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# Characterisation & Process Control of Pumping Systems in the Dairy Industry

## Abstract

The interaction between control of pumping systems in the dairy industry and the performance of the process has been investigated. Pumping in a precooling system at Massey University No. 1 Dairy Unit was chosen as a case study.

The requirements of the precooling system were determined from previous work done by dairy technologists. Part of these requirements were that:

i) microbial damage to milk must be minimised by good temperature control, specifically by cooling the milk down to 18°C immediately after milking as specified in the New Zealand Dairy Industry Farm Dairy Code of Practice (COP).

ii) handling should be gentle to minimise damage to the milk fat globule membrane by avoidance of cavitation and foaming.

However controlled pumping, which minimises damage to the fat globule membrane, has been reported to decrease the cooling capacity of the plate heat exchanger (PHE). The precooling system at No. 1 Dairy Unit was modified to allow continuous monitoring of key process variables (temperatures, flows and pressures). These were logged continuously and automatically to allow analyses to be carried out for whole milking sessions.

The analysis shows that the releaser pump in the precooling system at No. 1 Dairy Unit was oversized. This resulted in the pump only operating for 10 to 50% of the time and consequent inefficient usage of cooling water.

In general the average temperature of the milk entering the vat complied with the COP requirement. However, as a consequence of the pump control system, the instantaneous temperature at times exceeded the COP recommended temperature.

The analysis showed that cooling of the milk held up in the PHE during the pump-off phase contributed significantly to the cooling performance of the system. The present set up of the releaser pump pumping regime is based on a fixed pump-on phase of 6

seconds. The pump starts when the milk level reached a predetermined level in the milk receiver tank, which holds the milk coming from the cows. The duration of the pump on phase was set so that there would always be a milk fluid head in the receiver tank; which was decided by the relative size of the pump and receiver tank. The present pumping regime did not make best use of the ability of the system to cool the milk held up in the PHE during the pump-off phase. By simply changing the pump-on phase to 3s, more milk could be held up during the pump off phase in the PHE, giving a 10% increase in efficiency in the use of the cooling capacity of the water. This was achieved without changing the size of the PHE or any additional capital investment.

Synchronising the water with milk flow rate resulted in further gains in efficiency of cooling water usage but this resulted in an increase in the temperature of milk exiting the PHE. This conflict of goals made evident that an improvement in efficiency could only be attained by using cooler water, which could be achieved by additional equipment such as a cooling tower. However it is recommended that any modification to the process must be accompanied by a reanalysis of the performance of the system in conjunction with an appropriate control system to optimise the performance of the system.

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Last, but most of all, to God, to whom I dedicate all of my life.

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# Nomenclature

*Roman*

| | |
|---|---|
| $c$ | Intercept of plot in Figure A.7 ($m^3$/hr) |
| $c_1$ | Conversion constant in equation A.2 = 1 kPa/mV |
| $c_2$ | Conversion constant in equation A.3 =0.5 kPa/mV |
| $c_3$ | Conversion constant in equation A.10 =1 mA/mV |
| Cp | Specific heat capacity (J/(kgK)) |
| g | Acceleration due to gravity (m/$s^2$) |
| H | Head (m) |
| i | Current row |
| M | Volumetric flow rate of milk ($m^3$/hr) |
| $m_{grad}$ | Gradient from plot of water flow rate vs square root of pressure drop (Figure A.7) ($m^3$/(hr.$kPa^{0.5}$)) |
| n | Number of readings |
| $\Delta P$ | Change in pressure (kPa) |
| P | Pressure (kPa) |
| R | Resistance (used to convert mA to mV voltage) ($\Omega$) |
| V | Voltage (mV) |
| W | Volumetric flow rate of water ($m^3$/hr) |

*Greek*

| | |
|---|---|
| $\phi$ | Heat transfer rate (J/s) |
| $\eta$ | Efficiency of cooling water usage |
| $\theta$ | Temperature (°C) |
| $\rho$ | Density (kg/$m^3$) |

*Subscripts*

| | |
|---|---|
| 1 | First end of the plate heat exchanger |
| 2 | Second end of the plate heat exchanger |
| in | At inlet |
| mi | Milk in |
| mo | Milk out |
| out | At outlet |
| wi | Water in |
| wo | Water out |

*Abbreviations*

| | |
|---|---|
| CIP | Cleaning in place |
| COP | New Zealand Dairy Industry Farm Dairy Code of Practice (1994) |
| FFA | Free fatty acids |
| MFGM | Milk fat globule membrane |
| NPSH | Net positive suction head |
| PHE | Plate heat exchanger |
| TS | Total solids |

# 1 Introduction

The dairy industry is one of the major industries in New Zealand. In 1999 it had a turnover of 7.4 billion NZ dollars. In the year 1998/1999 the amount of milk processed was nearly 10.5 billion litres including the production of about 347 000 tonnes of whole milk powder (New Zealand Dairy Board, 2000).

The transport of milk at the farm and through the different processes at the factory, such as milk powder manufacture, is often achieved by centrifugal pumps, which are relatively easy to maintain. One requirement in milk processing is for the gentle handling of the milk as damage to the milk can have negative effects on process efficiency, for example fouling (Fang, 1998) and product quality.

Automatic control of dairy processes is based on fixed set point control, that is, the process is regulated at temperatures or flow rates that have been determined by results from previous production trials. A more efficient strategy would be to control the operations to maximise the desirable outcomes and to minimise undesirable outcomes. However, this strategy requires a greater understanding of the manufacturing process to identify desirable and undesirable outcomes and their causes. Thus process control involves not only the design of controllers but also a full analysis of the process being controlled.

In milk transport, one undesirable outcome that has been clearly identified in previous work is the damage done to the milk fat globule membrane (MFGM). One of its causes is pump cavitation (Fang, 1998), which therefore must be avoided. The desirable outcomes in milk handling must be identified by the analysis of each individual operation.

Previous work in the Food Technology Department (Steven, 1996) had indicated that the characteristic pump head curves of a Fristam FP712 pump varied with the rheological properties of the fluid. Without a detailed knowledge of these characteristic curves it would not be possible to design suitable process control systems for evaporators where the total solids (TS) content, and hence the viscosity, varies from one effect to the other.

The performance of a pump with milk concentrates of different TS contents was investigated as a means of familiarisation with the operation of centrifugal pumps. This work was performed on reconstituted milk solutions to simulate pumping between the effects of an evaporator. It confirmed that the TS content affected the pumping head curves substantially. But there were significant difficulties with air entrainment during the experiment, which also had a substantial effect on the pump head curves. These findings were reported in a paper presented at a conference (Dorsey *et al.*, 1998) and can be found in Appendix 1.1. The paper deals with the effect of air inclusion in the pumping of reconstituted skim milk concentrates. Preliminary results were also obtained for whole milk concentrates and a summary of the pump head curve obtained is given in Appendix 1.2. However, much further work needs to be done before the pump head curves for water can be used to predict the performance of the pump when pumping milk concentrates; this was not the main interest of this thesis, which focuses on process control.

The purpose of a farm milk handling system is to milk the cow and to transport the milk to the bulk storage vat for tanker collection. The fresh milk is filtered, and must be cooled as fast as possible to minimise microbial growth and enzymatic damage.

Previously, uncontrolled pumping of milk had been used to transport milk from the milking area to the bulk storage vat. However, this resulted in the milk receiver being pumped empty resulting in cavitation and foaming, which are both known to cause damage to the MFGM. The introduction of pump control to avoid cavitation and foaming also resulted in a reduction of cooling performance of farm precooling systems (Thomson, 1998).

This work investigates the process control of centrifugal pumps in the precooling system at a farm. Since fresh milk is Newtonian, with a viscosity similar to water (Bloore, 1981), the pump characteristic head curve is well known.

An analysis of the pumping and cooling characteristic of a farm precooling system is reported. While the analysis method used is generic, the analysis is performed on a specific case study: Massey University No.1 Dairy Unit, which was used because of convenience of access.

Previous work at this farm shows that temperature requirements for the precooling system are not always met and that there is a prospect that cooling water previously available free of charge will be billed at approximately $27 000 per annum (Roberts, 1998).

This study will focus on the precooling system requirements for milk microbial and enzymatic quality and on the efficiency of water usage while maintaining the no cavitation requirement.