	81.35	340.78	457.99	11.14	0.66
ΔE	248	123.64	3.83	13.16	81.27	352.03	457.60	11.04	0.64
All	248	121.85	3.95	13.39	81.34	341.56	457.94	11.13	0.65

The maximum milk flow rate and inlet temperatures varied when different targets were regarded as important. There was no great variation in the desirability value of all scenarios investigated which were optimised (Table 5.5). The optimisation results indicated that the inlet air drying temperature significantly influences the bulk, colour, particle size, and reconstitution properties of spray dried camel milk powders. The inlet air temperature of 121.85 °C and feed flow rate of 248 cm^3/h were obtained as the most desirable solutions for the optimum laboratory spray drying conditions when all response variables were set as important. At optimized condition, the predicted values for moisture content, particle size, dispersibility, wettability, bulk density and ΔE were 3.95 %, 13.39 µm, 81.34 %, 341.56 s, 457.94 kgm^{-3} and 11.13 respectively, indicating the suitability of the model to be used in optimizing the spray drying process for production of camel milk powder.

5.3.8 Particle morphology of spray dried camel milk powder

The particle morphology of the spray dried and commercial camel milk powders as observed under a standard electron microscope are given in Fig. 5.6.



Where camel milk powders dried at:

a. Inlet temperature 110 °C, Milk flow rate 166 cm^3/h
b. Inlet temperature 110 °C, Milk flow rate 248 cm^3/h
c. Inlet temperature 120 °C, Milk flow rate 166 cm^3/h
d. Inlet temperature 120 °C, Milk flow rate 248 cm^3/h
e. Inlet temperature 130 °C, Milk flow rate 166 cm^3/h
f. Inlet temperature 130 °C, Milk flow rate 248 cm^3/h
g. Commercial camel milk powder

Figure 5. 6: SEM images of camel milk powder spray dried at different processing conditions at X5000 magnification

The morphology of powder particles is affected by the nature of the feed, degree of heat treatment, composition and processing parameters. The camel milk powder in this study showed particles with larger vacuoles that have some of the small particles entrapped on the surface. The structure of the laboratory spray dried powders differed from those commercially produced. The commercial whole milk powder particle surfaces were spherical and rough with small cracks, dents and pores (Fig. 5.6 g) (Fyfe et al. 2011; Kim, Chen, and Pearce 2009). The particles produced by the laboratory scale spray dryer at the different temperatures had collapsed structures (Fig. 5.6 a-f). The collapsed structure could be related to the lower inlet spray drying air temperatures and low feed concentration. These findings are in agreement with those of other studies in which samples of skimmed and whole cow milk were spray dried using laboratory, industrial and pilot spray dryers (Kim, Chen, and Pearce 2002, 2009; Nijdam and Langrish 2006; Fyfe et al. 2011). The authors of these studies observed that at lower feed concentration and lower temperatures, the particle structures were more collapsed compared to those produced at higher temperatures and feed concentration. The low gas permeability of the surrounding skin inflates once the particle temperature surpasses the local ambient boiling point, and the vapour pressure within the vacuole rises above the local ambient pressure. High drying temperature leads to faster moisture evaporation that results in faster drying and hardening of the skin, and less migration of the fats, protein and other dissolved substances to the droplet surface before skin formation (Kim, Chen, and Pearce 2009). As the particle moves towards the cooler regions of the dryer, the hardened and dry skin (due to fast moisture evaporation) limits the deflation of the hollow particle (Pisecky 2012; Kim, Chen, and Pearce 2009). However, at low inlet temperatures, the skin remains damp and supple for longer so that the hollow particle can collapse and shrink as it cools (Hassan and Mumford 1993; Nijdam and Langrish 2005). The formation of skin and vacuole within a milk particle is enhanced after skin development at the surface and is clearer in the laboratory scale dryer, as opposed to industrial dryers, because particle agglomeration obscures this phenomenon (Kim, Chen, and Pearce 2009). Therefore, use of a laboratory spray dryer to understand the vacuole and skin formation is preferred to the industrial processes due to a lower particle agglomeration.

5.3.9 Thermal properties of the spray dried camel milk powders

The stability of food products during processing and storage are dependent on thermal characteristics such as glass transition, melting points and freezing points (Rahman 2009, 2006). The glass transition of the spray dried powders is an indicator of storage stability, and any slight increase of the moisture content results to a decrease of the T_g. Moreover, a further decrease in T_g below the room temperature leads to a sticky product, thus, limiting shelf life of the product (Santhalakshmy et al. 2015). From our findings, the T_g depended on the moisture content of the samples and increased with decreasing moisture content (Table 5.6) indicating that both the inlet air temperature and milk flow rate influenced the thermal properties of the spray dried camel milk powders. These results are similar to the values and trends observed in laboratory spray dried cow milk powders where the glass transition of the powders increased with decreasing moisture content (Nijdam and Langrish 2005). The data on thermal characteristics of the camel milk powders are represented in table 5.6.

Table 5. 6: Thermal characteristics of spray dried camel milk powders.

Sample	CM 1158	CM 1160	CM 1265	CM 1270	CM 1375	CM 1380	CMM
Moisture content (%)	5.19±0.29	4.82±0.25	4.06±0.20	3.87±0.09	3.56±0.08	3.31±0.12	3.26±0.09
Onset T_g (°C)	37.49±1.26	37.32±1.84	37.76±1.12	38.48±0.24	38.73±1.14	38.98±1.51	44.21±2.11
Inflection	45.22±0.39	45.73±1.14	45.27±1.37	45.52±0.74	45.88±0.56	45.96±1.02	50.02±0.51
End set T_g(°C)	76.14±0.93	76.74±0.87	79.15±3.6	78.81±0.60	71.53±3.73	80.45±1.23	69.21±3.90
$\Delta C_{p\ (Wg^{\wedge}-1)}$	0.09±0.00	0.1±0.01	0.09±0.00	0.1±0.01	0.08±0.01	0.07±0.01	0.04±0.00
First melting point of fat							
Onset (°C)	8.58±0.24	1.91±0.17	6.68±0.21	9.19±0.23	12.55±0.24	12.78±0.3	15.74±0.50
Maximum slope (°C)	9.89±1.32	9.72±0.45	7.97±0.48	11.97±1.34	24.63±0.93	24.56±0.68	24.25±1.21
Peak (°C)	13.85±0.52	11.8±0.95	8.08±1.35	13.61±0.88	24.1±0.97	23.84±0.68	24±0.07
End set (°C)	19.56±0.35	16.89±0.55	14.98±1.81	18.7±2.24	30.23±1.46	28.78±0.66	30.45±0.47
Second melting point of fat							
Onset (°C)	13.88±0.60	14.25±1.09	12.81±1.89	14.08±1.57	25.1±0.65	24.92±1.36	28.78±0.9
Maximum slope (°C)	35.04±1.30	35.85±0.31	35.42±0.00	34.18±2.65	35.62±0.05	34.29±1.15	39.75±1.79
Peak (°C)	29.75±0.81	26.49±1.68	32.92±0.58	30.21±3.04	34.65±0.40	33.71±0.77	42.00±3.60
End set (°C)	42.71±0.05	43.54±0.17	44.16±0.71	42.57±0.34	43.39±1.65	42.96±1.30	49.15±1.43

A sample DSC thermogram of spray dried camel whole milk powder is given in figure 5.7 comprising three endothermic peaks (F_1, F_2 & SM) and two shifts (T_g). The first two endothermic peaks indicated fat melting whilst the last larger endothermic peak represents the melting of non-fat solids (Rahman et al. 2012). In the determination of the glass transition of freeze-dried whole and skim camel milk powders, it was observed that whole milk powders had two T_g at -5 and 32 °C and the skim milk powder one T_g at 46 °C (Rahman et al. 2012). However, our findings in the shifts and the glass transition temperatures differ from these findings of camel milk. The variation could be due to the range of the temperature used in determining the thermogram, the milk composition as influenced by diet, processing conditions and the moisture content of the milk powder samples. The final shift in the heat capacity of the last endothermic peak could be due to the interactions between the particles after melting has taken place (Rahman et al. 2012).

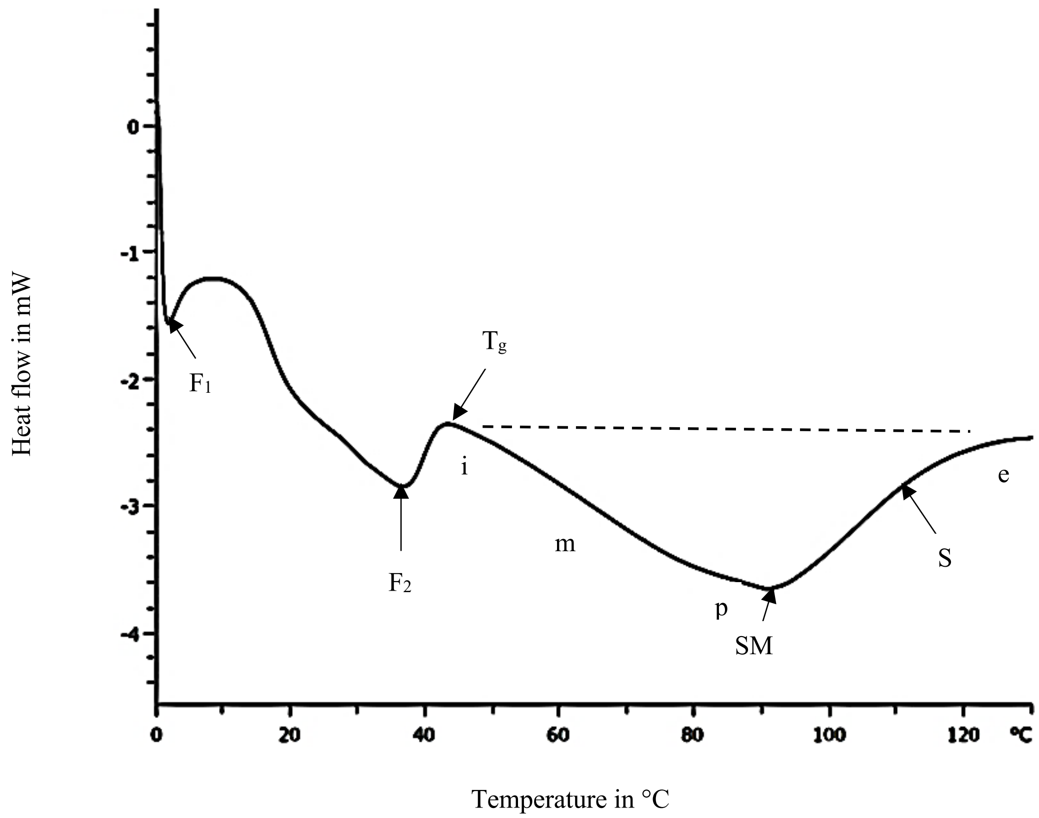


Figure 5. 7 Sample DSC thermogram of spray dried camel whole milk powder (T_g: first glass transition, F_1: first fat-melting, F_2: second fat-melting, SM: solids-melting, i: onset, m: maximum slope, p: peak, e: end, S: structure formation).

5.4 Conclusions

In this work, the effects of milk flow rate and inlet drying air temperature on the physical, optical and thermal properties of spray dried camel milk powder were investigated. The findings indicated that the inlet drying air temperatures significantly influenced moisture content and the colour properties of the powders. However, the bulk and reconstitution properties were significantly influenced by the milk flow rate. The particle morphology of laboratory spray dried milk powders greatly differed from the commercial ones. With increase in inlet air temperature and a decrease in milk flow rate, the glass transition temperature of the milk powders increased.

This study has advanced the understanding of spray drying of camel milk; in particular, how the inlet drying air temperature and milk flow rate can be optimised to produce camel milk powders of desired physical, thermal and optical properties at laboratory scale. However, further steps need to be undertaken to transfer these results to industrial scale. Moreover, hyperspectral imaging as a non-destructive methodology in determining the quality of spray dried camel milk powders should be considered. In addition, microbial quality determination is vital in safeguarding the keeping quality and safety of camel milk powders.

The use of spray drying to obtain camel milk powder can be an alternative to reduce losses associated with fresh milk with limited accessibility to cooling, and to ensure nutritional security of the people living in arid regions during seasons of scarcity. Future work is needed to determine the feasibility of different scales of camel milk powder production, in terms of operability, availability of resources, and their energy demands. Moreover, availability of high solar insolation in the ASALs could be an alternative to fossil fuels to provide energy for camel milk powder production.

Limitations of the study

The influence of the processing conditions on the chemical composition of the camel milk powder is not presented in the current study. Moreover, experimental optimisation to counter check the numerical optimisation is not undertaken.

Acknowledgement

The first author, Jackline Akinyi Ogolla would wish to acknowledge Katholische Akademische Ausländer-Dienst (KAAD) for her research stay in Germany. This study is part of Global food supply (GlobE) project – RELOAD (FKZ 031A247 A) funded by the German Federal Ministry of Education and Research (BMBF) and the RE4Foods project (EP/L002531/1) funded by the Engineering and Physical Sciences Research Council (EPSRC), United Kingdom. The authors gratefully acknowledge their financial contributions. The authors further wish to thank Dr Helen McKee for proofreading the manuscript.

Conflict of interest

The authors declare that they have no conflict of interest.

References

Abu-Lehia, I. H., Al-Mohizea, I. S., & El-Behry, M. (1989). Studies on the production of ice cream from camel milk productd. *The Australian Journal of Dairy Technology*, *44*, 31–34.

Agrawal, R. P., Jain, S., Shah, S., Chopra, A., & Agarwal, V. (2011). Effect of camel milk on glycemic control and insulin requirement in patients with type 1 diabetes: 2-years randomized controlled trial. *European Journal of Clinical Nutrition*, *65*(10), 1048–1052. https://doi.org/10.1038/ejcn.2011.98

Al-Saadi, J., & Deeth, H. C. (2008). Cross-linking of proteins and other changes in UHT milk during storage at different temperatures. *Australian Journal of Dairy Technology*, *63*(3), 93–99.

Anglea, S. A., Karathanos, V., & Karel, M. (1993). Low-Temperature Transitions in Fresh and Osmotically Dehydrated Plant Materials. *Biotechnology Progress*, *9*(2), 204–209. https://doi.org/10.1021/bp00020a014

Bansal, V., Sharma, H. K., & Nanda, V. (2014). Optimisation of spray drying process parameters for low-fat honey-based milk powder with antioxidant activity. *International Journal of Food Science and Technology*, *49*(4), 1196–1202. https://doi.org/10.1111/ijfs.12416

Barbosa-Cánovas, G. V., Ortega-Rivas, E., Juliano, P., & Yan, H. (2005). *Food Powders: Physical properties, processing, and functionality*. https://doi.org/10.1146/annurev.food.102308.124155

Benkerroum, N., Mekkaoui, M., Bennani, N., & Hidane, K. (2004). Antimicrobial activity of camel's milk against pathogenic strains of Escherichia coli and Listeria monocytogenes. *International Journal of Dairy Technology*, *57*(1), 39–43. https://doi.org/10.1111/j.1471-0307.2004.00127.x

Birchal, V. S., Passos, M. L., Wildhagen, G. R. S., & Mujumdar, A. S. (2005). Effect of Spray-Dryer Operating Variables on the Whole Milk Powder Quality. *Drying Technology*, *23*(3), 611–636. https://doi.org/10.1081/DRT-200054153

Bruns, R. E., Scarminio, I. S., & Barros Neto, B. de. *Statistical design--chemometrics*. , (2006).

Chegini, G., & Taheri, M. (2013). Whey powder: Process technology and physical properties: A review. *Middle East Journal of Scientific Research*, *13*(10), 1377–1387. https://doi.org/10.5829/idosi.mejsr.2013.13.10.1239

Daza, L. D., Fujita, A., Fávaro-Trindade, C. S., Rodrigues-Ract, J. N., Granato, D., & Genovese, M. I. (2016). Effect of spray drying conditions on the physical properties of Cagaita (Eugenia dysenterica DC.) fruit extracts. *Food and Bioproducts Processing*, *97*, 20–29. https://doi.org/10.1016/j.fbp.2015.10.001

Di Renzo, G. C., Altieri, G., & Genovese, F. (2013). Donkey milk powder production and properties compared to other milk powders. *Dairy Science & Technology*, *93*, 551–564. https://doi.org/10.1007/s13594-013-0108-7

El-Agamy, E. I. (2007). The challenge of cow milk protein allergy. *Small Ruminant Research*, *68*(1), 64–72. https://doi.org/10.1016/j.smallrumres.2006.09.016

El-Hadi Sulieman, A. M., Ilayan, A. A., & El-Awad El Faki, A. (2006). Chemical and microbiological quality of Garris, Sudanese fermented camel's milk product. *International Journal of Food Science and Technology*, *41*(3), 321–328. https://doi.org/10.1111/j.1365-2621.2005.01070.x

El Zubeir, I. E. M. E., & Jabreel, S. O. (2008). Fresh cheese from camel milk coagulated with Camifloc. *International Journal of Dairy Technology*, *61*(1), 90–95. https://doi.org/10.1111/j.1471-0307.2008.00360.x

Elagamy, E. I. (2000). Effect of heat treatment on camel milk proteins with respect to antimicrobial factors: a comparison with cows' and buffalo milk proteins. *Food Chemistry*, *68*(2), 227–232. https://doi.org/10.1016/S0308-8146(99)00199-5

Elayan, A. A., Sulieman, A. M. E., & Saleh, F. A. (2008). The hypocholesterolemic effect of Gariss and gariss containing bifidobacteria in rats fed on a Cholesterol-Enriched Diet. *Asian Journal of Biochemistry*, *3*(1), 43–47. https://doi.org/10.3923/ajb.2008.43.47

Farah, Z., Streiff, T., & Bachmann, M. R. (1990). Short Communication: Preparation and consumer acceptability tests of fermented camel milk in Kenya. *Journal of Dairy Research*, *57*(2), 281–283. https://doi.org/10.1017/S002202990002690X

Farah, Zakaria. (1996). Camel Milk: Properties and Products. In *Camel milk properties and products.* zurich, Switzerland,: Swiss Centre for Development Cooperation in Technology and Management.

Farah, Zakaria, Streiff, T., & Bachmann, M. R. M. R. (1989). Manufacture and characterization of camel milk butter. *Milchwissenschaft*, *44*(7), 412–414.

Ferreira, S. L. C. L. C., Bruns, R. E. E., Ferreira, H. S. S., Matos, G. D. D., David, J. M. M., Brandão, G. C. C., … Dos Santos, W. N. L. N. L. (2007). Box-Behnken design: An alternative for the optimization of analytical methods. *Analytica Chimica Acta*, *597*(2), 179–186. https://doi.org/10.1016/j.aca.2007.07.011

Fitzpatrick, J. J., Iqbal, T., Delaney, C., Twomey, T., & Keogh, M. K. (2004). Effect of powder properties and storage conditions on the flowability of milk powders with different fat contents. *Journal of Food Engineering*, *64*(4), 435–444. https://doi.org/10.1016/j.jfoodeng.2003.11.011

Fox, P. F., & Kelly, A. L. (2012). Biochemistry of Milk Processing. In B. K. Simpson, L. M. L. Nollet, F. Toldra, S. Benjakul, G. Paliyath, & Y. H. Hui (Eds.), *Food Biochemistry and Food Processing* (second, pp. 465–472). Iowa: JohnWiley & Sons, Inc.

Fyfe, K., Kravchuk, O., Nguyen, A. V., Deeth, H., & Bhandari, B. (2011). Influence of Dryer Type on Surface Characteristics of Milk Powders. *Drying Technology*, *29*(7), 758–769. https://doi.org/10.1080/07373937.2010.538481

Goula, A. M., & Adamopoulos, K. G. (2008). Effect of Maltodextrin Addition during Spray Drying of Tomato Pulp in Dehumidified Air: II. Powder Properties. *Drying Technology*, *26*(6), 726–737. https://doi.org/10.1080/07373930802046377

Haddadin, M. S., Gammoh, S. I., & Robinson, R. K. (2008). Seasonal variations in the chemical composition of camel milk in Jordan. *Journal of Dairy Research*, *75*(01), 8–12. https://doi.org/10.1017/S0022029907002750

Hashim, I. B., Khalil, A. H., & Habib, H. (2009). Quality and acceptability of a set-type yogurt made from camel milk. *Journal of Dairy Science*, *92*(3), 857–862. https://doi.org/doi.org/10.3168/jds.2008-1408

Hassan, H. M., & Mumford, C. J. (1993). Mechanisms of Drying of Skin-Forming Materials.Iii. Droplets of Natural Products. *Drying Technology*, *11*(7), 1765–1782. https://doi.org/10.1080/07373939308916927

Hu, Z., Cai, M., & Liang, H. H. (2008). Desirability function approach for the optimization of microwave-assisted extraction of saikosaponins from Radix Bupleuri. *Separation and Purification Technology*, *61*(3), 266–275. https://doi.org/10.1016/j.seppur.2007.10.016

Inayat, S., Arain, M. A., Kahaskheli, M., & Malik, A. H. (2003). Study on the effect of processing onthe chemical quality of cheese made from Camel Milk. *Pakistan Journal of Nutrition*, *2*(2), 102–105.

Islam, M. A., Alam, M. R., & Hannan, M. O. (2012). Multiresponse optimization based on statistical response surface methodology and desirability function for the production of particleboard. *Composites Part B*, *43*(3), 861–868. https://doi.org/10.1016/j.compositesb.2011.11.033

Jinapong, N., Suphantharika, M., & Jamnong, P. (2008). Production of instant soymilk powders by ultrafiltration, spray drying and fluidized bed agglomeration. *Journal of Food Engineering*, *84*(2), 194–205. https://doi.org/10.1016/j.jfoodeng.2007.04.032

Khaskheli, M., Arain, M. A., Chaudhry, S., Soomro, A. H., & Qureshi, T. A. (2005). Physico-Chemical Quality of Camel Milk. *Journal of Agriculture & Social Sciences*, *1*(2), 164–166.

Kherouatou, N., Nasri, M., H., A., V., F., J., L., -ITAL, T., … Terra, N. (2003). A Study of the Dromedary Milk Casein Micelle and its Changes during Acidification. *Brazilian Journal of Food Technology*, *6*, 237–244. https://doi.org/10.1051/lait:2000141

Kim, E. H.-J., Chen, X. D., & Pearce, D. (2002). Surface characterization of four industrial spray-dried dairy powders in relation to chemical composition, structure and wetting property. *Colloids and Surfaces B: Biointerfaces*, *26*(3), 197–212. https://doi.org/10.1016/S0927-7765(01)00334-4

Kim, E. H.-J., Chen, X. D., & Pearce, D. (2005). Effect of surface composition on the flowability of industrial spray-dried dairy powders. *Colloids and Surfaces B: Biointerfaces*, *46*(3), 182–187. https://doi.org/10.1016/j.colsurfb.2005.11.005

Kim, E. H.-J., Chen, X. D., & Pearce, D. (2009). Surface composition of industrial spray-dried milk powders. 2. Effects of spray drying conditions on the surface composition. *Journal of Food Engineering*, *94*(2), 169–181. https://doi.org/10.1016/j.jfoodeng.2008.10.020

Koç, B., Sakin-YIlmazer, M., Kaymak-Ertekin, F., & BalkIr, P. (2014). Physical properties of yoghurt powder produced by spray drying. *Journal of Food Science and Technology*, *51*(7), 1377–1383. https://doi.org/10.1007/s13197-012-0653-8

Konuspayeva, G., Faye, B., & Loiseau, G. (2009). The composition of camel milk: A meta-analysis of the literature data. *Journal of Food Composition and Analysis*, *22*(2), 95–101. https://doi.org/10.1016/j.jfca.2008.09.008

Kurozawa, L. E., Park, K. J., & Hubinger, M. D. (2009). Effect of carrier agents on the physicochemical properties of a spray dried chicken meat protein hydrolysate. *Journal of Food Engineering*, *94*(3–4), 326–333. https://doi.org/10.1016/j.jfoodeng.2009.03.025

Laleye, L. C., Jobe, B., & Wasesa, A. A. H. (2008). Comparative study on heat stability and functionality of camel and bovine milk whey proteins. *Journal of Dairy Science*, *91*(12), 4527–4534. https://doi.org/10.3168/jds.2008-1446

Mehaia, M. A. (2006). Manufacture of fresh soft white cheese (Domiati type) from dromedary camel's milk using ultrafiltration process. *Journal of Food Technology*, *4*(3), 206–212.

Mujumdar, A. S., Huang, L.-X., & Chen, X. D. (2010). An overview of the recent advances in spray-drying. *Dairy Science &Technology*, *90*(2–3), 211–224. https://doi.org/10.1051/dst/2010015

Nijdam, J. J., & Langrish, T. A. G. (2005). An Investigation of Milk Powders Produced by a Laboratory-Scale Spray Dryer. *Drying Technology*, *23*(5), 1043–1056. https://doi.org/10.1081/DRT-200060208

Nijdam, J. J., & Langrish, T. A. G. (2006). The effect of surface composition on the functional properties of milk powders. *Journal of Food Engineering*, *77*(4), 919–925. https://doi.org/10.1016/j.jfoodeng.2005.08.020

Nollet, L. M., Toldrá, F., & Group, F. (2010). *Sensory Analysis of Foods of Animal Origin*. https://doi.org/10.1201/b10822

Ogolla, J. A., Dede, C., Okoth, M. W., Hensel, O., & Sturm, B. (2017). Strategies and Technologies for Camel Milk Preservation and Utilization of Non-Marketed Milk in Arid and Semi-Arid Areas. *East African Agricultural and Forestry Journal*. https://doi.org/10.1080/00128325.2017.1363686

Oldfield, D., & Singh, H. (2005). Functional Properties of Milk Powders. In *Food Science and Technology* (p. 146:365). New York-Marcel Dekker.

Pisecky, J. (2012). Handbook of milk powder manufacture. In V. Westergaard & E. Refstrup (Eds.), *GEA Process Engineering A/S (GEA Niro)* (Second Edi). https://doi.org/10.1007/978-1-908517-43-2

Quana, S., Tsuda, H., & Miyamoto, T. (2008). Angiotensin I-converting enzyme inhibitory peptides in skim milk fermented with Lactobacillus helveticus 130B4 from camel milk in Inner Mongolia, China. *Journal of the Science of Food and Agriculture*, *88*(15), 2688–2692. https://doi.org/10.1002/jsfa.3394

Rahman, M. S. (2006). State diagram of foods: Its potential use in food processing and product stability. *Trends in Food Science & Technology 17*, *17*, 129–141. https://doi.org/10.1016/j.tifs.2005.09.009

Rahman, M. S. (2009). Food Stability Beyond Water Activity and Glass Transtion: Macro-Micro Region Concept in the State Diagram. *International Journal of Food Properties*, *12*(4), 726–740. https://doi.org/Doi 10.1080/10942910802628107

Rahman, M. S., Al-Hakmani, H., Al-Alawi, A., & Al-Marhubi, I. (2012). Thermal characteristics of freeze-dried camel milk and its major components. *Thermochimica Acta*, *549*, 116–123. https://doi.org/10.1016/j.tca.2012.09.005

Reddy, R. S., Ramachandra, C. T., Hiregoudar, S., Nidoni, U., Ram, J., & Kammar, M. (2014). Influence of processing conditions on functional and reconstitution properties of milk powder made from Osmanabadi goat milk by spray drying. *Small Ruminant Research*, *119*(1–3), 130–137. https://doi.org/10.1016/j.smallrumres.2014.01.013

Roos, Y. H. (2010). Glass Transition Temperature and Its Relevance in Food Processing. *Annual Review of Food Science and Technology - (New in 2010)*, *1*(1), 469–496. https://doi.org/10.1146/annurev.food.102308.124139

Rüegg, M., & Farah, Z. (1991). Melting curves of camel milk fat. *Milchwissenschaft - Milk Science International*, *46*(5), 361–362.

Santhalakshmy, S., Don Bosco, S. J., Francis, S., & Sabeena, M. (2015). Effect of inlet temperature on physicochemical properties of spray-dried jamun fruit juice powder. *Powder Technology*, *274*, 37–

43. https://doi.org/10.1016/j.powtec.2015.01.016

Schuck, P. (2011). Dehydrated Dairy Products | Milk Powder: Physical and Functional Properties of Milk Powders. In *Encyclopedia of Dairy Sciences* (pp. 117–124). https://doi.org/10.1016/B978-0-12-374407-4.00122-9

Schuck, P., Dolivet, D., & Jeantet, R. (2012). *Analytical Methods for Food and Dairy Powder*. https://doi.org/10.1017/CBO9781107415324.004

Sharma, A., Jana, A. H., & Chavan, R. S. (2012). Functionality of Milk Powders and Milk-Based Powders for End Use Applications-A Review. *Comprehensive Reviews in Food Science and Food Safety*, *11*(5), 518–528. https://doi.org/10.1111/j.1541-4337.2012.00199.x

Singh, M. B., Fotedar, R., & Lakshminarayana, J. (2008). Camel Milk Consumption Pattern and Its Association with Diabetes among Raika Community of Jodhpur District of Rajasthan. *Ethno-Medicine*, *2*(2), 103–105.

Sturm, B., Hofacker, W., & Hensel, O. (2012). Optimizing the drying parameters for hot air dried apples. *Drying Technology*, *30*, 1570–1582. https://doi.org/10.1080/07373937.2012.698439

Sulieman, A. M. E., Elamin, O. M., Elkhalifa, E. A., & Laleye, L. (2014). Comparison of Physicochemical Properties of Spray-dried Camel’s Milk and Cow’s Milk Powder. *International Journal of Food Science and Nutrition Engineering*, *4*(1), 15–19. https://doi.org/10.5923/j.food.20140401.03

Tamine, A. Y. (2009). *Dairy Powders and Concentrated Products*. Ayr, UK: A John Wiley & Sons, Ltd.

Tonon, R. V., Brabet, C., & Hubinger, M. D. (2008). Influence of process conditions on the physicochemical properties of acai (Euterpe oleraceae Mart.) powder produced by spray drying. *Journal of Food Engineering*, *88*(3), 411–418. https://doi.org/10.1016/j.jfoodeng.2008.02.029

Tuohy, J. (1989). Some physical properties of milk powders. *Irish Journal of Food Science and Technology*, *13*(2), 141–152.

Walstra, P., Wouters, J. T. M., & Geurts, T. J. (2006). Dairy Science and Technology. In *Facilities* (Vol. 4). https://doi.org/9780824727635

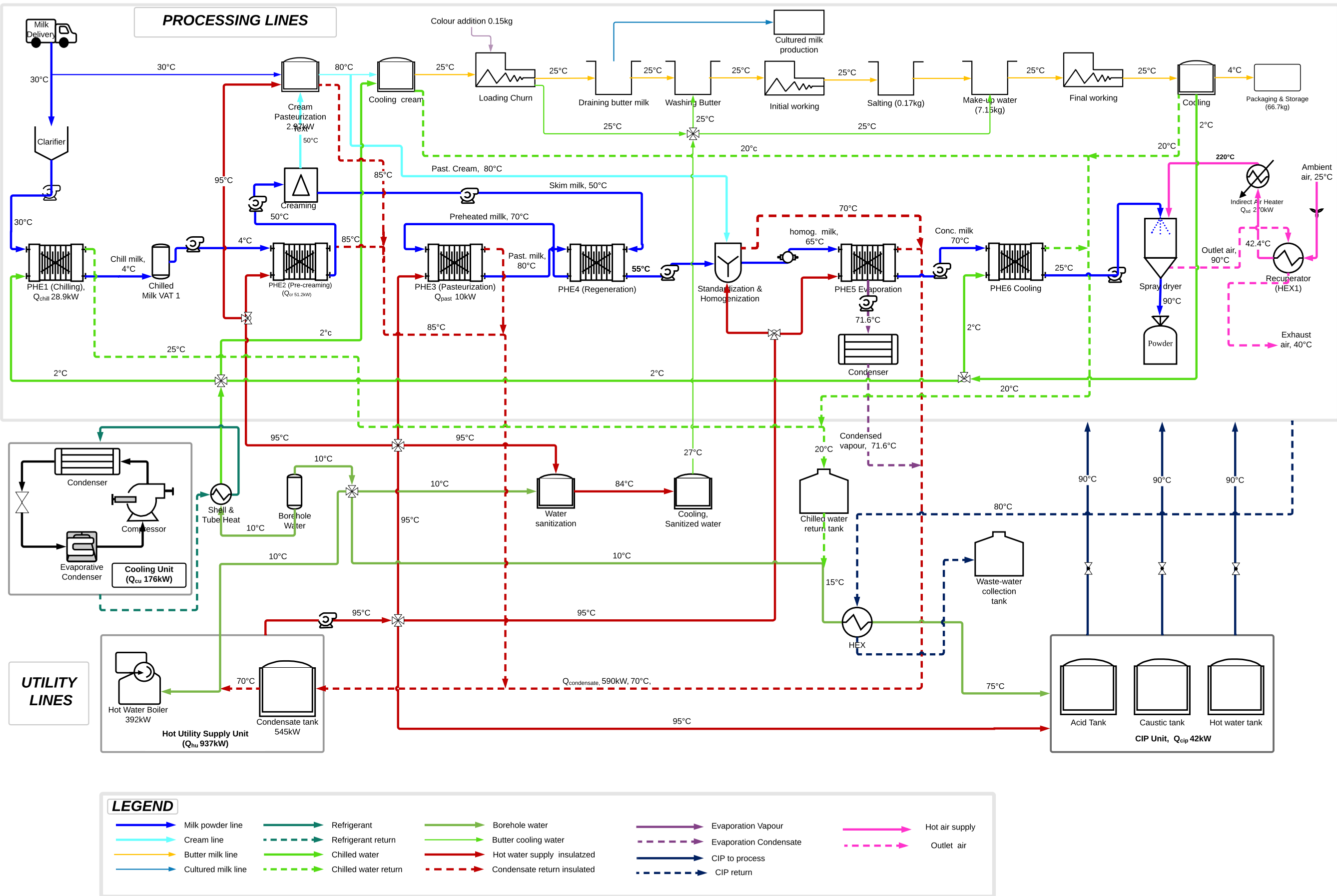
Westergaard, V. (2004). *Milk Powder Technology Evaporation and Spray Drying GEA Process Engineering engineering for a better world Preface to Fifth Edition*.

Yagil, R., Saran, A., & Etzion, Z. (1984). Camels’ milk: For drinking only? *Comparative Biochemistry and Physiology -- Part A: Physiology*, *78*(2), 263–266. https://doi.org/10.1016/0300-9629(84)90143-9

Yolmeh, M., Habibi Najafi, M. B., & Farhoosh, R. (2014). Optimisation of ultrasound-assisted extraction of natural pigment from annatto seeds by response surface methodology (RSM). *Food Chemistry*, *155*, 319–324. https://doi.org/10.1016/j.foodchem.2014.01.059

Zbikowska, A., & Zbikowski, Z. (2006). Stability of milk concentrates in hot coffee. *Polish Journal of Food and Nutrition Sciences*, *15/56*(S1), 253–258.

6.0 Development and Techno-economic feasibility analysis of a novel solar-powered process design for camel milk powder and butter processing plant for the ASALs



Abstract

Kenya's camel milk industry contributes significantly to the economic and nutritional needs of the populations in the Arid and Semi-arid Lands (ASALS). The production and consumption are limited to the ASALs populations due to the inadequacy of preservation technologies. Processing of the liquid milk into milk powder can increase its shelf life to up to 18 months as it is less susceptible to microbial growth. Therefore, in this study we assesed small scale industrial production potential of camel milk powder and use of the excess cream for butter production. Additionally, the technical and economic feasibility of a decentralized small scale hybrid solar-fuel oil production plant were analysed.

Using PinCH analysis, the developed process design was optimised, and heat recovery undertaken before solar integration following the IEA SHC Task 49 Guidelines. Solar simulation for both solar thermal and PV were undertaken using System Advisor Model (SAM), and the performance and financial parameters used to determine the feasibility of the integrations. For economic analysis, the modular method for capital estimation was used in capital cost determination and profitability of the enterprises was determined by the Net Present Value (NPV), payback period and discounted cash-flow rate of return (DCFROR) .Sensitivity analysis was done to assess how NPV is influenced by variations in selected parameters.

The findings indicated that for a processing plant running 200 days per annum with a daily powder and butter production of circa 350 and 70 kg respectively, the annual heating and electrical energy demands after heat recovery were 645 and 235 MWh respectively. Heat recovery resulted in 41.33% savings of thermal energy. To minimize the use of fossil fuels and electricity from the grid, solar heat and solar electricity integration were assessed, which resulted in annual thermal and electrical energy savings from fossil fuels of 293 and 165 MWh respectively. This in turn mitigated 332.37 tonnes of CO_{2e} per annum and annual financial savings of about €98,479. On economic analysis, with a class life of 15 years for the equipment, the capital and manufacturing costs were €18.23 million and an NPV of €19.40 million. The payment back period of 5 years and DCFROR of 58.0%. A 20% variation in revenue, resulted in a variation of 41.04% in NPV, thus signifying revenue had the highest impact on NPV.

In conclusion, this study has provided a holistic approach in process design for a novel decentralised small-scale hybrid solar fuel-oil and grid electricity industrial process design for milk and butter processing plant in the ASALs. It is highly encouraged that these results be utilized and applied to real world projects that intend to reduce industrial fossil fuel consumption and CO_2 emissions.

Key Words: Camel milk powder, camel milk butter, process design, PinCh analysis, solar integration, economic analysis.

6.1. Introduction

Approximately 43% of the land in Arid and Semi- arid Lands (ASALs) in Africa is used for livestock production (Koohafkan and Stewart 2008). The dairy sector comprising bovine, camel and goats is the largest agricultural subsector in Kenya, and its share in Growth Domestic Product (GDP) is circa 4% (KNBS 2018). Kenya's camel milk industry contributes to the economic and nutritional needs of the populations in the ASALs. The milk production and consumption are limited to the arid and semi-arid populations due to the inadequacy of preservation technologies (Ogolla et al., 2017). The existing preservation technologies can only preserve milk for a short duration of time, and the residents expressed the desire to have preservation technologies that could ensure the milk is kept for a longer duration and can also be available during the dry seasons (Ogolla et al. 2017). Based on this, Ogolla et al. (2019), carried out laboratory tests on spray drying of camel milk powder, to determine the optimal physical, thermal and optical properties of the dried powder. Milk powder can be kept for more than 18 months due to its low susceptiblility to microbial growth (Pisecky 2012). Industrial production of milk powder can be an alternative for the existing preservation technologies as described by Ogolla et al. (2017).

Industrial milk powder production, compared to fluid milk processing, is an energy-intensive process, entailing two processing stages, initially moisture content of the milk is reduced by evaporation followed by powder production through spray drying (Pisecky 2012). The established levels of specific thermal energy consumption for fluid milk processing are 0.47 GJ/m^3, 0.61 GJ/m^3, and 1.1 GJ/m^3 while for milk powder production were found to be, 1.32 GJ/m^3; 1.06 GJ/m^3 and 1.37 GJ/m^3 in Australia, Canada and Netherlands respectively (Prasad et al. 2004; Ramírez, Patel, and Blok 2006). It has been reported that milk drying, concentration, pre-heating treatment and packing account for 51 %, 45 %, 2.5 % and 1.5 % respectively of the total energy demand within the process. Moreover, the evaporation and drying stages account for 75 % and cleaning in place (CIP) approximately 25 % of the total energy demand used in milk powder production (Ramírez, Patel, and Blok 2006). In this regard, various studies have proposed a reduction of energy consumption in the dairy processing industry and recommended appropriate measures for achieving this objective.

Energy efficiency is critical not only in reducing costs but also in reducing CO_2 emissions and in reduction of the quantity of energy used per mass or volume of manufactured product (Meyers et al. 2016). Several authors have presented different approaches, however, optimal heat recovery through process integration using PinCH analysis has been reported to be the most practical in reducing energy demands in industrial processes (Kemp 2007a). PinCH analysis has been successfully applied in processes operating at low and medium temperatures in the dairy industry (Atkins, Walmsley, and Morrison 2010; Quijera, Alriols, and Labidi 2011).

In developing an optimized system, energy efficiency has to be critically considered by ensuring that heat recovery is put in place (Meyers et al. 2016). The energy savings and use in fluid milk processing such as production of cheese, pasteurized milk and cream across the globe have been characterized by a number of researchers (Xu and Flapper 2011, 2009; Ramírez, Patel, and Blok 2006; Xu, Flapper, and Kramer 2009). The utilization of emerging technologies such as radio frequency heating, membrane distillation, mono-disperse-droplet drying and air dehumidification by zeolites, and membrane contactor in skim milk powder production reviewed and an estimated savings in operational energy consumption of 60 % was realized (Moejes and van Boxtel 2017). Energy recovery in milk powder manufacture through spray dryer exhaust air heat recovery has been documented (Atkins, Walmsley, and Neale 2011). An innovative ultra-low energy milk powder plant design was presented by Walmsley et al. (2016). The authors estimated a reduction of 51.5 %, 19.0 %, and 48.6 % in thermal energy, electricity and emissions respectively in comparison to a modern milk powder plant through a total site heat integration, process and utility model approach.

Most industrial food processing industries are suited to renewable energy systems (RES) integration, particularly solar integration as they operate at temperatures below 100 °C (Kulkarni, Kedare, and Bandyopadhyay 2008; Sturm et al. 2015; Mekhilef, Saidur, and Safari 2011). However, the feasibility of RES integration depends on the company characteristics such as the size, geographical location, thermal load, country energy mix, governmental programmes and thermal load profile (Sturm 2018). A number of authors have proposed different approaches for integration of solar themal energy in industries after process optimization (Krummenacher and Muster 2015; Schmitt 2014; Sturm et al. 2015; Kulkarni, Kedare, and Bandyopadhyay 2008; Eiholzer et al. 2017). Integration of solar energy at industrial level can be undertaken both at supply level (total site analysis) and at process level (unit operation (UO)) (Schmitt 2014). In the milk industry, most studies have focused on solar integration at low temperature process level such as pasteurization and the CIP water (Anderson and Duke 2008; Quijera, Alriols, and Labidi 2011). The potential of solar collector incorporation in the provision of thermal energy in processing of milk and milk products, and the consequent reduction of greenhouse gas emissions (GHGs) has been presented in India by Sharma et al. (2017) and in Australia by Walmsley et al. (2016). The viability of solar thermal system integration for low (60-90°C) and medium temperature (90-160°C) processes in a dairy plant in Spain using mathematical modelling and PinCH analysis was evaluated (Quijera, Alriols, and Labidi 2011). The incorporation of solar heat into food processing is limited by the high solar capital installation costs (Quijera, Alriols, and Labidi 2011). Although a number of studies have indicated the potential for using solar concentrating collectors for high temperature applications there has been limited information on the applicability in the food industry (Plaza et al. 2015).

The design of heat supply systems in industry is principally determined by the fuel type used and the heat transfer fluid (HTF). In global south countries such as Kenya that have limited deposits of Liquified petroleum gas (LPG), natural gas, coal or oil, biomass is the primary energy source for heat supply systems. Milk processing plants in Kenya depend mainly on biomass feedstock such as wood fuel and agricultural residues as main sources of fuel. In addition, due to seasonal availability of biomass the same plants also use fossil fuels, mainly furnace oil. Explain cost and availability as it is limited. While few industrial processes are heated electrically, industrial cooling processes are powered mainly through electrical supply (Hassine et al. 2015). During periods of drought the quantity of electricity generated in the hydropower plants decreases which in turn leads to lower supply with constant demands and consequentially higher electricity prices (KPLC 2018; KAM 2018). However, during these seasons, Kenya receives higher solar irradiation, thus, providing a better potential for utilization of solar energy in the generation of electricity and also for provision of industrial process heat. The exemption from Value Added Tax (VAT) to solar cells, modules, photovolataic (PV) semiconductor devices and solar water heating (SWH) systems by the Kenyan government (KCIC 2018) coupled with the high solar irradiance in these regions provide an alternative energy source for an ASAL camel milk powder and butter processing plant (Ministry of Energy and Petroleum 2015). Further zero rating the import duties on solar energy equipment and their accessories and tax exemption on interest paid on loans from foreign sources for investing in solar sector (DLA Piper 2019).

Techno-economic feasibility is vital in determining the possibility for self-financing or for applying for a bank loan (Saravacos and Kostaropoulos 2012). It is important to ensure that the margin between value added products produced and the raw material, cover the overhead costs while at the same time they can meet the loan repayment within the stipulated time period. In locating a dairy plant, it is imperative to maximize profit, while minimizing losses, thus the location, energy, water supply, milk availability, market analysis, technical staff and the cost of raw milk are fundamental considerations (Pisecky, 2012). Further, to undertake an economic analysis of a process, use of process flow diagrams (PFD), analytical tables of materials, labour and energy requirements at each stage is essential (Turton et al. 2018).

This paper therefore, aims to develop a novel decentralized small-scale hybrid solar-fossil fuel-powered process design for a camel milk powder and butter processing plant for the ASALs. This is to design an optimised processing line that limits the utilisation of fossil fuels while optimising the utilisation of water and energy before incorporating renewable energy. Moreover, economic and technical feasibility that is critical for the ASALs with high camel milk production and limited in knowledge and resources in establishing the processing industries are analyzed.

In the first instance, we present an existing camel milk bulking center; then we describe a typical milk powder and butter processing plant design. Based on the process flow designs, we present the energy consumption, then the process optimisation using PinCH, further energy reduction based on economiser introduction in the boiler followed by heat recovery through a condensate recovery tank, and finally, integration of solar thermal and solar PV. Before concluding, we present the technical and economic feasibility analysis. This work is a culmination and extension of work previously published by the authors over recent years (Ogolla et al. 2017; Ogolla et al. 2019).

6.2 Methodology

6.2.1 Study site and Description

6.2.1.1 Geographical description of the study site (Isiolo County Climate)

Isiolo County lies in the drylands of Northern Kenya at a latitude of 0° 21’0 °N and a longitude of 37° 35’ 0 °E. With an area of approximately 25,940 km², the county has flat low lying plain rising gradually from an altitude of about 200 m (Lorian swamp (Habaswein) to approximately 300 m (Merti Plateau) above sea level (KNBS 2019a). The county experiences an annual mean temperature of 23.3 °C and bimodal rainfall with an annual average of 580.2 mm with the wettest months in November (143 mm) and April (149 mm). Administratively, the county is divided into three sub-counties: Isiolo Central, Garba Tula and Merti. Ecologically, the area is divided into three zones: the semi-arid (5%), arid (30%) and very arid zones (65%), characterised by variability in rainfall and vegetation types (Republic of Kenya 2018). The literacy level in the county is quite low with only 15% of the community being able to read and write. Thus, influencing the type of technology that has to be developed (Republic of Kenya 2018). Figure 6.1 indicates the proposed camel milk and butter processing plant location and camel distribution in the region.

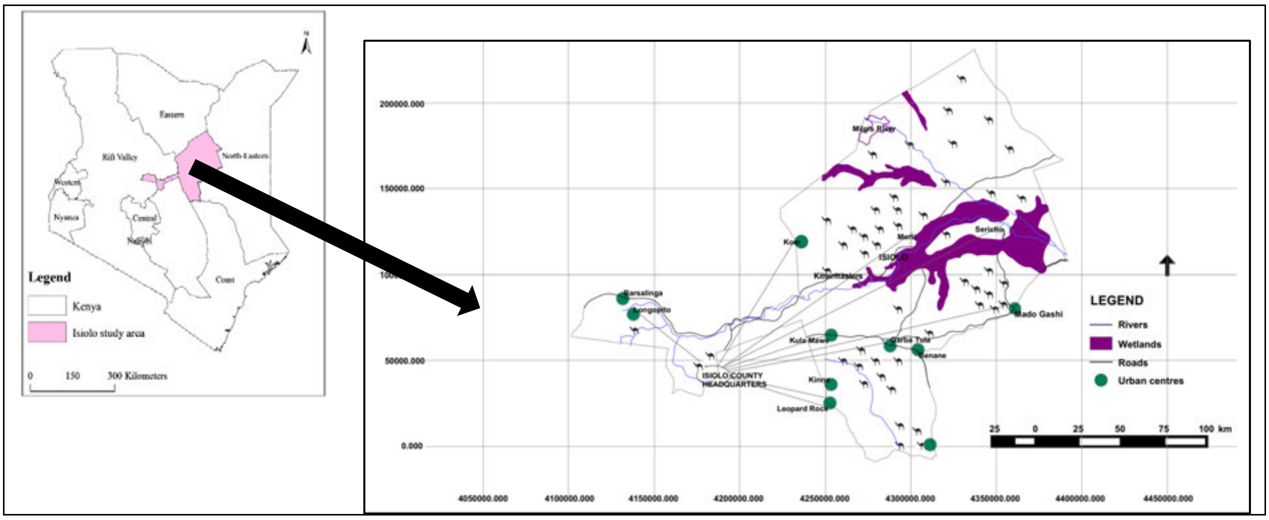


Figure 6. 1 Proposed camel milk and butter processing location and camel distribution in Isiolo County (Author’s own)

6.2.1.2 Livelihood

Due to the erratic rainfall experienced in the area, which limits crop production, livestock production is the backbone of the county's economy with over 80% of the population relying on it for livelihood (KNBS 2019b). Livestock production is characterised by pastoral systems that comprise sedentary, migratory and transhumant. However, most of the inhabitants are migratory and transhumant, and these have contributed to environmental degradation due to overgrazing caused by overstocking. The Borana and Somali pastoralists living in Isiolo predominantly keep a mix of livestock species with an estimated population of 40,300 camels (Stoker 2000; KNBS 2019a). Camels are predominantly kept for milk production both for household consumptions and commercial purposes (Noor et al., 2012). However, there are no value addition agro-based industries, therefore, contributing to the high food poverty index of 77% resulting in dependence on relief food which is further enhanced by the less farm produce harvested (FAO 2018).

6.2.1.3 Water resources

Poor accessibility to water resources characterizes the county with an average distance of 3 km to the nearest water sources for most households. About 6% and 35% of the households in the county have access to piped and potable water respectively. Although 59% of the residents use improved water sources, only 7% have access to clean and safe water within 5 km reach. Further 58% of the total water in the county is saline, limiting the water available for human usage. The four significant sources of water supply in Isiolo county are natural water sources (rivers, streams and springs); developed surface water (earth dams, sand/subsurface dams, tanks and pans); developed groundwater (wells, shallow wells, boreholes); and emergency water supply (government tankers) (Republic of Kenya 2018).

6.2.1.4 Energy resources

The primary energy source in the county is wood fuel with roughly 70 % of the households dependent on it (KNBS 2018). This has led to land degradation due to depletion of forests for charcoal production. Only 2,500 of the 31,326 households and 15 % of trading centers, with a few schools and health facilities, are connected to electricity (Republic of Kenya 2018). On average, the county experiences nine hours of sunshine per day and strong winds year round with a peak in July and August. This, therefore, depicts a vast potential for both solar and wind energy.

6.2.2 General Methodological approach description

The methodology utilised in this study is a combination of methodologies proposed by Quijera and Labidi (2013), presented by the IEA SHC Task 49 Guidelines (Krummenacher and Muster 2015) and the solar thermal integration methodology by Schmitt, (2014). Initially, the processing lines are designed, the processes characterized and optimized, the thermo-solar and solar electrical feasibility in the optimised process analysed and solar thermal and PV integrated. The analytical tools included: mass and energy balance; PinCH analysis, heat recovery estimation, simulation of solar thermal and PV by System analysis model (SAM); analysis of environmental variables and analysis of economic feasibility.

The energy consumption for the milk powder and butter production was estimated by considering each unit operation involved as proposed by Sanjuan, Stoessel, and Hellweg (2014). An initial brief description of the process unit is followed by theoretical calculation of the amount of thermal energy and electrical power requirements. A reference amount of 3,135 kg/day camel milk is used in the computation of the energy consumption of the milk powder and butter processing plant. This amount was based on our initial fieldwork study (Ogolla et al. 2017). The proposed milk powder and butter plant is expected to run for five days per week and 40 weeks annually excluding the seasons of low milk production. Table 6.1 summarizes the characteristics of the raw and standardized camel milk feed used in the process.

Table 6. 1 Feed characteristics of the raw and standardised camel milk

Raw camel milk composition		Standardised camel milk composition	
Parameters	**Percentage**	**Parameters**	**Percentage**
Moisture	87.3%	Moisture	88.5%
Fat	4.3%	Fat	3.5%
Protein	3.2%	Protein	3.0%
Lactose	4.3%	Lactose	4.1%
Ash	0.9%	Ash	0.9%
Specific gravity	1.03	Specific gravity	1.03
Density (kgm^{-3})	1026-1035	Density (kgm^{-3})	1026-1035
Specific heat capacity		Specific heat capacity	

Source: Faye et al. 2008 (raw camel milk) and authors' calculations (standardised milk)

The feed physicochemical characteristics, processing aids (such as air, hot water, and steam) and the processing parameters (time, the process energy demand) were estimated based on the standards proposed by GEA NIRO and findings by earlier works of the author (Ogolla et al. 2019; Pisecky 2012). The final moisture content of the milk powder was assumed to be about 3.0%, based on experimental data obtained by the authors and international standards on milk powder specifications (Ogolla et al., 2019; Westergaard, 2011).

6.2.3 Milk powder and butter processing

6.2.3.1 Current situation

From fieldwork data obtained, the cooling plant receives 2500 and 3500 litres of milk per day during the dry and wet seasons respectively. The currently available chiller has a capacity of 3000 litres, no value addition, and the excess milk during high seasons is sold at prices 34 % lower than during the seasons of scarcity (Ogolla et al. 2017). Chilling is dependent on on-grid electricity and in cases of power failure a diesel-powered generator is utilized.

6.2.3.2 Typical milk powder and butter processing

Ogolla et al. (2017) documented the absence of a milk powder processing plant, thus, a typical process for whole milk powder processing is presented in figure 6,2a (Pisecky 2012). To limit the losses amassed during the processing such as excess cream, butter is processed. Due to the nature of casein micelles in camel milk which differs from that of bovine milk, the butter processing operations adopted in this study (Fig 6.2b) is modified from that proposed by Farah, Streiff, and Bachmann (1989) accordingly.

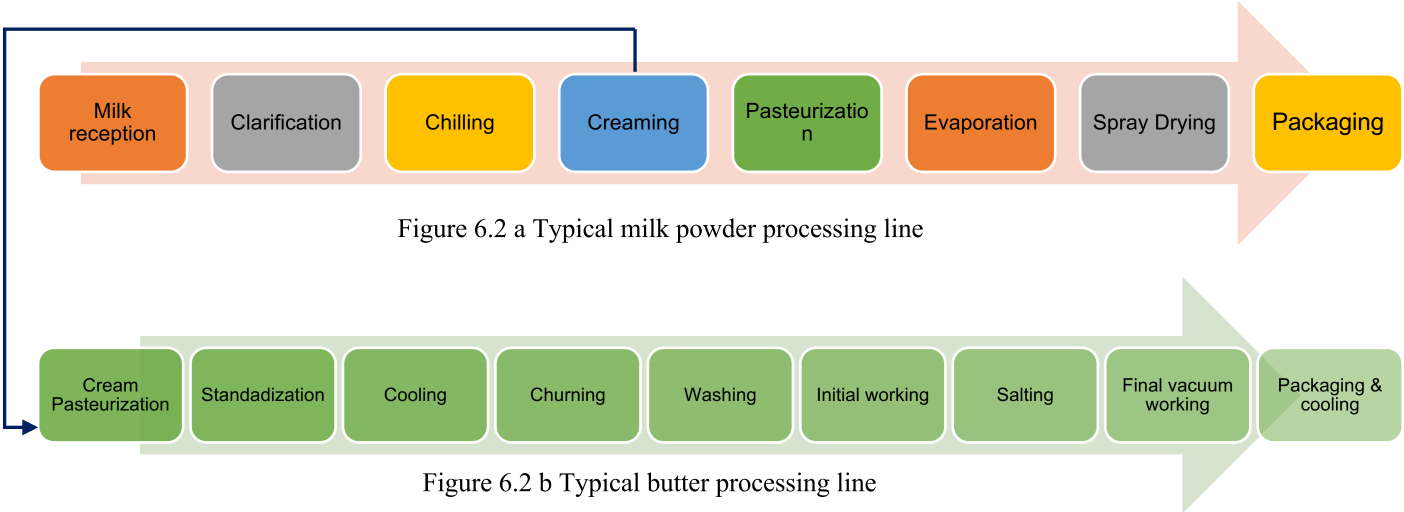


Figure 6.2 a Typical milk powder processing line

Figure 6.2 b Typical butter processing line

Figure 6. 2 Typical milk powder and butter processing lines

6.2.4 Energy, electrical and water consumption (Utilities)

A detailed heat and mass balance, process and utility models for a camel milk processing plant of 118 kg/h of milk powder and 66 kg/h of butter production was developed in an Excel^{TM} spread sheet. This model was developed based on the heat and electrical energy demand of an industrial milk powder plant design and validated against data from an existing Kenyan milk processing plant. The equations below were used to estimate the energy demands along the milk and butter processing lines:

The specific heat capacity c_p, of milk and water in kJ/kg K was estimated by equation (Eq.) 6.1.

$$c_p = \sum c_{p,i} \times x_i \qquad \text{Eq. 6.1}$$

where $c_{p,i}$ is the specific heat of the individual components and x_i is the mass fraction.

The heating and cooling demands in kW of the different streams $\dot{Q}_{h/c}$ was calculated based on equation 6.2:

$$Q_{h/c} = \dot{m}_s \times c_{p,s} \times \Delta T \qquad \text{Eq. 6.2}$$

where $\dot{m}_s$ is the mass flow rate in kg/s, ΔT is the difference between inlet and target temperature in °C.

The latent vaporising/condensing of streams in evaporation and spray drying unit was estimated by equation 6.3:

$$Q_{hv/cv} = \dot{m}_s \times h_{vap/cond,s.}$$ Eq. 6.3

where $h_{vap/cond,s}$ *is the enthalpy change in evaporation/condensation of stream s (kJ/kg water evaporated/condensed) and* m_s *is the rate of evaporation/condensation of water (kg/s).*

The thermal heating or cooling energy in kWh is thus estimated by equation 6.4.

$$Q_{h/c} = Q_{h/c} \times t_{s.}$$ Eq. 6.4

where t_s *is the time in hours per individual stream.*

Assumptions

- The total energy utilised in the drying of milk at 220 °C in the spray dryer was estimated based on modifications of the methodology proposed by Langrish (2009) to account for the losses as the thermal efficiency of spray dryer is often 50% (Masters 1994).
- To estimate the thermal energy required in evaporation, the absolute humidity of the inlet and outlet air at a relative humidity of 53%, ambient temperature of 25 °C was determined using psychometric charts. Similarly, the wet bulb temperature, enthalpies of air at ambient, inlet and exit of the dryer were determined using psychrometric charts were determined.
- The mass flow rate of water, and the temperatures of the cleaning water were determined following the rule, *'Cleaning with alkaline detergent should be done at the same temperature as the product has been exposed to, but at least 70 °C'* (Berk 2013; Singh and Heldman 2014).
- Based on the heat distribution medium which in our case for low process temperatures (less than 100°C) is hot water, a hot water boiler was selected. For higher temperatures for the spray drying process, a hot air fuel burner with indirect air heating was selected.
- The cooling unit comprises a refrigeration system that provides the chilling water for the cooling demands of the entire system.

6.2.5 Process Integration Analysis

Before solar thermal integration into a system can be realised, process energy efficiency has first to be established and optimized (Krummenacher and Muster 2015). PinCH analysis has been documented to be the most practical in reducing energy consumption in industrial processes (Kemp 2007a; Muster-Slawitsch, Brunner, and Fluch 2014). Therefore, in this study using the PinCH 3.0 software for batch processes developed by the University of Lucerne the possibilities for direct (DHR) and indirect (IDHR) heat recovery options were assesed (HSLU 2012).

6.2.6 Solar integration analysis

In the third part of our study, the integration of solar heat and cooling was explored after process optimization. In the evaluation of the solar thermal integration potential, the energy demands, and the temperatures were evaluated (Hassine et al. 2015). For solar PV, hourly electrical energy demands were assessed and used in sizing the system. Since this is a new application and solar collectors operate optimally at lower temperatures, the process was designed in such a way that the solar energy supplied to the process was optimized at delivery (Duffie and Beckman 2013).

6.2.6.1 Solar radiation of Isiolo County

Solar radiation data for the Isiolo County were obtained from the NASA Surface Meteorology and Solar Energy Database (NASA, 2018). Information used comprised of 22-year direct normal radiation (DNR), diffuse radiation (DR), and solar radiation clearness index (CI). The 22-year DNR, DR, and CI are illustrated in figure 6.3. Daily DNR ranged from 5.04 in November to 7.21 kWh/m^2 in September with an annual average of 6.28 kWh/m^2 while the DR ranged from 1.66 in July to 2.03 kWh/m^2 in November with a yearly average of 1.83 kWh/m^2. The CI ranges from 0.53 in November to 0.66 in September with an annual average value of 0.6. The most important characteristic of the solar irradiation in this region is that beam radiation is higher than diffuse radiation. The type of solar irradiation influences the type of solar technology utilised in the processing of the milk powder in the region. After determination of daily heat flow by each processing unit in the processing of milk powder and with the determination of the daily average of the solar radiation received on a horizontal surface, it is possible to correlate the solar demand and the solar irradiation at the same time. The higher the overlap between energy requirements and the total irradiance, the better the convergence between provision and demand. The energy used in milk powder processing entails both electrical and thermal energy with the temperatures of cooling water ranging from 4 °C to 10 °C while heat demand in the line of production is for temperatures from 25 °C to 220 °C.

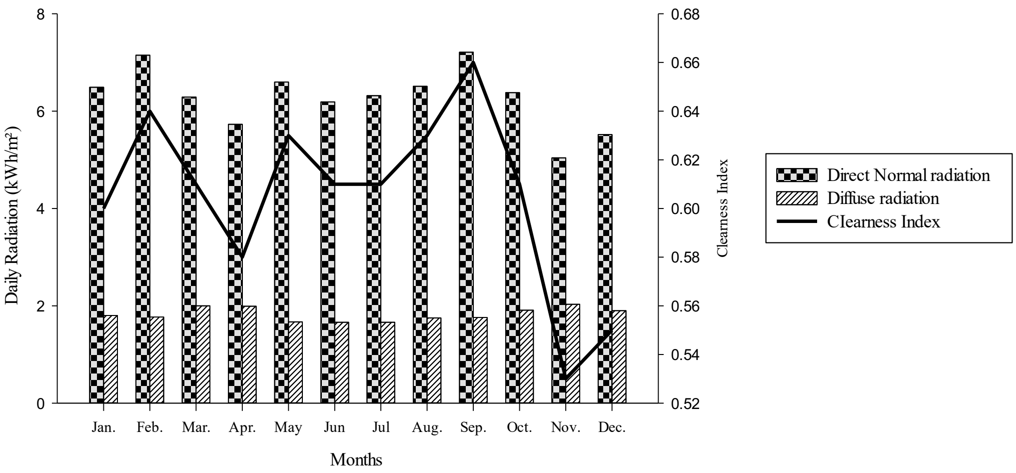


Figure 6. 3 Monthly Solar irradiation for Isiolo County

6.2.6.2: Solar PV & Heat integration

a. *System Advisor Model (SAM) simulation*

Solar PV and solar heat simulations were undertaken using SAM. SAM, a software package developed by National Renewable Energy Laboratory (NREL) is a performance and financial model designed to facilitate decision making in the renewable energy industry (Blair et al. 2018). By using hour to hour calculations, SAM models different systems such as concentrating solar power (CSP), solar water heating (SWH), geothermal power, wind power, biomass combustion and photovoltaic (PV) systems. The weather and solar intensity data used in SAM are from ground measurements, satellite, or a combination of both. SAM provides a graphical user interface (GUI) along with a unique built-in scripting language (called "LK") based on C++ to run simulation. SAM software is free of charge and has been actively developed and updated for several years, since 2005 and in this study we employ SAM version 2018.11.11 (Blair et al. 2018).

b. Simulation of Solar PV using the Detailed Photovoltaic Model in SAM

The detailed PV performance model option in SAM was used to determine the electrical loads that could be met by solar PV. The selection of the types of solar PV panels and inverters for electrical and mechanical demands in this study was limited to what is locally available in the Kenya market based on information from the Energy and Petroleum Regulatory Authority (EPRA) (ERC 2018). The Solar PV module selected was SunPower SPR-X22-370-D-AC and the inverter was Yaskawa Solectria Solar PVI 15 kW-208 (208 V) (2018) from the SAM detailed PV library. The characteristics and costs of the PV module and the inverter are given in table 6.2. The PV system is composed of four inverters and 200 modules resulting in a total module area of 326 m^2 and land area of 0.3 acres

Table 6. 2 PV Modules, array and inverter specifications (Solar4Ever 2019).

SunPower SPR-X22-370-D-AC module		**Yaskawa Solectria Solar PVI 15kW-208 inverter**	
PV Module/ array	**Specification**	**Inverter**	**Specification**
Manufacturer	SunPower	Manufacturer	Yaskawa
Type	Mono-crystalline silicon	Input	
Module efficiency(η_{pv})	22.71%	Maximum dc power	15805.8 W_{dc}
Maximum power (P_{mp})	370.116 W_{dc}	Maximum dc voltage	380 V_{dc}
Maximum power voltage (V_{pm})	59.6 V_{dc}	PV-voltage range and MPPT	225-380 V
Maximum power current (I_{pm})	6.2 A_{dc}	Maximum dc current	58.54 A_{dc}
Open Circuit Voltage (V_{oc})	70.1 V_{dc}	Maximum ac power	15050 W_{ac}
Short circuit current (I_{sc})	6.6 A_{dc}	Nominal ac power	15000 W_{ac}
Maximum system voltage (V_{dc})	380 V_{dc}	Nominal ac voltage	208 V_{dc}
Temperature coefficient of P_{mp}	-0.351% /°C	Power consumption at night	2.56 W_{ac}
Module area	1.63 m^2	Maximum efficiency	95.85%
No. of modules	240	Euro efficiency	95.44%
NOCT	46.84 °C	Admissible ambient temperature (at 95% RH)	52.8 °C
Output power tolerance	5/-0%		
Cost per Wp	€0.91	Cost per piece	€1516

The inverters in the system were connected in parallel so that the inverter bank's rated voltage limits are the same as those of a single inverter. The direct current (DC) to alternating current (AC) ratio of the designed system was estimated to be 1.23. Figure 6.4 gives the simulation process of the solar PV system.

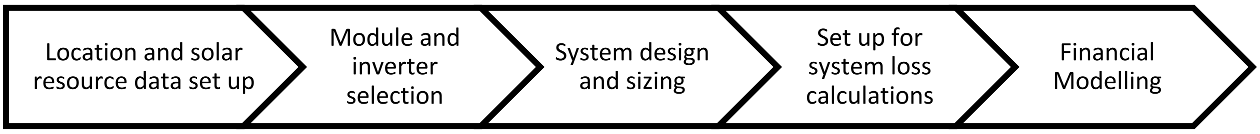


Figure 6. 4 SAM Simulation process flow for Solar PV

c. Solar heat integration

Schmitt (2014) offers a detailed methodology for solar heat integration in an industrial food process, in this study we adopted the methodology with some modifications as this is a new plant (Fig. 6.5).

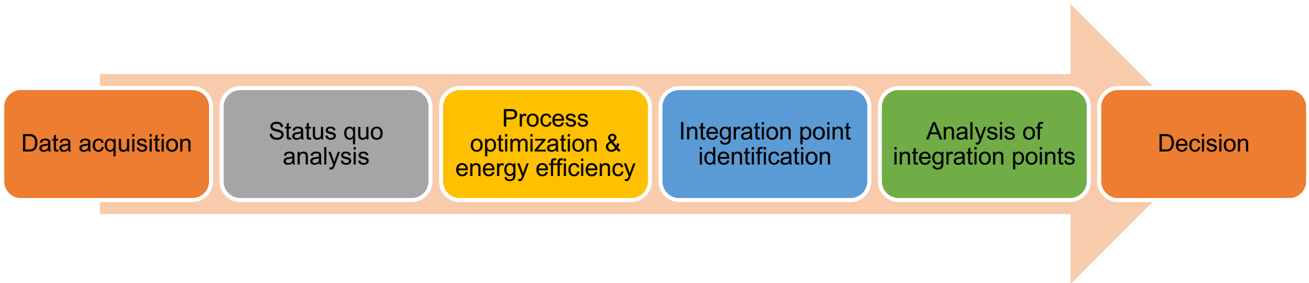


Figure 6. 5 Solar heating integration methodology (Modified from Schmitt 2016)

The solar thermal integration concept adopted in this study is SL_L_PI (Supply level liquid heat transfer medium indirect parallel integration), due to the ease of solar heat transmission into the supply level (Schmitt 2016; Hassine et al. 2015). Since the stream temperatures, with exception of the spray drying, were lower than 95 °C sensible heat storage with water was selected as it is economically feasible (Hassine et al. 2015).

d. Simulation of Solar Thermal using SWH performance model in SAM

In this section the integration of solar thermal for low temperature processes that require less than 100 °C, is simulated using the SWH performance model of SAM. The SWH module is categorically designed to assess both the Evacuated Tube Collector (ETC) and Flat Plate Collector (FPC) systems. The SWH module employs hot water usage profiles, shading, collector details, solar hot water tank and its heat exchanger, piping and pumping details, and includes cost analysis features. In facilitating the efficiency evaluation and cost analysis of both the ETC and FPC systems, the SWH module provides a library of hundreds of different ETC and FPC thermal solar collectors with their characteristic parameters. Figure 6.6 shows the flowchart that summarises the SAM SWH simulation setup process.

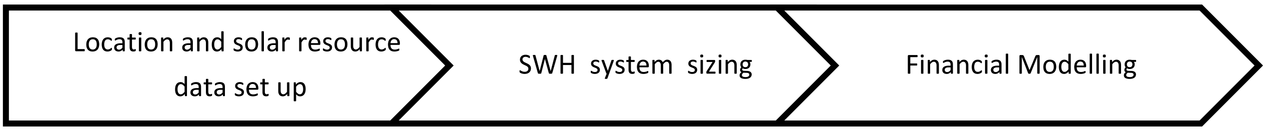


Figure 6. 6 SAM SWH Simulation process flow

e. SWH Model description

The amount of energy that is required below 100 °C and the average hot water demand of 24, 687 kg/day was used to estimate the thermal demands. SAM uses a closed loop evacuated plate collector model where the solar tank is filled with water from the mains, pumped through the heat exchanger and returned to the top of the tank (Fig. 6.7).

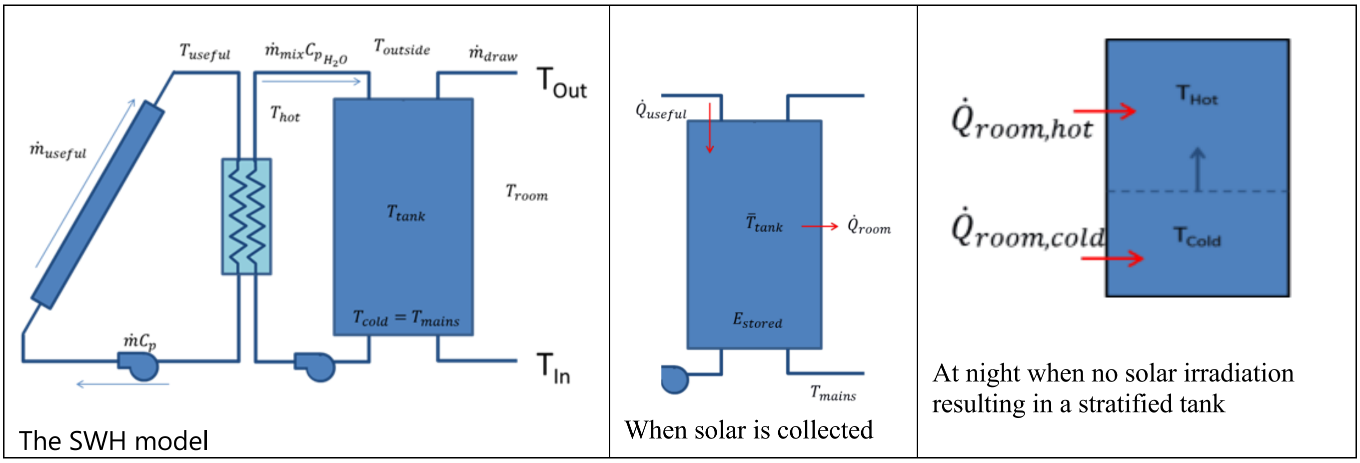


Figure 6. 7 The SWH Model indicating different states when solar is collected and at night when no solar irradiation occurs (Blair et al. 2018).

The area of the collector was determined based on the highest daily hot water demand, tilt angle set at latitude (0.792 °N) of Isiolo County and albedo at 0.3 since it is an arid area. The collector working fluid was propylene glycol (with 55–58% water content). The characteristics of the selected Oventrop Solar OV 5-24 AS AB tubular ETC as specified by the manufacturer are: Optical gain (*FRta*)) = 0.489, thermal loss coefficient (*FRUL)* = 1.59 Wm^{-2} K, unit area 6.12 m^2 and Incident Angle Modifier (*IAM)* = -0.95. For the solar water heat storage tank, the capacity of 7300 litres, height to diameter ratio of 2.00, heat loss coefficient (U) of 1.00 Wm^{-2} K and heat exchanger effectiveness of 75 % were selected. The maximum solar tank water, outlet and mechanical room temperatures were assumed to be 100, 55 and 20 °C respectively with an insulation with thermal conductivity of 0.043 $Wm^{-1} K^{-1}$ as recommended by ASHRAE (2013) based on the temperature ranges of hot water.

The mean hourly temperature of the tank when solar is collected ($\frac{dT_{tank}}{dt}$)is thus estimated by equation 6.5:

$$\frac{dT_{tank}}{dt} = \frac{Q_{useful} - Q_{room} + mC_p(T_{tank} - T_{mains})}{\rho V_{tank} C_p} \quad \text{Eq. 6.5}$$

At night, when no solar energy collection, the tank is assumed to be stratified into two nodes: one hot and one cold node. The differential equations for the cold node and hot nodes are given in equations 6.6 & 6.7 respectively:

$$\frac{dT_{cold}}{dt} = \frac{Q_{room,cold} + mC_p(T_{mains} - T_{cold})}{\rho V_{cold} C_p} \quad \text{Eq. 6.6}$$

$$\frac{dT_{hot}}{dt} = \frac{Q_{room,hot})}{\rho V_{hot} C_p} \quad \text{Eq. 6.7}$$

6.2.7 Auxiliary boiler

The auxiliary hot water boilers supply a certain amount of heat to the fluid when the solar system is unable to reach the set point temperature of the load. The energy rate delivered by the auxiliary system can be computed by using equation 6.8:

$$Q_{aux} = \dot{m}_L c_p \Delta T_L \quad \text{Eq. 6.8}$$

where ΔTL is the difference between the fluid temperature needed by the load and the fluid temperature supplied by the solar loop.

6.2.8 Carbon dioxide emissions reduction

The CO_2 emissions reductions were calculated from values provided by the Government of Kenya, (2018), by multiplying the conversion factor *(C_{factor})* by the saved thermal and electrical energy. The C_{factor} for fuel oil *($C_{factor\ th}$)* and electricity (*$C_{factor\ el}$)* were 0.335 and 0.18 *t*CO_2e/MWh respectively (Government of Kenya 2018). The conversion factors used from saved energy in MWh to *t*CO_2e mitigated is given in equations 6.9 and 6.10 for thermal ($tCO_2e_{mitigated\ th}$) and electrical ($tCO_2e_{mitigated\ el}$) systems respectively.

$$tCO_2e_{mitigated\ th} = Q_{saved\ th} \times C_{factor\ th} \qquad \text{Eq. 6.9}$$

$$tCO_2e_{mitigated\ el} = Q_{saved\ el} \times C_{factor\ el} \qquad \text{Eq. 6.10}$$

where $Q_{saved\ th}$ *and* $Q_{saved\ el}$ *are thermal and electrical energy savings*

6.2.9 Technical and economic feasibility

6.2.9.1 Total capital investment of the designed process

To estimate the fixed capital investment (FCI) cost, the definitive factorial methods as proposed by Perry & Green (2008), Saravacos & Kostaropoulos (2012) and Towler & Sinnott, (2013) was used. This entailed the use of a modular concept based on costs versus capacity charts developed by Guthrie and updated by Garret (Guthrie 1969; Guthrie 1974; Garret 2012). The modular concept method was chosen, as it is generally accepted as the best cost estimation method for detailed feasibility studies (Turton et al. 2018). The bare module factor comprises all supporting and connecting equipment to ensure the complete operation of the equipment. The bare module factor is obtained at base conditions and any deviation from the base conditions is accounted for by multiplying it by material factors of construction, plant location, system pressure and instrumentation (Ulrich 1984; Navarrete 1995). The material factor of steel was used since this is a food processing plant, in absence of information on the stainless steel material factor from the charts, a value of 2.0 was used as proposed by Saravacos & Kostaropoulos (2012).

The bare module of each equipment cost (C_{BM}) is estimated by equation 6.11 (Turton et al., 2018):

$$C_{BM} = C_P^O F_{BM} \qquad \text{Eq. 6.11}$$

where F_{BM} *is the bare module cost factor* C_P^O *is the purchased equipment cost at base conditions.*

Modular cost at base conditions (F_{BM}^{o}) is further estimated by equation 6.12

$$F_{BM}^{o} = [1 + \alpha_L + \alpha_{FIT} + \alpha_L \alpha_o + \alpha_E][1 + \alpha_M] \quad \text{Eq. 6.12}$$

where α_L *labor;* α_{FIT} *freight;* α_o *overhead;* α_E *engineering;* α_M *material factors.*

Since the proposed plant is a new facility to be established in completely undeveloped land, Green field costs (C_{GR}) and total module costs (C_{TM}), were also calculated. To estimate the C_{TM}, contingencies cost (15%) and contractor's fees (3%) for the new plant, were added to the bare module costs as indicated in the equation 6.13 (Miller 1965; Turton et al. 2018).

$$C_{TM} = \int_{i=1}^{n} C_{TM,i} = 1.18 \int_{i=1}^{n} C_{Bm,i} \quad \text{Eq. 6.13}$$

To estimate $C_{GR,}$ auxiliary facilities cost (site development, auxiliary buildings, utilities and off sites costs) is added to the total module cost. C_{GR} is thus the fixed capital investment cost (FCI).

$$FCI \ or \ C_{GR} = C_{TM} + 0.50 \int_{i=1}^{n} C_{BM,i}^{o} \quad \text{Eq. 6.14}$$

where n, *is the total number of pieces of equipment.*

The charts used in capital cost estimation are based on historical data (year 2000), to account for the cost escalation over the years due to inflation on materials and labour, the Chemical Engineering Plant Cost Index (CEPCI) of August 2018 was used to estimate individual equipment cost (Chemical engineering, n.d.) as give in equation 6.15.

$$C_P^O \ 2018 = C_P^O \ 2000 \left(\frac{\text{CEPCI in 2018}}{\text{CEPCI in 2000}}\right) \quad \text{Eq. 6.15}$$

Working capital (WC) was estimated by equation 16 and is based on modification of the method proposed by Towler & Sinnott, (2013).

$$\text{WC} = 0.015\text{FCI} + 0.275\text{C}_{\text{COP}} + 0.10\text{C}_{\text{RM}} \quad \text{Eq. 6.16}$$

where C_{COP} *is cash cost of production;* C_{RM} *is the raw material cost*

The sum of WC, FCI and land results in total capital investment (TCI).

6.2.9.2 Profit Analysis

In evaluation of the profitability of this project, the discounted profitability criterion was used taking into consideration the class life of food equipment (15 years), taxation rate (30%) and interest rate (13.5%) (Saravacos and Kostaropoulos 2012; Deloitte 2018). The basis of the project profitability is based on the net present value (NPV) as it is a clear indicator of time value for money and its effect on profitability.

a. *Cost of Manufacturing (C_{OM})*

The C_{OM} was estimated by equation 6.17 based on modified chemical engineering design texts such as storage spaces and nature of raw material for food processing design (Turton et al. 2018; Peters et al. 2003; Saravacos and Kostaropoulos 2012).

$$C_{OM} = 0.12FCI + 2.3475C_{OL} + 0.12R + C_{UT} + C_{WT} + C_{RM} \quad \text{Eq. 6.17}$$

where $C_{OL}, R,$ C_{UT} and C_{WT} are the cost of labour, revenue, utility and waste treatment respectively.

b. *Depreciation (d)*

To estimate *d,* the modified accelerated cost recovery system (MACRS) method for 15 years food equipment class life which utilizes a double declining balance method and switches to a straight-line method was used (AACE International 2016).

c. *Cash flow*

The after-tax cash flow (CF) was estimated by equation 6.18.

$$CF = (R - C_{OM} - d)(1 - t) + d \quad \text{Eq. 6.18}$$

where R is the revenue; d is depreciation, t is taxation rate (%)

d. Net present Value (NPV)

The basis of profitability is based on the NPV in this study as it is a clear indicator of time value for money and its effect on profitability and is estimated by equation 6.19.

$$NPV = \sum_{n=1}^{n=L} \frac{CF_n}{(1+i)^n} \qquad \text{Eq. 6.19}$$

where CF_n is cash flow in year n, L is project life in years and i is interest rate.

e. Discounted Cash-flow Rate of Return (DCFROR)

DCFROR is the maximum amount of interest that the project could pay and still break even after the end of the project and is estimated by equation 6.20.

$$\sum_{n=1}^{n=L} \frac{CF_n}{(1+i')^n} = 0 \qquad \text{Eq. 6. 20}$$

where i' is the discounted cash flow rate of return in percentage.

6.2.9.3 Sensitivity analysis

To ascertain the effect of uncertainties in the viability of the designed process, a sensitivity analysis was undertaken by varying the costs of raw material, manufacturing, fixed capital, revenue, interest rate and taxation rate by 20%. A tornado plot using Excel^{TM} was plotted to identify the critical factors influencing the profitability.

6.2.9.4 Sources of information

The market value from butter milk, butter and, milk powder was obtained from the internet and an average price estimated. The milk prices were based on our initial study in 2017 (Ogolla et al. 2017). From the process flow diagram (PFD) drawing mass and balance equations, the utility quantities (energy, water, fuel, electricity and chemicals) were estimated. The prices of fuel, compressed air and water; interest rate (13.5%), were obtained from the Kenya National of Bureau of statistics (KNBS) (2017) and taxation rate (30%) and inflation rate of 8.43% from Deloitte (2018).

Table 6. 3 Estimated unit costs in Euros used in economic analysis of the processing lines

Parameter	Units	Unit cost (€)	Parameter	Units	Unit cost (€)
Raw camel milk	Litres	0.67	Electricity	kWh	0.11
Raw water	Litres	0.17	Camel milk powder	kg	140.00
Salt & colorant	kg	0.50	Camel milk butter	kg	48.23
Refrigerant	Litres	0.18	Cultured camel milk	litres	0.50
Wastewater treatment	Litres	0.05	Labour/month	Persons	2.50
Fuel Oil	Litres	0.90			

Source: (KPLC, 2018; Ogolla et al., 2017)

6.2.9.5 Financial model for solar integration

The financial model used is the simple Levelized cost of energy (LCOE) calculator of SAM based on the fixed charge rate (FCR) method. LCOE represents the total project lifecycle costs. It is the present value of project costs expressed in cents per kilowatt-hour of electricity generated by the system over its life. LCOE calculated using equation 6.21 is useful in the financial viability analysis of basic, preliminary or feasibility projects (NREL 2018).

$$LCOE(real) = \frac{Cost_{ST,PV} + \sum_{n=1}^{L} \frac{OM}{(1+D_{real})^n}}{\sum_{n=1}^{L} \frac{Q_{ST,PV\ yield}}{(1+d_{nominal})^n}} \qquad \text{Eq. 6.21}$$

Where: Cost $_{ST,\ PV}$ is the project equity (initial investment), OM is annual project costs in year n, $Q_{ST,PV}$ (kWh) is the energy generated by the SWH or PV system in year n, D_{real} is the real discount rate, $d_{nominal}$ is the nominal discount rate, and L is analysis period in years

Based on the Kenya National Market considerations and published works solar thermal costings provided in Table 6.4 were used to perform the economic analysis of the SWH system cost. The storage volume of the solar tank was assumed to be half of the total daily hot water consumption as SAM does not account for overheating (Blair et al. 2018)

Table 6. 4 Summary of ETC-SWH system's cost

Item	Price
Collector cost	272.37 €/ m^2
Storage tank	962.36 € / m^3
Miscellaneous items (Pipes, fittings, etc.)	10% of costs of collector and tank
Shipping and handling	10% of costs of collector and tank
Installation	2% of costs of collector and tank
Sales tax	6% of overall cost

Source: Eicker et al. 2014; Allouhi et al. 2017; Otanicar, Taylor, and Phelan 2012

6.2.9.6 Performance analysis of SWH and Solar PV systems

To evaluate the performance of the SWH system, the solar fraction (SF), annual fuel energy saved in year 1 (kWh), capacity factor (c_{factor}), auxiliary energy delivered with and without the SWH (kWh) and CO_2 saved were used. The SF calculated using the equation 6.22.

$$SF = \frac{E_{solar}}{E_{solar}+E_{Aux}} \qquad \text{Eq. 6.22}$$

where E_{Aux} is the backup system energy needed to maintain the hot water at set temperature and E_{solar} is the energy supplied by the solar system

The PV system, the performance metrics used are c_{factor}, Energy yield in year 1 (kWh/kW) and performance ratio (PR). PR determines how effective PV is relative to its installed peak power is calculated using equation 6.23:

$$PR = \frac{E_{annual}}{E_{NR}\times \eta_{pv}} \qquad \text{Eq. 6.23}$$

where E_{NR} is the annual total radiation (nominal) (kWh and η_{pv} is module efficiency (%).

6.3. Results and discussion

6.3.1 Designed camel milk processing

6.3.1.1 Camel milk powder processing plant description

The proposed optimised milk powder and butter processing plant design is indicated in figure 6.8 where the incoming raw milk at a temperature of approximately 30 °C is filtered, then chilled to 4 °C to inhibit microbial growth that accelerates milk spoilage before creaming (Fox and Kelly 2012). Chilling also enhances the precipitation of fat globules by cryoglobulin enhancing the rate of creaming. Camel milk has a lower cryoglobulin content compared to cow milk thus it is slower creaming when cooled (Rüegg and Farah 1991; Kelly, O'Connell, and Fox 2003).

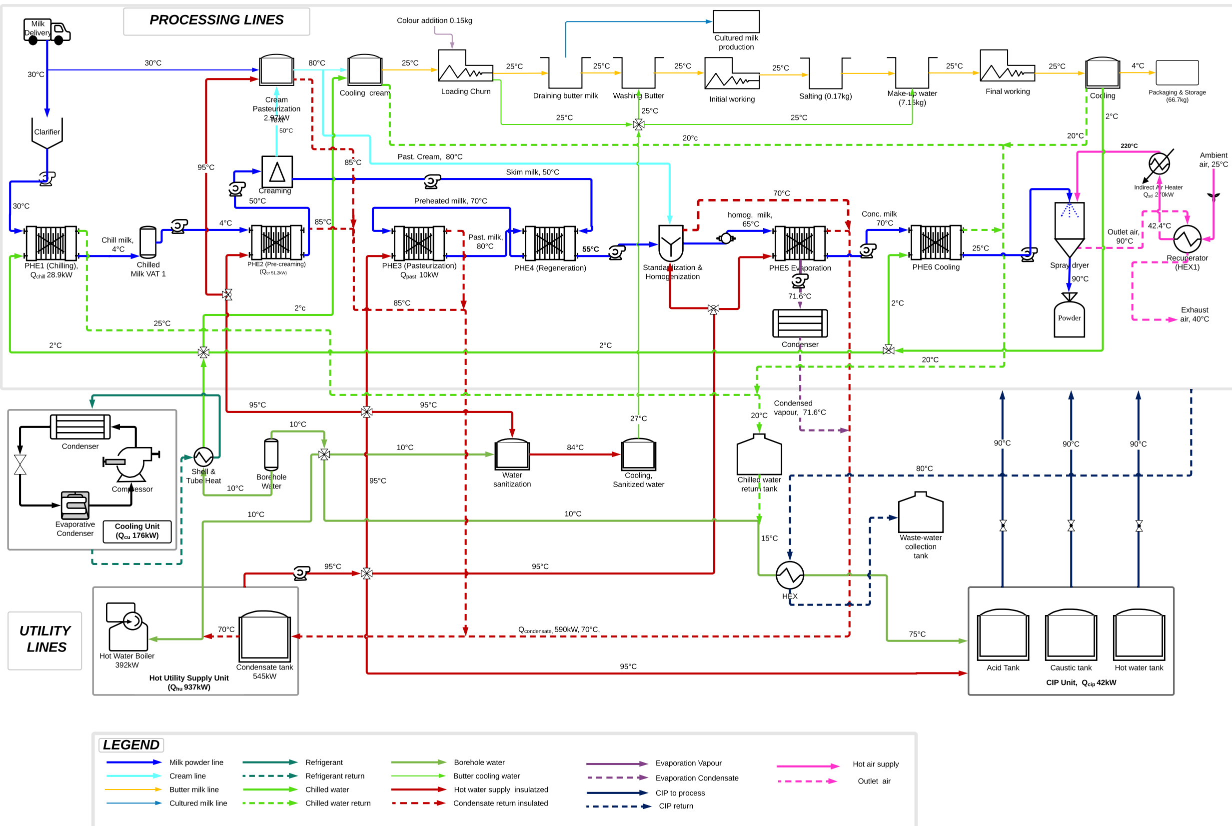


Figure 6. 8 Schematic representation of the optimized novel camel milk and butter processing plant

The chilled milk is heated through hot water to 50 °C for creaming through centrifugation. The separated cream is channelled to the butter processing line for pasteurisation as described in section 6.3.1.2. In order to denature ß-lactoglobulin and inactivate the enzymes such as lipase that are responsible for oxidative reactions, the milk is pasteurised in a plate heat exchanger (PHE) at 80 °C, held for 15 seconds. To minimise energy consumption, the pasteurised milk is cooled through regeneration by incoming raw milk to a temperature of 55 °C. Since the process is designed for whole milk powder production, the milk is standardised with pasteurized cream from the butter line to the desired fat content (3.5%). The standardised milk is preheated to 65 °C and homogenized at pressures of 138-172 bars. The single stage homogenization process, the pressure and temperature were selected since the fat content of the milk was less than 6% (Walstra, Wouters, and Geurts 2006; Fox and Kelly 2012). The homogenization decreases the fat globules to diameters <1 μm decreasing the viscosity of the milk, thus, inhibiting the agglutination of the fat globules due to the denaturation of the cryoglobulins. The homogenised milk is evaporated in a single stage falling film vacuum evaporator at 70 °C, at a pressure of 0.32 bars, cooled to a temperature of 25 °C before introduction into the spray dryer due to the nature of the atomizer. Evaporation of water leads to increased lactose and salt in milk while the soluble calcium and phosphates decrease due to the irreversible movement of the phosphates to the colloidal phase (Oldfield, Taylor, and Singh 2005; Le Graet and Brule 1982). In the spray dryer, the atomised concentrated milk droplets concurrently come into direct contact with hot air at 220 °C resulting in moisture evaporation and milk powder production of a total solids content of 97 % (Pisecky 2012). The air leaves the cyclone at approximately 90 °C while the product outlet temperature is approximately the drying air outlet temperature of 90 °C. Rapid evaporation of water from the milk during spray drying results in amorphous glassy lactose molecules that are hygroscopic and, thus, the powder cakes easily when exposed to humid conditions, however, there is a negligible influence on the protein composition (Kelly, O'Connell, and Fox 2003).

6..3.1.2 Butter processing description

The iodine content of the camel milk fat is 43.8-55% higher than that of cow milk (Faraq & Kebari 1992; Farah et al 1989; Purchase 1943). The high levels of iodine value limit the processing of camel butter in comparison to cow milk butter thus controlled butter processing of camel milk was utilized (Farah, Streiff, and Bachmann 1989). Farah et al., (1989) reported that the highest churning recovery (85%) was obtained from the cream with 22.5% fat churned for 11 minutes at 25 °C in Northern Kenya. Modification to this process was made to ensure that the butter is of high microbial quality and nutritious by ensuring the fresh milk is of high quality with no developed acidity. To reduce the effect of denaturation of the proteins, pasteurisation of the cream is undertaken at 80 °C for 30 minutes. First, the cream obtained from the creaming process is standardised to reduce the fat content from 40% to 22.5% by the addition of fresh camel milk. The pasteurised cream is divided into two portions, with approximately 130 kg channelled back to the milk powder processing line for full milk powder production. The remaining cream is rapidly cooled to 25 °C to enhance fat recrystallization while inhibiting bacterial growth. The cream is introduced in the churn, and carotene colour from carotene-rich vegetables (0.25% of the mass of the butterfat) is added. Churning is carried out at 25 °C for 11 minutes. During churning at the breaking stage, the temperature increases by about 1-3°C, therefore, breakwater is added at 20 °C to account for this increase, therefore maintaining the churning temperature of 25 °C. The butter grains are washed with water at 27 °C to impart firmness, remove excess buttermilk, reduce the intensity of undesirable off-flavours and improve the keeping quality. The amount of water used is equal to the drained amount. Initial working for the compact mass formation and excess moisture is also drained off. The butter is salted and worked further under vacuum to ensure equal distribution of the salt, reduce the air content of the butter from 5-7% to approximately 1.5% thus limit oxidation reactions and microbial growth. The water used as butter make-up water is disinfected through heating of the water to a temperature of 84 °C before cooling it to 27 °C and mixing it with the butter (Bylund 2003). Since the proposed plant is designed for isolated arid areas where water is critical, the treated waste water is used to water crops and vegetables in the factory gardens (Clark 2009). These vegetables can be sold or consumed by the local population, thus contributing to household food security.

6.3.2 Thermal and electrical demands of the optimized system

The hourly heating, cooling and mechanical demands are indicated in figure 6.9. In the proposed milk powder and butter processing plant, electricity is used for the cooling, and the mechanical operations such as homogenization, creaming and pumping unit operations. The plant operates 5 days a week and 40 weeks per year with an estimated annual heating demand and electrical (Cooling & Mechanical) demand of 1.244 and 0.256 GWh respectively.

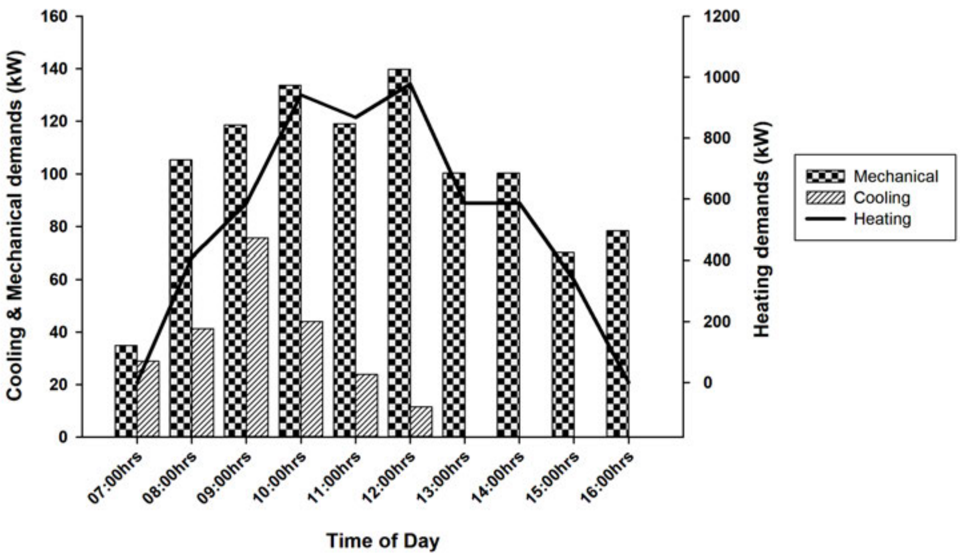


Figure 6. 9 Hourly heating, cooling and mechanical demands before optimization

6.3.2.1 Process Optimization

a. *Process data and stream table*

The opportunities for optimisation measures in the milk and butter process are presented followed by a second section that discusses potentials for integrating a solar thermal, cooling and mechanical system into the milk powder and butter process. The designed milk powder and butter processing plant has a batch cycle duration of 9 hours (Table 6.5). The process begins with chilling of raw milk at 07:00 hrs and ends at 16:00 hrs with CIP, indicated in table 6.4 as 0 h and 9 h respectively. The heating and cooling demand of the entire process is approximately 1.244 and 0.062 GWh respectively when no heat recovery is undertaken. Recycled outlet spray drying indicated as soft stream was set at 55 °C, to limit the clogging of the heat exchanger network (HEX) due to the critical humidity values at temperatures lower than 55 °C (Walmsley et al. 2014).

Table 6. 5 Stream data of the designed camel milk powder and butter processing lines

Stream No.	Type	ϑ_{in} (°C)	ϑ_{out} (°C)	$\dot{m}$ (kg/s)	$\dot{C}_p$ (kW/K)	Pressure (bar)	$\dot{Q}$ (kW)	Q (kWh)	Soft stream	t_{start} (h)	t_{stop} (h)
1	H	30	4	0.29	1.11	1	28.94	86.81		0	3
2	C	4	50	0.29	1.11		51.16	153.49		1	4
3	C	50	80	0.25	1		29.96	89.89		1.25	4.25
4	H	80	55	0.25	1		24.96	77.37		1.5	4.5
5	C	55	65	0.28	1.09		10.91	32.73		2.75	5.75
6	C	65	70	0.28	1.09		5.46	16.37		2.75	5.75
7	H	x=1	25	0.2	11.21	0.32	522	1567	yes	3	6
8	C	x=0	x=1	0.2		0.32	480.1	1441		3	6
9	H	70	25	0.08	0.26		11.53	34.58		3	6
10	C	10	84	0.08	0.33		24.59	24.59		2	3
11	H	84	27	0.08	0.33		19.02	38.04		2.25	3.25
12	C	25	220	1.24	1.27	1	246.99	740.97		5	8
13	H	90	25	1.25	2.77	1	180.23	540.68	yes	5	8
14	C	44.4	80	0.14	0.48		16.92	16.92		2	3
15	H	80	25	0.07	0.18		10.14	10.14		2.25	3.25
16	C	10	90	1	4.2		335.6	2684.8		1	9
17	H	90	25	1	4.2		272.68	2181.4	yes	1	9
18	H	25	5	0.02	0.04		0.82	0.82		3	4

Where H is the hot stream, C is the cold stream, x is steam quality; ϑ_{in} is supply temperature in °C; ϑ_{out} target temperature in °C; $\dot{C}p$ is the heat capacity flow, t_{start} and t_{stop} is the starting and end time of each stream in hours relative to the beginning of the batch respectively. Humidity of the inlet air at spray dryer inlet and outlet were 0.011 and 0.05 kg_{H2O}/ kg_{air} respectively.

b. Direct heat recovery possibilities (MER analysis)

The Gantt chart and associated equipment repeated operation period (EROP) are shown in figure 6.10. The time slice model (TSM) was utilized due to the dependency of the batch processes on time and its ability to predict the sufficient energy savings compared to the Time Analysis Model (TAM) (Eiholzer et al. 2017; Kemp 2007b; Linnhoff, Ashton, and Obeng 1988). The entire processing cycle was divided into 18 time slices (TS) with different duration and numbers of streams (Fig. 6.10) using a ΔT_{min} of 10 K (Kemp 2007b). Since the conditions in each TS are constant as described by Kemp, (2007b), the time slices were treated as continuous processes when designing the heat exchanger networks (HEN). TS1 contained one hot stream thus DHR was impossible, while the remaining TSs had both cold and hot streams, thus, indicating potential heat recovery (HR) was possible (Fig. 6.10).

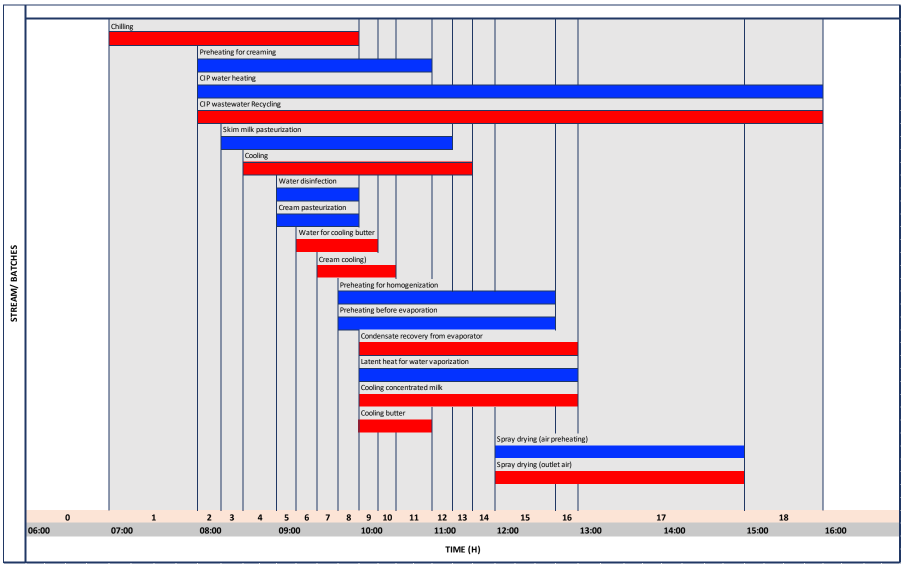


Figure 6. 10 Time Slice Gantt chart and associated (EROP) for milk powder and butter processing plant (The red lines denote hot streams while cold streams are denoted by blue lines).

In establishing HEN, determination of the maximum energy recovery (MER) was based on PinCH rules where the streams with the highest heat capacity were connected and higher heat capacity of streams above the PinCH to those below the PinCH (HSLU 2012; Kemp 2007b). Based on these rules, 19 HENs were identified from the MER analysis as indicated in table 6.6. The overall heat recovery is approximately 50.7 % of the hot and cold utility demand of about 0.56 & 0.02 GWh/a respectively. Taking into consideration the thermal efficiencies of the utility supply systems, the overall heat recovery decreases to 38.53%. From table 6.6, it can be deduced that the highest heat recovery is from recovery of evaporation condensate (HEX 7, 8, 9, &17), CIP wastewater recycling (HEX 2) and preheating of inlet spray drying air by the outlet spray dried air (HEX 15).

Table 6. 6 Heat exchanger Networks of Maximum Energy Recovery Analysis

HEX Nr.	Hot Stream	Cold stream	TS_{start}	TS_{end}	Energy kWh)
1	Raw milk chilling	Heating for creaming	2	8	53.4
2	CIP wastewater recycling	CIP water heating	2	18	2181.6
3	Cooling for standardised milk	Heating for creaming	4	6	8.4
4	Cooling for standardised milk	CIP water heating	7	8	10
5	Water cooling for butter production	Water disinfection	5	8	19
6	Cooling for standardised milk	Skim milk pasteurisation	8	12	29.9
7	Evaporator condensate recovery	Heating for homogenisation	9	15	19.8
8	Evaporator condensate recovery	Heating for creaming	9	11	51.2
9	Evaporator condensate recovery	CIP water heating	9	14	42.6
10	Cooling for standardised milk	Heating for homogenisation	13	13	1.3
11	Cooling for standardised milk	preheating before evaporation	13	13	1.6
12	cooling concentrated milk	CIP water heating	14	15	8.6
13	Spray drying (outlet air)	Heating for homogenisation	15	15	2.8
14	Spray drying (outlet air)	preheating before evaporation	15	15	4.1
15	Spray drying (outlet air)	Spray drying (air preheating)	15	17	163.6
16	Spray drying (outlet air)	CIP water heating	15	15	7.1
17	Evaporator condensate recovery	Spray drying (air preheating)	15	15	34.7
18	Spray drying (outlet air)	Latent heat for water vaporization	16	16	2.9
19	Spray drying (outlet air)	CIP water heating	17	17	42
Total					**2684.6**

The MER design was further optimized to limit the number of Heat exchangers (HEX) while ensuring optimal heat recovery at limited economic costs. This was undertaken by identifying the streams that occurred over several time slices, with highest heat capacities and where the heat capacities of streams above the PinCH were higher than those below it. Based on these principles the number of HEX were reduced from 19 to 9 with a decrease of about 2% of heat recovery (table 6.7).

Table 6. 7 Heat exchangers of optimized MER analysis

HEX Nr.	Hot Stream	Cold stream	TS start	TS end	Energy (kWh)
1	Raw milk chilling	Heating for creaming	2	8	35.6
2	CIP wastewater recycling	CIP water heating	2	18	2181.6
3	Cooling for standardised milk	Heating for creaming	4	8	37.5
4	Water cooling for butter production	Water disinfection	5	8	19
5	Cooling for standardised milk	Skim milk pasteurisation	9	12	24.9
6	Evaporator condensate recovery	Heating for creaming	9	12	64
7	Evaporator condensate recovery	CIP water heating	9	16	63
8	Evaporator condensate recovery	Heating for homogenisation	9	15	19.8
9	Spray drying (air preheating)	Spray drying (outlet air)	15	17	141
Total					**2586.4**

Further modifications were undertaken to reduce the number of HEX for technical and economic considerations based on the physical and social-economic conditions of the target area. Four main HEX networks were identified and the excess heat from other streams were channelled to a condensate tank that was mixed with the make-up water to reduce the amount of water and energy used, while also considering the equipment available in the market. This, thus, resulted in two PHEs i.e. PHE4 & PHE5, two HEXs i.e. HEX1& HEX2, and one condensate tank as indicated in figure 6.11 highlighted in purple.

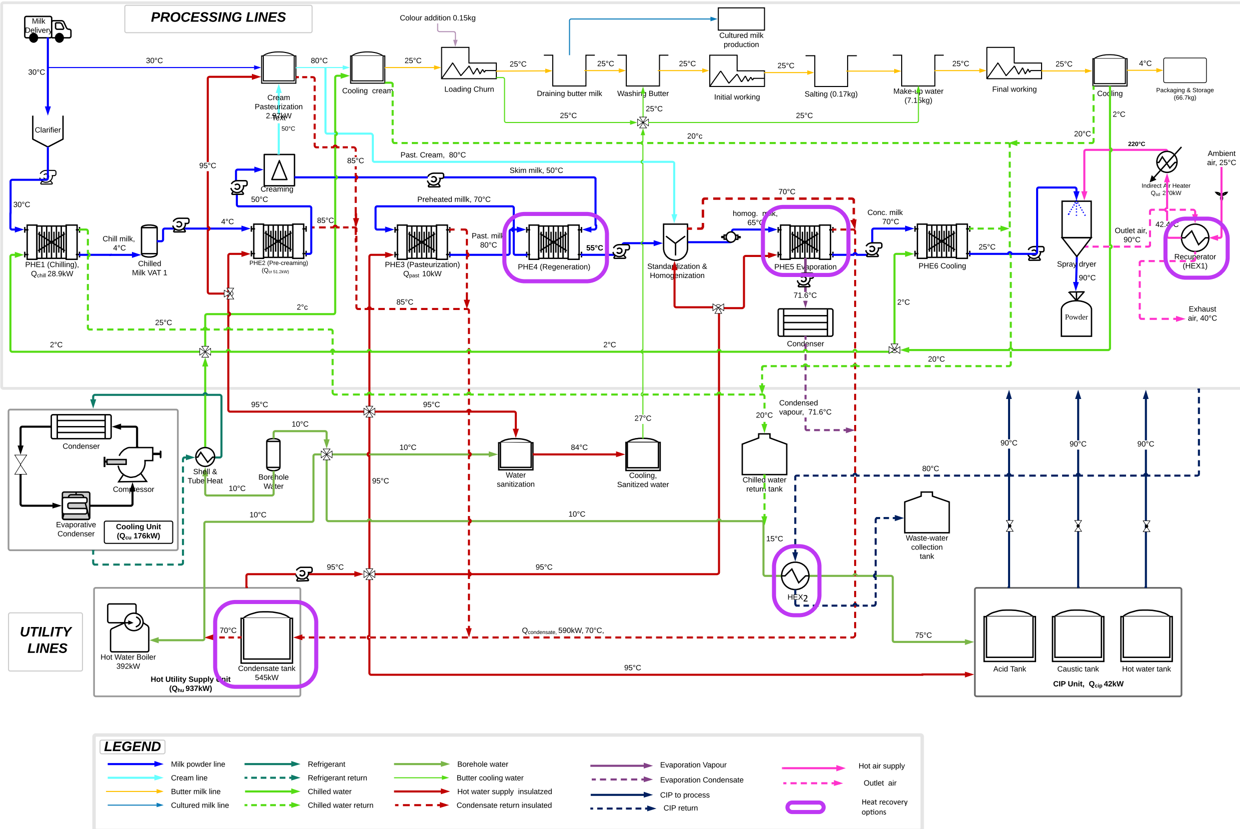


Figure 6. 11 The processing line after optimization indicating HEXs, PHE and condensate tank.

The total reduction in energy demanded was approximately 41.33%. In the regeneration unit, incoming raw milk is preheated by the pasteurized milk before being introduced into the pasteurization unit. This results in increase in temperature of preheated milk to 70 °C thus decreasing the heat demanded for both cooling of the standardised milk and pasteurization. To limit the energy used in the evaporation process, a falling film single stage evaporator was selected with mechanical vapor recompression since the capacity of the feed to be evaporated was less than 1000 kg/h (Pisecky 2012). This utilized the condensate instead of the hot water from the boiler. Further, to reduce the energy for CIP, the CIP water was preheated by the CIP wastewater to temperatures of 75 °C. Further energy use reductions were obtained by preheating the inlet drying air to the spray dryer from 25 °C to 42 °C through the recycled spray drying air.

6.3.3.2 Annual electrical and heating demands of the optimized plant

The annual electrical energy demands that entailed both mechanical and electrical demands were 200.0 MWh and 35.2 MWh respectively (Fig. 6.12) after heat recovery through process optimization. The efficiency of the chilling unit was assumed to be 66.6% based on the systems available in the market resulting in annual losses of 8.74 MWh (Fig. 6.12). Similarly, the thermal efficiencies of hot water boiler and indirect air heater for spray dryer were estimated to be 85% resulting in annual heating losses of 63.87 and 17.84 MWh/a respectively (Fig. 6.11) (Tawil and Ap, n.d.; Kemp 2012; Masters 1994; Viessmann 2013). Figures 6.12 and 6.13 give the Sankey diagrams of the thermal and electrical energy demands of the optimized designed milk and butter processing plant.

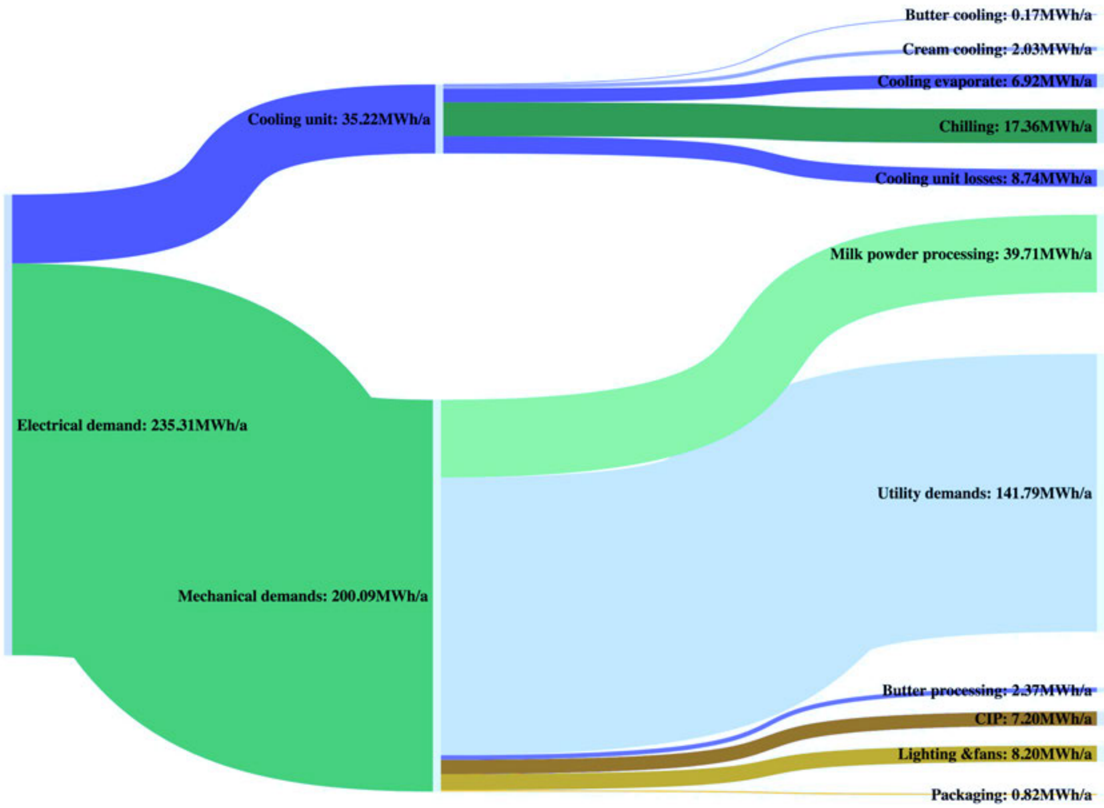


Figure 6. 12 Annual electrical consumption for the milk powder and butter processing plants

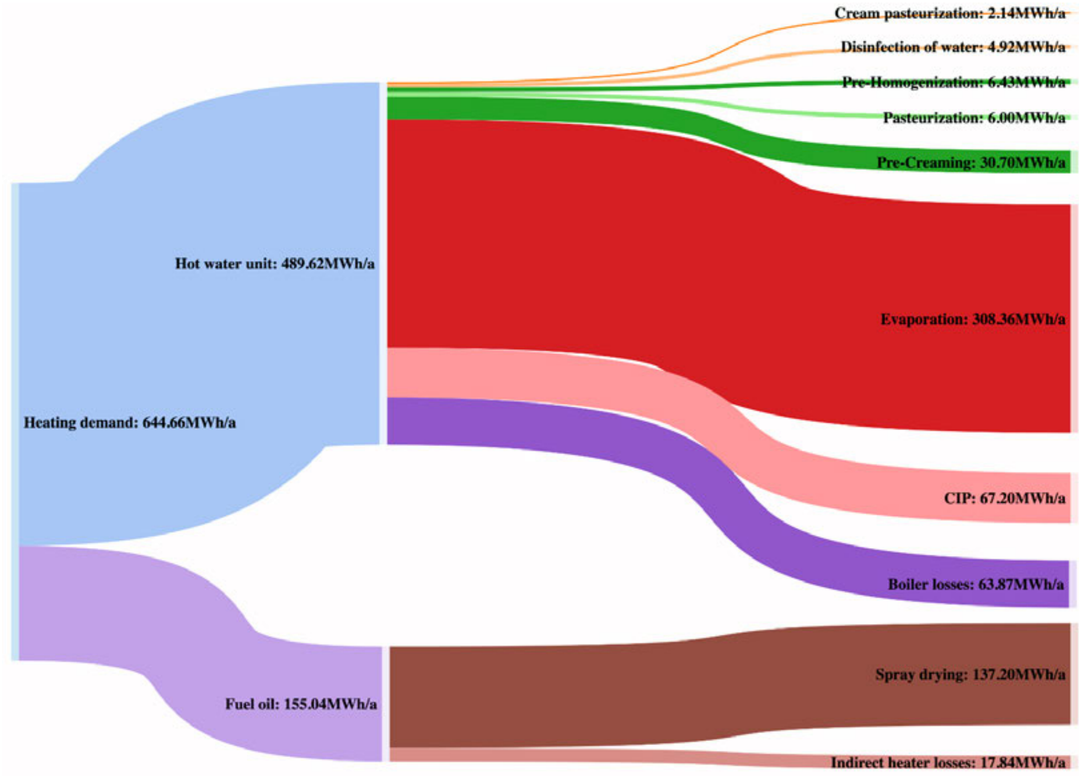


Figure 6. 13 Annual thermal demands for the milk powder and butter processing plants

6.3.3 Solar integration into the designed plant

6.3.3.1 Solar heat and PV integration analysis

In integrating the solar heat and PV it is vital to understand the hourly thermal loads and electrical demands of the systems (Sturm et al. 2015). Figure 6.14 indicates the hourly cooling, mechanical and thermal demands of the optimized processing plant. The highest heating and mechanical energy demand are at 12.00 hrs of 0.70 and 0.14 MWh respectively. This is because during this time the two most energy intensive processes: spray drying, and evaporation are occurring in tandem, requiring heat energy for evaporation of water and electrical energy for the motors and vacuum creation. Similarly, cooling demands are highest at 09:00 hrs of approximately 0.040 MWh.

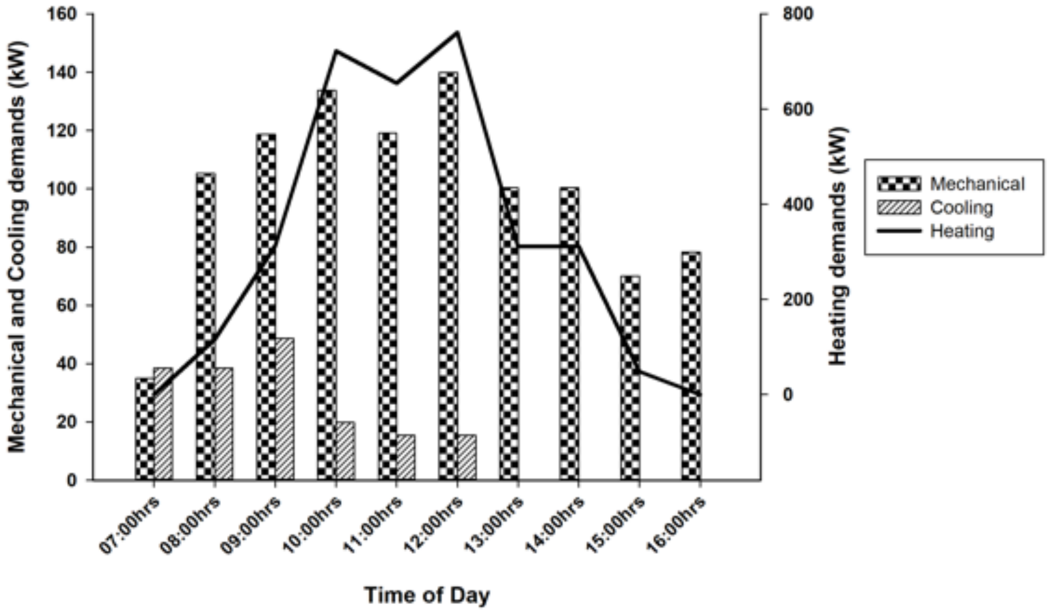


Figure 6. 14 Hourly cooling, mechanical and heating demands of the optimized processes.

6.3.3.2 Solar heat integration

The selection of Evacuated tube collectors (ETC) was based on the desired temperature range of the hot water supply as they perform better at the desired temperatures and very low heat losses compared to Flat Plate Collectors (FPC) (Mekhilef, Saidur, and Safari 2011). Further ETC accounts globally for 71% of the cumulated capacity in operation and 72% of the newly installed capacity (Weiss and Spörk-Dür 2019). In addition ETC has higher collector efficiency and shorter payback period and produces higher solar heat output compared to FPC thus the selection of its use in the process (Eiholzer et al. 2017).

The total number of ETC were 60 with a total collector area of approximately 367.2 m^2 and this can be installed with no difficulty in the proposed study area. Overall thermal losses were assumed to be 5% and the distance between the collectors were maintained above 2 m during installation to minimize shading losses. The hourly solar system energy output of the SWH, is given in figure 6.15 indicating highest energy output between 10:00 and 11:00 hrs.

The performance metric of the SWH was based on five main components: Solar fraction, annual energy saved, Auxiliary energy with and without solar and the capacity factor. Figure 6.16 gives the monthly energy delivered, energy demands without solar (Q auxiliary only), energy demands with solar (Q auxiliary) and the system energy. The low energy that is delivered in the months of February and September is due to the plant not operating due to limited camel milk supply.

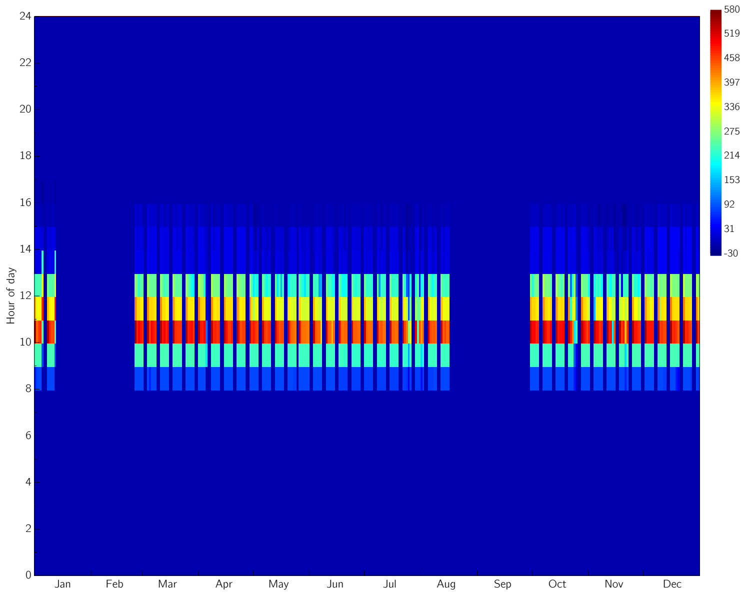


Figure 6. 15 Hourly system energy of the SWH in kW

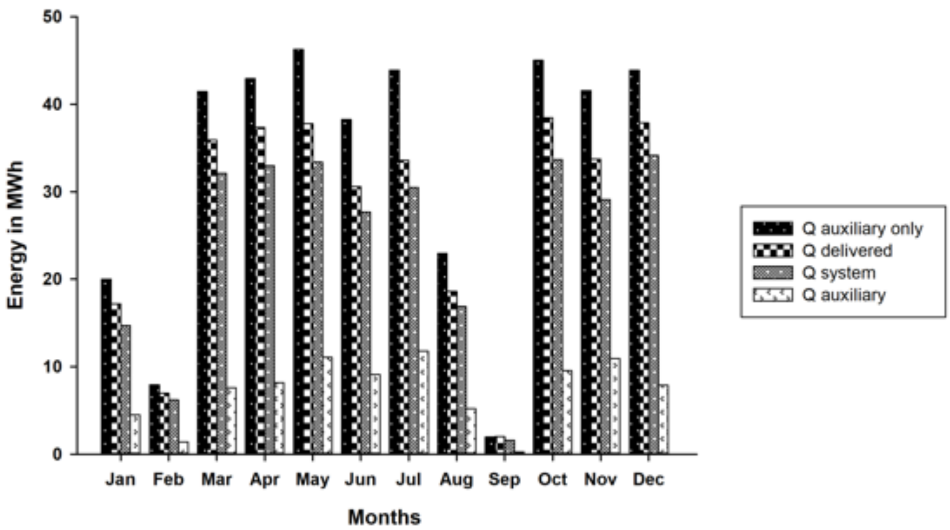


Figure 6. 16 Monthly energy of the Solar water Heater in MWh

The overall annual solar fraction was found to be 74.0% that corresponds to a net annual energy saving of about 293.01 MWh. The efficiency of the boiler (85%) was taken into consideration in calculating the hot water used per hour before modelling in SAM. However, without taking into consideration the boiler losses solar component would provide 249.06 MWh to the process. The capacity factor of the system was estimated at 20.6%; when the system was operated without solar incorporation, the annual auxiliary energy was 396.18 MWh while with solar incorporation, the extra energy provided by the hot water boiler will be 87.39 MWh. The substitution of fuel oil in the hot water boiler with solar energy, will result in a decline in the carbon footprint generated from the thermal energy of this plant (Buker and Riffat 2017). By considering the value of carbon dioxide content of fuel-oil equal to 0.335 tCO_2e/MWh (Meyers et al. 2016), a total amount of 98.16 tCO_2e per annum will be mitigated. Further the savings on the fuel oil to be purchased will decline by €22,674.89 based on the cost of heavy fuel oil (HFO) used in boilers in Kenyan industries. The LCOE for the SWH system was calculated to be 0.61€/kWh, however, the stability in the prices of solar collectors cannot assure a reduction in the capital cost in the long run (Weiss and Spörk-Dür 2019).

6.3.3.3 Solar PV system

The solar PV system size comprised 200 PV modules and 4 inverters with a total module area of 326.0 m^2 occupying approximately 0.3 acres of land resulting in annual electrical saving of 165.04 MWh for mechanical and electrical needs of the plant. Based on the power costs in Kenya of small industrial businesses, (CI1 415 V) 0.11€/ kWh at peak hours (KPLC 2018), this results in annual savings of €18,154.40. Additionally, 33.41 tCO_2e per annum mitigated. The hourly sub-array output by the system PV (Fig. 6.17), indicates variation in the optimal energy yield throughout the year and day. The month of December records the highest energy yield from 7:00 to 16:00 hrs while the lowest outputs are realized between the months of April and August. The performance metric of the PV system was based on the energy yield for the first year which was 2,230 kWh/kW; capacity factor of 25.6% and the PR of 0.77. The PV system was efficient as PR approached 80% indicating that approximately 77% of the solar energy generated by the system is available for the utilization by the plant (SMA 2016).

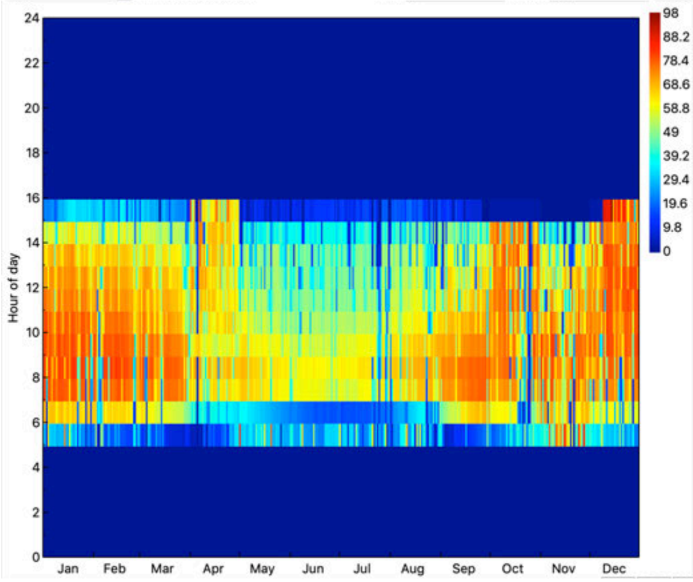


Figure 6. 17 PV Sub array output in kW

The highest energy production by the PV system is in the months of January and December with lowest energy yields in the months of June and July (Fig. 6.18). This can be attributed to lower temperatures and higher rainfalls in Isiolo County from May to July, which results in lower irradiation. This implies that the auxiliary energy supplied by the mains is higher, therefore, higher electricity costs than in January and December. Additionally, during the months that limited camel milk powder and butter are processed, such as the months of February and September, the excess electricity produced can be fed to the grid and sold to Kenya Power & Lighting Company Limited (KPLC) through the power purchase agreement. This will generate additional income for the plant. The LCOE for electrical generation by the PV system was estimated to be 0.06€/kWh which was lower than the electricity cost of 0.11€/kWh. However with the sharp decline in PV module prices (Fu, Feldman, and Margolis 2018), further cost reductions are foreseen.

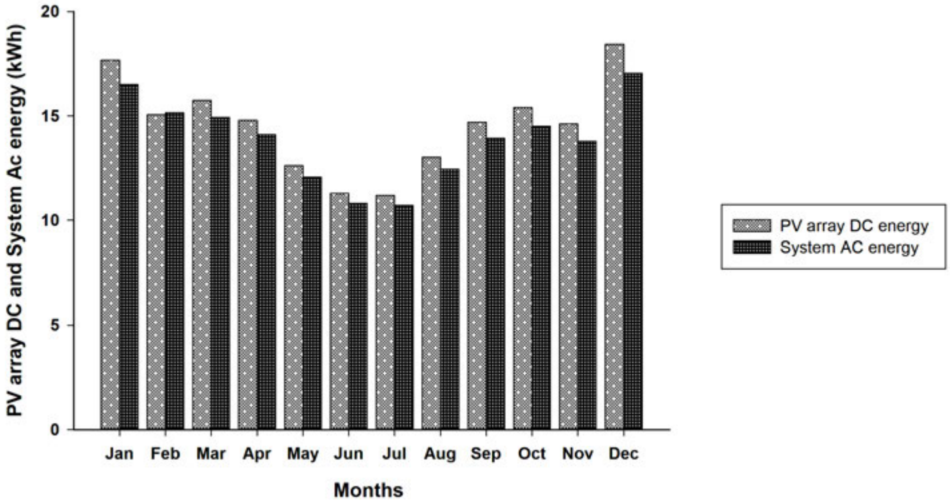


Figure 6. 18 Monthly PV DC and System AC energy of the designed systemin MWh

The losses for the PV system were characterized by irradiance, DC, and AC losses as indicated in Fig 6.19. The irradiance losses comprised soiling, shading and reflection losses which accounted for 6.43% of the losses. DC losses comprised both the modular and inverter losses and accounted for the largest share of the losses accrued of 18.62%.

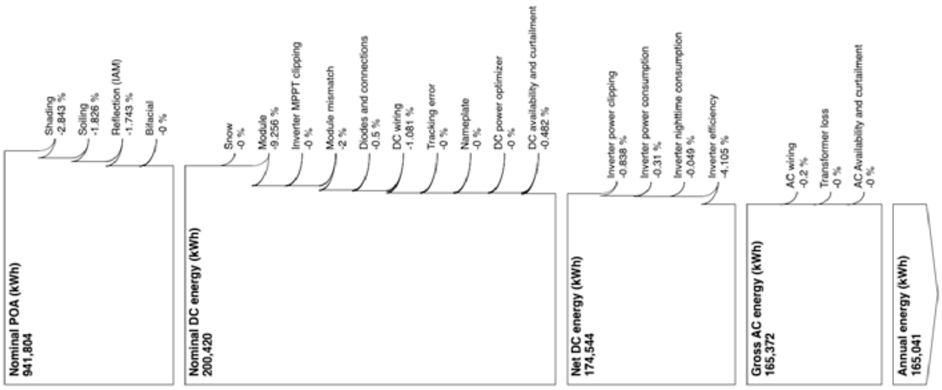


Figure 6. 19 PV system losses

6.3.4 Final process design

By incorporating the different heat recovery options and integrating solar energy for heating and electricity generation, table 6.8 indicates the heat recovery and the CO_2 savings at every step. Overall, through process optimization, heat recovery and solar thermal integration the heating demands were greatly reduced and resulted in mitigation of 298.96 *t*CO_2e per annum (Table 6.8). The highest heat recovery (81.64%) is mainly from the hot water unit where both solar water system, condensate recovery, evaporation condensate reuse, CIP water recovery and regeneration at the pasteurization system are employed. Similarly, electrical demands for mechanical and cooling processes, resulted in a saving of approximately 72.54% with CO_2 emissions reduction of 33.41 tCO_2e per annum (Table 6.8). CO_2 emissions reduction has been realised in industries through process optimization, followed by heat recovery and integration of solar thermal energy (Meyers et al. 2016) and our adoption of these approaches resulted in mitigation of approximately 332.37 *t*CO_2e per annum.

Table 6. 8 Energy demands and Savings for the different process designs

Process Design	Units	Hot water boiler	Indirect air heater	Electricity demands	*t*CO_2e saved	% fuel oil and electricity reduction
Before HR	MWh	1,070.81	173.24	255.93	0	0%
After HR through PinCH	MWh	531.64	155.04	235.31	190.43	38.53%
Selected HR options & condensate recovery	MWh	489.62	155.04	235.31	14.08	2.80%
After Solar PV integration	MWh	489.62	155.04	70.29	29.70	11.00%
After Solar Heat integration	MWh	196.61	155.04	70.29	98.16	19.53%
Total CO_2 savings	***t*CO_2e**	**292.86**	**6.10**	**33.41**	**332.37**	-
Total fuel oil /electricity savings	**MWh**	**874.20**	**18.20**	**185.64**	-	-
Cost savings	**€**	**67,650.90**	**1408.43**	**29,420.40**	**-**	
Unit Savings	**%**	**81.64%**	**10.51%**	**72.54%**		**-**

The overall fuel oil & electricity reduction of 71.86 % from the initial design has been attained. However, the energy savings realized is approximately 41.3 % which is at par with those realised in milk powder production through emerging technologies (Moejes and van Boxtel 2017), optimised evaporation (Walmsley, Atkins, Walmsley, & Neale, 2016), optimised total site utility systems (Walmsley et al., 2016), and ultra-low milk powder production (Walmsley et al., 2016).

The high energy recovery realized in this process is attributed to the assumption that no heat recovery takes place at the beginning of the process and by taking into consideration different heat recovery, fuel oil and electricity replacement options. The selection of fuel based indirect heater for spray drying as opposed to electricity is centred on the thermodynamic inefficiency of power generation, heat from electricity being two to three times more expensive and less safe to use than fuel based heating (Turton et al. 2018). The lower heat recovery from the spray dryer is due to the need to maintain the exhaust temperature above 55 °C to prevent accelerated powder fouling (Walmsley et al., 2014).

6.3.5 Techno and Economic feasibility of the designed plant

6.3.5.1 Economic feasibility analysis

The establishment of a processing plant is strongly influenced by the economic and technical aspects. For a milk powder and butter processing plant, different types of costs influence the financial feasibility of its establishment. Table 6.9 indicates the different estimated costs involved in establishing the proposed new processing plant, the total capital cost and manufacturing expenses were approximated to be 13.33 and 4.90 million Euros respectively. The working capital (WC) for a processing plant is approximated to be 20 % of the fixed capital (FC) (Saravacos and Kostaropoulos 2012), however, in the designed processing plant WC was 13.5 % of the FC indicating a slight variation which could be attributed to the introduction of solar accessories and differences in land rates. The payback period of the plant is approximately 5.2 years with a return on investment of 13.6 % after taxation (Table 6.9).

Table 6. 9 Economic analysis of the proposed camel milk powder and butter processing plant

Economic parameter	Units	Amount	Economic parameter	Units	Amount
Fixed investment capital					
1. Onsite costs	€	7,597,608.10	26. Raw material cost	€	418,000.00
2. Off-site costs	€	4,139,606.12			
Total Fixed capital investment	€	**11,737,214.27**	**Total direct manufacturing expense**	€	**2,866,078.71**

Economic Parameter	Units	Amount	Economic Parameter	Units	Amount
Working capital (WC)			*Indirect expenses*		
3. Raw material inventory	€	20,900	27. Plant indirect expense	€	227,928.24
4. Product & by-product inventory	€	245,228.47	28. Depreciation year 1	€	1,085,698.20
5. Cash on hand	€	122,614.24	**Total manufacturing expense**	€	**4,179,705.16**
6. Accounts receivable	€	490,456.94	29. Packaging & shipping	€	144,056.66
7. Credit for accounts payable	€	532,256.94	**Total product expense**	€	**4,323,761.81**
8. Spare parts inventory	€	176,058.21	30. General overhead expense	€	576,226.64
9. Solar accessories	€	4,088.32	31. Solar variable costs	€	4,580.94
10. **Total Working capital**	€	**1,591,603.12**	**32. Total Indirect expenses**	€	**2,456,490.68**
TOTAL CAPITAL COSTS (TCI)	**€**	**13,328,817.40**	**TOTAL OPERATING EXPENSE**	€	**4,904,569.39**
Direct expense			**Revenue**	€	**9,603,777.29**
11. Maintenance	€	303,904.33	Gross profit	€	**4,699,207.29**
12. Property & tax insurance	€	117,372.14	Taxes (30%)	€	2,881,133.19
13. Environmental charges	€	117,372.14			
14. Research & development	€	58,686.07	**Net cash flow/ net profit (CF)**	€	**1,818,074.71**
15. Utilities	€	853,238.06			
16. Labour	€	50,000.00			
17. Supervision	€	12,500.00			
18. Plant indirect expense	€	303,904.34	Equipment scrap value	€	759,760.81
19. Payroll charges	€	21,875.00	Payback time after tax	Years	5.17
20. Operating supplies	€	3,000.00	Payback time before tax	Years	2.84
21. Laboratory expenses	€	8,750.00	Return on investment	%	13.64
22. Clothing & laundry	€	8,750.00	Pre-tax ROI	%	35.26
23. Technical service	€	12,500.00			
24. Royalties	€	240,094.43	**NPV_{15}**	€	**19,397,905.00**
25. Packaging	€	336,132.21	DCFROR	%	58.00
Total Direct expense	**€**	**2,448,078.71**			

Depending on the estimate level, different methodologies are utilized in estimating investment costs such as current vendor costs, unit costs, capacity exponent ratio, step count method and factorial methods (Towler and Sinnott 2013; Peters et al. 2003). When estimating the cost of organic Rankine cycle (ORC) systems, Lemmens (2016), concluded care ought to be taken when total module costs is used in capital costs estimation to limit utilization of same module factors without considering the diversity in the integration requirements. Therefore, to counter this, we estimated the solar PV system and solar heat using SAM then integrated the results, before completing the economic analysis. To ensure reliability of the module factors, the equipment factors of stainless steel were utilized as this is a food industry establishment (Saravacos and Kostaropoulos 2012; Turton et al. 2018). The high investment costs for the establishment of this plant, will be difficult to realize in the region, however, through public private partnerships (PPP) and loans from credit institutions, it is possible to establish the plant. The plant is profitable and even higher interest rate of 58.0% (DCFROR) for loan repayment will be possible for the plant to break even and pay back the investment cost over its class life.

While the profitability and camel milk losses prevention characterized by trading in fluid milk is assured by the establishment of the plant, the high investment costs will limit its adoption by the target communities based on their socio-economic status. Further the camel milk supply chain is managed by women, the increase in constant supply of camel milk to the plant will significantly increase their income through assurance of a readily available market. However, their ability to raise the capital that is required for the establishment of the plant is limited to either grant from governmental organizations, developmental institutions or NGOs. Additionally, since the camel milk value chain is one of the most important value chains in Isiolo County as identified by the county government, the availability of funding and technical training from the county government could ensure the operation of the plant. However, the cost of the milk powder based on the current world prices (140 €/kg) will limit the accessibility and consumption of the product by the local communities. Thus, production of these powder and butter can be exclusively for export market which will fetch better prices that will increase the household income of the target communities. The proceeds from these export sales can then be utilized by the traders and producers to purchase other food components that can contribute to the household food and nutritional security.

6.3.5.2 Sensitivity analysis

The economic analysis of a project can only be based on the best estimates that can be made of the investment required and the cash flows. Yearly cash flows are influenced by changes in different parameters such as raw materials and operating costs, which will be dependent on the revenue generated based on sales volumes and prices of the products (Turton et al. 2018; Perry and Green 2008). From table 6.8, the NPV was estimated as 19.40 Million Euros and by adjusting the cost of manufacturing, fixed capital cost, revenue, interest rate and taxations rate assuming 20% error range the percentage variations in NPV is given in Fig. 6.20.

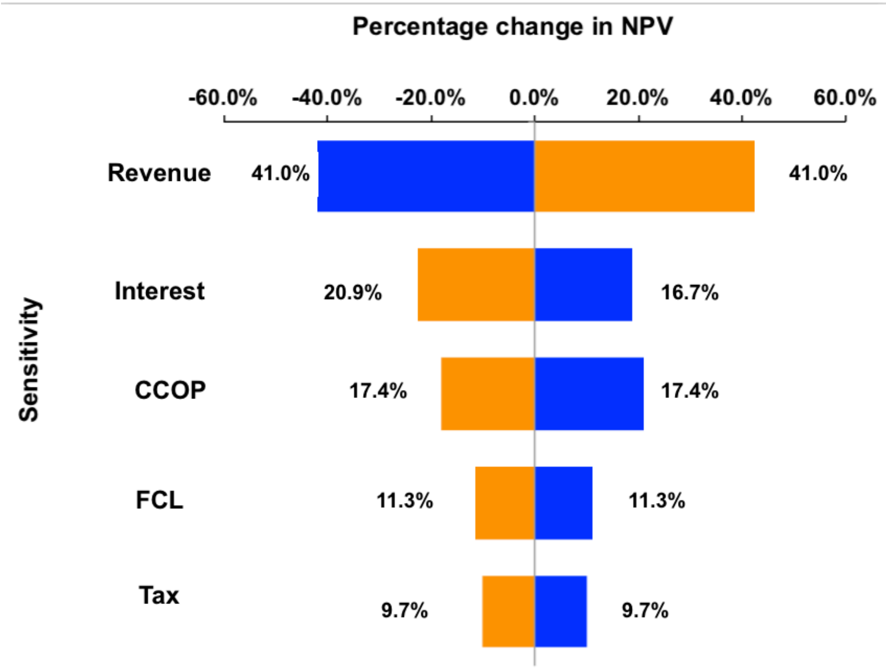


Figure 6. 20 Tornado chart on sensitivity analysis

This implies that the revenue generated by the plant from the sale of milk powder, butter and any other by-products such as fermented milk will significantly influence the NPV of the plant. Particularly the variation in world camel milk powder, butter and fermented milk by 20% will significantly influence the NPV. An increase in revenue by 20% based on the equipment class life of 15 years, will result in approximately 41.04% increase in NPV. Similarly, the interest rate, cost of production, fixed capital and tax rate when each is varied by 20% while keeping the rest constant, results in 20.9 %, 17.4 %, 11.3 % and 9.7 % variation in NPV respectively.

6.4 Conclusion and future work

In designing a processing line for camel milk powder and butter processing, care ought to be taken particularly at creaming and churning stages to preclude the assumptions that the processing lines are similar to that of bovine milk. This is because of the lower cryoglobulin and the high iodine value that influence creaming and churning of butter.

Process optimization, heat recovery options and solar integration have the potential to reduce fossil fuels for thermal and electrical energy demands of a milk powder and butter processing plant in the ASALs by circa 72.54%. Moreover, these measures reduce GHG emissions by approximately 332.37 tCO_2e per annum in the designed model camel milk processing plant. To attain these energy and emissions savings, the following seven measures are essential: evaporation condensate recovery, preheating of CIP water, regeneration at the pasteurization unit, condensate recovery from other processes, recycling the outlet hot air at spray drying and integrating solar heat and solar PV. Highest thermal energy savings are realised through process optimization, thus less investment costs during solar heat integration. The LCOE for PV realized from the simulation was slightly lower than the electricity from the grid in Kenya, thus substituting grid electricity with solar PV generated electricity is much cheaper and reduces CO_2 emissions.

In estimating the capital cost, utilizing the factorial method with the modular factor method is critical but should be industry specific. For instance, in the food industry most equipment are made of stainless steel that is contrary to the chemical industry thus employing a factor of 2, when no data is available is critical. By taking into consideration the steel module factor, the country specific interest, taxation and inflation rates, and solar costs, we can conclude that the estimates provided on the technical aspect can be used as a base when setting up such a plant.

It is highly encouraged that these results and methodologies be utilized and applied to real world projects that intend to reduce industrial fossil fuel consumption and CO_2 emissions. The use of these methodologies will aid in determining the thermal, cooling and mechanical energy demands before establishment of a camel milk powder and butter processing plants in the ASALs. In addition, the economic analysis presented in this study by taking into consideration all aspects from production to final marketing provides a great insight into the economic costs of establishing such a green camel milk powder and butter processing plant in the ASALs. The sensitivity analysis also illustrates the influence of various economic components on the NPV_{15}. By 20% variation of revenue, production costs, taxation, interest rate and fixed capital, the variation in has the greatest effect (41.04%) on NPV_{15}.

While the economic measures indicate that this is an attractive project with the projected revenues, payback period and DCFROR, the high production and capital expenses poses an impediment to its establishment based on the socio-economic status of the publics in the ASALs such as Isiolo County. Hence, subsidies and grants by the national and county governments, NGOs and other developmental organizations will be crucial in facilitating the investment costs and providing necessary subsidies for the establishment of the plant. With the subsidies and the grants, the processing of fluid camel milk to milk powder and butter has the potential to empower the women in the ASALs, ensure availability of the camel milk during dry seasons and thus contribute to food and nutritional security.

Limitations of the study

The unavailability of the actual costs of equipment limited the study to use modular costs and factors to estimate the capital costs. Moreover, the solar heat integration for the high temperature of spray drying process is not considered in this study.

Acknowledgement

The first author, Jackline Akinyi Ogolla would wish to acknowledge Katholische Akademische Ausländer-Dienst (KAAD) for her research stay in Germany. This research was conducted as part of the collaborative project ‘Reduction of Post-harvest Losses and Value Addition in East Africa Food Supply chains’ (RELOAD), funded through the initiative for Research on the Global Food Supply (GlobE) by the German Federal Ministry of Education and Research (BMBF) in cooperation with the German Federal Ministry for Economic Cooperation and Development (BMZ) (Grant Number 031A247D). Lastly, we are appreciative to our anonymous reviewers and the editor for their constructive feedback that substantially contributed to strengthening this paper.

Conflicts of interest

No potential conflict of interest was reported by the authors.

References

AACE International. 2016. “Recommended Practice No. 18R-97: Cost Estimate Classification System, Rev March 1, 2016.” https://doi.org/Recommended Practice No. 18R-97.

Allouhi, A, Y Agrouaz, Mohammed Benzakour Amine, S Rehman, M. S. Buker, T Kousksou, A Jamil, and A Benbassou. 2017. “Design Optimization of a Multi-Temperature Solar Thermal Heating System for an Industrial Process.” *Applied Energy* 206: 382–92. https://doi.org/10.1016/j.apenergy.2017.08.196.

Anderson, Timothy Nicholas, and Mike Duke. 2008. “Solar Energy Use for Energy Savings in Dairy Processing Plants.” In *IPENZ Engineering TreNz 2008-001*, 1–9.

ASHRAE. 2013. *2013 ASHRAE Handbook: Fundamentals*. *Design*. https://doi.org/10.1163/ej.9789004155947.i-937.23.

Atkins, Martin J, Michael R W Walmsley, and Andrew S Morrison. 2010. “Integration of Solar Thermal for Improved Energy Efficiency in Low-Temperature-Pinch Industrial Processes.” *Energy* 35: 1867–73. https://doi.org/10.1016/j.energy.2009.06.039.

Atkins, Martin J, Michael R W Walmsley, and James R Neale. 2011. “Integrating Heat Recovery from Milk Powder Spray Dryer Exhausts in the Dairy Industry.” *Applied Thermal Engineering* 31 (13): 2101–6. https://doi.org/10.1016/j.applthermaleng.2011.03.006.

Berk, Zeki. 2013. *Food Process Engineering and Technology*. *Elsevier*. https://doi.org/10.1016/B978-0-12-415923-5.00028-9.

Blair, Nate, Nicholas Diorio, Janine Freeman, Paul Gilman, Steven Janzou, Ty W. Neises, and Michael J. Wagner. 2018. “System Advisor Model (SAM) General Description.” Oak ridge.

Buker, M. S., and S.B. Riffat. 2017. “Build-up and Performance Test of a Novel Solar Thermal Roof for Heat Pump Operation.” *International Journal of Ambient Energy* 38 (4): 365–79.

Bylund, G. 2003. *Dairy Processing Handbook*.

Chemical engineering. n.d. “Economic Indicators.” 2018. Accessed November 13, 2018. https://www.chemengonline.com/site/plant-cost-index/.

Clark, J. Peter. 2009. *Practical Design, Construction and Operation of Food Facilities. Food Science and Technology International Series*. First. Burlington , USA: Elsevier Inc.

Deloitte. 2018. “International Tax Singapore Highlights 2018.”

DLA Piper. 2019. “Renewable Energy in Africa.” London, UK. https://doi.org/10.3149/fth.1201.38.

Duffie, J., and W Beckman. 2013. *Solar Engineering of Thermal Processes, 4th Ed.* Vol. 116. https://doi.org/10.1115/1.2930068.

Eicker, U., A. Colmenar-Santos, D. Borge-Diez, L.Teran, and M. Cotrado. 2014. “Economic Evaluation of Solar Thermal and Photovoltaic Cooling Systems through Simulation in Different Climatic

Conditions: An Analysis in Three Different Cities in Europe." *Energy Buikding* 70: 207–23.

Eiholzer, Tobias, Donald Olsen, Sebastian Hoffmann, Barbara Sturm, and Beat Wellig. 2017. "Integration of a Solar Thermal System in a Medium-Sized Brewery Using Pinch Analysis: Methodology and Case Study." *Applied Thermal Engineering* 113 (February): 1558–68. https://doi.org/10.1016/j.applthermaleng.2016.09.124.

ERC. 2018. "Solar Photovoltaic Industry in Kenya." Nairobi.

FAO. 2018. "AGRICULTURAL TRADE, CLIMATE CHANGE AND FOOD SECURITY AGRICULTURAL COMMODITY MARKETS 2018 THE STATE OF." Rome, Italy.

Farah, Zakaria, Thomas Streiff, and M.R. Marc R Bachmann. 1989. "Manufacture and Characterization of Camel Milk Butter." *Milchwissenschaft* 44 (7): 412–14.

Faye, B, G Konuspayeva, S Messad, and G Loiseau. 2008. "Discriminant Milk Components of Bactrian Camel (Camelus Bactrianus), Dromedary (Camelus Dromedarius) and Hybrids." *Dairy Science & Technology* 88 (6): 607–17. https://doi.org/10.1051/dst.

Fox, P.F., and A.L. Kelly. 2012. "Biochemistry of Milk Processing." In *Food Biochemistry and Food Processing*, edited by Benjamin K. Simpson, Leo M.L. Nollet, Fidel Toldra, Soottawat Benjakul, Gopinadhan Paliyath, and Y.H. Hui, second, 465–72. Iowa: JohnWiley & Sons, Inc.

Fu, Ran, David Feldman, and Robert Margolis. 2018. "U . S . Solar Photovoltaic System Cost Benchmark : Q1 2018." *Nrel*, no. Novmnber: 1–47. https://doi.org/10.7799/1325002.

Garret, D.E. 2012. "Appendix 1: EQUIPMENT COST ESTIMATES." *Chemical Engineering Economics*. https://doi.org/10.1007/978-94-011-6544-0.

Government of Kenya. 2018. "National Climate Change Action Plan (Kenya) 2018-2022." Vol. I. Nairobi, Kenya.

Graet, Y Le, and G Brule. 1982. "Effect of Concentration and Drying on Mineral Equilibria of Skim Milk and Retentates." *Lait* , 113–25.

Guthrie, K. M. 1969. "Capital Cost Estimating,." *Chem. Eng.* 76 (3): 114.

Guthrie, K. M.. 1976. "Process Plant Estimating Evaluation and Control." *Engineering and Process Economics* 1 (3): 241–43. https://doi.org/10.1016/0377-841x(76)90011-5.

Hassine, Ilyes Ben, Annabell Helmke, Stefan Heß, Pierre Krummenacher, Bettina Muster, Bastian Schmitt, and Hans Schnitzer. 2015. "Solar Process Heat for Production and Advanced Applications: Integration Guideline." *IEA SHC Task 49*.

HSLU. 2012. "PinCH - An Analysis and Design Tool for Process Integration."

KAM. 2018. "Manufacturing in Kenya Under the 'Big 4 Agenda.'"

KCIC. 2018. "Kenya Solar Pv Market Assesment." Nairobi; Kenya.

Kelly, A. L. L., J. E. E O'Connell, and P. F. F. Fox. 2003. "Manufacture and Properties of Milk Powders."

In *Advanced Dairy Chemistry: Vol. 1. Proteins*, 1:1027–62. Boston, MA: Springer US. https://doi.org/10.1007/978-1-4419-8602-3_29.

Kemp, Ian C. 2007a. *Pinch Analysis and Process Integration: A User Guide on Process Integration for the Efficient Use of Energy*. *Pinch Analysis and Process Integration*. Second edi. Elsevier Ltd. https://doi.org/http://dx.doi.org/10.1016/B978-075068260-2.50003-1.

Kemp, Ian C. 2012. "Fundamentals of Energy Analysis of Dryers." In *Modern Drying Technology*, 4:1–45. https://doi.org/10.1002/9783527631728.ch21.

Kemp, Ian C. 2007b. *Pinch Analysis and Process Integration*. Second edi. Elsevier Ltd. https://doi.org/10.15713/ins.mmj.3.

KNBS. 2017. "Kenya Economic Survey 2017."

KNBS. 2018. "Kenya Integrated Household Budget Survey 2015-2016." Nairobi, Kenya.

KNBS. 2019a. *2019 KENYA POPULATION AND HOUSING CENSUS VOLUME I : POPULATION BY COUNTY AND SUB-COUNTY*. Vol. I. Nairobi, Kenya: Government Printers.

KNBS. 2019b. "Economic Survey 2019." Nairobi.

Koohafkan, P, and B A Stewart. 2008. *Water and Cereals in Drylands*. *Food and Agriculture Organization of the United Nations and Earthscan*. Food and Agriculture Organization of the United Nations and Earthscan.

KPLC. 2018. "Electricity Cost Tariffs & Schedule of Tariffs 2018." Nairobi, Kenya.

Krummenacher, Pierre, and Bettina Muster. 2015. "Solar Process Heat for Production and Advanced Applications Methodologies and Software Tools for Integrating Solar Heat into Industrial Processes." *IEA SHC Task 49*.

Kulkarni, Govind N., Shireesh B. Kedare, and Santanu Bandyopadhyay. 2008. "Design of Solar Thermal Systems Utilizing Pressurized Hot Water Storage for Industrial Applications." *Solar Energy* 82 (8): 686–99. https://doi.org/10.1016/j.solener.2008.02.011.

Langrish, T.A.G. 2009. "Multi-Scale Mathematical Modelling of Spray Dryers." *Journal of Food Engineering* 93 (2): 218–28. https://doi.org/10.1016/j.jfoodeng.2009.01.019.

Lemmens, Sanne. 2016. "Cost Engineering Techniques & Their Applicability for Cost Estimation of Organic Rankine Cycle Systems." *Energies* 9 (7). https://doi.org/10.3390/en9070485.

Linnhoff, B., G.J. Ashton, and E.D.A. Obeng. 1988. "Proceess Integration of Batch Processes." *Institution of Chemical Engineers Symposium Series* 109: 221–37.

Masters, Keith. 1994. "Scale-up of Spray Dryers." *Drying Technology* 12 (1–2): 235–57. https://doi.org/10.1080/07373939408959955.

Mekhilef, S., R. Saidur, and A. Safari. 2011. "A Review on Solar Energy Use in Industries." *Renewable and Sustainable Energy Reviews* 15 (4): 1777–90. https://doi.org/10.1016/j.rser.2010.12.018.

Meyers, Steven, Bastian Schmitt, Mae Chester-Jones, and Barbara Sturm. 2016. “Energy Efficiency, Carbon Emissions, and Measures towards Their Improvement in the Food and Beverage Sector for Six European Countries.” *Energy* 104: 266–83. https://doi.org/10.1016/j.energy.2016.03.117.

Miller, C. A. 1965. “Factor Estimating Refined for Appropriation of Funds.” *Chem. Eng. Cost File* 7: 92.

Ministry of Energy and Petroleum, Kenya. 2015. “The Energy Bill, 2015 Arrangement of Clauses.”

Moejes, S.N., and A.J.B. van Boxtel. 2017. “Energy Saving Potential of Emerging Technologies in Milk Powder Production.” *Trends in Food Science & Technology* 60: 31–42. https://doi.org/10.1016/j.tifs.2016.10.023.

Muster-Slawitsch, Bettina, C. Brunner, and J. Fluch. 2014. “Application of an Advanced Pinch Methodology for the Food and Drink Production.” *Iley Interdiscip Rev Energy Environ* 3 (6): 56–74.

Navarrete, P. F. 1995. *Planning, Estimating, and Control of Chemical Construction Projects*. New York: Marcel Dekker.

NREL. 2018. “NREL System Advisor Model (SAM). 2018. ‘SAM Help System.’”

Ogolla, J.A., B. Kulig, L. Bădulescu, M.W. Okoth, G. Esper, J. Breitenbach, O. Hensel, and B. Sturm. 2019. “Influence of Inlet Drying Air Temperature and Milk Flow Rate on the Physical, Optical and Thermal Properties of Spray-Dried Camel Milk Powders.” *Food and Bioprocess Technology*. https://doi.org/10.1007/s11947-019-2243-5.

Ogolla, Jackline Akinyi, Christian Dede, Michael Wandayi Okoth, Oliver Hensel, and Barbara Sturm. 2017. “Strategies and Technologies for Camel Milk Preservation and Utilization of Non-Marketed Milk in Arid and Semi-Arid Areas.” *East African Agricultural and Forestry Journal*. https://doi.org/10.1080/00128325.2017.1363686.

Oldfield, D J, M W Taylor, and H Singh. 2005. “Effect of Preheating and Other Process Parameters on Whey Protein Reactions during Skim Milk Powder Manufacture.” *International Dairy Journal* 15 (5): 501–11. https://doi.org/10.1016/j.idairyj.2004.09.004.

Otanicar, T., R. A. Taylor, and P. E. Phelan. 2012. “Prospects for Solar Cooling – an Economic and Environmental Assessment. Sol Energy 2012;86(5):1287–99.” *Solar Energy* 86 (5): 1287–99.

Perry, Robert H., and Don W. Green. 2008. *Perry’s Chemical Engineers’ Handbook*. Eighth. Vol. 1. The McGraw-Hill Companies, Inc. https://doi.org/10.1036/0071422943.

Peters, Max, Klaus Timmerhaus, Ronald West, and Max Peters. 2003. *Plant Design and Economics for Chemical Engineers*.

Pisecky, Jan. 2012. *Handbook of Milk Powder Manufacture*. Edited by Vagn Westergaard and Ejnar Refstrup. *GEA Process Engineering A/S (GEA Niro)*. Second Edi. https://doi.org/10.1007/978-1-908517-43-2.

Plaza, Diego Martinez, Inmaculada Cãnadas Martinez, Gustavo Mallol Gasch, Félix Téllez Sufrategui, and

José Rodríguez García. 2015. "A Case Study of the Feasibility of Using Solar Concentrating Technologies for Manufacturing Ceramics." *Journal of Cleaner Production* 87: 977–91. https://doi.org/10.1016/j.jclepro.2014.09.090.

Prasad, Penny, Robert Pagan, Michael Kauter, Nicole Price, and Patrick Crittenden. 2004. "Eco-Efficiency for the Dairy Processing Industry The UNEP Working Group for Cleaner Production in the Food Industry."

Quijera, José Antonio, María González Alriols, and Jalel Labidi. 2011. "Integration of a Solar Thermal System in a Dairy Process." *Renewable Energy* 36 (6): 1843–53. https://doi.org/10.1016/j.renene.2010.11.029.

Quijera, José Antonio, and Jalel Labidi. 2013. "Pinch and Exergy Based Thermosolar Integration in a Dairy Process." *Applied Thermal Engineering* 50 (1): 464–74. https://doi.org/10.1016/j.applthermaleng.2012.06.044.

Ramírez, C. A., M. Patel, and K. Blok. 2006. "From Fluid Milk to Milk Powder: Energy Use and Energy Efficiency in the European Dairy Industry." *Energy* 31 (12): 1648–68. https://doi.org/10.1016/j.energy.2005.10.014.

Republic of Kenya. 2018. "Isiolo County Intergrated Development Plan (CDP)." Isiolo. https://doi.org/10.1017/S0022278X00014853.

Rüegg, M., and Z. Farah. 1991. "Melting Curves of Camel Milk Fat." *Milchwissenschaft - Milk Science International* 46 (5): 361–62.

Sanjuan, Neus, Franziska Stoessel, and Stefanie Hellweg. 2014. "Closing Data Gaps for LCA of Food Products: Estimating the Energy Demand of Food Processing." *Environmental Science & Technology* 48: 1132–40. https://doi.org/10.1021/es4033716.

Saravacos, George, and Athanasios E. Kostaropoulos. 2012. *Handbook of Food Processing Equipment*. Second. Springer. https://doi.org/10.1007/978-3-319-25020-5_4.

Schmitt, Bastian. 2014. "Integration Thermischer Solaranlagen Zur Bereit- Stellung von Prozesswärme in Industriebetrieben." Shaker Verlag.

Schmitt Bastian. 2016. "Classification of Industrial Heat Consumers for Integration of Solar Heat." In *Energy Procedia*, 91:650–60. https://doi.org/10.1016/j.egypro.2016.06.225.

Sharma, Ashish K., Chandan Sharma, Subhash C. Mullick, and Tara C. Kandpal. 2017. "Potential of Solar Industrial Process Heating in Dairy Industry in India and Consequent Carbon Mitigation." *Journal of Cleaner Production* 140: 714–24. https://doi.org/10.1016/j.jclepro.2016.07.157.

Singh, R. Paul, and Dennis R. Heldman. 2014. *Introduction to Food Engineering*. Edited by Steve L. Taylor. 4th ed. Elsevier. https://doi.org/10.1016/B978-0-12-398530-9.00005-X.

SMA. 2016. "Performance Ratio-Quality Factor for the PV Plant." Kassel, Germany.

Solar4Ever. 2019. "Sunpower Solar Panel Review." 2019. https://www.solar4ever.com.au/Sunpowersolarpanelreview.php.

Stoker, Jeanie. 2000. "Keeping You Informed." *Home Healthcare Nurse* 18 (6): 371–72. https://doi.org/10.1097/00004045-200006000-00012.

Sturm, Barbara. 2018. "Vorgelegt von: Dr. Agr. Barbara Sturm Witzenhausen, Januar 2018." Universität Kassel.

Sturm, Barbara, Steven Meyers, Yongjie Zhang, Richard Law, Eric J. Siqueiros Valencia, Huashan Bao, Yaodong Wang, and Haisheng Chen. 2015. "Process Intensification and Integration of Solar Heat Generation in the Chinese Condiment Sector - A Case Study of a Medium Sized Beijing Based Factory." *Energy Conversion and Management* 106: 1295–1308. https://doi.org/10.1016/j.enconman.2015.10.045.

Tawil, Elie, and Leed Ap. n.d. "Boiler Fuels , Emissions and Efficiency."

Towler, Gavin, and Ray Sinnott. 2013. *Chemical Engineering Design: Principles, Practice and Economics of Plant and Process Design*. *Chemical Engineering Design*. Second Edi. Elsevier. https://doi.org/10.1016/B978-0-08-096659-5.00022-5.

Turton, Richard, Joseph A. Shaeiwitz, Debangsu Bhattacharyya, and Wallace B. Whiting. 2018. *Analysis, Synthesis, and Design of Chemical Processes*. 5th editio. Upper Saddle River, NJ, USA: Pearson Education International.

Ulrich, Gail D. 1984. *A Guide to Chemical Engineering Process Design and Economics*. New York: John Wiley & Sons. https://doi.org/10.1002/aic.690300636.

Viessmann. 2013. "Oil/Gas Boilers for Medium and High Output."

Walmsley, Michael R.W., Timothy G. Walmsley, Martin J. Atkins, and James R. Neale. 2016. "Sustainable Milk Powder Production Using Enhanced Process Integration and 100 % Renewable Energy." *Chemical Engineering Transactions* 52: 559–64. https://doi.org/10.3303/CET1652094.

Walmsley, T.G:, M. J. Atkins, M.R.W. Walmsley, and J. R. Neale. 2016. "Appropriate Placement of Vapour Recompression in Ultra-Low Energy Industrial Milk Evaporation Systems Using Pinch Analysis." *Energy* 116 (2): 1269–81. https://doi.org/dx.doi.org/10.1016/j.energy.2016.04.026.

Walmsley, T.G., M. J Atkins, M. R. W Walmsley, J.R. Neale, Philip M., and R.H. Peesel. 2016. "Total Site Utility Systems Optimisation for Milk Powder Production." *Chemical Engineering Transactions* 52: 235–40. https://doi.org/10.3303/CET1652040.

Walmsley, Timothy G., Martin J. Atkins, Michael R.W. Walmsley, Matthias Philipp, and Ron-Hendrik Peesel. 2016. "Process and Utility Systems Integration and Optimisation for Ultra-Low Energy Milk Powder Production." *Energy*, 1–15. https://doi.org/10.1016/j.energy.2017.04.142.

Walmsley, Timothy G., Michael R.W. Walmsley, Martin J. Atkins, James R. Neale, and Chloe M. Sellers.

2014. "An Experimentally Validated Criterion for Skim Milk Powder Deposition on Stainless Steel Surfaces." *Journal of Food Engineering* 127: 111–19. https://doi.org/10.1016/j.jfoodeng.2013.11.025.

Walstra, P, J T M Wouters, and T J Geurts. 2006. *Dairy Science and Technology*. *Facilities*. Vol. 4. https://doi.org/9780824727635.

Weiss, Werner, and Monika Spörk-Dür. 2019. "Global Market Development and Trends in 2018." *Solar Heat Worldwide Report*. Vol. 1.

Westergaard, Vagn. 2011. "Milk Powder Technology Evaporation and Spray Drying."

Xu, Tengfang, and Joris Flapper. 2009. "Energy Use and Implications for Efficiency Strategies in Global Fluid-Milk Processing Industry." *Energy Policy* 37 (12): 5334–41. https://doi.org/10.1016/j.enpol.2009.07.056.

Xu, Tengfang, and Joris Flapper 2011. "Reduce Energy Use and Greenhouse Gas Emissions from Global Dairy Processing Facilities." *Energy Policy* 39 (1): 234–47. https://doi.org/10.1016/j.enpol.2010.09.037.

Xu, Tengfang, Joris Flapper, and Klaas Jan Kramer. 2009. "Characterization of Energy Use and Performance of Global Cheese Processing." *Energy* 34 (11): 1993–2000. https://doi.org/10.1016/j.energy.2009.08.014.

7. General Discussion

7.1 Strategies and technologies for camel milk preservation and utilization of non-marketed milk in arid and semi-arid areas

This study in Chapter 4 examines the strategies and technologies that are employed by camel milk producers and traders to limit the milk losses. Further the study presents the utilization of non-marketed milk that would have been considered as losses. The identification of these strategies and technologies in the two sub-counties of Isiolo County assessed began at farm level through to consumption level employing the supply chain approach. By employing a mixed method design in data collection which comprise of both qualitative and quantitative data collection methods (Creswell and Clark 2011), the limitations of applying only one methodology is abated and rich data in breadth and depth is collected (Molina-Azorin 2016).

The results in Chapter 4 show that the camel milk supply chain in Isiolo County is characterised by players who performed five main chain functions: production, primary transportation, collection, secondary transportation and retail (Table 4.3). The actors identified along the camel milk supply chain are retailers, bulking traders, non-bulking traders, motorcycle operators, land cruiser operators and producers. These actors perform chain functions of secondary transportation (retailers, cart and bus drivers); collection (Bulking and non-buking traders); primary transportation (motorcycles and land cruiser operators) and production (producers). The losses that were characterized in the present study were mainly spillages, spoilages and economic along the supply chain. Spoilages along the supply chain were mainly due to unhygienic milk handling practice, delay in milk delivery, mechanical problems by the buses, carts, Landcruiser and motorcycles; chemical and physical contamination and lack of milk preservation technologies. Spillages were majorly due to poor terrain, overloading of the vehicles, unreliable transportation and loosely tied containers and these increased during the wet season (Table 4.4). Migration of camels during the dry season, sickness of camels, insecurity, mixing of milk from different milking and lack of market in wet season were main contributors to economic losses.

Seasonal fluctuations in Isiolo County affected the camel milk production, losses, consumption, rejects, sales and pricing. Our findings in Chapter 4 were similar to other findings across the world where availability of forage and water during the rainy season resulted in increased yield (Hussein 1999; Elhadi, Nyariki, and Wasonga 2015). Often it is assumed that milk that is not sold is often characterised as losses based on spillage, spoilage or market glut (Nori 2010). In this study, the variation of the volume and the utilization of non-marketed milk was season dependent, 8.1% and 2.4% of the total yield in wet and dry season respectively. Chapter 4 findings indicated that the non-marketed milk was either discarded, consumed, fed to the calf, processed or offered to the neighbours (Chapter 4, Fig 4.4). However, the volume and quantity was season dependent, with higher volumes discarded in the wet season while during the dry season, largest percentage was processed by allowing natural fermentation into *Susaac* and sugar added (Fig. 4.4) (Noor, Bebe, and Guliye 2012). Bush (1995) and Sikana, Kerven, and Benkhe (1993) documented that among the pastoral communities in Africa, non-marketed milk was presented as a gift to neighbours in order to fortify the social ties and to seek help from wealthy households. In addition, among the pastoral communities, herd replacement and growth is of great value as opposed to immediate economic gain, thus calves are allowed to feed on the dam irrespective of the season (Western and Finch 1986; Holden, Coppock, and Assefa 1991).

The preservation technologies for camel milk in Isiolo County (Fig. 4.5), were heating, cooling and value-added technologies. The heating entails fumigation of the milk container and boiling, while the cooling technologies entailing freezing, utilization of *qoodha*, chilling and simple evaporative cooling (fig 4.6 a-f). These preservation technologies are similar to those reported by different authors for Kenya, Ethiopia and Somalia (Seifu 2007; Wayua, Okoth, and Wangoh 2012; Tabary 2018). Further, these technologies utilize conventional energy sources mainly firewood and charcoal, despite the ban on logging and the health risks associated with use of these bio-fuels (Chapter 4) (Lim et al. 2012; Gathui and Ngugi 2010). The value-added products which are mainly produced during the wet seasons are butter, cheese and yoghurt. These are sold within the localities (Nori et al. 2006; Sadler et al. 2009). This finding on preservation technologies available in the study area implies that the technologies employed are only able to preserve the milk for a short duration of time and thus cannot be kept for a longer duration. This infers that there is no surety of available preserved milk during the dry seasons. Thus, the consumers are not cushioned against the high prices (75.3% higher, Table 4.4) during this season. To be able to withstand the higher prices, the consumers consume fresh or powdered bovine milk depending on availability and proximity to the urban centres in neighbouring counties such as Meru. Further the high volume of milk sold during the dry season due to the high market prices (Table 4.4) has been documented to be driven by the need of the households to purchase cereals and proteins or pay debt (Elhadi, Nyariki, and Wasonga 2015; Hussein 1999).

This study further provided insights into the powder properties that are preferred by the consumers of powdered milk in the ASALs. The attributes of storability, transportability and affordability (Chapter 4, Fig. 4.8) were characterised as important aspects of the powder by the respondents. These attributes differ from those reported by Akweya, Gitao, and Okoth (2012), as the respondents considered packaging, colour, taste, aroma and thickness were critical for liquid milk. The powder preference can be related to the findings above where spillages and spoilages are common due to poor terrain, unreliable transportation and loosely tied containers which inhibit transportation of fluid milk. Further affordability is critical as during dry seasons, high prices inhibit consumption of camel milk.

Overall the technologies and strategies employed along the camel milk value chain in Isiolo County elucidated both the traditional and modern practices to preserve the milk and limit the losses. It also revealed how the non-marketed milk is utilized in the study area and the different value addition practices to camel milk. It further identified the gaps that exists in ensuring availability of milk throughout the year, the technological considerations for technological development in value addition of camel milk and the socio-economic status of the target group.

7.2 How the inlet drying air temperature and milk flow rate influence the physical, optical and thermal properties of spray-dried camel milk powders.

The desire by the residents in the study area in Isiolo County and the unavailability of preservation technologies for longer shelf life as deduced from Chapter 4, prompted the research on milk powder production from camel milk. Spray drying is the most common methodology that is used in the production of milk and milk product powders (Mujumdar, Huang, and Chen 2010). The study on how the physical, optical and thermal properties of spray dried camel milk powder are influenced by processing conditions mainly inlet drying air temperatures and milk flow rate are addressed in Chapter 5. By employing a general factorial experimental design with two independent and a dependent co-factor, the experimental data was fed into the Design-Expert® Software Version 10 (DX10) (Stat-Ease, Inc., Minneapolis, USA) and analysed using the response surface methodology (RSM). The effect of the two independent variables (flow rate and inlet temperature) on the physical, colour and reconstitution properties of the spray dried camel milk powders were investigated to determine the optimal conditions by employing a randomised two by three factorial design. The RSM was chosen due to its ability to detect the interactions between the inlet temperature and flow rate, and a possible quadratic term of inlet temperature and the flow rate (Ferreira et al. 2007).

Findings of the present study in Chapter 5 indicate higher viscosity (Fig. 5.1) and lower total solids (table 5.2) compared to other studies (Khaskheli et al. 2005; Farah 1996; El-Hadi Sulieman, Ilayan, and El-Awad El Faki 2006). The variation of our study findings with literature can be attributed to difference in diet, geographical location, number of milking per day and lactation period that influence the physical characteristics of camel milk (Konuspayeva, Faye, and Loiseau 2009). However, the pH and density (table 5.2, Chapter 5) were within the ranges stipulated within the literature implying that irrespective of the feed, diet, lactation period and number of milking, pH and density are not significantly influenced (Kherouatou et al. 2003).

Physical and functional properties of milk powders such as moisture content, reconstitution and bulk properties are important for recombination and use in the manufacture of other food products (Koç et al. 2014; Birchal et al. 2005). Despite significant research on how spraying drying conditions influence these properties in bovine, goat and donkey milk, less research has been undertaken on CM (Oldfield and Singh 2005; Reddy et al. 2014; Di Renzo, Altieri, and Genovese 2013). Studies on thermal properties of freeze dried CM powders and how feed direction and concentration influence physicochemical properties of spray dried CM powders have been presented by Rahman et al. (2012) and Sulieman et al. (2014) respectively. The study in Chapter 5 aimed to fill the gap that has not been addressed in the literature on how the spray drying conditions particularly the inlet air drying temperature and feed rate influenced the physical, optical and thermal properties of camel milk.

To limit microbial contamination and increase the shelf life, milk powders moisture content is maintained below 3.0% (Pisecky 2012), however, from our findings (Chapter 5) the CM powders moisture contents were slightly higher and ranged from 3.3-5.5% (Table 5.2). The variation in the moisture content could be attributed to the nature of the feed and the inlet air drying temperatures. It has been documented by Sulieman et al. (2014) that the more the concentrated the feed, the lower the moisture content, however, our samples were not concentrated thus the higher moisture contents. Further, while increase in the moisture content was attributed to decrease in inlet air drying temperature and increase in milk flow rate, the model outcome implied that the inlet air drying temperature had a greater influence than the milk flow rate (Table 5.3).

Powder bulk properties which entail tapped bulk density, loose bulk density, Hausner ratio, compressibility and Carr Index are important for handling, packaging and measurement of milk powders (Barbosa-Cánovas et al. 2005; Sharma, Jana, and Chavan 2012). High inlet air drying temperatures result in faster moisture evaporation, faster surface hardening, leading to hollow and porous particles and thus lower bulk densities as observed in Chapter 5, (Fig. 5.4 a & b) and in literature (Tonon, Brabet, and Hubinger 2008; Bansal, Sharma, and Nanda 2014). This further enhances the occluded air within the particles, thus increasing the susceptibility of the powders to oxidation and also bigger packaging volumes are essential (Kurozawa, Park, and Hubinger 2009; Goula and Adamopoulos 2008). Commercially the milk powders bulk density ranges between 400-630 kgm^{-3} (Barbosa-Cánovas et al. 2005; Schuck, Dolivet, and Jeantet 2012), this slightly differed from the findings in Chapter 5, (Fig 5.4 a & b), which ranged from 390-480 kgm^{-3}. This can be attributed to the difference in the processing conditions such as the concentration and type of feed, the nozzle utilized and the drying parameters (Masters 1994; Pisecky 2012; Sharma, Jana, and Chavan 2012).

Surface hardening is enhanced by increasing the spray drying temperatures thus lowering dispersibility (Reddy et al. 2014). A similar effect was observed in the laboratory spray dried CM at higher temperatures of 130 °C (Chapter 5; Fig 5.3 a). On the other hand, wettability increased with an increase in inlet air drying temperature, however, the values of 120 s were higher than those reported in literature of both goat and bovine milk powders (Westergaard 2011; Schuck, Dolivet, and Jeantet 2012; Reddy et al. 2014). Instant powders are wetted within less than 60 s, CM powders in this study wetted at greater than 120 s hence limiting its reconstitution at home. This could be attributed to lipophilic properties due to the fat molecules present on the milk powder surface, that are hydrophobic thus decreasing the wettability of the powders (Kelly, O'Connell, and Fox 2003; Zbikowska and Zbikowski 2006; Kim, Chen, and Pearce 2002). Further increasing the inlet air drying temperature decreases the moisture content as reported by Chegini and Taheri (2013), and similar observations were made in this study (Fig. 5.3 b). The reconstitution properties of the CMM powders produced by the laboratory spray drier were less than those desired industrially of > 85% for dispersibility and < 60 s for wettability (Schuck, Dolivet, and Jeantet 2012). The study in Chapter 5 only investigated two parameters, the inlet air drying temperature and the milk flow rate, however, other factors such as the type of atomiser, drying methodology, nature of feed, concentration of feed, pre-treatment of feed and presence of amphiphilic agents also influence the reconstitution properties (Reddy et al. 2014; Zbikowska and Zbikowski 2006; Fox and Kelly 2012). Moreover, industrially to enhance the powder reconstitubility and ensure instantization for recombination and reuse, surface active agents are added and agglomeration of the powders through multistage spray drying is practised (Pisecky 2012; Kelly, O'Connell, and Fox 2003).

While great difference in the effects of inlet air drying and milk flow rate on the different characteristics assessed exists, there was limited variation in the particle morphology of the powders as observed under the SEM (Fig. 5.6). The particles appeared with collapsed structure in different milk powders have been attributed to lower inlet drying temperatures, low milk concentration and utilization of two fluid nozzle at laboratory scale (Chapter 5) (Nijdam and Langrish 2006; Kim, Chen, and Pearce 2009; Fyfe et al. 2011). At low temperatures (<180 °C), the skin remains damp and supple for longer so that the hollow particle can collapse and shrink as it cools (Hassan and Mumford 1993; Nijdam and Langrish 2005). Low feed concentration and higher drying temperature results in faster moisture evaporation, faster drying, skin hardening and inhibits migration of protein and other dissolved substances to the droplet surface before skin formation (Kim, Chen, and Pearce 2009). As the particle moves towards the cooler regions of the dryer, the hardened and dry skin limits the deflation of the hollow particle (Pisecky 2012; Kim, Chen, and Pearce 2009).

Colour properties (L*, a*, b* and ΔE) play a significant role in acceptability of food products and thus milk powders. These properties are influenced by the effect of heat treatment on the biochemical components of the food. Decrease in moisture content due to high inlet air drying temperatures coupled with low milk flow rate (Fig. 5.2) exposes the sugars and proteins in the milk resulting in caramelisation and Maillard reactions decreasing the L* values (Daza et al. 2016; Schuck, Dolivet, and Jeantet 2012). Further the a* values tended towards the redness parameter when the inlet air drying temperature increased and the milk flow rate decreased, this can be attributed to the enzymic and non-enzymic reactions that take place during drying of the milk (Sulieman et al. 2014; Reddy et al. 2014; Sturm, Hofacker, and Hensel 2012). Nollet, Toldrá, and Group (2010), established that in foods of animal origin inclusive of powders, ΔE values higher than 3.8 as observed in Chapter 5, (Fig. 5.5 d), implies that it is possible to perceive the colour change visually. Melanoidin formation due to Maillard reaction is enhanced with increase inlet air drying temperature and decreased milk flow rate (Table 5.2), similar findings have been observed in apples (Sturm, Hofacker, and Hensel 2012).

Thermal properties of milk powders are dependent on thermal characteristics such as freezing temperature, glass transition temperature (T_g) and melting point. Storage stability of milk powders is determined by T_g, which decreases with increase in moisture content (Table 5.6) (Chapter 5; Nijdam and Langrish 2005). The lower the T_g, the less stable the milk powder and the stickier the milk powder particularly at temperature below the room temperature (Santhalakshmy et al. 2015). While the findings in Chapter 5 are similar to that of freeze-dried and skim milk camel milk powders (Rahman et al. 2012), there is a slight variation in the onset T_g temperature and the endothermic peaks on the DSC thermogram. Rahman et al. (2012) reported that temperature range in determining the thermogram, milk composition and the milk powder of the samples have an influence in the T_g and the endothermic peaks of the milk powders.

To determine numerical optimisation, the Derringer desirability function in Design of Expert (DoE) (Islam, Alam, and Hannan 2012; Hu, Cai, and Liang 2008) was utilized. Weighting based on their importance, bulk density, ΔE, moisture content, dispersibility, wettability and particle size were used to determine the optimal minimum inlet air drying temperature and milk flow rate at laboratory level. The results in Chapter five (Table 5.5) indicated that though there was only a slight variation in all the desirability values in all the optimised scenarios analysed, the optimal inlet air drying temperature and milk flow rate for the equipment used were 121.85 °C and 248 cm^{-3} h respectively.

The assessment of the influence of the two parameters contributed to the literature on spray drying of camel milk by providing great insights on the thermal, physical and optical properties of the camel milk powder dried at laboratory scale. Moreover, it indicated the variation between the commercially available powders and the laboratory produced camel milk powders, provide insight in the variation on particle morphology, glass transition temperatures and how these properties are influenced by the spray drying parameters. Further, the ability to understand the influence of these properties, provide a good basis on factors to consider when establishing a camel milk powder processing plant.

7.3 Development and techno-economic feasibility analysis of a novel hybrid-powered process design for camel milk powder and butter processing plant for the ASALs

This study in Chapter 6 presented the development and techno-economic feasibility of a novel hybrid solar, fuel and grid powered process design for camel milk powder and butter processing plant in the ASALs. The incorporation of butter processing line is to limit the losses that accrue due to discarding of cream during whole milk powder production. Additionally, in designing the butter processing line, the variations in the chemical composition of the camel milk from the bovine milk was considered to ensure optimal processing that is specific to camel milk. Specifically, the fat composition of 22.5%, churning time of 11 minutes and the churning temperature of 15 °C were used. The processing line is designed to run 5 days a week and 40 weeks per year exclusive of the seasons of low milk yield (Fig. 6.8, Chapter 6). The processing lines were first designed through PFDs and energy balances, then optimised through PinCH analysis, heat recovery determined before solar integration. Utilising the IEA TASK 49 methodology (Krummenacher and Muster 2015), together with that introduced by Schmitt (2014) on the feasibility of solar integration, ensured that the cost of solar investment could only be accrued after the processes have been optimized. This resulted in economic savings that is often realised due to integration of solar without initially optimizing the process. Further using the modular costs capital estimation methodology, the FCI was estimated and the profit analysis of the designed plant was estimated through the Net Present Value.

Process integration, process intensification, energy efficiency measures and integration of renewable energy are currently globally recognised as important measures to reduce the CO_2e emissions (Meyers et al. 2016; Eiholzer et al. 2017; Muster-Slawitsch, Brunner, and Fluch 2014; Sturm et al. 2015). This study employed these measures which resulted in mitigation of 332.37 tCO_2e annually due to savings in fuel oil and electricity of 892.40 MWh and 185.64 MWh respectively (Table 6.8, Chapter 6).

Findings in Chapter 6 (Table 6.8) indicated that process optimization accounted for the highest heat recovery. PinCH analysis enabled the visualization of the opportunities for optimal energy recovery through direct heat recovery along the processing lines and resulting in a net saving of 531.64 MWh of energy. This accounted for 38.53% of the total energy savings and utilizing the PinCH methodology for thermal savings in the dairy and beer industries have also been documented of savings of 67 % and 27.4 % respectively (Walmsley et al. 2015; Eiholzer et al. 2017). To limit increase in HEX network area of between 50-150 % after process optimization with PinCH in the dairy industry (Walmsley et al. 2015), only nine HENs were identified with maximum energy recovery options. This, thus, resulted in a reduction of 2.0% of energy recovered but economic savings are realized due to the lower number of HEN enacted. Moreover, based on the temperature of the condensates, technical and socio-economic status of Isiolo County population, four HEXs were selected and additional heat recovery was obtained through channelling hot water streams from the processes to a condensate recovery tank (Fig. 6.11).

Selection of solar compared to other renewable energy sources in this study such as wind, is due to its promising option for hot water production for industrial sectors (Mekhilef, Saidur, and Safari 2011; von Storch et al. 2016) and the high solar irradiation in the Isiolo County. The payback period for solar heat integration is relative high compared to other energy efficiency measures, often 3-5 years the food industry and thus its integration should be based on a long term vision of the plant (Sturm et al. 2013; Meyers et al. 2016). In this study guided by the LCOE cost of solar heat integration through simulations in SAM of 0.61€/kWh, the 60 ETCs of system size 165.04 kWh resulted in an annual solar thermal output of 293.01 MWh that were able to meet approximately half of the processing heating demands of temperatures below 100 °C (Fig. 6.16 & Table 6.8). Moreover, solar heat integration cost also guided the decisions of utilising fuel oil for the spray drying processes whose temperature demands were higher than 100 °C. The solar energy output to the process depended on the processing and was lowest in the months of February and September when limited milk was processed (Fig. 6.16).

Substitution of electrical demands for the cooling and mechanical processes resulted in a system of comprising of 200 PV monocrystalline modules and four inverters with a size of 326 m^2. The electrical savings and CO_2 mitigated were 165.05 MWh and 33.41 tCO_2e annually. The continuous reduction in PV modules costs over the years across the globe and in Kenya presents a better alternative for harnessing electrical energy from solar PV to meet electrical demands (Fu, Feldman, and Margolis 2018). Moreover, in Kenya, the constant increase in the cost of electricity (KPLC 2018), while the ASALs receive high solar irradiation, coupled with VAT exemption of solar PV accessories provides a great incentive for the utilization of solar PV for electricity generation. During the months where no or limited processing of camel milk butter and powder occurs, the electrical energy generated from the PV system can be fed to the grid and extra income generated by the plant (Fig. 6.18). The LCOE for the PV system was 0.06€/kWh which was lower than 0.11€/kWh charged for industries of similar capacity (KPLC 2018).

The performance metrics utilized in this study for solar integration comprised of solar fraction (SF) for SWH, performance ratio for PV system and both capacity factor and annual energy saved for both systems. In the SWH model, the SF of 0.74 and the capacity factor of 20.6 % implied that approximately 74.0% of the total hot water demands for camel milk powder and butter processing could be met by the SWH system. The performance metric of the PV system was based on the energy yield for the first year which was 2,230 kWh/kW; capacity factor of 25.6% and the PR of 0.77. The PV system was efficient as PR approached 80% indicating that approximately 77% of the electricity generated by the system is available for the utilization by the plant, thus only 23% are characterized as losses (SMA 2016).

Technical and economic aspects strongly influence the establishment of a processing plant. The FCI was the sum of all the inside battery limits (ISBL), land and the offsite battery limits (OSBL) inclusive of solar PV and solar heat capital investments which was estimated to be €11.74 million. Manufacturing expenses were also estimated to be €4.90 millions with an NPV of €19.40 million. The economic analysis also estimated a payback period of about 5.2 years and return on investment of 13.64 % (Table 6.9) based on current world prices. However, a drop in the pricing could have a significant impact on the revenue which will affect the payback period, return on investment and the NPV. Further a sensitivity analysis on the variation of NPV with 20% change in manufacturing costs, FCI, taxation rate, interest rate and revenue, indicated that 20% variation in revenue had the greatest impact on NPV of 41.04% (Fig. 6.20). The impact of revenue on the NPV is a clear indication of the impact of the effect of variation in milk powder, butter and the by products such as fermented milk prices on the profitability of the enterprise. To limit the utilization of same factors, module factors were equipment and sector specific, while solar costings were independently determined before integration (Lemmens 2016; Saravacos and Kostaropoulos 2012; Turton et al. 2018).

The long shelf life of the milk powder limits the losses associated with the fluid milk in the study area while also ensuring its availability during the dry season. This will significantly contribute to the nutritional and food security needs of the publics in the ASALs while also empowering the women who entirely controls the camel milk supply chain in Isiolo County. Whereas the camel milk powder is easily portable and storable as demanded by the respondents in the study area from the findings in Chapter 4, figure 4.8, the affordability aspect will limit the uptake by the local community. This can be attributed to the high investment costs and the high powder cost (€140/kg). Based on the socio-economic status of the population in this region, it will only be possible to realize the establishment of this novel plant through incentives, grants and subsidies from the county government, national government, developmental organizations and NGOs. Additionally, the high market price of the camel milk powder and butter can be exploited as an export commodity for the county thus the monetary gain can be channelled towards improving the household income and thus overall purchasing power of the household. This will in turn contribute to improved nutritional and food security of the household as they are able to make diverse dietary choices based on their increased income levels.

The study in Chapter 6 is crucial, in providing in depth information on the energy, technical and economic demands of a camel milk powder and butter processing plant for the ASALs. In addition, it provides a step wise process on how fossil fuel and electricity can be reduced through process optimization before solar integration. Further the tonnes of CO_2 emissions mitigated at each level of heat recovery and integration of solar PV and heat is provided.

References

Akweya, B A, C G Gitao, and M W Okoth. 2012. "The Acceptability of Camel Milk and Milk Products from North Eastern Province in Some Urban Areas of Kenya." *African Journal of Food Science* 6 (19): 465–73. https://doi.org/10.5897/AJFS10.061.

Bansal, Vikas, Harish Kumar Sharma, and Vikas Nanda. 2014. "Optimisation of Spray Drying Process Parameters for Low-Fat Honey-Based Milk Powder with Antioxidant Activity." *International Journal of Food Science and Technology* 49 (4): 1196–1202. https://doi.org/10.1111/ijfs.12416.

Barbosa-Cánovas, Gustavo V, Richard W Hartel, Ronald G Labbe, Daryl B Lund, David B Min, Leo M L Nollet, James L Steele, John R Whitaker, and Rickey Y Yada. 2005. *Encapsulated and Powdered Foods*. Taylor & Francis Group, LLC.

Birchal, Viviane S., M. Laura Passos, Glória R. S. Wildhagen, and Arun S. Mujumdar. 2005. "Effect of Spray-Dryer Operating Variables on the Whole Milk Powder Quality." *Drying Technology* 23 (3): 611–36. https://doi.org/10.1081/DRT-200054153.

Bush, Jennifer. 1995. "The Role of Food Aid in Drought and Recovery: Oxfam's North Turkana (Kenya) Drought Relief Programme, 1992-94." *Disasters* 19 (3): 247–59. https://doi.org/10.1111/j.1467-7717.1995.tb00343.x.

Chegini, Gholamreza, and Mojtaba Taheri. 2013. "Whey Powder: Process Technology and Physical Properties: A Review." *Middle East Journal of Scientific Research* 13 (10): 1377–87. https://doi.org/10.5829/idosi.mejsr.2013.13.10.1239.

Creswell, John W, and Vicki L Plano Clark. 2011. *Designing and Conducting Mixed Methods*. *Applied Linguistics*. 2nd ed. Vol. 2nd. Thousand Oaks, California, USA.: Sage publications. https://doi.org/10.1111/j.1753-6405.2007.00096.x.

Daza, Luis Daniel, Alice Fujita, Carmén Silvia Fávaro-Trindade, Juliana Neves Rodrigues-Ract, Daniel Granato, and Maria Inés Genovese. 2016. "Effect of Spray Drying Conditions on the Physical Properties of Cagaita (Eugenia Dysenterica DC.) Fruit Extracts." *Food and Bioproducts Processing* 97: 20–29. https://doi.org/10.1016/j.fbp.2015.10.001.

Eiholzer, Tobias, Donald Olsen, Sebastian Hoffmann, Barbara Sturm, and Beat Wellig. 2017. "Integration of a Solar Thermal System in a Medium-Sized Brewery Using Pinch Analysis: Methodology and Case Study." *Applied Thermal Engineering* 113 (February): 1558–68. https://doi.org/10.1016/j.applthermaleng.2016.09.124.

El-Hadi Sulieman, Abdel Moneim, Abdalla Adam Ilayan, and Ahmed El-Awad El Faki. 2006. “Chemical and Microbiological Quality of Garris, Sudanese Fermented Camel’s Milk Product.” *International Journal of Food Science and Technology* 41 (3): 321–28. https://doi.org/10.1111/j.1365-2621.2005.01070.x.

Elhadi, Yazan Ahmed, Dickson M Nyariki, and Oliver V Wasonga. 2015. “Role of Camel Milk in Pastoral Livelihoods in Kenya: Contribution to Household Diet and Income.” *Pastoralism* 5 (1): 8. https://doi.org/10.1186/s13570-015-0028-7.

Farah, Zakaria. 1996. *Camel Milk: Properties and Products*. *Camel Milk Properties and Products.* zurich, Switzerland,: Swiss Centre for Development Cooperation in Technology and Management.

Ferreira, S.L.C. L C, R.E. E Bruns, H.S. S Ferreira, G.D. D Matos, J.M. M David, G.C. C Brandão, E.G.P. G P Da Silva, et al. 2007. “Box-Behnken Design: An Alternative for the Optimization of Analytical Methods.” *Analytica Chimica Acta* 597 (2): 179–86. https://doi.org/10.1016/j.aca.2007.07.011.

Fox, P.F., and A.L. Kelly. 2012. “Biochemistry of Milk Processing.” In *Food Biochemistry and Food Processing*, edited by Benjamin K. Simpson, Leo M.L. Nollet, Fidel Toldra, Soottawat Benjakul, Gopinadhan Paliyath, and Y.H. Hui, second, 465–72. Iowa: JohnWiley & Sons, Inc.

Fu, Ran, David Feldman, and Robert Margolis. 2018. “U . S . Solar Photovoltaic System Cost Benchmark : Q1 2018.” *Nrel*, no. Novmnber: 1–47. https://doi.org/10.7799/1325002.

Fyfe, Kim, Olena Kravchuk, Anh V. Nguyen, Hilton Deeth, and Bhesh Bhandari. 2011. “Influence of Dryer Type on Surface Characteristics of Milk Powders.” *Drying Technology* 29 (7): 758–69. https://doi.org/10.1080/07373937.2010.538481.

Gathui, T.W., and W. Ngugi. 2010. “Bioenergy and Poverty in Kenya : Attitudes , Actors and Activities.” *Policy Innovation Systems for Clean Energy Security (PISCES)*.

Goula, Athanasia M., and Konstantinos G. Adamopoulos. 2008. “Effect of Maltodextrin Addition during Spray Drying of Tomato Pulp in Dehumidified Air: II. Powder Properties.” *Drying Technology* 26 (6): 726–37. https://doi.org/10.1080/07373930802046377.

Hassan, Haydar M, and Clive J Mumford. 1993. “Mechanisms of Drying of Skin-Forming Materials.Iii. Droplets of Natural Products.” *Drying Technology* 11 (7): 1765–82. https://doi.org/10.1080/07373939308916927.

Holden, Sarah J, D Layne Coppock, and Mulugeta Assefa. 1991. “Pastoral Dairy Marketing and Household Wealth Interactions and Their Implications for Calves and Humans in Ethiopia.” *Human Ecology* 19 (1). https://doi.org/10.1007/BF00888976.

Hu, Zhuoyan, Ming Cai, and Han Hua Liang. 2008. "Desirability Function Approach for the Optimization of Microwave-Assisted Extraction of Saikosaponins from Radix Bupleuri." *Separation and Purification Technology* 61 (3): 266–75. https://doi.org/10.1016/j.seppur.2007.10.016.

Hussein, Abdi Abdullahi. 1999. "The Role of Pastoralism in Ensuring Food Security in the Horn of Africa. A Case Study on Somali National Regional State of Ethiopia." In *Proceedings of a Workshop Sponsored by Pastoral and Environmental Network in the Horn of Africa. Kampala, Uganda*. Kampala, Uganda.

Islam, Md. Azharul, Md. Rabiul Alam, and Md. Obaidullah Hannan. 2012. "Multiresponse Optimization Based on Statistical Response Surface Methodology and Desirability Function for the Production of Particleboard." *Composites Part B* 43 (3): 861–68. https://doi.org/10.1016/j.compositesb.2011.11.033.

Kelly, A. L. L., J. E. E O'Connell, and P. F. F. Fox. 2003. "Manufacture and Properties of Milk Powders." In *Advanced Dairy Chemistry: Vol. 1. Proteins*, 1:1027–62. Boston, MA: Springer US. https://doi.org/10.1007/978-1-4419-8602-3_29.

Khaskheli, M., M.A. Arain, S. Chaudhry, A.H. Soomro, and T.A. Qureshi. 2005. "Physico-Chemical Quality of Camel Milk." *Journal of Agriculture & Social Sciences* 1 (2): 164–66.

Kherouatou, N., M. Nasri, Attia H., Frederico V., Lafise J., Taniwaki -ITAL, Marta H, and Nelcindo Terra. 2003. "A Study of the Dromedary Milk Casein Micelle and Its Changes during Acidification." *Brazilian Journal of Food Technology* 6: 237–44. https://doi.org/10.1051/lait:2000141.

Kim, Esther H.-J., X. D. Chen, and David Pearce. 2002. "Surface Characterization of Four Industrial Spray-Dried Dairy Powders in Relation to Chemical Composition, Structure and Wetting Property." *Colloids and Surfaces B: Biointerfaces* 26 (3): 197–212. https://doi.org/10.1016/S0927-7765(01)00334-4.

Kim, Esther H.-J., X. D. Chen, and David Pearce. 2009. "Surface Composition of Industrial Spray-Dried Milk Powders. 2. Effects of Spray Drying Conditions on the Surface Composition." *Journal of Food Engineering* 94 (2): 169–81. https://doi.org/10.1016/j.jfoodeng.2008.10.020.

Koç, Banu, Melike Sakin-YIlmazer, Figen Kaymak-Ertekin, and Pinar BalkIr. 2014. "Physical Properties of Yoghurt Powder Produced by Spray Drying." *Journal of Food Science and Technology* 51 (7): 1377–83. https://doi.org/10.1007/s13197-012-0653-8.

Konuspayeva, G., B. Faye, and G. Loiseau. 2009. "The Composition of Camel Milk: A Meta-Analysis of the Literature Data." *Journal of Food Composition and Analysis* 22 (2): 95–101. https://doi.org/10.1016/j.jfca.2008.09.008.

KPLC. 2018. “Electricity Cost Tariffs & Schedule of Tariffs 2018.” Nairobi, Kenya.

Krummenacher, Pierre, and Bettina Muster. 2015. “Solar Process Heat for Production and Advanced Applications Methodologies and Software Tools for Integrating Solar Heat into Industrial Processes.” *IEA SHC Task 49*.

Kurozawa, Louise Emy, Kil Jin Park, and Miriam Dupas Hubinger. 2009. “Effect of Carrier Agents on the Physicochemical Properties of a Spray Dried Chicken Meat Protein Hydrolysate.” *Journal of Food Engineering* 94 (3–4): 326–33. https://doi.org/10.1016/j.jfoodeng.2009.03.025.

Lemmens, Sanne. 2016. “Cost Engineering Techniques & Their Applicability for Cost Estimation of Organic Rankine Cycle Systems.” *Energies* 9 (7). https://doi.org/10.3390/en9070485.

Lim, Stephen S, Theo Vos, Abraham D. Flaxman, Goodarz Danaei, Kenji Shibuya, Heather Adair-Rohani, Markus Amann, et al. 2012. “A Comparative Risk Assessment of Burden of Disease and Injury Attributable to 67 Risk Factors and Risk Factor Clusters in 21 Regions, 1990-2010: A Systematic Analysis for the Global Burden of Disease Study 2010.” *The Lancet* 380 (9859): 2224–60. https://doi.org/10.1016/S0140-6736(12)61766-8.

Masters, Keith. 1994. “Scale-up of Spray Dryers.” *Drying Technology* 12 (1–2): 235–57. https://doi.org/10.1080/07373939408959955.

Mekhilef, S., R. Saidur, and A. Safari. 2011. “A Review on Solar Energy Use in Industries.” *Renewable and Sustainable Energy Reviews* 15 (4): 1777–90. https://doi.org/10.1016/j.rser.2010.12.018.

Meyers, Steven, Bastian Schmitt, Mae Chester-Jones, and Barbara Sturm. 2016. “Energy Efficiency, Carbon Emissions, and Measures towards Their Improvement in the Food and Beverage Sector for Six European Countries.” *Energy* 104: 266–83. https://doi.org/10.1016/j.energy.2016.03.117.

Molina-Azorin, Jose F. 2016. “Mixed Methods Research: An Opportunity to Improve Our Studies and Our Research Skills.” *European Journal of Management and Business Economics* 25 (2): 37–38. https://doi.org/10.1016/j.redeen.2016.05.001.

Mujumdar, Arun S., Li-Xin Huang, and Xiao Dong Chen. 2010. “An Overview of the Recent Advances in Spray-Drying.” *Dairy Science &Technology* 90 (2–3): 211–24. https://doi.org/10.1051/dst/2010015.

Muster-Slawitsch, Bettina, C. Brunner, and J. Fluch. 2014. “Application of an Advanced Pinch Methodology for the Food and Drink Production.” *Iley Interdiscip Rev Energy Environ* 3 (6): 56–74.

Nijdam, J. J., and T.A.G. Langrish. 2005. “An Investigation of Milk Powders Produced by a Laboratory-Scale Spray Dryer.” *Drying Technology* 23 (5): 1043–56. https://doi.org/10.1081/DRT-200060208.

Nijdam, J.J., and T.A.G. Langrish. 2006. “The Effect of Surface Composition on the Functional Properties of Milk Powders." *Journal of Food Engineering* 77 (4): 919–25. https://doi.org/10.1016/j.jfoodeng.2005.08.020.

Nollet, Leo ML, Fidel Toldrá, and Francis Group. 2010. *Sensory Analysis of Foods of Animal Origin*. CRC press. https://doi.org/10.1201/b10822.

Noor, Issack Mohamed, Bockline Omedo Bebe, and Abdi Yakub Guliye. 2012. "Analysis of an Emerging Peri-Urban Camel Production in Isiolo County, Northern Kenya." *Journal of Camelid Science* 5: 41–61.

Nori, Michele. 2010. "Along the Milky Way: Marketing Camel Milk in Puntland, Somalia." *European Journal of Development Research* 22 (5): 696–714. https://doi.org/10.1057/ejdr.2010.40.

Nori, Michele, Matthew B. Kenyanjui, Mohammed Ahmed Yusuf, and Fadhumo Hussein Mohammed. 2006. "Milking Drylands: The Marketing of Camel Milk in North-East Somalia." *Nomadic Peoples* 10 (1): 9–28. https://doi.org/10.3167/082279406781020392.

Ogolla, Jackline Akinyi, Christian Dede, Michael Wandayi Okoth, Oliver Hensel, and Barbara Sturm. 2017. "Strategies and Technologies for Camel Milk Preservation and Utilization of Non-Marketed Milk in Arid and Semi-Arid Areas." *East African Agricultural and Forestry Journal*. https://doi.org/10.1080/00128325.2017.1363686.

Oldfield, David, and Harjinder Singh. 2005. "Functional Properties of Milk Powders." In *Food Science and Technology*, 146:365. New York-Marcel Dekker.

Pisecky, Jan. 2012. *Handbook of Milk Powder Manufacture*. Edited by Vagn Westergaard and Ejnar Refstrup. *GEA Process Engineering A/S (GEA Niro)*. Second Edi. https://doi.org/10.1007/978-1-908517-43-2.

Rahman, Mohammad Shafiur, Halaa Al-Hakmani, Ahmed Al-Alawi, and Insaaf Al-Marhubi. 2012. "Thermal Characteristics of Freeze-Dried Camel Milk and Its Major Components." *Thermochimica Acta* 549: 116–23. https://doi.org/10.1016/j.tca.2012.09.005.

Reddy, Ravula Sudharshan, C T Ramachandra, Sharanagouda Hiregoudar, Udaykumar Nidoni, Jagjiwan Ram, and Mouneshwari Kammar. 2014. "Influence of Processing Conditions on Functional and Reconstitution Properties of Milk Powder Made from Osmanabadi Goat Milk by Spray Drying." *Small Ruminant Research* 119 (1–3): 130–37. https://doi.org/10.1016/j.smallrumres.2014.01.013.

Renzo, Giovanni Carlo Di, Giuseppe Altieri, and Francesco Genovese. 2013. "Donkey Milk Powder Production and Properties Compared to Other Milk Powders." *Dairy Science & Technology* 93: 551–64. https://doi.org/10.1007/s13594-013-0108-7.

Sadler, K, C Kerven, M Calo, M Manske, and A Catley. 2009. "Milk Matters: A Literature Review of Pastoralist Nutrition and Programming Responses."

Santhalakshmy, Swaminathan, Sowriappan John Don Bosco, Sneha Francis, and Mallela Sabeena. 2015. "Effect of Inlet Temperature on Physicochemical Properties of Spray-Dried Jamun Fruit Juice Powder." *Powder Technology* 274: 37–43. https://doi.org/10.1016/j.powtec.2015.01.016.

Saravacos, George, and Athanasios E. Kostaropoulos. 2012. *Handbook of Food Processing Equipment*. Second. Springer. https://doi.org/10.1007/978-3-319-25020-5_4.

Schmitt, Bastian. 2014. "Integration Thermischer Solaranlagen Zur Bereit- Stellung von Prozesswärme in Industriebetrieben." Shaker Verlag.

Schuck, Pierre, Dolivet Dolivet, and Romain Jeantet. 2012. *Analytical Methods for Food and Dairy Powder*. West Sussex: John Wiley & Sons, Ltd. https://doi.org/10.1017/CBO9781107415324.004.

Seifu, Eyassu. 2007. "Handling, Preservation and Utilization of Camel Milk and Camel Milk Products in Shinile and Jijiga Zones, Eastern Ethiopia." *Marketing* 10: 13–17.

Sharma, Anup, Atanu H. Jana, and Rupesh Shrikant Chavan. 2012. "Functionality of Milk Powders and Milk-Based Powders for End Use Applications-A Review." *Comprehensive Reviews in Food Science and Food Safety* 11 (5): 518–28. https://doi.org/10.1111/j.1541-4337.2012.00199.x.

Sikana, P.M., C.K. Kerven, and R.H. Benkhe. 1993. "From Subsistence to Specialised Commodity Production: Commercialisation and Pastoral Dairying in Africa." Pastoral Development Network, ODI.

SMA. 2016. "Performance Ratio-Quality Factor for the PV Plant." Kassel, Germany.

Storch, H. von, M. Roeb, H. Stadler, C. Sattler, A. Bardow, and B. Hoffschmidt. 2016. "On the Assessment of Renewable Industrial Processes: Case Study for Solar Co-Production of Methanol and Power." *Applied Energy* 183: 121–32.

Sturm, Barbara, Werner Hofacker, and Oliver Hensel. 2012. "Optimizing the Drying Parameters for Hot Air Dried Apples." *Drying Technology* 30: 1570–82. https://doi.org/10.1080/07373937.2012.698439.

Sturm, Barbara, Stephan Hugenschmidt, Sharon Joyce, Werner Hofacker, and Anthony P. Roskilly. 2013. "Opportunities and Barriers for Efficient Energy Use in a Medium-Sized Brewery." *Applied Thermal Engineering* 53 (2): 397–404. https://doi.org/10.1016/j.applthermaleng.2012.05.006.

Sturm, Barbara, Steven Meyers, Yongjie Zhang, Richard Law, Eric J. Siqueiros Valencia, Huashan Bao, Yaodong Wang, and Haisheng Chen. 2015. "Process Intensification and Integration of Solar Heat Generation in the Chinese Condiment Sector - A Case Study of a Medium Sized Beijing Based

Factory." *Energy Conversion and Management* 106: 1295–1308. https://doi.org/10.1016/j.enconman.2015.10.045.

Sulieman, Abdel Moneim E., Osama M. Elamin, Elamin A. Elkhalifa, and Loouis Laleye. 2014. "Comparison of Physicochemical Properties of Spray-Dried Camel's Milk and Cow's Milk Powder." *International Journal of Food Science and Nutrition Engineering* 4 (1): 15–19. https://doi.org/10.5923/j.food.20140401.03.

Tabary, Zoe. 2018. "With Refrigerated ATMs, Camel Milk Business Thrives in Kenya." *Reuters*, 2018.

Tonon, Renata V., Catherine Brabet, and Míriam D. Hubinger. 2008. "Influence of Process Conditions on the Physicochemical Properties of Acai (Euterpe Oleraceae Mart.) Powder Produced by Spray Drying." *Journal of Food Engineering* 88 (3): 411–18. https://doi.org/10.1016/j.jfoodeng.2008.02.029.

Turton, Richard, Joseph A. Shaeiwitz, Debangsu Bhattacharyya, and Wallace B. Whiting. 2018. *Analysis, Synthesis, and Design of Chemical Processes*. 5th editio. Upper Saddle River, NJ, USA: Pearson Education International.

Walmsley, T.G., M.R.W. Walmsley, J.R. Neale, and M.J. Atkins. 2015. "Pinch Analysis of an Industrial Milk Evaporator with Vapour Recompression Technologies." *Chemical Engineering Transactions* 45: 7–12. https://doi.org/10.3303/CET1545002.

Wayua, Francis O., Michael Wandayi Okoth, and John Wangoh. 2012. "Survey of Postharvest Handling, Preservation and Processing Practices along the Camel Milk Chain in Isiolo District, Kenya." *African Journal of Food, Agriculture, Nutrition and Development* 12 (7): 6897–6912.

Westergaard, Vagn. 2011. "Milk Powder Technology Evaporation and Spray Drying."

Western, David, and Virginia Finch. 1986. "Cattle and Pastoralism: Survival and Production in Arid Lands." *Human Ecology* 14 (1). https://doi.org/10.1007/BF00889211.

Zbikowska, Alicja, and Zdzislaw Zbikowski. 2006. "Stability of Milk Concentrates in Hot Coffee." *Polish Journal of Food and Nutrition Sciences* 15/56 (S1): 253–58.

8. Reflection on methodologies, policy implications, outlook and conclusions

8.1. Reflection of methodologies and limitations

Prior to any technological development, it is critical to first ascertain the setbacks within the community, the solutions available and the gaps that exists before any technological development, through community engagement. Mixed methods utilized in Chapter 4 has been documented to be intuitive, involving and great insight as it applies both the quantitative and qualitative data collection methods (Creswell & Clark, 2011; Molina-Azorin, 2016). Further in characterizing the losses and identifying the technological and strategies for camel milk preservation, the supply chain and actor approach was utilized. The approach used ensured that at each point of the supply chain, the different losses, technologies and strategies were characterized. Moreover, by quantifying the amount of non-marketed milk and their utilization, the methodology ensured that the assumption of non-marketed milk being characterized as losses was avoided, thus actual losses were documented. The main limitation of this approach was that part of the study in Chapter 4 utilized semi-structured questionnaires and Key informant interviews who were susceptible to recall bias. However, the bias was reduced by the direct observations, measurements and FGDs.

Consequently, before embarking on the milk powder production at laboratory level, the findings from the preceding study (Chapter 4), determined the type of value addition that was most preferred and practical for the area of study. The experimental design employed in Chapter 5 to assess the influence of inlet air drying temperature and the milk flow rate on the different milk powder properties was a randomized two by three factorial design. The ability of the Response Surface Methodology (RSM) to detect both linear and quadratic interactions was critical in selection of its utilization in this study (Ferreira et al. 2007). Moreover, the ability to visualize the interactive effects of the two independent variables and the response variables using the 3D response surface plots derived from the regression models, ensured that the best possible models were selected. As a second step, the multi-response goal conflict was optimised using Derringer's desirability function. The optimal inlet drying air temperatures and flow rate of the response from physical, colour and reconstitution properties of camel milk powder were obtained. By optimising the responses to the same weight of 1 and limiting the desirability range of the responses between

0 to 1, the credibility of the numerically optimises conditions attained were determined (Hu et al. 2008; Islam et al. 2012).

Establishing a milk food processing plant requires knowledge of mass and energy demands, which are attained through PFDs. The calculations of the thermal and electrical energy demands were determined at UO level and based on production volumes which permitted for the generation of a detailed mass and energy balance in each component. In integration of RES in a food processing plant, it is essential to determine the economic and technical feasibility of its integration. Therefore, by adopting and modifying the methodologies proposed by Schmitt (2014) for solar thermal integration and the two-stage methodology IEA/SHC TASK 49/IV, the process was optimised, and the solar thermal integration points were identified for optimal solar benefits realization. Using PinCH analysis for process optimization was critical in having a great understanding into all possible heat recovery options along the different streams. Based on the PinCH findings on the available heat recovery options, the streams with maximum energy recovery options was selected and further technical and economic feasibility guided the conclusive selection of the final heat recovery streams. The use of SAM for solar simulations in this study was based on the possibility that SAM not only provide the solar demands but also provides insight into the extra auxiliary energy that ought to be supplied while indicating the financial feasibility of the project through the LCOE components and also performance metrics of the systems designed.

Fixed capital is used in estimating the operating expenses, calculation of depreciation, cash flow and profitability of the project, thus is significant in developing the process economics. Thus, employing the factorial method using the modular costs for capital estimation while taking into consideration the nature of the plant, equipment, inflation rates, and CEPCI limits the great variation in cost estimation. Whilst these values are a rough estimate, the presentation of the scope of the investigation through the module and project costs considered have been provided, which has enhanced the usability and comparability of the results. Moreover, the capital cost, variable and maintenance costs for the solar integration was provided by SAM and finally integrated into the economic analysis, this prevented the assumptions of solar costs in the economic analysis.

8.2. Research Needs

There are many areas of research needs that could be pursued, however, five critical have been identified based on the results of the present study and are elaborated in the follow-up paragraphs.

- Determination of the willingness to pay for camel milk powder and butter in the study area: The high global prices that milk powder fetches can be inhibitory to purchasing of the camel milk powders, however, the camel milk producers through the national and county governments subsidies can result in a decrease in pricing.
- Further research on nutritional analysis of the spoilt camel milk for quantification of nutritional losses associated with milk spoilage: The consumption of *Susaac* when fresh milk is not sold is common in the study area. Hence, research on the nutritional losses associated with consumption of such milk will be crucial in understanding the extra nutritional needs of the population particularly the children for supplementation purposes.
- Assessment of nutritional and chemical composition of camel milk as influenced by spray drying this will be significant in determining if there is any need for fortification: Drying of milk has an influence on the volatile and chemical components of the milk as could be observed by the variations in the colour and moisture content. Thus, further research can be undertaken to understand how processing influence them, for ease of fortification of the powders for nutritional enhancement. Further, when CM powder is fortified with food products such as flour, it can enhance the nutritional composition of these food products thus aiding in elimination of hidden hunger that is rampant in the ASALs of Kenya.
- Comparison of utilization of solar PV and solar heat in meeting the heating demands of the designed processing lines. This will be key in determining which is a cheaper investment option and technically feasible for the region.
- Design of a solar techno and economic feasibility of a process design of condensed camel milk for the ASALs: While this study has presented the process design for milk powder and butter processing, future outlook can be in the process design for condensed milk powder which require less energy demands, investment and running costs compared to the milk powder production. This can be attributed to the absence of the spray drying process that demands higher energy consumption.

- Application of the study findings to real life situations: This can be made possible by availability of funds that can set up the plant and compare the electrical demands, heating demands and economic costs.

8.3. Policy implications

The results of this study have some policy implications and development implications. The findings revealed that gaps exist in the camel milk supply chain which comprised of inadequate preservation technologies that contribute to the camel milk losses and the price fluctuations during the dry seasons. Therefore, in order to improve the benefits that the pastoral communities who dependent heavily on camel milk as a source of livelihood and nutritional security, the County government, national government, Non-Governmental and international donors need to focus on strategies that not only contribute to short shelf life camel milk preservation technology but also alternative preservation technologies that can cushion the camel milk actors from the physical, chemical and economic losses. These interventions will halt the high price fluctuations while also ensuring availability of camel milk is in season of scarcities.

Milk powder and butter production in addition to already value-added products that are being produced in the region, will contribute to the big four agenda that has been put in place by the government of Kenya. Having identified food security through value addition as one critical component, milk powder production will limit the losses accrued due to fluid milk storage and will also provide additional income to those employed along the supply chain while also ensuring the milk availability during the dry seasons. This will contribute to the food security of the region, since the pastoral communities can be able to have access to the camel milk during the season of scarcity and the amount of money they would have spent on purchasing other milk or from sales of the powder and butter, will be channelled towards family household food basket for purchase of cereals, vegetables and other protein sources.

The Kenya NCCAP 2018-2022 is a five-year plan that is aimed to lower GHG emissions and aid Kenya in meeting the its Nationally Determined Contribution goal of abating the emissions by 30% by 2030. The designed camel milk powder and butter processing plant is devised to optimize energy efficiency and limit GHG emissions as revealed in Chapter 6 findings. The findings utilised the inflation rates, taxation rate and interest rates that are country specific. This provides great insight for county governments in the ASALs of Kenya on the investment and the savings that can be accrued in the camel milk supply chain when they adopt milk powder and butter production. The energy efficiencies measures applied in this study through the stepwise heat recovery are not only limited to the milk powder and butter processing lines but can be used in other food value chains that can be preserved through powder processing.

Moreover, the integration of solar in the process design limiting biomass and fuel oil in the designed plant will reduce carbon emissions and preserve forests that act as carbon sequestering. The existing moratorium on logging in Kenya limits the utilisation of firewood, however, the ASALs have higher solar irradiation that can be harnessed by the counties and utilize them for camel milk preservation. Hence, the county governments should put in place additional policies and subsidies that ease the adoption and integration of solar into food processing industries thus contributing to the food security of the ASALs.

The economic and technical feasibility of the presented camel milk powder and butter processing plant for the ASALs require huge investments as deduced from study 3. This will be an impediment to the camel milk producers and retailers. However, Isiolo County having recognised CM value chain as one of the most vital one for the livelihood of the population, can facilitate a private public partnership where they can partner with other international agencies, financial institutions and the farmer groups to set up the plant. From the economic analysis, the payback period is approximately five years, thus the venture can be profitable in a short run.

8.4. Conclusions

In this study the camel milk value chain in Isiolo is characterised, identifying the main actors which comprised of the camel milk producers, primary transporters, collectors, secondary transporters and retailers. The milk preservation technologies present in Isiolo County comprised both modern and traditional technologies. The technologies available were mainly for cooling that preserved milk for shorter duration of time. Moreover, the technologies depended on electricity diesel from the grid and diesel or cooling and firewood and charcoal for boiling. The non-marketed milk utilisation was season dependent with highest amount (28.8%) being discarded in the wet season compared to 9.0% in the dry seasons. While limited availability of milk during the dry season promoted the processing of approximately 22.4% compared to 11.2% in the wet season processed.

Acceptability of camel milk powder as an alternative value-added product was based on transportability, shelf life and affordability.

Based on the need for longer shelf life products to limit the camel milk losses in Isiolo County, the assessment of the influence of inlet drying air temperature and milk flow rates at laboratory scales on physical, optical and thermal properties were investigated. was undertaken and comparison made to industrially produced camel milk powders. While the milk flow rate significantly influenced the bulk and reconstitution properties, the moisture content and colour properties were significantly influenced by inlet air drying temperature. The glass transition temperature was directly proportional to the inlet temperature but inversely proportional to the milk flow rate.

The development of the process design for camel milk powder and butter processing plant in the ASALs that operates 200 days per year (40 weeks, 5 day per week) has been presented. Through process optimization, and solar integration, fossil fuel and electricity from the grid fossil fuel consumption was reduced by approximately 71.86% resulting in a mitigation of 332.37 tCO_2e per annum. The economic analysis provided rough estimates of the investment costs required to establish the plant, manufacturing costs and how profitable the enterprise will be in the long run. The sensitivity analysis also provided a great illustration on the influence of various economic components on the NPV_{15} by 20% variation, with revenue having the greatest effect (41.04%) on NPV_{15}.

The designed camel milk powder and butter processing plant has the ability to ensure availability of camel milk during dry seasons due to the long shelf life of the product. Moreover, the camel milk supply chain in Isiolo is mainly characterized by women, and thus establishing of this plant has the potential to empower the women due to increased and constant supply of the milk to the plant thus increased sales and limited losses in trading in fluid milk over long distances. Both the marketing and processing of the camel milk into powder has the ability to contribute to the household food and nutritional security in terms of income generated from the sales which will improve the purchasing power of the households and thus better nutritional choices. Though, the enterprise is profitable based on the NPV_{15} (€ 19.4 million), the short payback period (5.2 years) and the DCFROR (58.0%), the high investment costs of (€13.34 million) will limit its establishment based on the socio-economic status of the publics in the ASALs. This can only be realized through financial and technical support from the county or national government, NGOs or developmental agencies.

References

Creswell, J. W., & Clark, V. L. P. (2011). Designing and conducting mixed methods. In *Applied Linguistics* (2nd ed., Vol. 2nd). https://doi.org/10.1111/j.1753-6405.2007.00096.x

Molina-Azorin, J. F. (2016). Mixed methods research: An opportunity to improve our studies and our research skills. *European Journal of Management and Business Economics*, *25*(2), 37–38. https://doi.org/10.1016/j.redeen.2016.05.001

Schmitt, B. (2014). *Integration thermischer Solaranlagen zur Bereit- stellung von Prozesswärme in Industriebetrieben* (Vol. 157). Shaker Verlag.

Summary

The dairy sector comprising bovine, camel and goats milk production is the largest agricultural subsector in Kenya, and its share in gross domestic product (GDP) is approximately 4%. Kenya's camel milk plays a significant role in meeting the nutritional and economic needs of the publics in the Arid and semi-arid lands (ASALs), despite this, there is limited information on the preservation technologies, losses, utilisation of non-marketed milk along the camel milk supply chain and on its value-added products. Besides, spray drying has been documented to produce milk powders that have long shelf lives of up to 18 months thus limiting losses associated with fluid milk storage. Nonetheless, there is limited data on spray drying application in the camel milk industry. Further, the ASALs are characterised by high solar irradiation, providing an opportunity for utilization of solar energy in the preservation of camel milk, yet, no harnessing of this solar irradiation has been explored. Moreover, development and techno-economic feasibility of establishing a decentralised small-scale hybrid solar-fossil fuel camel milk powder and butter processing plants in the ASALs has not been explored. Thus, the overall aim of this dissertation is to enhance the understanding of the camel milk supply chain in the ASALs, camel milk powder production and to present the development and techno-economic feasibility of a novel decentralised small-scale hybrid solar-fossil fuel powered process design for camel milk powder and butter processing plant for the ASALs.

Therefore, to meet the overall dissertation aim, the following three specific objectives were formulated:

1. To examine the technologies and strategies used in camel milk preservation in the ASALs and the utilization of the non-marketed milk.
2. To determine the influence of inlet air drying temperature and milk flow rate on the thermal, physical and optical properties of spray dried camel milk.
3. To develop and determine the techno-economic feasibility of a novel decentralised small-scale hybrid solar-fossil fuel powered process design for camel milk powder and butter processing plant for the ASALs.

Different methodologies have been used to answer the three objectives as described in the subsequent paragraphs:

Objective 1: This entailed characterizing the preservation technologies and losses along the camel milk supply chain and utilization of non-marketed milk using a mix of qualitative and quantitative methods. Data were collected in two sub-counties Garba Tula and Isiolo Central in Isiolo County of Kenya using semi-structured questionnaires, focus group discussions (FGDs), key informant interviews (KII) and direct observations (DO) along the entire camel milk supply chain. Both descriptive and inferential statistical analyses for quantitative data and thematic coding for qualitative data were used for analyses of the data gathered. The results indicated the camel milk losses varied by seasons characterized by spoilages and spillages increasing by 81.0% and 79.1% respectively in the wet season. The main strategies employed for milk loss reduction were maintenance of hygienic practices (88% producers, 61% traders), smoking of the milk handling equipment (68% producers, 10% traders), and simple cooling (13% producers). High cost and limited technical feasibility restricted the utilization of modern preservation technologies such as chilling and refrigeration. For non-marketed milk, 28.8% and 9.0% was discarded in the wet and dry seasons respectively while 11.2% and 22.4% was processed. Transportability, affordability and shelf life were mentioned as important attributes for camel milk powder acceptability. These findings illustrated the need for appropriate milk preservation technologies for longer shelf life camel milk products in the ASALS.

Based on the need for a longer shelf life product and need for longer preservation technologies, spray drying trials were undertaken under objective 2. The thermal, physical and optical milk powder properties are fundamental to understanding the quality, stability, final application and portability of milk powders. Therefore, objective 2 explored the influence of different spray drying parameters (inlet air drying temperature & milk flow rate) on the physical, thermal and optical properties of laboratory produced camel milk powder. Employing a three (110, 120 & 130 °C) by two (166 & 248 cm^3/h) factorial design and comparing the results with commercially available camel milk powders, study 2 specifically evaluated the influence of these two parameters on the reconstitution, particle, bulk, colour, and thermal properties of the camel milk powders. Utilizing ANOVA and Response Surface Methodology (RSM), the findings indicated that the inlet drying air temperatures significantly influenced moisture content, and the L* a* b* colour properties

($p<0.0001$) of the powders. Conversely, the bulk and reconstitution properties were significantly influenced by the milk flow rate ($p<0.0001$). The thermograms of all the milk powders had three endothermic peaks and two shifts. The onset of the glass transition increased in temperature with decreasing moisture content of the powders varying from 37.49 °C to 44.21 °C. Scanning electron microscopy (SEM) images of the laboratory spray dried powders were hollow and collapsed compared to the commercial samples which were spherical and rough with small cracks, dents and pores. The results demonstrated that both the inlet drying air temperature and the milk flow rate influenced the thermal, optical and physical properties of laboratory spray-dried powders. These findings are important in understanding the spray drying characteristics of camel milk powder and are thus significant for industrial production of the powders.

Having ascertained the possibility of producing the camel milk powders at laboratory level and compared the properties with commercially available powders, industrial production of the powders is thus feasible to limit the losses along the camel milk supply chain in Isiolo County. Hence, objective 3 explored the development and techno-economic feasibility of establishing a novel decentralised small-scale solar-fuel oil hybrid camel milk and butter processing plant in the ASALs. Additionally, it also assessed the suitability of the designed processing plant to meet the nutritional and food security needs of the ASALS publics. Using mass and energy balances, the process flow designs (PFD) were designed for raw camel milk processing of 3,135 kg/day into 356.1 kg of powder and 66.5 kg butter. The plant was designed to run for 5 days a week and 40 days per year excluding the seasons of low milk production. To ensure energy efficiency and limit fossil fuel consumption, the process was optimised, heat recovery undertaken before solar integration according to the IEA SHC Task 49 Guidelines. Through PinCH analysis, the heat recovery (HR) points were identified, the maximum energy recovery (MER) streams selected, based on techno-economic feasibility of the ASALs, final heat exchanger networks (HEN) were selected. Solar PV and heat integration feasibility were assessed through simulation by systems advisor model (SAM) before integration into the optimised system. The techno-economic feasibility of establishing the plant, was explored through the modular factorial method for capital estimation while the profitability of the plant was evaluated based on the after-tax cash flow, net present value (NPV), payback time and discounted cash flow rate (DCFROR). Further, sensitivity analysis was undertaken to determine the influence of variation in revenue, cost of manufacturing,

capital cost, taxation rates and interest rates on NPV_{15}. The findings in objective 3 indicated that to establish this camel milk powder and butter processing plant for the ASALs, employing optimization processes through PinCH analysis resulted in circa 38.53% energy savings. To further minimize the use of fossil fuels and electricity from the grid, solar heat and solar integration were assessed, which resulted in annual fuel oil and grid electrical savings of 293.01 and 165.05 MWh respectively from 644.66 and 235.31 MWh respectively. This in turn reduced GHG emissions by 332.37 tonnes of CO_2e per annum and resulted in annual financial savings of approximately €98,479.30. While the processing of the fluid camel milk to powder and butter will limit the losses attributed to fluid milk marketing, the investment cost (€11.74 million) is huge. This will hinder the realization of the establishment of this plant based on the socio-economic status of the publics in the ASALs. For it to empower the women who control the camel milk supply chain in the county, financial supports in form of grants, subsidies and incentives from the government, NGOs and developmental organizations. The venture is profitable in the long run with a payback period of 5.2 years, return on investment of 13.4%, DCFROR of 58% and an NPV_{15} of €19.40 millions. The sensitivity analysis further indicated that revenue has the highest impact on the NPV_{15}, implying that fluctuations in world camel milk powder prices by 20% decreases the NPV_{15} by 41.04%. In conclusion, this study has provided a stepwise holistic approach in optimal process design, solar integration and economic analysis for a decentralised small-scale hybrid solar-fossil-fuel industrial process design for milk and butter processing plant in the ASALs. It is highly encouraged that these results be utilized and applied to real world projects that intend to reduce industrial fossil fuel consumption and CO_2 emissions.

This research adds to the scientific knowledge of the camel milk supply chain and camel milk powder production. Moreover, this thesis provides further insights into the design and techno economic feasibility of establishing a camel milk powder and butter processing plant through harnessing solar irradiation that is characteristic of the ASALs inhibited by the camels. While the plant setting is in Kenya, this thesis findings can be replicated by taking into consideration the specific place conditions. Further this study contributes to the Kenya Government Big Four Agenda that is, among others, geared towards food security through value addition. In addition, Kenya's National Climate Change Plan enacted in 2018, is committed to the United Nations Framework for Climate Change (UNFCC) which emphasizes on reduction of greenhouse gases

(GHG) emissions and thus by harnessing solar energy and optimizing the processes limits the use of fossil fuels.

Zusammenfassung

Der Milchsektor, welcher die Milchproduktion von Rindern sowie Kamelen und Ziegen umfasst, ist der größte landwirtschaftliche Teilsektor in Kenia. Sein Anteil am Bruttoinlandsprodukt (BIP) beträgt etwa 4%. Der kenianischen Kamelmilch kommt eine bedeutende Rolle bei der Befriedigung der Ernährungs- und Wirtschaftsbedürfnisse der Bevölkerung in den ariden und halbtrockenen Gebieten (ASAL) zu. Nichtsdestotrotz gibt es nur wenige Informationen über Konservierungstechnologien, Verluste, die Verwendung von nicht vermarkteter Milch entlang der Kamelmilch-Lieferkette und über ihre Produkte mit erhöhtem Mehrwert. Bekannt ist jedoch, dass durch Sprühtrocknung Milchpulver hergestellt werden kann, welches eine Haltbarkeit von bis zu 18 Monaten hat und somit die Verluste im Zusammenhang mit der Lagerung von Flüssigmilch begrenzen kann. Dennoch gibt es nur wenige Daten über die Anwendung von Sprühtrocknung in der Kamelmilchindustrie. Eines der Merkmale von ASAL ist deren hohe Sonneneinstrahlung. Sie bietet die Möglichkeit, die Sonnenenergie bei der Konservierung von Kamelmilch zu nutzen, was jedoch bisher noch nicht untersucht wurde. Dementsprechend fand bisher auch keine Entwicklung und keine Untersuchung der techno-ökonomische Machbarkeit einer kleinen, dezentralen, solar-fossilen Hybridanlage zur Verarbeitung von Kamelmilchpulver und Butter in den ASAL statt. Das primäre Ziel der vorliegenden Dissertation ist daher, das Verständnis der Kamelmilch-Lieferkette in den ASAL und der Kamelmilchpulverproduktion zu verbessern sowie die Entwicklung und techno-ökonomische Machbarkeit eines neuartigen dezentralisierten, solar-fossilem Hybridprozesses in kleinem Maßstab für Kamelmilchpulver- und Butterherstellung in den ASAL darzustellen.

Um das genannte Gesamtziel der Dissertation zu erreichen, wurden daher die folgenden drei konkreten Ziele formuliert:

1. Untersuchung der Technologien und Strategien, die bei der Konservierung von Kamelmilch in ASAL eingesetzt werden und Analyse der Verwendung der nicht vermarkteten Milch.

2. Bestimmung des Einflusses der Trocknungsluft-Eingangstemperatur und der Milchflussrate auf die thermischen, physikalischen und optischen Eigenschaften von sprühgetrockneter Kamelmilch.
3. Entwicklung und Bestimmung der techno-ökonomischen Durchführbarkeit eines neuartigen dezentralen, kleinmaßstäblichen, solar-fossilen Hybrid-Prozessdesigns für Kamelmilchpulver- und Butterherstellung für die ASAL.

Die zum Erreichen der genannten drei Zielsetzungen verwendeten Methoden werden in den folgenden Absätzen näher erläutert:

Zielsetzung 1 umfasst die Charakterisierung der Konservierungstechnologien und der Verluste entlang der Kamelmilch-Lieferkette und die Verwendung von nicht vermarkteter Milch mit einer Mischung aus qualitativen und quantitativen Methoden. Die Daten wurden in zwei Unterbezirken (Garba Tula und Isiolo Central) in Isiolo County in Kenia mit Hilfe von halbstrukturierten Fragebögen, Fokusgruppendiskussionen (FGDs), Interviews mit wichtigen Akteuren (KII) und direkten Beobachtungen (DO) entlang der gesamten Kamelmilch-Lieferkette gesammelt. Für die Analyse der gesammelten Daten wurden sowohl deskriptive und inferenzstatistische Analysen für quantitative Daten, als auch thematische Kodierungen für qualitative Daten verwendet. Die Ergebnisse zeigten, dass die Kamelmilchverluste, welche maßgeblich durch Verderb und Verlusfe gekennzeichnet sind, je nach Jahreszeit variieren und in der Regenzeit um 81,0% bzw. 79,1% zunehmen. Die wichtigsten Strategien zur Verringerung der Milchverluste waren die Einhaltung hygienischer Praktiken (88% der Erzeuger, 61% der Händler), das Räuchern der Milchverarbeitungsutensilien (68% der Erzeuger, 10% der Händler) und die einfache Kühlung (13% der Erzeuger). Hohe Kosten und eine begrenzte technische Durchführbarkeit schränken den Einsatz moderner Konservierungsmethoden wie z.B. Kühl- und Kältetechnik ein. Bei nicht vermarkteter Milch wurden in der Nass- und Trockenzeit 28,8% bzw. 9,0% verworfen, während 11,2% bzw. 22,4% verarbeitet wurden. Transportfähigkeit, Erschwinglichkeit und Haltbarkeit wurden als wichtige Eigenschaften für die Akzeptanz von Kamelmilchpulver genannt. Diese Ergebnisse verdeutlichten den Bedarf an geeigneten Milchkonservierungstechnologien für eine längere Haltbarkeit von Kamelmilchprodukten in den ASALS.

Ausgehend von der Notwendigkeit einer längeren Haltbarkeit des Produkts und dafür geeigneter Konservierungstechnologien wurden unter Zielsetzung 2 Versuche zur Sprühtrocknung durchgeführt. Die thermischen, physikalischen und optischen Eigenschaften von Milchpulver sind grundlegend für das Verständnis der Qualität, Produktstabilität, Endanwendung und Transportierbarkeit von Milchpulver. Daher wurde im Kontext von Zielsetzung 2 der Einfluss verschiedener Sprühtrocknungsparameter (Trocknungsluft-Eingangstemperatur und Milchflussrate) auf die physikalischen, thermischen und optischen Eigenschaften von im Labor hergestelltem Kamelmilchpulver untersucht. Unter Verwendung eines 3 (110, 120 & 130 °C) x 2 (166 & 248 cm^3/h) faktoriellen Designs und dem Vergleich der Versuchsergebnisse mit kommerziell erhältlichen Kamelmilchpulvern wurde in Studie 2 speziell der Einfluss dieser beiden Parameter auf Rekonstitution, Partikel, Volumen, Farbe und thermische Eigenschaften der Kamelmilchpulver untersucht. Die Ergebnisse, erlangt durch ANOVA und Response Surface Methodology (RSM), zeigen, dass die Temperaturen der einströmenden Trocknungsluft den Feuchtigkeitsgehalt und die L* a* b*-Farbeigenschaften ($p<0,0001$) der Pulver signifikant beeinflussten. Umgekehrt werden die Volumen- und Rekonstitutionseigenschaften signifikant durch die Milchflussrate ($p<0,0001$) beeinflusst. Die Thermogramme aller Milchpulver weisen drei endotherme Spitzen und zwei Verschiebungen auf. Der Beginn des Glasübergangs nimmt mit abnehmendem Feuchtigkeitsgehalt der Pulver von 37,49 °C bis 44,21 °C zu. Verglichen mit den rasterelektronischen (REM) Aufnahmen der kommerziellen Proben zeigen die im Labor hergestellten Milchpulver hohle und kollabierte Partikel. Die kommerziellen Milchpulver weisen hingegen kugelförmige, raue Partikel mit kleinen Rissen, Eindellungen und Poren auf. Die Ergebnisse zeigen, dass sowohl die Temperatur der einströmenden Trocknungsluft als auch die Milchflussrate die thermischen, optischen und physikalischen Eigenschaften beeinflussen. Diese Ergebnisse sind wichtig für das Verständnis der Sprühtrocknungseigenschaften von Kamelmilchpulver und daher für die industrielle Produktion der Pulver von Bedeutung.

Nachdem die Möglichkeit der Herstellung der Kamelmilchpulver auf Laborebene ermittelt und die Eigenschaften mit kommerziell erhältlichen Pulvern verglichen wurden, ist die industrielle Herstellung der Pulver somit machbar, was dazu beitragen kann, die Verluste entlang der Lieferkette in Isiolo County verringern. Zielsetzung 3 untersuchte daher die Entwicklung und die techno-ökonomische Machbarkeit der Errichtung einer neuartigen dezentralisierten, kleinen Solar-

Heizöl-Hybridanlage zur Verarbeitung von Kamelmilch und Butter in den ASAL. Darüber hinaus wurde auch die Eignung der geplanten Verarbeitungsanlage zur Erfüllung der Ernährungs- und Ernährungssicherheitsbedürfnisse der Bevölkerung der ASALS untersucht. Unter Verwendung von Massen- und Energiebilanzen wurden die Prozessfließbilder (PFD) für die Verarbeitung von 3.135 kg/Tag Kamelrohmilch zu 356,1 kg Milchpulver und 66,5 kg Butter ausgelegt. Die Anlage wurde für einen Einsatzzeitraum 5 Tagen pro Woche und 40 Wochen pro Jahr ausgelegt, da Jahreszeiten mit geringer Milchproduktion ausgeschlossen wurden. Um die Energieeffizienz zu gewährleisten und den Verbrauch an fossilen Brennstoffen zu verringern, wurde der Prozess optimiert, wobei die Wärmerückgewinnung vor der Solarintegration gemäß den Richtlinien der IEA SHC Task 49 durchgeführt wurde. Durch eine Pinch-Analyse wurden Punkte zur prozessinternen Wärmerückgewinnung (HR) identifiziert, die Ströme zur maximaler Energierückgewinnung (MER) ausgewählt und, basierend auf der techno-ökonomischen Machbarkeit, ein finales Wärmetauschernetzwerk (HEN) entworfen. Die Nutzbarkeit der Photovoltaik (PV) und der Wärmeintegration wurde vor der Integration in das optimierte System durch Simulation mittels Systemadvisormodell (SAM) bewertet. Die techno-ökonomische Durchführbarkeit der Errichtung der Anlage wurde durch eine modulare, faktorielle Methode zur Kapitalschätzung untersucht, während die Rentabilität der Anlage auf der Grundlage des Cashflows nach Steuern, des Nettogegenwartswerts (NPV), der Amortisationszeit und des diskontierten Cashflows (DCFROR) bewertet wurde. Des Weiteren wurde eine Sensitivitätsanalyse durchgeführt, um den Einfluss von Schwankungen bei Einnahmen, Herstellungskosten, Kapitalkosten, Steuersätzen und Zinssätzen auf den NPV_{15} zu bestimmen. Die Ergebnisse von Zielsetzung 3 zeigen, dass die Errichtung dieser Kamelmilchpulver- und Butterherstellungsanlage für die ASAL unter Anwendung von Optimierungsprozessen durch die Pinch-Analyse zu einer Energieeinsparung von ca. 38,53 % führt. Zur weiteren Minimierung des Verbrauchs fossiler Brennstoffe und der Elektrizität aus dem Netz wurden Solarwärme und Solarintegration bewertet, was zu jährlichen Einsparungen von 644,66 bzw. 235,31 MWh bei Heizöl und bei elektrischem Strom zu 293,01 bzw. 165,05 MWh führt. Dies wiederum reduziert die Treibhausgasemissionen (GHG) um 332,37 Tonnen CO_{2e} pro Jahr und führt zu jährlichen finanziellen Einsparungen von etwa 98.479,30 €. Während die Verarbeitung der flüssigen Kamelmilch zu Pulver und Butter die Verluste bei der Vermarktung der flüssigen Milch begrenzen kann, sind die Investitionskosten (11,74 Millionen Euro) hingegen enorm. Dies wird die

Realisierung der Errichtung dieser Anlage unter Berücksichtigung des sozioökonomischen Status der Bevölkerung in den ASAL behindern. Um die Frauen, die maßgeblich an der Kamelmilch-Lieferkette im County beteiligt sind, dazu zu befähigen, müssten finanzielle Unterstützungen in Form von Zuschüssen, Subventionen und Anreizen von Regierung, NGOs und den Entwicklungsorganisationen gewährt werden. Mit einer Amortisationszeit von 5,2 Jahren, einer Rendite von 13,4%, einem DCFROR von 58% und einem NPV_{15} von 19,40 Millionen Euro wäre das Unternehmen langfristig rentabel. Die Sensitivitätsanalyse zeigte außerdem, dass die Einnahmen die größten Auswirkungen auf den NPV_{15} haben, was bedeutet, dass Schwankungen der weltweiten Kamelmilchpulverpreise um 20% den NPV_{15} um 41,04 % senken würden. Zusammenfassend lässt sich sagen, dass diese Studie einen schrittweisen, ganzheitlichen Ansatz für die optimale Prozessgestaltung, solare Integration und die wirtschaftliche Analyse für eine dezentralisierte, kleinindustrielle, solar-fossile hybride Milchpulver- und Butterherstellungsanlag in ASAL geliefert hat. Es wird empfohlen, dass diese Ergebnisse genutzt und auf reale Projekte angewandt werden, welche den industriellen Verbrauch fossiler Brennstoffe und die CO_2-Emissionen reduzieren wollen.

Diese Untersuchung ergänzt das wissenschaftliche Verständnis über die Kamelmilchlieferkette und die Kamelmilchpulverproduktion. Darüber hinaus liefert diese Arbeit weitere Einblicke in das Design und die techno-ökonomische Machbarkeit der Errichtung einer solchen Anlage zur Verarbeitung von Kamelmilchpulver und Butter unter Nutzung der Sonneneinstrahlung, welche charakteristisch ist für die von Kamelen bevölkerten ASAL. Während sich der untersuchte Standort in Kenia befindet, können die Ergebnisse dieser Arbeit unter Berücksichtigung der spezifischen Bedingungen auf andere Standorte angewendet werden. Darüber hinaus leistet diese Studie einen Beitrag zur Big Four Agenda der kenianischen Regierung, die unter anderem auf Ernährungssicherheit durch Wertschöpfung ausgerichtet ist. Zusätzlich zu erwähnen ist, dass Kenias National Climate Change plan, welcher 2018 in Kraft trat, dem Rahmenwerk der Vereinten Nationen für den Klimawandel (UNFCC) verpflichtet ist, was den Schwerpunkt auf die Reduzierung der Treibhausgasemissionen legt und somit durch die Nutzung der Sonnenenergie und die Optimierung der Prozesse den Einsatz fossiler Brennstoffe einschränkt.

Appendices

Appendix 1: Interview Guides

Appendix 1 a: Producer questionnaire

PRODUCER QUESTIONNAIRE

QUESTIONNAIRE ON LOSSES AND VALUE-ADDED PRODUCTS ALONG THE CAMEL MILK VALUE CHAIN IN ISIOLO COUNTY, KENYA

Questionnaire No. ☐ Interviewer code ☐ Start time ☐ End time ☐

Date of interview: Day ☐ Month ☐ Year ☐ Location ☐

INTRODUCTION

I am a Kenyan PhD student at the University of Kassel implementing a study on losses in the production and marketing of the Camel Milk in Isiolo with the aim of understanding the appropriate technology to minimize losses.

Consent

The information that you share with me, is confidential and will only be used for purposes of research.

You are free to stop the interview at any stage, if you feel you would not like to continue.

Your participation in the interview is voluntary with no monetary or any physical gain.

Do you agree to proceed? Yes ☐ No ☐ Signature ☐

The conversation will take a maximum of 30 minutes

SECTION A: SOCIO-ECONOMIC & DEMOGRAPHIC CHARACTERISTICS OF THE HOUSEHOLD

A. [The purpose of this section is to get an insight about the general characteristics of households, social economic activities)

Particulars and characteristics	**Herd owner details**
Age in (years)	
Gender of respondent	Male ☐ Female ☐
Head of household	Male ☐ Female ☐
Marital status	Married ☐ Separated ☐ Single ☐ Divorced ☐
Educational level	☐ None ☐ Primary school ☐ Secondary school ☐ Vocational ☐ University ☐Postgraduate
Major occupation	☐ Crop farming ☐ Livestock keeping ☐ Business ☐ Wage employment ☐ None ☐ Others (specify)...............................

Household size	Children (<18 years)	Male☐ Female☐
	Adults (19-45 years))	Male☐ Female☐
	Adults (>45 years))	Male☐ Female☐
Total income of the household per year (Kshs.)		
Distance to the nearest market (km)		
Distance to the nearest water point (km)		
Main source of water for camel use	☐ Rain fed ☐ Well ☐ Rivers ☐ Piped water ☐ None ☐ Others (specify)...............................	

SECTION B. CAMEL PRODUCTION

10. **How many years have you been involved in commercial camel milk business?** ☐
11. **How many camels of these breed do you have that are lactating?** ☐
12. **Randomly select five lactating camels and record the following information**

			Average milk yield per day		
Camel ID	Breed	Present Parity	At calving (1-3 months)	Mid lactation (4-6 months)	Drying off (7-9 months)
1					
2					
3					
4					
5					

13. **At what time in the morning, afternoon and evening do you normally milk your camel in the following seasons?**

Time of day	Dry season	Long rains	Short rains
Morning			
Afternoon			
Evening			

How often would you have liked to sell your milk in a day irrespective of the season? Why?

14. **Estimate the daily milk off take in litres from your herd during the following seasons. (Take into consideration the herd size in Question 11)**

	Long rains	Short rains	Dry seasons
Total herd off take (litres)			

15. **Do you clean the milking equipment before milking?** Yes ☐ No ☐
16. **Do you wash your hands before milking?** Yes ☐ No ☐

17. **Do you check the udder of the camels before milking?** Yes ☐ No ☐
18. **Do you clean the udder before milking?** Yes ☐ No ☐
19. **Do you filter the milk after milking?** Yes ☐ No ☐
20. **Do you refrigerate your milk?** Yes ☐ No ☐
21. **Do you cover your milk during storage?** Yes ☐ No ☐
22. **Do you boil your milk after milking?** Yes ☐ No ☐
23. **Do you wash your hand with soap and water or only water?** Soap and water ☐ water ☐
24. **Do you treat the water before use in milking activities?** Yes ☐ No ☐
25. **Do you get veterinary services?** Yes ☐ No ☐
26. **Do you buy drugs from the agro vet?** Yes ☐ No ☐

SECTION C. MARKETING OF MILK

27. **At what time in the morning, afternoon and evening do you normally sell your milk in the following seasons**

Time of day	Dry season	Long rains	Short rains
Morning			
Afternoon			
Evening			

28. **Estimate the total milk sold in liters per day during each of the following seasons.**

Season	Long rainy season	Short rainy	Dry season
Quantity in litres			
Price per litre			

29. **What percentage of your milk do you sell to the following buyers?**

Buyer	Consumer	Traders	Hawker	Milk Bar	Cooperative	Others ....
Percentage						

30. **Do you mix the milk from the different milking?** Yes ☐ No ☐
31. **If No, why?** ____________________
32. **Do you consume or sale the evening milk?** Consume ☐ Sell ☐
33. **If sell, do you sell it immediately or the next morning?** Immediately ☐ Next morning ☐
34. **If you sell the evening milk the next morning, how do you preserve it to ensure that it does not spoil before morning?**

____

35. **Are there times that you don't sell all your milk/ rejected?** Yes ☐ No ☐

36. If yes, on average how many litres of your milk is rejected per week during the dry and wet seasons?

Long rainy season	Short rainy	Dry season

37. How do you utilize this milk?

Sale them at a discounted price (specify the price)	☐	
Household consumption	☐	
Process it into other products. Specify…………………………..	☐	
Dispose off	☐	

38. If product development how do you carry out this?

39. How long in minutes do you travel to the milk collection centers/ market during these seasons? (The mode the respondent uses is the one that you should fill in).

Mode of transport	Dry season	Wet season	
Vehicle			Minutes
Travel on foot by holding milk			Minutes
Travel by pack animals			Minutes
Travel by ox or donkey)			Minutes
Travel by motorbike			Minutes
Collected at the milking point			Minutes

40. **Are there spillages that occur on your way to the market?** Yes ☐ No ☐ **if no skip to 46.**

41. If yes how many litres of milk do you finally sell at the market/ milking point in a day in the following seasons?

Long rainy season	Short rainy	Dry season

42. **Do you sell your milk individually or as a group?** Individual marketing ☐ Group marketing ☐

43. **Why do you sell the milk in the form stated?**

SECTION D: CONSUMPTION

44. How many litres of milk do you consume in your household during the following seasons?

Long rainy season	Short rainy	Dry season

45. How often do you consume the camel milk in the following forms?

Form	Often	Rarely	Never
Raw			
Boiled			
Tea			
Boiled			
Smoking			
Suusa (fermented)			
Others (specify).................			

SECTION E: MILK POWDER

46. Have you ever consumed milk powder? Yes ☐ No ☐

47. How likely or unlikely are you to purchase camel milk powder?

Very Likely ☐ Somewhat likely ☐ Somewhat unlikely ☐ Very unlikely ☐

How important are these attributes to you regarding milk powder?

Attribute	Very important	Important	Neither important nor unimportant	Somewhat important	Not important
Storability	☐	☐	☐	☐	☐
Solubility	☐	☐	☐	☐	☐
Affordability	☐	☐	☐	☐	☐
Transportability	☐	☐	☐	☐	☐
Taste	☐	☐	☐	☐	☐
Colour	☐	☐	☐	☐	☐

48. What are the main challenges that you face as a commercial camel milk businessperson?

1.
2.
3.

49. Gender specific activities

Activity	M	F	C
Milking of the camel			
Selling and distribution of the milk,			
Grazing the camel			
Decisions on what quantity of milk to sell			
Decisions on how to use the proceeds from Camel milk sales			
Decisions on where to sell the milk to.			
Milk preservation or value addition			
Attend trainings related to camel milk			

50. Have you received any training on the following activities?

Activity	Yes	No	From whom?	Since when
Handling of milk				
Processing of milk				
Feeding of camel				
Transportation of milk				
Marketing of milk				
Quality analysis of milk				
Others ...				

Thank you very much for your time and response

Appendix 1 b: Traders questionnaire

1. How long have you been in this business and what prompted you to engage in this kind of business?

……

……

2. What are the main challenges in camel milk marketing?

……

……

3. Are there any tests that you carry at the point of collection? How do you determine that the quality of milk you receive are of high quality? What are these tests?

……

……

4. Understanding the marketing chain

Buyer	Transportation mode of the seller to get to the buyer?	Container for transportation of the trader to get to the buyer?	Transportation distance of the Trader to get to the buyer?	Price per liter of milk buying from farmer	Price per litre selling to the other traders/consumer	Transportatio n cost

Please rank 1 Often and 5 least

Buyer
1. Consumers
2. Traders/ Hawkers
3. Brokers
4. Co-operative
5. Others (specify …………

Transportation mode
1. Head/ Hand
2. Donkey/ Ox Cart
3. Motorcycle
4. Public transportation
5. Bicycle

Containers
1. Plastic
2. Metallic (aluminium cans)
3. Melamine
4. Porcelain
5. Others …………………….

5. To understand the traded quantities of camel milk per day

Parameter	Dry Season	Wet Season	Normal Season
Total milk in litres received per day from farmers			
Total milk in litres accepted by the traders			
Total milk rejected in litres from the producers			
Total milk rejected by the buyers			
Total milk sold to the buyers			
Total milk volume converted to other products			
Price per litre of milk			

6. How do you utilize the milk that has been rejected by the buyers or which remains unsold?

………

………

7. Please mention any other camel milk products that you sell apart from the fresh milk, whether self-made or bought and resold? Explain why?

………

………

8. What are your thoughts on strategies that can be introduced to increase the shelf life of camel milk?

………

………

9. What do you think can be done to improve the camel milk value chain?

………

………

10. What are your thoughts on introduction of a new product such as camel milk powder in terms of your willingness to trade?

………

………

………

11. What are your thoughts on the willingness of consumers on the acceptability of and willingness to purchase this product?

………

………

Thank you very much for your time and response

Appendix 1 c: Key informant interview guide

Government / Non-government representative

1. Tell me more about the camel milk issues in Isiolo and what are the specific challenges in the development of the camel milk value chain? (2000-2015)
2. What still needs to be done to further develop the value chain and by whom?
3. Please tell me more about other major players involved in the camel milk value chain.
4. What were some of the issues you find challenging in the development of camel milk value chains?
5. As a growing business and important source of livelihood, what is your plan in this strategic year, as a government to improve this Camel Milk chain?
6. What are your opinions on solar energy compared to electricity for camel milk handling, storage and processing?

Anolei / Tawakal women group

1. Tell me more about the business, your challenges, quantity received and whom you work closely with?
2. Are there tests that you carry out at the milk collection point (reception point), How do you do this and what are the major quality issues that often arise?
3. How do you manage to meet the daily quantity of milk that your customers in Eastleigh,Nairobi, demand? Have there been instances where milk has been returned due to poor quality? And if yes how frequent and what are the major actions that you take?
4. What are your future plans as a main key player in the camel milk value chain?
5. What is your opinion on the feasible technology for losses reduction in the camel milk value chain?
6. What are your opinions on solar energy compared to electricity for milk handling, storage and processing?

Appendix 1 d: Focus Group discussion guide

A specific checklist of questions used during managing focus group discussion interviews with community members in Isiolo District, Kenya

FGD Duration: 60 –120 Minutes

Objective: To complement the data that is obtained from the questionnaires

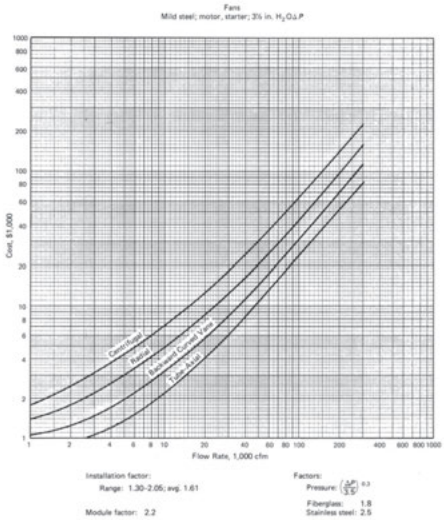
Approach: To undertake interviews with community in the study site in order to understand the importance of camel milk understand the marketing chain and the challenges involved therein for the improvement of the chain.

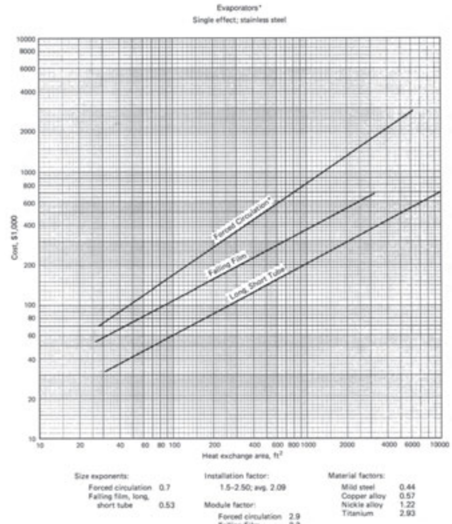
Participants : 6-8 members.

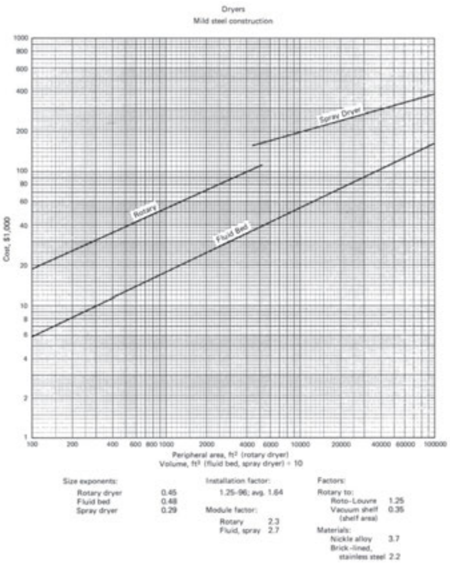
1. What are the main livelihood activities in this area?
2. When did the camel milk trading begin and what were the factors that influenced this and how do you carry out the marketing of milk?
3. What are the main activities that are carried out in milking, Handling, Transportation and marketing and who is responsible and why and how much do they cost?

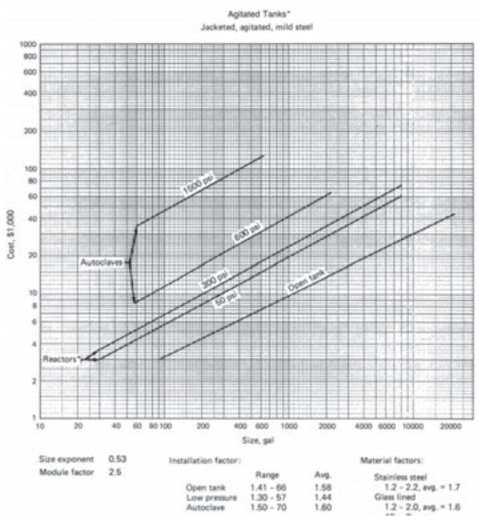
4. What are the factors that influence the pricing of camel milk and how do you handle these deviations? Do the price vary depending on seasons? And how much does this cost?
5. Is there a way you categorize households based on the number of camels they have?
6. What support is given by NGO and government in the production, transportation, storage, handling and marketing of Camel milk?
7. What are the major challenges in production and marketing of camel milk and are there ways that you tackle them and what influences your choice of the buyer?
8. What are your opinions concerning drying of camel milk? Will this be acceptable and what attributes do you think is of great significance to

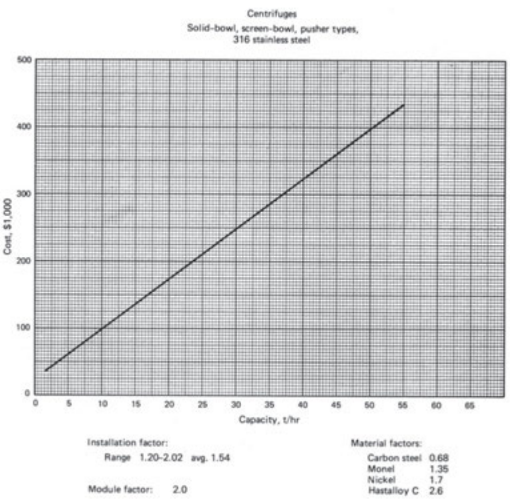
Appendix 2: Guthrie Charts

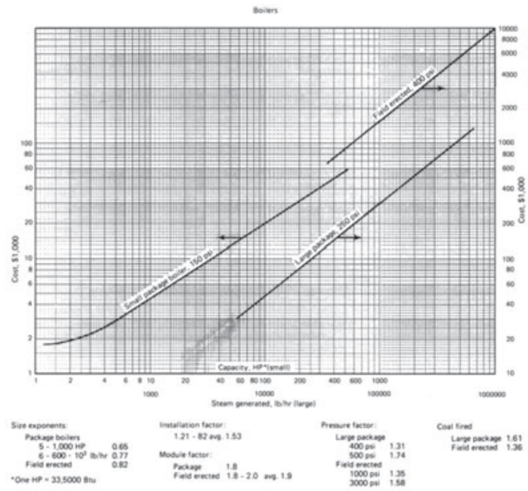




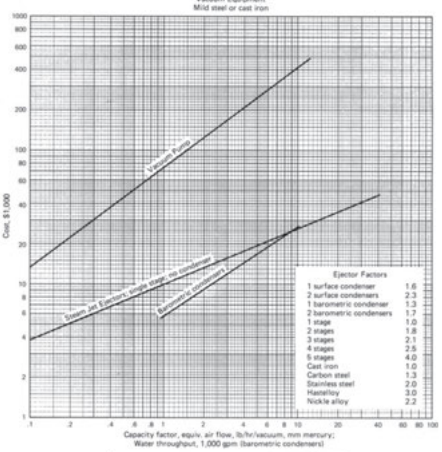








Vacuum Equipment
Mild steel or cast iron

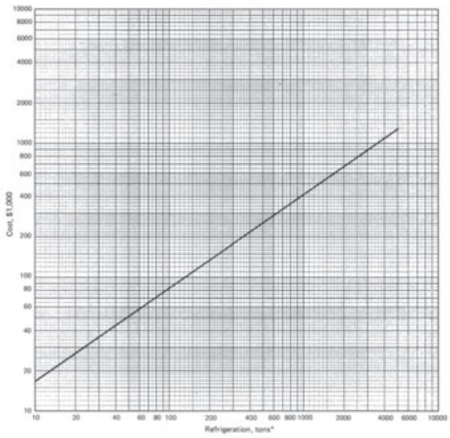


Size exponents:

Vacuum pumps	0.75
Steam jet ejectors	0.42
Barometric condensers	0.67

Installation factor 1.12
Module factor 2.2

Refrigeration
40° F temperature



Size exponent 0.69

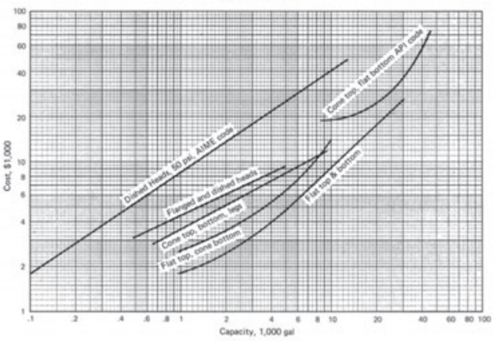
*One ton = 12,000 Btu

Installation, Module factor
1.38-53; avg. 1.46

Evaporative temperature factors:

+20F	1.5
0	1.9
−20	2.4
−40	3.5

Tanks, (Small)
304 stainless steel

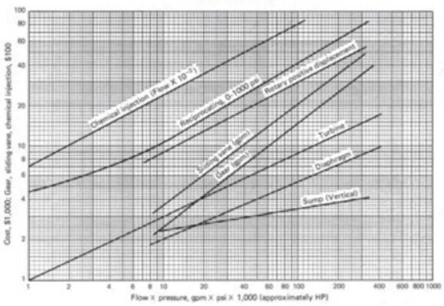


Size exponent

Dished head, 50 psi	0.68
Flanged, dished head	0.48
Cone top, bottom, legs	0.57
Flat top, bottom	0.93

Factor
316/304 stainless steel 1.39

Pumps, Miscellaneous
Mild steel construction



Factors

	Reciprocating	Turbine	Chemical Injection
Size exponent	0.59	0.47	0.52
Installation		1.38	1.58
Module factor	3.3	1.80	2.83
Cast iron	1.0		1.0
Cast steel	1.8		1.25
Stainless	2.4		1.95
Nickel alloy	5.0		
0-150 psi	1.0		1.0
150-500	1.32		1.37
500-1000	1.53		1.79

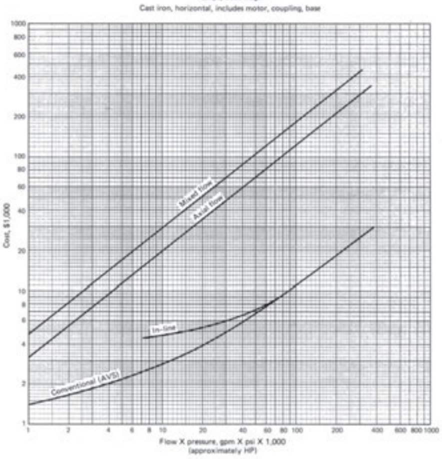
General installation factor:
1.25 - 2.40; avg. 1.74

Other size exponents:

Diaphragm	.43
Rotary	.52
Gear	.75
Sump	.15

Factors:
Reciprocating: ΔP (1,000 - 5,000)/(0 - 1,000) = 3.8
Sump: 3600/1800 rpm = 1.2
1200/1800 in. = 1.5
Chemical injection: Fixed/variable speed = 1.67

Pumps, Centrifugal
Cast iron, horizontal, includes motor, coupling, base



Factors:

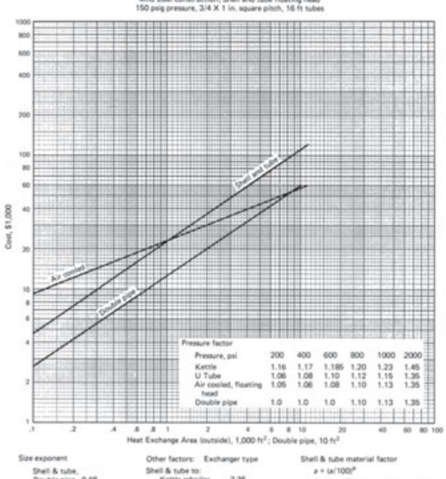
	Conventional	In-line	Axial Flow	Mixed Flow
Size exponent			0.79	0.79
Installation	1.30	1.27	1.58	1.32
Module factor	1.5	1.75	2.05	1.70
Cast steel	1.4	1.3		
316 stainless	2.0	1.6		
Copper alloy	1.3			
Nickel alloy	3.6			
Titanium	5.7			

Pressure factor:

	to 150 psi	150-500 psi	500-1000 psi
In-line	1.00	1.48	1.92
Conventional	1.0	1.62	2.12

Factors:
Conventional: APS/AVS = 1.6
In-line: vertical/horizontal = 0.89
Mixed, axial flow: vertical/horizontal = 1.12

Heat Exchangers; Shell and Tube, Double Pipe, Air Cooled
Mild steel construction; Shell and tube floating head
150 psig pressure, 3/4 X 1 in. square pitch, 16 ft tubes



Size exponent

Shell & tube, Double pipe	0.68
Air cooled	0.39

Installation factor
1.23-2.10, avg. 1.61

Module factor

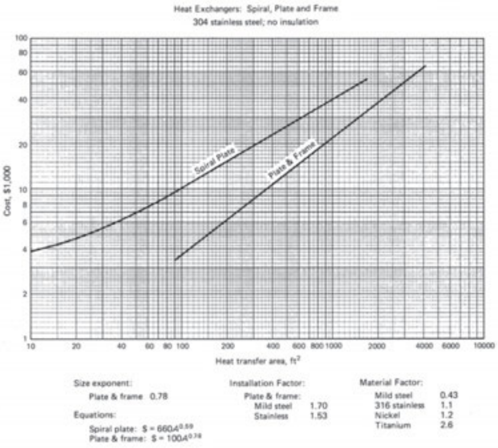
Shell & tube	3.2
Double pipe	1.8
Air cooled	2.2

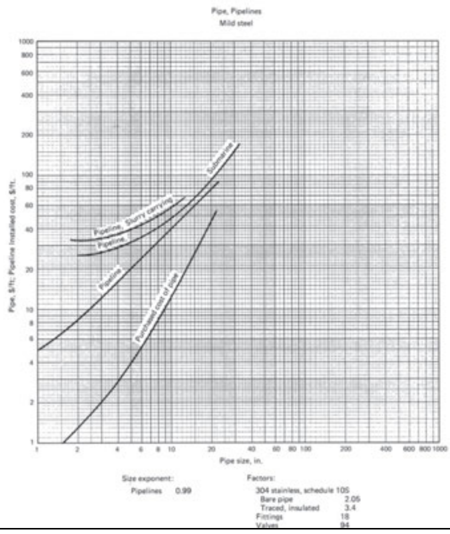
Other factors: Exchanger type
Shell & tube to:

Kettle reboiler	2.35
U-tube	1.85
Fixed tube sheet	1.79

Shell & tube material factor
$a = (a/100)^b$

Shell	Tube	a	b
CS	SS	1.75	0.13
SS	SS	2.70	0.07
CS	monel	2.1	0.13
monel	monel	3.3	0.08
CS	Ti	5.2	0.16
Ti	Ti	9.6	0.06
CS	moly	1.40	0.05
moly	moly	1.67	0.16
CS	Admiralty	1.08	0.05



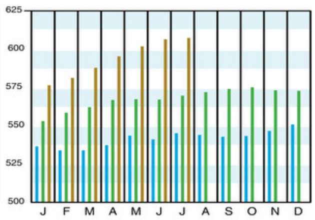


Appendix 3: CEPCI chart

CHEMICAL ENGINEERING PLANT COST INDEX (CEPCI)

(1957–59 = 100)	July '18 Prelim.	June '18 Final	July '17 Final
CE Index	607.3	605.2	569.6
Equipment	740.1	738.1	686.7
Heat exchangers & tanks	656.2	654.0	603.6
Process machinery	724.3	716.9	685.9
Pipe, valves & fittings	966.5	967.7	876.6
Process instruments	422.7	427.9	403.9
Pumps & compressors	1025.8	1017.9	984.7
Electrical equipment	538.0	536.2	520.8
Structural supports & misc.	809.9	805.3	739.9
Construction labor	335.6	332.3	330.4
Buildings	602.5	600.8	561.7
Engineering & supervision	308.1	307.3	313.3

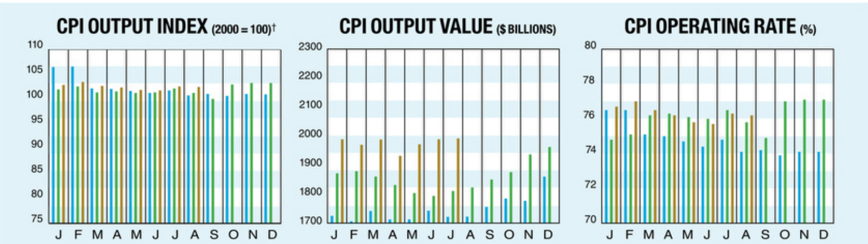
Annual Index:
2010 = 550.8
2011 = 585.7
2012 = 584.6
2013 = 567.3
2014 = 576.1
2015 = 556.8
2016 = 541.7
2017 = 567.5



Starting in April 2007, several data series for labor and compressors were converted to accommodate series IDs discontinued by the U.S. Bureau of Labor Statistics (BLS). Starting in March 2018, the data series for chemical industry special machinery was replaced because the series was discontinued by BLS (see *Chem. Eng.*, April 2018, p. 76–77.)

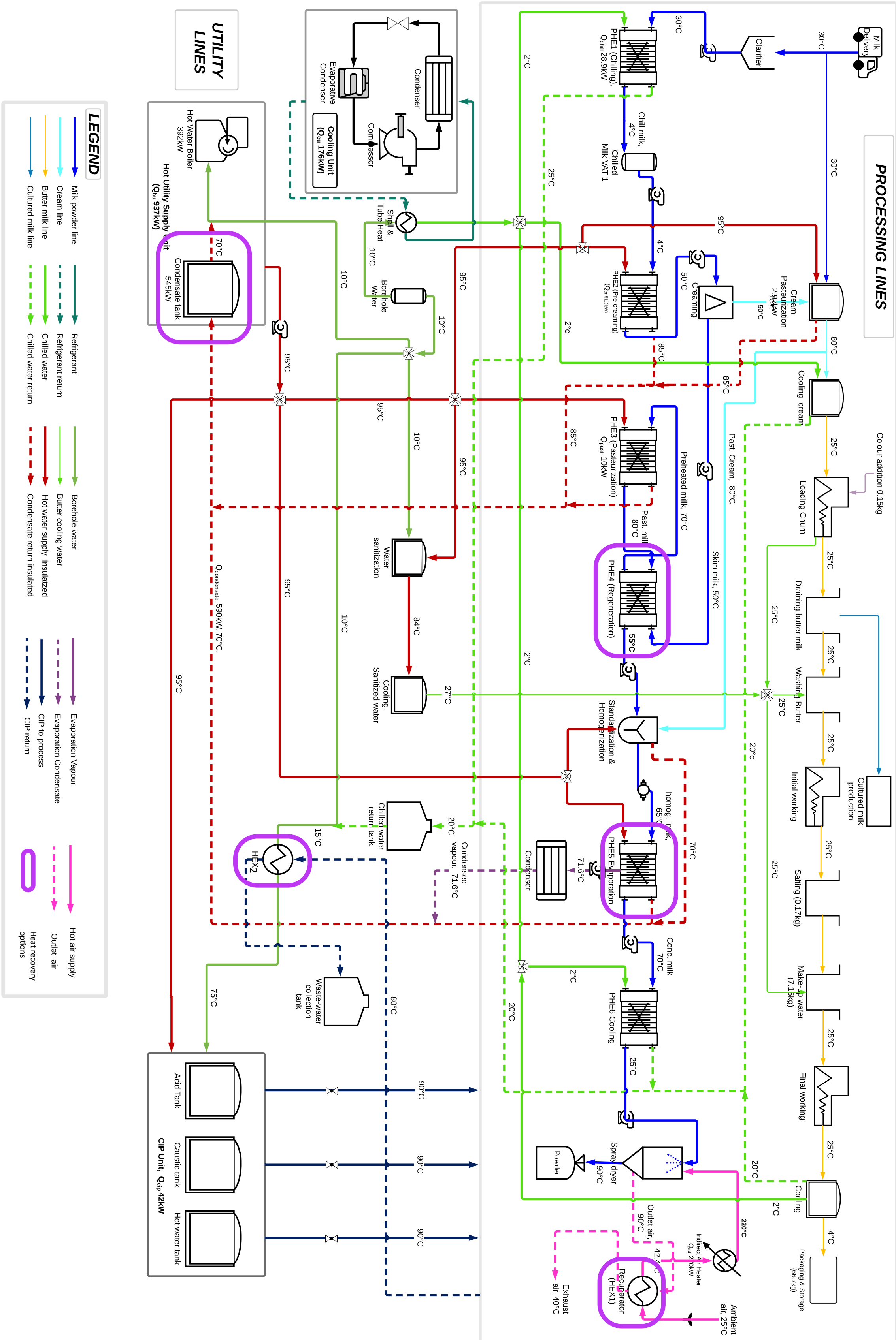
CURRENT BUSINESS INDICATORS

	LATEST	PREVIOUS		YEAR AGO
CPI output index (2012 = 100)	Aug. '18 = 102.4	Jul. '18 = 102.7	Jun. '18 = 102.2	Aug. '17 = 99.5
CPI value of output, $ billions	Jul. '18 = 1,992.3	Jun. '18 = 1,989.0	May '18 = 1,973.6	Jul. '17 = 1,762.4
CPI operating rate, %	Aug. '18 = 76.2	Jul. '18 = 76.5	Jun. '18 = 76.1	Aug. '17 = 74.9
Producer prices, industrial chemicals (1982 = 100)	Aug. '18 = 279.1	Jul. '18 = 277.8	Jun. '18 = 273.9	Aug. '17 = 252.8
Industrial Production in Manufacturing (2012 =100)*	Aug. '18 = 104.6	Jul. '18 = 104.3	Jun. '18 = 104.0	Aug. '17 = 101.4
Hourly earnings index, chemical & allied products (1992 = 100)	Aug. '18 = 183.0	Jul. '18 = 183.4	Jun. '18 = 183.8	Aug. '17 = 177.3
Productivity index, chemicals & allied products (1992 = 100)	Aug. '18 = 96.6	Jul. '18 = 96.7	Jun. '18 = 96.8	Aug. '17 = 96.9



*Due to discontinuance, the Index of Industrial Activity has been replaced by the Industrial Production in Manufacturing index from the U.S. Federal Reserve Board.
†For the current month's CPI output index values, the base year was changed from 2000 to 2012
Current business indicators provided by Global Insight, Inc., Lexington, Mass.

Appendix 4 Optimized Camel milk powder and butter processing plant for the ASALs.



ISSN 0931-6264