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Thermophysical properties of coconut milk

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Abstract

Thermal conductivity and specific heat of coconut milk were measured by a thermal conductivity probe apparatus and a differential scanning calorimeter (DSC), respectively. Thermal diffusivity of coconut milk was then calculated from experimental results of thermal conductivity, specific heat, and density. It was found that thermal conductivity, specific heat, density, and thermal diffusivity of coconut milk samples with 20–35% fat content at 60–80 °C were in the range of 0.425–0.590 W/m °C, 3.277–3.711 kJ/kg °C, 969.00–983.05 kg/m^3, and $1.325–1.634 \times 10^{-7}$ m^2/s, respectively. The empirical models for each property as a function of fat content and temperature were obtained.

Keywords: Coconut milk; Thermal conductivity; Specific heat; Thermal diffusivity

1. Introduction

Coconut milk is a milky white oil-in-water emulsion. It is obtained from extraction of coconut flesh with or without added water. It contains fat, water, carbohydrate, protein, and ash with the major components being water and fat.

Coconut milk is one of the popular cooking ingredients in Thailand. Among the popular Thai food dishes using coconut milk are curries and dessert. The importance of coconut milk to Thai industries has prompted food scientists and food engineers in this country to develop new products from coconut milk for use as ingredients in household recipes both for the Thai market and for export.

Generally, food composition and temperature are the important factors affecting thermal properties (Mohsenin, 1980; Sweat, 1995; Rahman, 1995; Saravacos & Maroulis, 2001). Choi and Okos (1986) developed general models for the prediction of thermal properties of food products as functions of contents of basic food components (i.e., fat, protein, moisture, carbohydrate, fiber, and ash) and their thermal properties (i.e., thermal conductivity, specific heat, and thermal diffusivity). In those models, it was assumed that each component had the same thermal properties without considering the structure of the different food materials (Sweat, 1995). Thus, empirical models of thermal properties developed for each specific food material should give a more accurate prediction.

Thermal conductivity and specific heat are commonly measured by the line heat source probe and the differential scanning calorimeter (DSC), respectively. Thermal diffusivity is determined from the thermal conductivity, specific heat, and density.

Most research works on thermal conductivity measurements of food dealed with solid materials. The line heat source probe is based on pure conduction. The line heat source probe is unsuitable for nonviscous fluids due to natural convection that arises during measurements. The added effect of convection increases the rate of heat transfer through the specimen.

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Sweat (1995) recommended the addition of 0.5% agar to water to turn it into gel when measuring thermal conductivity with the line heat source probe. It was estimated that 0.5% agar would probably increase thermal conductivity by about 2%.

Murakami, Sweat, Sastry, and Kolbe (1996) reported that without adding convection-deterrent material to the specimens of water and glycerine, convection would start after 10 s and 70 s, respectively. The obvious change in the slope of the time (t) vs. temperature (T) plots indicates that convection effects can be easily eliminated by limiting data analysis to the linear portion of the t–T plot. Thus, with 11 W/m of heat, water, and more viscous liquids can be used as either test or calibration materials without adding convection-deterrent materials.

The information on thermal properties, especially thermal conductivity, of coconut milk has not been reported probably because of the oil-in-water emulsion nature of coconut milk that easily separates into two different phases, i.e., a heavy aqueous phase and a lighter cream phase. This causes the difficulty in applying the line heat source probe method due to the unstable and low viscous characteristics of coconut milk. Therefore, in this study, the addition of emulsifier into coconut milk coupled with homogenization are necessary to prevent the separation of emulsion and make it more viscous.

The main objective of this work was to investigate the effects of fat content and temperature on the thermophysical properties, i.e., thermal conductivity, specific heat, thermal diffusivity, and density of coconut milk. The empirical models from the study would be useful for thermal processing of coconut milk.

2. Materials and methods

2.1. Preparation of coconut milk

Fresh coconut milk without added water from a local market was stored at room temperature and passed through cloth filters before the experiments. The initial fat content of coconut milk was determined using the AOAC (1990) method. The whole coconut milk samples were diluted by distilled water to obtain the fat concentrations of 20, 25, 30, and 35%, respectively.

The samples were heated at 70 °C for 1 min to prevent deterioration by spoilage caused by micro-organisms and chemical change caused by lipase. For the thermal conductivity measurements, 0.6% Montanox 60 (Polyoxyethylene sorbitan monostearate) was added to the samples before homogenizing in a two-stage homogenizer (GEA Model NS200 6L, Italy) at 25/3 MPa.

2.2. Proximate analysis

These analyses included fat, moisture, protein, and ash. The fat content was determined using the AOAC (1990) method. The oven method was used for the water content. The Kjeldahl method was used for protein determination. For ash content, the sample was first dried in an oven at 105 °C before being transferred to a muffle furnace at 550 °C, until a white or light gray ash resulted.

2.3. Determination of thermal conductivity of coconut milk

Nithatkusol (1998) designed thermal conductivity probe using the line heat source technique. The probe was made of a stainless steel needle used to house nichrome wire as a heater wire and thermocouple. The cylindrical sample holder was made of acrylic with a diameter of 50 mm and height of 95 mm. During the measurement of thermal conductivity, the probe was inserted longitudinally into sample that was filled in the sample holder. The sample was equilibrated to the desired temperature by a water bath. Then a current was applied and time-temperature data was recorded. Thermal conductivity was calculated using Eq. (1).

$$k = \frac{Q \ln(t_2/t_1)}{4\pi(T_2 - T_1)} \tag{1}$$

where k is thermal conductivity (W/m °C), Q is heat input per unit length of the line heat source (W/m), T is temperature (°C) and t is time (s).

Before measuring the samples, the probe was calibrated with 0.5% agar gel and glycerine. The expected values of 0.5% agar gel and glycerine at 30 °C was 0.628 and 0.289 W/m °C, respectively (Sweat & Haugh, 1974). The measured average thermal conductivity (3 replications) of 0.5% agar gel at 30 °C was 0.624 ± 0.007 W/m °C, an approximately 0.64% deviation from the expected value. The measured average thermal conductivity (3 replications) of glycerine at 30 °C was 0.286 ± 0.008 W/m °C, an approximately 0.81% deviation from the expected value.

2.4. Determination of specific heat of coconut milk

The coconut milk samples were measured by the power compensate differential scanning calorimeter (DSC), model Pyris1, Perkin Elmer, USA, at a scanning rate of 5 °C/min.

The instrument was calibrated according to the manufacturer's specification. Thermograms of sample, baseline, and sapphire, as a standard with a known specific heat value, were used to determine the specific heat of sample using Eq. (2).