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Cleaning studies of coconut milk foulants formed during heat treatment process

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ABSTRACT

To elucidate cleaning of coconut milk foulants, swelling and dissolution of model coconut milk foulants found in batch and continuous heat treatment processes were investigated. The model coconut milk foulants were immersed in aqueous sodium hydroxide (NaOH) solutions at pH range of 7–12. Both model deposits showed little swelling at pH less than 10; increasing pH beyond 10 resulted in a rise of extent of swelling. Proteins and fats in the deposits were removed by NaOH solution. Although some components in the deposits could not be removed by soaking the deposit in NaOH, swollen deposits were less cohesive. Strength of swollen deposits was measured using fluid dynamic gauging (FDG) technique and it was found that the strength decreased with increasing pH of NaOH solution (shear stresses reduced from ~5 to ~3.5 Pa). Hence, using NaOH solution at appropriate pHs could improve the cleaning efficiency of coconut milk foulants. However, the strength of the deposit formed from a continuous heat treatment process, which was stronger than that obtained from a batch process, could not be measured using FDG (normal stress ~800 Pa, shear stress ~30 Pa). This suggests that other cleaning agents or cleaning conditions should be adopted in cleaning of the deposit formed during continuous heat treatment.

Keywords: Cleaning; Coconut milk; Fluid dynamic gauging (FDG); Fouling, Swelling

1. Introduction

Coconut milk is an oil-in-water emulsion obtained from aqueous extract of coconut meat. Moisture and fat are major components in coconut milk and the reported composition (in wt%) are: moisture, 54.1; fat, 32.2; protein, 4.4 and carbohydrate, 8.3 (Popper et al., 1966). Coconut milk is used in traditional Asian dishes and is available worldwide in various forms. In order to preserve coconut milk, heat treatment is required. For instance, pasteurization involves heating the milk to temperature of 72 °C for 20 min (Seow and Gwee, 1997) whereas ultra-high temperature (UHT) treatment of coconut milk requires heating the milk at 121 °C for 20 min (Arumughan et al., 1993).

Deposits form on heating surfaces during heat treatments of food products and daily cleaning is generally usual (Changani et al., 1997). Cleaning or removal of deposit layers from equipment surfaces is observed in two modes: (i) cohesive breakdown where rupture is at deposit–deposit bonds and (ii) adhesive breakdown where rupture is at deposit–substrate bonds resulting in a clean substrate. Similar to other processes, equipment fouled with coconut milk deposits is usually cleaned by a combination of chemical and mechanical methods. First, the deposit is softened by the action of cleaning solution, and then is removed by a mechanical action such as scouring and pigging. Alkali solutions are common in cleaning of food soils as they are known to break down proteins (Lelieveld et al., 2003) and saponify triglycerides found in fat into water soluble fatty acid salts (Plett, 1985; Fryer and Asteriadou, 2009). In addition to alkali solution, large amount of surfactant content and elevated temperature are used in cleaning of triglycerides (Jurado-Alameda et al., 2012; Cunault et al., 2013). Other cleaning agents used in cleaning of fatty food soils are enzymes and ozone (Jurado-Alameda et al., 2012). Cleaning of coconut milk deposits is also done by alkali solution. Nevertheless, the cleaning is poorly understood and

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Nomenclature

h	clearance (m)
m_0	initial mass of a deposit (kg)
m_f	final mass of a deposit (plateau) (kg)
M	mass flow rate (kg s^{-1})
P_s	suction stress (Pa)
r	FDG nozzle radius (m)
R	initial rate of swelling (min^{-1})
t	time (min)
δ	thickness of a deposit (m)
δ_f	final thickness of a deposit (plateau) (m)
δ_0	initial thickness of a deposit (m)
Δm	mass change (kg)
ε_m	maximum extent of swelling estimated from gravimetric measurements
ε_δ	maximum extent of swelling estimated from FDG measurements
μ	viscosity (Pa s)
ρ	density (kg m^{-3})
τ	shear stress (Pa)

many of the protocols used are anecdotal. For instance, softening of the deposit during chemical cleaning due to swelling is controlled by pH and optimum pHs for rate of swelling and swelling suppression of protein deposits have been reported (Bird and Fryer, 1991; Mercadé-Prieto et al., 2007; Saikhwan et al., 2010). However, there is no report of optimum pH used in cleaning of coconut milk foulant.

Unlike dairy deposits, little work has been done on coconut milk foulants. Nonetheless, literature shows some similarities between the two deposits. When milk is heated, milk proteins start to denature and aggregate, whereas ions will tend to precipitate, both result in fouling (Rosmaninho et al., 2007). Denaturation of proteins in coconut milk upon heating was also reported. As protein that is not water soluble acts as an emulsifying agent for the oil–water emulsion of coconut milk, the instability of the emulsion upon heating is a result of denaturation of coconut milk proteins (Seow and Gwee, 1997). Denaturation temperatures of proteins in coconut milk were observed at about 92 and 110 °C (Seow and Goh, 1994). The denaturation at 92 °C was suggested to be due to the denaturation of globulin whereas the denaturation at 110 °C was attributed to the denaturation of albumins and some globulins (Kwon et al., 1996). Fats were reported to have little or no effect on milk fouling (Visser and Jeurnink, 1997). Although compositions of milk (87% water, 5% lactose, 3.06% protein, 4.0% fat, 0.4% mineral: Walstra and Jenness, 1984) and coconut milk are different and the liquids show different rheological behaviours (Narataruksa et al., 2010), the aforementioned experimental findings suggest the denaturation of coconut milk proteins as the cause of fouling.

The swelling behaviour of a given deposit in cleaning solution is of importance in understanding chemical cleaning of the deposit. For instance, swelling studies of β-lactoglobulin (β-Lg) gels and whey protein gels were used to elucidate cleaning of milk deposits (Mercadé-Prieto et al., 2007; Saikhwan et al., 2010). This paper reports the study of swelling of coconut milk deposits in sodium hydroxide (NaOH) in order to understand the cleaning of the deposit. Furthermore the information obtained from this work could be used to optimize cleaning protocols of coconut milk foulants. The technique of fluid dynamic gauging (FDG) was employed to measure swelling kinetics and strengths of coconut milk foulants soaked in NaOH solutions of varying pH. A detailed description of FDG and procedures of using FDG in measuring swelling kinetics have been reported elsewhere (Chew et al., 2004; Saikhwan et al., 2007; Gordon et al., 2010).

2. Experimental

2.1. *Preparation of coconut milk*

Coconut milk was obtained by squeezing fresh shredded coconut meat in distilled water at 45 °C. The ratio of coconut meat to distilled water used was 500 g coconut meat to 200 ml distilled water; this is a typical ratio used in extracting coconut milk. Amounts of fat and protein in the extracted coconut milk were estimated using liquid extraction as described by Narataruksa et al. (2010) and Kjeldahl method (AOAC, 1990) respectively. It was found that on average in 100 ml, the extracted coconut milk contained 2.63 ± 0.04 g of protein and 31.6 ± 1.3 g of fat respectively.

2.2. *Formation of deposits*

Coconut milk deposits were generated on sample plates (SS 304, thickness of 0.6 mm). Two methods of deposit formation were employed to investigate coconut milk foulants formed during heat treatments in batch and continuous processes.

2.2.1. *Batch process (BP)*

Heat treatment of coconut milk in a batch system is common in small scale production. To simulate a batch heat treatment system, coconut milk deposits were formed by heating coconut milk in an apparatus (Fig. 1(a)) from room temperature (heating rate of ~1 °C min^{-1}). A thermometer was immersed in coconut milk to measure temperature of the coconut milk. Once the coconut milk was at 70 °C, heating was continued for 20 min. After that, the sample plates (SS304, 10 mm × 70 mm, 0.6 mm thickness) were removed from the apparatus, rinsed in distilled water to remove excess coconut milk, drained and weighed. During heating, an overhead stirrer was used (100 rpm) to ensure uniform temperature of coconut milk and avoid film forming at the top surface of coconut milk. Larger rotational speed was avoided as this is avoided in the real process; high rotational speed results in instability of coconut milk after heating. The sample plate surface temperature measured by a thermocouple was recorded as 80–90 °C which is slightly less than the reported denaturation temperature of coconut milk protein (Seow and Goh, 1994).

2.2.2. *Continuous process (CP)*

Coconut milk deposits were generated using an apparatus similar to that reported by Hooper et al. (2006) simulating a continuous pasteurization process. Coconut milk was recirculated through the deposition cell, a laboratory co-current heat exchanger, shown in Fig. 1(b). A sample plate (SS304, 25 mm × 120 mm, 0.6 mm thickness) was placed inside the deposition cell as substrates for coconut milk deposits. Thermocouples were used to record temperature at different positions (Fig. 1(b)). The coconut milk was preheated in a beaker held in a water bath (~50 °C) and in silicone tubing immersed in hot water (95 °C) before entering the deposition

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