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EXPERIMENTS ON SOLIDIFICATION WITH NATURAL CONVECTION IN A RECTANGULAR ENCLOSED REGION

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NOMENCLATURE

L, height of the enclosure [cm];
T_c, temperature of cooling water [°C];
T_i, initial temperature [°C];
T_{sat}, solidification temperature [°C];
X, vertical coordinate measured from the bottom of the enclosure [cm];
y, horizontal coordinate measured from the top of the enclosure [cm];
Y', half-width of the melt region [cm];
Y_o, distance from the center line to solid-mold interface [cm].

Greek symbols

δ, $= Y'/Y_o$, relative width of the melt region;
ϕ, $= (T_i - T_{sat})/(T_{sat} - T_c)$, dimensionless temperature representing superheat in the melt.

INTRODUCTION

HEAT TRANSFER problems with solidification/melting are encountered in a large number of industrially important situations and have been the subject of investigations for over a century. However, until recently, the heat transfer was assumed to be by conduction only, neglecting natural convection set up by thermal gradients [1]. Some recent papers, however, give analytical solutions which account for the natural convection effects in 1- and 2-dim. systems [2-5]. Experimental results have also been reported for some cases [6, 7].

EXPERIMENTAL APPARATUS AND PROCEDURE

A schematic diagram of the experimental set-up is shown in Fig. 1. It essentially consists of an experimental cell, a controlled temperature bath, thermocouples and a data acquisition system. The experimental cell was made of two square steel walls 0.2 × 0.2 m which were 0.02 m apart. The side walls were made of Plexiglas and were insulated. These served as molds and their effect was included in the model [4]. The steel walls could be maintained at a constant temperature by circulating water from the constant temperature bath through the steel tanks or jackets of which these walls formed one side each. The 0.02 m distance between the side walls ensured laminar, natural convection currents using paraffin wax as the solidifying material (solidification temperature, $T_{sat} = 61.5$°C). The temperatures were measured using iron–constantan thermocouples fixed at predetermined positions.

Paraffin wax was melted in a separate container to a temperature above its melting point and was poured into the experimental cell and the cover for the top was put into place for insulation purposes. Since there was symmetry about the central plane (Fig. 1), temperature was measured in one half of the cell. The thermocouple readings were recorded by a 3052A Hewlett Packard Data Acquisition system. The system has a digital voltmeter, a fast scanner, a real time clock and a calculator. It was programmed to scan all the thermocouples every 30 s. The time taken to scan all the thermocouples was less than 1/5 of a second.

RESULTS AND DISCUSSION

The variation of temperature with time for different thermocouples, for T_i = 72°C (ϕ = 0.32) and aspect ratio ($L/2Y_o$) = 1.75 cm is shown in Fig. 2. The plots are drawn only for selected thermocouples for clarity. The thick lines show the results from the analytical study made by the authors [4]. The parameters y/Y_o and x/L show the horizontal and the vertical positions of the thermocouples from the center and the bottom of the enclosure respectively. The figure shows that the experimental points fall reasonably within the theoretical range except during the initial stages of the experiment where the deviation is due to the turbulence created by pouring the molten wax into the cell and which takes certain time to subside.

The location of the interface as a function of time has been interpolated from Fig. 2 and plotted in Fig. 3 where the lines show the analytical results computed from eqn. (20d) of [4]. The comparison between the experimental results and the computed values is very good.

Similar good comparisons of the temperature profiles and the interface locations obtained from the experimental and theoretical calculations were obtained for other values of the aspect ratios (2.5, 3) and superheat (0.61, 0.66, 0.83). The plots are not reproduced here for want of space but are available in [8].

CONCLUSIONS

The model [4] takes into account the effects of laminar natural convection on solidification in a 2-dim. rectangular system. The model is borne out well by the experiments.

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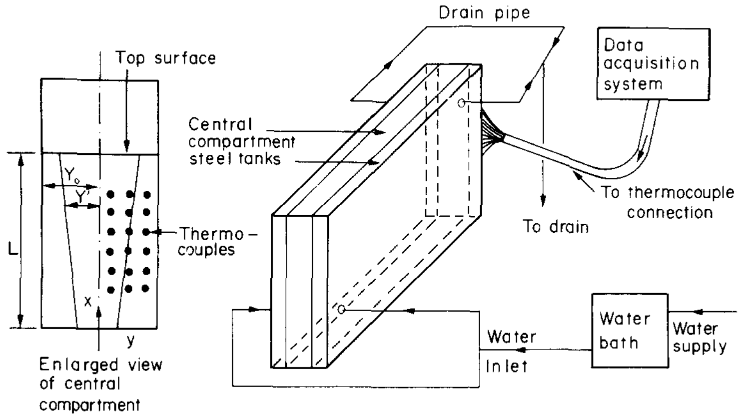

FIG. 1. Experimental set-up.

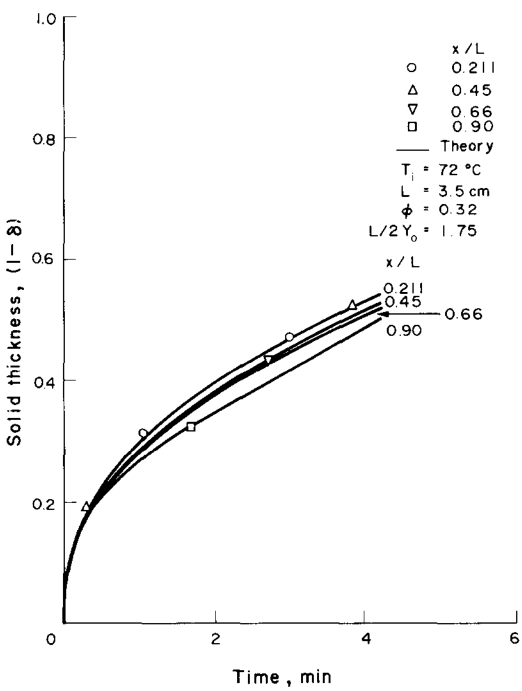

FIG. 2. Temperature vs time.

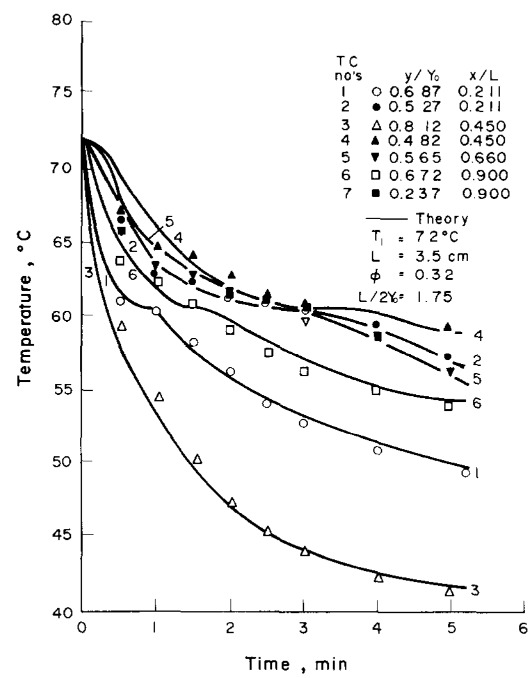

FIG. 3. Solid thickness vs time.

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