Thermophysical Properties of Fresh and Frozen Pineapples

S. Chaiwanichsiri, K. Laohasongkram, C. Thunpithayakul and S. Mekmanee

ABSTRACT

*The specific heat and thermal conductivity of pineapple (*Ananas comosus (L.) Merr. var. caefenne*) were determined at high (60 to 100°C) and low (-10 to -30°C) temperatures and at moisture contents of 60 to 80% using a modified form of the method of mixtures for specific heat and the line probe method for thermal conductivity. At high temperatures, the thermal properties of the samples varied with temperature and moisture content while at subzero temperatures only dependence on moisture content was significant. Regression analyses indicated that at high temperatures*

$C_p = 3.224 - 0.0063T + 0.0075M + 5.44 \times 10^{-5}T^2$ ($R^2 = 0.946$) and $k = 1.577 - 0.0376T - 0.0030M + 1.68 \times 10^{-4}T^*M + 1.96 \times 10^{-4}T^2$ ($R^2 = 0.975$).

At low temperatures the relationships were found to be

$C_p = 1.750 + 3.49 \times 10^{-3}M$ ($R^2 = 0.874$) and $k = 3.082 - 0.0270T - 0.0719M - 0.0004T^2 + 0.0005M^2$ ($R^2 = 0.942$).

INTRODUCTION

Pineapples are one of the most economically important fruits in Thailand, largely because they can be used to make many products. It is useful to know the thermal properties of pineapples in order to calculate the appropriate times and temperatures for different heat transfer processes (Muzilla *et al.*, 1990). Several papers have reported the effects of moisture, temperature, fibre, fat, carbohydrate, etc. on the thermal properties of food materials (Mohsenin, 1980; Sweat, 1974; Lamberge and Hallstrom, 1986). The objectives of this research were (1) to determine the specific heat and thermal conductivity of pineapples at 60 to 100°C and at -10 to-30°C and 60-80% moisture contents and (2) to determine the dependence of these properties on temperature and moisture content.

Specific heat

Several methods for measuring the specific heat of food materials have been reviewed by Mohsenin (1980). The method of mixtures has been used to measure the specific heat of dried products such as grain (Kazarian and Hall, 1965), shredded coconut (Murakami, 1980), soybeans (Alam and Shove, 1972) and restructured pork /soy hull mixtures (Muzilla *et al.*, 1990).

The modified method of mixtures of Hwang and Hayakawa (1979), where the samples and medium are not physically mixed together, was used to measure the specific heat of cookie dough (Kulacki and Kennedy, 1978) and for this study.

Differential scanning calorimetry is another method for measuring the specific heat of foods such as peanuts (Young and Whitaker, 1973) and defatted soy flour (Wallapapan et al., 1984). This method is more precise and less time consuming but is more expensive and requires more sample preparation.

Thermal conductivity

The thermal conductivity of food is usually measured using either steady-state or transient methods. The steady-state method most widely used in foods is the guarded hot plate used for fats, meats, gelatins (Lentz, 1961) and tomato paste (Drusas and Saravacos, 1985). The concentric cylinder has been used for powdered foods (Ojha *et al.*, 1967; Reidy and Rippen, 1971). This method is more suitable for low moisture products because of the problem of moisture loss during measurement.

The transient-type measurement requires less time and is more suitable for moist foods (Mohsenin, 1980). This type includes the Fitch method (Reidy and Rippen, 1971; Walters and May, 1963) and the probe method. The probe method was modified from the line heat source method and has been used in a variety of foods such as fruits and vegetables (Sweat, 1974; Lazano *et al.*, 1979), dairy products (Sweat, 1978) and meat products (Baghe-Khandan *et al.*, 1982; Muzilla *et al.*, 1990).

MATERIALS AND METHODS

Sample preparation

Samples were prepared from fresh pineapples (*Ananas comosus* (L.) Merr. var. caefenne) with a circumference of 40-45 cm. The amounts of moisture, protein, fat, fibre and ash were determined using standard methods

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(AOAC, 1984). The carbohydrate content was obtained using the difference method. To obtain low moisture (60 and 70%) samples, 2 cm thick, fresh pineapple slices at 80% moisture were dried at 90°C in a tray dryer to the desired moisture level. For high temperature (60°-100°C) measurements, samples were heated to the desired temperature in a tray dryer and kept in a water-bath until measurements were done, while for the low temperature (-10° to-30°C) measurements, the samples were frozen under an air blast freezer at -70°C until they reached the desired temperature and the frozen samples kept in a controlled-bath using propylene glycol and dry ice.

The samples for specific heat measurement were cut into 1x1x1-cm cubes and packed in polyethylene bags. The samples used for thermal conductivity measurements were cut into 2-cm thick slices and put in a calorimeter.

Specific heat measurement

The specific heat of the samples were measured using the modified method of mixtures. The method was verified using glycerine at 15°C (C_p = 2.323 kJ/kg°C) as a reference and it was found to deviate approximately 2.8% from the reported values. The measurements were made at high temperatures (60°, 80° and 100°C) and low temperature (-10°, -18°, and -30°C). The temperatures of the samples were recorded using a chart recorder (CHINO model DR015). The heat capacity of the calorimeter was determined using water at 30°C equilibrated in the calorimeter and water at 65°C and calculated by equation (1).

$$C_{ps}.W_s.(\Delta T_s) = C_{pw}.W_w.(\Delta T_w) + H_c.(\Delta T_c) - L \quad (1)$$

where C_{ps}, C_{pw} = specific heat of sample and of water (kJ/kg °C)
W_s, W_w = weight of sample and of water (kg)
ΔT_s = temperature changes of sample (°C)
ΔT_w = temperature changes of water (°C)
H_c = heat capacity of the calorimeter (kJ/°C)
ΔT_c = temperature changes of the calorimeter (°C)
L = heat loss to the environment (kJ)
= $(C_{pw}.W_w + H_c + C_{ps}.W_s)(dT/dt)(t_F)$
t_F = final time (min)
dT/dt = slope of the straight line curve after equilibrium (°C/min)

The specific heat of samples at high temperatures was also determined by equation (1), by replacing the 65°C water by the samples. Those at low temperatures were determined using water at 65°C equilibrated in the calorimeter instead of water at 30°C and calculated using equation (2).

$$C_{ps}.W_s.(\Delta T_s) + LH = C_{pw}.W_w.(\Delta T_w) + H_c.(\Delta T_c) - L \quad (2)$$

where LH = total latent heat of fusion in the sample (kJ)
= 335 x (% moisture, wet basis) x W_s

Thermal conductivity measurement

The probe method (Baghe-Khandan *et al.*, 1982; Sweat, 1978) was used to measure the thermal conductivity of the samples. The thermal conductivity probe was constructed using a hypodermic tube with a length: diameter ratio of at least 25:1 (Mohsenin, 1980). A tube with this ratio can be assumed to be an infinite cylinder. The space inside the tube was filled with mercury which has a higher thermal conductivity than air. The heat source was a 0.20 mm nichrome wire connected to a 1.5 V dry cell. Glycerine at 20°C (k = 0.285 W/m °C) was used as the reference. The probe was calibrated with 4% agar at 25°C (k = 0.626 W/m °C) and found to deviate approximately 3.85% from the reported values. Measurements were done at high and low temperatures. The total heating time at each measurement was about 20 seconds. The thermal conductivity of the sample can be calculated from equation (3):

$$k = \frac{q}{4\pi\Delta T}\ln(t_2/t_1) \quad (3)$$

where q = heat supplied to the probe (W/m)
t = time (sec)

Statistical analysis

The data were collected in triplicates and analysed using the SPS programme for ANOVA. The relationships between the thermal properties, temperature (°C) and moisture content (%, wet basis) were obtained by multiple regression analysis.

RESULTS AND DISCUSSION

Composition

The composition of the fresh pineapple is shown in Table 1. The density of the pineapple was determined to be 1041 ± 2 kg/m^3 using the method of water displacement. The major component was water, which thus has a major effect on the thermal properties of fresh pineapple.

Table 1. Chemical composition of fresh pineapples

Component	Content (%)
Moisture	85.75 ± 0.52
Carbohydrate	14.29 ± 0.30
Protein	0.47 ± 0.01
Fibre	0.45 ± 0.03
Ash	0.30 ± 0.04
Fat	0.04 ± 0.01

Specific heat

From 60°C-100°C, the specific heat of pineapple increased with both temperature and moisture content (Fig. 1). The same trend was observed by Young and Whitaker (1973) for peanuts. The relationship between specific heat, temperature (T, °C) and moisture (M, % wet basis) was found to be:

$$C_p = 3.224 - 0.0063T + 0.0075M + 5.44 \times 10^{-5}T^2 \quad (4)$$
$$(R^2 = 0.946)$$

Siebel (1982) reported the relationship between specific heat and moisture content for food products having a moisture content higher than 80% to be $C_p = 0.837 + 0.0335$ M. Polley, Snyder and Kotnour (1980) reported the specific heat of pineapples (85.3% moisture) to be 3.68 kJ/kg°C at temperatures above freezing. At 85.3% moisture and 60°C, the C_p calculated from equation (4) was 3.68 kJ/kg°C and from Siebel's equation was 3.69 kJ/kg°C. These values are similar to those reported here.

At low temperatures, the specific heat of pineapple was lower than at high temperatures and varied only with moisture content (Fig. 2). This may be due to the specific heat of ice being lower than water and varying only slightly with temperature (Mohsenin, 1980). Polley *et al.* (1980) reported the specific heat of pineapple (85.3% moisture) below freezing to be 1.884 kJ/kg°C, which differs about 8.4% from those found in this experiment. The relationship between the specific heat and % moisture was

$$C_p = 1.750 + 3.49 \times 10^{-3}M \quad (5)$$
$$(R^2 = 0.874)$$

Thermal conductivity

The thermal conductivity of pineapple at various temperatures and moisture contents is shown in Figs. 3 and 4. At high temperatures, the thermal conductivity increased with both temperature and moisture. This is consistent with the results for apples (Lazano *et al.*, 1979), potatoes (Lamberge and Hallstrom, 1986), shredded coconut (Murakami, 1980) and meat products (Baghe-Khandan *et al.*, 1982; Muzilla *et al.*, 1990). The relationship between thermal conductivity, temperature and moisture can be described as

$$k = 1.577 - 0.0376T - 0.0030M + 1.68 \times 10^{-4}T{*}M + 1.96 \times 10^{-4}T^2 \quad (6)$$
$$(R^2 = 0.975)$$

Lamberge and Hallstrom (1986) reported the correlation between k and temperature (°C) in the range of 20-90°C for potatoes to be $k = 0.624 + 0.00119T$. Sweat (1974) reported the correlation between k and moisture content for fruits and vegetables having a moisture content higher than 60% to be $k = 0.148 + 0.0049M$. Sweat (1974) also reported the value of k for pineapples

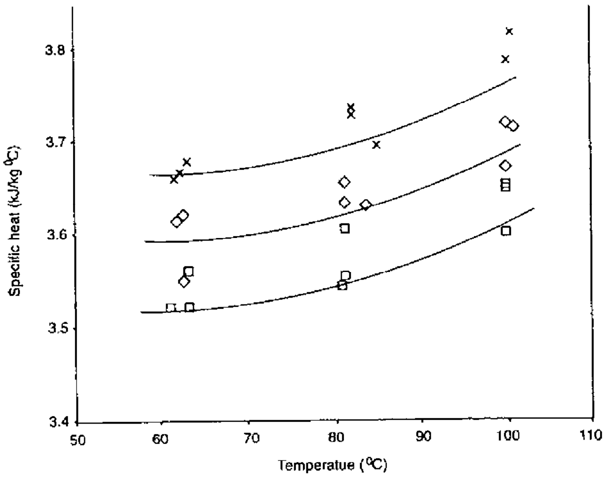

Fig. 1. Specific heat of pineapples at high temperature and moisture levels. (□ 60-65%, ◊70-75%, and x 80-85%)

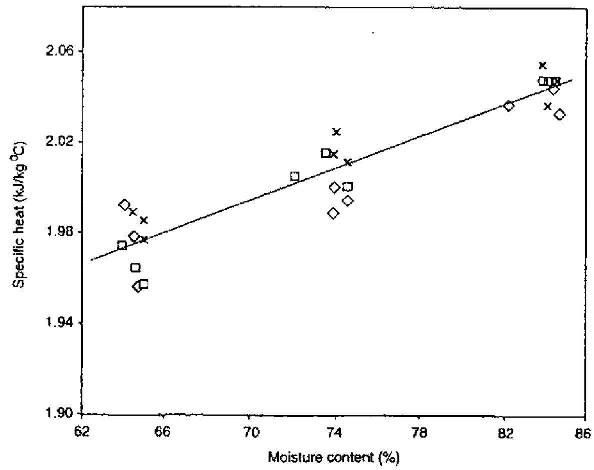

Fig. 2. Specific heat of pineapples at low temperature and moisture levels. (□ 10° ± 1°C, ◊ -18° ± 1°C, and x -30° ± 1°C)

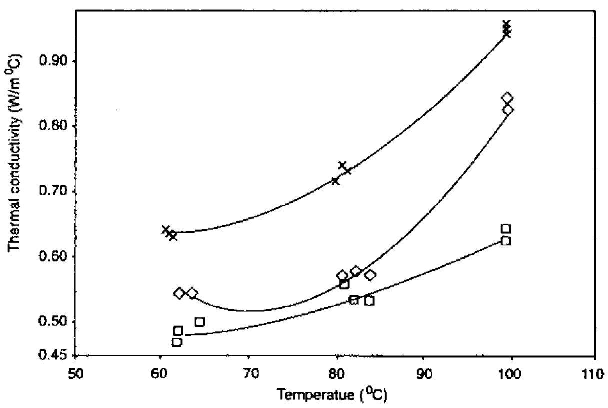

Fig. 3. Thermal conductivity of pineapples at high temperature and moisture levels (□ 60-65%, ◊70-75% and x 80-85%)

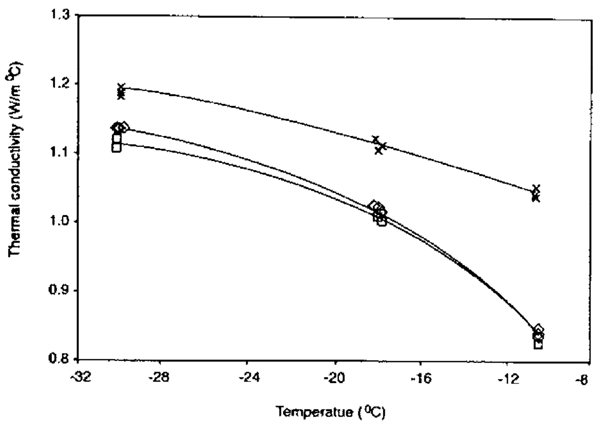

Fig. 4. Thermal conductivity of pineapples at low temperature and moisture levels. (□60-65%, ◊70-75%, and x 80-85%)

having 84.9% moisture to be 0.549 W/m °C at 27°C, which is about 5% lower than that found in this experiment at 60-65°C and 80-85% moisture content. The difference was due to the temperature difference of the samples.

At low temperatures, thermal conductivity was found to increase as the temperature decreased and as the moisture content increased. Samples with moisture contents lower than 75% showed less effect of moisture content on the conductivity values compared to those with higher moisture. This may be due to the thermal conductivity of ice depending on the shape and size of the solute crystals and may also be due to the proportion of water and ice in the samples (Mohsenin, 1980; Pham and Willix, 1989). The thermal conductivity of the samples at low temperature was found to be higher than those at high temperatures due to the higher thermal conductivity of the ice. This is consistent with a report by Pham and Willix (1989) on fresh lamb and fat. The relationship between temperature and moisture was

$$k = 3.082 - 0.0270T - 0.0719M - 0.0004T^2 + 0.0005M^2 \quad (7)$$

$(R^2 = 0.942)$

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