Determination of Thermophysical Properties of Liquid Food Products Using Newly Designed Heat Exchanger

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Abstract
The heat transfer is a very important factor during the processing and storage of many food and agricultural products. The specific heat is one of the important thermal properties for food industry to calculate the amount of heat applied along the food processing chain. The main objective of this study was to determine the specific heat using newly designed simple heat exchanger and to develop mathematical relationship between specific heat and dry matter percentage of liquid food product. Simple heat exchanger was designed to measure the specific heat in laboratory condition. Sugar solution, milk and papaya pulp with different concentrations were selected as liquid food product for the experiment. The prepared solutions were heated up to 80 - 90 °C temperature and were sent through the heat exchanger and water supply was done through outer tube of the heat exchanger with counter flow direction. Data were recorded after getting the continuous flow through heat exchanger. This experiment was conducted 20 times for each liquid concentration to obtain accurate results. Finally specific heat and dry matter percentage were recorded and the equations were developed for each product. According to the results there was a strong negative correlation between specific heat and concentration of specific food product. The newly designed device can be used for determination the specific heat of liquid food products.

Key words: Heat Exchanger, Specific heat, Fruit juice, Dry matter content

Introduction

The fruit juice could be defined in the most general sense as the extractable fluid from fruits. Fruits and their juices are good source of phytochemicals, in addition to the nutritive value of juices, additional health benefits increases the popularity of such products. The information is required by food researchers for the purpose of quality assessment and evaluation, process design, operation and control of food plants, equipment design, etc.

Specific heat is important to evaluate the behavior of these properties under process with temperature change. The lack of knowledge about this characteristics and its behavior under different temperature can result in an inadequate product processing with economical looses that could be easily avoid (Ibarz and Barbosa 1996). Many studies related to the influence of composition and temperature have been done to evaluate the thermophysical properties of food items such as orange, pineapple, mango and pummel (Telis-Romero et al. 1998).

The measuring of the specific heat for different food products in different concentrations is important in food processing engineering. The advanced technologies are available to measure the specific heat but it requires more sophisticated equipments which are not feasible for benefit of consumers, processors and producers in food processing industry under Sri Lankan condition. The development of a simple device for measuring specific heat is a requirement of the food industry as simple devices like calorimeters are not available at domestic level in rural areas. The specific heats of food stuffs depend very much, on their composition. Knowing the specific heat of each component of a mixture is usually sufficient to predict the specific heat of the mixture (Sweat 1986).

The broad objective of this study was to evaluate the thermal properties of locally available fruit juices. The specific heat of different food product with different concentration was determined using newly designed heat exchanger and development of the relationship between specific heat and dry matter for different food products and development of formula.

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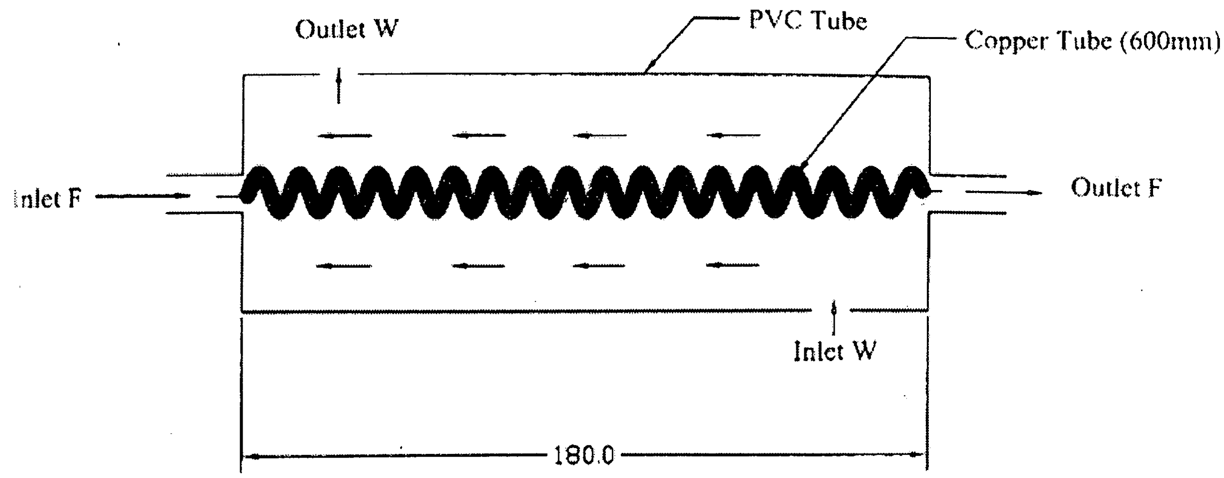
Figure 1. Designed heat exchanger (Inlet $_F$ - Inlet of the food product, Inlet $_w$ - Inlet of the water, Outlet $_F$ - Outlet of the food product, Outlet $_w$ - Outlet of the water)



Materials and Methods

The experiment was conducted in the laboratory of Department of Agricultural Engineering, Faculty of Agriculture. A device was designed and constructed for the experiment and primary purpose is the transfer of energy between two fluids named as a heat exchanger (Figure 1). A thermocouple was used for measuring temperature. The different concentrations of sugar, milk and fruit juice solutions were prepared by adding the distilled water for testing. The dry matter content was observed of the different liquid foods using gravimetric method and dry matter % were calculated using equation 1.

$$Dry\ matter\% = \left(\frac{\text{Wgt of oven dried sample - Wgt of empty crucible}}{\text{Initial Wgt of sample - Wgt of empty crucibla}}\right) x\ 100 \quad \text{.......................... (1)}$$

The prepared solutions were heated up to 80 - 90°C temperature and sent through the heat exchanger and water supply was done through outer tube of the heat exchanger with counter flow direction. Data were recorded after getting the continuous flow through heat exchanger. This experiment was conducted 20 times for each liquid concentration to obtain accurate results. Finally specific heat was recorded and developed the equations for each food product.

Specific heat of the solution was determined using equation 2 and 3.

$$Qw = M_wS_w(T_2 - T_2) \quad \text{................................ (2)}$$

$$Qf = M_fS_f(T_2 - T_2) \quad \text{................................ (3)}$$

Where; Q_f, Q_w = Heat transfer rate for food product/ water (kJ/s), m_f, m_w = mass flow rate food product/ water (kg/s), S_f, S_w = specific heat of a food product/ water (kJ/kg/°K), T_1-T_2 = The temperature difference between inlet temperature T_1 and exit temperature T_2.

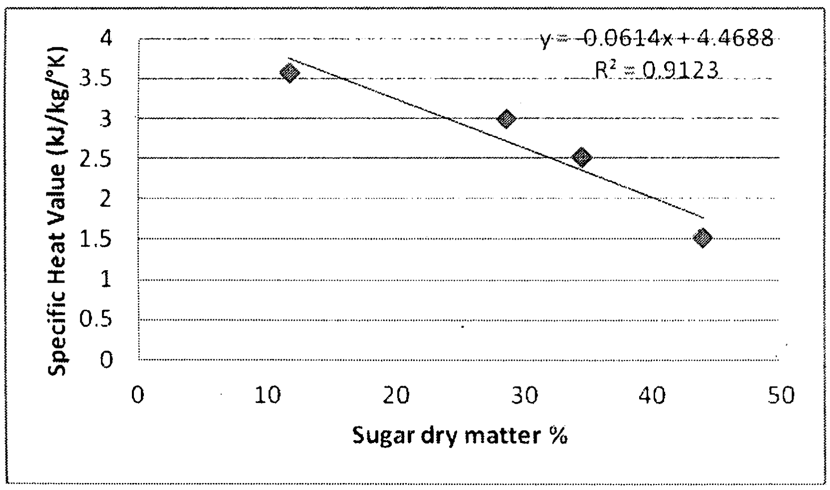


Figure 2: Specific heat value for different sugar concentration at room temperature (30°C)

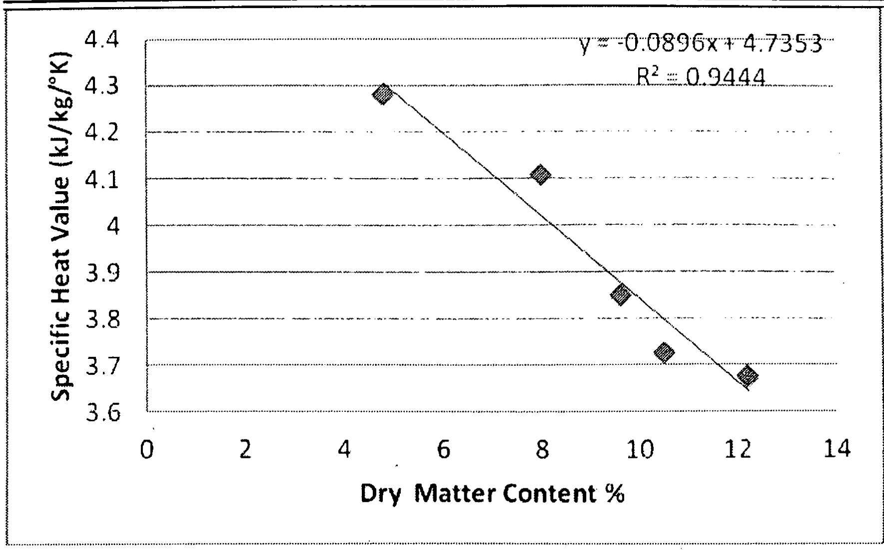


Figure 3: Specific heat content of different milk concentration at room temperature (30°C)

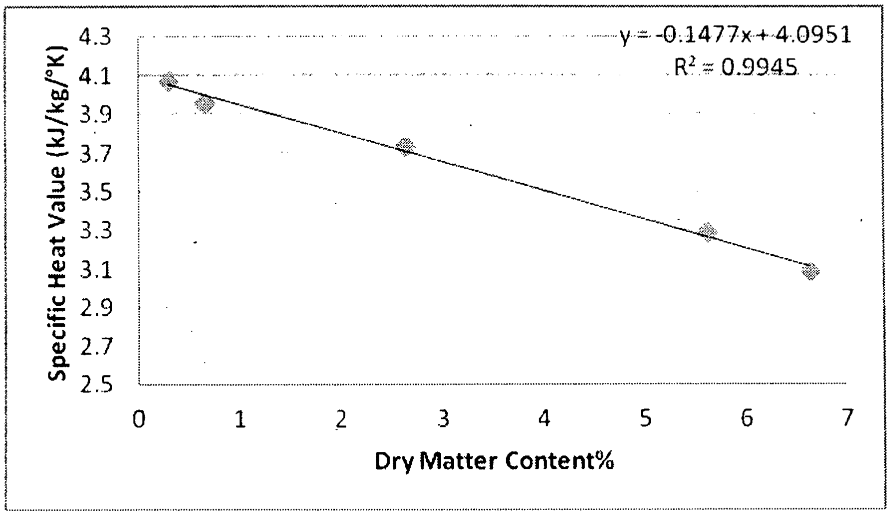


Figure 4: Specific heat content of different papaya concentration at room temperature (30°C)

Heat transfer rate (Q_w) for water could calculate using equation (2) because specific heat of water is 4.1868 kJ/kg^{0}C at room temperature.

From equation 1 and 2 following equation 4 can be derived.

$$M_w S_w (T_2 - T_1) = m_f S_f (T_2 - T_1) + Heat\ loss \ldots\ldots\ldots\ldots \quad (4)$$

Using linear regression curve, Specific heat of the liquid solution was calculated from slope of the curve.

The mathematical relationships were developed to determine the relationship of the dry matter content of the liquid products and the specific heat.

Results and Discussion

Determination of specific heat for sugar solution

According to the equation 3, the graphs were developed in between $m_w S_w \theta_w$ and $m_s \theta_s$ for different concentration of sugar solution. The calculations of specific heat for different sugar solutions were shown in the Figure 2.

Determination of specific heat for different milk concentrations

According to the Figure 3 specific heat content of different milk concentrations were given. The values were more reliable as R^2 was strong (R^2- 0.948).

Determination of specific heat for different papaya solutions

According to the observed results, though R^2 value for the relationship of the different food concentrations and specific heat values are higher than about 90%, the relationship of specific heat of the papaya juice showed strong relationship with the dry matter content (%). It revealed that there were about 99% probability to accept the equation and there was a 1% probability to reject the equation for papaya fruit juice. Rahman

(1995) showed that the specific values of apple juice (75° Brix) and orange juice (0.105) were 2.805 and 1.85 kJ/kg/°K, respectively. But the developed regression equations of tested liquid food products showed the higher specific values of water with sugar and milk products (at 0% dry matter content) and lower specific heat value of water was observed with papaya fruit juice.

Conclusions

Newly designed heat exchanger can be used for determination of specific heat of liquid food products as more reliable equation with R^2 was developed for different dry matter content of liquid food products using the device. Specific heats of different concentration of sugar, milk and papaya were determined with different dry matter contents.

References

Ibarz A and Barbosa-Cánovas GV 1996. Operaciones unitarias en la ingeniería de alimentos. Technomic, Lancaster, Pennsylvania. 1996, pp. 85–204.

Rahman S 1995 Food properties handbook. 192. New York, NY: CRC Press

Sweat VE 1986 Thermal properties of foods, In: Engineering Properties of Foods. ed. M.A Rao, and S.S.H. Rizvi, 49-87. New York, NY: Marcel and Dekker Inc.

Telis-Romero J, Telis VRN, Gabas AL, Yamashita F 1998. Thermophysical Properties of Brazilian Orange Juice as Affected by temperature and Water Content. J. Food Eng, 1998, 38, 27-40.