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COMMUNICATION I

Measurement of Thermal Conductivity of Foods *in Situ* by a Non-Steady State Method

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ABSTRAK

Sebuah prob kekonduksian terma yang bersumber haba garisan direkabentuk untuk memudahkan pembinaan dan memanjangkan hayat penggunaan prob dalam penentuan sifat terma makanan. Prob tersebut direkabentuk supaya pengganding suhu berada di luar pemanas silinder dan bukan diletakkan di dalam jarum hipodermik seperti yang digunakan oleh kebanyakan penyelidik. Penggunaan radas diperiksa dengan mengukur kekonduksian terma beberapa sampel makanan yang mempunyai kandungan air dan suhu yang berlainan. Perhubungan linear antara suhu dan logaritma masa diperolehi selepas 8 hingga 10 minit (r^2 = 0.985).

ABSTRACT

An improved line heat source thermal conductivity probe was designed to simplify the construction and extend the life of thermal conductivity probes for use in the determination of thermal properties of foods. The probe was designed with the thermocouple on the outside of a cylindrical heater instead of being placed inside a hypodermic needle as used by most researchers in the literature. The utility of the apparatus was checked by measuring the thermal conductivity of food samples with varying conditions of moisture content and at different ambient temperatures. Linearity of temperature versus logarithm of time was obtained after 8 to 10 minutes (r^2 = 0.985).

INTRODUCTION

Virtually all foods are heated or cooled during processing such as in pasteurization of milk, sterilization of meat, and chilling of fruits and vegetables. For the chemical engineer involved in the design of these processing equipment and conditions, the thermal properties of foods which are being processed must be known in order to allow the calculation and determination of the rate and amount of heat transfer to be carried out with accuracy. In most cases, these thermal properties are not immediately known and are therefore usually either computed by some empirical means (Singh 1982) or by making simplifying assumptions. There have been attempts to compile data on thermal properties of foods (Wallapan *et al.* 1988) but the literature is still lacking on foods that are consumed in the tropical countries. For this reason, a project was undertaken to develop a method of determining the thermal property of foods in Malaysia.

The probe method is the most attractive among the various techniques available for measuring thermal properties of foods because of its simplicity and short time requirements. Basically the method involves a line heat source probe which has been described in detail by Sweat and Haugh (1974).

Some of the problems still encountered in this method lie in the construction of the probe and the short utility time associated with the application of the probe method to the study of thermal properties of foods. This paper reports a design of an improved line heat source thermal conductivity probe which simplifies the construction and extends the life of thermal conductivity probes for use in the determination of thermal properties of foods.

THEORY

The phenomenon is that of an unsteady state heat transfer, the theory of which is based on the fact that the temperature rise at a point close to a line heat source in a semi-infinite solid when subjected to a step change heat source is a function of time, the thermal properties of the solid and the strength of the heat source. The expression from which the thermal conductivity of the solid may be obtained is:

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

MATERIALS AND METHODS

A probe was designed with a nickel-constantan thermocouple positioned on the outside of a cylindrical heater (240 V/1.4 kW, diameter 2.0 cm and length 15.5 cm) instead of being placed inside a hypodermic needle as used by most researchers in the literature (*Fig. 1*). The heater and thermocouple wires were connected to their leads and an extra line was connected to the heater wire to measure the voltage at a given current. The temperature rise of the probe heater was recorded at 30-second intervals for 20 minutes by a temperature recorder (Ellab CTF 84, Ellab A/S Copenhagen, Denmark) connected to the thermocouples.

The utility of the probe was checked by measuring the thermal conductivity of food samples with varying conditions of moisture content and at different ambient temperatures. The food samples were placed in a stainless steel cylindrical container of diameter 17.5 cm and length 18.0 cm with a loose insulated cover.

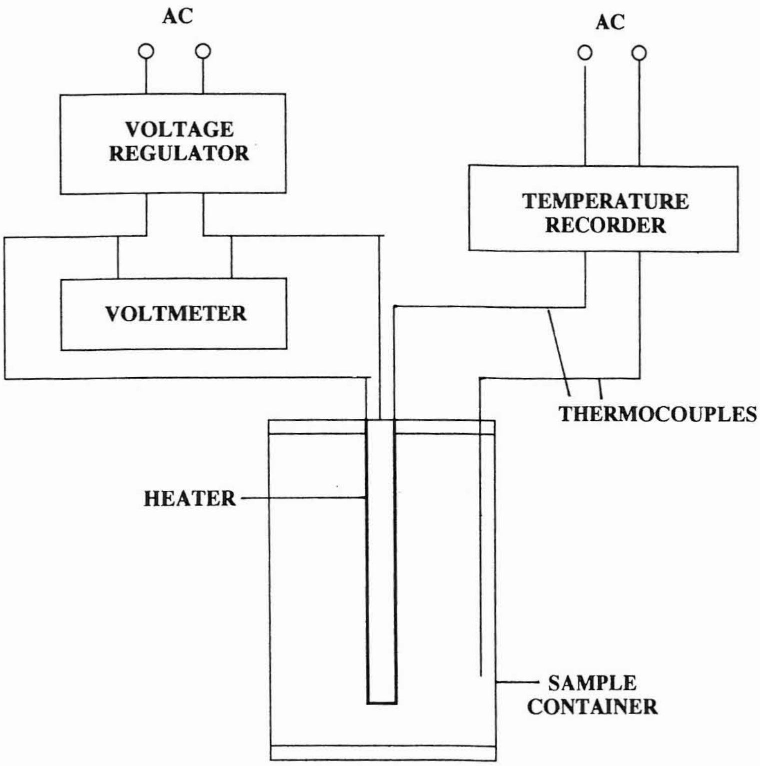

Fig. 1. A schematic representation of the thermal conductivity probe used in the study

RESULTS AND DISCUSSION

The application of the probe to foods was found to be successful when a voltage of about 20 V was used. This results in a linearity in the temperature profile versus logarithm of time which was obtained after 8 to 10 minutes (r^2 = 0.950 - 0.985) and continued for 20 minutes of measurement. A typical linear temperature rise for cocoa beans at 40°C with a moisture content of 24.6% is shown in *Fig. 2.*

From this study, a time correction factor of 70 seconds was determined to be necessary in the heat transfer calculations which improved the accuracy of thermal conductivity measurement. When a correction factor is introduced in the computations, an improved linear correlation results for the temperature profile giving a higher coefficient of determination (r^2 = 0.999).

In addition, the results also showed that the improved probe showed slower temperature rise (20 minutes) and low standard deviations. For example, the experiments carried out in this study where the thermal conductivity of cocoa beans was determined at moisture content of 7% -

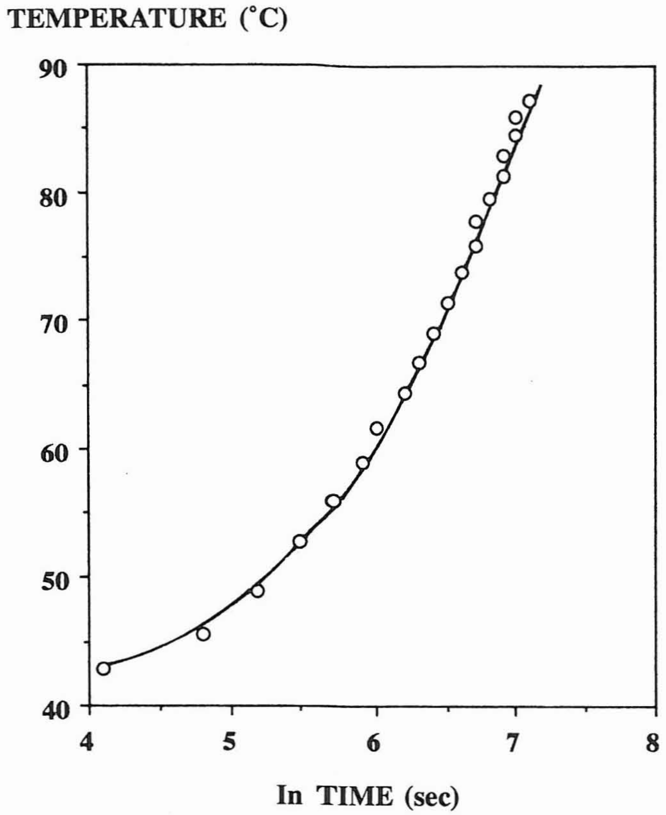

Fig. 2. An example of time-temperature curve obtained for cocoa beans

40% and at temperatures of 20 - 60°C showed standard deviations ranging between 0.006 and 0.010.

NOMENCLATURE

k	=	thermal conductivity of the sample
Q	=	continuous line heat source
t_0	=	a time correction factor
T_1	=	temperature at time t_1
T_2	=	temperatuire at time t_2

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