AN INVESTIGATION OF THE EFFECT OF VARIATION OF MOISTURE AND DENSITY UPON THERMAL CONDUCTIVITY AND SOME PHYSICAL CHARACTERS OF LOW DENSITY CONCRETE

Thesis for the Degree of M. S.

MICHIGAN STATE COLLEGE

Mohsinul Huq

1955

THESIS

This is to certify that the

thesis entitled

An Investigation of the Effect of Variation of Moisture and Density Upon Thermal Conductivity and Some Physical Characters of Low Density Concrete

presented by

Mohsinul Huq

has been accepted towards fulfillment of the requirements for

M.S. degree in M.E.

James T. Anderson
Major professor

Date March 8, 1955

O-169

AN INVESTIGATION OF THE EFFECT OF VARIATION OF MOISTURE AND DENSITY UPON THERMAL CONDUCTIVITY AND SOME PHYSICAL CHARACTERS OF LOW DENSITY CONCRETE

BY

MOHSINUL HUQ

A THESIS

Submitted to the School of Graduate Studies of Michigan
State College of Agriculture and Applied Science
in partial fulfillment of the requirements
for the degree of

MASTER OF SCIENCE

Department of Mechanical Engineering

1955

ACKNOWLEDGEMENTS

The author wishes to express sincere thanks and gratefulness to Dr. James T. Anderson without whose sincere and able guidance, advice, and keen interest, assistance and co-operation this work would not be possible.

The author also acknowledges the help and cooperation of Professor Donald R. Renwick in making the Refrigeration Laboratory facilities available.

The author expresses his thanks to Mr. Jack Tadman of Bacteriology and Dr. Snell of Civil Engineering for facilitating the use of their respective laboratories and equipment.

Lastly, the author wishes to thank Mr. C. M. Redman and Mr. D. W. Sebel of the Power Laboratory, Mechanical and Highway Department staff as a whole for their assistance toward the successful completion of the investigation.

ABSTRACT

This investigation deals with the determination of the effect of moisture upon thermal conductivity and some physical properties of low density concrete. In practical application, thermal insulation contains moisture. Thus the practice of using K values based upon dry conditions for design purposes is inadequate. Past investigators have been limited within a low range of moisture percentages in their investigation. In this investigation it has been attempted to establish upper limits as far as moisture concentration is concerned so that knowing at least the upper and lower limits of thermal conductivity, a more rational approach to design situations may be made.

The thermal conductivity was found from the established principle of sinusoidal variation of temperature on the surface of an infinitely thick block. The specific heat, flexural strength and compressive strength were found by conventional methods.

It was found that both flexural and compressive strengths increased with moisture content. It was also found that specimens of lower density absorbed more moisture.

The investigation was made with blocks of different densities and moisture content and it was found that the maximum gain in K was 1400 percent when the concrete block of dry density 25.5 lb/cft. absorbed 146 percent moisture by weight.

From this data obtained in this investigation an empirical formula was formulated as follows:

$$K = K_d \left(1 + .034\, M \frac{P_w}{P}\right)$$

where

K = Thermal conductivity at moisture content M and dry density P

K_d = Thermal conductivity of dry material

M = Moisture content percent by weight at that condition

P_w = Density of water lbs/cft.

P = Dry Density of material lbs/cft.

This formula applies to all the specimens in the present investigation. Attempts to fit the existing data of other investigators to the formula was successful for fibreglass, but not for corkboard.

TABLE OF CONTENTS

LIST OF FIGURES AND CURVES

INTRODUCTION

In recent years there has been a continuous increase in the construction of basementless houses in the United States. The main reason for this is economy and scarcity of materials. In these types of houses the most commonly used floors are concrete slab floors. These floors are sometimes constructed with heating pipes laid inside the slab and also at the edges of the rooms while some are equipped with space heaters or sometimes unheated altogether. In any case, there must be some heat loss through the slab to the ground and to the perimeter which is at a much lower temperature. In addition, there is also the question of condensation as well as lack of comfort due to the excessive perimeter loss.

As concrete is a good conductor of heat there is also heat loss to the earth. So to keep the room at a comfortable temperature condition either more heat input is necessary to make up the loss or some heat resisting insulating material must be placed between the floor and the earth.

It is also found that the main portion of the heat loss through the slab occurred at the edge rather than the undersurface. Therefore to cut down the heat loss, the undersurface should be insulated by a suitable sand and gravel fill and particular care should be given to the edge or perimeter insulation. The minimum thickness of this insulation should be two inches. It is also found that perimeter insulation can reduce the temperature gradient from the center of the slab to the edge by nearly about 30 percent[1].

While this method outlines the minimum requirements some precautions should be taken to insure satisfactory results. For example, 4 inches of gravel or coarse sand should underlie the slab, and also there should be a protective layer against moisture to avoid ground water seeping through. Because it is known that the thermal conductivity of materials particularly insulating materials varies with the absorption of moisture, it was decided to investigate the extent of this variation. Thus this investigation deals with the evaluation of moisture content for Zonolite Concrete blocks of varying dry densities. Also the method of placing the insulation should be given attention. Some of the practical applications are shown in Figure A-1.

The next question is what material should be used as the perimeter insulation. There is no standard product for it. But there are some factors which determine the type of insulation. Briefly, it should have low thermal conductivity, it should absorb less moisture, because, as previously stated, moisture in general increases thermal conductivity and secondly, excessive moisture can result in an uncomfortably damp floor. In addition, the material should have a high compressive and crushing strength - preferably above

---

1 Bareither H. D. and Landrum J. T., Concrete Floors and Basementless Houses, Small Homes Council, Univ. of Illinois, Urbana, F.43, 1948.

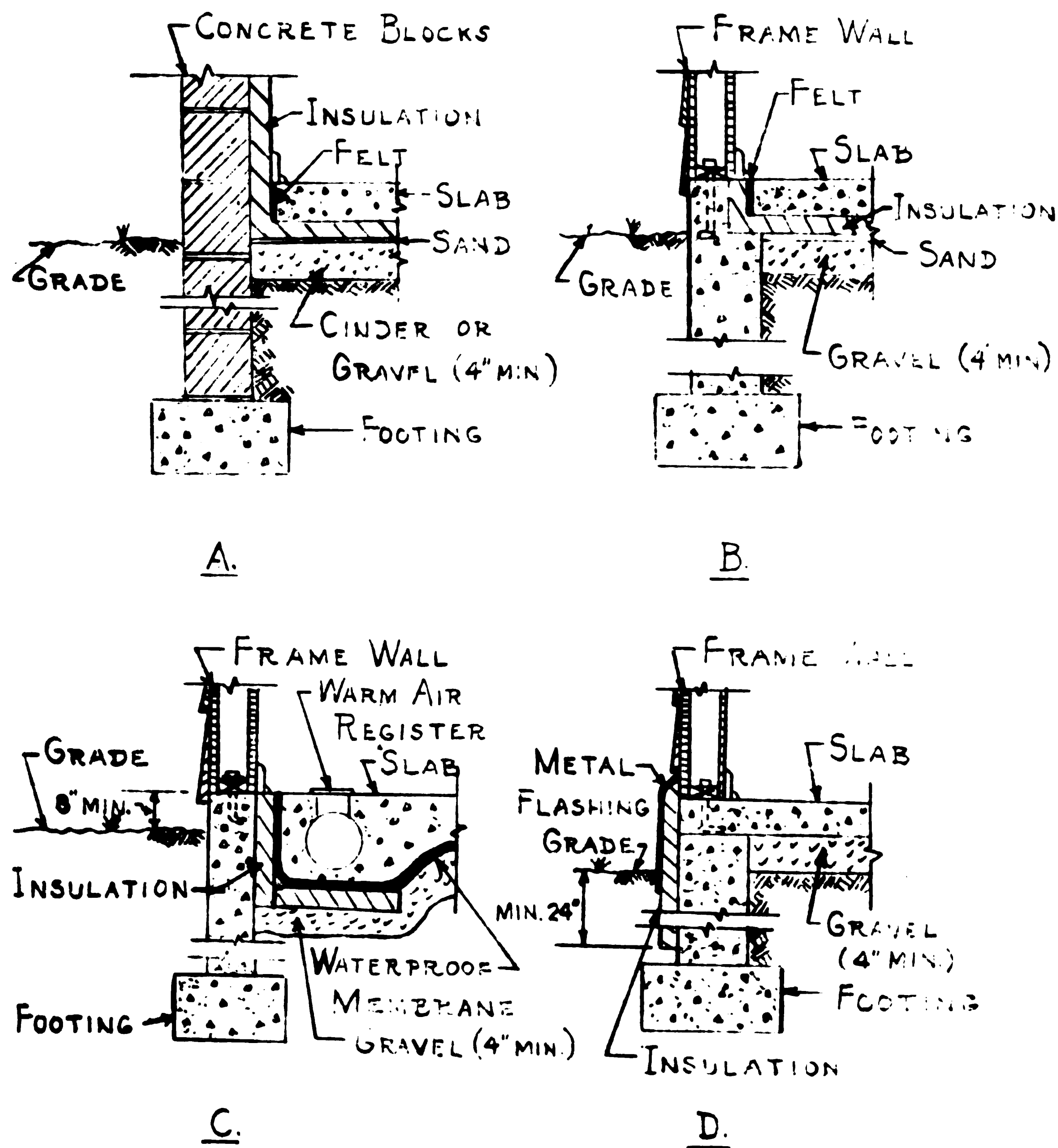


FIG A-1. VARIOUS APPLICATIONS OF PERIMETER INSULATION.

FIGURE A-1

500 lbs/sq.ft. and finally it should remain unaffected by soil chemicals and should resist the growth of vermin and fungi.

The effect of soil chemicals and the growth of vermin and fungi is beyond the scope of this investigation. Tests with various materials have been made by other investigators which will be discussed later. In the present investigation expanded Vermiculite or Zonolite cement concrete blocks were made with different mixture proportions and these specimen were experimentally checked for the effect of moisture on structural and heat transfer properties.

In actual practice, insulations are going to have a variable percentage of moisture due to operating conditions and due to migration within the insulation itself. This presents an exceedingly difficult situation to analyze. However, the present practice of using only dry K values does not seem to be adequate. It has been attempted here to establish the upper limits as far as moisture concentration is concerned. Thus knowing at least the upper and lower limits of thermal conductivity, a more rational approach to a design situation may be made.

The test procedure is described in detail in the later chapters and the results of these tests for different properties are shown in tables and graphs.

It should be noted that in the description, discussion, tabulation and graphs the specimens are marked as follows:

SPECIMEN NO.	DRY DENSITY LBS/C FT.	APPROXIMATE MIXTURE RATIO ZONOLITE: CEMENT
1	44.5	3 : 1
2	34.7	4 : 1
3	33.2	5 : 1
4	28.9	6 : 1
5	25.5	7 : 1

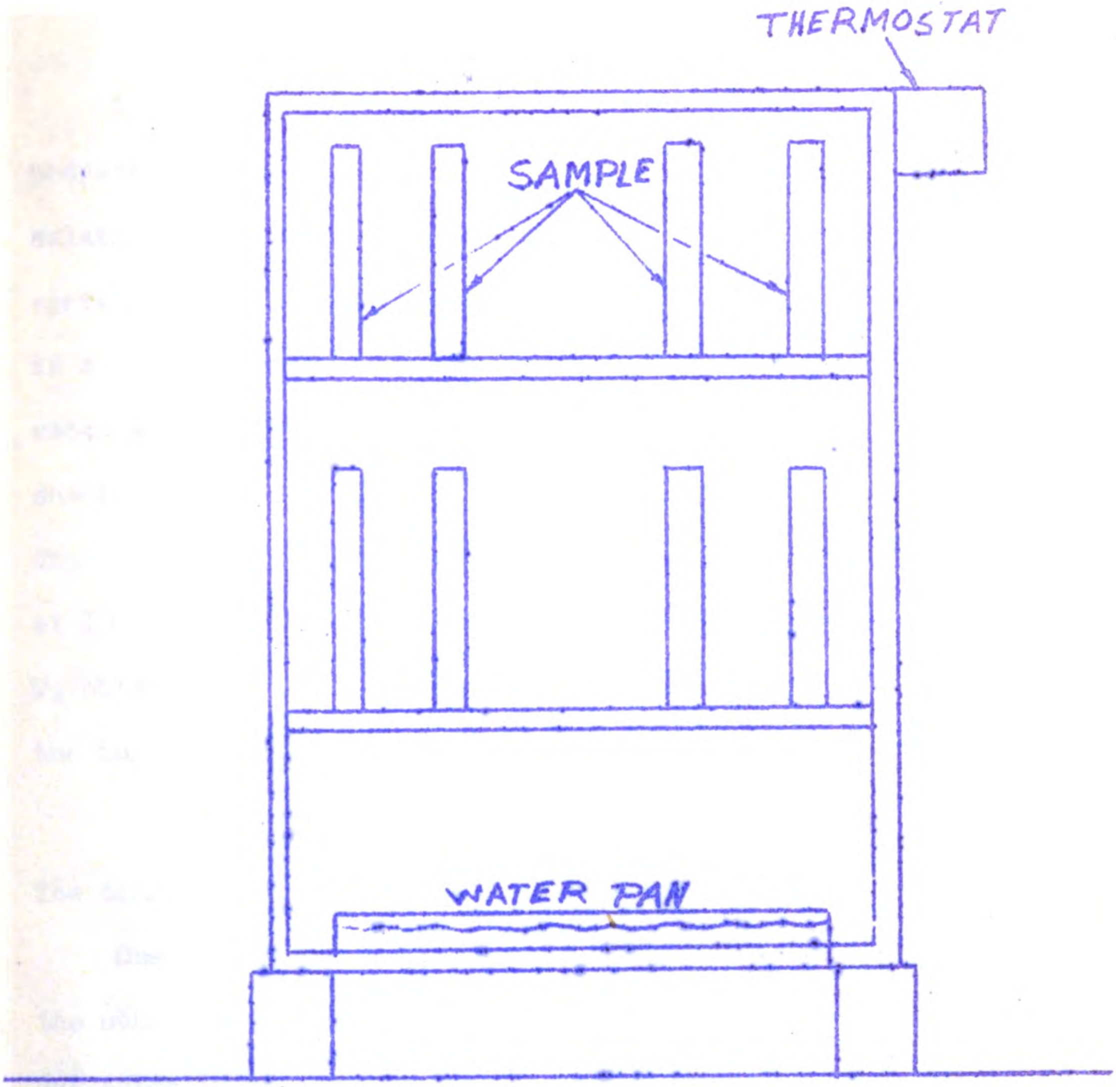


FIG A-5 DRYING AND HUMID CHAMBER

APPARATUS AND METHODOLOGY

MOISTURE ABSORPTION

Zonolite concrete samples 12" x 12" x 2" of different mixture proportions were cast. Zonolite is a grannular light weight insulating material made of expanded mica. Two lots of samples, each containing one sample of every proportion were taken and were heated in a dryer as shown in Figure A-5. The weight of each block was noted after certain interval of time. After a few hours the blocks showed a constant weight, W_1 which was taken as the weight at bone dry condition. The temperature of the dryer was kept approximately at 150°F. From the known volume ,V, of the blocks and the weight, W_1 obtained at the bone dry state the density of each sample at the bone dry state was found.

$$\text{Density} = \frac{W_1}{V} \quad \text{lbs/cft.}$$

The density calculation and results are shown in the appendix.

One lot of dry samples was then immersed in a water bath while the other was placed inside the humid chamber. The humid chamber was actually the dryer with the addition of an evaporating pan filled with water. The weight of each block was noted every 24 hours. The weights showed an increase with time. After a few days the weights finally remained constant. This constant weight W_2 was taken as the saturated weight.

Moisture absorbed and respective densities are tabulated as shown in the appendix, pages 57-65.

Moisture absorbed = $W_2 - W_1$

Two sets of curves as shown in Figure 2 and Figure 3 were plotted as moisture against time - one for the humid chamber and the other for the water bath.

STRUCTURAL PROPERTIES

Two lots of samples were cast for each compressive and flexural test. The cylindrical blocks for the compression test were 2 inches in diameter and 6 inches long while the rectangular blocks for the flexural test were 8" x 2"x2". To cure the blocks, a 28 day immersion in water was used before testing. Though in case of actual use the curing period would have been much longer, for practical purposes a 28 day period was deemed to be fairly good.

One lot was dried in the dryer to bone dry condition while the other lot was saturated with moisture in the humid chamber as described previously.

The faces of the blocks for the compression test were made accurately parallel by the addition of plaster so that the actual load acted through the axis and not in an inclined plane.

For the flexural test the blocks were placed on two supports 6 inches apart and the load was applied at the center as shown in Figure A-4. The deflection at the point of failure was noted and from the calibration curve as shown in Figure 8 in the appendix for the particular load ring the load at this particular deflection was noted. Knowing the dimension of the block, moment of inertia,

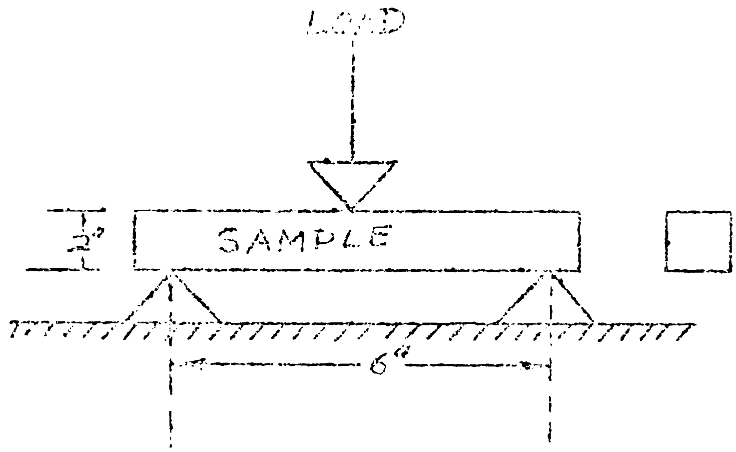


FIG A-4 FLEXURE TEST

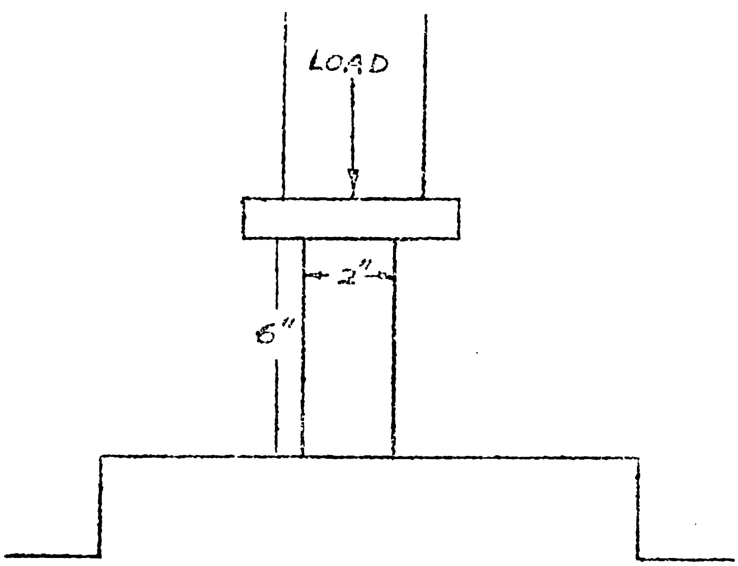


FIG A-4' COMPRESSION TEST

'I', distance of the extreme fibre from the neutral axis 'e', and the distance between the two supports 'L', the modulus of rupture was calculated as shown in the appendix, pages 41, 66 and 67.

$$\text{Modulus of Rupture} = \frac{\text{Load x exl}}{4 \ \text{I}} \quad \text{Lbs/sq.in.}$$

The compression test was carried out in a standard compression machine. In this case the load at failure was obtained directly from the machine. Knowing the area of the cylindrical blocks the compressive stress is merely $= \frac{\text{Load}}{\text{Area}}$.

The data and calculations are shown in the appendix, pages 41, 66 and 67.

SPECIFIC HEAT

For the determination of specific heat molds were made whose inside dimensions were 1" x 1" x 1". The walls were screwed together so that they could be opened easily. When the specimen became hard and stable it was hung in a small dryer. The volume and densities of the blocks were known from the previous experiments. So the weight of the blocks were also known. The blocks were dried in the heater for a few days and their weights, W_1, checked fairly close to the calculated weights. A laboratory calorimeter with a stirrer was taken. It's weight, W_2, was noted. Then water weighing, W_3, was taken in the calorimeter. The temperature, T_1, of the water and the temperature, T_2, of the inside of the heater was noted. Then the block was quickly dropped into the water. The water was kept well stirred and care was taken so that no water splashed at the time of dropping the block. The temperature, T_3, of the mixture was noted.

Heat gained by water and calorimeter = Heat lost by the block

or $W_3 \, Cp_3 \, (T_3 - T_1) + W_2 \, Cp_2 \, (T_3 - T_1) = W_1 \, Cp_1 \, (T_2 - T_3)$

where Cp_1 = specific heat of the dry block

Cp_2 = specific heat of the calorimeter

Cp_3 = specific heat of water.

As Cp_1 being the only unknown, it was calculated as shown in the appendix.

The specific heat of moisture laden blocks were found analytically as follows:

Let specific heat of the dry sample = Cp_1

specific heat of water = Cp

Wt. of dry sample = W_1

Wt. of water absorbed = W_2

specific heat of composite = C

Then $C\,(W_1 + W_2) = Cp_1 \times W_1 + Cp \; W_2$

$$\text{Therefore } C = \frac{Cp_1 \times W_1 + Cp \cdot W_2}{(W_1 + W_2)}$$

The calculations and the results are shown in detail in the appendix, pages 39, 40 and 70.

HEAT TRANSFER PROPERTIES

As the heat transfer properties of both dry and moisture laden samples had to be determined a practical difficulty arose due to the fact that input of heat has a considerable effect on the thermal migration of moisture. In addition, the possibility of sufficient evaporation to affect the apparent thermal properties of moisture laden blocks should be avoided. To avoid evaporation in the case of saturation samples and absorption in the case of bone dry blocks the specimen were always wrapped with aluminum foil. The migration of moisture from the hotter to the colder areas could be prevented by reversing the thermal gradient. In addition, any apparatus made for the reversal of heat flow should be such that the temperature variation would be sinusoidal to conform to the known solutions for transient heat flow. It was also decided to utilize the infinite solid approach with a cycle period of one hour instead of 12 hours used by Treichler[2]. The temperature of one face was varied by a method described later.

[3] Fourier's general equation for periodic function is:

$$f(t) = a_o + a_1 \text{ Cos } Wt + a_2 \text{ Cos } W\,2t + \cdots\cdots$$
$$\cdots\cdots + b_1 \text{ Sin } Wt + b_2 \text{ Sin } W\,2t + $$

where a_o, a_1, a_2 ...... b_1, b_2 .....are constant and W is frequency.

Temperature θ being a function of time and depth x according to Fourier's equation for conduction through infinitely thick slabs and sinusoidal temperature variation on the surface with flow in the x direction only, we have:

$$\theta_s = \theta_o + \theta_1 \text{ Sin } Wt \quad \text{When } x = 0$$

Where θ_1 = Maximum temperature variation at surface
θ_o = Mean Temperature
θ_s = Surface temperature
θ = Temperature variation from mean

After solution we have:

$$(1) \quad \theta_{amp} = \theta_1 e^{-x\sqrt{\frac{\pi n}{\alpha}}}$$

---

2 Treichler, W. W. Jr., Investigation of the Heat Transmission and Mechanical Properties of Several Types of Perimeter Insulation Under Dry and Saturated Conditions.

3 Ingersol. L. R, & zobel. O.J, Mathematical theory of heat. Boston, 1913

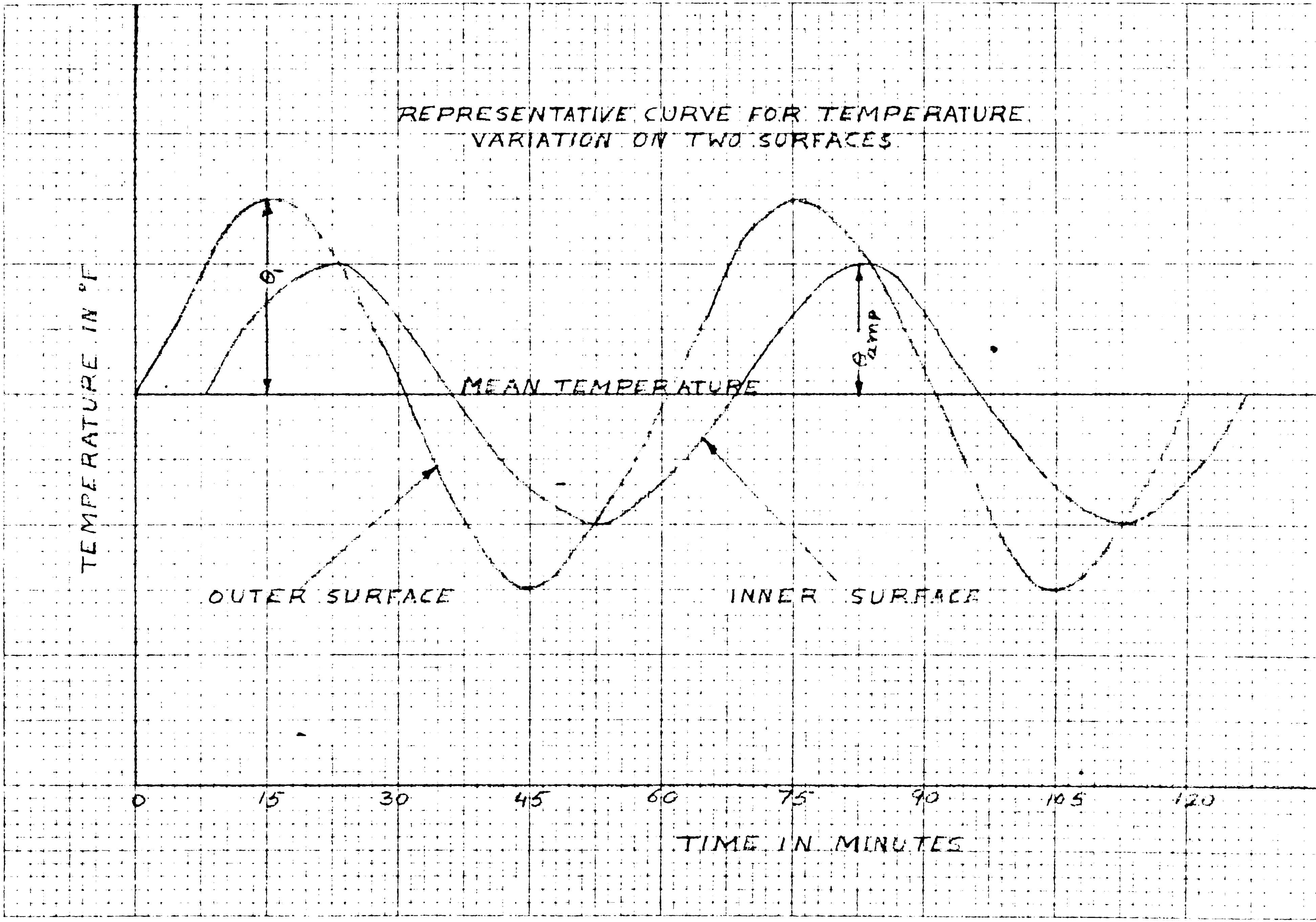

REPRESENTATIVE CURVE FOR TEMPERATURE
VARIATION ON TWO SURFACES
TEMPERATURE IN °F
MEAN TEMPERATURE
OUTER SURFACE
INNER SURFACE
θ
θamp
0
15
30
45
60
75
90
105
120
TIME IN MINUTES

FIGURE 1

where

θ_{amp} = maximum temperature variation at the inner surface, °F.

θ_1 = maximum temperation variation at the outer surface, °F.

x = distance between inner and outer face

n = number of cycles/hour

α = Thermal diffusivity, sq.ft./hr.

(2) Time lag $t = \frac{x}{2}\sqrt{\frac{1}{\alpha n \pi}}$

The time lag equation was not used as the basis of calculating thermal diffusivity because of difficulty of measuring precise times experimentally.

Now $K = \alpha C_p \rho$

The method of finding ρ and C_p has already been discussed. Therefore, knowing ρ, C_p and α, the thermal conductivity, K, may be calculated.

To experimentally reproduce infinite solid conditions with a sinusoidal temperature variation at the surface, a plywood box was made 38" x 38" x 8" with a removable top and a square opening 12" x 12" in the center of the bottom face. Another plywood box 42" x 42" x 26" in size was made with a removable top and a 12" x 12" hole at the center of the bottom surface. The smaller box was placed inside the other on supports which also served as a partition of the air space between the two boxes and the outside atmosphere. The boxes were oriented in such a way that there were air spaces of 2 inches around the sides, 6 inches at the bottom and 12 inches at the top.

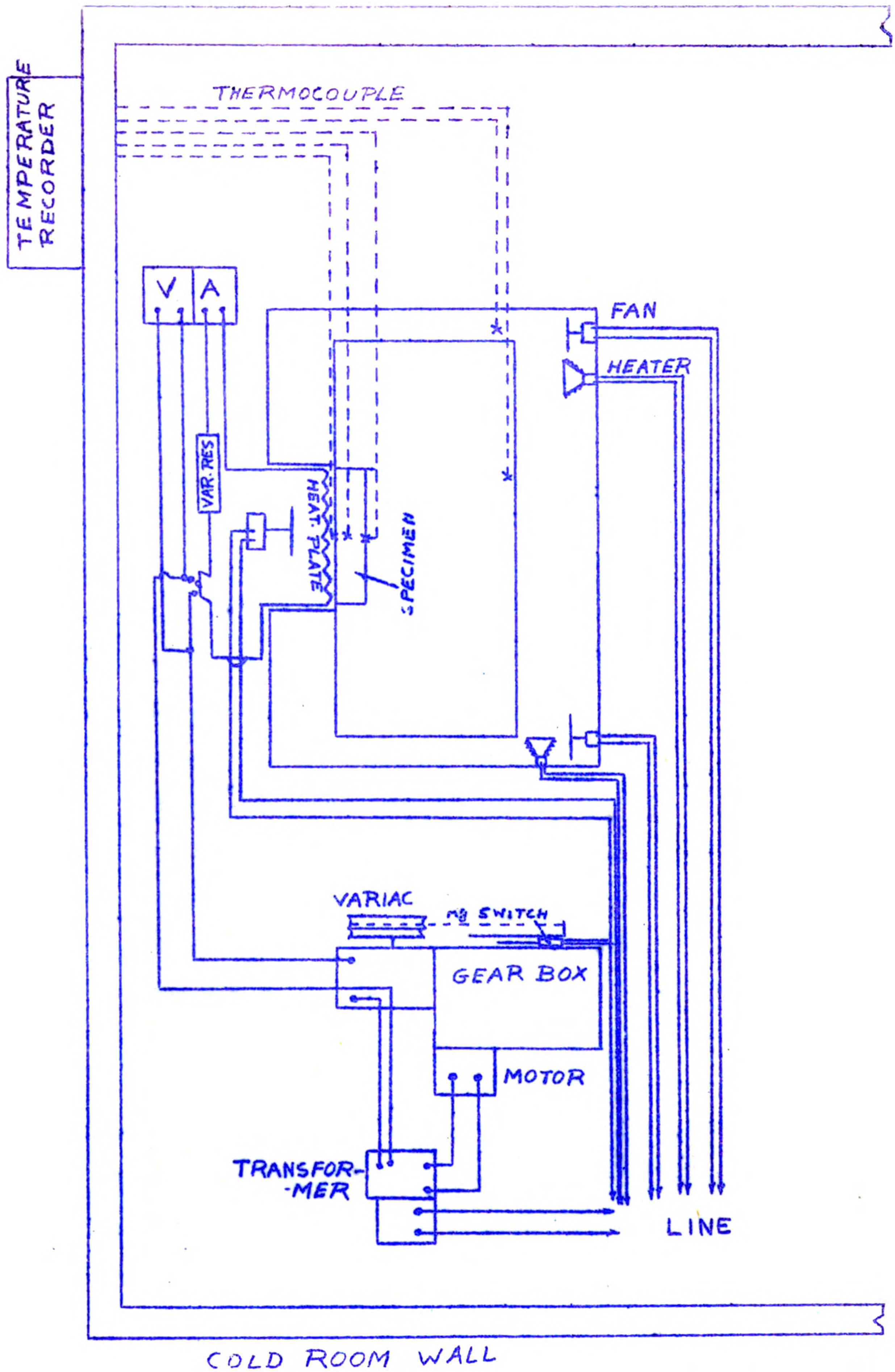


FIG. A-3 LAYOUT OF TEST EQUIPMENT

Two 500 watt heaters and two small fans were fitted -- one at the top of the air space and one at the bottom, to keep the inside air at a higher temperature than the air in the cold room, where the test was performed. The source of heat input to the samples was a plate heater, 12" x 12" in size and supported just below the 12" x 12" hole of the inner box. The specimen block was set on the heater plate and was surrounded by other blocks of same material, density and conditions, as the specimen.

The plate heater was connected to a 110 volt line through an ammeter, voltmeter, rheostat, variac, and constant voltage transformer as shown in the circuit diagram in Figure A-2. The variac control was supplied by a wooden pulley connected to a metallic rod fixed to the rotating shaft of a gear box on one side and a balanced weight on the other by a string. The gear box was so arranged that the shaft rotated one complete turn in one hour, which caused the variac control to complete one cycle. This varied the power input of the heater which produced the necessary sinusoidal temperature variation at the surface of the test sample. The constant voltage transformer was used to insure a constant input to the variac.

The test box set-up was supported above the floor of the cold room and a fan was set below it. The fan, by means of a mercury switch operated by a cam arrangement fitted to the gear shaft, operated only during the cooling portion of the heater cycle. This was done to balance the heating and cooling portions of the temperature sine curves.

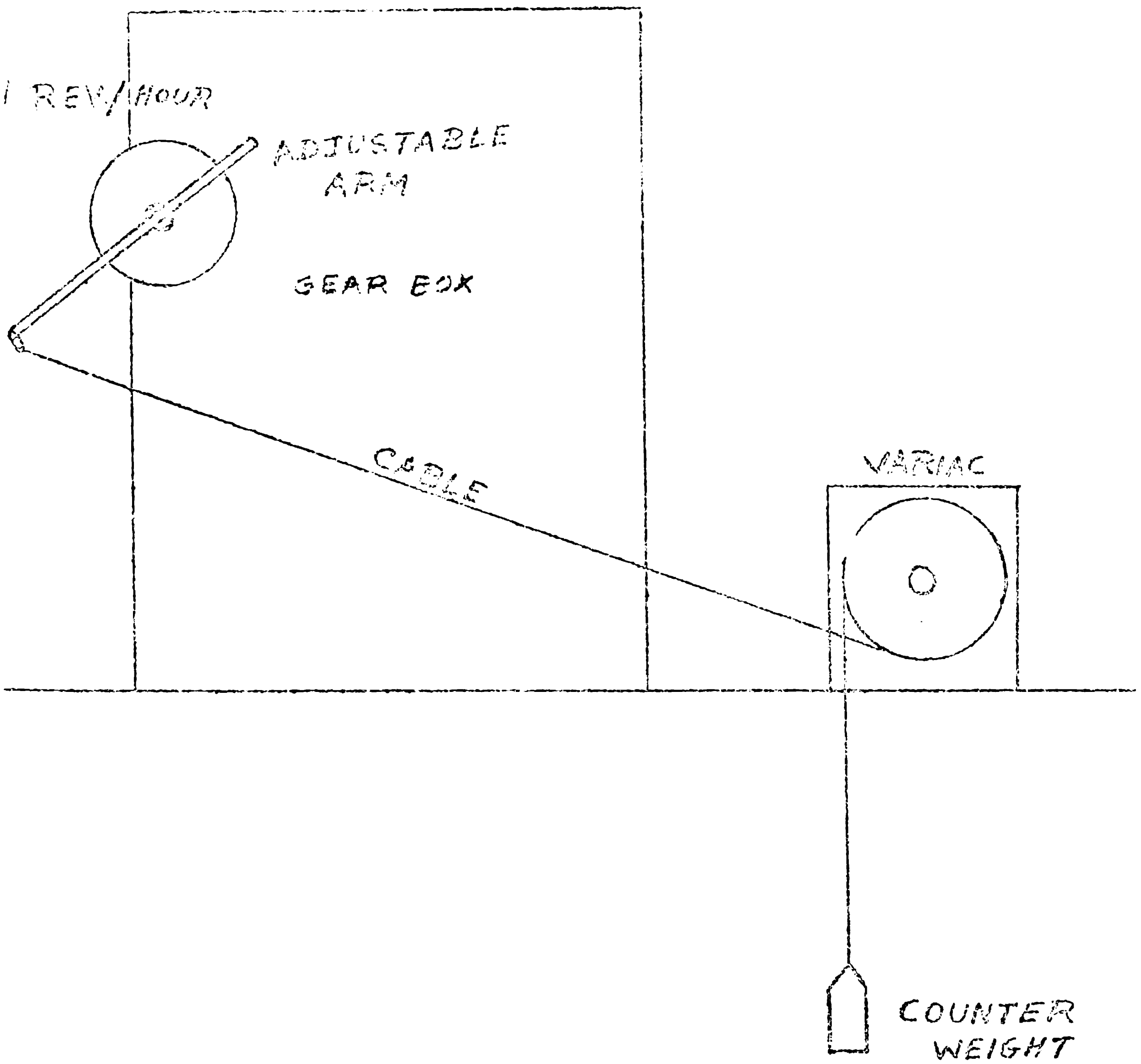


FIG A-3 ARRANGEMENT TO PRODUCE SINE WAVE

Copper constantan thermocouples were attached to the surface, at a depth of 1 inch and 2 inches of the specimen blocks, in the air space between the boxes and in the inner box. Temperatures were recorded automatically by means of a Brown Electronik Potentiometer mounted on the outside of the cold room. The temperature inside of the cold room was also recorded and controlled thermostatically from the outside. The inside temperature of the cold room was kept at about 42°F.

As the test method was an approach to infinite solid condition it took a long time to come to an equilibrium condition. When an equilibrium condition was reached, with smooth accurate sine curves, final readings were taken manually by means of a K-2 potentiometer reading up to .1°F. The results and calculations are shown in the appendix, pages 38 and 43 to 56.

PRECAUTIONS

Precautions were taken against fire. The plate heater was placed on asbestos paper instead of wooden supports. The walls of the boxes near the cone heaters were covered sheet metal so that heat could be conducted away. In addition, two automatic fire extinguishers were hung on the cold room wall. Electrical connections were checked and were well insulated.

As previously described care was taken to minimize any loss or gain in moisture in the block by covering it with aluminum foil. Sufficient time was allowed to insure definite thermal equilibrium conditions. In the interest of accuracy the final readings were taken with a manually operated K-2 potentiometer. Also the final readings were checked with initial readings. The K-2 potentiometer could read to one-tenth of a degree F., while one-half of a degree F. would be the nearest obtained with the automatic recorder. Moreover, there is the possibility of additional error in the linkage of the automatic recorder.

Other precautions were taken in the observation of the specific heat. The water in the calorimeter was constantly stirred. The castings of the small specimens for the specific heat tests were made carefully. The inside surfaces of the moulds were made smooth and were coated with a layer of oil before casting. The moulds were made in such a fashion that all the sides could be taken apart easily without harming the block itself. The casting was done on the same day as the other blocks to avoid errors in mixture proportion because the quantity of aggregate for casting the blocks for specific heat test was very small. The specimens were then kept under water for about 20 days for curing.

The cylindrical specimen for the compression test were kept under water for 21 days and then were dried. The two faces of the blocks were made parallel by addition of plaster so that the axis of load did not act in an inclined plane.

For greater accuracy, three readings were taken for each test.

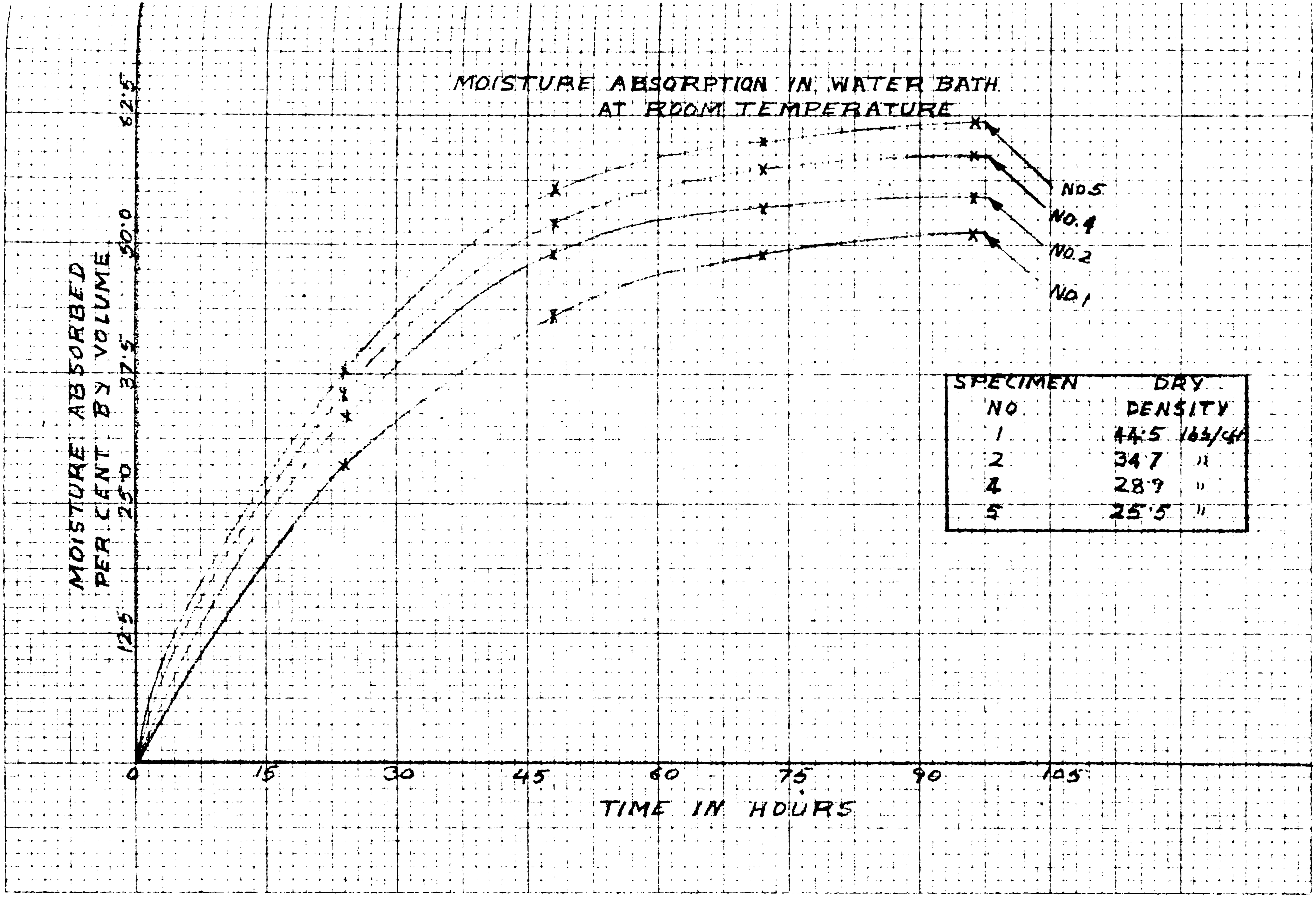

MOISTURE ABSORPTION IN WATER BATH
AT ROOM TEMPERATURE
MOISTURE ABSORBED
PER CENT BY VOLUME
0
12.5
25.0
37.5
50.0
62.5
15
30
45
60
75
90
105
TIME IN HOURS
NO.5
NO.4
NO.2
NO.1
SPECIMEN NO
DRY DENSITY
1
44.5 lbs/cft
2
34.7 "
4
28.9 "
5
25.5 "

FIGURE 2

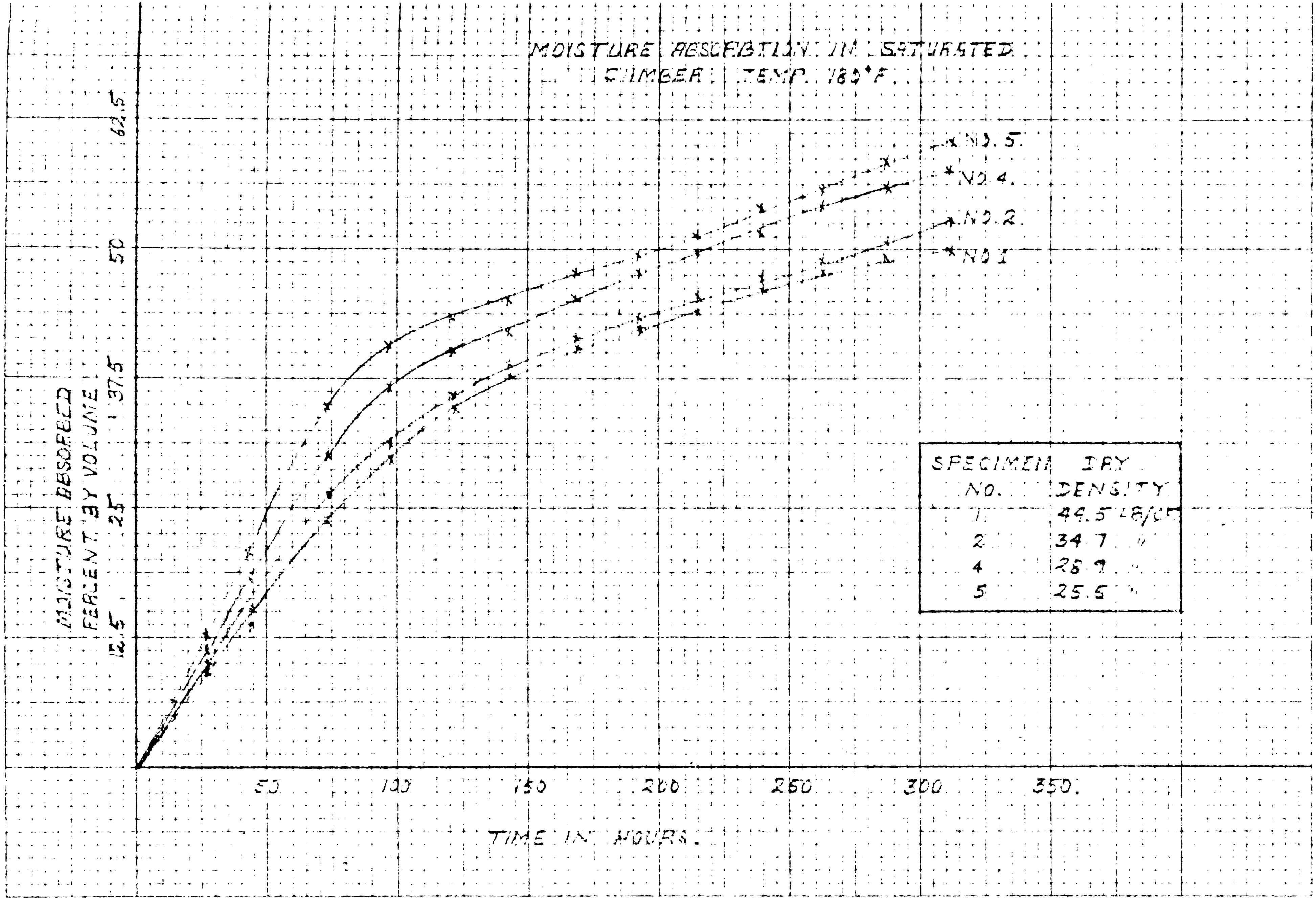

MOISTURE ABSORPTION IN SATURATED
CHAMBER. TEMP. 180°F.
NO. 5.
NO. 4.
NO. 2.
NO. 1
SPECIMEN NO. | DRY DENSITY
1 | 44.5 LB/CF
2 | 34.7
4 | 28.9
5 | 25.5
MOISTURE ABSORBED
PERCENT BY VOLUME
12.5
25
37.5
50
62.5
50
100
150
200
250
300
350.
TIME IN HOURS.

FIGURE 3

DISCUSSION AND CONCLUSION

MOISTURE ABSORPTION

The results of moisture absorption at different times are shown in the appendix and curves were drawn as shown in Figure 2 and 3. It should be noted that the moisture absorbed in each sample is expressed as a percent by volume because a percent by weight comparison can be extremely misleading when materials of large density difference are compared.

From Figure 2 and Figure 3 it is apparent that all the blocks absorbed moisture at a faster rate at the beginning. The rate was appreciably slowed down after about one hundred hours in the humid chamber and after about 50 hours in the water bath. If the total moisture absorbed in the humid chamber and the water bath are compared, then a difference in total moisture absorbed is noticed. The reason for this may be as follows:

First of all, in the test with water bath, even though precautions were taken to remove excess surface water, it was impossible to standardize the procedure;secondly, the operational temperature of the two methods was not the same. One was operating at 180°F. while the other was at room temperature of about 70°F., and if the specific volumes of water at these two temperatures are compared, it is found that the two results should vary by about 3 percent which is the order of the experimental variation found.

The results of moisture absorption tests as shown in the appendix indicate that the blocks have a high absorbtivity. Specimen No. 1

absorbed 50.9 percent by volume while No. 2 absorbed 52.3 percent, No. 4 absorbed 57.5 and No. 5, 59.9 percent by volume. The test also shows that the lower the dry density of the specimen the greater the moisture absorption on percent by volume basis. It was found from Treichler's work, who performed same type of investigation in 1952-53, that corkboard, fibreglass, foamglass, and styrofoam absorbed less moisture than the material under present investigation based on a percent by volume comparison.

STRUCTURAL PROPERTIES

The results of the compression and flexural tests are shown in the appendix.

These tests were performed after the blocks had been cured in water for about four weeks. Concrete attains its strength gradually with time. It is true that the insulations generally are not put to use shortly after being manufactured. For practical purposes four weeks seemed sufficient for the present investigation.

Flexural strengths are compared on the basis of modulus of rupture and the compressive strengths on the compressive stress. It is evident from the data obtained that the flexural and compressive strengths of the specimens increased with moisture. From the results and comparison with the properties of other insulating materials such as corkboard, styrofoam, foamglass and fibreglass as obtained by Treichler, it can be said that the specimen under investigation has good strength for use in insulation purposes within the range of densities as investigated. It can also be found easily from the data that the compressive as well as the flexural strength decreased rapidly with a decrease in density.

SPECIFIC HEAT

As a first precaution the blocks were cast with other blocks of the same proportion and density to avoid a difference in density with the main specimen blocks. But even then a slight error is always possible. To avoid this, three blocks of the same density were tested and the mean value was taken, as shown in the appendix. Secondly, as all the specimens were of lower density than water there was a tendency to float. This was avoided by taking a special type stirrer having a net so that it stirred the water as well as pressed it under water.

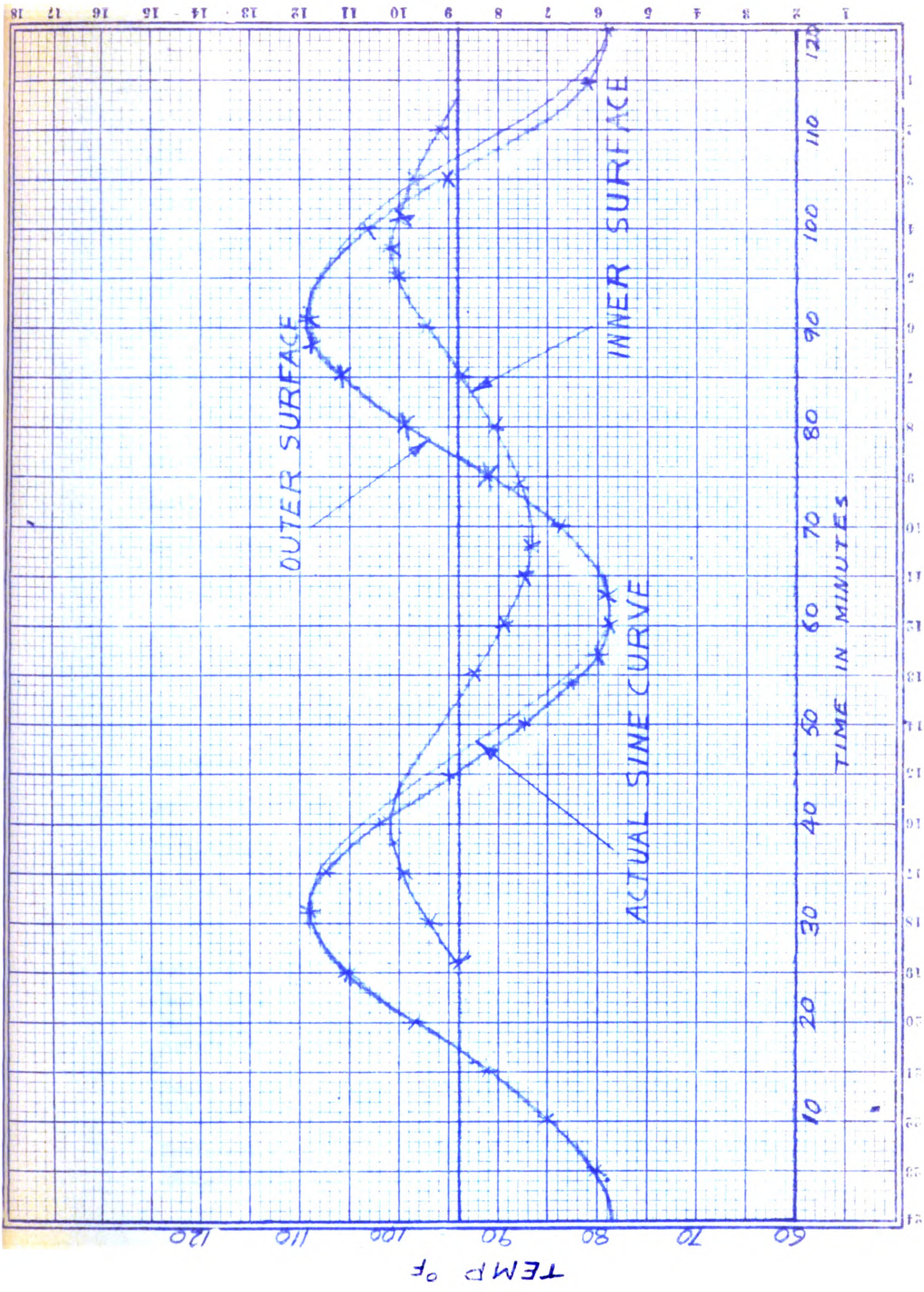
The specific heat of the blocks after absorption was calculated from the results of the specific heat of the dry blocks and that of water. This was done because no literature was available to find the values of the specific heat of moisture laden materials. The calculation and results are shown in the appendix, pages 39, 40 and 70.

HEAT TRANSFER PROPERTIES

The results of the heat transmission tests are shown in the appendix. Treichler investigated the same type of problem in 1952-53 with corkboard, fibreglass, foamglass and styrofoam. The construction of the main apparatus was similar to his with slight additions and alterations which were felt necessary. Treichler in his work covered the main specimen with fibreglass and investigated the properties based on the infinite solid theory. This was quite a deviation from the requirement that the infinite solid should be homogeneous. To avoid this error, a number of blocks were made of each specimen and the main specimen was covered on all sides by other blocks at least one block deep. As the blocks were not perfectly smooth there were some air films on the surfaces but still this was felt to be the most practical approach.

Secondly, during preliminary investigations the heater plate as well as the surfaces were seen to be heating up faster than the rate of cooling on the cooling period of the cycle. Lowering the temperature of the cold room meant just shifting the temperature axis and decreasing the temperature amplitude. To eliminate this effect a fan was placed below the heater plate which was run by a cam operated mercury switch fitted to the eccentric shaft of the gear box so that it only operated during the cooling period of the cycle. This produced a good result.

From Treichler's work it was found that corkboard has an inappreciable increase in thermal conductivity up to 20 percent moisture content by weight and then rises rapidly while fibreglass has a steady and constant rate of increase throughout the moisture range. Foamglass also showed results similar to fibreglass, but at a slower rate.


OUTER SURFACE
INNER SURFACE
ACTUAL SINE CURVE
TIME IN MINUTES
10
20
30
40
50
60
70
80
90
100
110
120
TEMP °F
60
70
80
90
100
110
120

McLaughin, Hechler and Queer[4] at Pennsylvania State, also worked with the problem of simultaneous heat transmission and moisture absorption properties of fibreboard. They found that up to about 10 percent moisture, the value of thermal conductivity stays almost constant and then rises rapidly. But these experiments did not deal with more than 25 percent moisture by weight so that it was not in the same range as the present investigation.

MacLean[5] in 1941 worked on this sort of problem on different kinds of wood with a maximum moisture content of 26 percent by weight. The wood showed a steady increase in K with the increase in moisture.

The influence of moisture on the thermal conductivity of grannular solids was studied by Devienne[6] in 1948-49. He reported that thermal conductivity increased rapidly at the beginning with an increase in moisture and then the rate of increase in conductivity decreased with further increase in moisture. Devienne did not particularly mention the name of the material he was investigating in his paper published in the Science Academy Journal of Paris. In the same paper an empirical formula was given for the correction

---

[4] McLaughin, E. R., Hechler, F. G., and Queer, E. R., Simultaneous Heat and Vapor Transmission Characteristics of an Insulating Material, A.S.H.V.E. Transaction, Vol. 48., 1942

[5] MacLean, J. D., Thermal Conductivity of Wood, Heating, Piping and Air Conditioning, Vol. 13, 1941

[6] Devienne, M., C. R. Acad. Sci. Paris, 226, 1948. Bosworth, R. C. L., Heat Transfer Phenomenon.

of thermal conductivity values for variation in moisture content as follows:

$$\frac{\log \dfrac{M_k}{M_p}}{K_k - K_p} = \text{Const.}$$

where M_k and M_p are masses of water absorbed at two different conditions K and P, and K_k and K_p are thermal conductivities. This empirical formula neither fits the results obtained in this investigation nor the investigation of Treichler.

Another investigator names Tanasawa[7] worked with foundry sand in 1935 in Japan. He found an interesting result in that the thermal diffusivity of foundry sand first increased and then decreased with increasing humidity to a maximum at 10 percent moisture by volume. The reason was that starting with dry sand, K increased rapidly at the beginning and then slowly to about five times its original value whereas Cp increased at a linear rate.

One of the most important factors which is encountered in this test is moisture migration with the addition of heat. Treichler used a 12 hour cycle which was felt favorable for moisture migration. Thus the cycle in this investigation was reduced to one hour. This period could be made shorter, but the difficulty of a greatly reduced temperature amplitude with the attendant measurement problem arises. To avoid the effect of moisture migration Tanasawa used periods of 1/40 to 1/80 seconds having a temperature difference of only 1/2°F. or less.

---

[7] Jacob, Max., Heat Transfer, Vol. I. 1949.

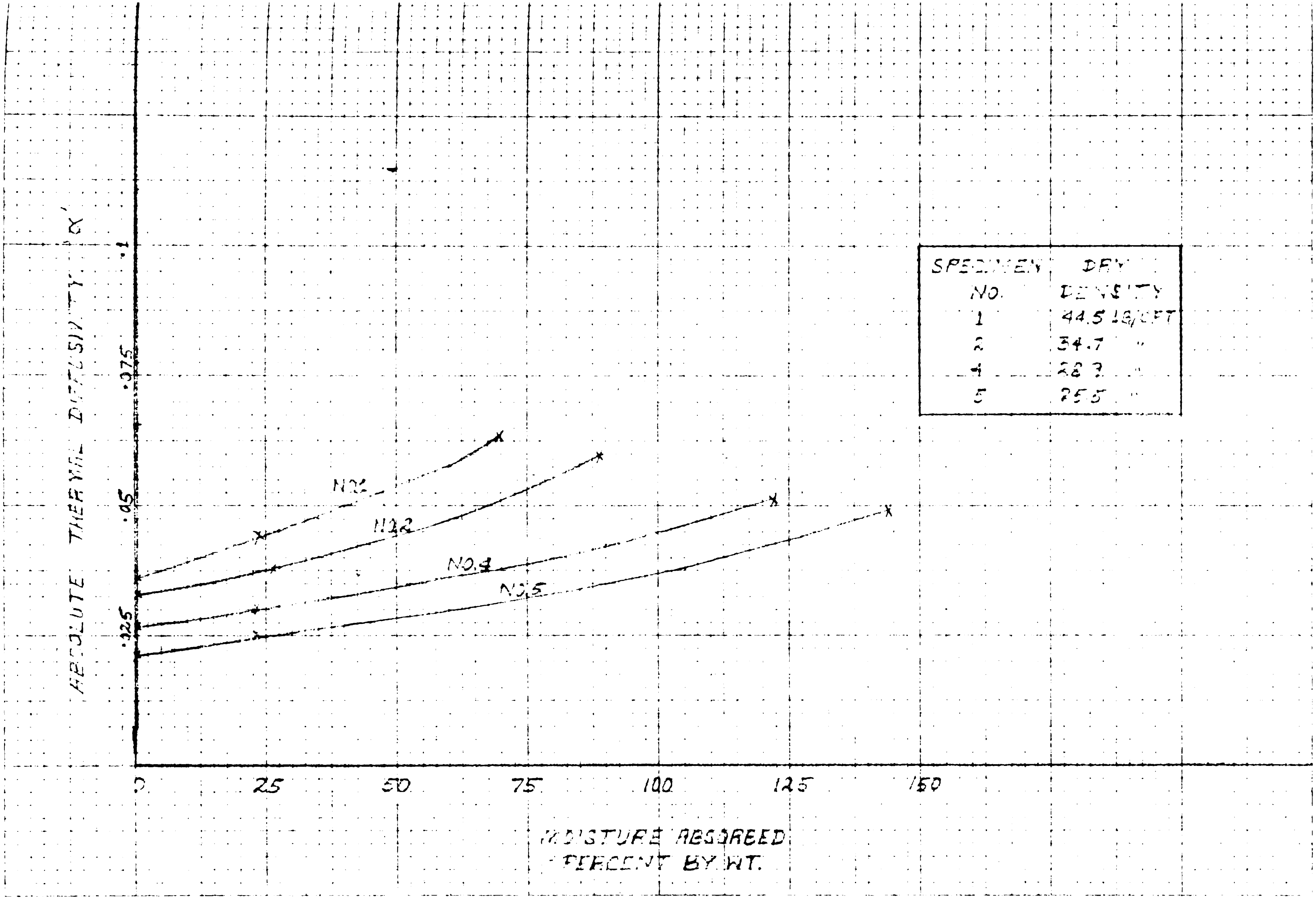

ABSOLUTE THERMAL DIFFUSIVITY, α'
.1
.075
.05
.025
0
25
50
75
100
125
150
MOISTURE ABSORBED
PERCENT BY WT.
No.1
No.2
No.4
No.5
SPECIMEN NO.
DRY DENSITY
1
44.5 LB/CFT
2
34.7
4
28.3
5
25.5

FIGURE 4

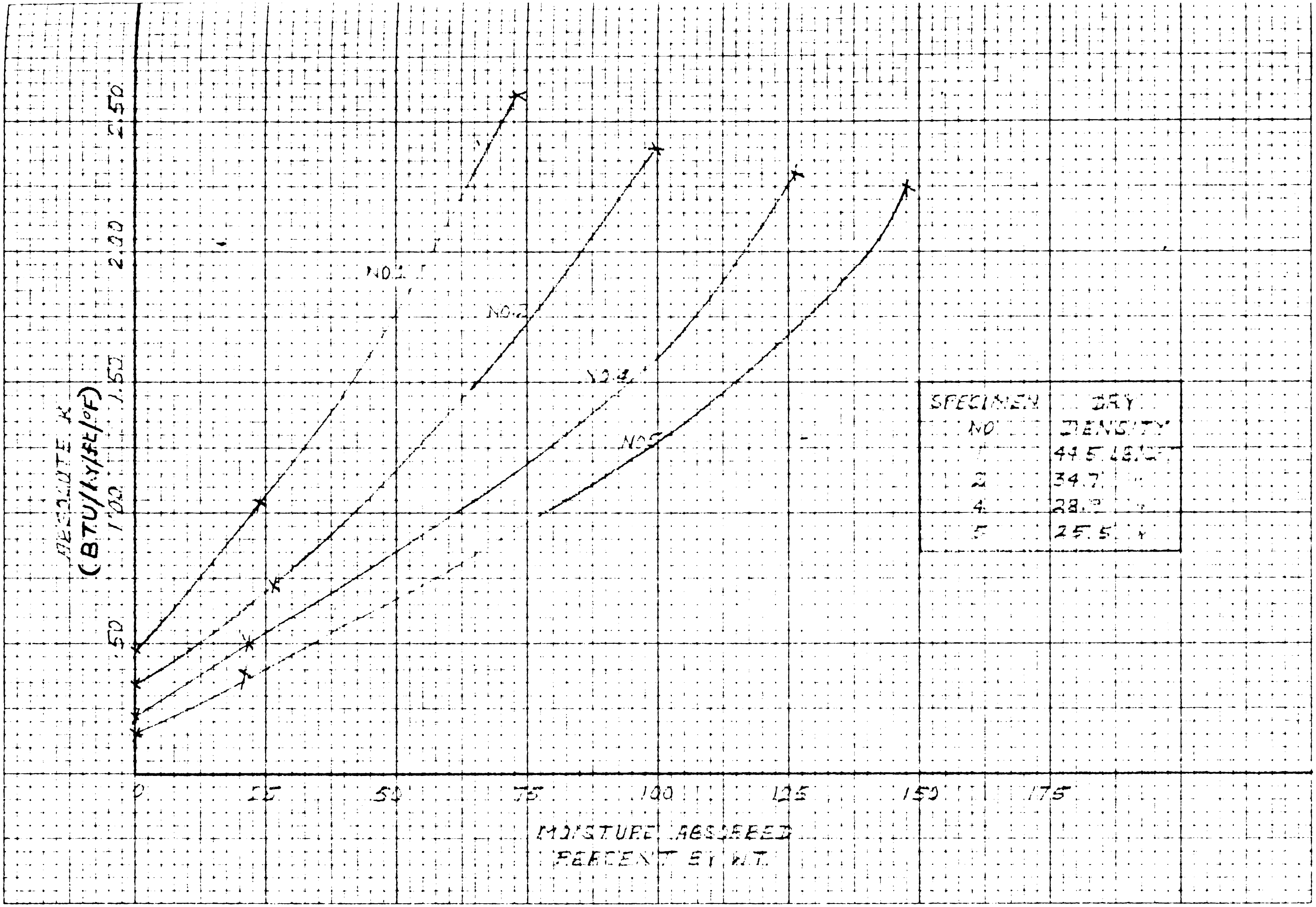

(BTU/hr/ft/°F)
.50
1.00
1.50
2.00
2.50
0
25
50
75
100
125
150
175
MOISTURE ABSORBED
PERCENT BY WT.
SPECIMEN NO
DRY DENSITY
2
4
5
34.7
25.5
NO.2
NO.4
NO.5

FIGURE 5

In this investigation a slight decrease was noted in the apparent densities of moisture laden samples after a period of 3 to 4 hours of test. The aluminum foil as well as the plate heater showed a slight deposition of moisture. Of course as blocks were removed when cold and as the room condition was as low as 40°F., a slight condensation was apparent. The maximum moisture loss was little less than 8 percent by wt. of moisture content, for two blocks while the rest averaged between 3 to 4 percent. The actual moisture migration was definitely less than this. To prove it, the sample showing the maximum loss of 8 percent was set to the same conditions and under test. The block, upon reaching equilibrium conditions, was immediately removed and weighed. The loss this time was 3.2 percent indicating that the moisture migration in this investigation was not excessive.

The specimens were tested for three different conditions -- dry, room condition, and saturated. The values of the thermal diffusivity α and thermal conductivity K were plotted against moisture absorbed as shown in Figure 4 and 5. Both the conductivity and the diffusivity were found to increase gradually with the increase in moisture content. This investigation covers a range up to 146 percent moisture by weight.

There have been attempts to correct K values for moisture content. Jacob[8] suggested the following factors to correct thermal conductivity

---

[8] Jacob, Max., Heat Transfer, Vol. I, 1949.

of building materials for various percentages of moisture content by volume.

Moisture Content	Correction Factor
1	1.3
2.5	1.55
5.0	1.75
10.0	2.10
15.0	2.30

These corrections do not quite fit the results of this investigation but are close. The results of Treichler is way off from these corrections.

The percent gain in K against the percent increase in moisture is plotted in Figure 6. Specimen No. 3 was omitted from the plottings as it showed almost the same density as No. 2, due to errors in mixing at the time of casting. The values of corkboard and fibreglass as obtained from Treichler's work are also included in this curve for comparison. It seems from this curve that the different specimens of zonolite concrete form a family of curves in which fibreglass tends to fit, but corkboard does not.

In Figure 7, the percent gain in K against the percent moisture absorbed, multiplied by the ratio of density of water to density of of material for all the blocks of Zonolite concrete as well as fibreglass are plotted. The Zonolite concrete group and the fibreglass group seems to fit in nicely forming almost a straight line except for two points, one for specimen No. 4 and another for No. 5.

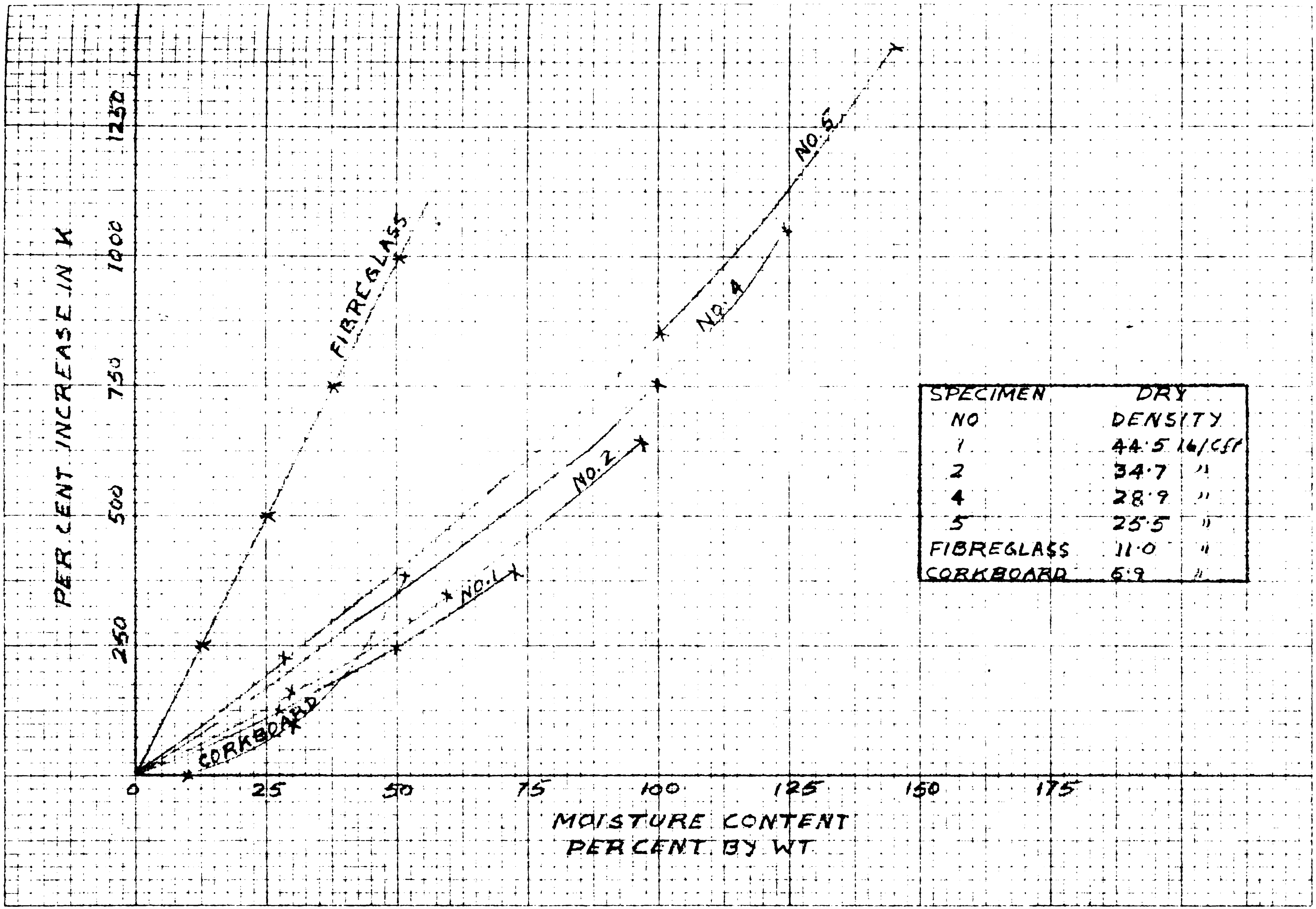

PER CENT INCREASE IN K
250
500
750
1000
1250
0
25
50
75
100
125
150
175
MOISTURE CONTENT
PERCENT BY WT
FIBREGLASS
NO. 5
NO. 4
NO. 2
NO. 1
CORKBOARD
SPECIMEN NO | DRY DENSITY
1 | 44.5 lb/cft
2 | 34.7 "
4 | 28.9 "
5 | 25.5 "
FIBREGLASS | 11.0 "
CORKBOARD | 6.9 "

FIGURE 6

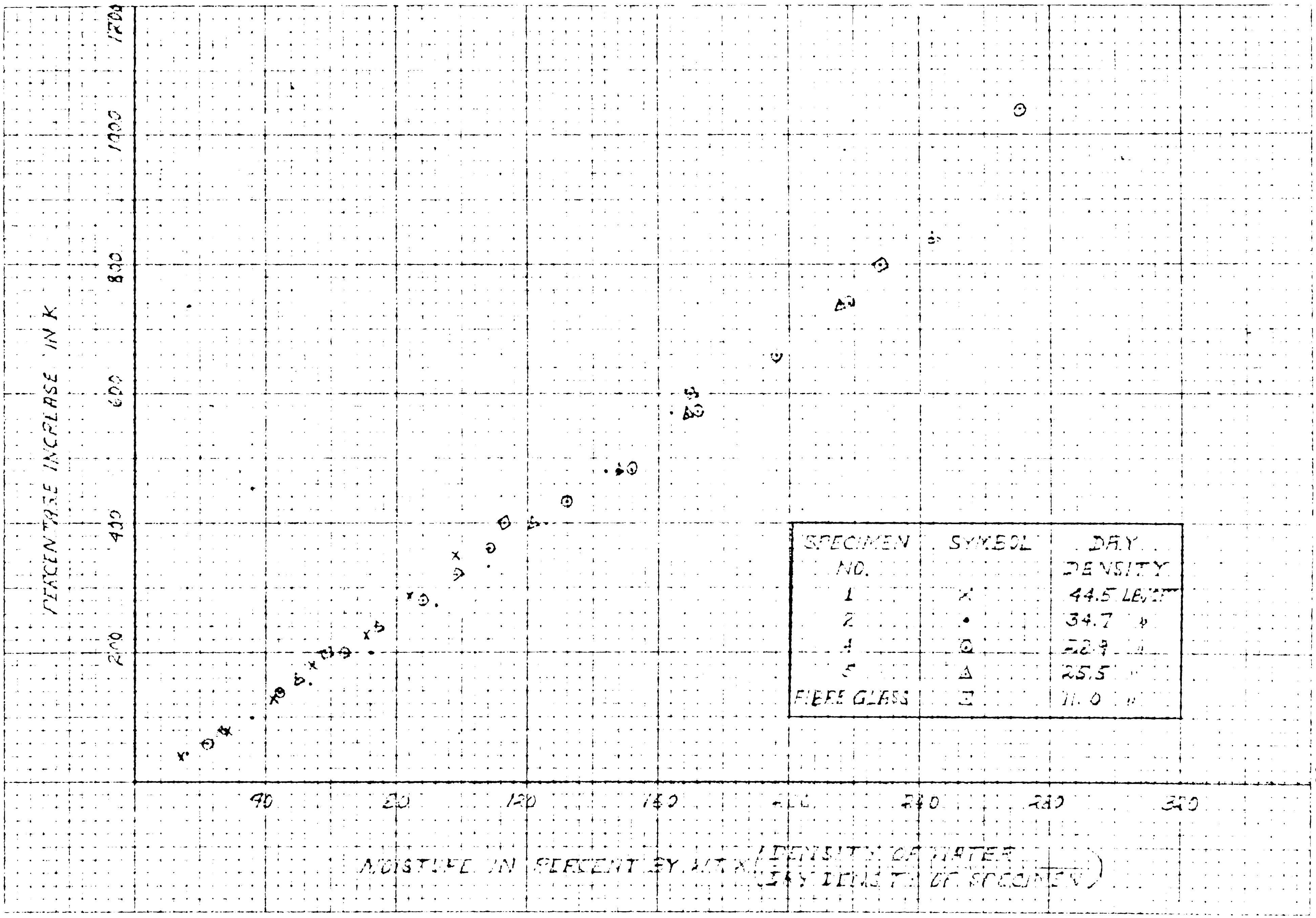

PERCENTAGE INCREASE IN K
200
400
600
800
1000
1200
40
80
120
160
240
280
320
SPECIMEN NO.
SYMBOL
DRY DENSITY
1
x
44.5
2
•
34.7
5
25.5
FIBRE GLASS
11.0
MOISTURE IN PERCENT BY WT.

FIGURE 7

Corkboard was also tried on this plot but it falls way below the others and does not fit the curve at all. The result of fibreboard from McLaughin and Queers' work was also tried, but as the range of their work was too low, it could not be plotted. The same case applied to MacLean's work with wood. Jacob's suggestion also did not seem to fit this curve. A probable reason as to why corkboard did not fit in could be given as the difference in structural form and characteristics in holding moisture.

From Figure 7 an empirical formula was formulated as follows:

$$K = K_d \left(1 + .034\, M \frac{P_w}{P}\right)$$

where

K = Thermal conductivity at moisture content M and dry density P

K_d = Thermal conductivity of dry material

M = Moisture content percent by weight at that condition

P_w = Density of water lbs/cft

P = Dry Density of material lbs/cft

The formula fits with all the specimen under this investigation except for two situations where the blocks has extreme moisture content. Attempts to fit the existing data of other investigators to the formula was successful for fibreglass, but not for corkboard.

A comprehensive table of results is given on page 36. The maximum percent gain in K is 1400 percent when the block of dry density of 25.5 lbs/cft absorbed 146 percent moisture by weight. Other results are shown in the tables in the Appendix.

RECOMMENDATION

In dealing with the method of determining the values of thermal conductivity by the method so far described, thought should be given as how closely moisture migration effect can be eliminated to have more precise results.

Thought should also be given to find out a better experimental method of finding the specific heat of the moisture laden material instead of doing it analytically.

The cycle period of one hour seems to be quite good, but may be varied to decrease migration effect if necessary.

A method of either some fillings or making the surfaces of the blocks perfectly smooth or some other means to avoid the effect of air spaces between solids should be adopted for precise results.

It is also recommended that the effect of variation of moisture on thermal conductivity for various other insulations be investigated. Grouping of materials on the basis of their characteristics should be done. The recommended formula for different groups should be tried, if possible, so that the properties of some other material of alike structure could be forcast fairly correct without going into elaborate investigation.

MLIT-232

Sheet No. 36

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Computation log of Perimeter insulation test of Zonolite Concrete blocks of different dry densities

Observers Mohsinul Huq

Date Dec, 19 54

No.	Specimen No.	Moisture % by vol.	Moisture % by wt.	Density ρ' (lb/cft.)	Sp. heat of dry block (B.T.u/lb/°F)	Sp. heat of water at 70°F & 180°F (B.T.u/lb/°F)	Sp. heat of the Specimen (B.T.u/lb/°F)	Amplitude of first surface temp θ_{amp}	Amplitude of second surface temp θ	Thermal diffusivity α (ft²/hr)	Thermal conductivity K (B.T.u/hr(ft)(°F))
1	#1	0	0	44.5	.322	–	.322	16.25	7.5	.036	.515
2	#2	0	0	34.7	.3	–	.3	16.0	7.0	.032	.334
3	#3	0	0	33.2	.3	–	.3	14.5	6.0	.03	.299
4	#4	0	0	28.9	.276	–	.276	14.0	5.5	.025	.20
5	#5	0	0	25.5	.26	–	.26	16.75	6.0	.02	.134
6	#1	16.75	23.6	55.1	.322	.998	.453	16.0	8.0	.044	1.09
7	#2	15.1	27.2	44.2	.3	.998	.437	18.0	8.5	.039	.775
8	#3	14.0	26.4	46.25	.3	.998	.447	16.5	7.5	.038	.78
9	#4	11.25	23.5	41.0	.276	.998	.410	16.5	7.5	.030	.52
10	#5	9.5	23.4	37.2	.26	.998	.398	19.75	8.0	.027	.40
11	#1	50.5	71.0	75.9	.322	1.002	.571	16.0	9.0	.064	2.62
12	#2	52.5	95.0	68.0	.3	1.002	.611	16.25	9.0	.061	2.42
13	#3	52.2	98.5	66.2	.3	1.002	.616	16.25	9.0	.061	2.5
14	#4	57.5	124.0	64.5	.276	1.002	.678	19.0	10.0	.053	2.3
15	#5	59.9	146.0	63.2	.26	1.002	.7	18.25	9.5	.05	2.27
16											
17											
18											
19											
20											
21											
22											
23											
24											
25											

Remarks:

APPENDIX

SAMPLE COMPUTATIONS

I. The determination of thermal diffusivity:

Specimen No. 4 at 23.5% moisture by wt.

Maximum variation in temperature of outer surface	θ_{amp}	=	16.5°F.
Maximum variation in temperature of inner surface	θ_1	=	7.5°F.
Number of complete cycles per hour	N	=	1
Distance between the two surfaces	x	=	.0834 ft.
Thermal diffusivity	α		

$$\theta_{amp} = \theta_1 \quad e^{-x\sqrt{\frac{\pi N}{\alpha}}}$$

or $$7.5 = 16.5\, e^{-.0834\sqrt{\frac{\pi \times 1}{\alpha}}}$$

or $$e^{.0834\sqrt{\frac{\pi}{\alpha}}} = \frac{16.5}{7.5}$$

$$= 2.19$$

or $$.0834\sqrt{\frac{\pi}{\alpha}} = .78$$

or $$\sqrt{\frac{\pi}{\alpha}} = 9.4$$

$$\frac{\pi}{\alpha} = 88.0$$

$$\alpha = .036 \quad ft^2/hr.$$

II. Determination of density:

Specimen No. 1 at 71.0 percent moisture by wt.

Weight of the block $W = 50.5$ lbs.

Volume of the block $V = 1 \times 1 \times 1/6 = .166$ cft.

$$\therefore \text{Density} = \frac{W}{V}$$

$$= \frac{50.5}{.166} = 75.9 \text{ lbs/cft}$$

III. Determination of specific heat:

Specimen No. 1 in dry state.

Wt. of the calorimeter and stirrer	W_1	= 176 gms.
Wt. of water	W_2	= 250 gms.
Wt. of the block	W_3	= 11.65 gms.
Temperature of water and calorimeter	T_1	= 71°F
Temperature of the block	T_2	= 285°F
Temperature of the mixture	T_3	= 74°F
Specific heat of the calorimeter	Cp_1	= .0919
Specific heat of water at 70°F	Cp_2	= .998
Specific heat of the block	Cp	

Heat gained by water and calorimeter = Heat lost by the block

$$W_1 \, Cp_1 \, (T_3 - T_1) + W_2 \, Cp_2 \, (T_3 - T_1) = W_3 \, Cp \, (T_2 - T_3)$$

or $176 \times .0919 \, (74 - 71) + 250 \times .998 \, (74 - 71) = 11.65 \times Cp \, (285-74)$

or $(16.1 + 249) \times 3 = 2458 \, Cp$

or $Cp = \frac{265.1 \times 3}{2458}$

$= .322$ BTU/lb/°F

IV. Determination of specific heat of moisture laden specimen:

Specimen No. 1 at 50.5 percent moisture by wt.

Weight of dry block	W_1 =	7.36 lbs.
Weight of water absorbed	W_2 =	5.24 lbs.
Specific heat of dry block	Cp_1 =	.322
Specific heat of water	Cp_2 =	1.002
Specific heat of composite	C	

$$W_1\ Cp_1 + W_2\ Cp_2 = (W_1 + W_2) \times C$$

$$7.36 \times .322 + 5.22 \times 1.002 = (7.36 + 5.22)\ C$$

$$2.29 + 5.22 = 12.58\ C$$

$$C = \frac{7.50}{12.58}$$

$$= .591$$

V. Determination of thermal conductivity:

Specimen No. 3 at 26.4 percent moisture by wt.

Thermal diffusivity	α =	.038
Specific heat	c =	.447
Density	ρ =	46.25

$$\alpha = \frac{K}{\rho c}$$

$$\text{or} \quad K = \alpha\ \rho c$$

$$= .038 \times 46.25 \times .447$$

$$= .78\ \text{BTU/hr./ft./°F.}$$

VI. Determination of modulus of rupture:

Specimen No. 1 at dry state.

Mean deflection = 30.15 divisions

From calibration curve on Fig. 8

Mean load at this deflection P_m = 555 lbs.

Moment of inertia $I = 1/12 \times 2 \times 2^3 = 1.133 \text{ in}^4$

Distance of extreme fibre from netral axis e = 1 inch

Distance between two supports L = 6 inch.

$$\text{Modulus of rupture} = \frac{P_m \times L \times e}{4\,I}$$

$$= \frac{555 \times 6 \times 1}{4 \times 1.33}$$

$$= 625 \text{ lbs/in}^2$$

VII. Determination of compressive stress:

Specimen No. 4 at saturated state.

Load at failure P = 830 lbs.

Area of the block $A = \frac{\pi \times D^2}{4} = \frac{\pi \times 4}{4} = \pi \text{ in}^2$

Compressive stress $= \frac{P}{A}$

$$= \frac{830}{\pi}$$

$$= 264 \text{ lbs/sq.in.}$$

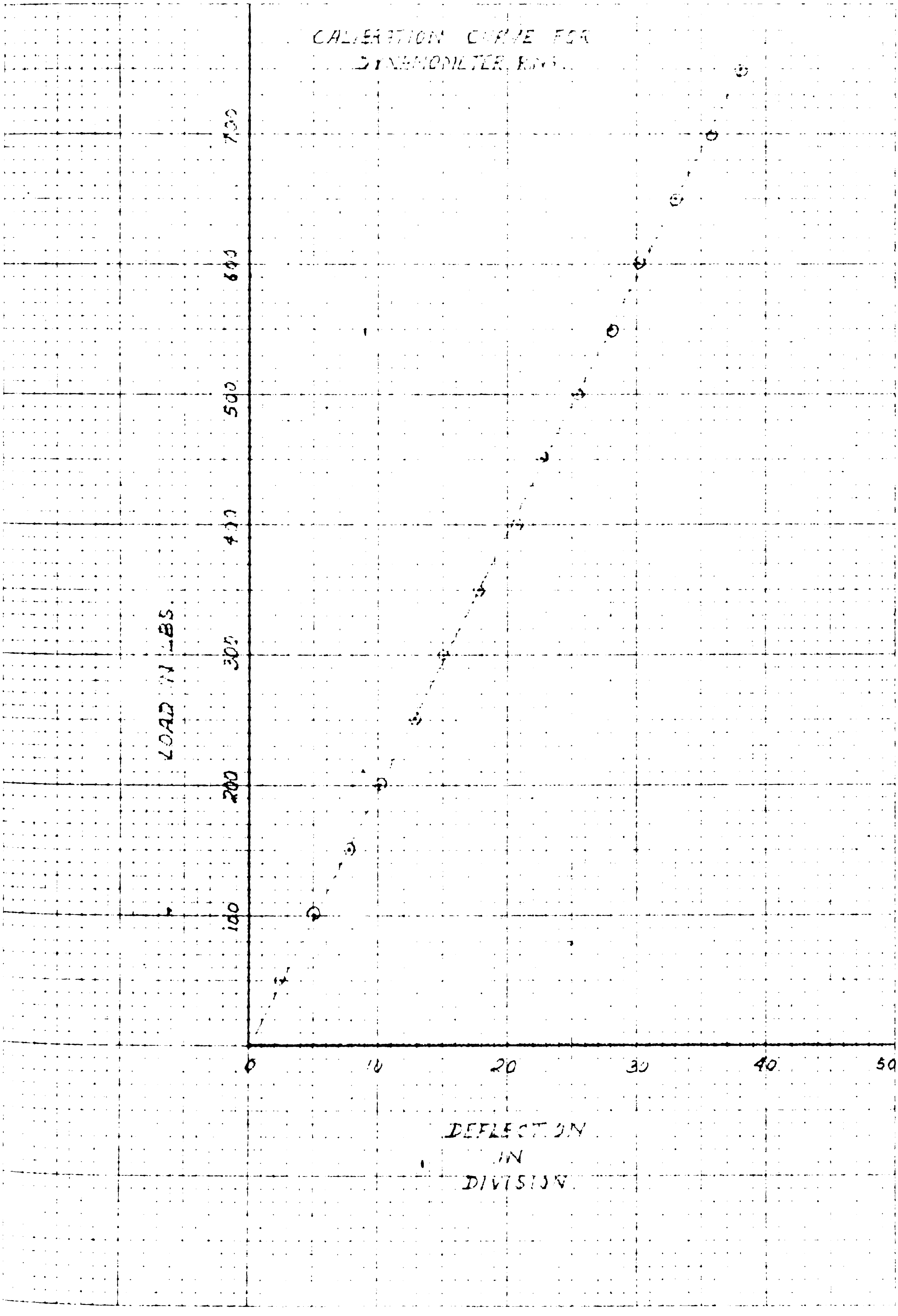

CALIBRATION CURVE FOR
DYNAMOMETER RING
LOAD IN LBS.
100
200
300
400
500
600
700
0
10
20
30
40
50
DEFLECTION
IN
DIVISION

FIGURE 8

MLIT-232 Sheet No. 43

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of specimen No. 1 dry Perimeter insulation test.

Observers Mohsinul Huq

Date Aug - Nov, 1954.

No.	Time for outer face.	Time elapsed for outer face	outer surface temp °F	Inner surface temp °F	Inner space temp (at outer face time) °F	Room air temp (at outer face time) °F.	Time elapsed for inner face.	Time for inner face.
1	9-15	0	79·25	96·0			25	9-40
2		5	81·1	100·5			30	
3		10	86·5	103·0			35	
4		15	93·7	104·0			38	
5		20	101·5	102·5			41	
6		27	111·0	101·0			45	10-00
7		30	111·6	97·6			50	
8		33	111·9	94·0			55	
9		40	104·5	90·5			60	
10	10-00	45	96·0	89·0			65	
11		50	89·1	89·4			68	
12		57	82·0	90·0			71	
13		60	79·0	92·2	± 4°F of Mean temp	Maintained within ± 3°F of 42°F	75	10-30
14		63	80·5	94·9			80	
15		70	88·2	99·0			85	
16	10-30	75	94·9	100·9			90	
17		87	111·7	102·8			94	
18		90	112·0	103·4			97	
19		94	111·9	102·5			101	
20		100	105·0	100·0			105	
21		105	97·0	97·8			110	11-05
22		110	98·5					
23		115	81·0					
24	11-15	120	79·0					
25								

Remarks:

MLIT-232

Sheet No. 44

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission properties of Specimen No. 2 dry.
Perimeter insulation test

Observers Mohsinul Huq

Date Aug-NOV., 19 54.

No.	Time for outer face (t_1)	Time elapsed for outer face.	outer face temp. °F	Inner face temp °F	Inner space temp (at t_1) °F	Room air temp (at t_1) °F	Time elapsed for inner face. °F	Time for inner face °F
1	11-10	0	78.5	94.0			26	11-36
2		5	80.0	97.0			30	
3		10	85.0	99.5			35	
4		15	90.9	100.0			38	
5		20	98.5	100.0			41	11-51
6	11-35	25	105.0	98.4			45	
7		28	108.6	95.0			50	
8		31	109.0	92.5	± 4°F of Mean temp	Maintained within ± 3°F of 42°F	55	12-05
9		35	107.2	87.2			60	
10	11-50	40	100.8	88.4			65	
11		45	93.7	86.5			68	
12		50	85.4	87.0			74	
13		54	80.7	91.0			80	
14	12-07	57	79.0	94.5			85	12-35
15		60	78.5	97.2			90	
16		63	78.9	100.8			95	
17		70	85.0	101.5			98	
18		75	91.0	99.7			101	
19		80	99.5	98.6			105	
20	12-35	85	105.9	96.0			110	1-00
21		88	108.9					
22		91	109.0					
23		100	103.2					
24		110	85.0					
25	1-10	120	79.3					

Remarks:

MLIT-232 Sheet No. 45

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of specimen No. 3 (Dry) Perimeter insulation test.

Observers Mohsinul Huq **Date** Aug - Nov, 1954.

No.	Time for outer face t_i	Time elapsed for outer face.	Outer face temp °F	Inner face temp °F	Inner Space temp at t_i °F	Room air temp at t_i °F.	Time elapsed for Inner face.	Time for inner face.
1	10-25	0	79.5	94.2			27	10-52
2		5	81.4	97.0			33	
3		10	82.2	97.5			36	
4		15	88.0	98.0			39	
5	10-45	20	95.0	96.7			45	11-10
6		25	104.4	95.0			50	
7		28	106.2	92.2			55	
8		31	106.0	89.6			60	
9		34	105.0	87.0			64	
10	11-05	40	97.6	85.7			68	
11		45	88.5	86.2			71	11-36
12		50	82.5	90.0	±4°F of Mean temp	Maintained within ± 3°F of 42°F	75	
13		55	80.0	92.5			80	
14		58	79.0	94.6			85	
15		61	78.8	96.2			90	
16	11-35	70	85.0	97.8			94	
17		80	95.4	98.0			98	12-03
18		85	103.5	95.0			102	
19		89	107.0	95.0			109	12-14
20		91	107.8					
21	12-00	95	103.8					
22		105	88.4					
23		110	84.5					
24		115	80.0					
25	12-25	120	77.0					

Remarks:

MLIT-232

Sheet No. 46

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of *Heat transmission Properties of specimen No. 4 dry. Perimeter insulation test.*

Observers: *Mohsinul Huq*

Date *Aug - NOV*, 19*54*.

No.	Time for outer face (t_1)	Time elapsed for outer face	Outer face temp °F	Inner face temp °F	Inner space Temp (at t_1) °F	Room air temp (at t_1) °F	Time elapsed for Inner face	Time for inner face.
1	9-20	0	80.0	95.0	±4°F of Mean temp	Maintained within ±3°F of 42°F	30	9-50
2		5	84.4	99.5			35	
3		10	87.2	100.8			40	
4		15	91.0	98.2			45	
5		20	95.5	95.6			50	
6	9-44	24	102.6	92.4			55	
7		27	107.9	90.0			60	
8		30	109.2	88.5			65	
9		33	108.5	87.2			70	
10		35	105.0	87.0			75	10-35
11	10-00	40	97.5	91.9			80	
12		50	85.5	95.5			85	
13		54	82.6	98.9			90	
14		57	81.6	99.5			95	
15		60	81.0	99.9			100	
16		65	83.0	98.9			105	
17	10-35	75	94.4	95.5			110	11-10
18		80	99.8					
19		85	105.5					
20		89	108.9					
21		94	107.8					
22	11-00	100	100.0					
23		106	89.2					
24		112	83.5					
25	11-19	119	81.0					

Remarks:

MLIT-232

Sheet No. 47

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of specimen No. 5 (Dry) Perimeter insulation test.

Observers Mohsinul Huq

Date Aug - Nov., 19 54.

No.	Time for outer face. t_1	Time elapsed for outer face.	outer face temp °F	Inner face temp °F	Inner space temp at t_1 °F	Room air temp at t_1 °F.	Time elapsed for inner face.	Time for inner face.
1	1-45	0	82.2	104.0			35	2-20
2		5	85.5	104.9			40	
3		11	91.2	103.2			45	
4	2-03	18	97.5	101.0			50	
5		22	107.0	95.2			55	
6		25	112.0	93.5			60	
7		28	115.0	91.4			65	
8		32	114.9	90.5	±4°F of Mean temp	Maintained within ±3°F of 42°F	72	
9		37	109.6	95.0			80	3-05
10		42	102.9	90.0			85	
11	2-32	47	93.2	101.2			90	
12		53	85.5	103.5			95	
13		57	82.4	103.6			102	
14	2-45	60	82.4	100.6			110	3-35
15		63	82.4					
16		70	90.0					
17		75	98.5					
18		81	105.5					
19		86	112.4					
20		89	114.6					
21		94	113.0					
22	3-25	100	104.0					
23		107	92.9					
24		115	85.5					
25								

Remarks:

MLIT-232

Sheet No. 48

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of Specimen No. 1 (16.75% Moisture by vol.)
Perimeter insulation test.

Observers: Mohsinul Aug

Date Aug - NOV, 1954.

No.	Time for outer face (t_1)	Time elapsed for outer face.	Outer face temp. °F	Inner face temp °F	Inner Space temp (at t_1) °F	Room air temp (at t_1) °F	Time elapsed for inner face.	Time for inner face.
1	2-10	0	83.0	104.1			27	2-37
2		4	85.2	106.8			32	
3		10	91.2	107.5			37	
4		15	99.5	103.0			45	
5	2-30	20	105.0	97.5			50	3-00
6		25	113.5	95.2			55	
7		29	115.0	91.5			60	
8		33	113.5	93.3			65	
9		40	104.9	96.5			69	
10		45	97.2	94.0	± 4°F of Mean temp	Maintained within ± 3°F of 42°F	75	
11	3-00	50	91.4	97.5			80	3-30
12		55	85.5	101.8			85	
13		59	84.0	105.5			90	
14		63	85.5	106.9			94	
15		70	90.5	107.2			97	
16		75	97.3	107.0			101	
17	3-30	80	105.5	102.2			107	3-57
18		85	113.2					
19		89	115.0					
20		93	115.0					
21		100	106.2					
22		106	97.5					
23	4-00	110	90.4					
24		115	85.5					
25		120	84.2					

Remarks:

MLIT-232

Sheet No. 49

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of specimen No. 3 (14.0% Moisture by Vol.)
Perimeter insulation test.

Observers: Mohsinul Huq

Date Aug- NOV, 19 54.

No.	Time for outer face (t_1)	Time elapsed for outer face	Outer face temp °F	Inner face temp °F	Inner Space temp (at t_1) °F	Room air temp (at t_1) °F	Time elapsed for inner face	Time for inner face.
1	10-15	2	99.9	102.2			32	10-45
2		10	97.0	103.2			37	
3		15	95.2	100.0			45	
4		23	106.0	90.4			50	
5		27	110.5	91.4			55	
6		30	112.2	88.2			60	
7		35	111.1	87.1			65	
8	10-53	40	101.0	88.6			70	
9		45	92.2	91.2			75	
10		50	81.5	90.0			80	11-33
11		55	81.0	90.0			85	
12		59	80.6	101.1			90	
13		65	84.0	102.0			95	
14		70	90.0	102.1			99	
15		75	97.0	100.5			104	
16	11-33	80	102.1	97.5			109	12-02
17		85	109.5					
18		89	111.3					
19		91	112.5					
20		100	104.0					
21		105	97.6					
22		110	87.1					
23	12-08	115	81.0					
24								
25								

(Inner space temp column, written vertically:) ±4°F of Mean temp

(Room air temp column, written vertically:) Maintained within ±3°F of 42°F.

Remarks:

MLIT-232

Sheet No. 50

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of Specimen NO. 4 (11.25% Moisture by Vol.) Perimeter insulation test.

Observers Mohsinul Huq

Date Aug-NOV, 19 54.

No.	Time for outer face (t_1)	Time elapsed for outer face.	outer face temp °F	Inner face temp °F	Inner space temp (at t_1) °F	Room air temp (at t_1) °F	Time elapsed for inner face	Time for inner face.
1	9-09	1	[illegible]	99.0	±4°F of Mean temp	Maintained within ±3°F of 42°F	29	9-37
2		7	[illegible]	103.5			35	
3		12	[illegible]	102.2			42	
4		[illegible]	97.5	97.5			49	
5		22	[illegible]	93.1			54	
6		26	[illegible]	89.4			59	
7		[illegible]	110.5	86.4			66	
8		[illegible]	111.3	91.0			75	10-23
9	9-48	[illegible]	[illegible]	98.6			85	
10		44	[illegible]	103.5			93	
11		[illegible]	[illegible]	104.0			97	
12		[illegible]	[illegible]	100.8			105	
13		60	[illegible]	97.5			112	11-09
14		64	[illegible]					
15		69	[illegible]					
16		73	[illegible]					
17		79	[illegible]					
18		[illegible]	[illegible]					
19	10-39	91	[illegible]					
20		96	[illegible]					
21		103	[illegible]					
22		105	[illegible]					
23		112	[illegible]					
24	11-06	[illegible]	[illegible]					
25								

Remarks:

MLIT-232

Sheet No. 51

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of specimen NO. 5 (9.5% Moisture by Vol.) Perimeter insulation test.

Observers Mohsinul Huq

Date Aug - NOV, 19 54

No.	Time for outer face (t_1)	Time elapsed for outer face.	Outer face temp °F	Inner face temp °F	Inner Space temp (at t_1) °F	Room air temp (at t_1) °F	Time elapsed for Inner face.	Time for inner face.
1	10-12	2	75.6	97.9			30	10-40
2		8	81.1	103.4		Maintained within ±3°F of 42°F.	37	
3		14	89.2	101.5			43	
4		18	99.2	95.0			52	
5		26	109.4	91.6	±4°F of Mean [illegible]		58	
6		29	113.5	86.7			66	11-16
7		32	114.0	87.4			73	
8		35	106.5	93.5			80	
9		43	96.4	99.4			85	
10	10-58	48	86.5	103.5			96	
11		57	77.9	100.6			104	
12		61	76.2	97.0			110	12-02
13		69	84.4	[illegible]				
14		74	93.2					
15		79	101.5					
16		83	107.2					
17	11-37	87	113.5					
18		91	113.5					
19		97	108.2					
20		104	95.4					
21		109	85.4					
22		114	75.0					
23	12-12	120	75.4					
24								
25								

Remarks:

MLIT-232

Sheet No. 52

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of Specimen No. 1. in saturated State Perimeter insulation test.

Observers: Mohsinul Huq

Date Aug-NOV, 1954.

No.	Time for outer face (t_1)	Time elapsed for outer face.	Outer face temp °F	Inner face temp °F	Inner space temp (at t_1) °F	Room air temp (at t_1) °F	Time elapsed for inner face.	Time for inner face.
1	9-11	1	83.5	103.0			25	9-35
2		8	86.4	106.5			30	
3		12	92.9	107.7			34	
4		17	102.5	107.4			40	
5		23	111.3	105.0			45	
6		27	114.4	101.5			50	10-00
7		31	115.5	95.9			55	
8		38	110.5	90.5			60	
9		43	105.0	88.8			65	
10		49	94.5	90.5			70	
11	10-03	53	90.9	95.9	± 4°F of Mean temp	Maintained within ±3°F of 42°F	75	
12		58	85.2	101.0			80	
13		64	86.2	105.5			85	
14		68	92.5	107.0			90	10-30
15		74	98.6	108.2			95	
16		78	105.0	106.8			100	
17		84	111.3	104.0			105	
18		88	114.6					
19		93	115.0					
20		99	108.6					
21		104	98.2					
22	10-58	108	88.2					
23		117	84.1					
24								
25								

Remarks:

MLIT-232

Sheet No. 53

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of *Heat transmission Properties of Specimen No. 2 in Saturated State Perimeter insulation test.*

Observers: *Mohsinul Huq*

Date *Aug - Nov*, 19 *54*

No.	Time for outer face t_1	Time elapsed for outer face.	Inner face temp °F	Outer face temp °F	Inner Space temp at t_1 °F	Room air temp at t_1 °F.	Time elapsed for inner face.	Time for inner face.
1	2-12	2	83.5	104.6			25	2-35
2		8	87.4	107.8			32	
3		13	96.0	108.9		Maintained within ± 3°F of 42°F	36	
4		18	104.2	104.5			44	
5		24	113.3	96.5			53	
6		28	116.5	91.7	± 4°F of Mean temp		60	
7		34	113.5	89.9			67	
8		42	104.2	95.5			75	
9		49	97.2	101.0			50	3-30
10	3-04	54	89.0	105.5			85	
11		59	85.2	108.2			90	
12		63	85.2	108.9			95	
13		69	94.1	105.5			103	
14		76	104.5	101.5			109	3-59
15		82	111.4					
16		87	114.2					
17		90	114.5					
18		94	112.5					
19		99	109.2					
20	3-54	104	103.3					
21		112	91.8					
22		117	85.7					
23								
24								
25								

Remarks:

MLIT-232

Sheet No. 54

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of Specimen No. 3 in saturated State
Perimeter insulation test

Observers Mohsinul Huq

Date Aug-NOV, 1954

No.	Time for outer face t_1	Time elapsed for outer face	Outer face temp °F	Inner face temp °F	Inner space temp at t_1 °F	Room air temp at t_1 °F	Time elapsed for inner face	Time for inner face
1	2-50	0	81.5	104.2			25	3-15
2		7	89.8	109.8			30	
3		13	95.2	112.4			35	
4		17	102.4	111.6			40	
5		21	109.3	107.5	±4°F of Mean temp		45	3-35
6		24	115.5	105.7		Maintained within ±3°F of 42°F	50	
7		28	118.5	98.0			55	
8		33	115.5	93.5			60	
9		37	113.9	92.2			65	
10		44	101.1	92.4			70	4-00
11		49	93.4	97.7			75	
12	3-44	54	88.3	102.3			80	
13		60	86.0	107.1			85	
14		66	89.8	111.6			90	
15		73	92.6	112.0			95	
16		79	107.5	111.1			100	4-30
17		84	115.7	108.5			105	
18		88	118.0	103.4			110	
19		92	118.5					
20	4-29	99	108.8					
21		104	98.1					
22		109	91.2					
23		117	86.5					
24								
25								

Remarks:

MLIT-232 — Sheet No. 55

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of specimen No. 4 in saturated State. Perimeter insulation test.

Observers Mohsinul Huq

Date Aug - Nov, 1954.

No.	Time for outer face t_1	Time elapsed for outer face	outer face temp °F	Inner face temp °F	Inner space temp at t_1 °F	Room air temp at t_1 °F	Time elapsed for inner face	Time for inner face
1	10-11	1	55.4	106.5			25	10-35
2		8	58.8	111.8			30	
3		13	93.5	114.2		Maintained within ± 3°F of 42°F	35	
4		19	105.0	112.0			40	
5		23	115.1	102.4			50	11-00
6		28	121.6	97.1			55	
7		32	122.2	95.0	± 4°F of Mean temp		60	
8		39	116.5	93.9			65	
9		44	103.4	95.0			70	
10	10-59	49	93.7	99.1			75	
11		55	82.2	104.4			80	11-30
12		59	86.0	109.6			85	
13		63	87.6	112.5			90	
14		67	94.0	114.0			95	
15		74	102.1	113.7			100	
16		79	108.9	109.0			105	
17		83	116.2					
18		88	122.0					
19		93	121.3					
20	11-49	99	114.7					
21		104	105.1					
22		109	97.9					
23		114	87.2					
24		117	86.0					
25								

Remarks:

MLIT-232

Sheet No. 56

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Heat transmission Properties of Specimen No. 5 in saturated state perimeter insulation test

Observers: Mohsinul Huq

Date Aug-NOV, 1954

No.	Time for outer face t_1	Time elapsed for outer face.	Outer face temp °F	Inner face temp °F	Inner space temp at t_1 °F	Room air temp at t_1 °F	Time elapsed for inner face.	Time for inner face.
1	11-52	2	86.5	107.2			25	12-15
2		6	87.2	113.0			31	
3		9	91.8	114.6			36	
4		14	98.0	109.0	± 4°F of Mean temp	Maintained within ± 3°F of 42°F	45	
5		19	107.1	103.9			50	
6		22	104.4	99.1			55	
7		26	122.9	95.4			60	
8		30	123.0	93.3			65	
9		34	121.6	92.9			68	
10		39	117.3	97.6			73	1-03
11	12-34	44	105.7	103.0			80	
12		49	95.9	107.1			85	
13		54	88.1	112.5			90	
14		59	87.0	114.0			95	
15		64	89.0	113.0			100	
16		69	95.0	109.0			105	1-35
17		74	103.4	105.5			109	
18		79	110.9					
19		83	116.0					
20		88	122.1					
21	1-24	94	121.9					
22		99	114.4					
23		104	106.0					
24		109	98.8					
25		119	86.2					

Remarks:

MLIT-232 Sheet No. 57

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Moisture absorption test of Zonolite Concrete blocks of different dry densities for Perimeter insulation test.

Observers Mohsinul Huq

Date July-Aug., 1954

No.	Specimen No.	Date of observation	Time of observation	Wt. recorded	Dimension of the block	Volume of the block (Cft)	Density at bone dry State (lbs/cft)
1	#1	16th July	9 A.M.	8.6	12"x12"x2"	.166 cft.	
2		16 "	4-30. P.M	8.35	"	"	
3		17 "	9-30 A.M	7.7	"	"	
4		17 "	5 P.M	7.4	"	"	
5		18 "	8 AM.	7.36	"	"	
6		18 "	5 P.M	7.36	"	"	
7		*19 "	10 A.M.	7.36	"	"	44.5
8							
9	#2	16th July	9 A.M	7.2	"	"	
10		16 "	4-30 P.M	6.7	"	"	
11		17 "	9-30 A.M	6.1	"	"	
12		17 "	5 P.M	5.8	"	"	
13		18 "	8 A.M.	5.75	"	"	
14		18 "	5 P.M	5.75	"	"	
15		*19 "	10 A.M.	5.75	"	"	34.7
16							
17							
18	#3	16th July	9 A.M	6.6	"	"	
19		16 "	4-30 P.M	6.3	"	"	
20		17 "	9-30 A.M	5.9	"	"	
21		17 "	5 P.M	5.6	"	"	
22		18 "	8 A.M	5.5	"	"	
23		18 "	5 P.M.	5.5	"	"	
24		*19 "	10 A.M.	5.5	"	"	33.2
25							

Remarks: * The wts. at the star marked dates and time are taken as bone dry state and corresponding density as bone dry density.

The specimen are numbered according to the variation of proportion of cement & zonolite which shews the variation in dry density.

MLIT-232

Sheet No. 58

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of *Moisture absorbtion test of Zonolite-Concrete blocks of different dry densities for Perimeter insulation test.*

Observers: *Mohsinul Huq*

Date *July - Aug.*, 19*54*.

No.	Specimen No.	Date of observation	Time of observation	Weight recorded (lbs.)	Dimension of the block	Volume of the block (cft)	Density at bone-dry state (lbs/cft)
1	# 4	16 July	9 A.M.	5·9	12"x12"x2"	·166	
2		16 "	4-30 P.M.	5·7	"	"	
3		17 "	9-30 A.M.	5·2	"	"	
4		17 "	5 P.M.	4·9	"	"	
5		18 "	8 A.M.	4·8	"	"	
6		18 "	5 P.M.	4·8	"	"	
7		* 19 "	10 A.M.	4·8	"	"	28·9
8							
9							
10	# 5	16 "	9 A.M.	5·1	"	"	
11		16 "	4-30 P.M.	4·9	"	"	
12		17 "	9-30 A.M.	4·65	"	"	
13		17 "	5 P.M.	4·4	"	"	
14		18 "	8 A.M.	4·25	"	"	
15		18 "	5 P.M.	4·25	"	"	
16		* 19 "	10 A.M.	4·25	"	"	25·5

Remarks: * As illustrated in Previous sheet.

MLIT-232

Sheet No. 59

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Moisture absorption test of zonolite Concrete blocks of different dry densities in humid Chamber for Perimeter insulation test.

Observers: Mohsinul Huq

Date July - Aug, 19 54.

No.	Specimen No.	Date of observation	Time of observation	Hours lapsed	Temp. inside Chamber (°F)	Absolute wt. (lbs)	increase in wt. (lbs)	Absolute Moisture absorbed (lbs)	Moisture absorbed % by vol.	Density at saturated state (lbs/cft)
1	#1	21 July	4 P.M.	0	150	7·36	0	0	0	
2		22 "	4 "	24	150	7·4	·04	·04	·386	
3		23 "	4 "	48	150	7·4	·04	·04	·386	
4		24 "	4 "	72	180	8·2	·84	·84	8·1	
5		25 "	4 "	96	"	9·1	1·74	1·74	16·8	
6		26 "	4 "	120	"	9·9	2·54	2·54	24·5	
7		27 "	4 "	144	"	10·55	3·19	3·19	30·8	
8		28 "	4 "	168	"	10·95	3·59	3·59	34·7	
9		29 "	4 "	192	"	11·25	3·89	3·89	37·6	
10		30 "	4 "	216	"	11·5	4·14	4·14	40·0	
11		31 "	4 "	240	"	11·75	4·39	4·39	42·5	
12		1 Aug	4 "	264	"	11·95	4·59	4·59	44·5	
13		2 "	4 "	288	"	12·15	4·79	4·79	46·2	
14		3 "	4 "	312	"	12·35	4·99	4·99	48·3	
15		4 "	4 "	336	"	12·5	5·14	5·14	49·6	
16		* 5 "	4 "	360	"	12·6	5·24	5·24	50·5	75·9
17		6 "	4 "	384	"	12·6	5·24	5·24	50·9	
18										
19										
20										
21										
22										
23										
24										
25										

Remarks: * saturated state

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of *Moisture absorption test of zonolite Concrete blocks of different dry densities in humid chamber for Perimeter insulation test*

Observers: Mohsinul Huq

Date July-Aug, 1954

No.	Specimen No.	Date of observation	Time of observation	Hours lapsed	Temp. inside Chamber (°F)	Absolute wt. (lbs)	increase in wt. (lbs)	Absolute Moisture absorbed (lbs)	Moisture absorbed % by vol.	Density at saturated state (lbs/cft)
1	#2	21, July	4 PM	0	150	5.75	0	0	0	
2		22 "	4 "	24	150	5.75	0	0	0	
3		23 "	4 "	48	150	5.8	.05	.05	.484	
4		24 "	4 "	72	180	6.65	.9	.9	8.7	
5		25 "	4 "	96	"	7.65	1.9	1.9	18.4	
6		26 "	4 "	120	"	8.5	2.75	2.75	26.5	
7		27 "	4 "	144	"	9.05	3.3	3.3	31.9	
8		28 "	4 "	168	"	9.4	3.65	3.65	35.2	
9		29 "	4 "	192	"	9.65	3.95	3.95	38.6	
10		30 "	4 "	216	"	9.85	4.21	4.21	41.6	
11		31 "	4 "	240	"	10.05	4.46	4.46	43.0	
12		1st Aug.	4 "	264	"	10.25	4.65	4.65	45.2	
13		2 "	4 "	288	"	10.5	4.85	4.85	47.0	
14		3 "	4 "	312	"	10.75	5.1	5.1	497	
15		4 "	4 "	336	"	11.0	5.2	5.2	50.2	
16		*5 "	4 "	360	"	11.25	5.45	5.45	52.5	68.0
17		6 "	4 "	384	"	11.25	5.45	5.45	52.5	

Remarks: * saturated state

MLIT-232

Sheet No. 61

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Moisture absorption test of Zonolite Concrete blocks of different dry densities in humid chamber for perimeter insulation test

Observers: Mohsinul Huq

Date July-Aug, 1954

No.	Specimen No.	Date of observation	Time of observation	Hours lapsed	Temp. inside the chamber	Absolute Weight (lbs)	Increase in weight (lbs)	Absolute Moisture absorbed (lbs)	Moisture Absorbed Percent by volume	Density at saturated state (lbs/cft)
1	#3	21 July	4 P.M.	0	150	5.5	0	0	0	
2		22 "	"	24	150	5.6	.1	.1	.965	
3		23 "	"	48	150	5.7	.2	.2	1.93	
4		24 "	"	72	180	6.45	.95	.95	9.15	
5		25 "	"	96	"	7.55	2.05	2.05	19.4	
6		26 "	"	120	"	8.45	2.95	2.95	28.5	
7		27 "	"	144	"	8.95	3.45	3.45	33.3	
8		28 "	"	168	"	9.25	3.75	3.75	36.2	
9		29 "	"	192	"	9.45	3.95	3.95	38.2	
10		30 "	"	216	"	9.65	4.15	4.15	40.0	
11		31 "	"	240	"	9.85	4.35	4.35	42.0	
12		1 Aug	"	264	"	10.1	4.6	4.6	44.5	
13		2 "	"	288	"	10.35	4.85	4.85	46.8	
14		3 "	"	312	"	10.55	5.05	5.05	48.9	
15		4 "	"	336	"	10.8	5.3	5.3	51.2	
16	*	5 "	"	360	"	10.9	5.4	5.4	52.2	66.2
17		6 "	"	384	"	10.9	5.4	5.4	52.2	
18										
19										
20										
21										
22										
23										
24										
25										

Remarks: * These conditions are taken as saturated

MLIT-232

Sheet No. 62

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Moisture absorption test of zonolite concrete blocks of different dry densities in humid chamber for perimeter insulation test.

Observers: Mohsinul Huq

Date July-Aug, 1954.

No.	Specimen No.	Date of observation	Time of observation	Hours lapsed	Temp. inside Chamber	Absolute wt. (lbs)	Increase in wt. (lbs)	Absolute Moisture absorbed (lbs)	Moisture absorbed % by vol.	Density at saturated state (lbs/cft.)
1	#4	21 July	4 P.M	0	150	4.8	0	0	0	
2		22 "	4 "	24	150	4.9	·1	·1	·965	
3		23 "	4 "	48	150	5.0	·2	·2	1.93	
4		24 "	4 "	72	180	5.8	1.0	1.0	9.65	
5		25 "	4 "	96	"	7.1	2.3	2.3	22.2	
6		26 "	4 "	120	"	8.1	3.3	3.3	31.8	
7		27 "	4 "	144	"	8.7	3.9	3.9	37.6	
8		28 "	4 "	168	"	8.95	4.15	4.15	40.0	
9		29 "	4 "	192	"	9.15	4.35	4.35	42.0	
10		30 "	4 "	216	"	9.4	4.6	4.6	44.5	
11		31 "	4 "	240	"	9.65	4.85	4.85	47.7	
12		1 Aug.	4 "	264	"	9.9	5.1	5.1	49.2	
13		2 "	4 "	288	"	10.15	5.35	5.35	51.6	
14		3 "	4 "	312	"	10.4	5.6	5.6	54.0	
15		4 "	4 "	336	"	10.65	5.85	5.85	56.5	
16	*	5 "	4 "	360	"	10.75	5.95	5.95	57.5	64.5
17		6 "	4 "	384	"	10.75	5.95	5.95	57.5	
18										
19										
20										
21										
22										
23										
24										
25										

Remarks: * Saturated state

MLIT-232

Sheet No. 63

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Moisture absorption test of Zonolite Concrete blocks of different dry densities in humid Chamber for Perimeter insulation test.

Observers: Mohsinul Hug

Date July - Aug, 1954

No.	Specimen No.	Date of observation	Time of observation	Hours lapsed	Temp. inside Chamber (°F)	Absolute wt. (lbs)	Increase in wt. (lbs)	Absolute Moisture absorbed (lbs)	Moisture absorbed % by vol.	Density at saturated state (lb/cft)
1	#5	21 July	4 P.M.	0	150	4·25	0	0	0	
2		22 "	4 "	24	150	4·25	0	0	0	
3		23 "	4 "	48	150	4·25	0	0	0	
4		24 "	4 "	72	180	5·45	1·2	1·2	11·6	
5		25 "	4 "	96	"	6·9	2·65	2·65	25·6	
6		26 "	4 "	120	"	8·0	3·75	3·75	36·2	
7		27 "	4 "	144	"	8·5	4·25	4·25	41·0	
8		28 "	4 "	168	"	8·75	4·5	4·5	43·5	
9		29 "	4 "	192	"	8·9	4·65	4·65	44·9	
10		30 "	4 "	216	"	9·1	4·85	4·85	46·8	
11		31 "	4 "	240	"	9·3	5·05	5·05	48·7	
12		1 Aug	4 "	264	"	9·55	5·3	5·3	51·2	
13		2 "	4 "	288	"	9·8	5·55	5·55	53·5	
14		3 "	4 "	312	"	10·05	5·8	5·8	56·0	
15		4 "	4 "	336	"	10·25	6·0	6·0	58·0	
16	*	5 "	4 "	360	"	10·45	6·2	6·2	59·9	63·2
17		6 "	4 "	384	"	10·45	6·2	6·2	59·9	
18										
19										
20										
21										
22										
23										
24										
25										

Remarks: * saturated state

MLIT-232

Sheet No. 64

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Moisture absorption test of Zonolite Concrete blocks of different dry densities in water bath for perimeter insulation test.

Observers: Mohsinul Huq

Date July - Aug, 1954

No.	Specimen No.	Date of observation	Time of observation	Hours lapsed	Room temp. °F	Absolute weight (lbs)	Increase in weight (lbs)	Absolute Moisture absorbed (lbs)	Moisture absorbed Percent by volume	Density at saturated state (lb/cft)
1	#1	21 July	2 P.M.	0	71	7.36	0	0	0	
2		22 "	"	24	68	10.36	3.0	3.0	29	
3		23 "	"	48	68	11.9	4.54	4.54	43.7	
4		24 "	"	72	70	12.36	5.0	5.0	48.2	
5	*	25 "	"	96	72	12.75	5.39	5.39	52.0	76.7
6		26 "	"	120	76	12.75	5.39	5.39	52.0	
7										
8										
9	#2	21 July	2 P.M	0	71	5.75	0	0	0	
10		22 "	"	24	68	9.25	3.5	3.5	33.8	
11		23 "	"	48	68	10.8	5.05	5.05	49.6	
12		24 "	"	72	70	11.0	5.25	5.25	53.6	
13	*	25 "	"	96	72	11.75	6.00	5.00	55.5	71.6
14		26 "	"	120	76	11.75	6.00	5.00	55.5	
15										
16										
17	#3	21 July	2 P.M.	0	71	5.50	0	0	0	
18		22 "	"	24	68	8.90	3.40	3.4	32.8	
19		23 "	"	48	68	10.50	5.00	5.0	49.2	
20		24 "	"	72	70	10.70	5.20	5.2	53.0	
21	*	25 "	"	96	72	11.30	5.80	5.8	55.0	68
22		26 "	"	120	76	11.30	5.80	5.8	55.0	
23										
24										
25										

Remarks: * These are taken as saturated Condition.

MLIT-232

Sheet No. 65

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Moisture absorption test of zonolite Concrete blocks of different dry densities in water bath for perimeter insulation test

Observers { Mohsinul Huq

Date July - Aug. 1954.

No.	Specimen No.	Date of observation	Time of observation	Hours lapsed.	Room temp. °F	Absolute weight (lbs)	increase in weight (lbs)	Absolute Moisture absorbed (lbs)	Moisture absorbed Per cent by volume	Density at saturated state (lbs/cft)
1	#4	21 July	2 P.M	0	71°F	4.8	0	0	0	
2		22 "	"	24	68	8.5	3.7	3.7	35.2	
3		23 "	"	48	68	10.3	5.5	5.5	54.0	
4		24 "	"	72	70	10.8	6.0	6.0	57.0	
5		25 "	"	96	72	10.9	6.1	6.1	59.1	
6	*	26 "	"	120	76	10.95	6.15	6.15	60.0	66.2
7										
8										
9	#5	21 July	2 P.M.	0	71	4.25	0	0	0	
10		22 "	"	24	68	8.05	3.8	3.8	36.7	
11		23 "	"	48	68	10.00	5.75	5.75	55.5	
12		24 "	"	72	70	10.45	6.2	6.2	59.8	
13	*	25 "	"	96	72	10.75	6.5	6.5	62.6	64.5
14		26 "	"	120	76	10.75	6.5	6.5	62.6	
15										
16										
17										
18										
19										
20										
21										
22										
23										
24										
25										

Remarks: * These are taken as saturated condition.

MLIT-232

Sheet No. 66

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of *Flexural test on 8"x2"x2" zonolite concrete blocks of different dry densities in bone dry state in Perimeter insulation test.*

Observers: *Mohsinul Huq*

Date *July*, 19*54*

Specimen No.	No. of observation	Deflection readings (div)	Mean Defl. reading (div)	Load at failure 'P' (lbs)	Mean load at failure 'P_m' (lbs)	Moment of Inertia 'I' (in^4)	Distance of extreme fibre from Axis 'e' (in)	Length between supports 'L' (in)	Modulus of rupture at mean Load $P_m = \frac{P_m x L x e}{4 I}$
#1	1	31		570		1·33	1	6	
	2	29·5	30·15	545	555	"	"	"	625
	3	30		550		"	"	"	
#2	1	27		500		"	"	"	
	2	26	26	480	480	"	"	"	540
	3	25		460		"	"	"	
#3	1	24		445		"	"	"	
	2	26	24·3	480	451·6	"	"	"	508
	3	23		430		"	"	"	
#4	1	11		200		"	"	"	
	2	14·5	13	270	240	"	"	"	270
	3	13·5		250		"	"	"	
#5	1	7		75		"	"	"	
	2	4	5·6	110	105	"	"	"	118
	3	6		130		"	"	"	

Remarks:

MLIT-232 Sheet No. 67

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Flexural test on 8"x2"x2" Zonolite Concrete blocks of different dry densities in saturated state for perimeter insulation test.

Observers Mohsinul Huq

Date July, 1954.

No.	Specimen No.	No. of observation	Deflection Reading (Div)	Mean deflection reading (Div)	Load at failure P (lbs)	Mean Load at failure P_m (lbs)	Moment of Inertia I (in⁴)	Distance neutral axis to extreme fibre 'e' (in)	Length between supports 'L' (in)	Modulus of rupture at mean Load = $\frac{P_m \times L \times e}{4I}$
1	#1	1	37.		680		1.33	1	6	
2		2	36	35	665	646.6	"	"	"	726
3		3	32		595		"	"	"	
4										
5										
6	#2	1	31		570		"	"	"	
7		2	33	32.8	610	605	"	"	"	690
8		3	34.5		635		"	"	"	
9										
10										
11	#3	1	28		520		"	"	"	
12		2	32	31.3	580	576.6	"	"	"	648
13		3	34		630		"	"	"	
14										
15										
16	#4	1	24		425		"	"	"	
17		2	23	22	430	375.0	"	"	"	422
18		3	19		250		"	"	"	
19										
20										
21	#5	1	12		220		"	"	"	
22		2	15	14.3	280	165	"	"	"	185
23		3	16		295		"	"	"	
24										
25										

Remarks:

MLIT-232 Sheet No. 68

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Compression test on 2" diameter 6" long Zonolite Concrete cylindrical blocks of different dry densities at the bone dry state in Perimeter insulation test

Observers Mohsinul Huq

Date July, 19 54

Specimen No.	No. of observation	Load at failure 'P' (lbs)	Mean load at failure P_m (lbs)	Area 'A' (in²)	Compressive stress $\frac{P_m}{A}$ " (lbs/in²)
#1	1	1140		3.14	
	2	990	1100	"	350
	3	1170		"	
#2	1	730		"	
	2	790	780	"	248
	3	820		"	
#3	1	700		"	
	2	720	720	"	229
	3	740		"	
#4	1	450		"	
	2	400	420	"	134
	3	390		"	
#5	1	200		"	
	2	210	210	"	67
	3	220		"	

Remarks:

MLIT-232

Sheet No. 69

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Compression test on 2" diameter 6" long Zonolite Concrete Cylindrical blocks of different dry densities at saturated state in Perimeter insulation test.

Observers Mohsinul Huq

Date July, 1954.

No.	Specimen No.	No. of observation	Load at failure 'P' (lbs)	Mean load at failure 'P_m' (lbs)	Area 'A' (in^2)	Compressive stress $= P_m/A$ (lb/in^2)
1	#1	1	1420		3·14	
2		2	1430	1420	"	453
3		3	1410		"	
4						
5						
6	#2	1	1140		"	
7		2	1090	1100	"	350
8		3	1070		"	
9						
10						
11	#3	1	1050		"	
12		2	1045	1060	"	338
13		3	1075		"	
14						
15						
16	#4	1	830		"	
17		2	825	830	"	264
18		3	835		"	
19					"	
20						
21	#5	1	640		"	
22		2	585	600	"	192
23		3	575		"	
24						
25						

Remarks:

MLIT-232

Sheet No. 70

MECHANICAL ENGINEERING LABORATORY
MICHIGAN STATE COLLEGE

Running Log of Specific heat test of zonolite Concrete block 1"x1"x1" of different dry densities for the Perimeter insulation test.

Observers: Mohsinul Huq

Date Aug, 1954.

Specimen No.	No. of observation	Wt. of Calorimeter and stirer (gms)	Wt. of water (gms)	Wt. of the block (gms)	Temp. of water and Calorimeter (°F)	Temp of the body (°F)	Temp. of the mixture (°F)	Specific heat of calorimeter (B.T.U/lb/°F)	Specific heat of water (B.T.U/lb/°F)	Specific heat of the block (B.T.U/lb/°F)	Mean specific heat of the block (B.T.U/lb/°F)
#1	1	176	250	11.65	71	200	74	.0919	.998	.322	
	2	″	″	″	70	200	72.8	.0919	.998	.32	.322
	3	″	″	″	70	200	74.2	.0919	.998	.324	
#2	1	″	″	9.1	72	200	74.5	.0919	.998	.3	
	2	″	″	″	73	200	74.7	.0919	.998	.305	.3
	3	″	″	″	70	200	73	.0919	.998	.295	
#3	1	″	″	8.75	70	200	74.2	.0919	.998	.31	
	2	″	″	″	65	200	69	.0919	.998	.30	.305
	3	″	″	″	72	200	76	.0919	.998	.31	
#4	1	″	″	7.6	72	200	75.2	.0919	.998	.276	
	2	″	″	″	71	200	74	.0919	.998	.27	.276
	3	″	″	″	76	200	79.8	.0919	.998	.282	
#5	1	″	″	6.7	71	200	75.5	.0919	.998	.26	
	2	″	″	″	70	200	76	.0919	.998	.269	.26
	3	″	″	″	72	200	75	.0919	.998	.251	

Remarks:

BIBLIOGRAPHY

1. Dill, Richard S., W. C. Robinson and H. E. Robinson, Measurement of Heat Losses from Slab Floors, U. S. National Bureau of Standards, Washington Building Material & Structures Reports B. M. S. 103, 1945.

2. Bareilher H. D. and J. T. Landrum, Concrete Floors and Basementless Houses, Small Homes Council, Univ. of Illinois, Urbana, Bulletin F.43, 1948.

3. Jacob, Max, Heat Transfer, Vol. I, 1949.

4. Jacob, Max & G. A. Hawkins, Elements of Heat Transfer and Insulation, 1942.

5. Wilkes, G. B., Heat Insulation, 1950.

6. MacLean, J. D., Thermal Conductivity of Wood, Heating, Piping, & Air Conditioning, Vol. 13, 1941.

7. Bosworth, R. C. L., Heat Transfer Phenomenon.

8. Devienne, M., Effect of Moisture on Thermal Conductivity of Grannular Materials, C. R. Acad. Sci. Paris, 1948.

9. Hechler, F. G., E. R. McLaughin, E. R., E. R. Queer, Simultaneous Heat and Vapour Transfer Characteristics of an Insulating Material, A.S.H.V.E. Transactions, Vol. 48, 1942.

10. Treichler, W. W., Jr., Investigation of the Heat Transmission and Mechanical Properties of Several Types of Perimeter Insulation Under Dry and Saturated Condition. M. S. Thesis, Michigan State College, 1953

11. Ingersol, L. R., & O. J. Zobel, Mathematical Theory of Heat, Boston, 1913.