UNIVERSITY OF ROORKEE,
ROORKEE (U.P.)

Certified that the attached dissertation on........ In-Place Testing of
.... Insulated Systems." ....
was submitted by
.... Sri G.K. Sharma. ....
and accepted for the award of Degree of Master of Engineering in ....." Applied Thermodynamics
..............(Refergeration & Air Conditioning) ....
....
vide Notification No. .... Ex/82/E-218 (Exam)/1965 ....
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Dated........ October 21, 1965 ....

(S.S. Srivastava)
Assistant Registrar (Exam.)

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IN - PLACE TESTING OF INSULATED SYSTEMS

THESIS
submitted in partial fulfilment of the
requirements for the degree of
MASTER OF ENGINEERING
IN
Applied Thermodynamics — Refrigeration & Airconditioning

GOPAL KRISHAN SHARMA

DEPARTMENT OF MECHANICAL ENGINEERING
UNIVERSITY OF ROORKEE
ROORKEE (INDIA)

September, 1963

C E R T I F I C A T E

Certified that the dissertation entitled "In-place testing of insulated systems" which is being submitted by Sri Gopal Krishan Sharma as a partial fulfilment of the requirement for the degree of Master of Engineering in Mechanical Engineering of the University of Roorkee, is a record of bonafide work carried out by him under my supervision and guidance. The results embodied in this thesis have not been submitted for award of any other degree or diploma.

This is to certify further that he has worked for a period of four and half months for the Master of Engineering Thesis at the University of Roorkee.

B. C. Raychaudhuri
26/9/63

(B. C. Raychaudhuri)
Senior Scientific Officer,
Head of Heat Transfer Section,
Central Building Research Institute,
R O O R K E E (India)

Roorkee
Dated
September 26, 1963.

A C K N O W L E D G E M E N T S

The work has been done under the able guidance of Sri B.C.Raychaudhuri , Senior Scientific Officer, Head of Heat Transfer Section, Central Building Research Institute, Roorkee onme part time teacher at University of Roorkee, whose deep theoretical background coupled with his vast practical experience in the field of heat transfer, spread over a span of many years, has been of great utility and the author wishes to express his deep and sincere gratitude to him for the same.

The author is highly indebted to Prof. M.V.Kamlani, Head of Mechanical Engineering Department and Sri Rajendra Prakash, Reader in Mechanical Engineering Department for extending facilities for carrying out this work and encouraging from time to time.

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C O N T E N T S

S U M M A R Y

In-place test studies on glass wool insulated six inches thick wall of a cold storage, conducted at University of Roorkee during summer monsoon in 1963, revealed remarkable variations of apparent conductivity 'k' with packing density. The heat transfer across the wall was measured by means of heat-flow-meters put at exterior and interior faces and temperature distribution was measured by means of several thermo couples placed at the faces and in the body of the insulation. The temperature distribution curves were plotted and by drawing tangents at the inter-faces dt/dL values were obtained. Fourier's Law of steady state heat conduction was applied to obtain thermal conductivity by dividing heat flow rate by dt/dL. Three days' time was given before recording the data to ensure that the insulation was nearly in thermal equilibrium. The temperature distribution curves in all the cases were convex upward (when T as ordinate L as abscissa), thereby giving a steeper temperature gradient on cold side. For a practically constant rate of heat flow this meant a decreased 'k' value at low temperature. At any packing density the conductivity was found higher at higher temperature.

The effect of packing density on 'k' value was also observed. Densities were changed by removing or adding the insulation layers. Moisture contents in the insulation were obtained for every set of packing density by taking insulation samples from both the cold and hot sides in air tight glass weighing bottles and calculating the percentage loss in weight after drying at 105 deg. C in the oven. It was observed that as the density increased conductivity decreased till a density of 4.125 lbs/cubic feet was reached when it was minimum 0.336 BTU inch/sq. ft. hr. deg. F at 85 deg. F, and 0.241 at 42 deg. F. The average moisture content at 85 deg. F mean temperature was 0.3% while that at 42 deg. F mean temperature was 7.0%. Any further increase in density resulted in increase of conductivity. When the density was reduced to 2.25 tons/cu. ft., the conductivity increased to 0.590 that is 75.6% at 85 deg. F and to 0.336 that is 39.4 percent at 42 deg. F. A greater rise at 85 deg. F being attributed to radiation effect being greater at higher mean temperatures. The above results were obtained from innbtion slabs without using any vapour barier and where 85 deg. F indicated the hot face temperature while 42 deg. F indicated the cold face temperature. Three densities were tried with the use of vapour barrier on the hot side while the cold side was kept exposed to the refrigerated space. For changing the packing density the vapour barrier was removed and again put every time. Because of partial removal of moisture the conductivity decreased from those at the same packing density and without vapour barrier. At the density of 4.125 lbs/cu.ft. the conductivity decreases from 0.336 to 0.334 that is 0.6% at 81 deg. F for a decrease of 0.11 % in moisture and from 0.241 to 0.225, that is 6.6% at 42 deg. F for a decrease of 1.4 % in moisture content, temperature dependency of 'k' being neglected between 81 deg. F and 85 deg. F.

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INTRODUCTION

There are many factors and conditions which effect the thermal conductivity of insulating materials. Some of these are within the materials themselves, some are result of conditions under which heat transfer takes place and other s are within the mechanism by which heat is transferred through the material. Some of the factors inherent in the material are structure, density and moisture content. Some of those which may be attributed to conditions under which heat is transferred are mean temperature and in some cases orientation of test sample. Most changes which effect the overall rate of heat transfer, through the sample will also disturb the relationship between the amounts given off by radiation, convection or conduction. An analysis of the effect on thermal conductivity of a given material caused by changing any one of the foregoing factors may thus become very complicated. For instance, increasing the density of a material may either increase or decrease its thermal conductivity depending upon the structure of the material and the range over which the density is changed. The moisture content will have a greater effect on the thermal conductivity of some materials than on others . Likewise the orientation of a sample, that is, the direction of heat flow through the sample may have a major effect on some samples while on others there may be no effect what-so-ever.

As is well known, heat is transferred through most insulating materials by a combination of conduction, convection and radiation. Any change in the structure, density or moisture content of the sample or variation of test conditions will usually affect differently the rate of heat transfer by various methods. The overall effect may be one of increasing or decreasing the conductivity.

The purpose of the work described here was to set up test conditions and to provide apparatus by which in-place test studies be conducted on glass wool insulated six inches thick cold storage wall. No attempt was made to cover a long list of factors affecting the thermal conductivity so as to furnish a complete analysis of the conductivity as affected by these factors. However, the variation of thermal conductivity with density of packing with and without vapour barrier so as to include the effect of moisture was thoroughly studied.

The use of laboratory thermal conductivities was questioned due to the effect of moisture distribution within the insulating walls. Moreover the thermal conductivity tests made in the laboratory will not tell the true story of the performance of the insulating materials under actual conditions of usage because of difficulty rather impossibility of duplicating field conditions in the laboratory.

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METHOD USED.

Glass wool is a fibrous material with a large amount of air in a continuous air type of arrangement. Heat is transferred across the air spaces by radiation, conduction, and (or) convection. If the open spaces are small, as would occur when tightly packed, the transfer of heat is by radiation across the space, by conduction of air in the air space, and by solid conduction of fibres. With relatively small temperature drops across the air spaces, the heat transfer through the whole mass may be taken as by conduction. But in case of loosely packed wool the radiation becomes an important factor with a greater temperature difference across the air spaces. Furthermore, convection currents are also set up. In such a case, a coefficient of conductivity cannot correctly represent its apparent conductivity. Since it has been a common practice among engineers to employ a 'k' valye for all sorts of materials, the total heat transmitted by all the modes will be taken as conducted through the insulation and Fourier's equation of heat flow would be applicable. The

'k' value will in a true sense be $k_{apparant}$
The method will be to determine rate of heat transfered by heat-meter and the temperature gradient in the wall by thermo - couples placed at different depths into the insulation.

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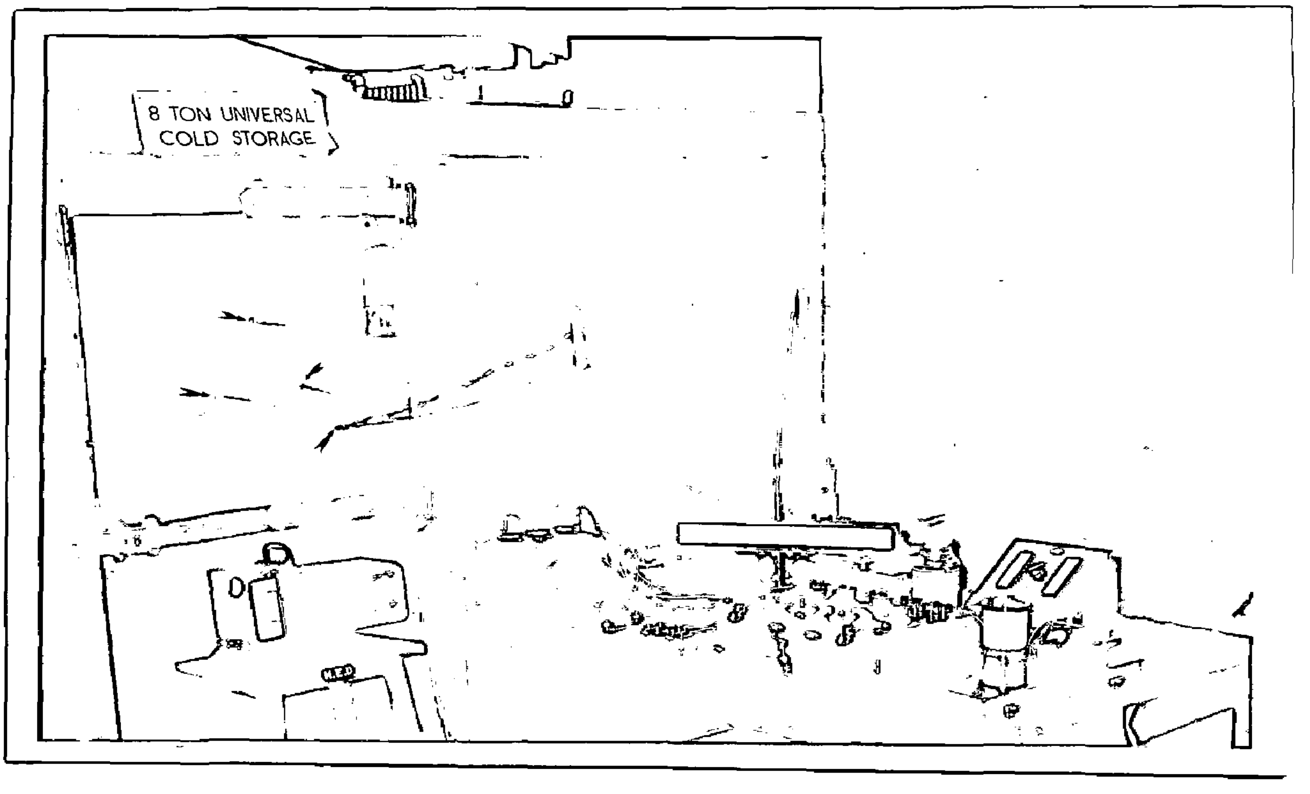
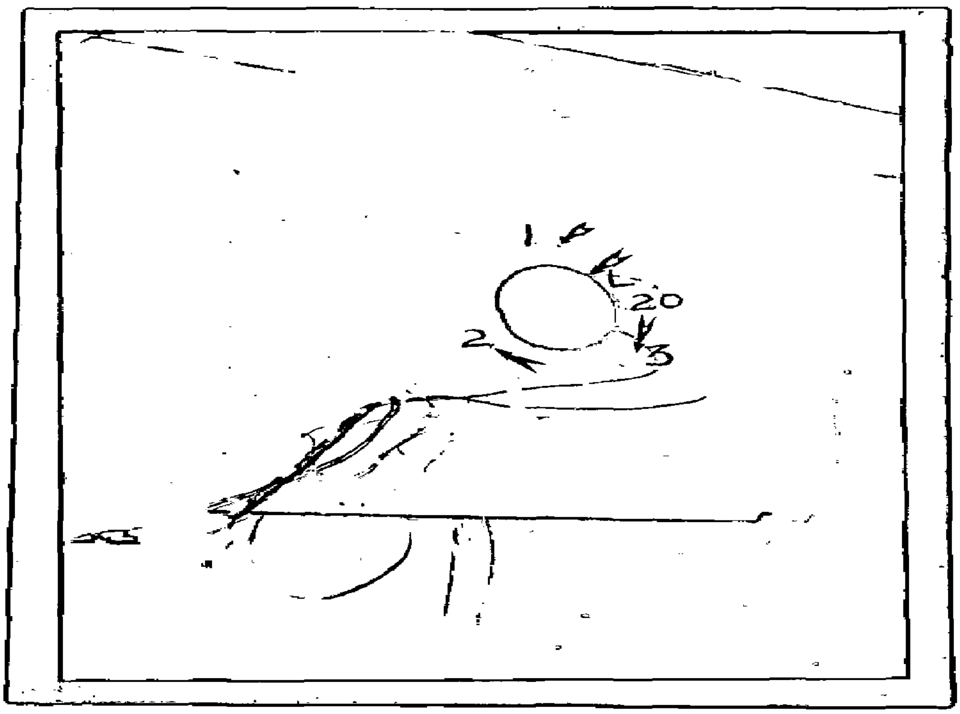


- VIEW OF THE COMPLETE EXPERIMENTAL [illegible]

DESCRIPTION OF APPARATUS :

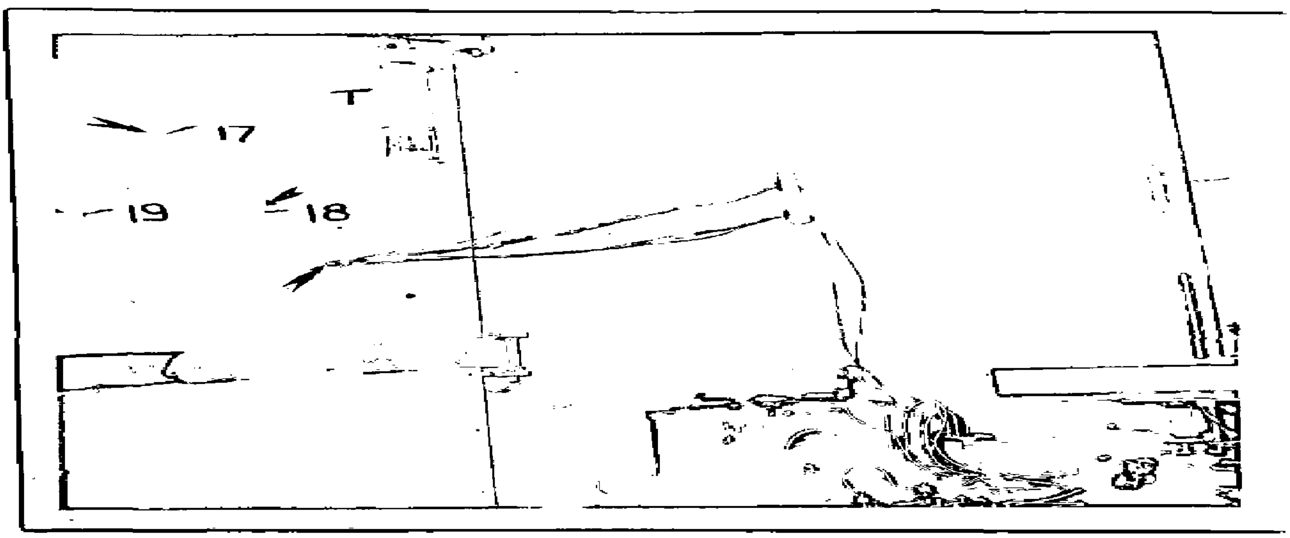
The cold storage on which tests were conducted was of eight tons capacity. This was a walk-in-type cooler and housed inside the laboratory room. The dimensions of the cold room were 12 x 12 x 6½ cu. ft. and of its door were 6 x 2½ x ½ cu. ft. The upper half portion of the door was used as the test pannel. The metallic sheets from both sides of the door were replaced by ¼" thick plywood boards. The insulation was held in position in the panel by these two plywood boards which were secured to the frame of the door by wood screws. The inner board was screwed permanently while the hot side one was removable for the purpose of adding or removing insulation from the test pannel to vary the packing density. Heat flow through the insulation was measured by the use of heat-meters.

A heat-meter(1) is composed of multi-junction thermopile arranged in a bakelite slab. The thermopile consists of a series of thermo couples so positioned that one set of junctions (hot junctions) is in a plane adjacent and parallel to one face of the bakelite slab;



F[illegible] - I[illegible] VIEW OF THE
OU[illegible] PLYWOOD BOARD
S[illegible]G CIRCULAR HEAT
FL[illegible]TER . 'L' IS ONE
OF T[illegible]O LEADS OF
THE HEAT FLOW METER
AND '20' IS THE EMBEDDED
THERMOCOUPLE,(1,2,3)
ARE THE EXTERIOR I[illegible]
FACE THERMOCOUPLES.

the other set of junctions ("Cold junctions") is in a plane adjacent and parallel to the other face of the slab. Heat flow through the slab generates an electromotive force due to difference in temperature between the hot and cold junctions of the thermopile. Each heat-meter is calibrated by means of guarded-hotplate arrangement and the calibration constant in B.T.U. per hour sq. ft mv is determined for a given value of heat-meter temperature which is obtained from thermocouple embedded in the heat-meter. The change in thermopile electromotive force due to temperature occurs in a consistant manner; correction from the base calibration temperature may be represented by the help of a curve. Two heat meters were used one at the exterior interface and one at interior interface to measure the heat entering and leaving the wall. A proper thermal contact between the heat-meter and the board surface was obtained by using a very thin soft cloth under the meter plates, and by pressing the heat meter firmly against the board. The cloth also facilitated heat-meter removal, after completing the work, without any damage to its contact surface with the board. A mild adhesive like quickfix was used and a

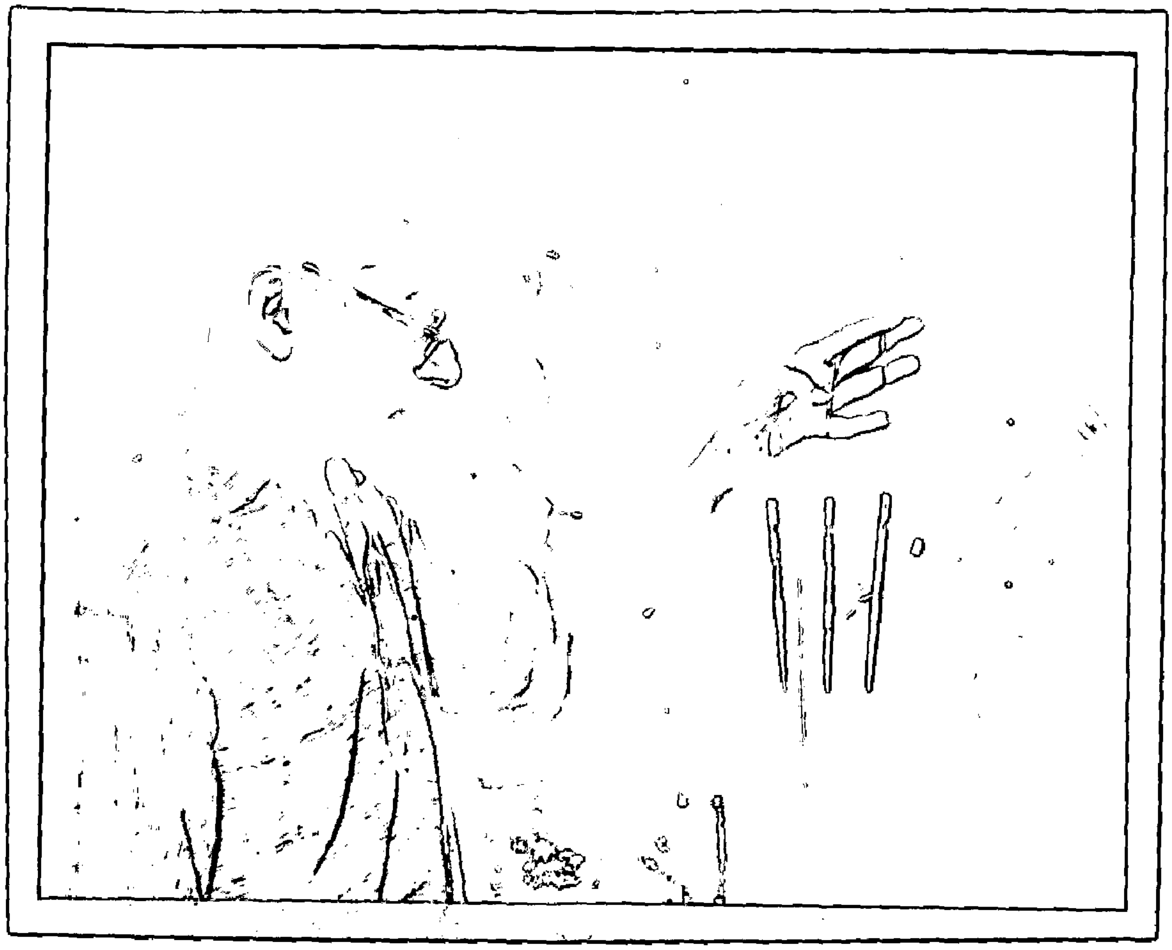


3. THERMOCOUPLES (1
19) HANGING ON
PEGS; T° S
AND WET BUL
RMOMETERS.

definite precaution was taken not to allow any air film getting entrapped between the meter and the board. If this be not prevented, the air film would cause the heat-meters readings to be incorrect.

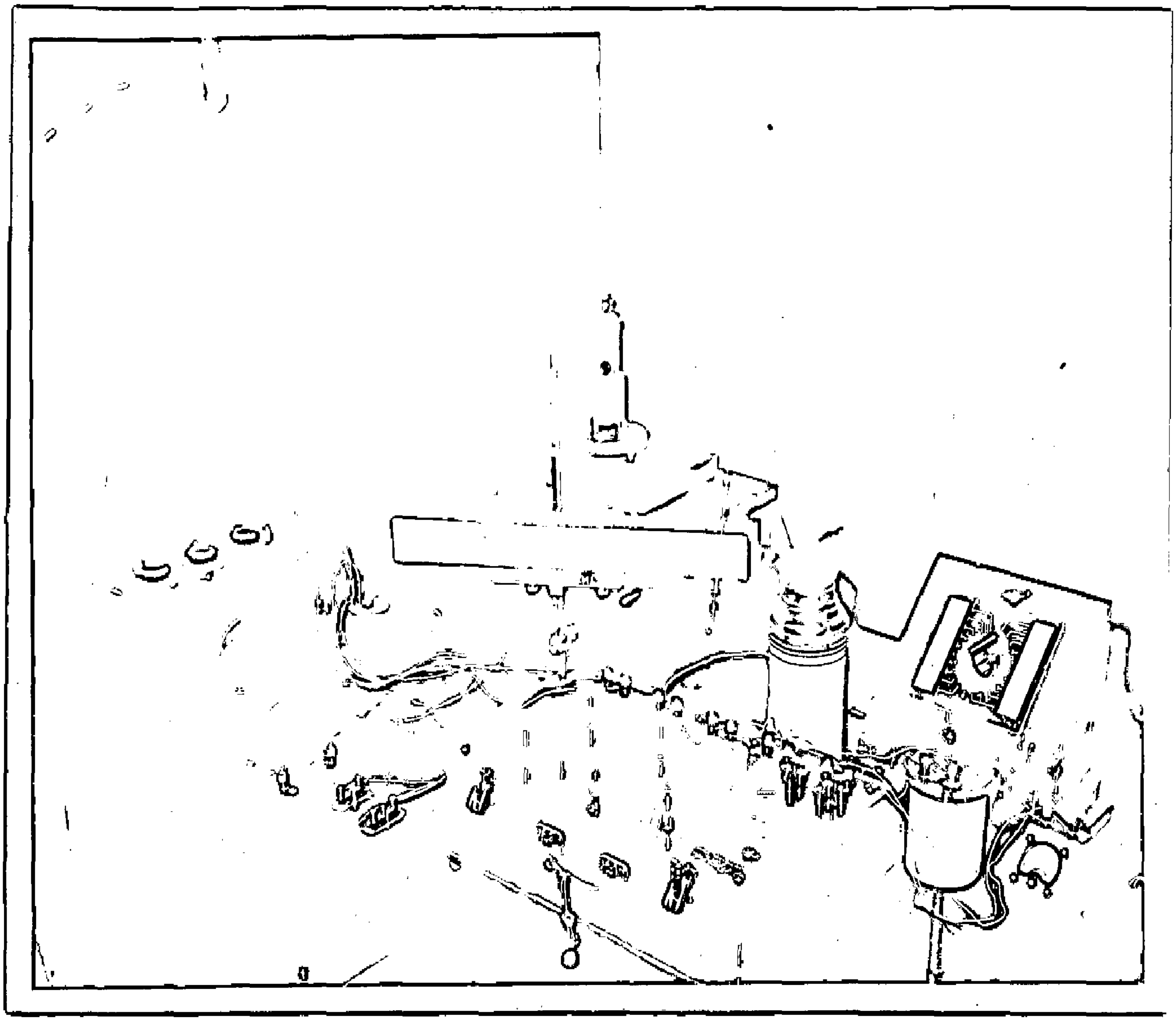
The hot side meter had a constant of 23.2 BTU/ hr. sq. ft. mv. at 85 deg. F and the cold side meter had a constant of 11.77 BTU/ hr. sq. ft. mv. at a temperature of 42 deg. F. as corrected for the temperatures mentioned with the help of temperature correction curves. These values were supplied by the heat transfer section of Central Building Research Institute Roorkee, through the courtesy of which these heat meters were obtained.

Copper-constantan thermo-couples were used for measuring various temperatures. To determine the temperature distribution across the insulation, thermocouples were put at the two interfaces and at one third points of the insulation pack. Ambient temperatures inside and outside were determined by keeping hot junctions at five inches distance from the boards into the space. Five inches long wooden pegs were fixed to the plywood with quickfix and hot junction



4. HANGI... ...UTHOR'S HAND ARE THREE ...
USED ... ...ING THERMOCOUPLES (11, ...
14, 15 ... ...ULATION BODY.

were kept at their projecting end. The thermo-couples for the interface temperature were placed on the plywood boards and kept in position by the adhesive tape, but slightly off the junction. A little of quickfix was used to keep the junctions in contact with the board. However, care was taken against the use of too much quickfix which would otherwise form an insulating coating on the hot junction. To put the body thermo-couples in place correctly, presented a problem. The easiest way and the one which was adopted was to use thin wooden skews of length 6 inches equal to the insulation thickness, which could be inserted into the insulation pack. The thermo-couples were fixed at one third points on the skew. Since wood with much higher thermal conductivity than the insulation, would effect the heat flow meter reading, the skew was not placed in the test space. Test space is the insulation field space enclosed by the heat- meters. Instead, three skews each with two thermo-couples at one third points were inserted into the insulation so as to form the edges of an imaginary symmetrical triangular prism enclosing the test space. The mean of the three in-place thermocouple readings was taken as the temperature in the test space at the position of that plane parallel to the



5. - MEASURI[illegible] [illegible]ENTS - IN THE BAC[illegible]
CAN BE S[illegible] [illegible]VANOMETER.

test surface. Likewise for the interfaces, three thermo-couples were put on each board in the pattern of a triangle with the hot junctions at vertices. For ambient temperatures also three pegs were fixed on each board. In all 20 (twenty) thermo-couples were used with relative position as shown in Fig. 6 .

The thermo-couples leads were connected through a twenty point selector switch to a manually operated potentiometer. The potentiometer had a least count of 0.1 micro volt and was thus sufficiently purposeful to read the emf. (0.171mv) generated corresponding to the lowest temperature encountered ; 40 deg. F. This is the temperature at which the cold storage was maintained. The electrical outputs of the heat-meters were also delivered to the same potentiometer.

The Galvanometer used was moving coil type with lamp and scale arrangement and had a sensitivity of 1 mm. / 3 micro volt., when scale was put at a meter distance from it. Six volt storage battery was used for the lamp and two volts were tapped from it for the potentiometer. A standard cell was used for the standardization of the potentiometer and crushed ice filled in a thermos flask was used as cold junction.

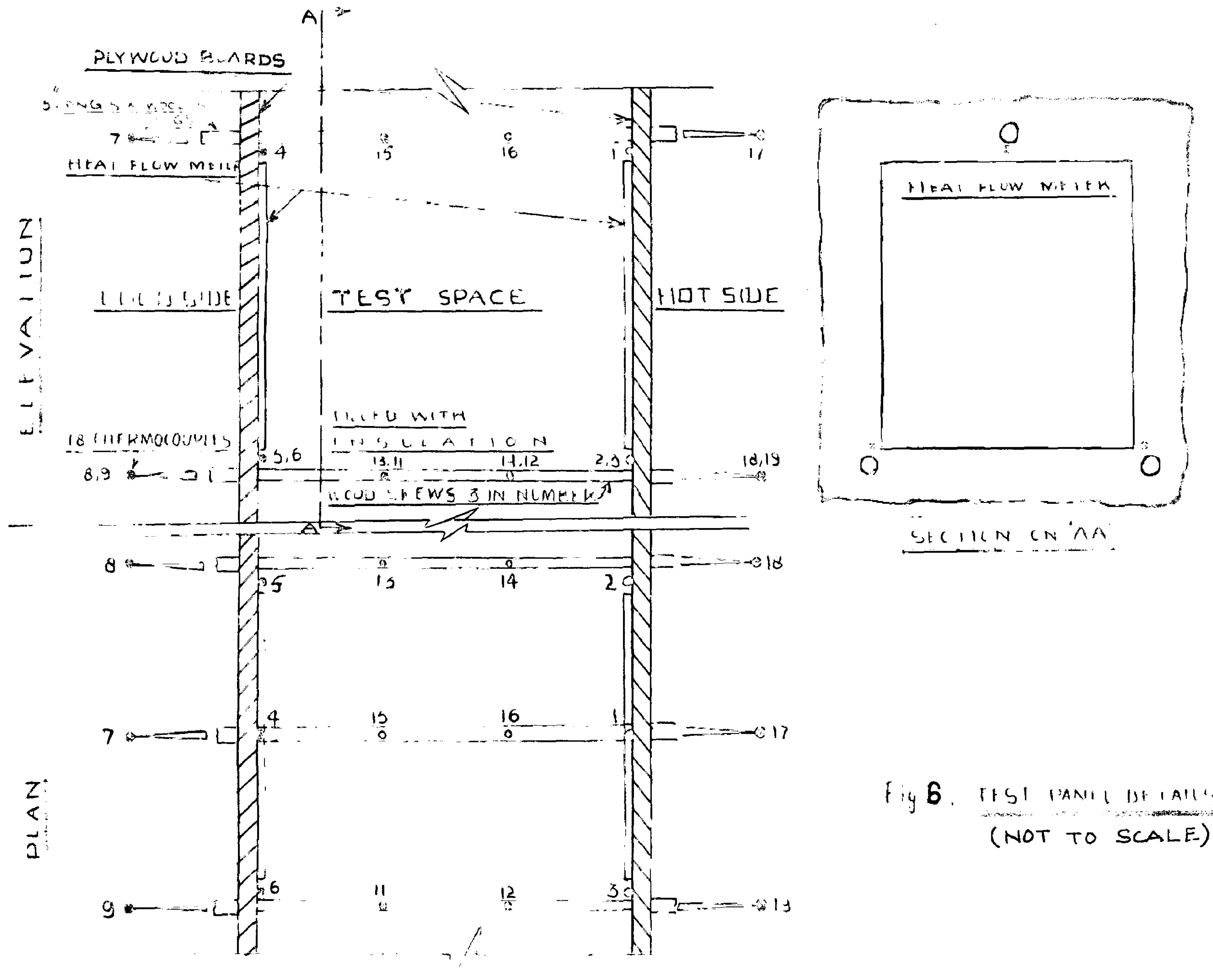


Fig 6. TEST PANEL DETAILS
(NOT TO SCALE)

DIMENSIONS & SPECIFICATIONS:

Item	Description.	Remarks.
Insulation	Glass wool	
Test panel	Face Area $= 2\frac{1}{3} \times 1\frac{3}{8}\ ft^2$ (net)	
	Width = 6 inch.	Kept same for all sets.
	Centre ht. above ground = 5 ft.	Kept same for all sets.
Temperature measurement	By Copper-Constantan thermo couples.	Cold junction temp. 32 deg. F (ice)
Heat flow rate measurement	By heat-flow-meters.	Exterior meter- Fabricated and calibrated by C.B.R.I, Roorkee 6 inch dia. 1/16 inch thick. Constant 22.2 BTU/hr.sq.ft mv at 125 deg. F. Interior meter - Manufactured by Bechkman and Whitley, U.S.A. 4½ inch. sq. plate. 1/16" thick. Constant 11.169 BTU/hr.sq.ft.mv at 80 deg. F.
E.M.F. measurement	By portable potentiometer, Galvanometer (moving coil)	Least count 0.1 micro volt. Sensitivity 1mm per 3 micro volts.
Time of the year.	Late Summer 1963 (Aug.-Sept.)	At such time variation in minimum and maximum temperatures is not much.
Place of In-Place tests on cold storage.	University of Roorkee (India)	30 deg. N. latitude.

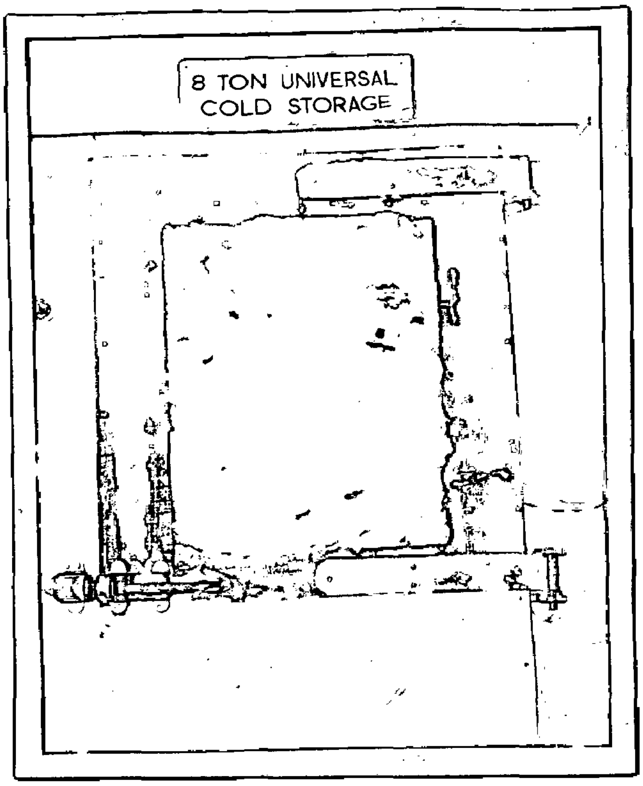
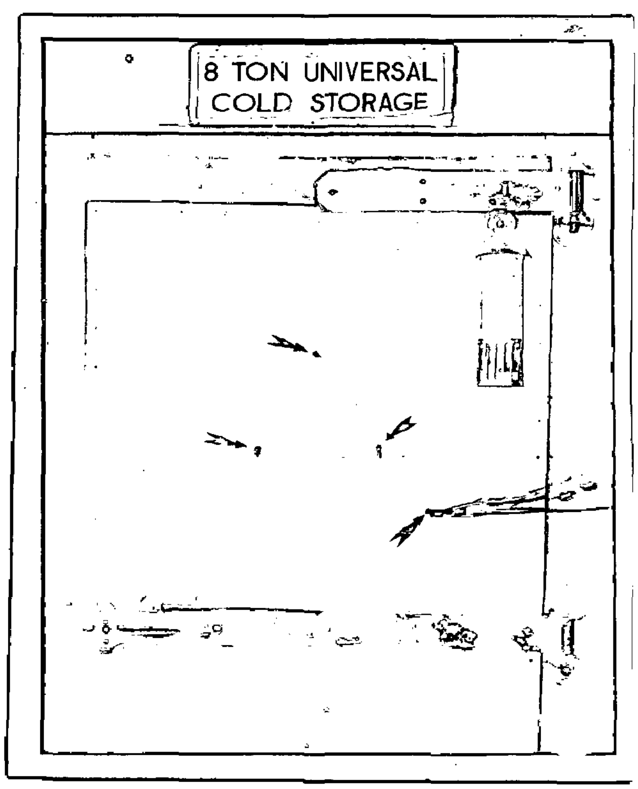


FIG. 7. GL... ...L PA...
TH... ...F PANEL



OUTER VI...
TEST PANEL.

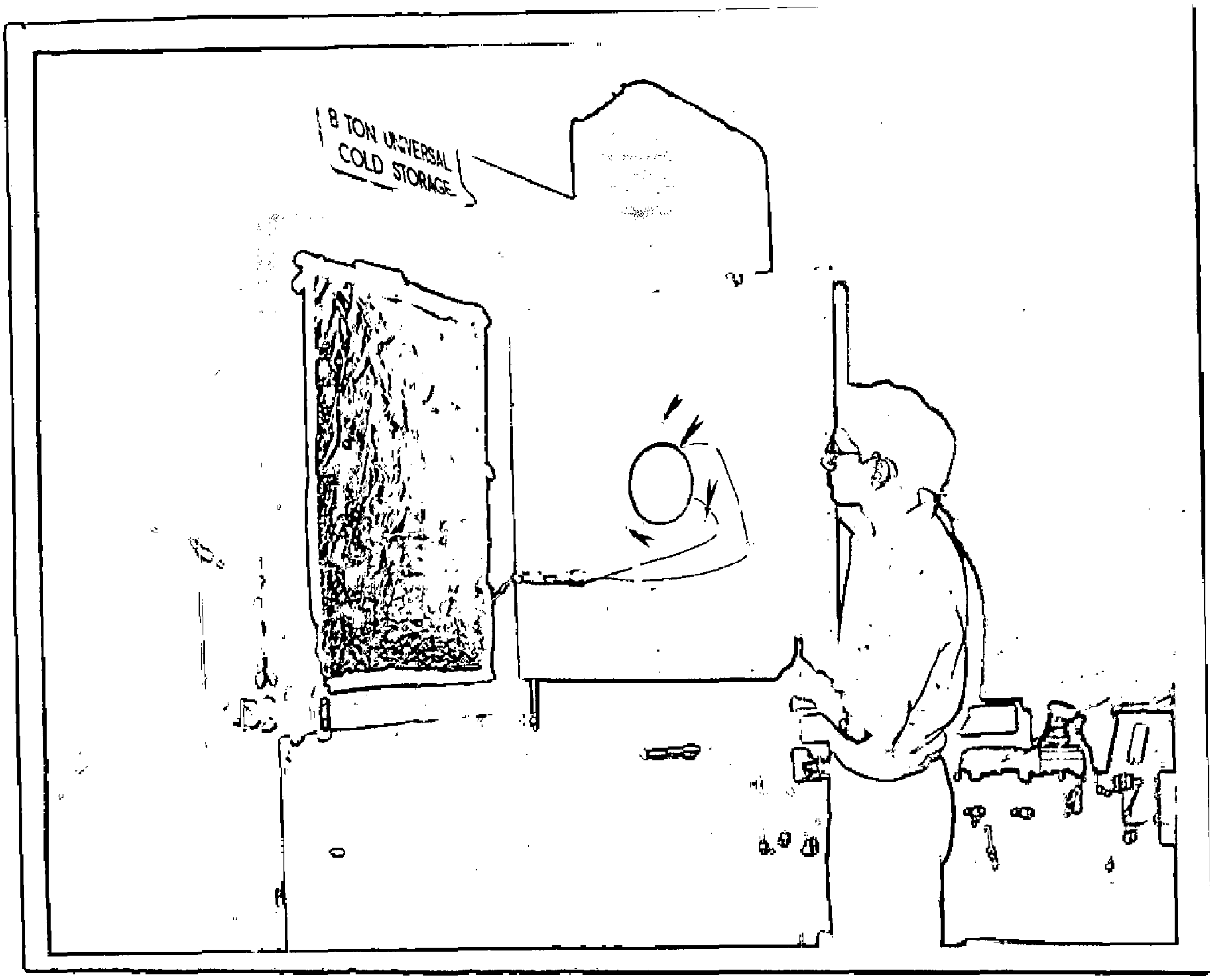
TEST PROCEDURE:

Before starting the plant the whole pack of insulation was removed from the panel and weighed accurately. The pack was then put back in the panel and three skews each carrying two thermo-couples were inserted at their position. The outer board was put in place and screwed to the frame of the door.

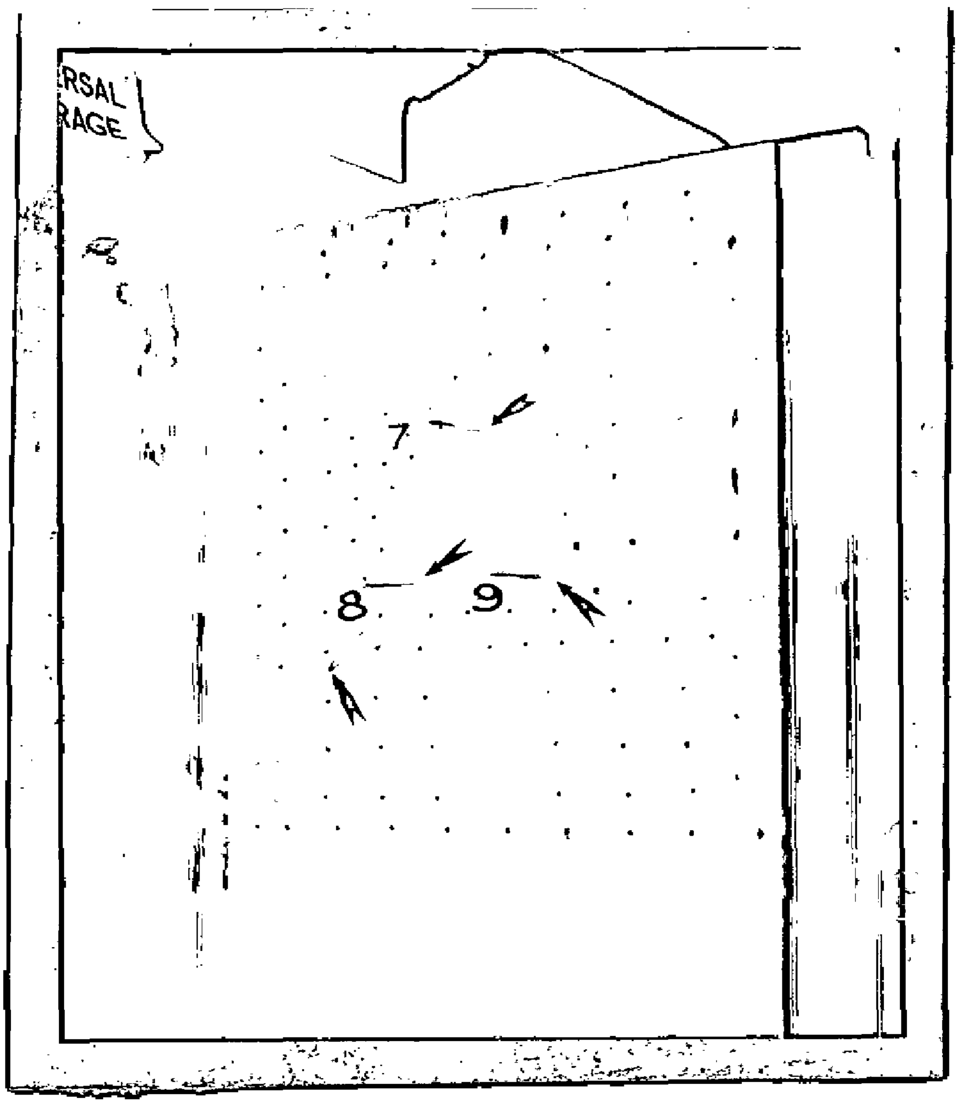
The plant was started . It maintained a temperature of 42.5 (±2.5) Deg. F. After 3 day's (to bring the insulation in thermal equilibrium) the various temperatures and heat flow rates were measured. Since there was a variation of 5 deg. F inside the cold storage, the reading were started just a fractional degree before 40 deg. F and continued till just a fractional degree after 40 deg. F. In all the true senses though the ambient inside temperature was not exactly 40 deg. F but the variation was too small a fraction of a degree to be detected on the temperature gauge with naked eyes. To a fair degree of engineering accuracy it was assumed, therefore, that all the readings were taken when the inside temperature was constant at 40 deg. F.

It was remarkable to note that the outside temperature was steady all the 24 hours with a very negligible variation of not more than 1 deg. F. It was firstly because of such a time (August-September) of the year when there was little differencein the maximum and minimum temperatures of the day and secondly due to the storage effect of the laboratory in which the plant was housed. Thus giving a stabilizing time of three days for each set and taking the readings at times when the internal ambient air temperature was close to 40 deg. F and with roughly constant outside ambient air temperature, would guarantee that the thermal state was more or less steady.

As a matter of fact it took slightly more than 15 minutes to read 20 thermo-couples and two heat-meter readings and since the inside temperature went sufficiently off 40°F during this time, only body thermo-couples (nos. 11,12,13,14,15 & 16) and interface thermocouples (Nos. 1,2,3,4,5 & 6) and heat-meter readings were taken. Inside ambient temperature was obtained from the temperature gauge provided on the plant and outside temperature from the thermometer hung outside near the outer face of the panel. These readings were however checked at times with the thermo-couple readings. Clock thermograph was used to find the 24 hours variations



9 - AUTHOR REMOVING THE OUTER BOARD CHANGING THE PACKING DENSITY. ALU... FOIL USED AS VAPOUR BARRIER ON THE O... FACE O... ...ATION PACK IS ALSO VISIBL...



10. I … D BOARD
WI … ES, (7, 8
9) THE … ERMCCOL
B WOOD

in the outside conditions and was also placed near the outerface of the panel.

Fourteen sets of readings were taken in a day at an interval of nearly one hour for one density of packing. After completing the set, the outer board was removed and swung aside as shown in Fig. 9. The glass wool samples from exterior and interior interfacesof the pack were taken in separate air tight weighing bottles for moisture content determination. The samples were dried at 105 deg. C for four hours in an electric oven and the loss in weight due to moisture removal was determined.

The packing density was calculated by dividing the weight of the pack by the volume of the panel which was nearly 2 cu. ft. (2.04 cu. ft. exactly) . Several densities of packing below and above the original one were tested and moisture contents determined for all.

The behaviour of the glass wool was studied with vapour barrier also. No vapour dam was used. A number of holes ¼" diameter were drilled in the inner board to let thevapours move out of the insulation into the cold space. A vapour barrier, aluminium foil sheet was put on the outer face of the pack to check the entry of vapour from outside into the insulation.

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Date 20th August, 1963.

SET NO. 1

(WITHOUT VAPOUR BARRIER)

Average outside Temp = 87 deg.F
Av. outside rel.Hum. = 60%
Av. moisture content = 3.6%
Av. Packing density = 3.5lbs/cu.ft.

Thermo-couple.	10hr.	11hrs.	12hrs.	13hrs	14hrs	16hrs	17hrs	18hrs	19hrs	22hrs	23hrs	24hrs	1hr.	2hr.	mv Mean	°F To
1.	1.170	1.163	1.175	1.178	1.165	1.169	1.168	1 .180	1.173	1.181	1.171	1.171	1.174	1.173		
2.	68	58	80	72	73	70	71	70	70	71	71	73	69	74	1.171	
3.	63	62	72	71	79	71	72	62	72	73	72	71	72	73		85
16	0.890	0.885	0.881	0.879	0.872	0.879	0.871	0.8 90	0.881	0.881	0.878	0.886	0.879	0.884		
14	82	74	72	81	65	75	78	81	79	85	72	79	85	80	0.879	
12	71	91	71	83	80	83	78	71	78	75	81	91	72	80		72
15	0.570	0.576	0.568	0.562	0.572	0.576	0.568	0.560	0.563	0.556	0.571	0.568	0.565	0.568		
13	75	71	61	73	76	59	58	70	59	61	66	59	69	52	0.565	
11	60	63	51	55	62	78	58	68	74	63	59	60	62	67		58
4	0.205	0.201	0. 204	0.216	0.228	0.202	0.215	0.231	0.221	0.219	0.216	0.214	0.219	0.216		
5	.23	09	19	15	06	04	19	28	25	18	16	23	20	17	0.216	
6	31	06	09	10	10	02	14	18	18	17	16	26	17	19		42
Heat-meter																
Outer	0.095	92	93	93	91	98	94	91	92	93	92	92	93	93	0.093	
Inner	0.181	80	78	78	77	79	73	78	82	79	79	75	77	76	0.178	

SET NO. 2

(WITHOUT VAPOUR BARRIER)

Date 23rd August, 1963.

Average outside Temp. = 86 deg.F.
Average outside Rel.Hum = 62%
Average Moisture content = 3.6%
Average packing density = 2.75lb/cu.ft.

Thermo couple	10 hrs.	11	12	13	14	16	17	18	19	22	23	24	1	2	mv. Mean	°F Temp
1	1.170	61	60	60	68	60	53	58	57	53	59	68	52	53		
2	1.171	68	71	62	72	58	54	62	56	50	59	62	54	56	1.161	84.5
3	1.173	63	69	59	61	52	58	60	62	50	58	58	48	61		
16	0.901	890	892	872	898	912	01	893	891	95	90	76	91	98		
14	0.906	895	88	76	92	906	08	0893	78	903	878	98	92	96	0.893	72.5
12	0.886	81	76	84	910	916	892	95	86	906	878	910	905	899		
15	0.595	95	600	595	93	87	69	82	603	589	575	73	68	85		
13	0.585	93	602	691	91	89	74	81	601	592	92	78	64	86	01587	56.5
11	0.580	88	91	92	89	89	83	78	91	88	601	582	70	84		
4	0.212	32	12	26	32	221	32	08	12	15	038	38	32	27		
5	0.208	36	24	28	22	27	18	09	14	01	39	40	38	25	0.224	42.0
6	0.206	40	224	30	19	25	06	10	25	26	41	326	23	25		
Heat-meter.																
Outer	0.108	12	11	08	10	10	06	07	09	13	14	10	13	12	0.110	
Inner	0.208	15	09	06	13	11	12	08	06	03	09	15	12	13	0.210	

SET NO. 3.

(WITHOUT VAPOUR BARRIER)

Average outside temp. = 85DegF
Average outside Rel.Hum. =62%
Moisture contentAv. =3.6%
Av.packing density =2.25lbs/cu.ft.

Date 26th August, 1963.

T.cs	10hrs.	11	12	13	14	16	17	18	19	22	23	24	1	2	mv. Mean	°F Temp.
1	1.156	52	62	70	62	62	46	42	42	38	42	42	52	51		
2	1.152	46	61	70	61	52	44	41	41	40	46	41	50	52	1.150	84.1
3	1.150	40	69	60	61	48	44	48	42	48	38	46	50	51		
16	0.891	76	91	62	75	83	76	71	83	77	72	86	83	82		
14	0.892	72	92	65	86	81	75	80	81	77	68	92	89	82	0.888	72.1
12	0.880	82	88	71	81	88	89	69	88	78	62	99	81	83		
15	0.626	19	19	15	11	15	21	12	08	04	11	08	10	12		
13	0.612	02	05	15	12	11	11	18	03	02	12	08	11	10	0.611	60.1
11	0.609	04	05	18	11	10	09	20	06	01	15	10	12	14		
4	0.211	15	21	15	21	10	18	09	16	08	21	24	22	18		
5	0.210	16	12	10	22	12	20	08	06	10	23	17	24	22	0.215	42.0
6	0.208	20	25	06	16	08	16	12	06	08	18	09	25	12		
Heat meters																
Outer	0.141	46	42	48	48	45	42	40	40	41	47	46	45	46	0.144	
Inner	0.261	66	63	70	72	62	61	60	69	68	69	69	68	68	0.266	

SET NO. 4.

(Without Vapour Barrier)

Av.outside temp. = 86 ^{o}F
Av.outside Rel.Hum = 60%
Av.moisture content=3.6%
Ag.packing density =4.125lb/cu.ft.

Date 29th August , 1963.

T.Cs	10hrs.	11	12	13	14	16	17	18	19	22	23	24	1	2	mv	°F Mean Temp.
1	1.181	71	70	74	72	73	80	68	69	70	63	75	78	65		
2	1.171	70	7 3	69	71	70	70	71	70	68	58	80	72	73	1.170	80
3	1,173	72	71	72	72	72	62	72	72	68	62	65	171	80		
16	0.879	71	50	50	55	70	69	71	68	61	59	72	68	68		
14	0.872	68	60	50	65	72	65	65	71	58	62	70	68	69	0.865	71.5
12	0.862	66	61	62	65	80	59	58	62	55	65	71	70	65		
15	0.581	70	89	85	75	65	58	61	86	83	78	76	73	77		
13	0.576	68	92	91	65	61	55	56	92	82	79	74	78	78	0.576	58.6
11	0.570	59	85	93	83	52	54	64	95	91	76	76	73	80		
4	0.238	0.238	0.227	25	15	32	11	11	32	32	12	12	10	10		
5	0.239	41	25	36	01	18	08	27	22	36	08	1 4	01	20	0.222	42.4
6	0.236	40	38	32	25	18	09	27	19	40	06	15	15	19		
Heat meter																
outer	0899	903	903	891	898	899	899	902	900	901	899	897	898	898	0.899	
Inner	0.171	73	72	74	69	68	75	72	73	71	72	72	73	72	0.172	

TEST NO. 5

(Without Vapour barrier)

Date 1st September, 1963.

Av. outside temp. = 88 °F
Av. outside Rel.Hum = 60%
Av. moisture content =3.6%
Av.packing density=4.625lb/cu.ft.

T.Cs	10hrs	11	12	13	14	16	17	18	19	22	23	24	1	2	mv Mean	°F Temp.
1.	1.193	92	76	90	78	92	79	88	69	81	84	85	88	82		
2	1.186	78	75	81	91	93	76	88	75	85	85	92	86	80	1.184	85.6
3	1.179	89	73	79	94	92	86	92	80	86	92	79	82	81		
16	0.861	58	68	74	58	65	59	72	76	61	51	39	67	64		
14	0.862	59	71	73	56	68	58	74	72	58	52	50	67	62	0.863	71.4
12	0.870	72	76	69	60	60	63	72	68	52	54	47	69	62		
15	0.578	90	82	72	76	91	86	88	76	80	91	91	84	80		
13	0.582	81	82	80	78	88	83	81	77	80	89	85	80	85	0.582	58.8
11	0.584	73	81	68	77	85	84	80	82	85	87	85	86	84		
4	0.212	07	10	10	16	18	20	206	01	03	08	06	03	08		
5	0.215	06	11	18	20	06	18	204	08	01	05	12	01	14	0.210	41.8
6	0.218	06	16	13	16	16	08	07	02	02	02	11	205	15		
Heat meter																
Outer	0.0945	48	44	46	47	43	42	41	45	41	45	48	47	48	0.0945	
Inner	0.185	86	84	80	78	79	75	74	74	78	81	84	80	82	0.182	

S ET N O. 6.

(VAPOUR BARRIER ON HOT SIDE)

Date September 5, 1963.

Average outside temperature = 82°F
Av. outside Rel. Hum. = 70%
Av. moisture content = 2.9%
Av. packing density = 4.625lb/cu.ft.

T.Cs	10hrs.	11	12	13	14	16	17	18	19	22	23	24	1	2	mv Mean	°F Temp.
1	1.058	58	56	59	62	60	52	51	57	60	57	57	58	56		
2	1.060	59	55	53	61	60	51	51	53	57	57	57	59	60	1.057	80
3	61	63	59	54	56	61	55	52	52	58	58	55	58	58		
16	0.798	799	801	801	799	81 0	795	801	789	796	792	795	803	799		
14	0.795	792	805	803	806	792	786	808	812	804	788	796	788	803	0.798	68.5
12	0.791	789	799	803	809	796	785	805	808	801	784	788	792	804		
15	0.518	16	06	10	04	08	02	11	16	15	11	18	12	12		
13	0.514	15	10	10	05	03	06	08	20	02	22	08	08		0.510	55.5
11	0.509	05	18	14	10	02	03	02	05	04	07	15	18	10		
4	0.202	07	198	198	212	08	06	198	202	18	188	201	08	01		
5	0.198	201	196	198	215	10	10	186	195	211	195	201	206	208	0.202	41.5
6	0.196	205	195	192	210	02	01	188	189	214	206	192	212	196		
Heat meter																
Outer	0.0815	11	12	16	16	18	21	16	18	14	15	14	12	12	.0815	
Inner	0.155	52	58	58	56	51	55	56	52	52	59	55	56	58	0.155	

SEPT. 9, 1963.

SET NO. 7.

(VAPOUR BARRIER ON HOT SIDE)

Av. outside temperature = 83 °F
Av. outside Rel.Hum. = 64%
Av. mois-ture content = 2.9%
Av. packing density =4.125lbs/cu.ft

T.Cs	10hrs.	11	12	13	14	16	17	18	19	22	23	24	1	2	mv Mean	°f Tempt
1.	1.082	88	94	93	89	92	98	89	98	94	96	90	91	90		
2	1.086	96	96	93	85	90	98	95	83	92	96	88	91	89	1.091	81.5
3	0.086	96	92	90	84	90	91	92	86	98	91	92	95	97		
16	0.822	20	20	24	28	25	23	20	15	21	21	28	23	21		
14	0.812	18	26	16	22	28	18	18	25	18	02	23	21	24	0.820	69.5
12	0.816	22	22	07	14	16	18	16	08	27	12	29	18	24		
15	0.525	30	25	27	28	29	31	26	29	18	26	30	31	30		
13	0.528	31	20	27	24	33	33	19	21	22	28	32	35	22	0.527	66.25
11	0.526	35	21	29	25	35	36	15	20	21	25	27	31	27		
4	0.211	08	11	08	08	01	11	08	05	06	11	03	09	08		
5	0.205	10	12	10	01	02	08	02	04	05	14	05	09	10	0-206	41-5
6	0.206	10	14	02	01	01	03	06	11	06	12	06	04	11		
Heat meter																
Outer	0.806	05	05	08	06	08	06	04	02	03	07	07	09	08	0.0806	
inner	0.153	55	56	55	52	51	51	55	53	52	52	54	52	51	0.153	

SET NO. 8.

(VAPOUR BARRIER ON HOT SIDE)

Av. outside temperature = 84°F
Av. outside Rel. Hum = 62%
Av. moisture content = 2.9%
Av. packing density = 3.51bs/cu.ft.

Date September 12, 1963.

T.Cs	10hrs.	11	12	13	14	16	17	18	19	22	23	24	1	2	mv Mean	°F Temp.
1.	1.114	15	16	11	18	07	09	21	22	08	11	09	08	15		
2	1.111	16	15	20	21	09	15	16	08	18	06	12	18	17	1.117	82.5
3	0.115	14	21	20	14	19	21	15	14	20	18	14	16	17		
16	0.845	41	42	47	46	45	48	46	43	50	40	43	47	42		
14	0.840	41	40	40	46	41	49	41	42	51	40	43	41	41	0.843	70.5
12	0.842	48	43	48	41	42	46	43	48	46	46	46	43	41		
15	0.538	38	45	46	47	43	49	42	41	48	40	40	41	38		
13	0.538	40	46	51	48	45	46	42	42	43	43	36	39	44	0.543	57
11	0.536	40	51	46	43	48	52	48	48	44	40	31	38	45		
4	0.201	11	08	04	05	14	05	04	09	11	10	12	10	06		
5	0.202	08	06	11	06	12	03	09	08	05	08	11	08	01	0.204	41.5
6	0.201	03	02	05	06	==	06	11	10	06	10	14	02	01		
Heat meter.																
Outer	0.0853	50	51	55	56	53	50	52	56	53	53	52	55	52	0.0853	
inner	0.166	64	64	65	66	66	64	65	64	63	66	67	63	67	0.165	

ACCURACY OF DATA:

It was observed that an electro motive force of 3 micro volts (corresponding to about 0.2 deg. F produced a deflection of one milimeter on the scale and since the accuracy in reading the scale was approximately one milimeter therefore the estimated accuracy of the temperature readings is ± 2 Deg. F.

The heat-meter readings are estimated to be correct to ± 2.5 %.

-:0:-

RESULTS EVALUATION.

Fourier's Law for the conduction of heat states that for steady flow, the rate of heat flow is equal to the product of three factors : area of the section, taken at right angles to the heat flow; temperature gradient, the change of temperature per unit length along the path of heat-flow; and a proportionality factor known as the thermal conductivity. In the field test set up the heat-meters measured rate of heat flow at the interfaces. The equation for heat flow at the interface may be written

$$q/A = k_i \, (dt/DL)$$

Where

- q = Rate of heat flow BTU/hr.
- A = Interfacial area of section through which q occurs; sq. ft.
- dt/dL = Slope of tangent to the curve of temperature distribution at interface, deg. F/inch.
- k_i = Thermal conductivity at interface BTU per hour sq. ft. deg. F per inch.

Therefore, the expression for conductivity at the interface is

$$k_1 = \frac{q/A}{dt/dL}$$

With respect to the thermal conductivity of the insulating material at the interface, this equation may be interpretted as follows :

The meter-measured heat flow per hr. per sq. ft. at a given interface divided by the slope of the tangent to the temperature distribution curve at that interface point is equal to the thermal conductivity of the insulating material at the interface.

The curve of temperature distribution and the developement of the tangents at the interfaces are important considerations in evaluating the data. The curves of temperature distribution for each packing density were drawn for the width of the panel equal to the distance between the interface surfaces of the heat-meters. Since test conditions were so chosen which ensured steady conditions the curve of temperature distribution should be practically a straight line for a short distance into the insulation. For drawing the tangents, the curves were extrapolated a little on both sides and the geometric property " A tangent is a Chord in its limiting case" was utilized. This method is similar to

SET NO 2

DATE 23rd AUG 63

AV. BULK DENSITY = 2.75 lbs/cu.ft.

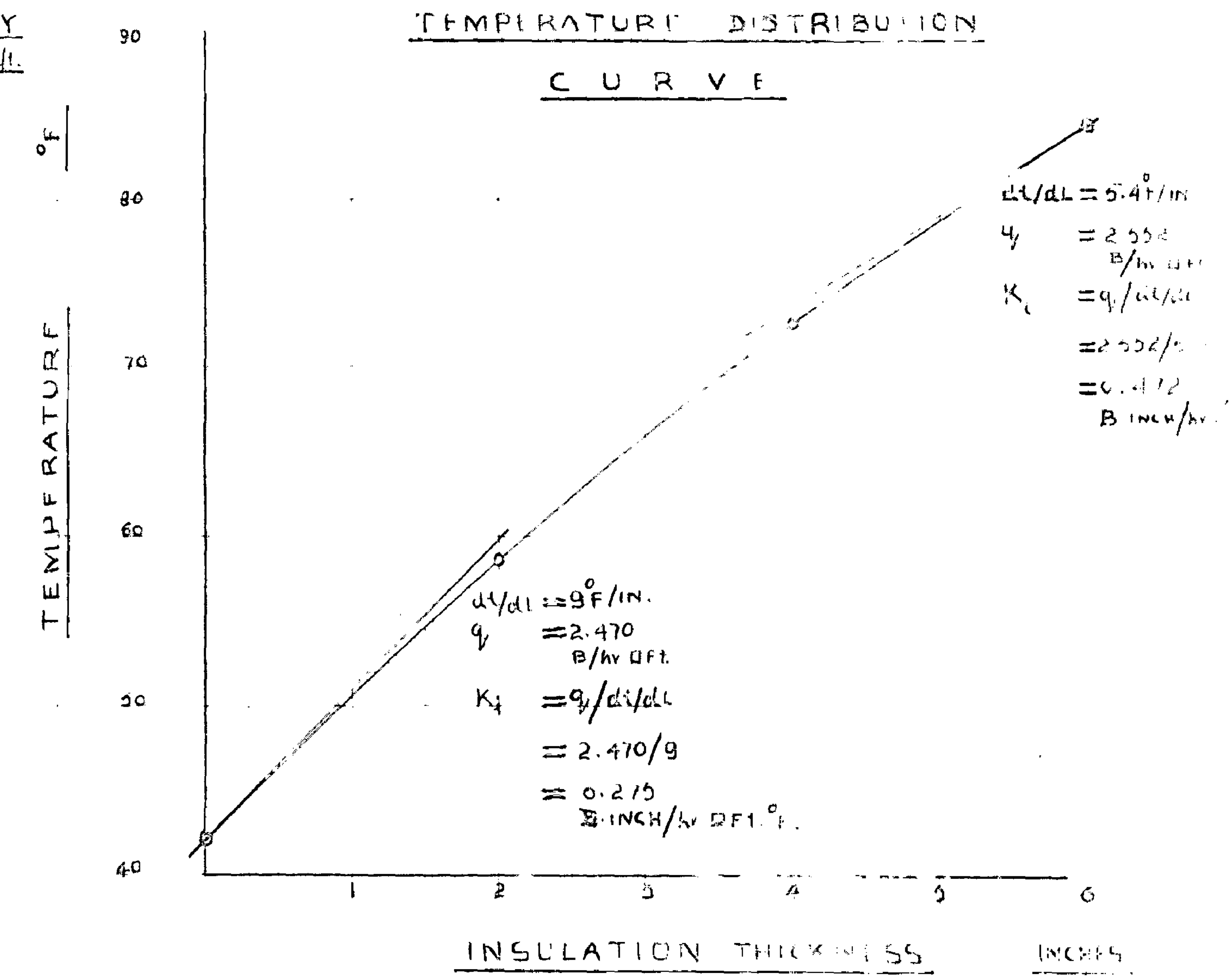

Fig 11.

that used by Simons [2]. Temperature distribution curve with tangents located has been shown for one case in Fig. 11. The conductivities reported are those at the interfaces and the temperatures shown are the mean temperatures over the steady state period of test.

The conductance of the insulation pack is obtained by dividing the heat flow rate by temperature difference across the pack. The temper·ture taken are the temperatures at interior and exterior interfaces. Expressing symbolically:

$$c = \frac{q/A}{dt.}$$

Where

c = Conductance BTU/hr. sq. ft. deg. F.

q/A = heat flow rate per unit area. BTU/sq. ft. hr.

dt = temperature difference between exterior and interior inter-faces deg. F.

Calculating for the second set.

$$c = \frac{2.47}{42.1} = 0.0587 \text{ BTU/hr. sq. ft. deg. F.}$$

The heat entering the cold space is nearly equal to that entering the wall. The former, contributing to the heat load is of practical importance and has been taken for calculations.

The design value of conductivity, K_D is obtained by multiplying the conductance value with the insulation thickness.

$$K_{Design} = C \times L.$$

Where

C = Conductance. BTU/hr. sq. ft. deg. F.

L = Insulation thickness in inches.

Calculating for the second set K_{design} is equal

to 0.0587 x 6 = 0.3522 BTU inch/ ht. sq. ft. deg. F.

Over all cofficient of heat transfer 'U' is obtained by the formula.

$$1/U = 1/U' - \left(\frac{2\ L}{K}\right)_{Plywood.}$$

Where

U = Overall coefficient of heat transfer and includes the effect of insulation pack and surface film; BTU/hr. sq. ft. deg. F.

U' = Overall coefficient of heat transfer for the test pannel embracing the affects of insulation pack, plywood, and surface film; assuming surface film coefficients being same on the plywood as well as on insulation pack surface.

$$= \frac{q/A}{t_o - t_1}$$

Where t_o and t_1 are external and internal embient temperatures.

L = thickness of plywood board in inches.

K = Conductivity of plywood in BTU inch/hr. sq. ft. deg. F.

Calculating U for the second set.

$$1/U = 46/2.47 - \left(\frac{2 \times 1/4}{0.9}\right)$$

from which U = 0.0551 BTU/hr. sq. ft. deg. F.

-:0:-

RESULTS

Av. packing density lbs/cft	Conductivity Bin/ft²hr °F	Moisture % by weight.	Conductivity B in/ft² hr °F	Moisture % by wt.	K_{design} B in/hr ft² °F	'U' B/hr ft² °F	Av. moisture % by wt.
WITHOUT VAPOUR BARRIER							
	at 42°F		at 85°F				
2.250	0.336	7.19%	0.590	0.268%	0.4428	0.071	3.7%
2.750	0.275	6.93%	0.472	0.283%	0.3522	0.0551	3.6%
3.500	0.260	7.12%	0.351	0.278 %	0.2928	0.0456	3.7%
4.125	0.241	7.26%	0.336	0.311%	0.2850	0.0448	3.7%
4.625	0.252	6.89%	0.348	0.305%	0.2970	0.0476	3.6%
WITH VAPOUR BARRIER ON HOT SIDE AND COLD SIDE EXPOSED							
	at 42°F		at 81°F				
3.500	0.232	5.37%	0.347	0.192%	0.2838	0.0450	2.8%
4.125	0.225	5.88%	0.334	0.185 %	0.2700	0.0427	3.0%
4.625	0.244	5.61%	0.344	0.182%	0.2892	0.0445	2.9%

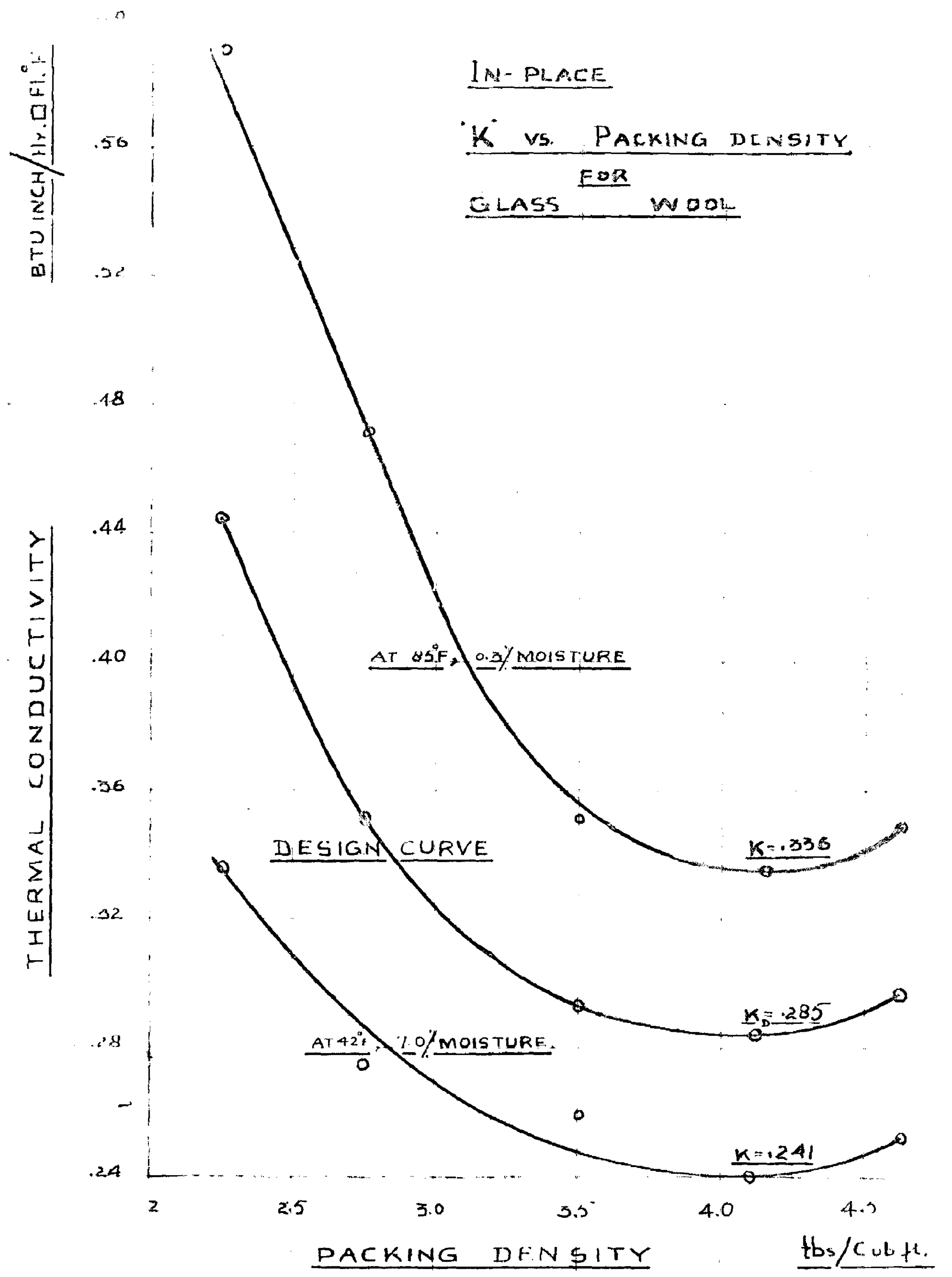
IN-PLACE
'K' VS. PACKING DENSITY
FOR
GLASS WOOL
AT 85°F, 0.3% MOISTURE
DESIGN CURVE
AT 42°F, 1.0% MOISTURE.
K=.336
K_D=.285
K=.241
THERMAL CONDUCTIVITY
BTU INCH/Hr. □ Ft. °F
.56
.52
.48
.44
.40
.36
.32
.28
.24
2
2.5
3.0
3.5
4.0
4.5
PACKING DENSITY
lbs/Cub ft.

Fig 12.

IN-PLACE

'K' vs PACKING DENSITY FOR GLASS WOOL WITH VAPOR BARRIER ON HOT SIDE

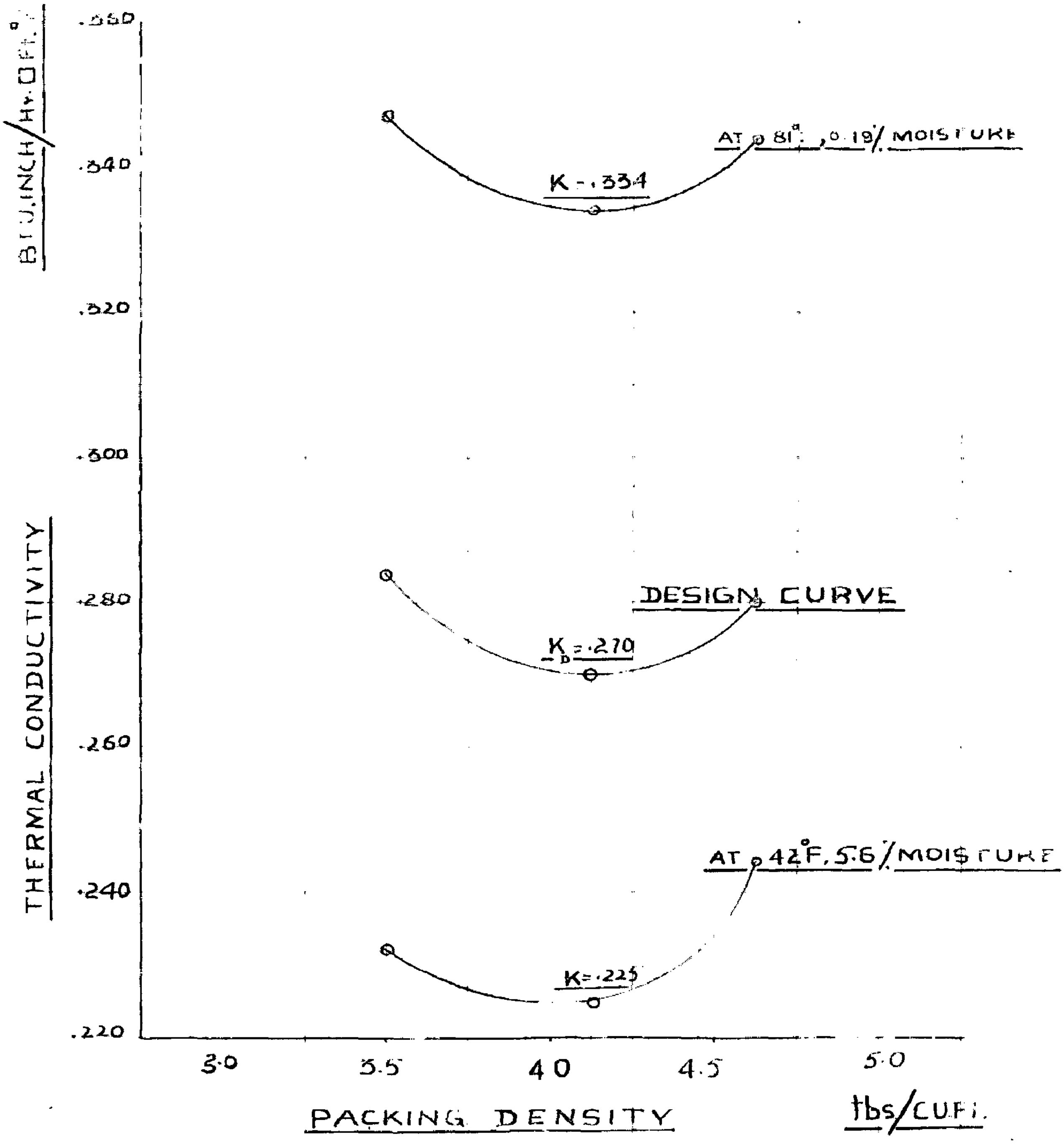

Fig 13.

IN-PLACE

'U' VS PACKING DENSITY FOR GLASS WOOL

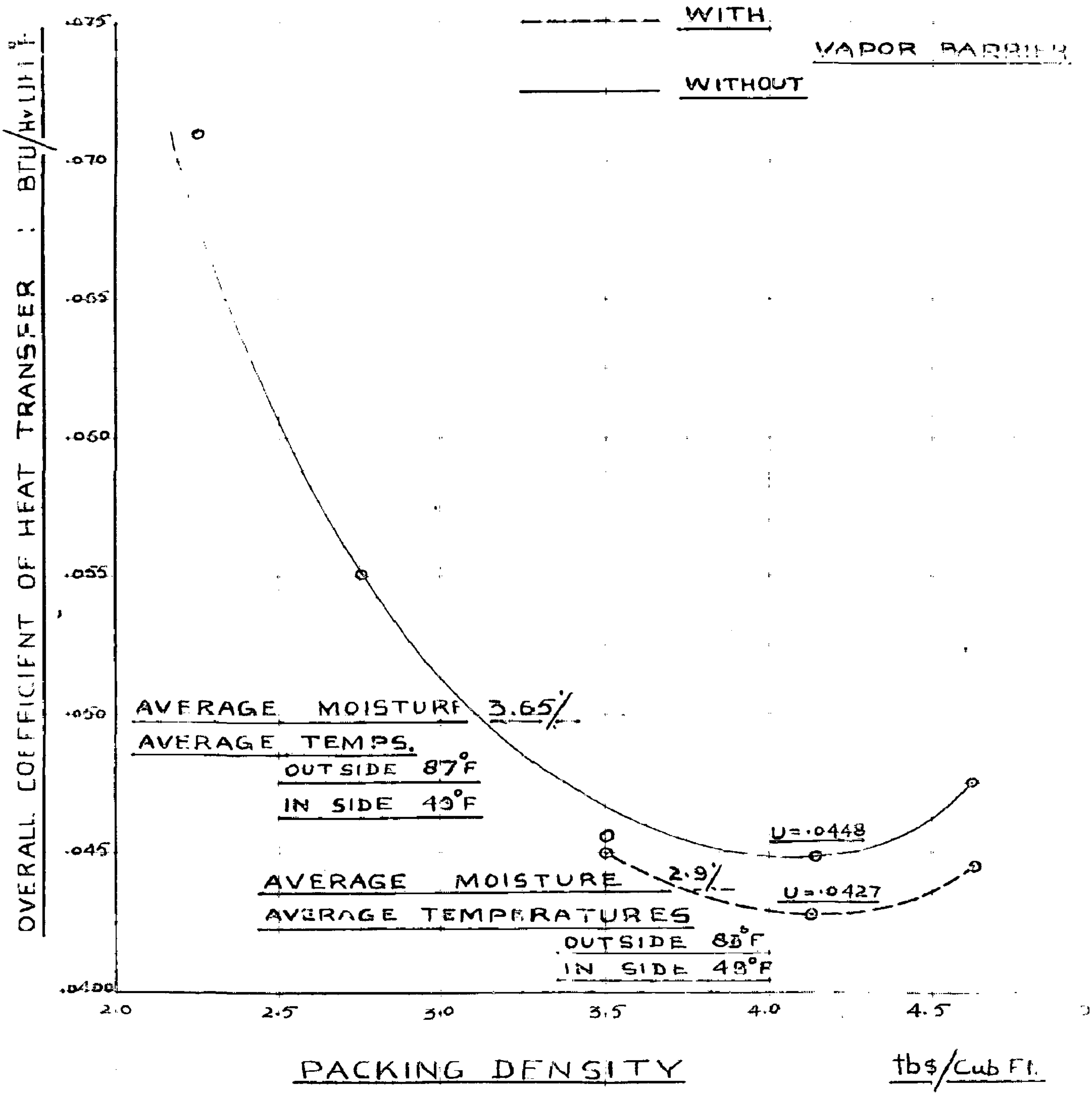

Fig. 14.

D I S C U S S I O N :

The results will be discussed under two sub-headings:

A. Justification of Results: - to show that the results are reasonable and in appreciable agreement with the work done by others, and are sufficiently accurate for engineering use.

B. Analysis of Results:

A. JUSTIFICATION OF RESULTS:

Glass wool is prepared by issuing molten glass in a small stream from furnace and breaking the mass into fine fibres by a blast of steam. This fibrous material in the form of wool has a high percentage of volume occupied by air in the form of continuous open spaces. A space filled with loose fibrous materials, for example rockwool, glasswool, shredded red wood bark etc. consis-ts largely of air. The weight of the lime stone or glass is roughly 165 lbs/cu.ft. but if glass wool be packed in a space to a density of 3 lbs/cu.ft. it would occupy only 2 percent of volume, the remainder being air.

The 'k' value of glass wool would obviously lie in between those of glass and air and appreciably towards the latter. The values of conductivity obtained varied from 0.241 BTU inch./sq.ft.hr. Deg. F. minimum to 0.59 maximum, these values being at different temperatures and different packing densities. The conductivity values of glass and air are approximately 5.5 and 0.169 (4) respectively which bracket these values and justify the results. Also the values obtained are in appreciable agreement to those obtained by other workers in this particular field. Some laboratory tests, of course have been conducted on glass-wool but unfortunately, comparatively little work seems to have been done on its in-place testing as the author has not so far come across even a single publication on its inplace data to compare with.
A similar work on in-place testing of red wood bark fibre was however conducted in U.S.A. by Edward Simons (2), Consulting Engineer San Francisco, on walls of various cold storages. Rowley, Jordan and Lander (5) tested at University of Minnesota many insulating materials for conductivity values

at different low mean temperatures and found that for a glass wool specimen (dry) one inch thick packed to a density of 1.65 lbs/cu. ft. the 'k' values at 42 deg. F and 85deg F were 0.257 BTU inch. /hr. sq. ft. Deg. F and 0.298 respectively. The corresponding in-place values obtained by the author are 0.336 BTU inch/hr. sq. ft deg. F at 42 deg. F & 0.59 at 85 deg. F at a slightly higher density of 2.25 lbs/cu. ft. Queer and Hechler (6) found that 'k' values (dry specimen) at packing densities of 2.49 and 3.12 lbs/cu. ft. & at mean temperature of 65 deg. F were 0.257 & 0.251 respectively while the corresponding values obtained by author are 0.397 and 0.322 respectively. With vapour barrier on hot side and cold side exposed, the minimum and maximum values obtained are, for the range of packing densities tested, 0.225 at 42 deg. F and 0.347 at 81 deg. F which are less than those without vapour barrier. <u>It is seen that the in-place values are higher than the established laboratory values in all the cases</u>. The difference being because of test conditions being widely different in laboratory and the field tests.

Allcutt and Ewens[3] investigated the question of convection in certain insulators, using a square vertical plate apparatus with a heater sixteen inches square and guard four inches wide surrounding the heater, they found, with thickness varying from one to four inches, that glass wool (1.5 lbs/cu. ft) showed a remarkable variation of conductivity with thickness. With increase in thickness, increase in the conductivity was observed. It is due to the convection currents in the sample being more at greater widths and also due to the change in contact resistance between the plate and the sample. Thickness being different (6" in-place, 1" laboratory) in the two cases is therefore, one of those factors which explain the increased in-place values over those obtained by Rowley, Jordan and Lander[5]. Another important factor which explains this increase is moisture in insulation. Moisture has a pronounced effect on the thermal conductivity of insulating materials. The conductivity of water is 4.8 BTU.inch/hr. sq. ft. Deg. F which is more than 15 times that of glass wool at ordinary temperatures & packing densities. If moisture is present in insulation one would expect the 'k' value to be higher than that of dry material.

The effect of moisture on the conductivity is very difficult to determine accurately, because in making a thermal conductivity test, a temperature difference between two sides of the specimen is maintained and moisture always tends to migrate from warmer to colder side.

In interpretting these results, it should be noted that all previous works with which the in-place values have been compared for agreement were made under laboratory conditions, with extreme care taken to prevent any condensation of moisture within the material. The thermal conductivity measurement as made in the dry state (A.S.T.M. Specifications) in the laboratory will not tell the true story of the performance of insulating material under actual conditions of usage.

B. ANALYSIS OF RESULTS:

The line of temperature distributionacross the wall is convex upward in all the cases. For a practical constant rate of heat flow, the decrease in conductivity to overcome the steeper temperature gradient on the cold side is quite evident. It is found that 'k' value at 85 deg. F is greater than that at 42 deg. F. with average moisture content of 3.6 percent. This is explained by 3 factors - the conductivity of glassfibre, the conductivity of air in the air spaces and the inner radiation, all of which increase with increase of temperature to give a combined greater value of apparant conductivity at higher temperature.

Because the constitution of glass wool involves air spaces within the pack, there is usually an appreciable amount of heat transfer by convection and readiation. The amount of heat transferred by radiation across an air space between parallel surfaces is proportional to difference of fourth power of surface temperatures. Thus radiation may be an important factor in the transmission of heat through a porous material particularly at low packing density when sufficient temperature difference exists across the pore. Moreover the rate of radiant heat will be much greater at higher mean temperature than it will be at low even though the temperature difference may be same in both cases (because of the fourth power law). This explains greater change of conductivity at lower packing densities for the same two mean temperatures. At density of 2.25 lbs/cu.ft. conductivity increases from 0.336 BTU inch/hr. sq.ft. deg F. to 0.59 i.e. 75.6 percent for a temperature rise from 42 deg. F to 85 deg. F while at 2.75 lbs/cu.ft. the increase is only 61% for the same temperature rise.

It is interesting to note that the effect of moisture is much less pronounced than the effect of conduction radiation and (or) convection upon conductivity. Therefore, although at 85 deg. F the moisture is 0.3% and at 42 deg. F the moisture is 7% the apparent conductivity at any packing density was more for the higher temperature i.e. 85 deg. F but for moisture consideration where it should have been less.

Since heat is transferred through a material by conduction, by radiation through open spaces and by any gas that is enclosed in the material, and sirce increaseing the density of a given material changes its charactoristics for heat flow by each of these three methods, there is no simple straight line relation between density and overall conductivity, that will apply to the insulating material. Two phys icists J.D. Verschoor and Paul Greebler(7) at John Manville Research Centre have derived an expression fot thermal conductivity of gas within insulation. Expressing symbolically :

$$K_{cd} = K_g \frac{L_f}{L_f + L_g}$$

Where

K_{cd} = Apparent 'K' due to gas conduction. BTU inch/hr. sq. ft. deg. F.

L_f = Equivalent pore size of fibrous insulation in microns.

= 0.785 D/f.

D = Fibre diametor in microns.

f = Fractional volume of insulation occupied by fibers.

L_g = Mean free path of gas molecules in free gas, microns.

L_g is a function of temperature and pressure. It is inversely proportional to pressure and increases with increase of temperature.

K_g = Thermal conductivity of free gas BTU inch./hr. sq. ft deg. F

It is assumed that the fibres lie in planes parallel to mat which they form but that they are otherwise randomly orientated. It is further assumed that the direction of heat flow is perpendicular to the planes in which the fibres lie. This assumption being consistent with many practical application of fibrous insulations. Also it is assumed that fibres are uniform in diameter and that the insulation is free from any non fibrous solid particles.

At atmospheric pressure the value of L_g is much less as compared to L_f. As L_f is decreased, it has a direct effect on K_{cd} which decreases with it. The decrease in L_f can be effected by increase in packing density which which means that as the density increases K_{cd} decreases.

Heat transfer by radiation can be treated by considering the fibrous insulation as successive plates of fibres perpendicular to the direction of heat flow. The average spacing between the plates is L_f, since this is the average distance that a photon of the radiation field can move in the direction of heat flow before encountering a fibre. The expression for the apparent conductivity contributed by radiation has been derived by physicists J. D. Verschoor and Paul Greebler[7].

$$K_{ra} = 2.74 \times 10^{-13} \frac{T_m^3 \quad L_f}{a^2}$$

Where

K_{ra} = Apparent 'K' due to radiation BTU inch/hr. sq. ft. deg. F

T_m = Absolute mean temperature in Deg. R.

L_f = as before, pore size in m cron.

a = Fraction of incident radiant energy absorbed by a fibre, dimensionless.

It is evident that K_{ra} like K_{cd} decroases with decrease of L_f , that is, with increase in packing density.

Convection rate of heat transfer also has a direct bearing on L_f. Glass wool consists largely of air and since the air passages are continuous they offer little resistance to air flow when loosely packed or conversely high resistance to convection curronts when closely packed thus decreasing K_{cv} with increase of density, that is, with decrease of L_f.

Fig. 12 shows that in the curve for 85 deg. F the 'K' value at bulk density of 2.25 lbs/cu.ft. is 0.59 BTU inch. /hr.sq.ft.deg.F which falls to 0.336 as density is increased to 4.125 lbs/cu.ft. At the low packing density, f, the fractional volume occupied by the fibres is much less with the result that L_f , the effective pore size, which varies inversely with f has a high magnitude. As the density is increased more fibres come in to space thereby increasing f and decreasing L_f . K_{cd} , K_{cv} and K_{ra} being directly dependant upon L_f also decrease with decrease in L_f. But there is another contributory factor to 'K' – the series solid conduction, which acts otherwise. Series sold conduction contributes a percentage of total thermal conductivity equal to the volume fraction of the fibre present. This factor being directly dependant upon f, increases with decrease in L_f thus always acting in opposition to the previous three factors which decrease with decrease in L_f. Thus whereas K_{cd}, K_{cv}, K_{ra} have decreasing effect on 'K', the solid conduction calling the corresponding conductivity by K_s, has an increasing effect. At any packing density the 'K' value is the summation of all the four values that is K_{cd}, K_{cv}, K_{ra}, K_s. The curve of (K_{cd} + K_{cv} + K_{ra}) if be drawn against packing density, will be a dropping curve while that of K_s will be a rising curve. It will be seen that a density of 2.25 lbs/cu. ft. the 'K' value is 0.59. BTU inch/hr. sq. ft. deg. F. As the density is increased the decrease in (K_{cd} + K_{cv} + K_{ra}) is much more than the increase in K_s with the result that there is a net decrease in 'K' value. Till the packing density of 4.125 lbs/cu. ft. is reached where the increase in 'K_s' nullifies the decrease in (K_{cd} + K_{cv} + K_{ra}). This is the value of packing density at which 'K'; the overall conductivity is minimum.

Any further packing would mean the increase in K_s over weighing the decrease in (K_{cd} + K_{cv} + K_{ra}) with the result of net increase in 'K', the overall apparant conductivity.

Moisture is one of the most difficult problems to cope with in an insulated low temperature structure. For cold storages moisture penetration is most serious during summer when the outdoor temperature and absolute humidity are high while the indoor temperature and absolute humidity are low. These condi-rions cause a difference in the vapour pressure outside and inside of the cold storage which forces the moisture into the insulation through the outside surface. As the p vapour passes through the wall towards the inner side, it soon falls to a temperature corresponding to the dew point which causes condensation and moisture accumulation in the insulation. When a vapour barrier is placed on the outside surface of the insulation it acts to reduce the vapour flow from outside into the insulation. If the inside surface be exposed, the vapour pressure gradients from the body of the insulation to the conditions at the surface of the refrigerating coil tend to cause vapour flow into the refrigerated space with the result of net decrease in overall moisture, content in the insulation. As already discussed the conductivity of the insulating material decreases with decrease in its moisture content, the effect of vapour barrier in causing a decrease in the conductivity is evident.

The decrease in average moisture content due to applying vapour barrier was only from 3.65% to 2.9% with the result the corresponding decrease in conductivity was not much. One reason for a small decrease in average moisture content may be attributed to a small period of time (4 days) given to every set for attaining stabilized conditions and the other to the partial exposure of the cold surface. Because of heat meter being placed on the wooden board, it was not possible to remove the board so as to give full exposure to the surface. However sufficient number of ⅛" holes were made in the board to create conditions as nearly to the full exposure.

CONCLUSIONS:

From the In-place Testing of six inches thick glass wool insulated wall of a cold storage, the following conclusions are derived:

1. In-place thermal conductivity values are higher than the laboratory values.

2. Thermal conductivity is higher at higher temperature.

3. All other factors affectingthe conductivity remaining constant, there is a finite value of packing density at which thermal conductivity is minimum.

4. Vapour barrier affects in decreasing the thermal conductivity.

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