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REVIEW ARTICLE **OPEN ACCESS**

Physical, Rheological and Thermal Properties of milk and Condensed milk -A Review

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ABSTRACT

Physical, rheological and thermal properties of milk, sweetened condensed milk (SCM) working liquid (i.e. buffalo milk plus sugar required to produce SCM) and condensed milk are required for mathematical modeling in heat transfer, mass transfer and power requirement assessment during processing in all types of batch and continuous heat exchangers. These properties depend upon the composition, concentration, temperature and shear rates applied during processing. These properties should be expressed in empirical/mathematical models to be used in computational and design software for performance evaluation during processing and equipment's design. Several authors have presented empirical models physical and rheological properties like density, surface tension, viscosity and rheological parameters. The thermal properties like thermal conductivity, specific heats and thermal diffusivities have been reviewed to present in models for utilization in heat and mass transfer evaluation as well as in the design of heat exchangers at various operating parameters. It was reported that at the same total Solid the specific gravity and density of condensed milk decreased as the pre heating temperature was increased from 100 to 110°C and remain constant on further increasing the temperature to 120°C for concentrated milk up to 39% TS. Several authors have reported the effect of temperature and shear rates on rheological properties and its impact on heat induced changes in products and quality of products. It would also reflect the energy requirement of processing in continuous heat exchangers along with quality and safety of foods.

Keywords: Performance evaluation, rheological parameters, empirical /mathematical models etc.

Introduction

The review on physical, thermal and rheological properties of milk and concentrated milk is indispensible for evaluation of heat and mass transfer process during manufacturing process. As these properties vary depending upon temperature, pressure, and applied shearing rates during processing in continuous heat exchangers, various models have been developed depending upon the factors affecting it.

These properties are also essentials for mathematical modeling of heat transfer characteristics and power requirement of heat exchangers for processing of liquid food products. Several authors have presented the empirical models with the effects of temperature, shear rates on the properties of the liquid foods and its impact on heat induced changes and quality of final products and also on the energy and power requirements. The review has been surveyed for proper utilization by the designers and performance evaluators. The physical, thermal and rheological properties are reviewed as under:

Density/ Specific Gravity:

The average specific gravity of milk and skim milk at 15.5°C was reported as 1.032 and 1.036 (Hunziker, 1949). The specific gravity of buffalo milk was reported as 1.0341, 1.0272 and 1.0263 at 20, 27 and 29°C respectively (Prakash, 1963; Kuila *et. al.*, 1963; Roy and Chandra, 1978). (Agarwala 1973) reported the empirical correlation for density of concentrated milk upto 28% TS at 90°C temperature as given below:

$$\rho = 0.9861\ (S)^{0.045} + \frac{0.004}{\rho^{1.32(55-T)} + \rho^{1.32(T-55)}} - 0.55 \times 10^{-3}\ T$$

Where, ρ = density, g/cm^3, T = bulk temperature in °C and S = % Total solid

Kesseler (1981) have presented the correlations for density of whole milk over the temperature range from 0 to 150°C as follows:

$$\rho = 1033.7 - 0.2308\ T - 2.46 \times 10^{-3}\ T^2$$

Where, ρ = density, kg/m^3 and T = Temperature, °C

Hunziker (1949) gave the specific gravity of whole milk with 18% sucrose, sweetened condensed milk and evaporated milk as 1.0913, 1.3085 and 1.066 respectively. De (1982) reported the value of specific gravity for condensed milk as 1.303 and 1.282 at 16°C and 49°C respectively. However these values for skim sweetened condensed milk were reported as 1.355 and 1.33. Raju (1989) reported that the specific gravity of condensed milk decreased as the preheating temperature was increased from 100 to 110°C and remained constant on further increasing the temperature to 120°C for concentrated milk up to 39 % total solids. At 45.5 and 52 % TS concentrated milk, the decrease in specific gravity was noticed only after 115°C of preheating. The specific gravity of sweetened condensed milk working liquid (SCM WL) was reported as follows with correlation coefficient of 0.8 which was significant at P≤ 0.01 (Badshah and Kohli,1999):

$$\textbf{Specific gravity} = 1.1195(1/T)^{0.04163}\ (C)^{0.05016}$$

Where,
T = temperature from 20 to 90°C and C = % TS from 28 to 76%

Surface Tension:
The average surface tension of cow and buffalo milk at 27°C were 45 and 47.25 dynes/cm respectively With the increase of temperature from 115 to 120°C for 48 % TS concentrated milk, the surface tension remained 45.75 to 46.0 dynes/cm. The surface tension of buffalo milk at 27°C were 48.74 to 49.86 and 44.58 to 46.20 dyne/cm by drop method and Platinum ring method respectively (Sharma, 1963).
The effect of temperature preheating (T from 20 to 90°C) on surface tension (σ in N/m)) of sweetened condensed working liquid (SCM WL) as reported empirically with correlation coefficient was -0.97 by Badshah and Kohli (1999) was as follows:

$$\boldsymbol{\sigma} = 251.766\ (T)^{-0.5}$$

Where,
σ = Surface tension in N/m and T is temperature from 20 to 90°C.

Thermal Conductivity:
Sharma and Roy (1983) developed a model for predicting the thermal conductivity (K in Kcal/hr m. °C) in terms of Fat (F) and SNF (S) of buffalo milk at a temperature of 42-43°C:

$$\mathbf{K} = 8.484 \times 10^{-1} - 4.6 \times 10^{-3}\ F - 2.35 \times 10^{-2}\ S$$

Riedel (1949) proposed the following temperature (T in °C) dependent model for determining K in terms of Kcal/m. hr. °C for fluid food products of S % TS :

$$\mathbf{K} = (0.486 + 0.00155\ T - 0.00000\ T^2)\ (1 - 0.0054\ S)$$

Where
S = percent solid by weight = (10 +2 F) φ
F = per cent fat and φ = evaporation ratio

The effect of concentration (X from 37 to 72 % TS) and temperature (40 to 90°C) on thermal conductivity in Watt/m. K of whole milk can be expressed as (More and Prasad, 1988):

$$\mathbf{K} = (0.59 + 0.0012\ T)\ (1 - 0.0078\ X)$$

Specific Heat:
Agarwala (1973) developed the following empirical correlation to determine specific heat (Cp in Kcal/ Kg °C) for temperature upto 90°C and concentration (X in % TS) of milk upto 28% TS (wb):

$$\mathbf{Log}\ \mathbf{C_p}^{1/2} = (-0.000086\ X + 0.00077)T + (0.00328X - 0.0265)$$

Dickerson (1968) observed that the specific heat (Cp) was found to be almost independent of temperature for liquid foods of low solid content and presented the following model for specific heat determination:

$$\mathbf{C_p} = 4 + 0.006\ (1 - S)$$

Where,
Cp = specific heat in KJ/kg °C and S = fraction of solid content

Ahmad (1990) stated that the specific heat of milk concentrates in the temperature range of 40 to 80°C and TS range from 8 to 30 % can be expressed as:

$$\mathbf{C_p} = [m_w + (0.328 + 0.0027\ T)\ m_s]\ 4.18$$

Where,
Cp = Specific heat in KJ/kg K, mw = % water content, ms = per cent solid and T = degree Kelvin.

Rheological Properties of Milk and Condensed Milk:
At 20°C the average value of absolute viscosity of buffalo milk was reported as 2.245 and that of cow milk as 2.127 centipoise (Chandra and Roy (1977). For buffalo milk the relation for absolute viscosity (μ) in Pascal-second at temperature (T) in °C from 20 to 100°C by Kesseler (1981) was established as:

$$\boldsymbol{\mu} = 0.326\ x10^{-2} - 0.5927\ x\ 10^{-4}\ T + 0.32143\ T^2$$

The viscosity values were found to decrease with forewarming temperature from 100 to 110°C and increased with temperature from 110 to 120°C (Raju, 1989).Effect of temperature (from 20 to 76°C) and concentration on viscosity of sweetened condensed milk working liquid (from concentration 28 to 50% TS on wet basis) was reported by Badshah and Kohli (1999) for shear rate range of 100 to 1200s as follows:

$$\mu = 7.895\ x\ 10^{-6} \exp(42.76/T)\ C^{0.99}\ \gamma^{0.36}$$

The correlation for sweetened condensed milk working liquid (SCM WL) of concentration range 50-75% TS (wb), with temperature range 20-60°C and shear rate range from 100 -1200 s-1 was developed by Badshah and Kohli (1999) as:

$$\mu = 2.20\ x\ 10^{-9}\ \exp(28.79/T)\ C^{4.36}\ \gamma^{-0.195}$$

Comparing the coefficients of shear rates in both equations, it can be said that the viscosity would decrease with shear rate in SCM WL of 50 to 75% TS showing the pseudoplastic behavior in contrast to SCM WL of 28 to 50% TS showing the dilatant behavior.
Patil and Patel (1992) developed a relationship for increase in viscoelasticity of sweetened condensed milk prepared after fore warming at 90 ± 2°C for 10 minutes. The relationship could be expressed as:

$$\boldsymbol{\eta} = 126.3751\ \text{Exp}\ (0.04331\ t)$$

Where,
η = Viscosity, centi poise and t = period in days

Regarding the effect of preheating temperature, Favstova and Karabraya (1967) observed an increase in the casein particle size, fat separation and average viscosity of Sweetened condensed milk (SCM) with the increase of preheating temperature from 85 to 106°C.

Mastakov (1972) found that higher preheating temperature of 95 to 120°C followed by immediate cooling to 70 – 75 °C resulted in SCM of better stability than those obtained from milk heated to 85 – 95 °C and held at this temperature.
Raju (1989) used five different forewarming temperatures viz. 100, 105, 110, 115, and 120°C without holding. The viscosity values of condensed milk were found to decrease with increase in temperatures from 100 to 110°C, and were found to increase with the temperature increasing from 110 to 120°C. The forewarming temperature of 110°C was found to produce SCM with lower viscosity values.
Alverez *et al.*, (1989) obtained rheogram during ascending and descending velocity cycle at 20°C, which showed the hysteresis loop and indicated that the flow behavior of SCM was dependent on time. Thixotropy increased the consistency index but had only a slight influence on flow behavior index with the exception of condensed milk, which was pasteurized at 90 to 100°C for 15-20 seconds and condensed at reduced temperatures at 60 - 80°C. Initially the condensed milk was slightly pseudoplastic and thixotropy was influenced by temperature, which was disappeared at temperature greater than 30°C.

Heat Induced Changes in Processed Milk

General structure of OPN contain highly negatively charged, extracellular matrix protein so lack in secondary structure (Wang K, 2008) with molecular weight of 33 kDa (nascent protein) and 44 kDa (on posttranslational modification) (Kundu *et al.,* 2006). Coming towards amino acid of OPN. Human milk contains 298 amino acid and Bovine milk contains 262 amino acid. Bovine milk lacks series of 22 residues corresponding to residues 188 – 209 in human OPN (Figure 2.1) 182 AA identical (61%) in both milk OPN. Both open to proteolytic separating which is near to RGD and SVVYGLR series. Huge fraction of milk OPN put in place in fragmented form with uncovers integrin binding moties. Proteolytic cleavage closed to integrin binding motives and it enlarges the integrin binding properties of OPN (Yamashita *et al.,* 2005).

Pre-heating or fore warming affects the quality of milk product and also further performance of sterilization, evaporation, crystallization operations. These are reviewed as follows-

Effect of forewarming on heat stability and fouling:

Burton (1965) reported that that the forewarming of milk before exposure of the product to more rigorous processing parameters resulted in reduced scaling and fouling of heat transfer surfaces. Higher heat stability and reduced fouling rates were reported for fore warmed milk in comparison to unforewarmed milk for total milk solids greater than 13.5 percent (Whittier and Webb, 1950). Fox and Morrisssey (1977) suggested that forewarming between 80 to 100°C range lowered the heat stability of milk by promoting kappa casein and betalactoglobulin interaction.

Effect of forewarming on protein denaturation:

The rate of denaturation of betalactoglobulin with the rise of temperature from 60 to 100°C in cow and buffalo milk has been studied extensively (Bucke *et al.,* 1974; Stephen and Ganguli, 1074, El-Shazly *et al.,* 1978). They observed that there was more denaturation of betalactoglobulin in buffalo milk whey protein as compared to that in cow milk whey proteins. Stephen and Ganguli (1978) noticed that the denaturation of buffalo betalactoglobulin increased from 7.8 % on heating at 65°C for 10 minutes to 76.9% at 100° C for 10 minutes. Casein as such is quite stable to heat but prolonged heating caused the accumulation of whey proteins and milk salts on casein micelles. This changed the natural shape and size of casein micelles lattice network as reported by Ruegg and Blanc (1978) and Freeman and Magino (1981). Smits and Brouwershaven (1980) concluded that the interaction between betalactoglobulin and Kappacasein was because of intermolecular S-S bonds. In addition to these bonds, hydrophobic bonds also play an important part. The association product resulted with noodle like particles whose size was dependent upon the ratio of betalactoglobulin and Kappa casein.

Oral Hygiene

Microbes in dental biofilm produce organic acid upon exposure to fermentable dietary carbohydrate. Repeated reduction in pH at biofilm tooth interface lead to slow demineralization of dental hard tissues. Development of dental caries. Dental caries prevent by mechanical removal of dental biofilm such as cleaning using tooth brush but does not remove full biofilm (Prasad *et al.,* 2011). Bovine milk OPN may reduce dental biofilm formation by binding to surface of bacterial cells (Schlafer *et al.,* 2012). Without affecting cell viability and impact on amount of biofilm formed in flow cells. OPN protein used in mechanical tooth cleaning procedure. OPN provided by eg. a mouth rinse or a chewing gum, it reduce amount of biofilm formed on tooth surfaces. OPN might be valuable adjunct to professional and self-performed oral hygiene procedures with dental caries control (Sodek *et al.,* 2000).

Conclusion

In the design and performance evaluation of heat exchangers and evaporators, the models of thermo-physical properties and rheological properties are important, which can be selected as per requirement and parameters of operations. The physical, thermal and rheological models are summarized for utilization in performance evaluation and design problems. The effects on heat induced changes such as effects on heat stability of cow and buffalo milk, denaturation of whey proteins and effects on casein micelles of milk are described in brief to understand the effects on quality of processed products.

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