NATIVE MILK FAT GLOBULE MEMBRANE DAMAGE – MEASUREMENT AND EFFECT OF MECHANICAL FACTORS IN MILK POWDER PROCESSING OPERATIONS

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“Trust in the LORD with all your heart
and lean not on your own understanding;
in all your ways acknowledge him,
and he will make your paths straight.”

The Bible: Proverbs, chapter 3 verses 5-6

Abstract

The goal of this work was to measure native milk fat globule membrane (NMFGM) damage in a number of processing operations within the milk powder manufacturing process.

Analysis of the literature showed that NMFGM damage was not well understood, particularly as caused by processing operations within factories. Reliable methods of measuring NMFGM damage were not available; current methods had limited scope or were qualitative in nature. In the highly mechanised dairy industry, damage to the NMFGM can lead to serious quality and financial losses owing to consequences such as lipolysis and creaming. The aims of this work were to develop new techniques for measuring NMFGM damage, and to use these in assessing the effects of a number of operations within the milk powder process.

The majority of time was spent on developing two new tests, the selective lipolysis (SL1) test and the particle size zoning (PSZ) test. The SL1 test measures a chemical consequence of NMFGM damage, that is the production of free fatty acids (FFAs). The PSZ test measures a physical consequence of NMFGM damage, that is the change in the fat globule size distribution.

Controlled experiments were used to measure NMFGM damage in process operations including pumping, agitation, preheating and evaporation. For these operations, variables such as shear, time, temperature, air inclusion and cavitation were investigated. Surveys of two industrial milk powder plants were also conducted.

The results showed that the SL1 and PSZ tests were reproducible, sensitive enough to detect NMFGM damage in a number of process operations, and, together, could give a reasonably comprehensive picture of NMFGM damage. The results of pumping and agitation experiments were consistent with previous research, but were more comprehensive. The effects on measured NMFGM damage of the presence of separated fat in foam or as churned fat have hardly been described by previous workers. Results for the effects of preheating and evaporation on NMFGM damage are new, and challenged the findings of previous research.

The need to improve the flexibility and practicality of the SL1 and PSZ tests, so they can be used as widely as possible to gain a comprehensive picture of NMFGM damage across many dairy processes, was identified. Studies should be made to connect the results of the particle size zoning and selective lipolysis tests with product quality and process efficiency data from industrial sites.

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List of Abbreviations

Abbreviation	**Definition**
IFA	incubation fatty acids
OFA	original fatty acids
ADV	acid degree value
CIP	clean(ed)-in-place
CL	calf lipase
DSI	direct steam injection
FAPF	fatty acids from protected fat
FAUPF	fatty acids from unprotected fat
FF	free fat
FFA(s)	free fatty acid(s)
GLC	gas-liquid chromatography
KOH	potassium hydroxide
LPL	lipoprotein lipase
P.R.	primary region
PF	protected fat
PHE	plate heat exchanger
PLC	programmable logic controller
PPL	pig pancreatic lipase
PSD(s)	particle size distribution(s)
SL1 test	selective lipolysis test – version 1
SL2 test	selective lipolysis test – version 2
SLFA	selective lipolysis fatty acids
UHT	ultra high temperature
UPF	unprotected fat

Chapter 1
Introduction

Virtually all of the fat in milk is found in the form of spherical globules, the disperse phase of an emulsion in milk plasma. Each globule is surrounded by a native milk fat globule membrane (NMFGM) composed of mostly surface-active lipids and proteins. The NMFGM constitutes approximately 2% of fat globule mass and therefore less than 1% of the total solids in milk but has an essential role in the stability of the emulsion.

The NMFGM acts as a barrier between the core fat and the milk plasma. This barrier resists such phenomena as:

- Linkages between, or coalescence of, fat globules, and consequent changes in milk fat globule size distribution.
- Enzymes that attack milk fat to convert them into free fatty acids (FFAs).

The composition of the NMFGM is very different from the two phases it separates – globular fat and milk plasma (Mulder & Walstra, 1974). Most globular fat is in the form of triacylglycerols. NMFGM fat consists mostly of phospholipids. Milk plasma includes proteins in the form of casein micelles, colloidally dispersed serum (whey) proteins and enzyme, but the NMFGM is largely unique. The NMFGM protein has an amino acid pattern similar to that of the apical cell-membrane of the lactating cell (Keenan et al., 1970).

The unique composition of the NMFGM makes it a significant component. Its function however, makes it a critical component! If the NMFGM is breached (i.e. if NMFGM damage has occurred) the above mentioned phenomena result, and the quality of the milk is reduced. McPherson & Kitchen (1983) asserted that "Thus many current problems of the dairy industry are directly related to an understanding of this unique membrane system."

The NMFGM is easily damaged during handling operations such as milking, storage at the farm and transportation. Even the simple process of chilling the milk can lead to changes in the NMFGM such as loss of phospholipids (Anderson et al., 1972) and alterations to the protein composition (Thompson et al., 1961). Breaches of the NMFGM can lead to physical changes such as disruption of fat globules, with subsequent difficulties in separation into cream and skim milk, and chemical changes such as lipolysis, with consequent formation of off-flavours. Any uncovered fat globule surface resulting from damage to the NMFGM is almost instantly covered by serum proteins and casein micelles (Walstra et al., 1999). It is therefore useful to differentiate between the NMFGM, which consists mainly of phospholipids and proteins derived from the apical membranes of secretory cells of the cow, and the milk fat globule membrane found in processed milk, which also contains serum proteins and casein micelles.

In New Zealand, around 13 billion litres of milk are processed each season at 29 manufacturing sites (http://www.fonterra.com/content/aboutfonterra/factsandfigures/default.jsp, March 2004). This equates to an average of over 2 million litres processed at each site in New Zealand every day of the season. This high throughput, coupled with the tendency for milk to lose its quality rapidly over time, means that even small delays in production can result in significant financial loss to the industry.

The New Zealand dairy industry has put considerable effort into making itself as cost-effective, and its products as attractive to customers, as possible, including efforts to:

- Maximise milk quality entering factories.
- Reduce microbial contamination in factories.
- Minimise product losses through the reprocessing of waste streams and fine particulates.
- Maximise the sizes of factories and therefore reduce capital costs.
- Minimise transportation costs.

This has made the New Zealand dairy industry highly mechanised.

Evidence of this mechanisation can be seen in many parts of the New Zealand dairy industry. On farms, it is typified by the universal use of pipeline milking machines, and storage of milk in large silos, often of up to 28,000 litres in the case of farms with large herds. Milk tankers transport the milk from the farm and can carry up to 27,000 litres at one time (http://meadowfresh.net.nz/about_milk/from_moo_to_you.php, 2004). However, in some parts of the country, the milk is transported very long distances by train, from intermediate storage sites to the factories. New Zealand dairy factories are among the largest in the world, many having multiple storage silos in excess of 250,000 litres individual capacity, with considerable use of pumps to transport the milk around the factory.

With the push for mechanisation and larger factories, potentially significant financial losses may be created through loss of product quality resulting from rough handling of the milk. While the handling of raw milk on dairy farms has been studied to some extent, very little attention has been paid to raw and pasteurised milk in factory processing steps following farm handling. Such processes include, in addition to pasteurisation, storage, pumping, separation, and thermal processes such as preheating and evaporation.

Various authors have highlighted the potentially harmful effects of poor milk handling, during process operations, that damages the milk fat. Such effects include fouling of heat exchangers, poor cream separation and flavour defects. These effects result in loss of product and poor milk and cream quality. While no formal cost analysis has been applied to these effects, it is clear they do cost money, and given the size of the New Zealand dairy industry must be taken seriously. Damage to the NMFGM in process operations within factories was the focus of the present work.

The work began with the aim of using existing NMFGM damage measurement techniques to assess NMFGM damage in milk powder manufacturing processes, because milk powders constitute over 30% of all New Zealand dairy products. (http://www.fonterra.com/content/aboutfonterra/factsandfigures/default.jsp, 2004), and very little research has been conducted on the impact of milk powder manufacturing operations on the milk powders. It was hypothesised that incremental increases in NMFGM damage in individual operations within the milk powder manufacturing process would contribute to an overall loss of milk powder quality.

However, it became clear over time that the NMFGM damage measurement tests based on the measurement of lipolysis, which were initially chosen, were not reliable enough to allow a valuable survey of NMFGM damage in some situations. Hence, much of the early work could only highlight the weaknesses of the existing tests.

Therefore, the first objective of this project was to develop a technique for the measurement of NMFGM damage.

A second objective was to identify and analyse the factors that affect damage to the NMFGM using the measurement techniques devised.

The final objective was to make case studies of the damage occurring in a number of key operations or equipment found in milk powder plants where the factors identified in reaching the second objective could be found.

Therefore, this thesis is an account of an ongoing journey that began with concepts on NMFGM damage that ultimately had to be redeveloped before the original aim of the work could be pursued.