Copyright is owned by the Author of the thesis. Permission is given for a copy to be downloaded by an individual for the purpose of research and private study only. The thesis may not be reproduced elsewhere without the permission of the Author.
To whom it may concern

I would like to declare that the paper and digital copies are the same. One hard bound copy and the digital copy are deposited in the university for public record.

Best Regards,

Arunee Srichantra
STUDIES OF UHT-PLANT FOULING BY FRESH, RECOMBINED AND RECONSTITUTED WHOLE MILK

EFFECTS OF PREHEAT TREATMENTS

A THESIS PRESENTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY IN FOOD ENGINEERING

BY

ARUNEE SRICHANTRA

2008
Abstract

The objective of this study was to investigate the effects of preheat treatments on fouling by fresh whole milk (FWM), recombined whole milk (RCB) and reconstituted whole milk (Recon) in the high-temperature heater of indirect UHT plants.

Various preheat treatments prior to evaporation during milk powder manufacture were applied to skim milk powder (SMP, 75 °C 2 s, 85 °C, 155 s and 95 °C, 155 s) and whole milk powder (WMP, 95 °C, 33 s). These preheat treatments were so-called “evaporator preheat treatments”. Skim milk powder (SMP) and whole milk powder (WMP) were derived from the same original batch of pasteurised FWM to remove the effects of the variation in milk composition between different milk batches. These SMPs were recombined with anhydrous milk fat and water to prepare RCB, and WMPs were reconstituted with water to prepare Recon. Then, (homogenized) FWM, RCB and Recon were subjected to various preheat treatments (75 °C, 11 s, 85 °C, 147 s and 95 °C, 147 s) prior to UHT processing. These preheat treatments were so-called “UHT preheat treatments”. Temperature difference (hot water inlet temperature – milk outlet temperature) was taken as a measure of the extent of fouling in the high-temperature heater. The slope of the linear regression of temperature difference versus time (for two hours of UHT processing) was taken as fouling rate (°C/h).

Increasing both evaporator and UHT preheat treatments resulted in increasing fouling rate and total deposit weight for all three whole milk types for several milk batches. In the case of FWM, there was no reduction in fouling rate with increasing UHT preheat treatment whether FWM was homogenized then preheated, preheated then homogenized or not homogenized at all. These findings, which are wholly consistent and well replicated, are in apparent conflict with the results of most previous comparable studies. Possible reasons for this are explained.

Further investigations of the effects of homogenization relating to the role of whey protein on the surface of the fat globules showed that whey protein associated with the membrane covering the surface of fat globules for homogenized then preheated FWM, RCB and Recon and that association increased with increasing heating process stage. The increasing association of whey protein with the milk fat globules membrane with increasing severity
of heating process stage became faster when preheat treatment was more severe: the association of whey protein plateaued on intermediate temperature heating when the milks were preheated at 75°C, 11 s and on preheating when the milks were preheated at 95°C, 147 s.

In the case of FWM, the thickness of the membrane covering the surface of fat globules for homogenized then preheated FWM, which increased with the severity of heating process stage, was greater than the thickness of the membrane in preheated then homogenized FWM. Preheating then homogenization resulted in the greater interfacial spreading of small molecules on the surface of fat globules, i.e. whey protein or small molecules from the disintegration of casein micelles during preheating.

Possible basic mechanisms for UHT fouling in the high-temperature heater include: the reduction in the solubility of calcium phosphate and the deposition of protein as fat-bound protein and non-fat-bound protein. When non-fat-bound protein in milk plasma deposited, it could be a carrier for the deposition of mineral, such as, the precipitate of calcium phosphate in the casein micelles or the deposition of complexes between whey protein and casein micelles.
Acknowledgements

I wish to express my sincere gratitude to my chief supervisor Dr. Owen McCarthy for his long and patient guidance throughout the project. I am thankful for the kindness of Dr. David Newstead who has had his peace disturbed by me during his retirement. Many thanks for sharing your soul as a dairy scientist with me. I also wish to thank Associate Professor Tony Paterson for the encouragement and sharing of your soul of positive leadership and help through my PhD.

I am indebted to the staff of the milk powder pilot and the UHT plants at Fonterra, Palmerston North. Thanks to Dennis Dugmore and Geoff Paterson for the setting up and running of the UHT plant who showed lots of patience with me. Special thanks to Gordon Groube for his fabulous support, guidance and assistance in making every trials happen at the UHT plant. Many thanks to Paul Mason for your awesome work for both recombining and UHT plants. Sincere thanks to Adam Duker for delivering your best on every fouling trial at the UHT plant and all hard work to dismantle the plate heat exchanger.

I would like to thank for the team of milk powder plant; Colin Knight, John Grant, Dennis Dugmore, Bill Barnes and Sue Adams. Thanks for lots of laughs and the friendship that you gave to me.

Many thanks to the staff of the Analytical Chemistry section for the analyses they carried out. In particular, Errol Conaghan and Freya Gwynne for their patience and assistance on the analysis of milk samples. Thanks for Aiqian Ye for his generous discussion and Amy Ye for her kindness of the analysis for milk samples.

I am thankful to Diana Mackereth for her training on work of Gel Electrophoresis and to Raewyn McRedmond on work of fat-bound protein. Many thanks to Alan Baldwin, who gave his booking to proceed my fouling trials. Special thanks to Dr. Skelte Anema for your expertise on PAGE analysis and dairy science.
I would like to thank Barbara Kuhn-Sherlock (Fonterra), Robert Crawford (Fonterra) and Dr. Nigel Grigg (Massey) for their helps in statistics. Thanks to Liza Zhang, Cheese laboratory, for her patience and support to my milk samples.

Thanks to Fonterra, Palmerston North (formerly the New Zealand Dairy Research Institute) for access to unpublished internal reports on trial work. Also, thanks to the Foundation for Research, Science and Technology, Wellington, New Zealand and the Royal Thai government who gave me financial support for my PhD.

Finally, thanks to Mum, Dad and my sisters (Amornrat and Pattara) for your support and patience on my long journey. Thank you to my husband, Wisanu, and my lovely daughter, Amy Srichantra, who always accept my roles and support me throughout my PhD.
Table of contents

Chapter 1 Project overview 1-1

Chapter 2 Literature review

2.1 Introduction 2-1

2.2 Processing of fresh whole milk 2-2
  2.2.1 Milk reception 2-2
  2.2.2 Milk separation 2-2
  2.2.3 Milk pasteurisation 2-2
  2.2.4 Standardization 2-2

2.3 Milk powder manufacture 2-2
  2.3.1 Evaporator preheating 2-2
  2.3.2 Evaporation 2-3
  2.3.3 Homogenization 2-3
  2.3.4 Drying 2-3

2.4 Recombining processes 2-3

2.5 Heat-induced changes in fresh, recombined and reconstituted whole milks 2-4

2.6 Fouling by fresh, recombined and reconstituted whole milk in the high-temperature heating section of heat exchangers 2-7
  2.6.1 Fouling measurement 2-7
  2.6.2 Factors affected UHT fouling 2-8

2.7 Correlation of fouling behaviour between a pilot plant and an industrial plant 2-11

2.8 Deposit composition 2-13

2.9 The effect of preheat treatments on UHT fouling by fresh, recombined and reconstituted whole milk 2-14
  2.9.1 Effect of UHT preheat treatment on UHT fouling by fresh, recombined and reconstituted whole milk 2-14
  2.9.2 Effect of evaporator preheat treatment on UHT fouling by recombined and reconstituted whole milk 2-16
Chapter 3 Materials and methods

3.1 Milk
3.2 Pasteurisation
3.3 Standardisation
   3.3.1 Fresh skim milk
   3.3.2 Fresh whole milk
3.4 Milk powder manufacture
3.5 Recombination and reconstitution
3.6 UHT pilot plant 1
3.7 UHT pilot plant 2
3.8 Measurement of fouling rate
   3.8.1 Fouling deposit recovery
3.9 Experimental design
   3.9.1 Milk Nos. 1, 2 and 3
   3.9.2 Milk Nos. 4 and 5
   3.9.3 Milk Nos. 6 and 7
   3.9.4 Milk No. 8
   3.9.5 Milk No. 9
   3.9.6 Milk Nos. 10 and 11
   3.9.7 Milk No. 2b
3.10 Summary of all experimental designs
3.11 Chemical analyses of liquid milks and fouling deposits
3.12 Analysis of fat-bound-protein in the cream layer
   3.12.1 Calculation of fat-bound protein with top-serum substraction
   3.12.2 Calculation of fat-bound protein without top-serum substraction
   3.12.3 Estimation of total surface area and total volume covered the fat globules of FWM, RCB and Recon
3.13 Polyacrylamide gel electrophoresis (PAGE)
3.14 Statistical analysis 3-30
3.15 Determination of the composition of liquid milk during UHT processing 3-34

Chapter 4 Determination of fouling rate
4.1 Introduction 4-1
4.2 Estimation of induction period 4-2
4.3 Results 4-4
4.4 Discussion 4-7
4.5 Conclusion 4-8

Chapter 5 Effect of preheat treatments on UHT plant fouling by whole milks
5.1 Introduction 5-1
5.2 Effect of UHT preheating on fouling rate 5-2
  5.2.1 UHT plant 1, Milk No. 1 5-3
  5.2.2 UHT plant 2, Milk Nos. 2 and 3 5-3
  5.2.3 UHT plant 2, Milk Nos. 2, 3 and 6-11 5-6
5.3 Effect of evaporator preheat treatment on UHT fouling by RCB 5-8
  5.3.1 Effect of evaporator preheat treatment on the fouling rates of RCB (Milk No.1, UHT plant 1) 5-8
  5.3.2 Effect of evaporator preheat treatments on fouling rate of RCB (Milk Nos. 2 and 3, UHT plant 2) 5-9
5.4 A comparison of the effects of UHT and evaporator preheat treatments on fouling rates of RCB 5-11
5.5 Effect of evaporator preheat treatment and UHT preheat treatment on the fouling rate of Recon 5-13
5.6 Effect of UHT preheat treatment on fouling by homogenized then preheated FWM and preheated then homogenized FWM 5-15
5.7 Effect of homogenization on UHT fouling by FWM 5-17
5.8 Effect of the presence of fat globules on UHT fouling by RCB 5-19
5.9 Effect of homogenization on the fouling rate of reconstituted skim milk 5-21
5.10 Effect of milk powder ageing 5-22
Chapter 6 Effect of preheat treatments on the milk fat globule membrane of whole milks

6.1 Introduction 6-1

6.2 Experimental approach to measurement of total fat-bound protein and individual proteins in FWM, RCB and Recon 6-1

6.2.1 Effect of correcting for top-serum protein in the cream layers of FWM, RCB and Recon as measured by examining the variation of fat-bound protein with preheat treatment and heating process stage 6-2

6.2.2 Mass balances between the fat and protein in the cream layer, top-serum, serum and sediment fractions of whole milk and the measured fat and protein contents of the milk samples 6-7

6.2.3 The proportion of total fat recovered in the cream layers of FWM, RCB and Recon on centrifugation 6-9

6.2.4 Estimation of the fraction of total surface area fraction and the fraction of total volume represented by the recovered fat globules (cream layer) and the unrecovered fat globules (top-serum, serum and sediment) of homogenized then preheated FWM, RCB and Recon 6-10

6.3 Effect of pasteurisation on the total fat-bound protein in the cream layer of FWM 6-12

6.4 Effect of milk preparation on total fat-bound protein and individual fat-bound proteins in homogenized then preheated FWM, RCB and Recon 6-13

6.5 Effect of heating process stage on total fat-bound protein and individual fat-bound proteins in homogenized then preheated FWM, RCB and Recon 6-17

6.5.1 Homogenized then preheated FWM 6-17

6.5.2 Recombined whole milk 6-21

6.5.3 Reconstituted whole milk 6-24

6.6 Effect of evaporator preheat treatment on total fat-bound protein and individual fat-bound protein in RCB 6-26

6.7 Fat-bound total whey protein and fat-bound total casein as proportions of total fat-bound protein in the cream layers of FWM, RCB and Recon 6-29
6.8 The effect of homogenization before or after UHT preheat treatment on total fat-bound protein and individual fat-bound proteins in FWM 6-31

6.9 Discussion 6-36

6.10 Conclusion 6-40

Chapter 7 Effect of preheat treatments on the total weight and composition of fouling deposits from whole milks

7.1 Objectives 7-1

7.2 Deposit appearance 7-1

7.3 Fouling rates, and total deposit weight and composition of the deposits from homogenized then preheated FWM, RCB and Recon 7-3

7.4 Effect of preheat treatments on total deposit weight and the weights of fat, protein, ash, phosphate, calcium, phosphorus and lactose in the deposits from homogenized then preheated FWM, RCB and Recon 7-6

7.4.1 Effect of UHT preheat treatment on the deposits from FWM, RCB and Recon 7-6

7.4.2 Effect of Evaporator preheat treatment on the deposit from RCB 7-9

7.5 Comparison of the effects of UHT preheating before and after homogenization on subsequent deposit formation by FWM 7-11

7.6 Effect of the presence of fat globules in the deposit from RCB 7-12

7.7 Composition of fouling deposits from FWM, RCB and Recon: effects of UHT and evaporator preheat treatments, and comparisons with changes in whole milk composition during UHT processing 7-13

7.7.1 Effect of UHT preheat treatment 7-13

7.7.2 Effect of evaporator preheat treatment 7-17

7.8 Comparison of calcium, phosphate and phosphorus, and calcium phosphate in the deposits on a mole basis 7-19

7.9 Discussion 7-21

7.10 Conclusions 7-24
Chapter 8 Overall discussion

References

Appendices

Publication