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Research Article

Determination of thermal conductivity of shiitake mushroom

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Abstract: The bulk thermal conductivity of shiitake mushroom as affected by moisture content and temperature was studied. Measurements were taken of moisture content between 25 and 85% wet basis and the temperature range of 30-90˚C. Bulk thermal conductivity was determined using a line heat source probe apparatus. The results revealed that bulk thermal conductivity increased with an increase in moisture content and temperature of shiitake mushroom. In addition, the experimental data was used to describe the moisture content and temperature effects on the bulk thermal conductivity of shiitake mushroom.

Keywords: food, bulk thermal conductivity, *Lentinular edodes*, moisture content, temperature, Thailand

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Introduction

Shiitake mushroom (*Lentinular edodes* (Berk.) Sing) is the second most farmed edible mushroom after the button mushroom, comprising 25.4% of worldwide production [1, 2]. It is especially popular for cultivation in China, Japan and other Asian countries. For many years shiitake mushrooms have been consumed, not only as a part of the normal diet, but also a delicacy due to its unique taste and flavour. It is rich in dietary fibre, minerals as well as vitamins, namely; thiamin, riboflavin, ascorbic acid and vitamin D_2, but it is low in calories and fat [1, 3, 4]. In addition, it has been attributed with many medicinal properties, such as reducing cholesterol, lowering blood pressure, anti-tumor, antimicrobial and improving liver function [3, 5]. However, it is highly perishable and has a short shelf life, thus further processing is required to increase its storage potential. There are many methods for processing of shiitake mushroom, such as pickling in vinegar, canning and drying. Thermal processing is generally applied to extend shelf life of food products [3]. The process design for thermal processing requires properties such as thermal conductivity. This property strongly depends on temperature, chemical composition (water, fat, protein, carbohydrate, fibre and ash) and state (frozen and unfrozen) of the product [6, 7]. As food and agricultural products have individual composition, the thermal properties are also different. Data on thermal properties of various food products have been widely reported in the literature, however, data on shiitake mushroom were not found. Therefore, the effects of moisture content and temperature on thermal conductivity of shiitake mushroom were investigated in this research.

Materials and methods

Sample preparation

Fresh shiitake mushrooms were selected and purchased from a local market in Bangkok and were then cleaned using tissue paper and cut into small pieces by a chopper. The size was controlled by setting the same mass load, rpm and chop time of chopper (9-10 fruiting bodies, 50 Hz and 17 sec, respectively). The initial moisture content of the samples was then determined first by the standard AOAC method. Chopped shiitake mushroom was dried in a hot air oven at 70˚C to get the desired moisture content of 65%, 45% and 25% wet basis. Each dried shiitake mushroom sample was kept in a plastic box which was sealed by plastic film to prevent moisture loss. Then it was refrigerated at 5˚C for at least 24 h to allow moisture in the samples to equilibrate before analysis. Finally, moisture content of the sample was checked again before use to ensure it was at the correct level.

Determination of thermal conductivity

A line heat source probe method based on a transient-state was used to measure the thermal conductivity of fresh and dried shiitake mushroom. The probe was designed by Nithatkusol [8], as shown in Fig. 1. It is made of a stainless steel needle (1.65 mm diameter and 75 mm length). A constant heat wire and thermocouple type T are inserted inside the probe and the cylindrical sample holder was made from acrylic with an outside diameter of 50 mm and a height of 95 mm.

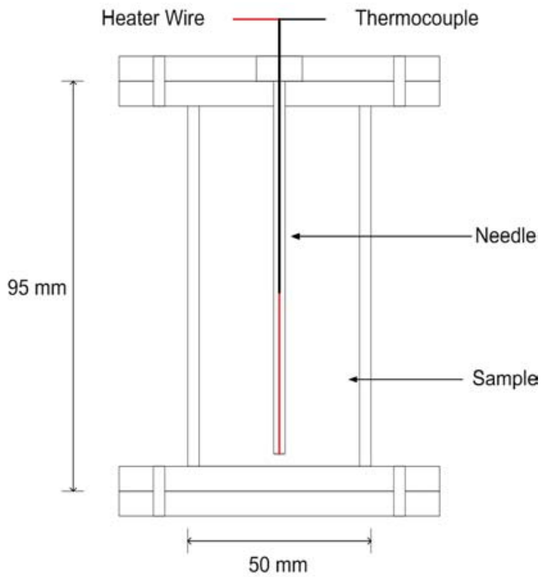

Figure 1. Thermal conductivity probe and sample holder.

To determine the bulk thermal conductivity of shiitake mushroom, samples at the desired moisture content and temperature were tightly packed inside the sample holder. The tightly filled sample was weighed and recorded. The bulk density of the sample in the sample holder was calculated by the ratio of mass to volume. Following this, the probe was inserted through the centre of the sample. Then the sample holder was placed in a water bath in order to heat it to the desired temperature. The thermal conductivity probe was then connected to a DC power supply, 0-30 V and 0-5A, which was used to transform indirect current to direct current and supplied to the heater wire and then displayed by an ammeter as shown in Fig. 2. The three thermocouple wires (at the centre of the probe, sample holder and water bath) were connected to a data logger and then connected to a personal computer to monitor and record temperature-time changes during measurement. Then 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 K), Q is heat input per unit length of the line heat source (W/m), T is temperature (˚C) and t is time (s). Before the measurement, the thermal conductivity probe was calibrated using 0.5% agar gel and compared with the reference value which was 0.628 W m^{-1}°C^{-1} at 30˚C.

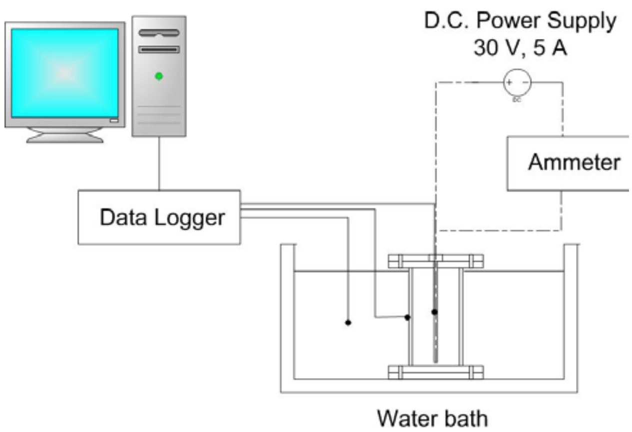

Figure 2. Thermal conductivity measurement system.

Experimental design

There were two factors studied in this work, i.e., moisture content and temperature. Moisture content was varied at 4 different levels 25, 45, 65 and 85%, whereas the temperature was controlled at 6 levels, i.e. 30, 40, 50, 60, 70 and 80◦C, respectively. A 2-factor factorial design was used in scheduling of the experiments with three replications in each case.

Data analysis

The results were reported as an average of three replicates. Analysis of variance of the two factors and interactions were applied to the different sets of data. Least significant differences were calculated by the Fisher test (α = 0.05). The analysis was performed using a standard statistical program.

Results and Discussion

The bulk density of shiitake mushrooms studied in this work was controlled in the range of 870.67 - 880.28 $kg.m^{-1}$. The measured values of bulk thermal conductivity with various moisture contents and temperature of shiitake mushroom are presented in Fig. 3. The thermal conductivity of shiitake mushroom in the moisture content range of 25-85% w.b. and temperature range of 30-80˚C varied from 0.2081 to 0.6714 W/m.K. It was found that bulk thermal conductivity of shiitake mushroom increased with an increase in moisture content and temperature, which was in agreement with some previous researchers who studied thermal conductivity of other mushrooms [7, 9]. Effects of both moisture content and temperature were found to be significant on bulk thermal conductivity of shiitake mushroom at a 95% confidence level.

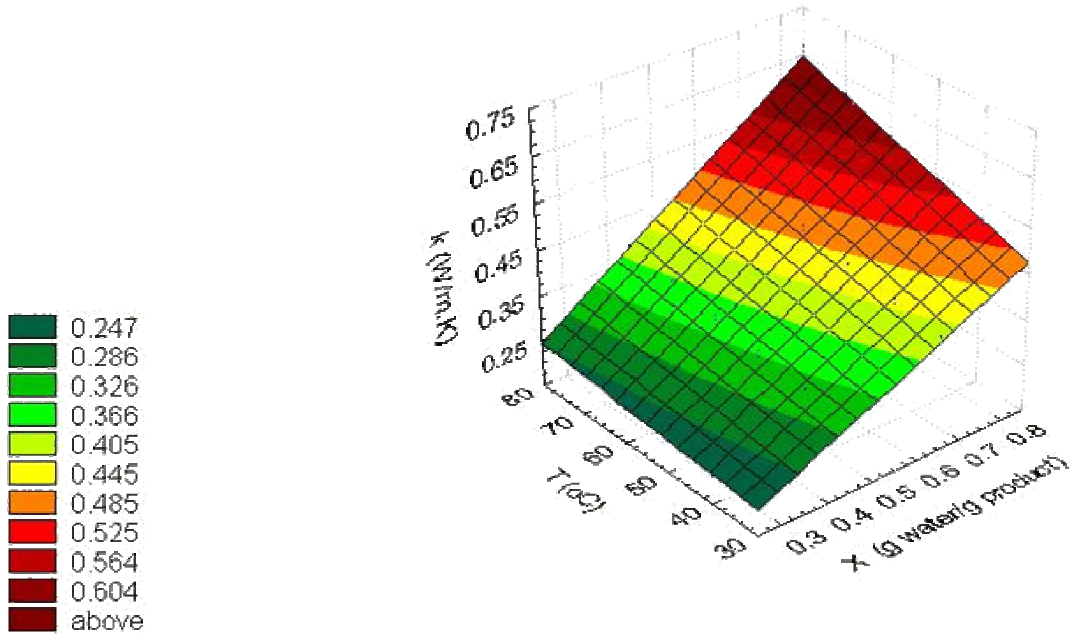

Figure 3. Bulk thermal conductivity of shiitake mushroom at moisture content levels of 25, 45, 65 and 85% w.b. and temperature range of 30 to 80˚C.

The relationship between bulk thermal conductivity, moisture content and temperature can be described by the following regression model. The R^2 and SE were 0.994 and 0.0113, respectively.

$$k = 0.105 + 0.316X - 0.000310T + 0.00434XT \quad (2)$$

where k is bulk thermal conductivity (W/m.K), X is mass fraction of moisture (g water/g product) and T is temperature (˚C).

The coefficient in Eq. 2 indicated that moisture content had stronger effect on bulk thermal conductivity than that of temperature. Furthermore, the values for bulk thermal conductivity of shitake mushroom calculated from Eq. 2 were compared with the results from other researchers [7, 9, 10] and the experimental data is shown in Fig. 4.

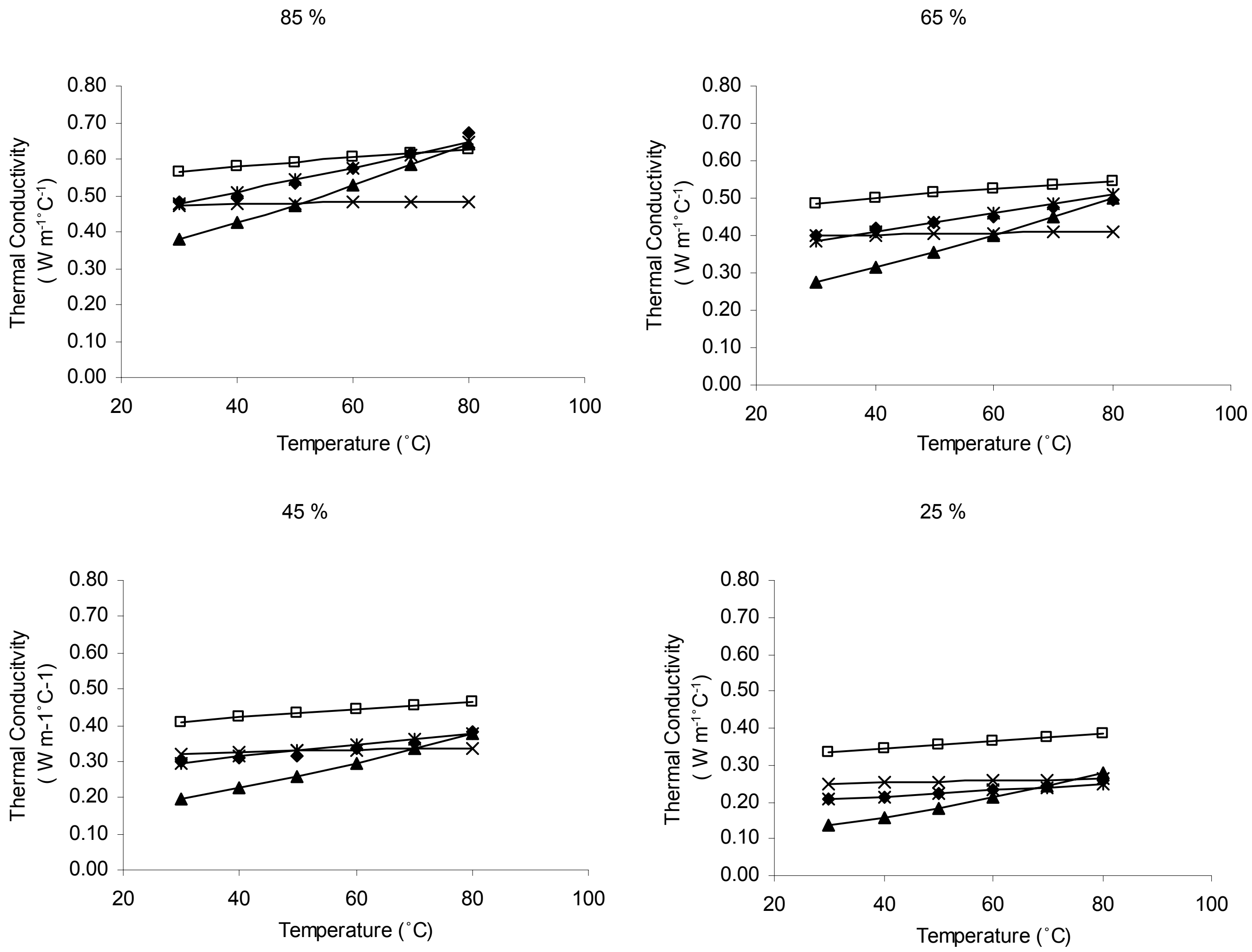

Figure 4. The experimental data and predicted bulk thermal conductivity of shiitake mushroom with 25-85% wb and temperature range of 30-80°C.

♦ = From experimental data

□ = From Choi and Okos (1986): $k = \sum_{i=1}^{n} k_i Y_i$ based on shiitake mushroom composition

▲ = From Tansakul and Lumyong (2008): $k = 0.0738 + 0.2571X^2 + 4.088\times10^{-3}XT + 1.64\times10^{-5}T^2$
(0.30<X<0.90 and 50<T(°C)<80)

× = From Shrivastava and Datta (1999): $k = 0.151 + 0.37X + 3.971\times10^{-5}BD + 2.348\times10^{-4}T$
(0.10<X<0.8968 and 40<T(°C)<70)

∗ = From equation 4.1: $k = 0.105 + 0.316X - 0.000310T + 0.00434XT$

Figure 4 reveals that increasing temperature resulted in an increase in bulk thermal conductivity at each moisture content. The predicted results from all equations showed a similar trend to that from the experimental values. However, the predicted values from Choi and Okos [10] were higher than the experimental values in each temperature and moisture content. In addition, other predicted equations [7, 9] were based on the data on thermal conductivity values of other types of mushroom (straw mushroom and button mushroom, respectively) which contain different composition and structure; therefore, different predicted values were obtained.

Conclusion

It was concluded from these results that an increase in moisture content and an increase in temperature resulted in an increase in the value of bulk thermal conductivity of shiitake mushroom. The bulk thermal conductivity varied from 0.2081 to 0.6714 W/m.K, with the moisture content range of 25-85 % wet basis and temperature range of 30-80°C.

Acknowledgments

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