NATURAL CONVECTION HEAT TRANSFER IN FOOD MATERIALS IN CYLINDERS

*S.Ramakrishna, S.N.L.Ramani, D.Jayaprakash, *S.Subrahmaniyam*

UNIVERSITY COLLEGE OF TECHNOLOGY, OSMANIA UNIVERSITY. HYDERABAD-500007,INDIA

*Email---ssubrahmaniyam@yahoo.co.in

Abstract:

Experiments are conducted in stainless steel containers with condensed milk and tomato ketchup. Isothermal water bath is used in heating and cooling. The container diameters ranged from 6-11.5 cm with L/D variation of 0.83 to 1.87. Transient temperature profiles at three axial positions at various radial positions are measured with pt 100 sensors. Rheological data are obtained. The experimental results are presented as heat transfer coefficients varying with time and discussed.

Introduction:

Heat transfer to food materials is an important phenomenon in processing industries (5). Free convective heat transfer in food materials, occurs in the absence of a mixing device in the container. Most of the food materials in the suspension form exhibit non-Newtonian rheology (3). A few studies on heat transfer in canned foods with suspensions as particulate matter are available (2). Natural convection in non-Newtonian liquids is often limited to steady state convection form cylinders, plates and different geometries (1,4).

Heat transfer in canned foods is an unsteady state free convection phenomenon. In the present paper, experimental work on two food materials viz., tomato ketchup and condensed milk are presented. These materials have a composition of several components in addition to water. Heat transfer is influenced by variation in thermo physical properties within the material due to local temperature and composition gradients.

Experimental details:

Stainless steel containers of different diameter and height with a thickness of 1 mm are used in the present experiments. These are available in market. The bottom of the containers is insulated with thermocol and acrylic sheet of 12 mm thickness. The heat transfer is presumed to be only in radial direction. The containers are placed in isothermal water bath (+/- 1k). The temperatures in the food material are noted with pt 100 sensors with digital output. Depending on the container size the temperature measuring points varied from 4 to 16 as given in fig1. The top of the container is also fitted with acrylic with 1.8 cm thickness with holes for sensors. Incase of experiments with container of diameter 11.4 cm, temperature profiles are measured at three axial locations.

Widely accepted and standard food materials of tomato ketchup and condensed milk are selected from the market for the present experiment. However no studies on composition effect on heat transfer are undertaken. The rheological data of these materials are studied using

Haake VT 500 Visco tester. As the experimental free convection velocities are expected to be low for non-Newtonian liquids the data are collected at low shear rates (0-50 sec^{-1}). The experimental results are given in table1.

Then the volume of ketchup used is measured and placed in the steel container. The steel container is placed inside the isothermal water bath. The readings of temperature in the food material are noted with time until equilibrium temperature is obtained as indicated by a digital watch. The range of variables is indicated in table2.

Results and discussions:

The nature of the transient temperature variation in the food materials is seen from the fig 2a. and 2b. In heating tomato ketchup temperature close to the container surface increases rapidly initially and the slope decreases with time eventually becoming zero. However, the temperatures near the center increase slowly starting with zero slope. This behavior is common to both ketchup and milk.

The radial temperature profiles fig 9(a& b) are noted only at middle plane for small diameter containers (6 & 7.2 cm). It is seen from the temperature profiles that a slight peak in the milk at approximately half the radial distance of the container radius is exhibited. The temperature gradients at the wall decreased with time as anticipated.

Experimental results of radial temperature distribution corresponding to three axial positions in the container (diameter 11.4 cm) are given in fig 4 to 7. From these figures heat flux variation with time is represented in fig 8. The milk heating experiments show low heat flux at the top close to air-milk interface. The heat flux increases at the middle and bottom positions. However the rate of variation with time is high in the middle and bottom locations. Similar variations are noted for milk cooling. The heat flux during cooling are noted to be smaller than during heating. This is expected as the apparent viscosity drops with increasing temperature.

The experiments with ketchup heating and cooling also a similar trend for bottom plane. It appears that no theoretical predictions of transient temperature distributions for this situation are available in literature.

The data are represented by heat transfer coefficients which are given below. *Heat transfer coefficients* for the present experiments are defined as

$$h=q / (T_w-T_b)$$

Where q is the wall heat flux measured from radial temperature distribution and T_b is the average food material temperature.

The results are shown in fig 3. The effect of diameter indicates an increase in heat transfer coefficient with increase in diameter and for both the cases heat transfer coefficient passes through the minimum.

Fig 10 indicates the average heat transfer coefficients for milk and ketchup for experiments conducted in the container of 11.4 cm diameter. The length average of local heat transfer coefficients is used as average heat transfer coefficients h_a. Generally low values of heat transfer coefficients for the food materials used are due to high apparent viscosities. For example, the ketchup viscosity is about 2500 cP whereas the condensed milk viscosity is 80 cP (table 1 &2). In addition the milk exhibited bingham plastic behavior. The cooling heat transfer coefficients of milk/ketchup are lower than that of heating. This is anticipated as viscous effect.

It is difficult at present to make any quantitative analysis of data. A mathematical solution neglecting the inertial forces of momentum and energy equations are to be solved to predict heat transfer coefficients.

Conclusions:

Experimental data for free convective cooling and heating of food materials are reported in this paper. The conclusions are

1) Transient temperature data for both materials studied indicate rapid heating near the wall initially and a decreasing slope as time progresses. Temperatures in the core (near the center) have a zero slope initially and increase only after about 10 min.
1) The container diameter shows an increase in heat flux and heat transfer coefficients for condensed milk cooling.
2) The radial temperature distributions with milk and ketchup show peak in temperature at a radial location equal to half the container radius.
3) Heat transfer coefficients (average) are higher for heating and about 10 to 20% lower for cooling experiments.
4) Thermal resistance of ketchup appears to be higher than that of condensed milk.
5) Rheological data show condensed milk as bingham plastic whereas the tomato ketchup can be represented by a power law model.

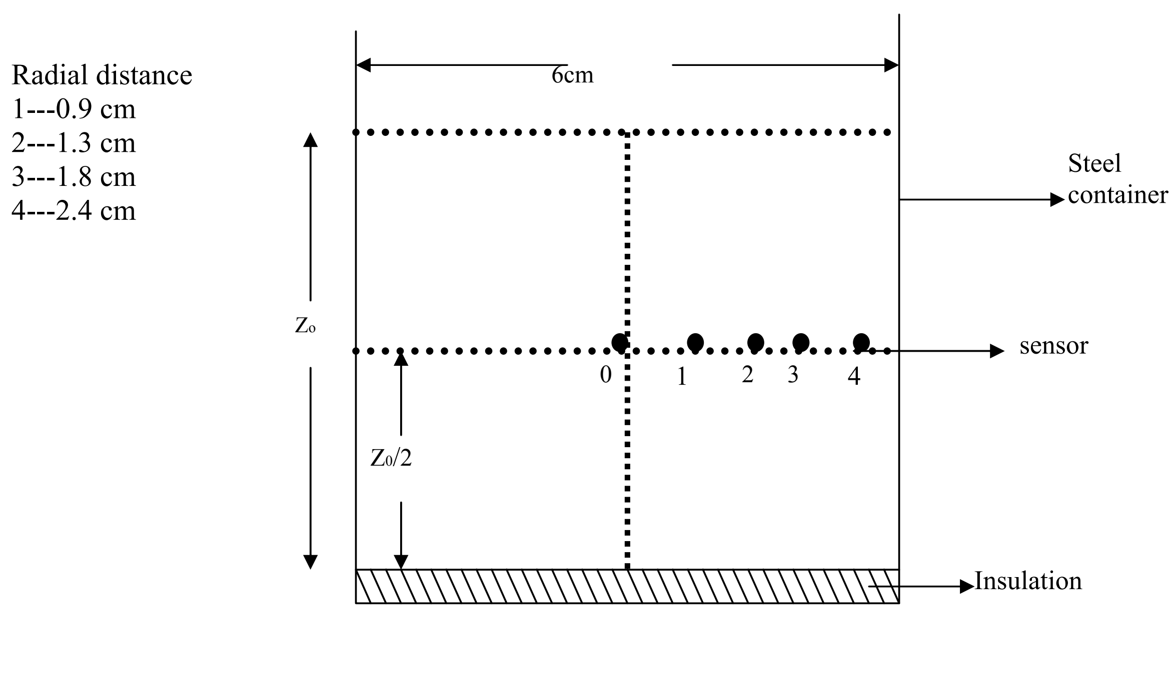


Fig 1(a) : Experimental setup for steel container of diameter = 6cm, Z_0 is the level of Food material.

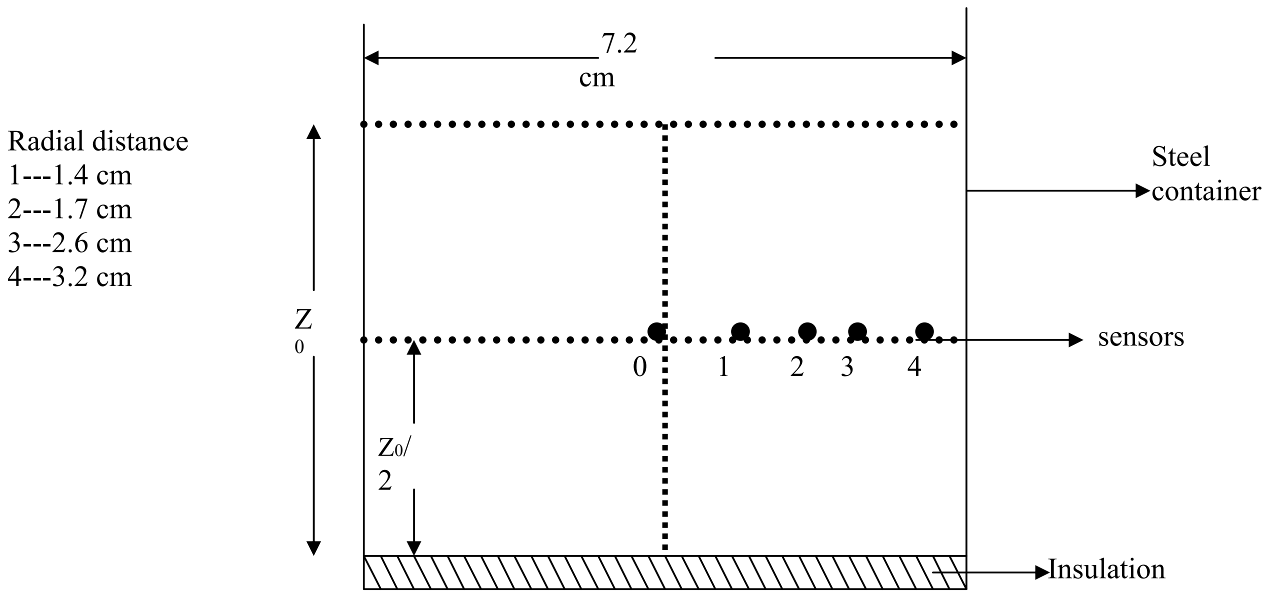


Fig 1(b) : Experimental setup for steel container of diameter = 7.2 cm, Z_0 is the level of Food material.

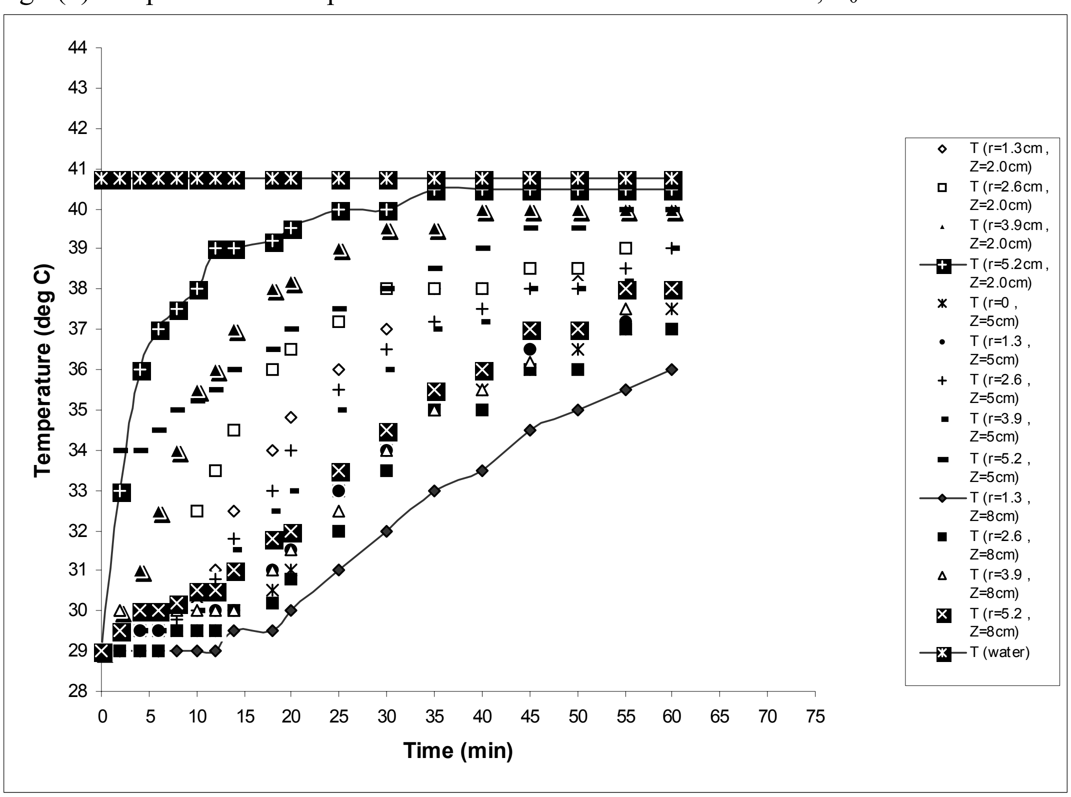


Fig 2 (a): Temperature Vs time graph for heating of milk, Initial temperature of water = 42°C and Initial temperature of milk = 29°C. Diameter of container = 11.4 cm.

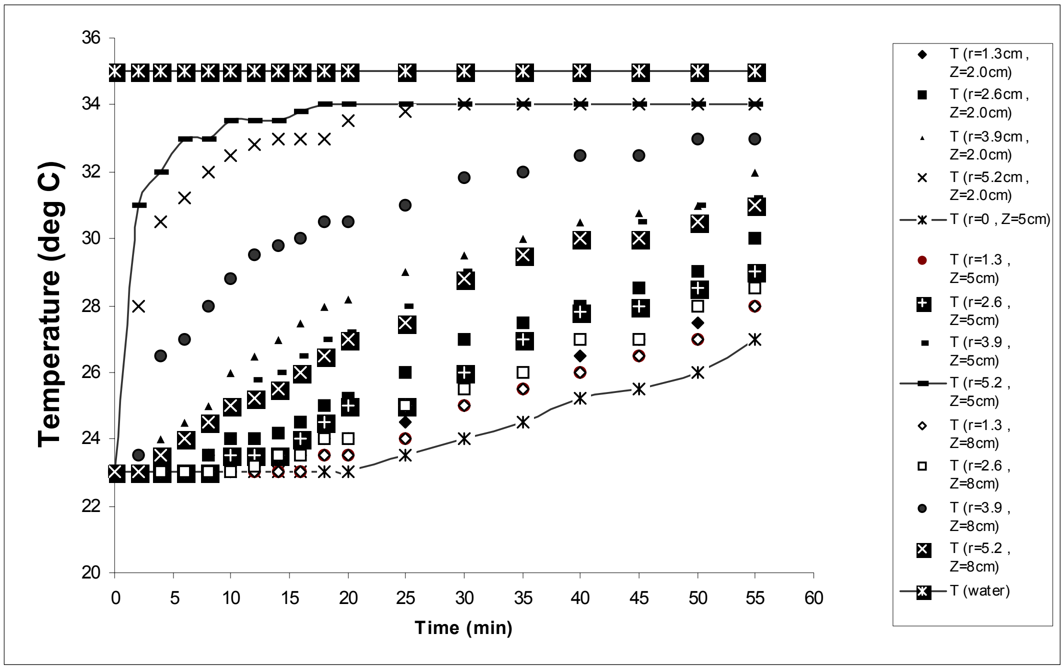


Fig 2 (b): Temperature Vs time graph for heating of Ketchup, Initial temperature of water = 36°C and Initial temperature of ketchup = 23°C. Diameter of container = 11.4 cm.

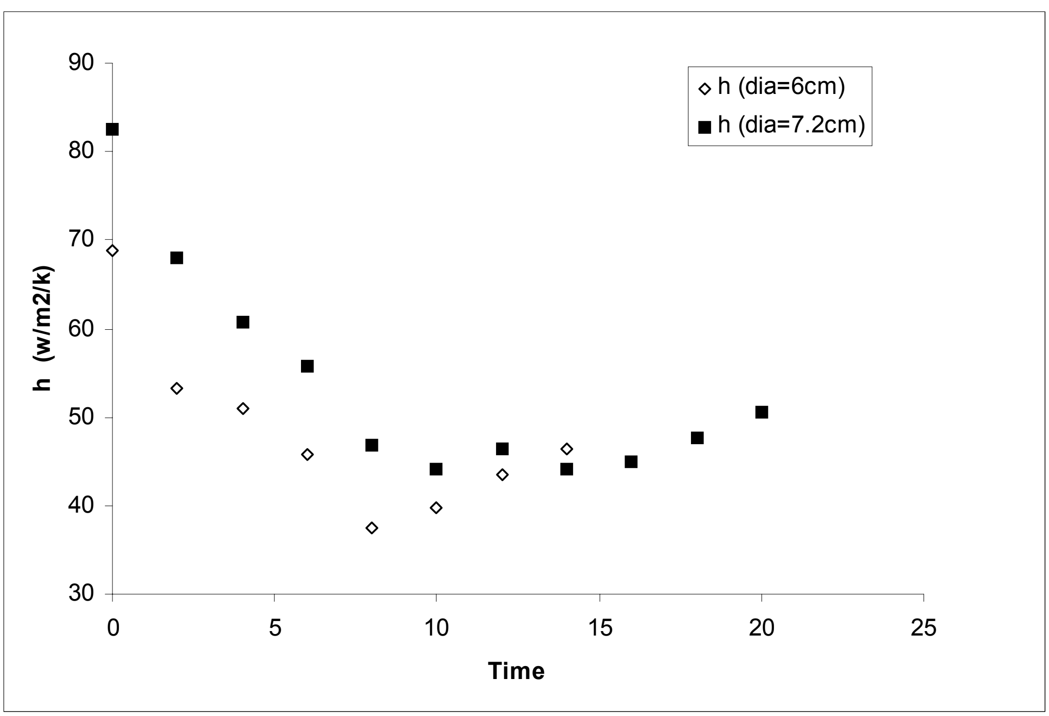


Fig 3: h Vs time graph for cooling of with containers of diameter 6 cm and 7.2 cm.

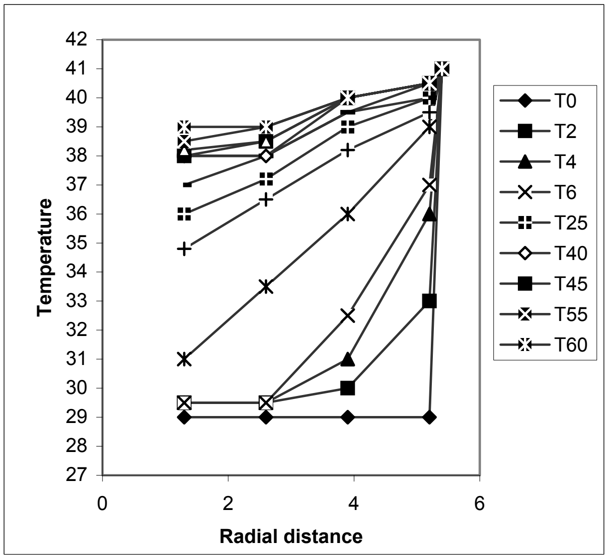


Fig 4(a): Radial distance Vs Temperature for heating Of milk with Twi = 42C and Tmi = 29C at a depth of Z = 5 cm (middle plane).

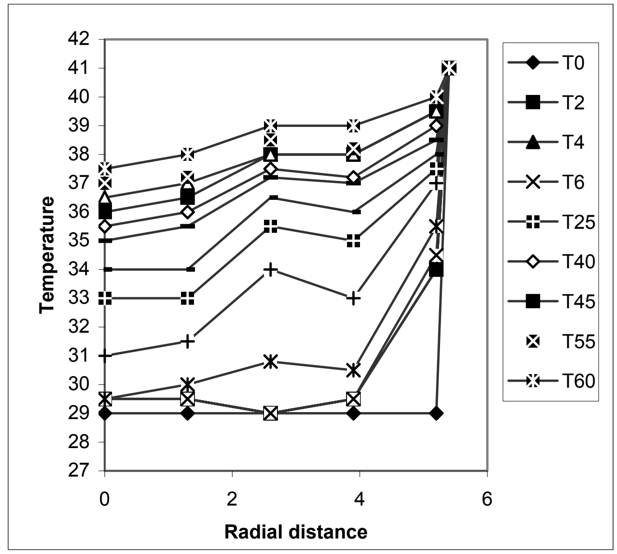


Fig 4(b): Radial distance Vs Temperature for heating Of milk with Twi = 42C and Tmi = 29C at a depth of Z = 2 cm (top plane).

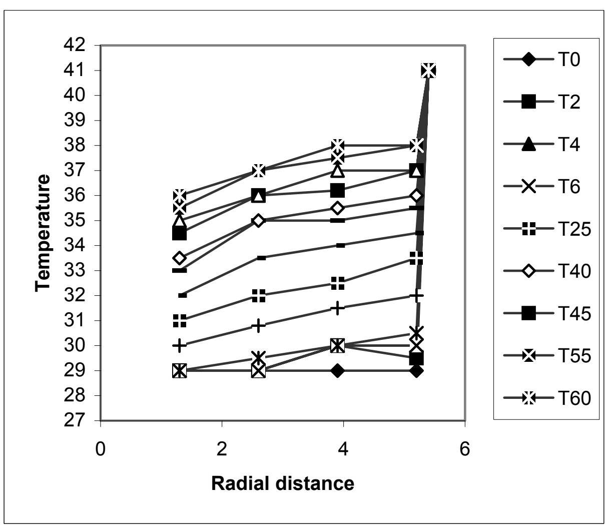


Fig 4(c): Radial distance Vs Temperature for heating Of milk with Twi = 42C and Tmi = 29C at a depth of Z = 8 cm (bottom plane).

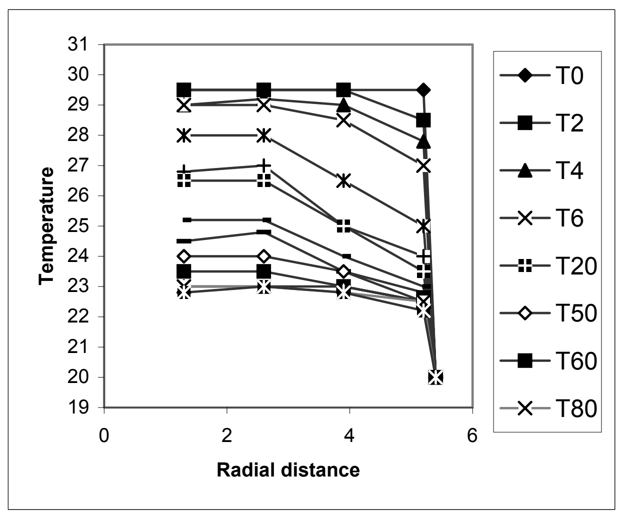
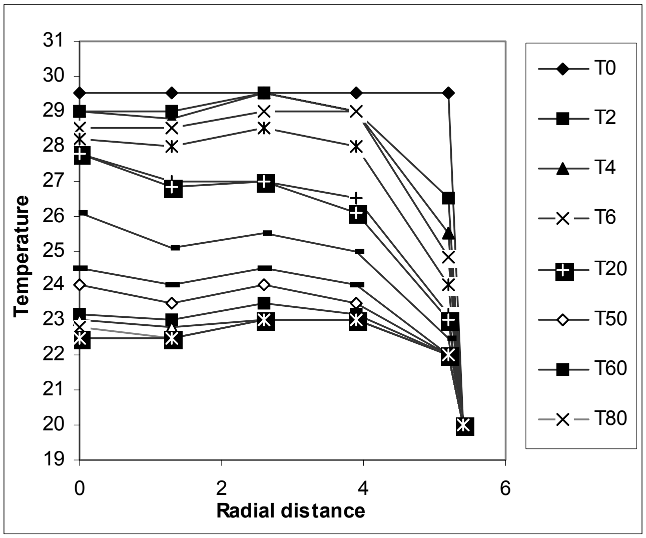


Fig 5(a): Radial distance Vs Temperature for cooling Of milk with Twi = 20C and Tmi = 29.5C at a depth of Z = 8 cm (bottom plane).



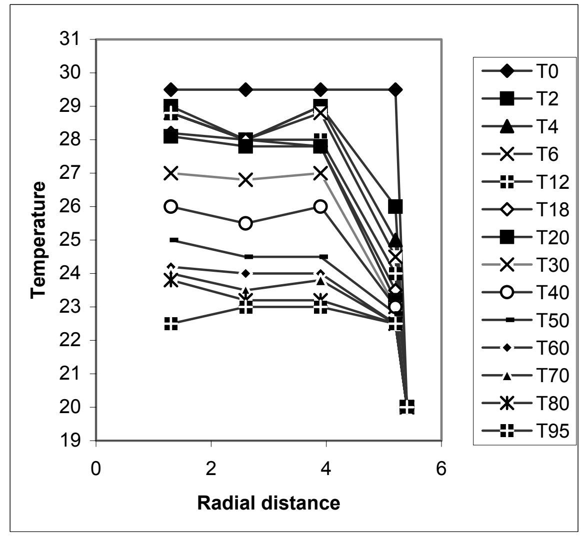
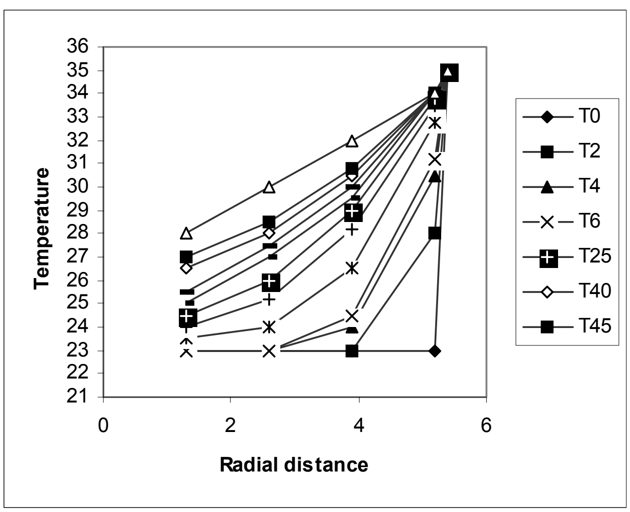


Fig 5(b): Radial distance Vs Temperature for cooling Of milk with Twi = 20C and Tmi = 29.5C at a depth of Z = 5 cm (middle plane).

Fig 5(c): Radial distance Vs Temperature for cooling of milk with Twi = 20C and Tmi = 29.5C at a depth of Z = 2 cm (top plane).



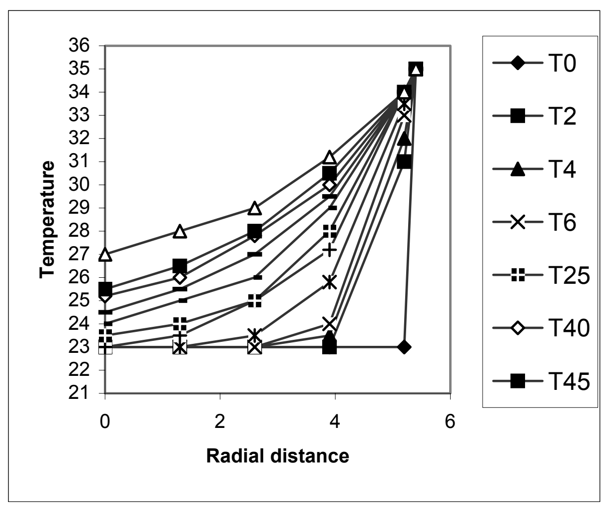


Fig 6(a): Radial distance Vs Temperature for heating of ketchup with Twi = 36C and Tki = 23C at a depth of Z = 2 cm (top plane).

Fig 6(b): Radial distance Vs Temperature for heating of ketchup with Twi = 36C and Tki = 23C at a depth of Z = 5 cm (middle plane).

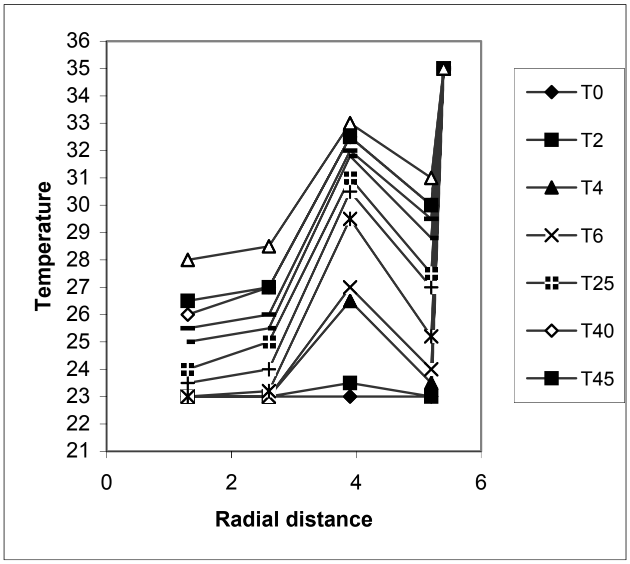


Fig 6(c): Radial distance Vs Temperature for heating of ketchup with Twi = 36C and Tki = 23C at a depth of Z = 8 cm (bottom plane).

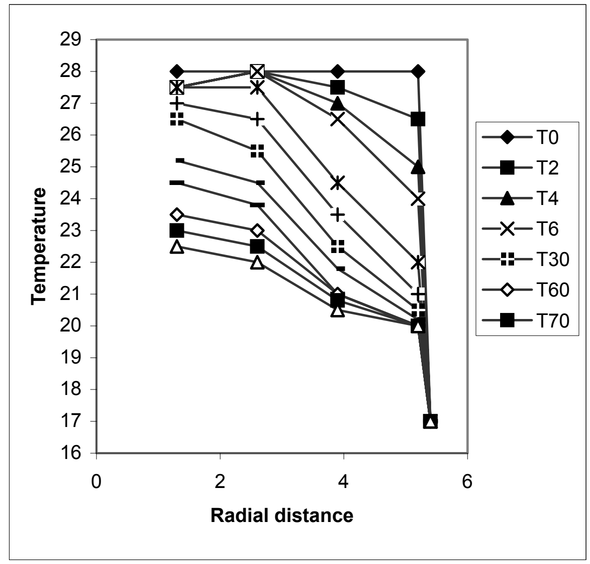


Fig 7(a): Radial distance Vs Temperature for cooling of ketchup with Twi = 16C and Tki = 28C at a depth of Z = 2 cm (top plane).

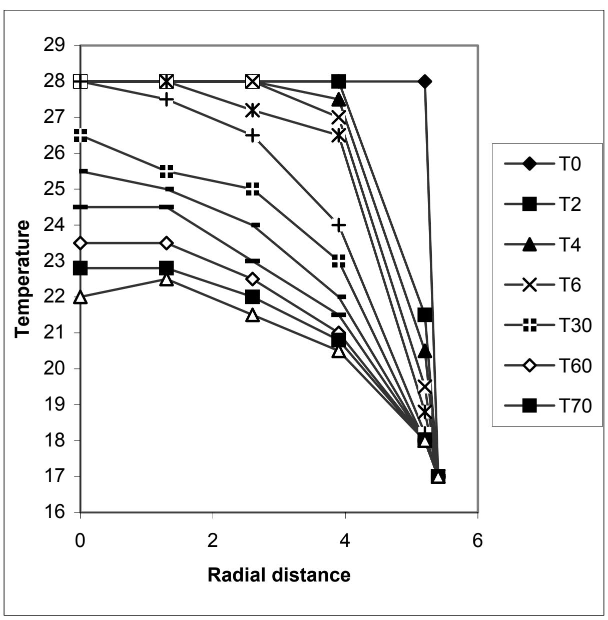


Fig 7(b): Radial distance Vs Temperature for cooling of ketchup with Twi = 16C and Tki = 28C at a depth of Z = 5 cm (middle plane).

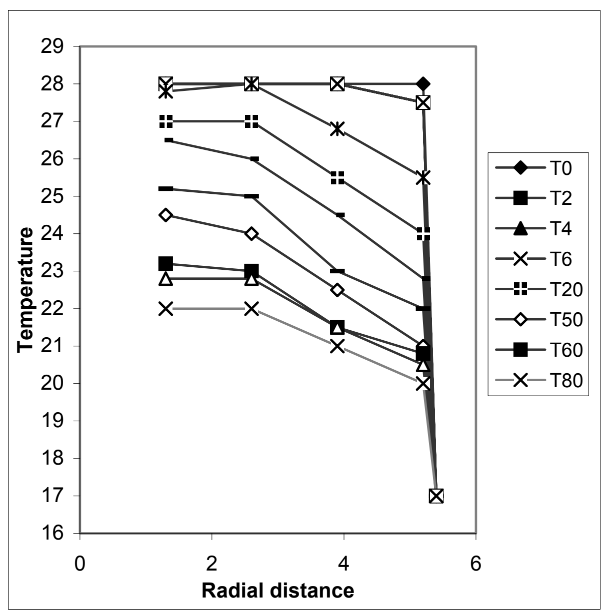


Fig 7(c): Radial distance Vs Temperature for cooling of ketchup with Twi = 16C and Tki = 28C at a depth of Z = 8 cm (bottom plane).

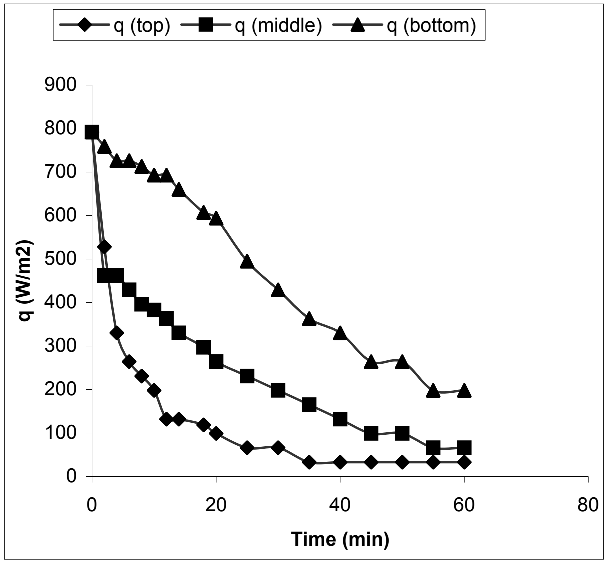


Fig 8(a): Heat flux Vs Time graph for milk heating with Twi = 42C, Tmi = 29C, with container dia = 11,4 cm.

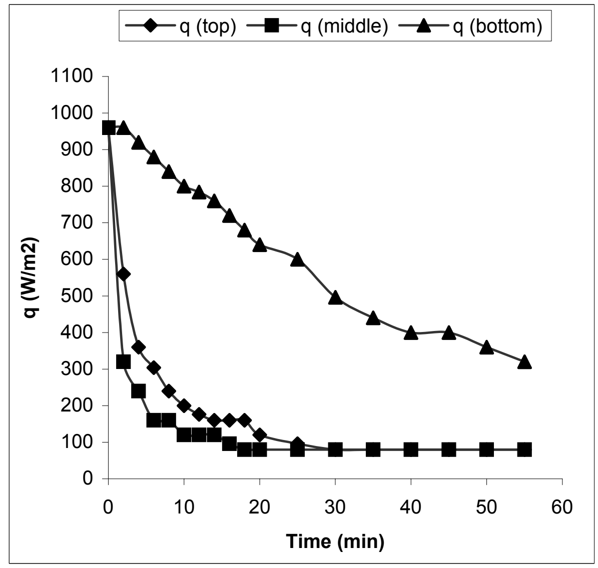


Fig 8(b): Heat flux Vs Time graph for ketchup heating with Twi = 36C, Tki = 23C, with container dia = 11,4 cm.

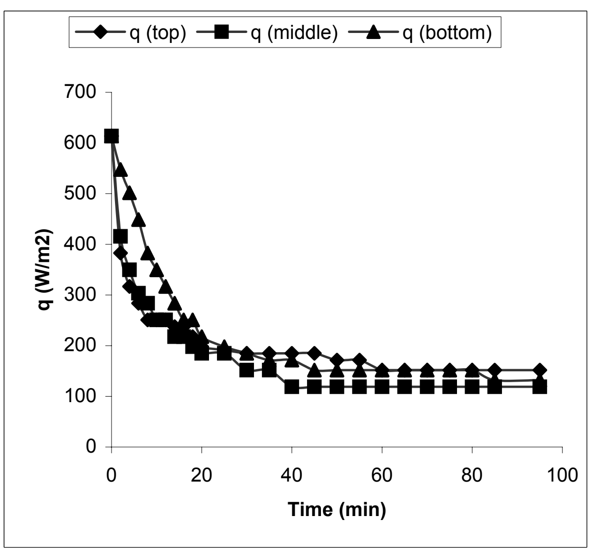


Fig 8(c): Heat flux Vs Time graph for milk cooling with Twi = 20C, Tmi = 29C, with container dia = 11,4 cm.

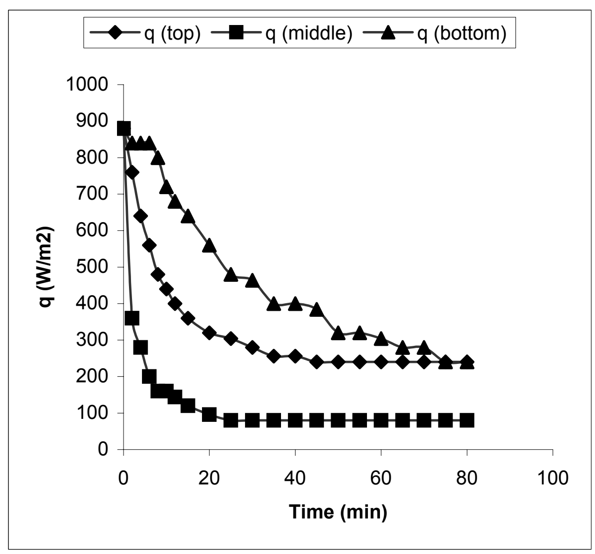


Fig 8(d): Heat flux Vs Time graph for ketchup cooling with Twi = 16C, Tki = 28C, with container dia = 11,4 cm.

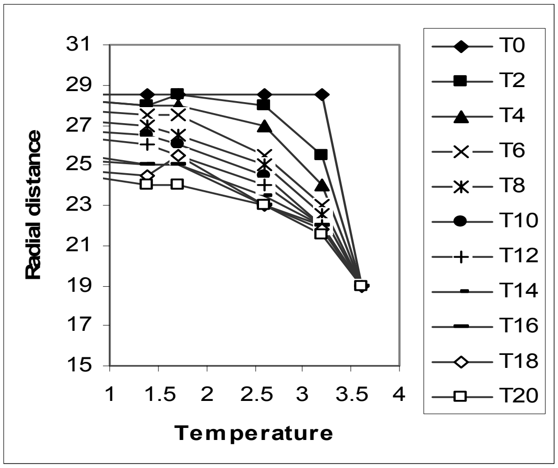


Fig 9(a): Radial distance Vs Temperature At middle plane for cooling of milk with Twi = 19C and Tmi = 28.5C, Diameter of container = 6 cm.

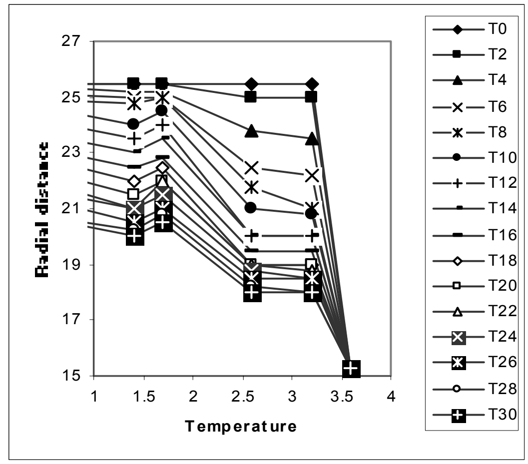


Fig 9(b): Radial distance Vs Temperature At middle plane for cooling of milk with Twi = 14.5C and Tmi = 25.5C, Diameter of container = 7.2 cm.

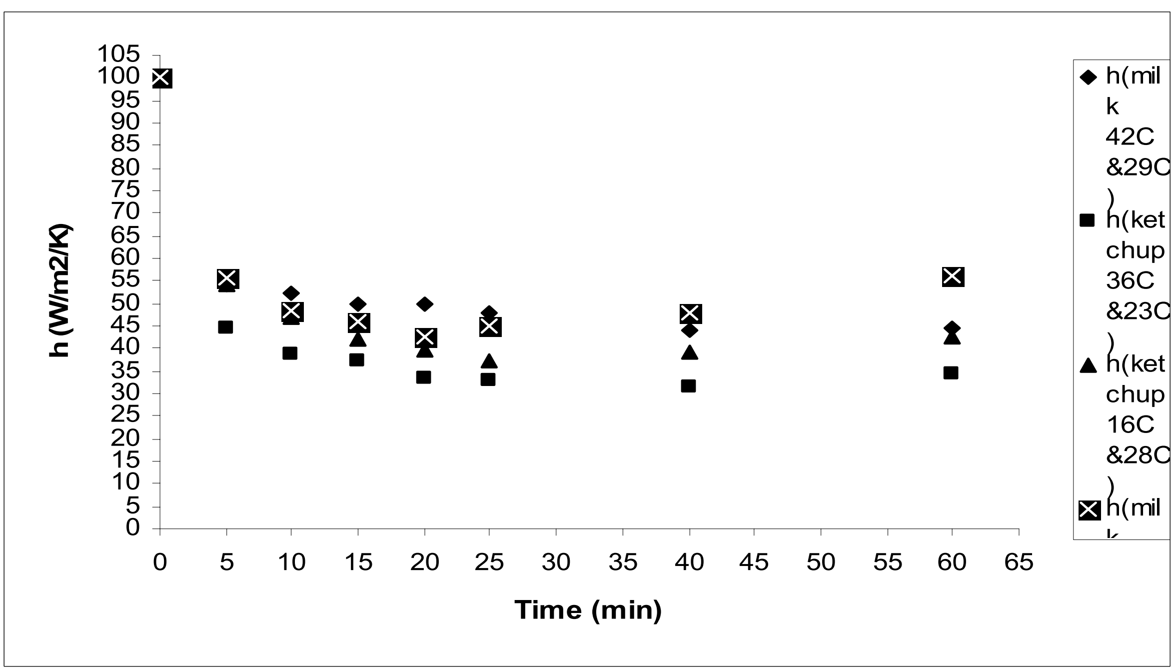


Fig 10: Heat transfer coefficient variation with time for heating and cooling experiments of milk and ketchup.

Table 1:Rhelogical data for tomato ketchup.

Temperature	n	k
25	0.29	11.62
30	0.31	9.202
40	0.2955	9.286
45	0.274	10.642
55	0.247	12.914
60	0.264	11.733

Table 2: Variable parameters

Container Diameters	L/D	dT (cooling or heating)
6	0.833333	5 to 13
7.2	1.166667	5 to 13
11.4	1.14	5 to 13

References:

1) J.P. Holman, Heat transfer (SI metric edition), Mc Graw hill, 1989.
2) T.Thattiyakul, M.A.Rao and A.K. Dutta Heat transfer to a canned corn starch dispersion under intermittent agitation, 20th annual conference on the Responsibilities of Thermal Processing Specialists, Nov 15, 2000, VA.
3) James.F.Steffe, 1996, Rheological methods in Food Process Engineering (second edition), Freeman press.
4) A.Acrivos, 1960, A Theoretical analysis of laminar natural convection heat transfer to non-Newtonian fluids, AIChE J,6,4,P:584.
5) R.Paul singh, 1993, Dennis R Heldman, Introduction to Food Engineering , second edition.
6) Seung Dong LEE and Kune Yull SUH, October,2003, Natural convection heat transfer in two dimensional semicircular slice pool, J.NUCLEAR SCIENCE AND TECHNOLOGY, Vol.40. No. 10, p.775-782.