

ANALYSIS OF MOISTURE REMOVAL EFFICIENCY AND
PARTICLE SIZE DEVELOPMENT INSIDE FLUIDIZED
BED DRYING PROCESS AT A FULL CREAM MILK
POWDER MANUFACTURING PLANT IN SRI LANKA

H. T. Jayawardane

(199258C)

A thesis submitted in partial fulfillment of the requirements for the
degree of Master of Science in Sustainable Process Engineering

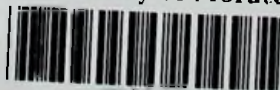
Department of Chemical & Process Engineering

University of Moratuwa

Sri Lanka

August 2023

University of Moratuwa



TH5265

TH5265
+

CD-ROM

66 "2023"
66.012 (043)

TH 5265

DECLARATION OF THE CANDIDATE AND SUPERVISOR

“I declare that this is my own work, and this thesis/dissertation does not incorporate without acknowledgement any material previously submitted for a degree or diploma in any University or other institute of higher learning and to the best of my knowledge and belief it does not contain any material previously published or written by another person except where the acknowledgement is made in the text.”

UOM Verified Signature

14 / 08 / 2023

.....
Signature

.....
Date

“I hereby grant the University of Moratuwa the right to archive and to make available my thesis or dissertation in whole or part in the University Libraries in all forms of media, subject to the provisions of the current copyright act of Sri Lanka. I retrain all proprietary rights, such as patent rights. I also retain the right to use in future works (such as articles or books) all or part of this thesis or dissertation.”


.....
Signature

14 / 08 / 2023

.....
Date

“I have supervised and accepted this thesis/dissertation for the award of the degree.”

Signed by Dr. H.H.M.P. Rathnayake

14 / 08 / 2023

.....
Signature of the Supervisor

.....
Date

ABSTRACT

Milk powder manufacturing can be identified as one of the leading industrial processes in the global dairy sector for cow milk preservation with nutrition purposes and processing as a raw material for many other food processing applications. The global milk powder market has already reached 11.2 million tonnes in 2020 and is expected to reach a volume of 14.1 million in 2026. Milk Powder is manufactured by dehydrating liquid milk by removing free moisture with some amount of bound moisture and leaving only milk solids by falling film evaporation and multi-stage drying processes. Milk powder has an extremely long shelf life when compared to raw milk and does not need refrigeration. This manufacturing process includes many chemical engineering unit operations, such as falling film evaporation, flash evaporation, direct steam injection, thermal vapor recompression, spray drying, fluidized bed drying, dehumidification, cyclone separation, screening, mixing, centrifugal separation, pasteurization, homogenization, etc. Drying processes play a significant role in the desired removal of moisture which will help particle size improvements as well as final milk powder quality parameter improvements.

Multi-stage drying processes are included in milk powder manufacturing for moisture removal. Three-stage dryers, as well as two-stage dryers are widely used in the process industry to achieve desired moisture removal with improved quality parameters. The two-stage drying process, which is a combination of spray drying and fluidized bed drying processes are widely used in Sri Lankan milk powder manufacturing plant operations. Among these two drying processes, the fluidized bed drying process will directly help to improve the particle diameter as well as desired final milk powder quality parameters like wettability, insolubility index, bulk density, etc.

In this study, the existing literature on the milk powder manufacturing process and fluidized bed dryer operations, including moisture removal were reviewed and analysed. In this study, the moisture removal process of a fluidized bed dryer is analysed with the aim of identifying the reason behind less solubility of produced full cream milk powder in hot water. Fluidized bed dryer operation can be identified as the main unit operation of the entire manufacturing process which directly helps to

improve the final product quality parameters like particle diameter, insolubility index, wettability, bulk density, etc. To analyse the moisture removal process of full cream milk powder, samples were collected from the inlet of the fluidized bed dryer, from the heating section, and from the cooling section, as well as the full cream milk powder outlet. Moisture removal activity is compared with the design parameters of the equipment and reviewed the moisture removal gradient to predict the improvement of particle diameter which directly affect the solubility characteristics.

In addition, final milk powder product particle size improvement in each section of the fluidized bed dryer were analyzed and compared with the literature values to have a sound idea about quality improvements. This study shows that the moisture removal process is the key process operation, which determines the final product quality related to the solubility and particle size development of full cream milk powder. The study identifies a relationship between the moisture removal process as well as gradual particle size development along the fluidized bed that would support the related industries in Sri Lanka to improve the full-cream milk powder manufacturing process.

Keywords: Multi-effect Falling Film Evaporation, Spray Drying, Fluidized Bed Drying, Moisture Removal, Particle Development.



DEDICATION

This thesis is dedicated to my research supervisor Dr. Mahinsasa Rathnayake, who taught me that teachers go beyond textbooks and inspire from the heart.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to my research supervisor Dr. Mahinsasa Rathnayake for the immense guidance, motivation and knowledge to steer me in the right direction whenever he thought I needed it.

I would also like to thank Prof. Mahinsasa Narayana, Dr. Ashok Fonseka, Prof. Padma Amarasinghe, Prof. P.G Rathnasiri, Prof. Shantha Amarasinghe and all the lecturers who have supported me throughout my MSc study. Without their passionate teachings and help, I could not have successfully completed my MSc degree.

Finally, I must express my very profound gratitude to my family for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them.

TABLE OF CONTENTS

Declaration of the candidate and supervisor.....	ii
Abstract	iii
Dedication	v
Acknowledgement.....	vi
Table of contents	vii
List of figures.....	ix
List of tables	xi
List of abbreviations	xii
1.0 Introduction	01
2.0 Literature review.....	03
2.1 Multi Effect Falling Film Evaporator Plant.....	06
2.1.1 Falling Film Evaporators with Milk Distribution Systems.....	13
2.2 Multistage Drying Plant.....	18
2.2.1 Product Atomization.....	19
2.2.2 Spray Drying & Fluidized Bed Drying with Fines Recovery..	22
3.0 Experimental Methodology.....	31
3.1 Initial modification of existing fluidized bed dryer.....	33
3.2 Sample collection and preparation.....	35
3.3 Moisture Level Measurements & Testing Procedure.....	36
3.4 Temperature Measurements.....	37
3.5. Insolubility Index Measurements.....	37
3.6 SEM Analysis	38
3.7 Particle Size Analysis.....	38
4.0 Results & Discussion.....	39
4.1 Moisture Content Along the FBD and Temperature Gradient Analysis.	39

4.2 Insolubility Index Analysis.....	41
4.3 SEM Analysis and Particle Size Distribution.....	42
5.0 Conclusion.....	52
References	53
Appendix.....	56



LIST OF FIGURES

Figure 2.1: Block diagram for general milk powder manufacturing process flow

Figure 2.2: Process flow diagram of four-effect falling film evaporator plant

Figure 2.3: Milk Preheaters

Figure 2.4: Preheaters (P5, P4, P3, P2, & P1) & Falling Film Evaporators
(E1, E2, E3 & E4)

Figure 2.5: DSI Unit and Holding Tube locations at Process Plant (b) DSI Unit

Figure 2.6: (a)Falling Film Evaporator Tube Sheet

(b) Milk Distributor Bowl at the top of the tube sheet of the evaporator.

Figure 2.7: Vapor Separators VS1, VS2, VS3, VS4 attached to each four effects of evaporators

Figure 2.8: Separated vapor is directed to the next evaporator jacket as a heating medium

Figure 2.9: Concentrate Collecting System and Pumping System of Falling Film Evaporator

Figure 2.10: Surface condenser of Four Effect Falling Film Evaporator system.

Figure 2.11: Two TVR System

Figure 2.12: One TVR system

Figure 2.13: Spray Dryer with taller body and small diameter & Pressure Nozzle Atomization

Figure 2.14: Rotary Wheel Atomizer Disk

Figure 2.15: Pressure Nozzles

Figure 2.16: Two Stage Drying Operations (Spray Dryer with Fluidized Bed Dryer)

Figure 2.17: Steam Radiator Air Heater System

Figure 2.18: Steam Air Heater working principle

Figure 2.19: Two Stage Drying with Fines Recovery System, Major Components

Figure 2.20: a) Cyclone Bottom Hoppers with Rotary Valves

b) One Feed Dual Cyclone System

Figure 2.21: Fluidized Bed Drying Major Components

Figure 3.1: Modified Damper with Teflon Sheet - Vibro Fluidized Bed Dryer

Figure 3.2: View of the Fluidized Bed Dryer Metal Net taken from the Spray Dryer
Outlet

Figure 3.3: Sample collection points from an operating fluidized bed dryer

Figure 4.1: Moisture Content Along the Fluidized Bed Dryer

Figure 4.2: Temperature Measurements Along the Fluidized Bed Dryer

Figure 4.3: Insolubility Index Variation of Experimental Batches Vs. Insolubility
Benchmark Value

Figure 4.4: Fine particles injection system in full cream milk powder manufacturing
process

Figure 4.5: Electron microscopy pictures of spray dried dairy powders agglomerated
at different stages of the drying process. Particle collisions at high (left)
and at low (right) moisture content.

Figure 4.6: **(a)** SEM Image of Full cream milk powder Sample after fluidized bed
drying operation.

(b) SEM Image of Full cream milk powder Sample after fluidized bed
drying operation

Figure 4.7: Particle Size with Cumulative Volume Variation

Figure 4.8: Particle Diameter with Volume Frequency (%)

LIST OF TABLES

Table 2.1: Scenario Evaluation with Stages of the Processes

Table 2.2: Evaporator Temperature and Pressure Conditions

Table 3.1: Sample Point Descriptions and Location

Table 3.2: Identification of quality parameters of each milk batch

Table 3.3: Process Operating Parameters

Table 4.1: Average Insolubility Index of Final Milk Powder of each Batch

Table 7.1: Temperature and Moisture Measurements

Table 7.1: Temperature and Moisture Measurements

Table 7.2: Temperature and Moisture Measurements

Table 7.3: Temperature and Moisture Measurements

Table 7.4: Temperature and Moisture Measurements

Table 7.5: Temperature and Moisture Measurements



LIST OF ABBREVIATIONS

Abbreviation	Description
CCP	Critical Control Point
DSI	Direct Steam Injection
FBD	Fluidized Bed Dryer
FCMP	Full Cream Milk Powder
SEM	Scanning Electron Microscope
SMP	Skim Milk Powder
SNF	Solid Non-Fat
TS	Total Solids
TVR	Thermal Vapor Recompression
VS	Vapor Separator
WMP	Whole Milk Powder