The Effect of Milk Fat Globule Membrane Damage in the Absence of Air on Fouling in Heat Exchangers

A Thesis Presented in Partial Fulfilment of the Requirements for the Degree of Master of Technology in Food Technology of Massey University

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February 1998

乳脂球膜的破损在无空气介入时对换热器中牛乳结垢的影响

该论文是新西兰梅西大学食品技术专业
硕士学位的必要组成部分

方砾

一九九八年二月

To my dear wife and daughter

Thanks for their understanding and moral support!

Abstract

The fouling by whole milk of processing plant surfaces, especially in heat exchangers, is a serious problem, but is incompletely understood despite extensive past investigations. While milk fat has generally been thought to play a minor role in fouling, the results of some previous work suggest that this is not always the case. The state and form of the fat, as well as processing conditions, may have effects on milk fouling behaviour.

Careless mechanical handling of whole milk is known to cause fat damage. The present study set out to investigate the effect on fouling of damage to the milk fat globule membrane (MFGM) by mechanical stresses in the absence of air.

Pasteurised non-homogenised whole milk was deliberately stressed to differing degrees by passing it through a cavitating pump a variable number of times. The extent of damage was measured using four different techniques: a free fat (FF) test (a modified extraction method), a lipolysable free fat (LFF) test (free fatty acid determination after incubation of the sample with pig pancreatic lipase, a technique developed during this work), particle size distribution (PSD) measurement by laser light scattering, and confocal laser scanning microscopy (CLSM).

The fouling behaviour of both damaged and undamaged milk was investigated by heating the milk from about 4°C to about 94°C in a custom built double pipe heat exchanger, which could be disassembled easily to access the fouling layer. Milk flowed in the annulus, with a Reynolds number range of about 220-310. The fouling rate was measured and expressed as the rate of increase of the overall resistance to heat transfer, normalized using the overall heat transfer coefficient determined at the start of a run.

The fouling rate exhibited by damaged milk (normalized by the rate for undamaged milk, to account for batch-to-batch variation) was found to increase significantly with the extent of cavitation treatment. There was also a clear positive relationship between both the FF and LFF contents of milk and the extent of cavitation treatment, suggesting strongly that the observed increases in fouling rate were the result of increased MFGM damage.

PSD measurement and CLSM both showed that cavitation caused the appearance in the milk of some large, irregularly shaped fat globules, presumably the result of coalescence. The FF results, and observation by CLSM, indicated that only a small proportion (< 6°C) of the total milk fat had to be measurably damaged to cause extensive fouling.

The fat contents of the fouling layers were found to be very high (>45% on a dry weight basis). Although some of the experimental conditions, especially the low Reynolds numbers, may have contributed to this result, other fouling investigations made in New Zealand have produced similar results.

It is hypothesised that large globules formed by the coalescence of native globules whose membrane have been damaged could migrate more easily to the stainless steel heating surface. There, they could act as anchor points for the build-up of a fouling layer with a continuous protein phase. This hypothesis is supported by CLS micrographs of the fouling layer. Further investigation is warranted.

Recommendations are made for improving the methods used to measure MFGM damage, fouling and fouling rate, and the structure of the fouling layer.

ACKNOWLEDGEMENTS

Today, my dream of studying for the Master's Degree in the Department of Food Technology at Massey University many years ago comes true. I had happy and, of course, hard-working times here which will be a beautiful memory in my life.

During my study, I met so many warm-hearted people who had given me friendly supports. First, I would like to thank my supervisors Dr. Tuoc K. Trinh and Dr. Owen J. McCarthy for their kind supervision and encouragement throughout this project. For me, they are real rigorous scholars and helpful friends.

I also like to give my special thanks to Mr. Byron Mckillop, who was always patient with my questions and helped me in building the experimental rig, and Mr. Allistair Young, who helped me in obtaining the milk for the experiments. I will remember his kindness and humour.

Professional advice from Mr. Jaap Evers, Mr. Kevin Palfrayman and Dr. Alistair MacGibbon at the New Zealand Dairy Research Institute was valuable in the understanding of free fat and free fatty acids. Mr. Tuan Truong gave me much helpful advice and information on the topic of milk fouling. Dr. Mike Taylor of Massey University gave me guidance related to milk fat.

I appreciate those Massey staff who gave me technical support during this research, especially Ms. June Latham, Mr. Steve Glasgow, Mr. Mark Dorsey, Ms. Elizabeth Nickless, Dr. Al Rowland, Mr. Garry Radford and others.

Financial support from the New Zealand Dairy Board was highly appreciated. The New Zealand Rennet Company kindly supplied me some calf lipase.

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R_F:	heat transfer resistance of fouling deposit (m^2KW^{-1})
U:	heat transfer coefficient after fouling formation ($Wm^{-2}K^{-1}$)
U_o:	heat transfer coefficient prior to fouling formation ($Wm^{-2}K^{-1}$)
d_{vs}:	volume surface average diameter of fat globules (μm)
$N_i/\Delta d$:	number frequency ($ml^{-1}\mu m^{-1}$)
d_o:	outlet diameter of inside tube (mm)
d_i:	inlet diameter of inside tube (mm)
D_o:	outlet diameter of outside tube (mm)
D_i:	inlet diameter of outside tube (mm)
Q':	flow rate of milk (L hr^{-1})
t_m:	milk outlet temperature (°C)
T_m:	milk inlet temperature (°C)
t_w:	hot water outlet temperature (°C)
T_w:	hot water inlet temperature (°C)
ρ_{milk}:	milk density (Kgm^{-3})
μ_{milk}:	milk viscosity (Pa s)
c_p:	heat capacity ($KJKg^{-1}K^{-1}$)
S':	area of milk cross section (m^2)
d_e:	equal diameter of milk cross section (mm)
V':	milk velocity (m s^{-1})
Re:	Reynolds number
ΔT_m:	logarithmic temperature difference (°C)
Q_1 (Q_m):	energy needed to heat up milk (W)
Q_2 (Q_w):	energy given by the hot water (W)
A:	heat exchange area (m^2)
Q'_{water}:	flow rate of hot water (L hr^{-1})
ρ_{water}:	water density (Kgm^{-3})
R_FU_o:	fouling rate (min^{-1})