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EXPERIMENTAL HEAT TRANSFER STUDIES IN THE SOIL BELOW COLD STORES

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Abstract

This work is devoted to verify, experimentally, a mathematical model used by the authors for solving the problem of heat transfer in the soil below cold stores. The time required for the soil to achieve $0^{\circ}C$, and the ground heat losses were investigated. Comparison between the numerical and experimental results showed that the mathematical model is acceptable.

1. Introduction

Due to the difference in temperature between the one floor cold store and the soil below it, heat will be unavoidably transferred through the floor construction. If the ammount of heat being transferred from the soil is not compensated by outside heat sources, the temperature of the soil will be continuously reduced to achieve zero and negative temperatures. Consequently, freezing of water presented in the soil may cause floor heaving as a result of the soil expansion.

A two-dimensional heat transfer model was presented and solved numerically for the case when the cold store is built directly on the ground surface [1]. The aim of this work is to verify this model experimentally.

2. Experimental Set-up

An experimental model was designed to represent a cold store built on the ground surface, taking into consideration the geometrical similarity. The experimental Set-up was constructed in the soil thermal properties laboratory, Faculty of Engineering, Alexandria University [2]. Figure 1 illustrates schematically the experimental set-up which consists mainly of a refrigerated surface laid on the upper free surface of an insulated wooden box filled with dry sand of $k = 0.42\ W/m^{o}C$ and $\alpha = 0.001\ cm^{2}/s$ at $22^{o}C$ [3].

The refrigerated surface is the bottom surface of one mm thickness copper box (24 cm width, 74 cm length and 3 cm depth). The width of the box was chosen to represent a 12 m cold store width (scale 1:50). The length was taken as three times the width to construct a

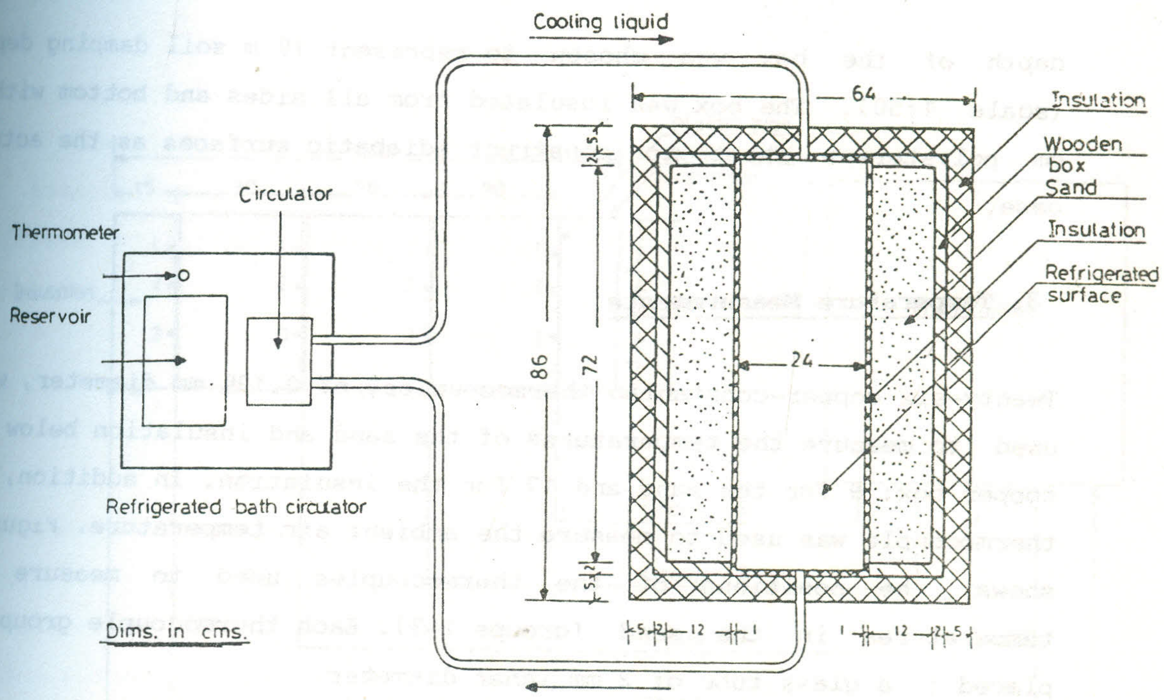

Fig.1 - Schematic diagram of the experimental set - up.

two-dimensional model. The box has two openings for inlet and outlet of the cooling liquid. This box was insulated from all sides and bottom with one cm polysterene sheet to represent the insulated floor and walls of the cold store. To reduce the heat gain from the surroundings to the upper surface, it was insulated with five cm polysterene sheet. A refrigerated bath circulator, was used to cool, circulate and control the temperature of the cooling liquid flowing through the copper box. The wooden box dimensions are: 50 cm width, 72 cm length and 21 cm depth. Since the effect of a cold store, built directly on the ground surface, on the surrounding soil diminishes at a distance equals to its half width [4], the width of the wooden box was taken as twice the refrigerated surface width. The depth of the box was chosen to represent 10 m soil damping depth (scale 1:50). The box was insulated from all sides and bottom with 5 cm polystyrene sheet to construct adiabatic surfaces as the actual case.

3. Temperature Measurements

Twenty-six copper-constantan thermocouples, of 0.125 mm diameter, were used to measure the temperatures of the sand and insulation below the copper box: 9 for the sand and 17 for the insulation. In addition, one thermocouple was used to measure the ambient air temperature. Figure 2 shows the positions of the thermocouples used to measure the temperatures in the sand (groups 1-3). Each thermocouple group was placed in a glass tube of 2 mm inner diameter.

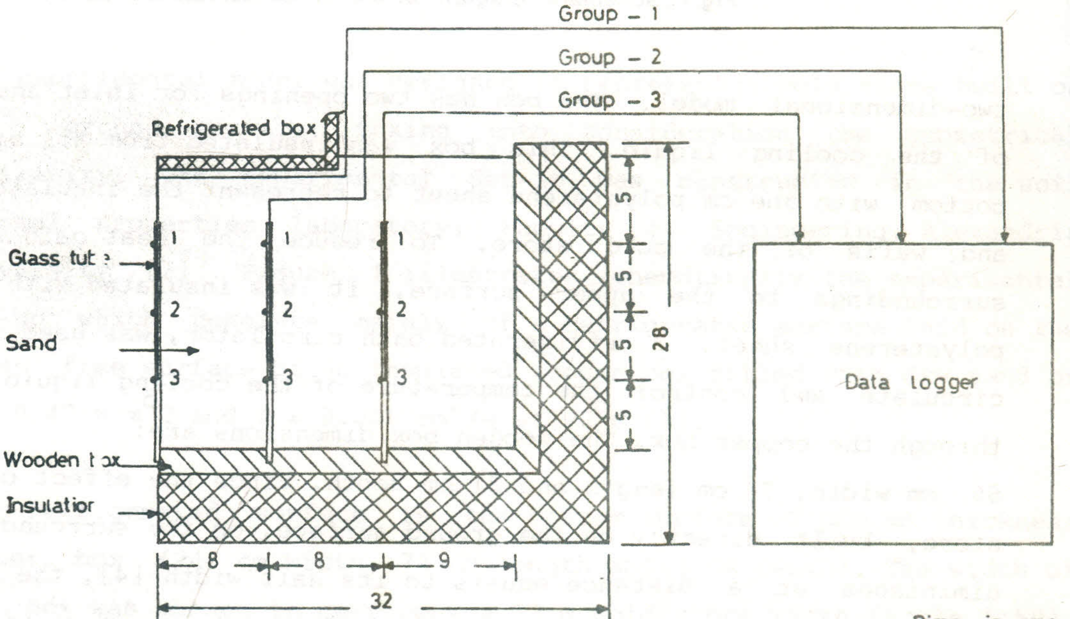

Fig.2 – Positions of thermocouples for Groups 1, 2 & 3 in the sand.

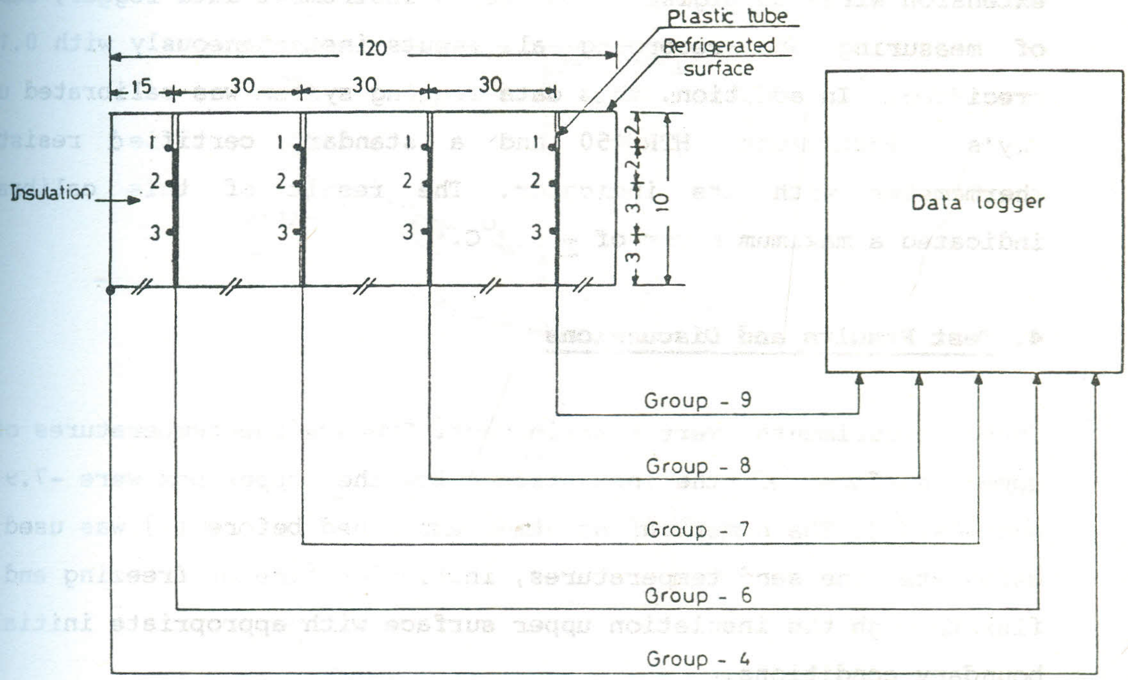

Fig. 3 - Positions of thermocouples for Groups 6,7,8 & 9 (within insulation thickness) and bottom central surface.

Dims. in mms.

Figure 3 demonstrates the positions of the thermocouples used to measure the temperatures within the insulation thickness and the center of the bottom surface. Tweleve thermocuples (groups 6-9) were used to measure the temperatures through the insulation thickness. Each thermocouples group was placed in a plastic tube of 2 mm diameter. One thermocouple (G-4) was used to measure the temperature at the midpoint on the insulation bottom surface.

Four thermocouples were used to measure the temperature of the upper surface of the insulation below the copper box: two at the middle of the insulation upper surface, and two at the end sides. All thermocouples were fixed by an adhesive plastic tape and connected via extension wires to Digistrip II, Kay's Instrument data logger, capable of measuring and recording all inputs instantaneously with 0.1°C precision. In addition, this data logging system was calibrated using Kay's instrument HTR/150 and a standard certified resistance thermometer with its indicator. The result of this calibration indicated a maximum error of ± 0.2°C.

4. Test Results and Discussions

Three experiments were carried out. The average temperatures of the upper surface of the insulation below the copper box were -7.9, -11 and -14.7°C. The numerical solution explained before [1] was used to calculate the sand temperatures, initiation time of freezing and heat flux through the insulation upper surface with appropriate initial and boundary conditions.

Figure 4 demonstrates the variations of the numerical and measured sand temperatures for thermocouples groups 1,2 & 3 , respectively for average insulation temperature -7.9°C. Similar results were obtained for the temperature -11 and -14.7°C. The maximum percentage deviation between the numerical and experimental results is 10 %.

The initiation time of freezing can be predicted from Figure 5 which gives the temperature-time variation of thermocouple G-4 for the three experiments. The measured values of the initiation time of freezing, for the three experiments, were 72, 60 and 32 hours respectively. The corresponding numerical values were 69.5, 57.2 and 29 hours respectively.

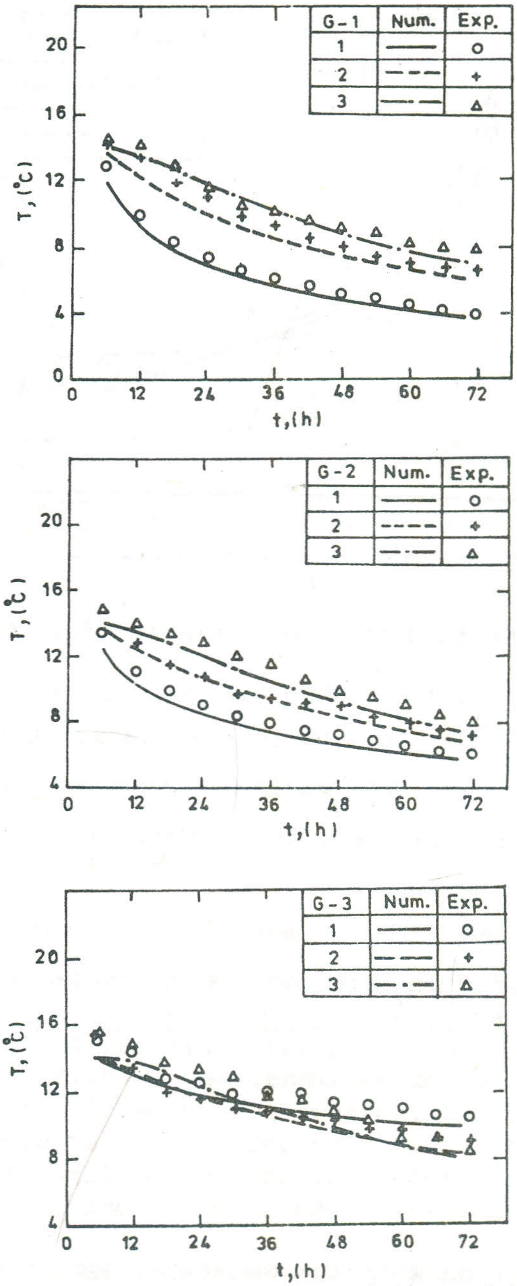

Fig.4. Temperature-time variation of the sand
($T_C = -9.7°C$)

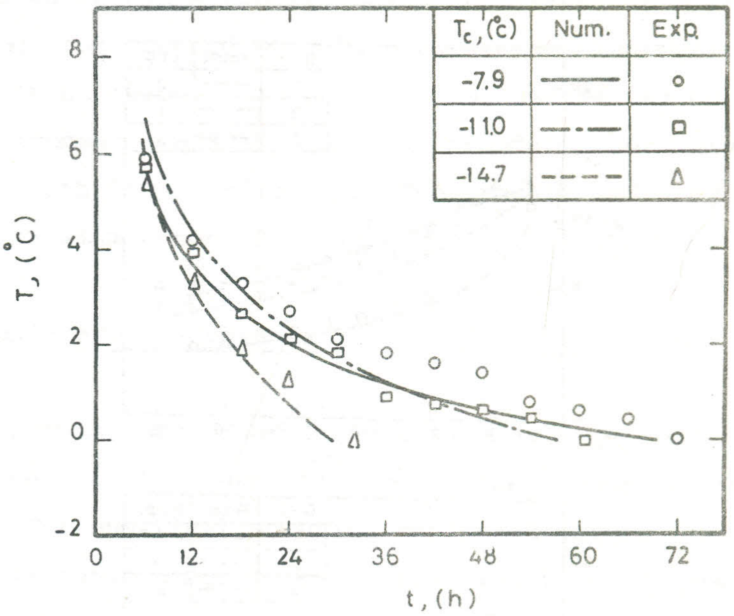

Fig. 5 - Temperature variation of thermocouple G-4.

Heat flux through the insulation surface, at t = 18h, is given in Figure 6 as an example. The maximum percentage deviation between the numerical and experimental results is about 8%.

The deviation between the numerical and experimental results is reasonable considering the unavoidable errors in numerical solution and measuring instruments beside the approximations in estimating the boundary conditions.

V. Conclusion

From the comparison between the numerical and experimental results it can be concluded that the mathematical model presented for solving the problem of heat transfer in the soil below cold stores is acceptable.

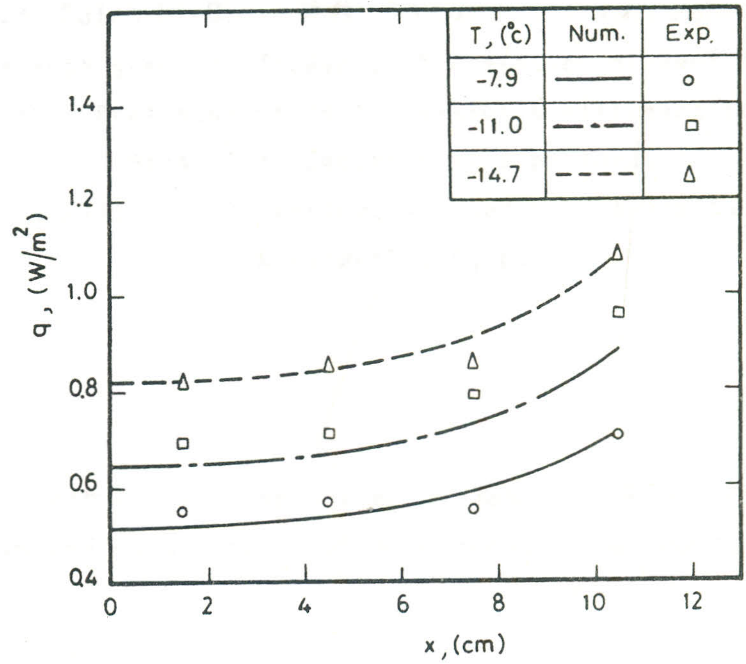

Fig. 6 - Heat flux distribution (t = 18 h.) .

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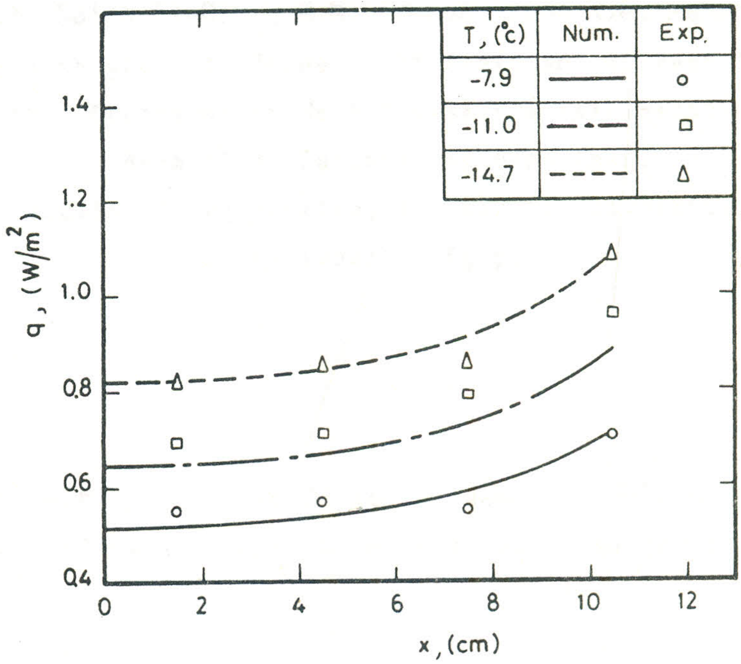

Fig. 6 - Heat flux distribution (t = 18 h.) .

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