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Influence of pre-heat temperature, pre-heat holding time and high-heat temperature on fouling of reconstituted skim milk during UHT processing

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ABSTRACT

The effects of pre-heat temperature (65–95 °C) and holding time (5 and 25 s) on fouling of reconstituted skim milk at high-heat temperatures of 135–150 °C using a bench-top UHT plant were investigated. Fouling was monitored by observing the variation in overall heat transfer coefficient (OHTC) with time and consisted of an induction phase (non-fouling) and a decline phase (fouling). A significantly shorter run-time was obtained with pre-heating at 65 °C than with pre-heating at 75, 85 and 95 °C. A longer holding time (25 s) in the pre-heating section significantly increased the run-time of the plant compared with 5 s holding. The high-heat temperature also affected the OHTC and run-time; similar run-times were observed at 135, 140, 142 and 145 °C but at 150 °C there was no induction phase and fouling rapidly occurred. Overall, pre-heating at 85 °C or 95 °C for 25 s, combined with a high-heat temperature of 145 °C, and pre-heating at 95 °C for 25 s combined with high-heat temperatures of 142 °C, produced the longest run-times of the bench-top UHT plant.

1. Introduction

Fouling of heat exchangers during ultra-high temperature (UHT) processing is a major issue for dairy processing as it affects the run-times of UHT plants and hence the economics of processing. Several factors which influence fouling including processing conditions have been identified. Processing temperature is considered to be probably the most important factor (Bansal and Chen, 2006; Burton, 1968) as it affects both the nature and extent of fouling (Burton, 1988; Lund and Bixby, 1975). At temperatures between 75 and 110 °C, a soft, voluminous, protein-rich deposit (Type A) forms while at higher temperatures a hard, granular, mineral-rich deposit (Type B) forms.

Heat treatments, both in the pre-heat and high-heat sections of UHT plants, cause denaturation and aggregation of whey proteins and interactions between whey proteins and casein micelles. The extent and type of association between whey proteins and casein micelles depends on the severity of the heat treatment, and also the pH of milk prior to heating (Singh et al., 1995). The whey proteins are highly structured proteins with a compact globular structure held together by hydrophobic, covalent and hydrogen bonding (Swaisgood, 1982). They are heat-sensitive and can be denatured if heated at temperatures above their denaturation temperature. The thermal behaviour of whey proteins is dominated by beta-lactoglobulin (β-Lg), the most abundant whey protein, which is irreversibly denatured at ⩾70 °C (Swaisgood, 1982). The β-Lg denaturation process involves the following steps: dissociation of the quaternary structure (it exists naturally as a non-covalently linked dimer), change in the conformation of the polypeptide chain exposing previously buried hydrophobic sections and a free –SH group, and aggregation via disulphide bridging, through –SH–disulphide interactions, and hydrophobic bonding (Relkin and Launay, 1990). The unfolding of β-Lg is important for fouling as it is highly reactive in the unfolded state and aggregates with other β-Lg molecules, κ-casein in the casein micelles and other whey proteins. It also adheres to heat transfer surfaces leading to fouling of heat exchangers (Delplace et al., 1994).

The significance of pre-heating in reducing deposit formation during UHT processing of milk has been recognised (Bell and Sanders, 1944; Burton, 1968; Lyster, 1965). This step in the UHT process is commonly referred to as the protein stabilisation stage (Lewis and Deeth, 2009). A reduction in deposit formation in the UHT section can be achieved by increasing the degree of β-Lg denaturation in the pre-heat section (de Jong, 1996). Bell and Sanders (1944) suggested that pre-heating also influences the fouling

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behaviour of milk salts as the milk salts precipitate to some extent in the pre-heater, resulting in less mineral deposit in the high-heating section. The effect of various pre-heat temperatures (70–110 °C) at holding times of 30–120 s on deposit formation from raw cows' milk in an indirectly heated UHT plant was investigated by Patil and Reuter (1986). They observed an increase in operational time (i.e. time before cleaning is required) of a UHT pilot plant by up to 2 times by pre-heating milk at 90 or 100 °C for a holding time of 90 or 120 s. This conflicts with more recent findings (Srichantra et al., 2006) that an increased fouling rate occurred as the pre-heat temperature was increased in a UHT pilot plant during processing of recombined, reconstituted and fresh whole milk.

There are no published studies on the effects of pre-heat temperatures (at different holding times) in combination with a range of high-heat temperatures on the fouling properties of reconstituted milk. The current study aimed to determine time–temperature combinations for the pre-heat and high-heat sections that would prolong the run-time of a bench-top UHT plant. The pre-heat temperatures studied were 65, 75, 85 and 95 °C at holding times of 5 and 25 s. The high-heat temperatures studied at a holding time of 6 s were 135, 140, 142, 145 and 150 °C.

2. Materials and methods

2.1. Reconstituted milk preparation

Low-heat skim milk powder obtained from Murray Goulburn Co-operative Co. Ltd (Victoria, Australia) was used for all experiments to ensure standard conditions. To achieve fouling in a reasonable time, a model milk system was prepared by adding 0.15 mM of $CaCl_2{\cdot}2H_2O$ to reconstituted skim milk (120 g powder/L of milk) prepared by dispersing skim milk powder in distilled water at 30 °C with continuous stirring. Stirring was continued until all the powder dissolved. The milk was then passed through a wet muslin cloth filter to remove any undissolved particles. The calcium chloride was added to the reconstituted milk with continuous stirring. The milk was left at room temperature for one hour to hydrate and allow release of entrapped air before being processed in a bench-top UHT plant.

2.2. UHT processing

A flow diagram of the bench-top UHT plant used in the experimental trials is shown in Fig. 1. The complete description of the plant can be found in Prakash (2007). The plant was instrumented with thermocouples located at the inlet and outlet of the pre-heater and the outlet of the sterilizer and holding section and a PC-based data acquisition system allowed real-time monitoring of data as described in Prakash et al. (2010). Milk flow rate was determined by measuring the time required to collect a known volume of milk. Three measurements were recorded every 5 min for the entire run and their average represented the flow rate.

The plant operating conditions for the trials were: pre-heat temperatures 65, 75, 85 or 95 °C, measured at the outlet of the pre-heat section at the beginning of the run; pre-heat holding times 5 or 25 s; and high-heat temperatures 135, 140, 142, 145 or 150 °C (measured at the outlet of the sterilizer at the beginning of the run) for a holding time of 6 s. The combinations of temperatures used are shown in Table 1. After heat treatment, the milk was cooled to ⩽35 °C in a water-jacketed cooler. The flow rate of the milk was maintained at 180 mL/min using a positive displacement pump (Netzsch-Nemo Helical Rotor pump coupled to a 0.55 kW motor, Stauff Pumps, Brisbane, Australia). The order of trials at different combinations of pre-heat temperature, pre-heat holding time and high-heat temperatures was randomized. All experiments were carried out in duplicate.

The UHT runs were stopped when the temperature at the outlet of the sterilizer dropped below 120 °C or, earlier, if deposits blocked the channel or if the back-pressure could not be maintained below 0.5 MPa.

2.3. Fouling determination

Fouling was monitored by changes in overall heat transfer coefficient (OHTC), measured using the following equation as described in Prakash et al. (2007)

$$\mathrm{OHTC} = \frac{GC_p\Delta\theta}{A\Delta T_{lm}}, \tag{1}$$

where G is the mass flow rate of the milk in kg/s; the Reynolds Number (Re) of the flow was calculated as 6.36×10^4, which falls in the turbulent flow regime (Holman, 2010); C_p the specific heat of reconstituted milk in J/(kg °C) – this was calculated taking into account the specific heat capacity and mass fraction of the milk powder component, specific heat capacity = 3750 J/(kg °C) (the specific heat capacity of calcium was not included as a negligible amount of calcium was added to the mixture); $\Delta\theta$ the temperature difference between the inlet and outlet of the UHT section, in °C; A the heat exchanging surface area of the tubing = 1.627×10^{-5} m^2;

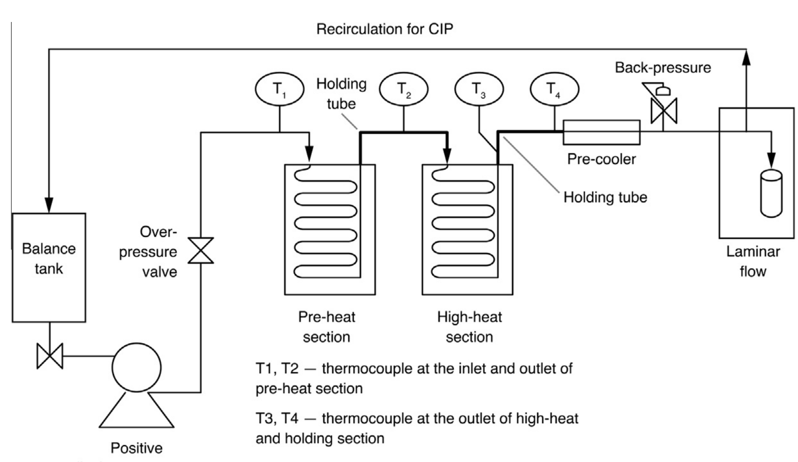

Fig. 1. Flow diagram of the bench-top UHT plant.