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# Model Based Analysis of the Operation and Control of Falling Film Evaporators

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# Summary

Falling film evaporators are a widely used process in the New Zealand dairy industry. They are well suited for the removal of water and are most commonly used as the first stage of the milk powder production process. In New Zealand milk powders are a major export product, so the falling film evaporator is an important part of the Dairy industry. However, there appears to be very little understanding of the design, operation and control of falling film evaporators. The work discussed in this thesis aims to overcome this problem.

This work will derive, develop and analyse a model of the Evaporator A plant at Kiwi Co-op Dairies Ltd. The purpose of developing the evaporator model is to analyse the optimisation and controllability of the plant. A steady state model for the plant will be developed specifically for the optimisation studies and a linear dynamic model for the controllability studies.

The production of milk powders is a two stage process. Falling film evaporators are used to remove approximately 80 % of the water contained in the milk. This produces a highly viscous milk concentrate that cannot be further concentrated using evaporators. The remaining water is removed using spray dryers, which can be operated to produce special powder properties. The powder is easy to transport and relatively free from potential bacterial attack.

Evaporation is an energy intensive process and it is advantageous to minimise its energy requirements. This is the aim of the evaporator optimisation studies. Falling film evaporators are more energy efficient than spray dryers and many evaporator plants also use two stages, with different energy efficiencies. So, the total evaporation cost depends on the process operating conditions. However, there are various operating constraints, which restrict the evaporator capacities. These constraints will be determined and used to develop the constrained optimisation method.

In this thesis the optimum operating conditions for the Kiwi Evaporator A plant, working with Whole Milk, are determined. The optimisation problem is two dimensional, for the TVR compressor steam pressure and the TVR evaporator section product mass flow. Various other process variables, such as the DSI temperature and the TVR product dry mass fraction also have optimum values. These are discussed in the thesis also.

There are also many operational problems with industrial falling film evaporator plants. For example the preheat sections of industrial plants can often suffer de-aeration problems, boiling in holding tubes and flash vessel flooding problems. These problems will be investigated and simple solutions determined.

In the Dairy industry evaporators have to operate under a vacuum, since the milk proteins become de-natured when heated above 70 °C. This means that a small hole in the evaporator, or preheat section, will allow non-condensable gases to leak into the process. In addition milk, itself, often contains dissolved gases that evaporate out of the milk, when it flashes in the preheat

section. It is shown, in this thesis, that the presence of non-condensable gases causes a temperature difference to occur between the top and bottom of the flash vessels. The de-aeration lines from the flash vessels must have correctly sized orifice plates, so that the gases are removed.

It is possible for milk to evaporate in the preheat section holding tubes. In is shown to cause a number of problems, such as flash vessel flooding, that are detrimental to the preheat section operation. The milk pressure must not fall below its vapour pressure. It is shown that correct sizing of the preheat section DSI pump and holding tube orifice plate is essential.

The controllability of falling film evaporators is very important. There are several reasons why the production of milk powder can be difficult to control. A linear dynamic model for the evaporator plant will be developed and used to determine why falling film evaporators are difficult to control. The purpose of this work is to understand the fundamental controllability problems with the plant. Currently, there does not appear to be any fundamental understanding of why falling film evaporators are difficult to control.

The results of the controllability analysis show that the temperature control loops of the evaporator plants at Kiwi is satisfactory. A problem was found with the DSI temperature control loop, due to the need to measure the milk temperature after the holding tubes. This caused a significant delay that meant the controller could not provide adequate disturbance rejection. However, a solution to the problem was developed, where a surface temperature probe was used directly after the DSI, with a cascade control loop.

The most serious control problem was the product dry mass fraction control loop. The evaporator is designed to overcome the film wetting criteria, while simultaneously operating with the maximum energy efficiency and minimum residence time. These design aims mean there is little mixing in the process and a large pseudo-delay that occurs in the dry mass fraction control loop. Both these problems mean the controller cannot provide adequate disturbance rejection for the product dry mass fraction control loop.

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