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MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

1 THERMAL PROPERTIES OF CO_2 SILICATE MOLDS/CORES

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4 ABSTRACT Thermal properties of foundry sand determine to a great extent the rate of heat extraction from castings and thus influence their quality. Thermal properties of interest of CO_2 silicate molds are thermal conductivity, specific heat, heat accumulation factor and thermal diffusivity. The effect of variation of % of sodium silicate, gassing time and ramming strokes on aforementioned thermal properties of foundry sand have been reported.

To know the independent, interactive and higher order effects of process parameters on the yield, experiments were planned according to central composite rotatable design with half replicate. The adequacy of the model was tested using analysis of variance and accuracy by experimental data.

Finally, it has been concluded that such studies would be helpful to control the properties of molds/cores and thereby the quality of castings.

NOMENCLATURE

b_m	Heat accumulation factor
b_o, b_i, b_{ii}, b_{ij}	Constants of equation (5)
C	Specific heat
I	Current
J	Joule's constant
K	Thermal conductivity
L	Length
m	Weight of specimen
r_1 , r_2	Radii
Y_u	Response for u^{th} test
V	Voltage
X_{iu}	Level of i^{th} factor in u^{th} test

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T_1 , T_2	Temperatures corresponding to radii r_1 and r_2 respectively
ρ	Density of sand system
α	Thermal diffusivity
m_1	Weight of calorimeter

1.0 INTRODUCTION

Sand is the principal molding material. The selection of a proper type of sand is one of the major decisions responsible for controlling the qualities of castings. The knowledge of various properties of sand viz; mechanical, chemical, thermal etc., serves as guidelines for the proper selection of sand for a given application. Thermal properties[1,2] of sand play an important role as they govern the rate of heat transfer, nucleation and grain growth during solidification of castings. Thermal properties of sand of interest for a foundry engineer are thermal conductivity (K), specific heat (C), heat accumulation factor (b_m) and thermal diffusivity (α).

Conventional type of probe yields non-uniform hardness of the mold which may lead to the hazardous accidents in case of non-mechanised foundries. With this in view, miniprobe gassing technique has been developed[3]. It is conventional type of the probe open at the bottom but having external diameter under 1.0 mm. Miniprobe is found to be more versatile and allows to gas sodium silicate sand mass at any location, upto any desired depth and in any appropriate direction.

Experiments were planned in accordance with the 'design of experiments' using central composite rotatable design with half replicate. Using the experimental results, mathematical models have been evolved by applying response surface methodology[4]. The adequacy of the models has been tested by analysis of variance, using a computer program[5] CADEA-1, and their accuracy by experimental data.

2.0 THEORY

Thermal conductivity 'K' and specific heat 'C' of foundry sand has been evaluated using equations (1) and (2) respectively.

$$K = \frac{VI \ln (r_2/r_1)}{J.2\pi L(T_1-T_2)} \quad (1)$$

$$C = \frac{\frac{VIt}{J} - m_1 c_1 (T_1-T_2)}{m (T_1-T_2)} \quad (2)$$

Both progressive and directional solidification of castings depend upon the heat transferability of the mold materials. It is to be noted that higher the value of heat accumulation factor (b_m) of the mold, more will be the solidification time.

'b_m' can be calculated as follows:-

$$b_m = \sqrt{K \rho C} \quad (3)$$

In foundry engineering, the temperature distribution during unsteady state is influenced by thermal conductivity as well as storage capacity of the substance. The value of thermal diffusivity (α) can be computed from equation (4).

$$\alpha = K/\rho C \quad (4)$$

3.0 EXPERIMENTATION

To obtain an idea of independent, interactive and higher order effects, second order designs are preferred [4,6]. We have used central composite rotatable design with half replicate. The estimated response, Y_u , at a point on the fitted second order surface is given by equation (5).

$$Y_u = b_o + \sum_{i=1}^{f} b_i x_{iu} + \sum_{i=1}^{f} b_{ii} x_{iu}^2 + \sum_{i<j} b_{ij} x_{iu} x_{ju} \quad \ldots \quad (5)$$

The conditions under which experiments were conducted are given in Table-1.

Blind holes to insert four miniprobes were drilled axially. Fifth miniprobe was inserted in the central hole in the specimen. Figs. 1 and 2 illustrate experimental setups used to determine thermal conductivity (K) and specific heat (C) respectively. In order to supply the same heat input to all specimen, voltage and current were kept constant. In case of thermal conductivity determination, the potentiometer reading was noted down only when steady state was reached. Then 'K' was calculated using eqn. (1). But in case of determination of specific heat, potentiometer readings were noted down upto 70 to 80 minutes at an interval of ten minutes. The curves were plotted between time and temperature to calculate specific heat. It is to be noted that conversion tables were used to find temperature corresponding to a certain potentiometer reading.

4.0 RESULTS AND DISCUSSION

Mathematical models have been formulated using the experimental results. Using these models, effects of different process parameters, on the above mentioned thermal properties, have been evaluated and are discussed below.

4.1 THERMAL CONDUCTIVITY (K)

Relationship between thermal conductivity and % of sodium silicate exhibits a maxima (fig. 3). With the increase in % of sodium silicate, the amount of sodium carbonate and Silica gel produced increases hence an increase in the value of K. It is

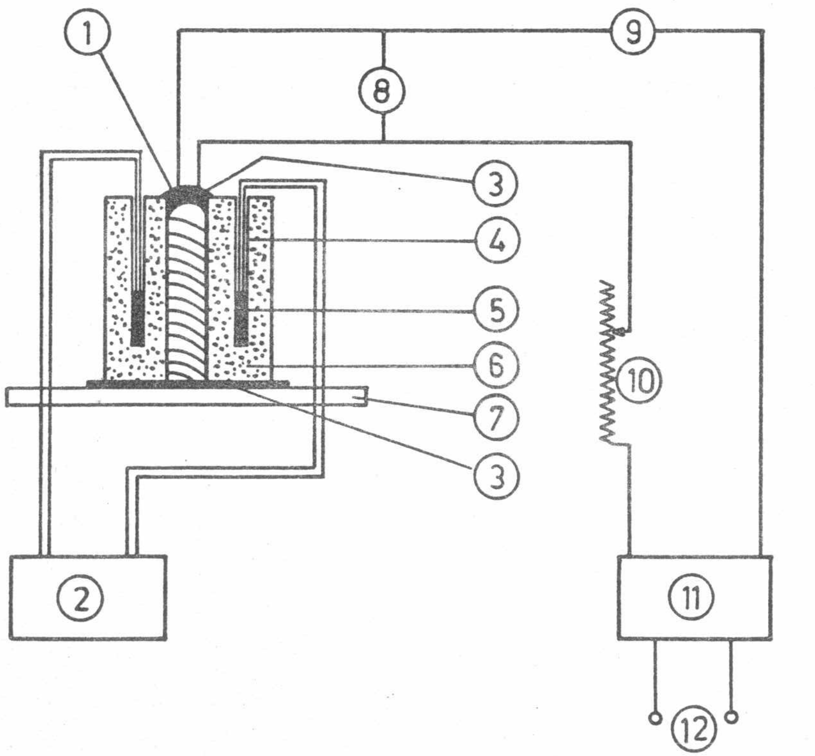

Fig.1 Schematic layout of thermal conductivity apparatus.
1. Heating coil, 2. Potentiometer, 3. Glass wool, 4. Thermocouple, 5.Mercury, 6. Specimen, 7.Asbestos sheet 8. Voltmeter, 9. Ammeter, 10. Rheostat, 11. Voltage regulator and 12.Power supply.

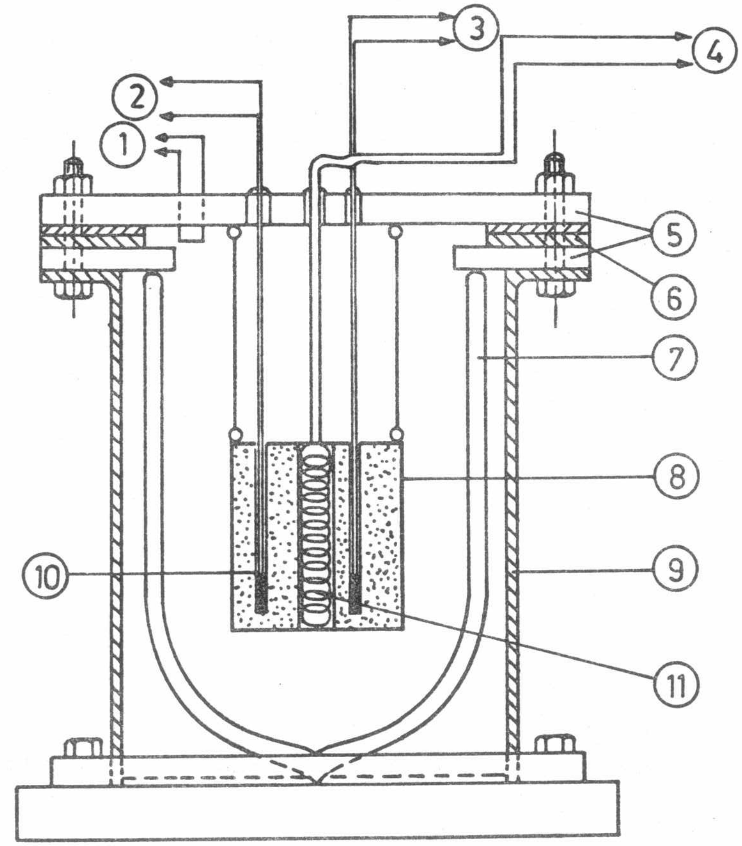

Fig. 2 Schematic diagram of specific heat apparatus.
1. To vacuum pump, 2,3. To potentiometer, 4. To main supply, 5. Acrylic sheet, 6. Washer, 7. Dewar flask, 8. Calorimeter and 9. Outer casing. 10.Mercury, 11. Heating coil

so because the value of K for sodium carbonate and silica gel is more than that of sand. Further, increase in the value of X_1 results an increase in the amount of unreacted sodium silicate whose thermal conductivity is lower than that of silica gel and sodium carbonate. It explains the other half part of the curve.

As shown in fig. 4, thermal conductivity is found to attain a maximum value with the increase in gassing time. As in earlier case, the increase in thermal conductivity is obviously due to the formation of more amount of sodium carbonate and silica gel.

Except a slight drop in 'K' at low values of X3, it exhibits an ascending trend, fig. 5. 'K' increases with increased ramming because the compactness of the sand system increases which encourages true conduction as the grains move nearer to each other.

4.2 SPECIFIC HEAT (C)

In the beginning, Na_2CO_3 formation is increasing and the amount of unreacted sodium silicate is quite small hence there is a small increase in specific heat, Fig. 6. But beyond a certain % of sodium silicate where the formation of Na_2CO_3 is almost stabilized and the unreacted sodium silicate is increasing, there is a drop in the value of 'C' because specific heat of sodium silicate is lower than that of Na_2CO_3 as well as silica gel.

Increase in gassing time, initially decreases the specific heat. But onwards, it increases (fig. 7). Upto a certain amount of CO_2 - gas, it reacts fully with sodium silicate. Beyond this, the excess CO_2 gas remains entrapped within the mold. Since the CO_2 gas fills up the pores in the mold, it results in the increased specific heat of the entire mold.

With the increase in number of ramming strokes, the amount of entrapped air/CO_2 gas goes on reducing. Since the specific heat of air/CO_2 gas is more than that of sand, the net effect of increase in X3 is to decrease 'C', Fig. 8.

Using the above results about thermal conductivity and specific heat, heat accumulation factor and thermal diffusivity were computed as given in figures 9-14. These results have not been discussed because they have been derived from the above discussed results.

5.0 CONCLUSIONS

From the above results and discussion, following conclusions have been drawn.

Thermal conductivity: Thermal conductivity of CO_2 - silicate increases upto a certain value of % of sodium silicate. Beyond this, it starts decreasing. The similar trend is exhibited by the increase in gassing time. However, an increase in no. of ramming strokes increases thermal conductivity, except for an initial drop.

Specific heat: Specific heat shows downward trend with the increase in % of sodium silicate as well as no. of ramming strokes. But with the increase in gassing time, it attains a minima.

Heat accumulation factor and thermal diffusivity: It is observed that b_m and α are also governed by % of sodium silicate, CO_2 gassing time and number of ramming strokes. It is evident that such studies would be helpful to control the properties of molds/cores and thereby the quality of castings.

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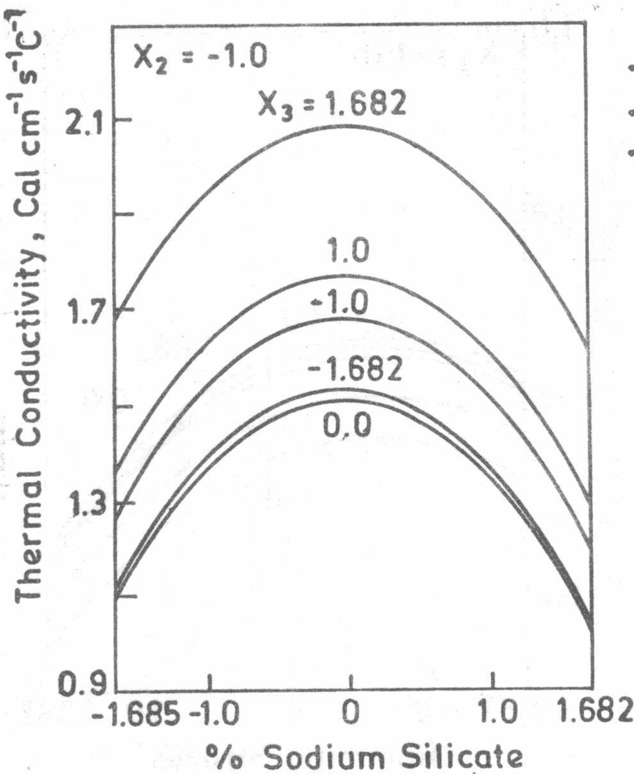

Fig.3 Relationship between % of sodium silicate and thermal conductivity of CO_2-silicate molds.

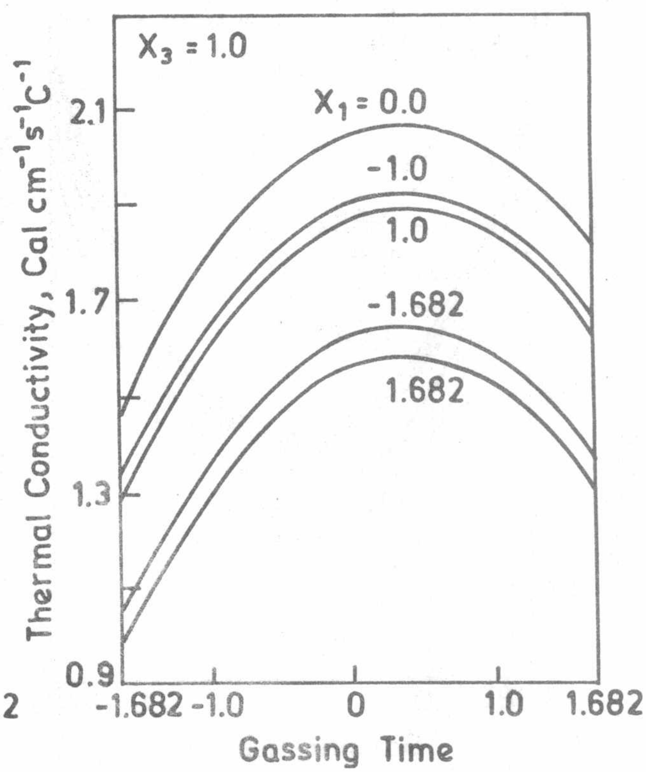

Fig.4 Relationship between CO_2-gassing time and thermal conductivity of CO_2-silicate molds.

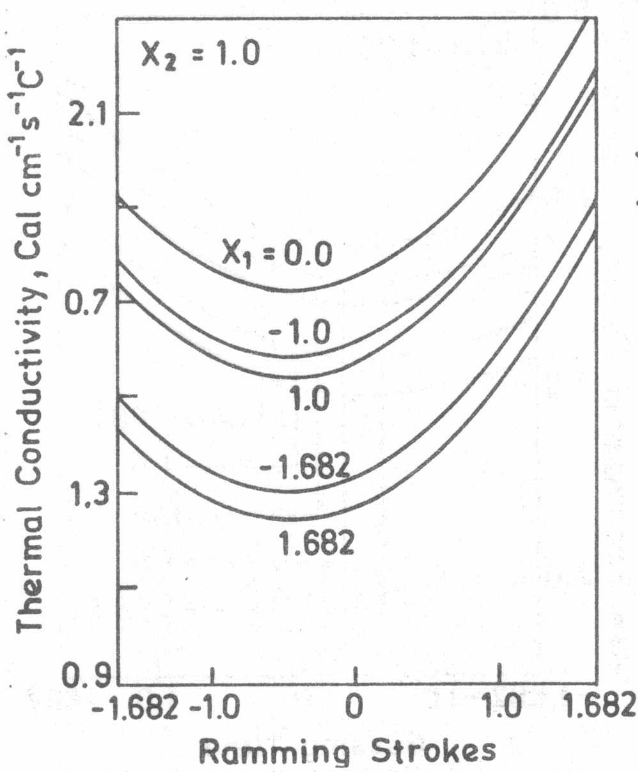

Fig.5 Relationship between No. of ramming strokes and thermal conductivity of CO_2-silicate molds.

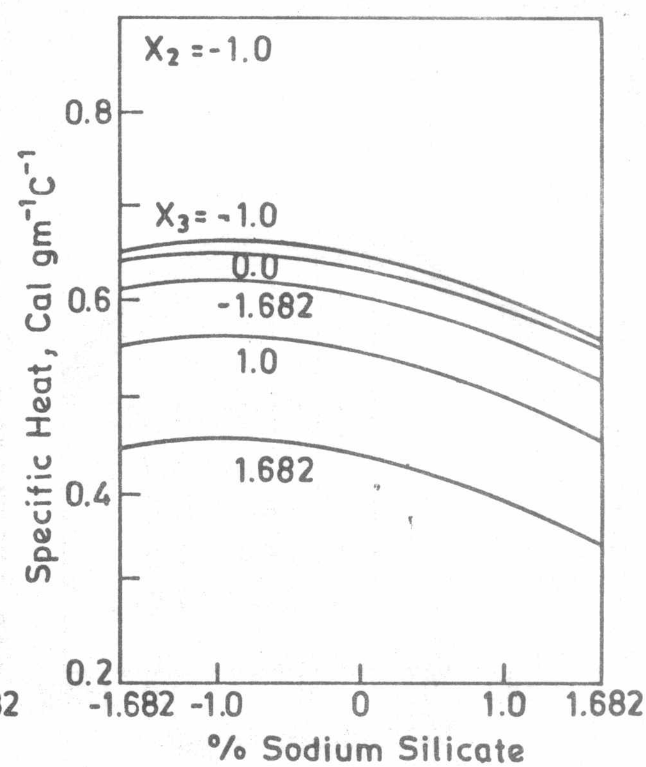

Fig. 6 Effect of % of sodium silicate on specific heat of CO_2-silicate molds

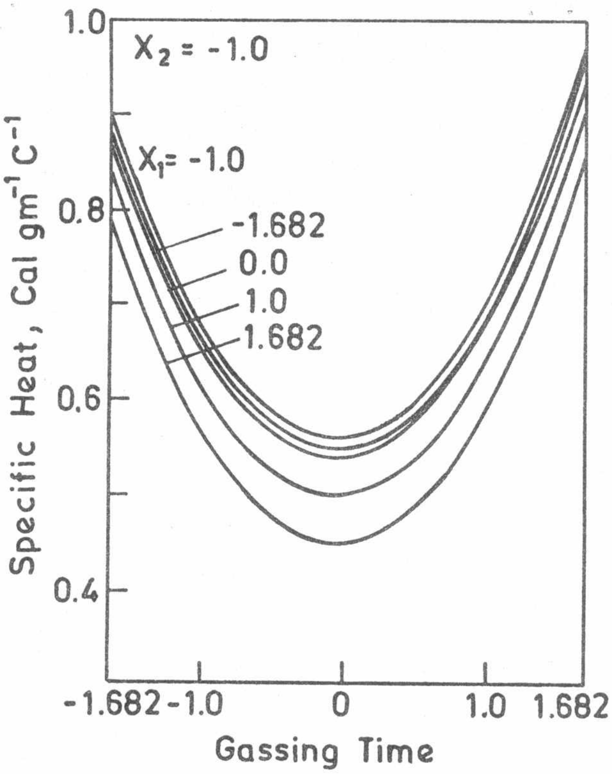

Fig.7 Effect of CO_2-gassing time on specific heat of CO_2-silicate molds.

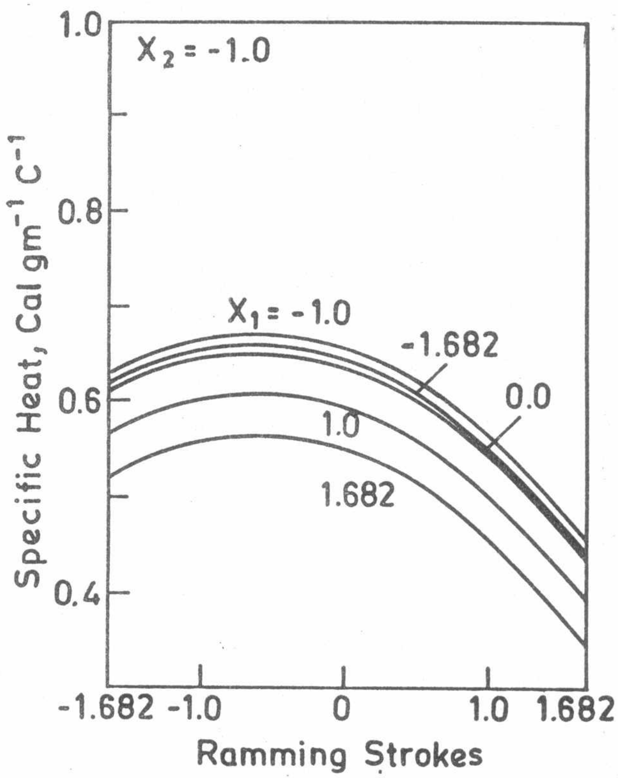

Fig.8 Effect of no. of ramming strokes on specific heat of CO_2-silicate molds.

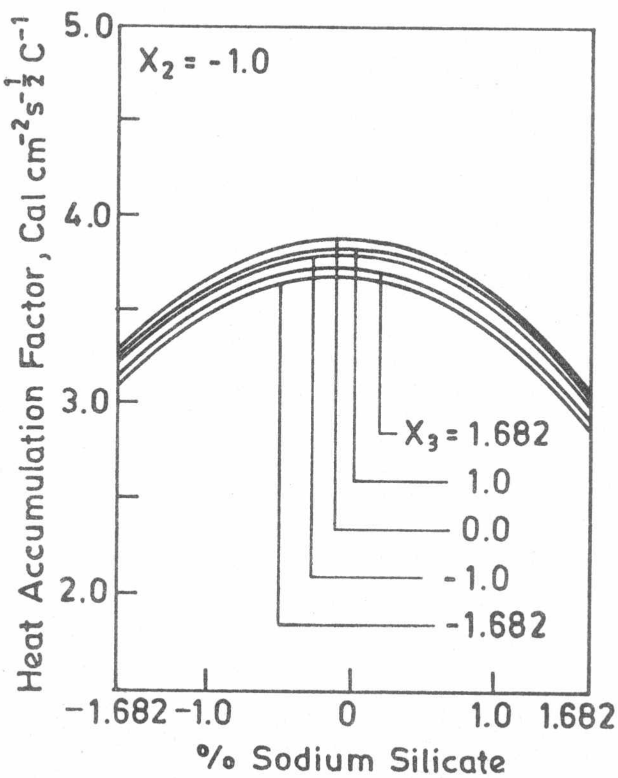

Fig.9 Variation of heat accumulation factor with % of sodium silicate

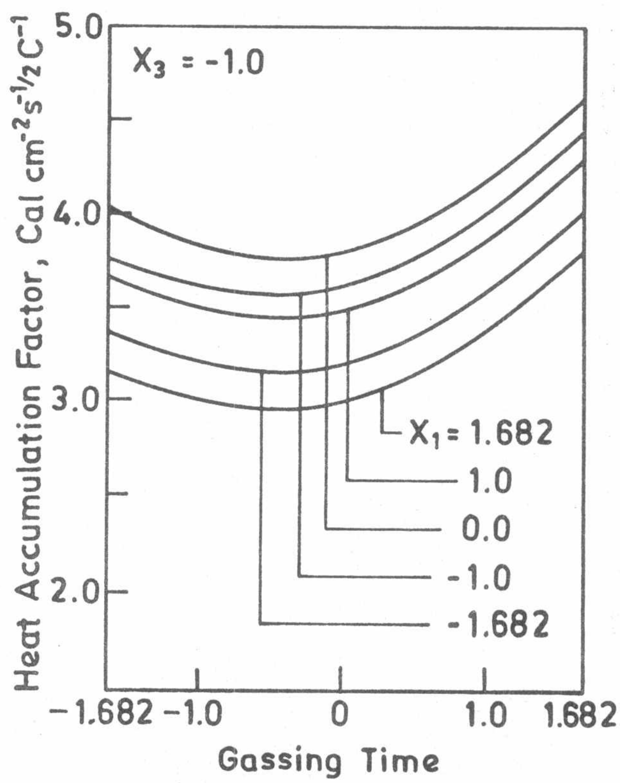

Fig.10 Variation of heat accumulation factor with CO_2-gassing time.

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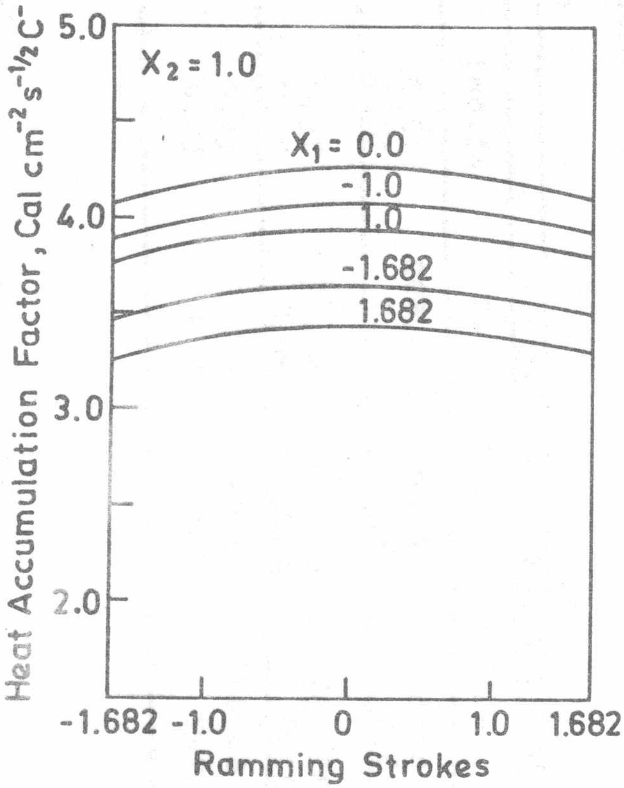

Fig.11 Variation of heat accumulation factor with no. of ramming strokes

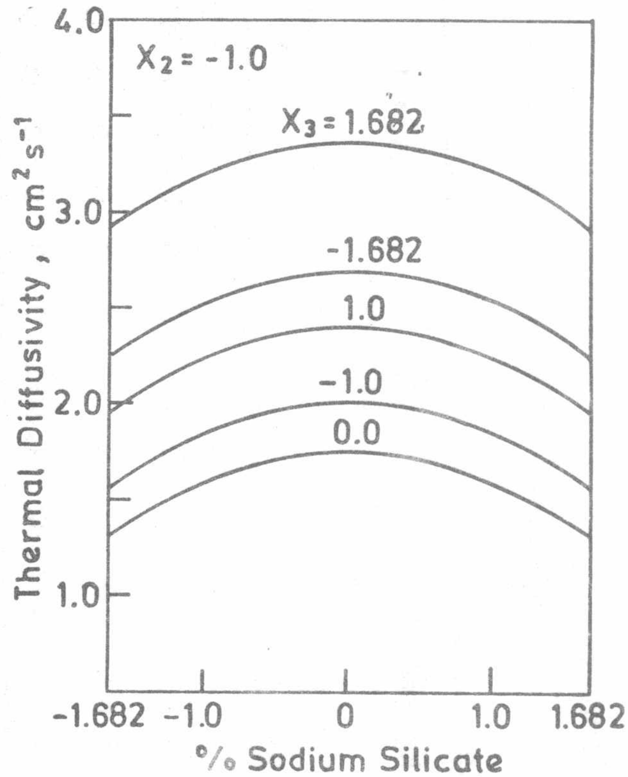

Fig.12 Relationship between % of sodium silicate and thermal diffusivity.

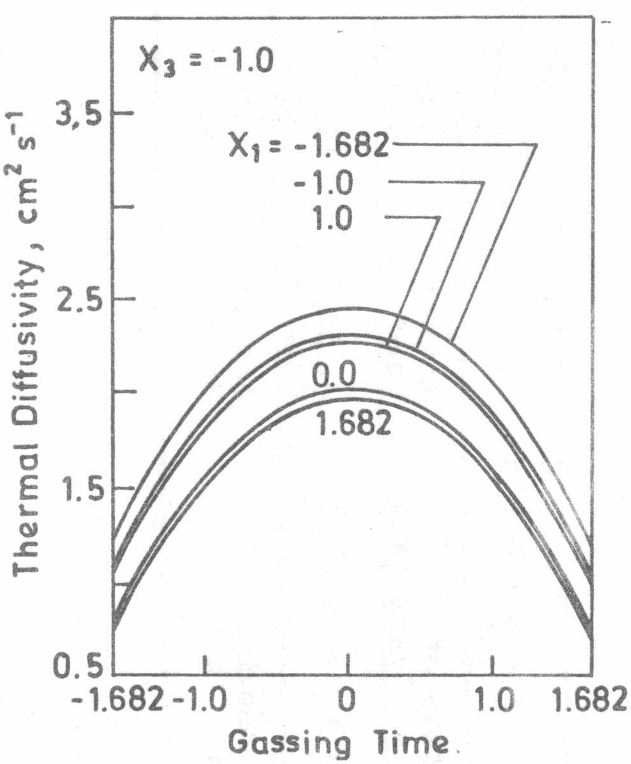

Fig.13 Relationship between CO_2-gassing time and thermal diffusivity.

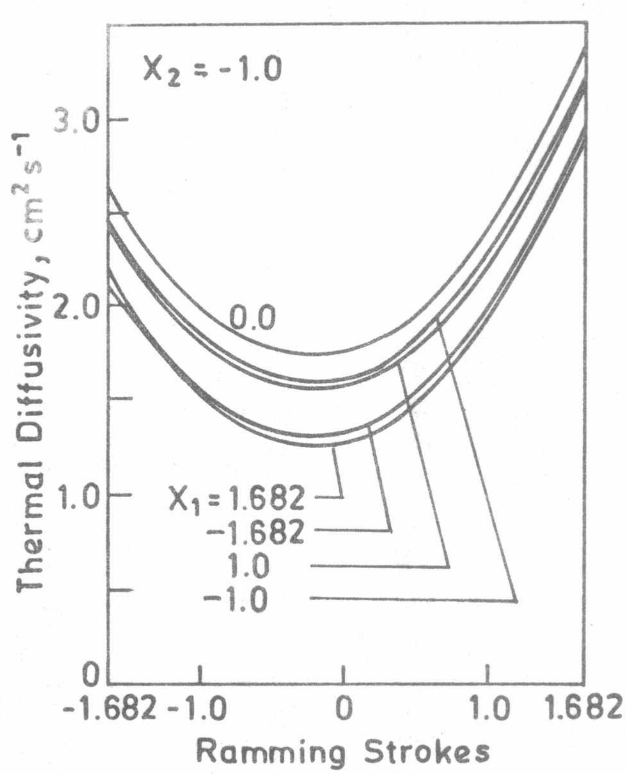

Fig.14 Relationship between no. of ramming strokes and thermal diffusivity.

TABLE-1

Ganges Sand from Allahabad (India)

Grain size	Weight of sand / specimen	Miniprobe Length	Miniprobe Hole diameter	Gas pressure	Gas flow rate	Temperature	Moisture
60-72 (0.251 to 0.211 mm)	200 g	30 mm	0.84 mm	1.4 kg cm^{-2}	5 litre min^{-1}	Room temperature	5.1 %

Plan of experiments

Test No. →	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
x_1	-1	1	-1	1	-1	1	-1	1	-1.682	1.682	0	0	0	0	0	0	0	0	0	0
x_2	-1	-1	1	1	-1	-1	1	1	0	0	-1.682	1.682	0	0	0	0	0	0	0	0
x_3	-1	-1	-1	-1	1	1	1	1	0	0	0	0	-1.682	1.682	0	0	0	0	0	0

Values of levels

F A C T O R S		L E V E L S -1.682	-1	0	+1	+1.682
Percentage of sodium silicate (X_1)	Actual	5.0	5.757	7.071	8.692	10.0
	Used	5.0	5.7	7.0	8.7	10.0
Gassing time, s (X_2)	Actual	25.0	31.237	43.301	60.02	75.0
	Used	25.0	31.0	43.0	60.0	75.0
No. of ramming strokes (X_3)	Actual	5.0	6.247	8.661	12.0	15.0
	Used	5.0	6.0	9.0	12.0	15.0