

DRYING OF SOLIDS

by

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## INTRODUCTION

### Introductory

The phenomena manifested in the drying of solid materials lends itself to a theoretical treatment involving some of the important laws of physical chemistry. More recently it has given rise to a rather extensive field in its practical application and became a subject of considerable importance to the chemical engineer. However, no references were found concerning the relationship existing between the factors affecting the drying of a substance and its body temperatures or temperature in the immediate vicinity. Since each of these factors is influenced by the temperature it was thought that a knowledge of the general nature of the temperatures within these regions would be beneficial in understanding the mechanism of the drying of solids.

The investigation involved a study of the mechanism of the drying of solids. It is interesting to note that although a great deal of space has been given to the factors influencing drying nothing is mentioned in the literature pertaining to the temperature gradient within the specimen and its immediate surroundings. In order to obtain this information a number of experiments were carefully designed

and carried out under well regulated and controlled conditions of air velocity, temperature, and humidity for a number of the most general cases.

The data obtained is indicative that a material subject to drying does not reach a uniform temperature until it approaches a state of dryness corresponding to its equilibrium moisture at the conditions under which it is being dried. It was also found that the surface temperature of the specimen was somewhat lower than that of the drying air within the immediate neighborhood.

An extensive search of the literature was made but no articles bearing directly upon the phase of the problem under investigation were found. However it was decided to include references or material from several articles treating on the subject in a different light while at the same time containing information pertaining to the present work.

#### LITERATURE

G. Frederick Smith and O.A. Rees, (1) discussed the construction of vacume drying equipment, giving the requirements necessary and the methods by which they were met.

T.K. Sherwood, (2) presented a discussion on the

factors influencing the drying of a solid during the different periods. Of these it was pointed out that the rate of drying of a solid during the constant rate period does not decrease proportionally with the surface obstructed if the material covering the surface is a good conductor of heat energy. By considering the expression, representing the heat received by radiation from the surroundings increased the rate of evaporation of moisture from the solid. If the over-all coefficient of heat transference remained unchanged, following the constant rate period, it was shown that evaporation remains the controlling factor, the falling rate being caused by a decrease in the effective surface area; whereas should the over-all coefficient become a decreasing function with time it would indicate that evaporation receded from the surface of the solid. Values of the over-all coefficient were obtained by embedding one end, the cold junction, of thermocouples beneath the surface of the specimen leaving the remaining end, the hot junction, to project into the drying atmosphere, and noting the potential developed in them. Experimental results led to the conclusion that moisture diffuses to and evaporates at the surface in the majority of solid substances.



T.K. Sherwood, ( 3 ) discussed the possibility of two general mechanisms by which moisture from the interior reaches the surfaces of a solid upon drying. Each of these was further subdivided in two general cases giving the classification.

"I-(a) Evaporation at the solid surface; resistance to internal diffusion of liquid small as compared with the resistance to removal of vapor from the surface.

I-(b) Evaporation at the solid surface; resistance to internal diffusion of liquid great as compared with the resistance to removal of vapor from the surface.

II-(a) Evaporation in the interior of the solid; resistance to internal diffusion of liquid small as compared with the total resistance to the removal of vapor.

II-(b) Evaporation in the interior of the solid; resistance to internal diffusion of the liquid great as compared with the total resistance to the removal of vapor."

By making the following assumptions: (a) the constancy of the diffusion constant; (b) a uniform liquid concentration throughout the solid at the start; (c) that the diffusion is wholly normal to the surface plane; (d) that the evaporation takes place at the surface and that the surface resistance to vapor diffusion may be considered negligible, that is the liquid concentration on the surfaces falls to

zero immediately after the start of the drying; and applying Newton's law of diffusion of moisture to an infinite sheet; a solution of the differential equation,  $D_{\theta} (C) = k D_x^2 (C)$ , was developed for the free moisture at any point in case, I-(b). This was used as the defining value of,  $f(x)$ , in the equation,  $E_m = 1/xR \int_0^R f(x) dx$ , for the total free moisture in the sheet, giving an intergal equation of the form,

$$E_m = 4/\pi R \int_0^R \left\{ \sin \pi x/2R \cdot E^{-\frac{(\pi/2)^2 (k\theta/R^2)}{1}} + \right. \\ \left. 1/3 \sin 3\pi x/2R \cdot E^{-\frac{9(\pi/2)^2 k\theta/R^2}{1}} \right\} dx$$

which upon integration becomes,

$$E_m = 8/\pi^2 \left\{ E^{-\frac{(\pi/2)^2 (k\theta/R^2)}{1}} + 1/9 E^{-\frac{9(\pi/2)^2 (k\theta/R^2)}{1}} + \right. \\ \left. 1/25 E^{-\frac{25(\pi/2)^2 (k\theta/R^2)}{1}} + \dots \dots \dots \right\}$$

conforming to an equation given later by Albert B. Newman.

Walker, Lewis, and McAdams, (4), in their texts book, Principles of Chemical Engineering, gives,  $-(dy/d\theta) = (8 aby)/L (4 a bL) (1)$  as the basic differential equation for air drying of solids under constant drying conditions, which by making equivalent substitutions becomes,  $-d(T-E)/d\theta = 8(a)(b)(T-E)/(4a bL)L = k(T-E)$ , (2) subject to the following limitations: (a) the moisture diffuses only in a direction normal to the exposed surface, and through a

cross-section of constant area; (b) the drying conditions are identical on both sides of the material; (c) the rate of surface evaporation under constant drying conditions is proportional to the fraction of surface wetted which is itself proportional to the free moisture concentration; (d) during the drying of the moisture concentration is at a maximum at the center of the sheet decreasing linearly to the value on its surface.

Briefly the equation was obtained by assuming a constant concentration gradient and that the average free moisture content may be considered to follow a locus midway between the center line and either face of the sheet, giving the expression,  $(a)(A)(y-W_s)(4/L)$ , for the water lost by diffusion per unit of time. If,  $(b)(A)(a_s)$ , represents the moisture lost by evaporation per unit of time and,  $(dy/d\theta)(A)(L/2)$ , the product of the rate of change of the average concentration and the volume of one half the sheet the equation,  $-(dy/d\theta)(A)(L/2) = (b)(A)(W_s)$  may be written since diffusion must quantitatively compensate for evaporation in order to keep the moisture content from becoming depleted at the surface. Similarly the following equation,  $-(dy/d\theta)(A)(L/2) = (4/L)(A)(y-W_s)$ , may be written. Hence by eliminating  $W_s$  from the equalities and dividing out the area the above differential equation



(1) is obtained which may be expressed as (2) and indicates that the rate of drying at any instant under any definite set of drying conditions is independent of the area of the surface of the material being dried, and is proportional to the percentage of free moisture on the dry basis.

The equation slightly modified is given in the integrated form for a few specific cases.

#### Nomenclature

- A = Area of either side of slab.
- L = Total thickness of slab.
- W = Units of weight of free moisture
- $\theta$  = Time
- a = Coefficient of diffusion, at a definite stock temperature
- b = Coefficient of surface evaporation for constant drying conditions.
- Y = Average free moisture concentration (units of weight per unit volume of stock)
- T = Total moisture of per pound of bone dry stock.
- E = The equilibrium moisture under any given set of drying conditions.
- k = Drying coefficient for any definite set of drying conditions.

T.K. Sherwood, (5), gave a summary of two previous art-

icles on the general mechanism of drying, with a discussion of some of the factors influencing the rate of drying of a solid substance. Particular reference was made to the division of the drying period into two sections, termed the, "constant-rate period" and the, "falling-rate period," "critical water content" being used to indicate the division of these periods. It was stated further that in general the, "falling-rate period" could be divided into secondary zones, one of which was referred to as the, "zone of unsaturated surface" the other as the, "zone in which internal diffusion was the controlling factor". The former following immediately after the, "critical moisture content" has been reached.

It was shown that during the, "constant-rate period" moisture leaving a material upon drying, may or may not do so by adiabatic evaporation, depending on whether or not it received its heat of vaporization only by conduction through the surface film or by the addition of a secondary source, as radiation from surroundings at a higher temperature, in which case the temperature of the moisture assumes a value higher than the wet-bulb temperature, while the differential partial pressure increases rapidly and gives rise to a more rapid rate of drying. High air velocities reducing the thickness of the surface film was also mentioned as an important factor affecting the rate of drying during this period.

During the period immediately following the constant-rate period, referred to as unsaturated surface drying it was considered that although the maximum rate of diffusion of internal moisture had ceased to exist, diffusion was not the controlling factor. In this period supposedly moisture reaches the surface sufficiently rapid that evaporation remains the controlling factor, and the falling rate results from a decrease in the wetted surface area. Some space was given to the fundamental laws, and the application of Fourier equations of heat conduction to the diffusion of liquids through solids.

These are discussed more fully in synopsis of other articles and will be omitted here. However it might be mentioned that in discussing these relationships it was stated to the effect that during the second zone of the falling rate period, since the rate at which moisture arrives at the surface is less than the rate at which it evaporates, it is probable that water in the solid near the surface tends to become depleted and the plane or locus of evaporation retreats from the surface, it supposedly being more pronounced in porous or fibrous materials, with little probability of it manifesting itself in more densely packed colloidal substances. Experimental data on the drying of pulp was used in plotting curves for bringing out points



in the discussion.

Albert B. Newman, (6), presented a discussion of the equations and their applications in calculating the free moisture content at any time after diffusion becomes the controlling factor, for a number of different shaped specimens.

The following solutions,

$$(C-C_1)/(C_0-C_1) = \frac{4}{\pi} \left\{ \begin{aligned} &\text{Cos}(\pi x/2a) \cdot E^{-\frac{(k\theta)(\pi/2a)^2}{}} \\ &+ \frac{1}{3} \text{Cos}(3\pi x/2a) \cdot E^{-\frac{(9k\theta)(\pi/2a)^2}{}} \\ &+ \frac{1}{5} \text{Cos}(5\pi x/2a) \cdot E^{-\frac{(25k\theta)(\pi/2a)^2}{}} \dots \dots \dots \end{aligned} \right\} (A)$$

And,

$$(W-C_1)/(C_0-C_1) = \frac{8}{\pi^2} \left\{ \begin{aligned} &E^{-\frac{(k\theta/a^2)(\pi/2)^2}{}} \\ &+ \frac{1}{9} E^{-\frac{9(k\theta/a^2)(\pi/2)^2}{}} \\ &+ E^{-\frac{25(k\theta/a^2)(\pi/2)^2}{}} \dots \dots \dots \end{aligned} \right\}$$

of the partial differential equation  $D(\theta) = k \frac{\partial^2}{\partial x^2} (C)$ , were given as a method for calculating the free moisture at any point, and the average free moisture content respectively at any instant if evaporation takes place from only the two opposite sides of a slab. The mid plane being chosen as  $x = 0$

A similar set of equations were obtained from a solution of the partial differential equation,  $D_{\theta}(C) = k \{D_x^2(C) + D_y^2(C)\}$ , (B) if evaporation takes place from the long faces of a rectangular shaped specimen, and its linear axis is taken as  $x = 0$  and  $y = 0$

Likewise if the specimen is of the nature of a rectangular parallelepiped solutions identical in character were given for the differential equation,  $D_{\theta}(C) = k \{D_x^2(C) + D_y^2(C) + D_z^2(C)\}$ , (C) if the center is selected as the origin and evaporation takes place from all six faces.

If the specimen is cylindrical in form with the ends closed, evaporation taking place from only the convex surface the solution for the differential equation,  $D_{\theta}(C) = k \{D_R^2(C) + 1/R \cdot D_R(C)\}$ , is given as:

$$(W-C_1)/(C_0-C_1) = 4 \left[ \frac{1}{R_1^2} \cdot E^{-\frac{(k\theta/a^2)R_1^2}{4}} + \frac{1}{R_2^2} \cdot E^{-\frac{(k\theta/a^2)R_2^2}{4}} \right]$$

for representing the average free moisture content of the material. Where the "R's", are roots of the Bessel function,  $J_0(x) = 0$

If in the case of the cylindrical shaped specimen evaporation takes place from the ends as well as the convex surface the differential equation is given as,  $D_{\theta}(C) = k \{D_R^2(C) + 1/R \cdot D_R(C) + D_y^2(C)\}$  and its solution as the pro-

duct of the right hand member of (3) and the solution of (B).

**Nomenclature:**

$C$  = The liquid concentration in the solid at any location at any time.

$C_0$  = The initial uniform liquid.

$C_1$  = The equilibrium liquid concentration, for any given set of conditions.

$\theta$  = Time

$k$  = Diffusion constant, or diffusivity.

$\bar{W}$  = Average liquid concentration in the solid at any time.

$a$  = Radius of cylinder, the half-thickness of a slab, or the half-thickness of a rectangular shape in the x-direction.

$b, c$  = The half-thickness of a rectangular shape in the y-and z direction, respectively.

T.K. Sherwood, (7), discussed the application of the equation,

$$E_m = 8/\pi^2 \left[ E^{-\frac{(k\theta/R^2)(\pi/2)^2}{1/9 \cdot E}} + \frac{-9(k\theta/R^2)(\pi/2)^2}{1/25 E^{-25(k\theta/R^2)(\pi/2)^2}} + \dots \right]$$

derived for calculating the moisture content at any time during the drying of a solid slab of infinite extent when internal diffusion was the controlling factor. It was



stated that since this equation was derived on the assumption that a uniform distribution of moisture in the solid existed at the beginning, it could not be expected to apply to a falling rate period in which an appreciable difference between the moisture content at the surface and the interior developed during the constant rate period although liquid diffusion was the controlling factor.

An equation,  $T = T_m - \frac{(x-R)^2}{R^2}(T_m - T_s)$ , representing the moisture gradient during the constant rate period was obtained from the general differential equation,  $D_x^2(T) = (d/k) \cdot D_\theta(T)$ , for the diffusion of a liquid in a solid. This solution was developed by showing that curves of the moisture gradient in a solid upon drying approaches a definite shape after which successive ones trend toward parallelism and reduce the differential equation to,  $D_x^2(T) = \text{constant}$ . It was used as the defining value of  $f(x')$  given in the equation,

$$v = 1/R \cdot \int_0^{2R} f(x') \sum_1^{\infty} \left( \text{Sin } n\pi x'/2R \cdot \text{Sin } n\pi x/2R \cdot E^{-kn^2\pi^2\theta/4R^2} \right) dx'$$

presented by Carslaw as a solution of the basic differential equation for the diffusion of moisture in a slab where the initial concentration is  $f(x')$ .

The integrated equation obtained was:

$$T = 2T_s / \pi \sum_1^{\infty} 1/n \{1 - (-1)^n\} \sin n\pi x / 2R \cdot E^{-kn^2 \pi^2 \theta' / 4R^2}$$

$$16/\pi^3 (T_m - T_s) \sum_1^{\infty} 1/n^3 \{1 - (-1)^n\} \sin n x / 2R \cdot E^{-kn^2 \pi^2 \theta' / 4R^2}$$

It was assumed that shrinkage was negligible and,  $v$ , could be replaced by,  $TD$ .

An equation for the total water content, obtained by integrating the concentration across the slab thickness was also developed. This was obtained by substituting the right hand members of the last equation and that derived for the moisture gradient in the equation,

$$E' = \int_0^{2R} T dx \int_0^{2R} f(x) dx'$$

and integrating,  $E'$ , being defined as the ratio of the free-water content at any time to the free-water content at the end of the constant rate period. The integrated equation obtained was:

$$E' = 24T_s / \pi^2 (T_s - 2T_m) \left[ E^{-p} + 1/9 E^{-9p} + 1/25 E^{-25p} + \dots \right]$$

$$192/\pi^4 (T_m - T_s) / (T_s - 2T_m) \left[ E^{-p} + 1/81 E^{-9p} + 1/625 E^{-25p} + \dots \right]$$

Experimental data obtained on the drying of brick clay were given for demonstrating the validity of these equations.

## Nomenclature:

- A = Face area
- D = Density of dry solid
- E = Ratio of total free-water content to initial free-water content
- E' = Ratio of total free-water content to free-water content at end of the constant-rate period, i.e., at critical point
- k = Diffusion constant of moisture through solid, with concentrations as weight per unit volume
- k' = Same with concentrations as weight of water per unit weight of dry solid = KD
- $p = \frac{kT^2\theta'}{4R^2}$
- R = Half slab thickness
- T = Free moisture concentration, weight of water per unit weight of dry solid
- $T_m$  = Same at center line of slab at critical point
- $T_s$  = Same at faces of slab at critical point
- v = Free-water concentration at any point
- W = Weight of water
- x = Distance from slab face
- $\theta$  = Time
- $\theta'$  = Time after critical point



## EXPERIMENTAL

### Apparatus

Since the exact type of equipment for an experimental study of the drying of materials was not available it was necessary to construct or make a complete assemblage of apparatus fulfilling the requirements to be met in the problem. The requirements, briefly, may be indicated as follows:

1. Provision for a well insulated drying chamber.
2. A heating unit, preferably electric, for obtaining temperatures from 100 to 200 degrees Fahrenheit.
3. A sensitive method for regulating and controlling the temperature within a small range.
4. Provision for effectively controlling the humidity of the entering air.
5. A method of insuring uniform and efficient air distribution.
6. An exacting method for measuring low air velocities.
7. A method for suspending and weighing the material being dried, obstructing the minimum surface possible.
8. A very sensitive method for measuring the temperature within the material and its immediate surroundings.
9. The general assembly and construction of the dif-

ferent units of the entire set up to be as free as possible from air leakage.

The apparatus constructed to meet the above qualifications is shown assembled in figure 1. The heating unit (see figure 1) containing eight independently controlled 250 watts, 220 volts heating elements is shown to the right in the figure. The heating elements were connected through bus bars to the switch indicated by the letter K to the source of power. The humidifier was placed to the left, immediately back of the air line connecting the heating unit and drying chamber. It contained two atomizers placed in opposition to each other immediately ahead of the entering air. These were connected to the source of supply indicated by the lines, A(air), and W(water). The drying chamber projecting forward is shown slightly further to the left. The balance for suspending and weighing the material as loss of moisture occurred was placed on top of this unit as indicated by the sketch, B. The instrument table containing a Leed Northope type K potentiometer, battery, standard cell, galvanometer and scale was placed on the extreme left. The cold junction for the thermocouples was placed between this and the drying chamber. The entire assembly occupied a floor space of five by twelve feet with air over-all height of five feet. One and one quarter inch

angle iron, and heavy galvanized iron were used throughout in the construction of the individual units. Eighty-five percent magnesia asbestos material was used for insulating purposes. A further description with semi-detailed drawing of the individual units is given in the following discussion.

The heating unit, (see figure 2) was constructed by welding together very heavy gage galvanized iron forming an open box rectangular in shape with a tapering inlet and exit to insure a uniform distribution of the air over the heating surface. The heating surface consisted of two 225 watts 220 volts heating elements placed on each of four baffles made from asbestos board. These baffles were arranged in the heating compartment as indicated in the diagram. The entering air struck the first baffle and was deflected upward as shown by the arrow. After passing over this it came in contact with the second baffle where it was deflected downward and made to pass between these two baffles. It then struck the third baffle and continued its course through the heater as indicated above.

The heating elements were connected to two main bus bars and arranged so they could be operated independently of each other. In addition the two located on the last baffle (number four) were placed in a thermostatically con-



trolled system which made it possible to maintain the temperature desired. The system for regulating and controlling the temperature is shown at the lower right in figure 2. It consisted of a toluene mercury expansion thermostat placed in the drying chamber. The toluene and mercury upon expanding or contracting formed a circuit that activated a small telegraph relay which in turn formed a circuit through a relay controlling the circuit of the heating element. It was considered better practice to use this arrangement as it required a very small current to operate the telegraph relay and thus reduced to a minimum the current through the thermostat. It gave satisfactory results throughout the experiment.

The humidifier (see figure 11) consisted of a rectangular chamber, divided into three compartments as indicated in the diagram. The air on passing through the first and second compartments was saturated with moisture by atomizers located near the floor in each of these sections. It then passed over a series of baffles, placed in the third section, designed to remove any moisture mechanically suspended, where upon it was carried to the heater through a three inch pipe containing a wet and dry bulb hygrometer.

The atomizers were constructed from ordinary iron pipe

fittings. Two pipes arranged concentrically with respect to each other and sealed at the base formed the stem of each atomizer. The smaller or inside pipe carried a fitting for attaching it to the air line. Similarly the larger or outside pipe was made attachable to the water line. The spray nozzle was formed by drilling a small hole in each of two caps fitted on the head of the stem, and could be adjusted by shifting their relative positions. Of this construction it should be mentioned that iron pipe fittings are not entirely satisfactory as they are subject to rapid corrosion, and the oxides formed have a tendency to collect and interfere with the spray. Brass fittings undoubtedly would have eliminated this difficulty, however they were not available at the laboratory.

The drying chamber was constructed by welding together one and a quarter inch angle irons forming a rectangular frame two and one half, by three and one half, by four feet on the sides. Heavy galvanized sheet metal used for the sides of the chamber was securely fastened to this frame, and to insure a minimum of air leakage all the joints were lapped and soldered. Provision was made for a door centrally located on the front side. The door which was removable was constructed from the same materials and held in position by a series of bolts. Leakage between it

and the drying chamber was practically eliminated by facing the joint with heavy asbestos lining. Air from the heating unit entered the drier through the funnel shaped inlet near the base. It then came in contact with a series of baffles designed and arranged to give uniform distribution and air circulation, where upon it was carried to the atmosphere through the exit placed slightly below the top as shown in the figure. A differential mercury monometer placed across a calibrated standard orifice inserted in the line connecting the heating unit and drying chamber was used for indicating and making it possible to hold within a small range, the desired air velocities. A mercury thermometer for obtaining the temperature of the entering air was also inserted in this line. To minimize heat exchanges and losses the entire assembly with the exception of the humidifying unit, was well insulated by covering it with a layer of eighty five percent magnesia asbestos insulating material two and one half inches deep.

The specimen was carried in a frame eight inches on a side made by welding together one quarter inch angle iron formed from light weight (one sixteenth inch) black iron sheet metal. This frame was suspended from a balance by a steel wire that passed through a small glass tube inserted near the center in the top of the drying chamber. The balance had a capacity of ten kilograms and was sensitive to



three or four grams.

Copper and constantan metals were used for thermocouples. These were constructed by taking four strands of constantan and one of copper wire thoroughly cleansing the ends, giving them a few twists, and welding them in an electric arc, care being taken not to form a large weld at the junction. After welding, each of these was dipped in an insulating varnish and baked approximately three hours, followed by air drying before installing for use. Nine thermocouples in all were used. These were placed in position by drawing one end of each through a small tube inserted in the top of the drying chamber near the instrument end to a length that it could be embedded in the specimen, when freely suspended from the balance, leaving the remaining end to be inserted in the cold junction bath. The cold junction bath consisted of two compartments arranged concentrically with respect to each other. The ends of the thermocouples were each inserted in a thin wall glass tube sealed at the base. These tubes were placed in the inner compartment which was packed with finely crushed ice. The outer compartment, extremely well insulated, was also packed with finely crushed ice. This arrangement was found to give more satisfactory results than where one compartment was used as the ice in the inner compartment melted very

slowly and apparently the exchange of heat was not so influential in causing temperature changes. The potential developed in the thermocouples was obtained by connecting each through a multipole switch to a Leeds and Northorp type K potentiometer and balancing it against a standard cell of known potential.

#### Procedure

The apparatus was constructed and assembled as discussed above. It first was operated for short periods of eight to ten hours in order to ascertain something of its working characteristics. From these tests, it was found that over a range of temperatures, that might be required in the experimental runs, the heat losses were sufficiently small as to not materially affect the temperatures in the drying chamber. When the drying chamber was operated in the neighborhood of one hundred sixty or seventy degrees fahrenheit; thermometers placed on the heater indicated only a few degrees rise in temperature while those placed on the drying chamber registered but a small change. It was decided that an efficiency test on the apparatus was unnecessary. A few preliminary tests on the drying of solid materials were made, in order to approximate the most favorable operating conditions for experimental test runs.

No data were kept on these as at best they could be but more than indicative of the conditions to be chosen.

Three experimental tests runs were designed and carried out. Each of these occupied a period of eight days of continuous operation. Test specimens were prepared from a material of a cellulose nature. This was treated by first letting it soak over night in a fifty gallon drum. It was then thoroughly agitated for one and one half to two hours with drum stirrers to insure a uniform suspension. The excess water was removed by filtering it through an ordinary cloth filter. The material from this operation was placed in large buchner funnels where a large portion of the remaining water was removed. It was then placed in forms and pressed into cubes eight inches on the side. A great deal of attention was required in this operation to obtain cubes of a uniform density. The cubes were then removed from the form and placed in a moist atmosphere for a period of at least twenty four hours to insure a uniform distribution of moisture throughout before subjecting them to drying.

#### Methods And Operation

Small thin wall glass tubes sealed at the base for inserting the thermocouples were embedded in the specimen



prepared as indicated above. These were spaced uniformly across a central section and injected to a depth one half that of the cube, one on either side being arranged so its base was exposed in the center of the corresponding face. Rigidly attached to the specimen, a similar tube was held in the near vicinity of these faces. The thermocouples were placed one in each tube and the specimen freely suspended in the drying chamber from the balance. The humidifier was adjusted to insure air fully saturated with moisture upon entering the heater. The temperature and air velocity were regulated at the desired values and the apparatus operated from two to three hours before any data was recorded. To insure that the cold junction bath had reached a temperature corresponding to the melting point of ice it was necessary to pack it at least three-quarters of an hour before any readings were taken.

After the apparatus had reached a steady state of operation, as indicated by the temperature regulator, temperatures of the inlet and exit air to the heating unit, and the drying chamber were recorded. The potentiometer was balanced against the standard cell and the electromotive force developed in the thermocouples was recorded at different intervals. Temperatures corresponding to the value of these readings were calculated or obtained graphically.

The equation of the curve in graph (1) for converting micro-volts to temperatures in degrees centigrade is,

$$T = \frac{-0.0037693 (0.0000142077 + 0.00001637636 \cdot E)^{\frac{1}{2}}}{0.00000819218}$$

and was obtained by making the micro-volts developed by the thermocouples at two definite temperatures, thus making it possible to evaluate the constants, A, and B, in the equation,  $E = AT + BT^2 + CT^3 - - -$ , where, E, represents the potential in micro-volts, and T, the temperatures in degrees centigrade, the terms above the second degree being neglected.

The graph was obtained by calculating the temperatures corresponding to potentials varying by 5000 micro-volts in the range between and including 10000 and 30000 micro-volts.

#### DATA

Data for each of three consecutive one hundred seventy two hour runs is tabulated in tables, I, II, and III respectively.

#### NOTES

Values marked with an \* indicates that the cold junction bath was not perfectly packed, or that it had not reached a constant temperature

Table I-Page 1 Temperature Variation, And Operation Conditions

Temperatures-C <sup>o</sup>										
1	2	3	Temp.of Oven	Temp.of Ent.Air	Temp.of Exit Air	Temp.of Heater	Time	Weight	Hg.Dif	
10957	10886	11192	130.0	64.0	110.0	App.Const.	10:00 a.m.	7435	2.53	
11062	11046	11350	132.0	64.0	112.0	" "	11:00 "	7360	3.65	
11220	11082	11515	132.0	66.0	113.0	" "	12:00 "	7282	3.72	
11362	11206	11908	136.0	66.0	116.0	" "	1:00 p.m.	7190	3.69	
11578	11372	12088	137.0	66.0	116.0	" "	2:00 "	7091	3.65	
11788	11540	12016	137.0	67.0	113.2	" "	3:00 "	6998	3.87	
11910	11675	11687	132.0	64.0	110.0	" "	4:30 "	6892	3.94	
11901	11662	11758	133.0	64.0	110.0	" "	5:00 "	6845	3.94	
11870	11620	12094	135.0	66.0	114.0	" "	6:00 "	6763	3.69	
11899	11523	12308	137.0	66.0	116.0	" "	7:00 "	6670	3.66	
11945	11506	12403	138.0	66.0	116.0	" "	8:00 "		3.69	
12005	11580	12614	138.0	66.0	117.0	" "	9:00 "	6500	3.75	
11998	11519	12680	138	66.0	118.0	" "	10:00 "	6425	3.78	
11979	11472	12762	138	64.0	118.0	" "	11:00 "	6337	3.63	
11921	11378	12736	138.0	66.0	117.0	" "	12:00 "	6255	3.55	
11833	11302	12729	138.0	64.0	117.0	" "	1:00 a.m.	6175	3.60	
11631	11171	12698	138.5	65.0	117.5	" "	2:00 "	6082	3.70	
11770	12688	14083	139.0	65.0	119.0	" "	3:30 "	5965	3.75	
12825	12750	14225	138.0	64.0	117.0	" "	5:30 "	5816	3.65	
12591	12876	14518	139.0	64.0	117.0	" "	6:30 "	5743	3.50	
12981	12925	14625	139.0	64.0	117.0	" "	7:30 "	5678	3.72	
13023	12972	14771	138.0	64.0	117.0	" "	8:30 "	5615	3.55	
13065	13022	14877	139.0	64.0	116.5	" "	9:30 "	5554	3.70	



Table I-Page 2 Temperature Variation, And Operation Conditions

1	2	3	Temp.of Oven	Temp.of Ent.Air	Temp.of Exit Air	Temp.of Heater	Time	Weight	Hg.Dif
13129	13068	15092	138.0	64.0	117.0	App.Const.	10:00 a.m.	5492	3.75
13202	13110	15240	138.0	64.0	117.0	" "	11:30 "	5435	3.65
13265	13120	15303	138.0	64.0	117.0	" "	12:30 p.m.	5374	3.60
13308	13102	15348	138.0	64.0	117.0	" "	1:30 "	6330	3.65
13343	13031	15361	138.0	64.0	117.0	" "	2:30 "	5276	3.70
13352	12935	15392	138.0	64.0	118.0	" "	3:30 "	5228	3.75
13289	12790	15440	138.0	64.0	118.0	" "	4:30 "	5175	3.65
13644	13633	15764	139.0	64.0	118.0	" "	5:30 "	6132	3.60
13734	13722	15913	139.0	64.0	118.0	" "	6:30 "	5085	3.55
13840	13832	16062	139.0	64.0	118.0	" "	8:00 "	5025	3.60
13935	13922	16253	140.0	64.0	118.0	" "	9:00 "	4975	3.65
14061	14145	16508	141.0	64.0	119.0	" "	10:20 "	4920	3.75
14158	14145	16508	141.0	64.0	119.5	" "	11:20 "	4882	3.75
14388	14128	16061	137.5	64.0	115.0	" "	10:15 a.m.	4520	3.65

Table II-Page 1 Temperature Variation Within Specimen

Column	Potential Developed In The Thermocouples								
	1	2	3	4	5	6	7	8	9
1	23097	12037	11125		10607	10718	11151	12057	20501
2	20487	12084	11825	11644	11454	11544	11822	12052	18683
3	20392	12076	11997	11964	11740	11767	11924	12093	18525
4	20067	12056	12049	12037	11914	11933	12002	11974	18192
5	19742	12131	12010	12008	11837	11907	12005	12047	17993
6	19552	12119	11996	11987	11731	11801	11943	12040	17688
7	19698	12080	11947	11898	11736	11804	11938	12010	17866
8	19898	12020	11904	11834	11756	11824	11863	11942	18082
9	19855	11971	11891	11853	11783	11851	11885	11896	18076
10	19665	11973	11887	11820	11735	11820	11876	11900	17925
11	19578	11963	11876	11824	11698	11781	11868	11877	17758
12	18986	11972	11868	11805	11620	11703	11856	11873	17038
13	19066	11813	11784	11775	11721	11771	11782	11791	17744
14	19001	11825	11774	11757	11685	11749	11763	11790	17497
15	19057	11917	11869	11778	11685	11777	11800	11870	17553
16	19063	11860	11797	11760	11660	11706	11794	11809	17665
17	19014	11849	11796	11768	11705	11742	11781	11793	17587
18	18535	11850	11800	11781	11748	11777	11784	11804	17100
19	18371	11861	11807	11795	11728	11761	11802	11822	17140
20	18758	11866	11815	11800	11728	11763	11808	11822	17387
21	20566	12468	12266	12141	12045	12077	12206	12380	18735
22	20618	12536	12396	12270	12184	12216	12338	12466	18870
23	20408	12577	12473	12390	12320	12336	12435	12614	18803
24	20535	12585	12521	12444	12426	12443	12510	12566	18652

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## Temperature Variation Within Specimen

Column	Potential Developed In The Thermocouples								
	1	2	3	4	5	6	7	8	9
25	20216	12624	12524	12514	12361	12487	12511	12603	18522
26	19950	12634	12550	12511	12325	12477	12534	12633	18285
27	20035	12645	12564	12501	12315	12481	12539	12628	18326
28	20127	12654	12557	12541	12375	12510	12542	12643	18439
29	20339	12707	12633	12556	12482	12548	12568	12656	18504
30	20362	12802	12657	12616	12611	12615	12637	12777	18679
31	20182	12861	12685	12652	12631	12642	12681	12858	18623
32	19624	12966	12830	12796	12620	12790	12796	12911	17891
33	20345	12985	12978	12815	12794	12800	12823	12940	18419
34	20615	13219	13050	12890	12726	12820	12975	13066	18029
35	21108	13494	13139	13064	12658	12872	13064	13322	17620
36	20461	13478	13204	12761	12685	12741	12781	13229	17347
37	20215	13241	12772	12612	12320	12585	12652	13036	17230
38	21667	14236	14207	13953	13948	13948	14057	14220	20180
39	21555	14755	14337	14300	14194	14206	14262	14522	20373
40	22100	15150	14817	14595	14482	14494	14650	15004	20562
41	21660	18610	15083	14751	14635	14655	14835	15198	20000
42	22322	15281	15004	14862	14751	14816	14976	15114	20142
43	21950	15470	15165	14952	14680	14817	15060	15325	19743
44	22392	15744	15193	15054	14844	15042	15160	15524	19748
45	22184	15883	15393	15218	15083	15203	15304	15764	20481
46	21525	15813	15374	15255	15002	15165	15350	15571	19932
47	22572	19184	16804	16673	16146	16523	16710	18574	21772
48	20500	15336	15224	15200	14889	15193	15220	15225	17970



Column	Potential Developed by Thermocouples								
	1	2	3	4	5	6	7	8	9
49	20132	15308	15043	14949	14716	14938	15042	15197	18958
50	21552	15892	14956	14924	14537	14656	14924	15458	20340
51	22338	16229	15278	14962	14692	14822	15224	15935	20628
52	21794	16735	15900	15348	14276	15185	15456	16102	20050
53	22560	16833	15536	15369	15364	15368	15436	16208	21256
54	22146	16624	15736	15561	15495	15493	15652	16270	20827
55	22563	16565	15646	15574	15523	15562	15652	16267	21165
56	22629	17011	15665	15587	15535	15538	15581	16511	21543
57	22801	17111	15714	15634	15611	15615	15664	16615	21637
58	22929	17185	16155	15732	15709	15686	15730	16697	21642
59	22810	17366	15860	15782	15509	15729	15809	16802	21621
60	22935	17462	15873	15771	15570	15763	15815	16890	21786
61	22681	17471	15860	15775	15326	15775	15831	16927	21596
62	22900	17650	15930	15804	15140	15794	15830	17039	21770
63	22626	17701	16038	15815	14860	15795	15895	17140	21705
64	22512	17813	15978	15884	15285	15828	15889	17209	21590
65	22040	17886	15941	15838	14790	15716	15896	17243	21399
66	22101	17862	15814	15736	15360	15708	15788	17165	21190
67	23290	18379	15923	15784	15450	15795	15783	17728	22083
68									
69	20392	12093	11997	11924	11740	11767	11964	12076	18525
70	20067	12049	12037	11974	11914	11933	12002	12056	18192
71	19552	12119	11996	11943	11731	11801	11987	12040	17688

Column	Potential Developed by Thermocouples								
	1	2	3	4	5	6	7	8	9
72	19698	12080	11947	11898	11736	11804	11938	12010	17866
73	19898	12020	11904	11834	11756	11824	11863	11942	18082
74	19855	11971	11891	11853	11783	11851	11885	11896	18076
75	19665	11973	11887	11840	11735	11820	11876	11900	17925
76	19578	11963	11877	11868	11824	11781	11824	11876	17758
77	18986	11972	11868	11805	11620	11703	11856	11873	17038

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## Operating Conditions Of Apparatus

Working Conditions Of Drying Chamber								
	Temp. of Dry Chamber	Temp. of Exit Air	Temp. of Heater	Temp. of Ent. Air	Mercury Differential	Weight	Time	Date
1	146.0	124.0	194.0	66.0	3.00 "	9183.0	6:00	p.m.
2	138.0	117.0	158.0	68.0	Approx. Con.	8978.0	8:00	"
3	137.0	115.0	157.0	65.0	" "	8875.0	9:00	"
4	137.0	114.0	157.0	64.0	" "	8783.0	10:00	"
5	137.0	119.0	154.0	64.0	" "	8710.0	11:00	"
6	136.0	112.0	155.0	64.0	" "	8614.0	Mid Night	
7	136.0	112.0	155.0	64.0	" "	8538.0	1:00	a.m.
8	136.0	113.0	156.0	64.0	" "	8425.0	2:00	"
9	135.0	112.0	157.0	64.0	" "	8346.0	3:00	"
10	135.0	111.0	155.0	64.0	" "	8247.0	4:00	"
11	135.0	111.0	156.0	64.0	" "	8161.0	5:00	"
12	134.0	109.0	150.0	64.0	" "	8064.0	6:00	"
13	134.0	111.0	149.0	65.0	" "	7813.0	9:00	"
14	134.0	111.0	146.0	66.0	" "	7724.0	10:00	"
15	134.0	111.0	145.0	65.0	" "	7636.0	11:00	"
16	134.0	111.0	147.0	64.0	" "	7566.0	Noon	
17	134.0	112.0	146.0	65.0	" "	7883.0	1:00	p.m.
18	134.0	110.0	140.0	65.0	" "	7405.0	2:00	"
19	134.0	109.0	142.0	66.0	" "	7335.0	3:00	"
20	133.0	110.0	144.0	66.0	" "	7260.0	4:00	"
21	136.0	115.0	156.0	68.0	" "	6927.0	8:00	"
22	136.0	115.0	157.0	67.0	" "	6844.0	9:00	"
23	136.0	115.0	156.0	66.0	" "	6765.0	10:00	"



Table II a-Page 2 Operating Conditions Of Apparatus

Working Conditions of Drying Chamber								
	Temp. of Dry Chamber	Temp. of Exit Air	Temp. of Heater	Temp. of Ent. Air	Mercury Differential	Weight	Time	Date
24	136.0	115.0	157.0	66.0	Approx. Con.	6680.0	11:00 p.m.	
25	136.0	114.0	155.0	65.0	" "	6605.0	Mid Night	
26	136.0	113.0	153.0	64.0	" "	6527.0	1:00 a.m.	
27	136.0	113.0	155.0	64.0	" "	6447.0	2:00 "	
28	136.0	113.0	155.0	64.0	" "	6377.0	3:00 "	
29	136.0	114.0	156.0	64.0	" "	6310.0	4:00 "	
30	136.0	114.0	156.0	66.0	" "	6240.0	5:00 "	
31	136.0	114.0	159.0	66.0	" "	6290.0	6:00 "	
32	134.0	112.0	148.0	64.0	" "	6093.0	7:15 "	
33	136.0	114.0	155.0	66.0	" "	6047.0	8:00 "	
34	137.0	115.0	158.0	66.0	" "	6000.0	9:00 "	
35	137.0	116.0	160.0	66.0	" "	5945.0	10:00 "	
36	138.0	117.0	161.0	65.0	" "	5867.0	11:00 "	
37	138.0	117.0	161.0	66.0	" "	5850.0	11:35 "	
38	138.0	119.0	164.0	65.0	" "	5670.0	3:00 p.m.	
39	138.0	120.0	165.0	64.0	" "	5580.0	4:40 "	
40	138.0	120.0	164.0	64.0	" "	5485.0	6:50 "	
41	138.0	118.0	160.0	66.0	" "	5415.0	8:30 "	
42	138.0	120.0	168.0	66.0	" "	5360.0	10:00 "	
43	138.0	119.0	164.0	66.0	" "	5282.0	Mid Night	
44	138.0	120.0	165.0	66.0	" "	5208.0	2:15 a.m.	
45	139.0	120.0	165.0	66.0	" "	5110.0	5:30 "	
46	140.0	118.0	164.0	66.0	" "	5052.0	7:00 "	
47	140.0	121.0	174.0	64.0	" "	4981.0	8:00 "	

Working Conditions of Drying Chamber								
	Temp. of Dry Chamber	Temp. of Exit Air	Temp. of Heater	Temp. of Ent. Air	Mercury Differential	Weight	Time	Date
48	138.0	115.0	153.0	66.0	Approx. Con.	4970.0	9:15 a.m.	8/23/32
49	136.0	114.0	155.0	66.0	" "	4920.0	11:30 "	" " "
50	140.0	120.0	178.0	66.0	" "	4865.0	1:30 p.m.	" " "
51	140.0	120.0	168.0	66.0	" "	4815.0	3:30 "	" " "
52	140.0	119.0	169.0	65.0	" "	4751.0	5:45 "	" " "
53	140.0	121.0	168.0	68.0	" "	4702.0	" "	" " "
54	140.0	120.0	166.0	66.0	" "	4648.0	10:00 "	" " "
55	140.0	120.0	168.0	66.0	" "	4600.0	Mid Night	8/24/32
56	142.0	122.0	168.0	66.0	" "	4555.0	2:00 a.m.	" " "
57	142.0	122.0	167.0	66.0	" "	4510.0	4:00 "	" " "
58	142.0	121.0	168.0	66.0	" "	4465.0	6:10 "	" " "
59	142.0	122.0	169.0	66.0	" "	4427.0	8:00 "	" " "
60	142.0	122.0	168.0	65.0	" "	4387.0	Noon	" " "
61	142.0	121.0	166.0	65.0	" "	4348.0	Noon	" " "
62	142.0	122.0	169.0	66.0	" "	4316.0	2:00 p.m.	" " "
63	142.0	121.0	169.0	66.0	" "	4283.0	3:45 "	" " "
64	142.0	120.0	175.0	66.0	" "	4228.0	7:00 "	" " "
65	142.0	120.0	168.0	67.0	" "	4147.0	Mid Night	" " "
66	142.0	120.0	168.0	66.0	" "	4060.0	6:00 a.m.	8/25/32
67	142.0	123.0	180.0	67.0	" "	4000.0	11:00 "	" " "
68	142.0	120.0	170.0	67.0	" "	3920.0	5:30 p.m.	" " "
69	137.0	115.0	167.0	65.0	" "	3875.0	9:00 "	" " "
70	137.0	114.0	167.0	64.0	" "	2783.0	" "	" " "
71	138.0	118.0	170.0	65.0	" "	" "	" "	" " "

Working Conditions of Drying Chamber								
	Temp. of Dry Chamber	Temp. of Exit Air	Temp. of Heater	Temp. of Ent. Air	Mercury Differential	Weight	Time	Date
72	136.0	112.0	165.0	64.0	Approx. Con.	2528.0		
73	136.0	113.0	160.0	65.0	" "	2425.0		
74	136.0	112.0	160.0	65.0	" "	2346.0		
75	135.0	111.0	160.0	64.0	" "	2247.0		
76	135.0	111.0	160.0	64.0	" "	2161.0		
77	135.0	114.0	160.0	64.0	" "	2064.0		



Table III-Page 1

## Temperature Variation Within Specimen

Column	Potential Developed in the Thermocouples								
	1	2	3	4	5	6	7	8	9
1	20685	12316	11388	11084	10873	11226	11452	11762	19576
2	20942	12890	12383	12237	12147	12298	12335	12300	19912
3*	18849	10787	.09854	.09900	.09621	.09831	10250	10520	17992
4	16240	.09038	.08305	.08200	.07956	.08386	.08386	.08759	14960
5	14612	.07111	.06199	.06060	.05880	.06059	.06214	.07250	13592
6	22286	15422	14231	14042	13880	14120	14260	15561	21245
7	22787	16243	15109	14851	14578	14930	15104	16285	21714
8	23151	16736	15556	15429	15284	15446	15515	16626	22052
9	22588	17161	16234	16102	16019	16110	16037	16868	21778
10	22008	17023	16143	12042	15997	16044	15956	16679	20945
11	21437	16705	15908	15837	15852	15819	15648	16426	20497
12	22275	17288	16040	15841	15794	15872	15857	16916	21268
13	21679	17117	16132	16020	15949	16022	15981	16703	20971
14	19320	16640	16075	16012	15965	15980	15903	16303	18467
15	22015	16404	14005	13518	13141	13227	13984	15972	21344
16	21638	16459	14681	14381	14095	13613	14618	16015	20686
17	22745	17344	15473	15203	15022	15282	15372	16895	21974
18	23275	17962	15987	15775	15605	15838	15864	17422	22421
19	21994	17584	16356	16277	16185	16247	16176	17024	21209
20	22804	18397	16580	16481	16402	16462	16367	17907	22097
21	22072	18015	16380	16352	16306	16297	16140	17560	21372
22	22882	18400	16347	16265	16123	16235	16128	17911	22087
23	21715	17967	16291	16246	16166	15647	16074	17538	21061
24	22610	18271	16091	16050	15988	15643	15898	17849	21631

TABLE III-Page 2

## Temperature Variation Within Specimen

Column	Potential Developed in the Thermocouples								
	1	2	3	4	5	6	7	8	9
25	23114	18928	16375	16143	16109	15146	16011	18349	22364
26	21974	18158	15835	15329	15251	15023	15255	17295	21362
27	23302	19353	16924	16824	16624	16754	16682	18811	22642
28	22786	19018	16851	16814	16734	16815	16595	18498	22029
29	23051	19202	16800	16734	16608	16657	16518	18679	22097
30	21689	19004	16555	16557	16511	16492	16306	18001	20900
31	20967	18082	16122	16261	16237	16164	15900	17502	19965
32	20653	18097	16055	16078	16069	16082	16068	16093	21720
33	21701	17719	16076	16065	15875	15924	15895	17860	20868
34	21815	18662	16126	15915	16087	16014	15883	18017	20740
35	22382	18539	15735	15614	15524	15631	15546	17811	21505
36	22952	19326	16325	16162	16000	16185	16155	18647	22069
37	23210	19795	16806	16703	16584	16723	16607	19094	22330
38	23178	19836	16868	16794	16695	16795	16666	19158	22395
39	23080	19861	16883	16818	16727	16814	16679	19223	22283
40	23422	20158	17000	16917	16792	16915	16806	19481	22642
41	22736	19550	15942	15855	15926	16380	16039	18310	21722
42	21713	19616	17037	17015	16898	16900	16797	18900	20921
43	21248	18902	16530	16631	16666	16254	16247	18409	20637
44	21392	19203	16409	16422	16351	16401	16252	18500	20668
45	21245	19151	16199	16202	16177	16189	16112	18305	20530

Column	Working Conditions Of Apparatus							
	Temp.of Dry Cham.	Temp.of Ent.Air	Temp.of Heater	Temp.of Exit Air	Mercury Differential	Weight	Time	Date
1	140.0	65.0	175.0	116.0	2.75	9307.0	5:00 p.m.	5/2/32
2	142.0	64.0	176.0	118.0	2.70	8800.0	10:30 "	" " "
3	143.0	65.0	178.0	122.0	2.80	7969.0	6:30 a.m.	5/3/32
4	141.0	64.0	166.0	118.0	2.80	7760.0	8:55 "	" " "
5	143.0	66.0	177.0	122.0	3.00	7456.0	1:00 p.m.	" " "
6	143.0	67.0	184.0	122.0	2.90	7141.0	6:00 "	" " "
7	144.0	68.0	183.0	122.0	2.95	6985.0	9:00 "	" " "
8	144.0	68.0	186.0	124.0	2.85	6830.0	Mid Night	" " "
9	144.0	68.0	184.0	122.0	2.80	6543.0	6:30 a.m.	5/4/32
10	142.0	68.0	184.0	120.0	2.50	6428.0	9:30 "	" " "
11	140.0	68.0	174.0	118.0	2.55	6346.0	Noon	" " "
12	144.0	68.0	171.0	120.0	2.50	6270.0	2:00 p.m.	" " "
13	142.0	68.0	168.0	118.5	2.65	6213.0	4:00 "	" " "
14*	134.0	66.0	199.0	105.0	2.60	6172.0	5:40 "	" " "
15	143.0	64.0	175.0	107.0	3.00	5940.0	1:15 "	5/5/32
16	142.0	66.0	188.0	117.0	1.50	5885.0	3:15 "	" " "
17	144.0	66.0	180.0	122.0	2.50	5817.0	6:00 "	" " "
18	145.0	68.0	176.0	122.0	3.00	5749.0	7:00 "	" " "
19	146.0	68.0	190.0	122.0	3.10	5642.0	Mid Night	5/5/32
20	146.0	68.0	176.0	122.0	3.25	5493.0	6:00 a.m.	5/6/32
21	445.0	68.0	168.0	118.0	3.15	5420.0	9:10 "	" " "
22	143.0	68.0	174.0	122.0	3.20	5360.0	Noon "	" " "
23	142.0	66.0	165.0	119.0	2.90	5304.0	3:00 p.m.	" " "



Column	Working conditions of Apparatus							
	Temp.of Dry Cham.	Temp.of Ent.Air	Temp.of Heater	Temp.of Exit Air	Mercury Differential	Weight	Time	Date
24	143.0	68.0	172.0	122.0	3.00	5246.0	5:45 p.m.	5/6/32
25	144.0	65.0	174.0	124.0	3.10	5180.0	9:00 "	" " "
26	148.0	64.0	220.0	121.0	1.00	5145.0	11:00 "	" " "
27	149.0	64.0	190.0	125.0	3.10	5108.0	1:00 a.m.	5/7/32
28	145.0	66.0	175.0	120.0	3.25	5070.0	3:00 "	" " "
29	144.0	66.0	166.0	121.0	3.50	4991.0	7:00 "	" " "
30	142.0	64.0	165.0	117.0	2.90	4957.0	9:25 "	" " "
31	141.0	66.0	162.0	114.0	3.00	4935.0	11:10 "	" " "
32	142.0	64.0	173.0	118.0	2.90	4900.0	1:10 p.m.	" " "
33	142.0	64.0	167.0	116.0	3.25	4881.0	3:70 "	" " "
34	141.0	67.0	171.0	117.0	3.15	4857.0	5:00 "	" " "
35	144.0	66.0	185.0	120.0	2.90	4785.0	10:30 "	" " "
36	144.0	67.0	190.0	122.0	3.00	4740.0	1:00 a.m.	5/8/32
37	144.0	66.0	180.0	122.0	3.10	4692.0	5:00 "	" " "
38	145.0	66.0	180.0	122.0	3.20	4648.0	8:30 "	" " "
39	144.0	66.0	178.0	122.0	3.15	4614.0	11:20 "	" " "
40	145.0	66.0	180.0	122.0	3.00	4569.0	3:00 p.m.	" " "
41	145.0	67.0	178.0	124.0	3.20	4532.0	6:30 "	" " "
42	143.0	65.0	164.0	119.0	3.12	4355.0	9:00 a.m.	5/9/32
43	142.0	64.0	164.0	116.0	3.06	4336.0	11:00 "	" " "
44	142.0	65.0	165.0	116.0	3.00	4300.0	3:15 p.m.	" " "
45	142.0	65.0	180.0	118.0	3.00	4286.0	5:00 "	" " "

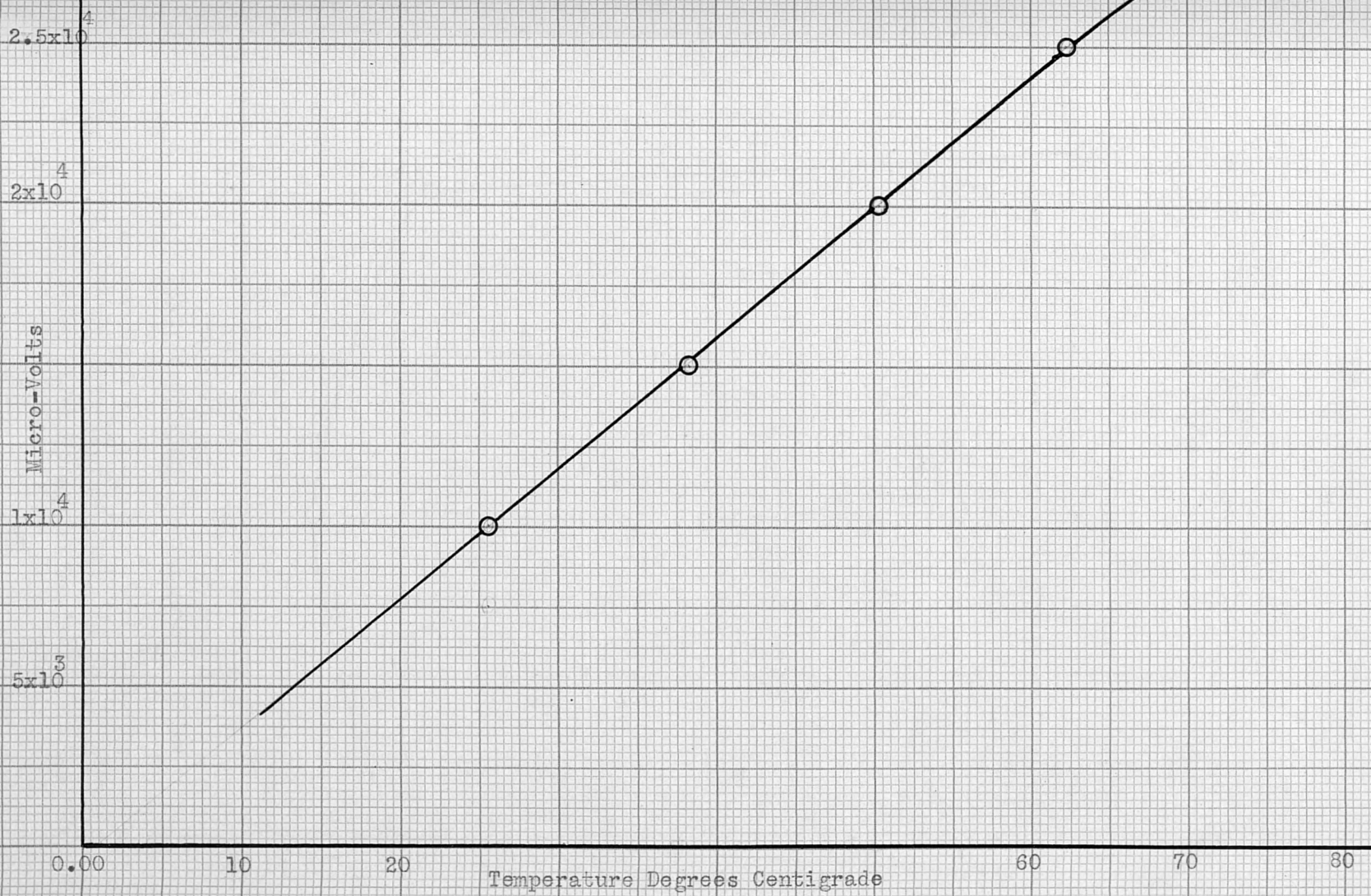
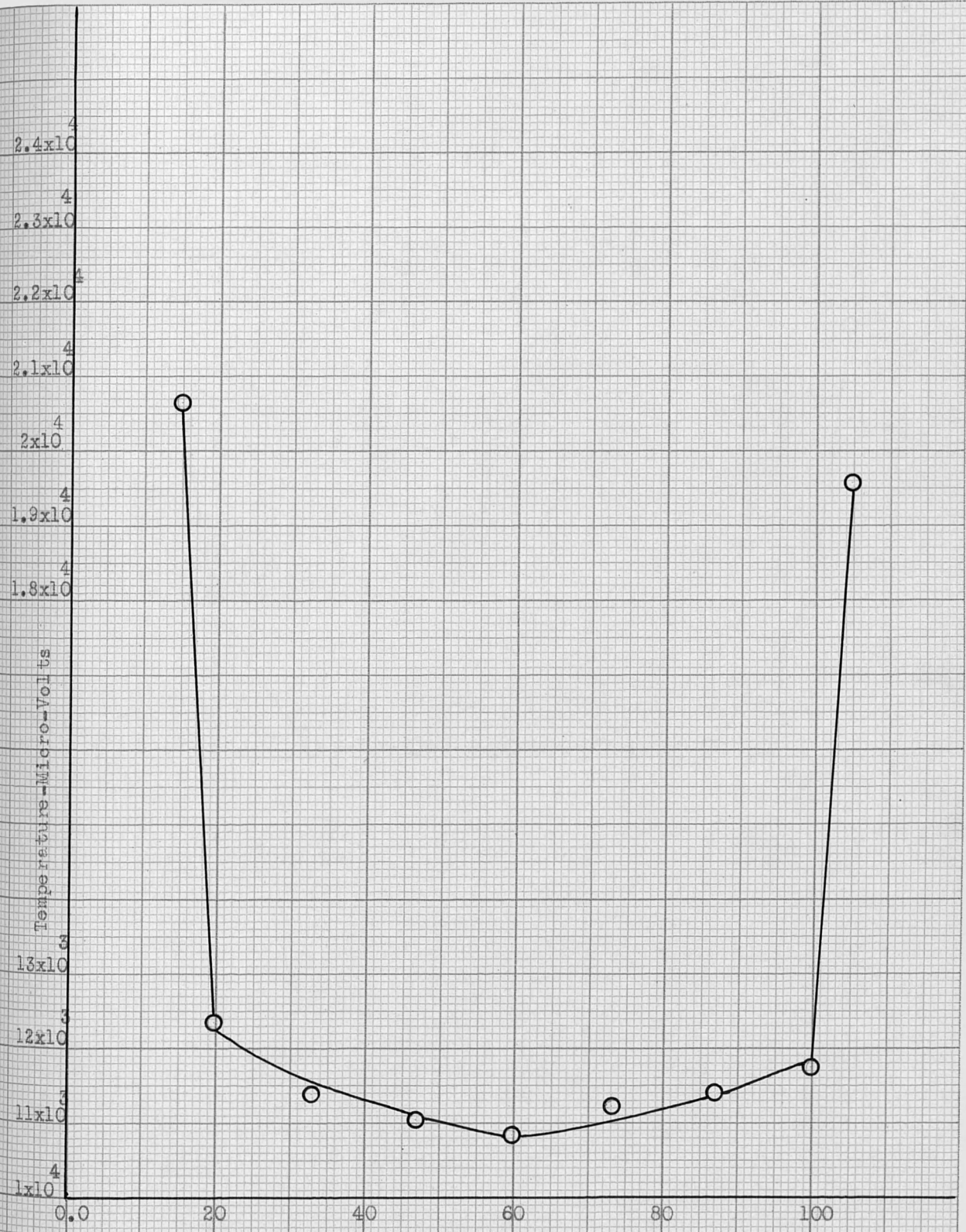


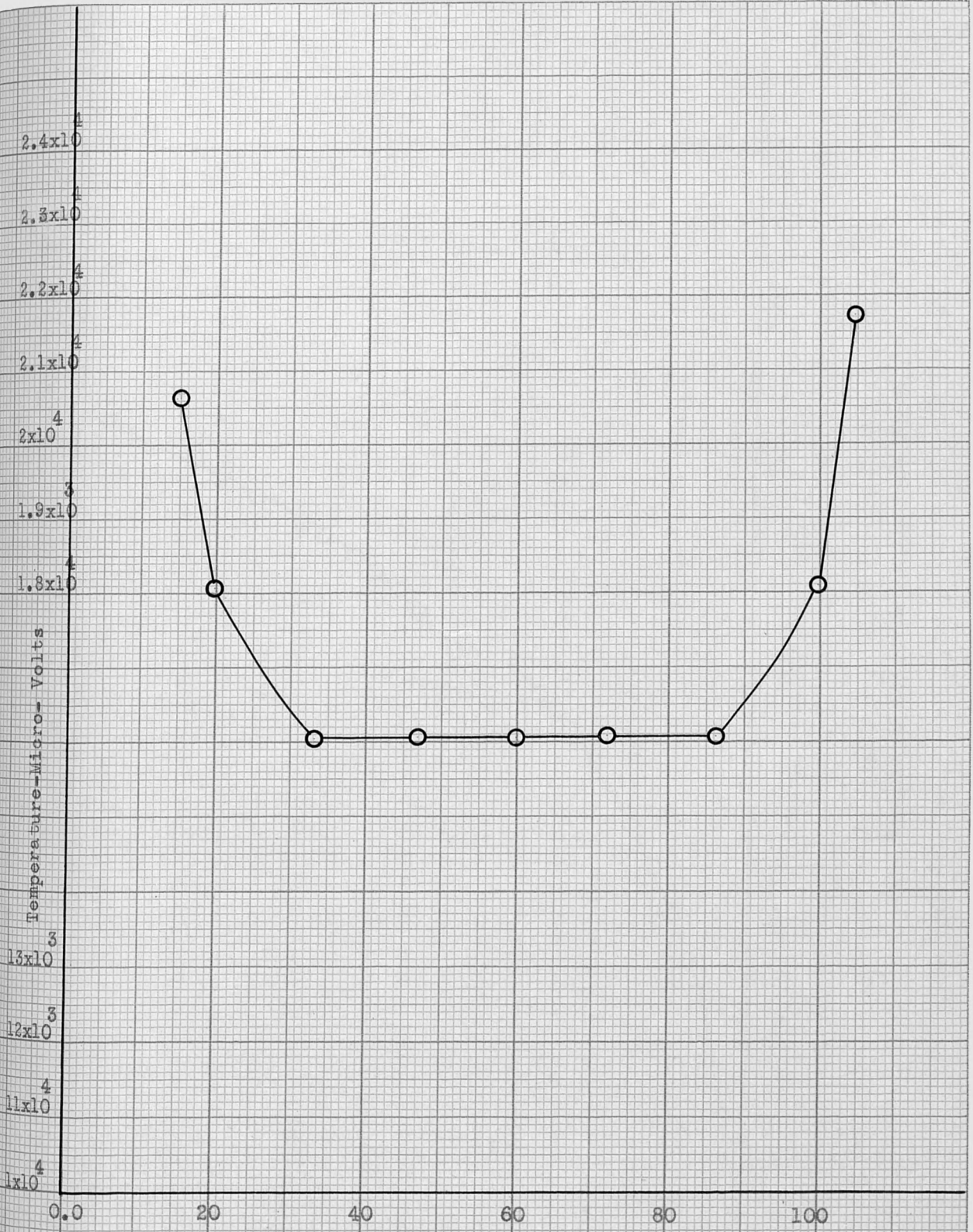
Fig.1 Micro-Volts Versus Temperature Curve



Space Distribution Of Thermocouples In The Cube

Fig. 1 Temperature Distribution Curve In The Specimen  
And Its Immediate Vicinity At The Beginning Of The Test Run





Space Distribution Of Thermocouples In The Cube

Fig. 2 Temperature Distribution Curve In The Specimen And Its Immediate Vicinity At The Close Of The Test Run

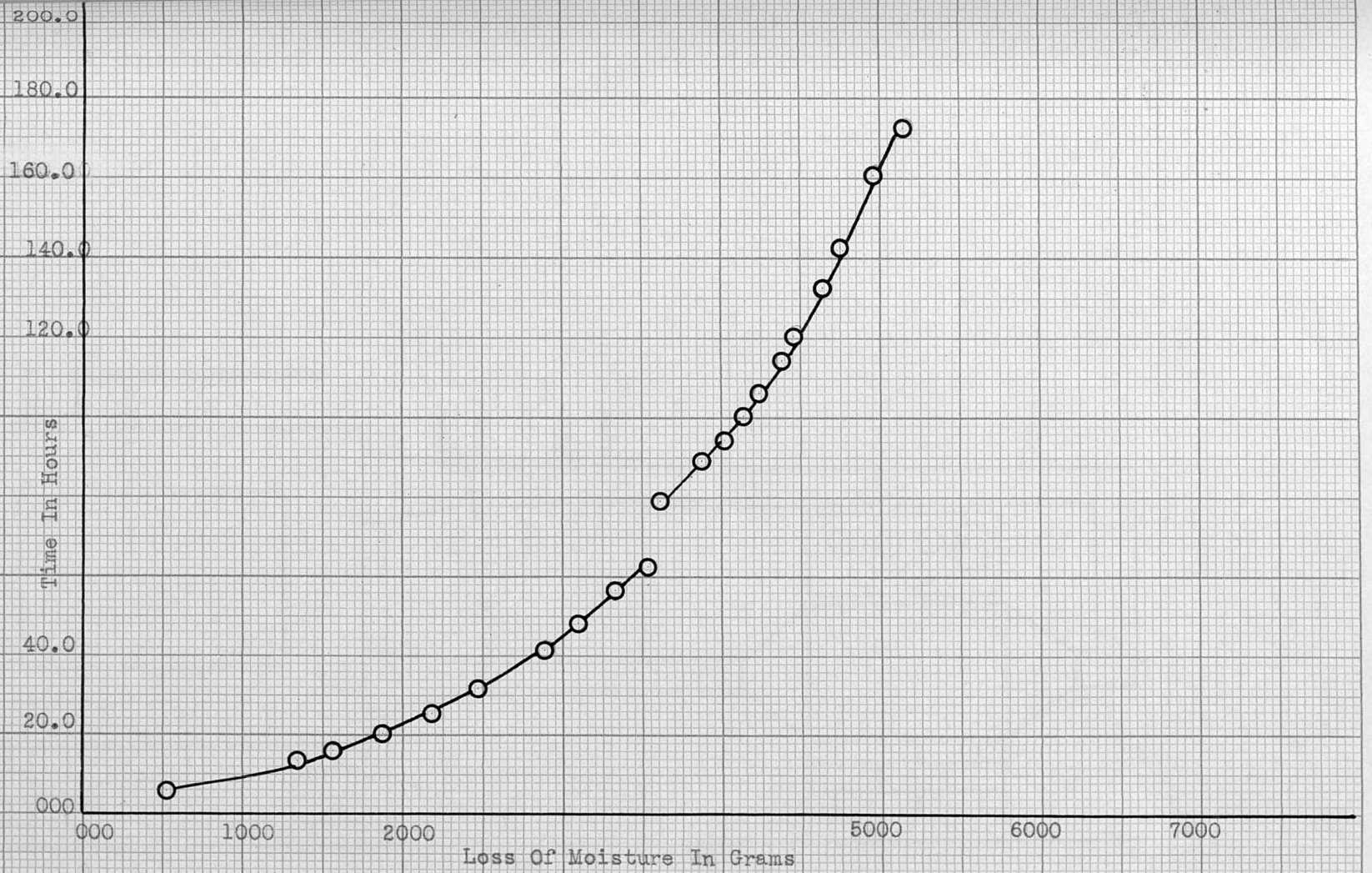


Fig. 4 Loss Of Moisture Versus Time Curve

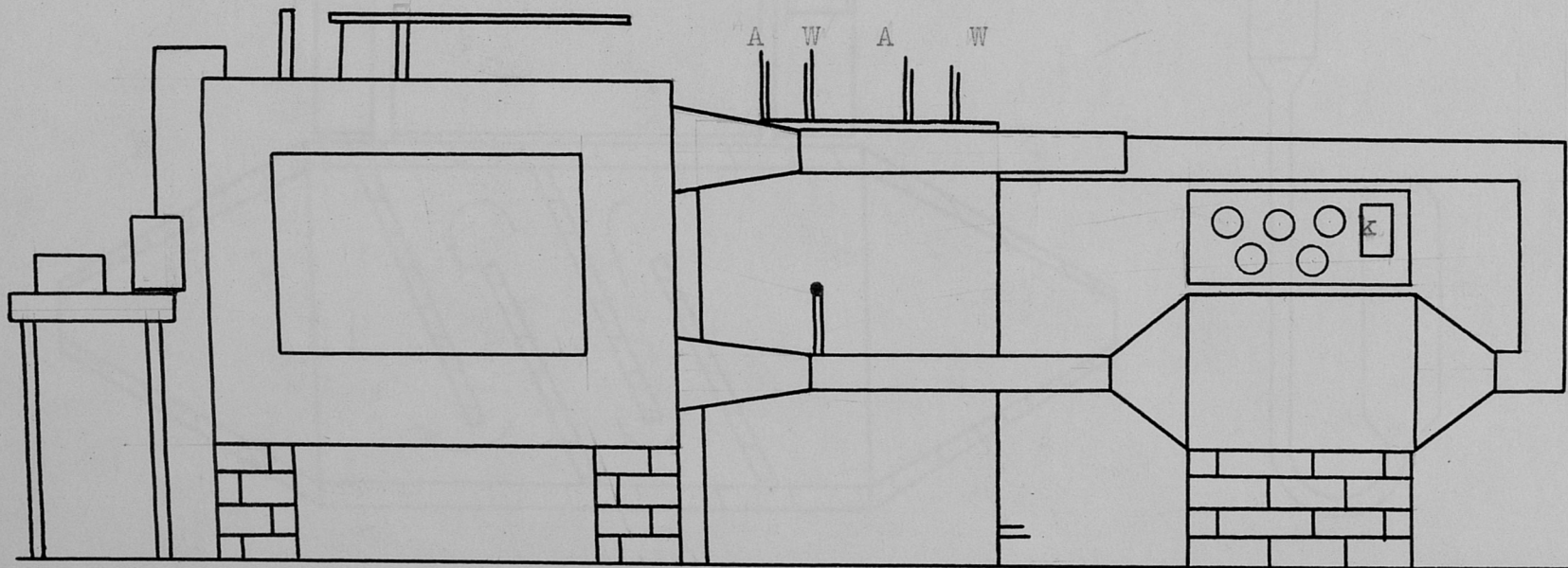


Diagram-I



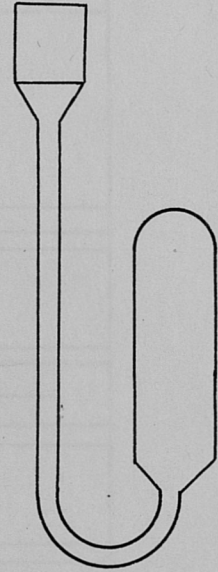
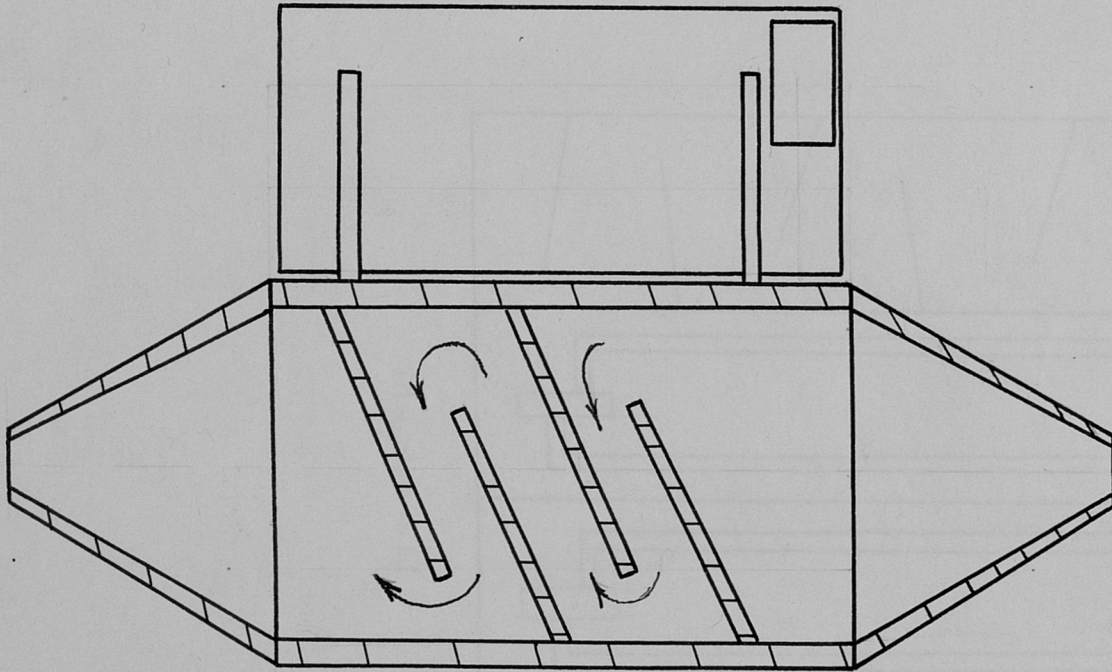


Diagram -II

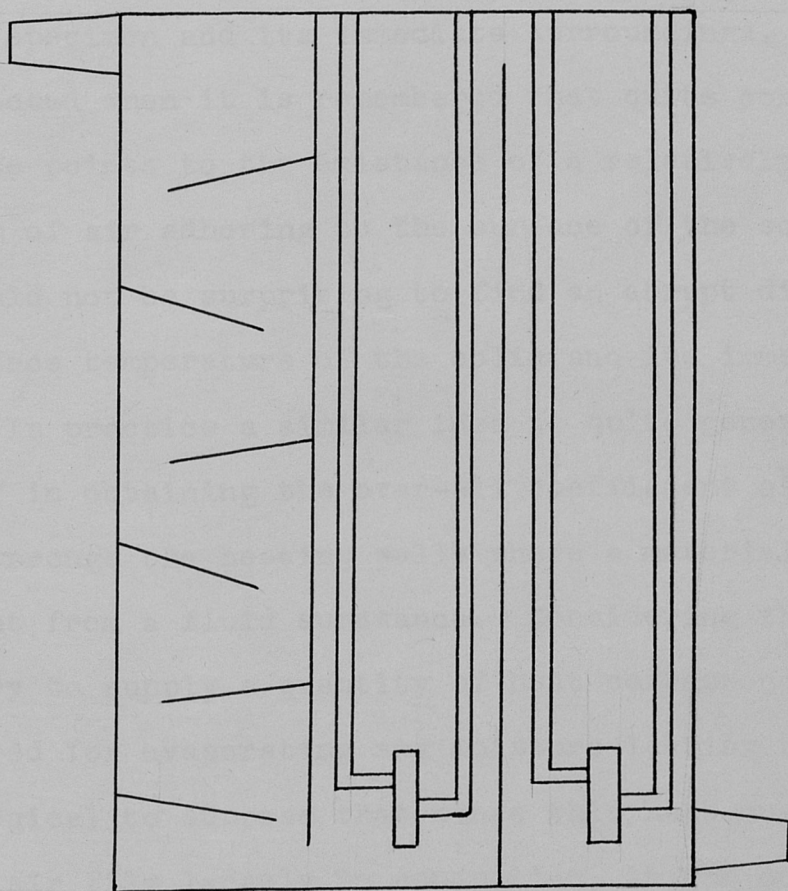


Diagram-III

## DISCUSSION OF DATA

The data tabulated is indicative that two entirely different distinct regions exist in the temperature gradient across the specimen and its immediate surroundings. This may be expected when it is remembered that quite conclusive evidence points to the existence of a relatively stationary film of air adhering to the surface of the solid, and it should not be surprising to find an abrupt difference in the surface temperature of the solid and its immediate vicinity. In practice a similar idea is quite generally made use of in obtaining the over-all coefficient of heat exchanges through the heating walls where a material is receiving heat from a fluid substance. Considering that it is necessary to supply a quantity of heat corresponding to that required for evaporating any moisture leaving the solid it is logical to suppose that since this heat must pass across the air film largely by conduction, it can do so only by the existence of a difference in the temperature at the solid-air interface. In addition the temperature difference across this region must be sufficiently large to supply the heat requisite for raising the temperature of the material being dried. It would, therefore, seem convenient to think of this portion of the temperature gradient as being similar to that formed where heat is



flowing across an insulating material having very poor conducting qualities. However to suppose that it is strictly linear throughout this region would hardly give a true picture of its variation because the temperature at the inner most face of the film does not remain constant but increases as the temperature of the material rises.

The temperature variation within the material it would seem at first thought should follow very closely Fourier's laws on the distribution of heat, as were discussed in the section of the literature concerning their applicability to the diffusion of moisture. Assuming that it does, the intergal equations, as were developed in the case for the diffusion of moisture and are identical with those for the diffusion of heat are indicative that loci of equal temperatures within the material are in part dependent upon its shape as well as its susceptibility to heat changes. This immediately gives rise to a question concerning the inapplicability of these equations in their present form to the actual conditions encountered in the drying of solid substances. In general it has been found that the diffusivity of moisture depends upon the nature of the material and varies independently with its temperature. It would then seem evident that if a substance were not of a uniform temperature and its temperature gradient depends upon its space con-

figuration, that the constant of diffusivity, as determined under a particular set of conditions and generally used in the equation for obtaining the free moisture of a substance would not remain a single valued quantity but would depend upon the space coordinates of the system under consideration. In addition to being subject to these influences, the temperature gradient in the system can hardly be expected to conform to that required by Fourier's laws on the flow of heat, since the material upon losing moisture does not preserve a homogeneous character, and further the moisture near the center being of a lower temperature upon diffusing toward the surface has a tendency to reduce the temperature gradient of the system as it approaches the surface. In all probability, as indicated by considering curves (2), (3), and (4) in common, the ideal situation conforming to the conditions required by the given equations exists only when the temperature of the material becomes uniform throughout and approaches that of the drying atmosphere, drying being effected only by the partial pressure difference existing because of the difference in the moisture concentration in the drying air and that on the surface of the solid graphs (2) and (3) were selected as representing respectively typical temperature distribution curves near the beginning and close

of a one hundred seventy two hour test run. In comparing these two curves it is evident that the material approached a more nearly uniform temperature as the drying operation was prolonged. Curve (4) represents the moisture lost by the material over the drying period. For the purpose of discussion it may be considered to form points of tangency to the vertices of the successive temperature distribution curves. It should be noticed that while the temperature gradient curves approach a straight line apparently they do so as the free moisture approaches zero or the equilibrium moisture content of the material is reached.

#### CONCLUSIONS

1. The temperature changes abruptly in the immediate neighborhood of a material subject to drying.
2. The temperature gradient within a material subject to drying does not strictly follow Fourier's laws for the flow of heat.
3. The diffusivity of moisture, it would seem, can hardly be considered a constant value for material with different space coordinates unless drying is effected only by the partial pressure difference caused by a difference in the moisture concentration of the drying atmosphere and that on the surface of the material.



4. The temperature of a material evidently approaches uniformity and that of the drying atmosphere as the moisture it contains approaches its equilibrium moisture content at the conditions under which it is being dried.

#### ACKNOWLEDGMENT

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