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Energy use for alternative full-cream milk powder manufacturing processes

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ABSTRACT

The process of manufacturing full-cream milk powder usually involves heating the full-cream milk, concentration and spray drying. Homogenization of milk is desirable for good quality powder with low insolubility index and low solvent extractable fat (free-fat). Energy savings can be obtained using an alternative process where only a high solids cream fraction (~45% total solids) is homogenized prior to mixing with the skim milk, concentration and drying. Homogenization of cream at high solids is made possible with the use of citrate as a processing aid. The quality of the powder and energy calculations for the various unit processes used for the alternative process (only cream homogenized) were compared with traditional full-cream milk powder production processes. The homogenization of the cream fraction only is an alternative to the homogenization of the whole of the milk for production of good quality powder, while saving energy for the homogenization step.

1. Introduction

The manufacture of full-cream milk powder involves various unit operations. In the traditional process, milk is standardized to the required ratio of fat to milk solids not fat (MSNF), preheated, concentrated to ~45–50% total solids (TS), homogenized and dried. Homogenization is optional but is used in most operations as it improves the physical properties of full-cream milk powder. Homogenization of the full-cream milk concentrate reduces the particle size of the fat globules, alters the interface of the globule and lowers the free-fat content of the powder (Vignolles et al., 2009). A higher free-fat content of powder has been related to inferior rehydration properties, reduced flowability and increased rate of oxidation (Vignolles et al., 2007). As the cost of water removal by evaporation is cheaper than that of spray drying an increase in the total solids of the feed from the evaporator into the dryer has been explored to reduce energy costs. An increase in total solids from 50% to 52% reduces energy consumption by 6% (Fox et al., 2010). However, increasing viscosity reduces the solubility of powders (Baldwin et al., 1980) and the efficiency of the drying process (Bloore and Boag, 1982).

A variation of the traditional process of full-cream milk powder manufacture involves separation of milk, heat treatment of skim milk and concentration prior to mixing with pasteurized cream, homogenization and drying (Hols and Van Mil, 1991). This alternate process reduces fouling during heat treatment but does not compromise the physical characteristics and oxidative stability of the powder (Hols and Van Mil, 1991). There are many other possible methods and order of unit processes that may be used for production of full-cream milk powder. Choosing the process for manufacture requires a consideration of not only the economics and energy requirements for the whole process but also its impact on the final milk powder quality.

The average specific energy for liquid milk processed by the Australian dairy manufacturing industry was 130.6 kW h/kL (0.47 GJ/kL) for liquid milk and 366.7 kW h/kL (1.32 GJ/kL) for mainly powder (Prasad et al., 2004). These values are comparable with a Canadian study, with specific energy of 169.4 kW h/kL (0.61 GJ/kL) for liquid milk and 294.4 kW h/kL (1.06 GJ/kL) for milk powder (Wardrop Engineering, 1997). Ramírez et al. (2006) also reported 305.6 kW h/kL (1.1 GJ/kL) for liquid milk and fermented products and 380.56 kW h/kL (1.37 GJ/kL) for milk powder from a Dutch study. Nicol et al. (2005) reported a difference in specific energy of 3.3 kW h/kL (0.012 GJ/kL) for a liquid milk process when 100% or 25% of milk is homogenized. The difference is equivalent to 1.1–2.6% of specific energy consumption for liquid milk production from examples above. This means that any alternate processing strategy that involves less homogenization can still result in a small overall energy savings without any major capital outlay. The energy reduction will have a direct impact on production cost savings and greenhouse gas emission reduction.

The present study investigates an alternative process for full-cream milk powder manufacture in which only the separated cream is homogenized prior to mixing with skim milk and

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evaporation of the recombined concentrate. For this approach, processing issues related to excessive shear thickening of creams on homogenization have to be overcome. Excessive thickening of cream is due to coalescence of fat globule under conditions where there is not sufficient interfacial material to stabilize the increased area of interface created as the fat globule size is reduced upon homogenization. The inclusion of emulsifying salts such as sodium citrate, which cause dissociation of the casein micelle (Udabage et al., 2000), reduces the clustering of fat globules and the viscosity of the homogenized cream (Anderson et al., 1977; Hansen, 1963).

The approach of only homogenizing the cream fraction and mixing with skim milk instead of the whole full-cream milk concentrate has not been previously examined. In the alternative process, citrate was added to the cream fraction (hereafter called citrated cream) prior to homogenization to improve the processability of the cream fraction. The quality characteristics of full-cream powders made using the alternative process with citrated cream and the energy requirements for the process were compared to those of other traditional processes of full-cream milk powder manufacture.

2. Materials and methods

2.1. Manufacture of full-cream milk powders

Raw milk was collected from a local dairy company for each of the two independent powder processing trials. For each trial, three production processes were used to produce powders.

Upon receipt, milk was pasteurized at 72 °C for 15 s at the Food Processing Centre of CSIRO Animal, Food and Health Sciences, Werribee, Australia and stored overnight at 4 °C. The composition of the raw milk and its fractions were also measured using a Lactoscope (Delta Instruments B.V., Kelvinlaan 3, 9207 JB Drachten, Netherlands).

The production processes examined for the preparation of the full-cream milk powders are given (Fig. 1). Raw milk was separated at 40 °C to produce cream and skim milk. The cream was divided into 3 portions and mixed with appropriate amount of skim milk to manufacture full-cream milk with similar composition as the raw milk. One portion of cream was used as is for standardization of the skim milk (Powder 1). The second portion was used as is for standardization with skim milk prior to homogenization at 22.5 MPa using a Rannie 3060, APV Australia Pty Ltd. (Powder 2). The third portion of cream was citrated by slow addition of 1 M trisodium citrate solution prior to homogenization of the cream portion at 22.5 MPa. The level of citrate added was selected based on ease of flow of homogenized cream with different citrate levels of 0.05, 0.1 and 0.2 mol added citrate/kg cream MSNF. The viscosity was measured using the Parr Physica rheometer MCR 301 at constant shear rate of 0.5 s^{-1} at 20 °C for 10 min. The homogenized citrated cream was then standardized with skim milk (Powder 3).

Each milk was then concentrated to ~44% total solids (TS) in a single effect swept surface thin film evaporator (Bertuzzi Luber M 150/0.75 L, APV Baker Pty Ltd, Springvale, Australia) with product inlet temperature of 40 °C and vapor temperature of 45 °C. The pressure in the unit was set at 96 kPa. To produce the powder, the concentrate was dried to ~3% moisture in a Niro production Minor spray drier (Niro A/S, Soborg, Denmark) with rotary atomisation (22,000 rpm atomisation speed, 190 °C inlet and 80 °C outlet temperatures).

2.2. Characteristics of powders

The fat, protein and lactose contents of the powder were carried out by Dairy Technical services Ltd. (5/352 Macaulay Road, Kensington Victoria, Australia 3031) according to Australian Standard (1988), IDF (1993) and IDF (1974) respectively. The solvent-extractable fat (free-fat) was determined using GEA Niro analytical method (GEA Niro analytical method No. A10a, 2005) using petroleum ether as the solvent. The petroleum ether/powder mixture was agitated in a flask in the shaking device for 15 min. The petroleum ether was evaporated and the flask with the remaining contents (free-fat) was dried in an oven for an hour at 102 °C ± 1 °C. Measurements were carried out in triplicate. The content of free-fat is expressed as a percentage of the powder.

The insolubility index was carried out according to Australian standard AS 2300.4.4 (1994). Briefly powder (10 g) was reconstituted in 100 mL of deionised water in a mixer at high speed (3800–4000 rpm) for 90 s at ~24 °C. De-foaming agent (2–3 drops) was added and the milk was left for 15 min. The mixture was transferred into a graduated 50 mL centrifuge tube with a conically graduated bottom. The sample was centrifuged (at 800×g for 5 min), the sediment-free liquid was removed by vacuum and the tube was filled again with deionised water to the 50 mL mark. The sediment was gently dispersed into the water phase with a piece of wire. The sample was re-centrifuged (at 800×g for 5 min). The volume of the resultant sediment was read and the results obtained were the average of the two readings.

The oxidative stability under accelerated conditions (0.5 MPa oxygen pressure) was determined using an OXIPRES (Mikrolab Aarhus A/S, Denmark) which measures oxygen uptake by the sample. A glass vessel containing the powder (12.5 g) was placed in the pressure cell and mounted onto the holding rack and heated to 80 °C. The initial oxygen pressure rises when the cell is heated to 80 °C from room temperature (~22 °C). The oxygen uptake was recorded as a function of time in duplicate.

2.3. Energy and mass balance

The energy and mass balance for pre-heating, separation, pasteurization, evaporation and spray drying for the three manufacturing process shown in Fig. 1 would theoretically be the same. The energy and mass balance for pre-heating, separation and pasteurization was calculated to allow comparison with published data. The comparison of energy differences will then be assessed only based on difference in the homogenization and mixing/standardization processes where either whole milk or cream only was fed through the homogenizer.

Specific energy (E in kW h/kL) for each operation was calculated using the following equations:

$$E = P/Q \tag{1}$$

where P is the rated power consumption of the equipment in kW (with efficiency factored in), Q is the flow rate in kL/h.

$$E = \xi^{-1}\rho c_p \Delta T \times 10^3 \tag{2}$$

where ξ is the efficiency of the heating system, ρ is the product density in kg/L, c_p is the specific heat in kW h/kg °C, ΔT is the temperature change due to heating in °C.

A c_p and ρ of 1.09×10^{-3} kW h/kg °C (3.94 kJ/kg°K) and 1.029 kg/L for 3.5% fat milk respectively (Hu et al., 2009) was used for calculation of energy requirement for pre-heating and pasteurization of raw milk as shown in Fig. 1. In both cases ξ of 80% was assumed which yielded an E value for pre-heating (4–40 °C) and pasteurization (37–72 °C) of 50.68 and 47.14 kW h/kL respectively. The energy for separation was based on a 3.5 kW APV milk separator running at 1500 rpm (7200 rpm bowl) at a flow rate of 0.84 kL/h for warm separation at 40 °C giving an E value of 4.2 kW h/kL. The energy for mixing a 1 kL batch of standardized milk and cream was calculated based on 10 min mixing time using a 1 kW mixer