

THE DRYING AND WARPING PROPERTIES OF SCHERER INSULATION

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## I INTRODUCTION

Interest in thermal insulation should be universal from both the domestic and the industrial standpoint. The obvious reason for domestic insulation is that of comfort and a saving of money in the home. From an industrial standpoint, the use of thermal insulation is important to prevent the loss of heat which is a direct loss in dollars. Another reason is that a well operated plant depends largely upon the accurate control of temperature, since the tendency is towards chemical processes where definite temperature control is required. Air conditioning has also come to the foreground. One of the most important needs in proper air conditioning is that of thermal insulation. (1)

In the Summer of 1937, Dr. P. C. Scherer of the Virginia Polytechnic Institute discovered that upon adding alkali to viscose, a china like material of considerable strength was produced. Upon adding aluminum to the mix hydrogen was evolved, and a porous mass was produced which upon setting and drying formed an excellent insulating material, porous in character.

In 1938, J. A. Radspinner investigated the product further and attempted to improve the product by the use of various fillers. He found that gypsum, when used in this capacity increased the strength and decreased the cracking upon setting. However, the difficulty remained that upon drying the product warped considerably. (15)

The problem is to find efficient means of drying to prevent warping and still produce a product of good insulating value.

## II REVIEW OF LITERATURE

### A. Insulation

#### 1. Insulating Materials

a. Thermal Conductivity The thermal conductivity of a substance is defined by Fourier's equation which states that the fundamental law of conduction is that the rate of heat flow is proportional to the area of cross section  $A$  and to the temperature gradient  $- dt/dL$ , both taken at the point. The proportionality factor  $k$  is called the thermal conductivity and is defined by the equation: (25)

$$dQ/dt = - kAdt/dL$$

Low values of thermal conductivity are essential for efficient insulation

b. Insulation Development In 1841 Peclet published his pioneering experiments in the field of measuring the conductivity of metals. The formulas which he derived applied equally well to the heat flow through insulating materials; and therefore with a method of actually measuring the property of conductivity and with rapid strides in industrial and mechanical fields, the development of insulating materials assumed its rightful place in ever increasing proportions.

Starting in the early seventies came the first commercial development of pipe covering in the form of plastic cements made from clay and asbestos fiber; next lime was mixed with sawdust, wool waste and paper pulp, with a flower adhesive or anything that would stay in place on a pipe and could be troweled on. Now insulation development in both pipe covering and block form have passed through the stages of generalities where one type

of material was used for all purposes, to the stage of specialization, where each rather narrow range of temperature and limiting condition of service has its own special material or materials, scientifically designed to give maximum efficiency and service. In the late seventies the first covering of definite thicknesses were developed and took the form of corrugated asbestos paper wrapped up to form an air cell type of covering.

In 1885, the now well known 85 per cent magnesia was discovered and it replaced the air cell type of covering for all but the low pressure steam lines. This material showed great effectiveness in preventing heat losses and became the general all around insulation. However, for cases of severe service, where, due to being subject to external damage this magnesia proved unsuitable, a molded material of asbestos fibers and water glass was being developed. As this latter material was less efficient than magnesia as an insulator, it became desirable to find a material as effective as magnesia and as durable as the molded fiber material.

Laminated asbestos felts were next fabricated into insulators, the laminations at first being wired together and later being cemented by sodium silicate. Various methods were used to improve the effectiveness of the laminated insulator, the most successful one being the imbedding of particles of cut sponge in the asbestos felts. Indenting the asbestos felts to form air pockets became another general practice.

In 1895 pure corkboard and pure cork pipe covering were developed for refrigeration purposes. This material contained no foreign bonding agents, since the natural gums sufficed for the purpose upon heat treatment of the material.

Fifteen years later, brown argillaceous material (limestone) was mixed with asphalt and formed into a synthetic cork-like insulation for refrigeration work.

When superheated steam came into general use and ordinary steam temperature crept above 550<sup>o</sup>F., it was discovered that magnesia was not the correct insulation because of its tendency to calcine and crack. Consequently by 1925, there had been developed a series of compositions employing diatomaceous earths as a base. Molded materials consisting mainly of lime for temperatures of 1000<sup>o</sup>F. to 1200<sup>o</sup>F. and of diatomaceous earth for temperatures of 1200<sup>o</sup>F. to 1600<sup>o</sup>F. came into use. For temperatures between 1600<sup>o</sup>F. to 2500<sup>o</sup>F., diatomaceous earth and clay were burned together into a brick form and this combined form affords satisfactory insulation for this type of service. (24)

c. Insulators and Their Ranges Various insulators are available for different ranges of temperatures. For low temperatures we have available vegetable cork; mineral wool blown from mineral slags and rock wool blown from argillaceous limestone both bonded with asphalt; kapok fiber; laminated wool-felt paper; insulation board made from bagasse fibers; insulation board made from licorice roots, various kinds of shredded lumbers, wheat straws; felted cattle hair; corrugated kraft paper; and most recently aluminum foil. For medium temperatures we have corrugated asbestos board; 85 per cent magnesia; laminated asbestos papers of various kinds, some containing indentations to provide air spaces, some containing small particles of cut sponge to space the laminations; various types of materials consisting only of asbestos fiber molded to shape with inorganic binders; and various types of rock wool products. For higher temperatures

of from 1200<sup>0</sup>F. to 1500<sup>0</sup>F. the available insulators are more limited. For the lower part of this temperature range, diatomaceous earth may be used in either its natural form in brick shapes or where larger sizes are desirable it may be bonded with a small amount of asbestos fiber or some magnesium carbonate. For the upper part of this temperature range, the diatomaceous earth is bonded with such materials as clays and greg and then calcined at temperatures higher than those for which the material is recommended for use.

There is also available a general line of cements specially designed for a purpose. The asbestos cements are generally not used for insulation in themselves, but find application as finishing cements to protect other insulating materials applied directly to the unit. However, there are magnesia cements, diatomaceous earth cements, and rock wool cements which are used to insulate surfaces which are irregular so that pipe covering blocks can not be used. (24)

d. Domestic Insulators Schaeffer (16) has divided the field of domestic insulators into three classes depending upon types.

1. The application of loose fill insulation materials to buildings already erected.
2. The installation of insulating materials in the form of bats between the studding in the walls of new houses or of buildings already erected.
3. The use of insulating board applied during or after the erection of a home.

e. Requirements of Insulators In general, the properties of an insulating material should include chemical and physical stability, it must not mold, powder, oxidize, disintegrate, crack, crumble, shrink or deteriorate in any way that will impair its original thermal or mechanical efficiency.

More specifically, the requirements of an insulator are: for low temperature work it must be highly resistant to moisture penetration or else entirely protected from moisture penetration. Further it must be resistant to mold growth. To date, no insulator has been found that is completely resistant to moisture penetration and the cost of protecting the insulator may be prohibitive. It must be repellant to vermin, or at least not harbor them, particularly if they are to be used for food storage insulation. For satisfactory service they must maintain their strength which in itself must be satisfactory even with the contained water on the surface which it might pick up during use.

In the low pressure field, insulators are mainly required to be sturdy, light in weight to permit of as light a structural support as possible, easy to apply and sufficiently effective to show adequate return on the investment.

For medium and high temperature fields, insulations of a more refractory nature are required, which will not crack, spall, or unduly compress under reasonable loads. The material must be proof against chemical decomposition or dehydration which would impair its insulating value.

The guiding factors for the choice of an insulator for a specific purpose are the temperature of operation, the thickness required, the weight required and permissible, the mechanical strength and the resistivity, restrictions on the method of application, the presence of fumes or moisture, the overall cost to obtain the desired heat saving and

low maintenance charges. (24)

## 2. Materials Similar to Scherer Insulation

Several products have been developed which are similar to Scherer Insulation, in that a reaction producing a gas occurs giving a porous structure to the specimens.

a. Porous Cementitious Mixtures Among these are the products developed by Johan A. Eriksson (5), Bruno Neuhof (12), Wallace A. Caldwell (1), Thomas Coxon (4) and Noel A. Hill (8). Eriksson's work involved a mixture which set to a porous mass after admixture with water and contained cement, lime and a metal such as zinc or aluminum which reacted with the other ingredients to generate a gas upon the addition of water. This gives a high degree of porosity with the pores separated by partitions so that air circulation is prevented. It has a high insulating value and can be molded into bricks, plates and walls. It also has a high strength which can be increased by decreasing the porosity. Neuhof prepared light stone, plaster and heat insulating materials by mixing mineral materials such as lime, cement and clay with the waste sulphite or sulphate lye from cellulose manufacture. Alkali carbonates were also used. Caldwell used a concrete mixture having a pH of 11.5 to 13.5 incorporated with a material such as powdered aluminum to evolve a gas with the alkali present and thus produce a porous structure. Coxon produced a plaster setting with a cellular structure. It contained finely divided anhydrite; a small amount of one or more accelerators such as potassium sulphate, zinc sulphate or aluminum sulphate; a small amount of gas producing ingredient and a small amount of portland cement. Hill produced porous asbestos-cement compounds by mixing cement, asbestos and a metal such as aluminum

or zinc powder with water and feeding the slurry onto a paper machine wherein laminated sheets are formed. The sheets are then treated with a solution of sodium hydroxide with or without an accelerator. Clay, diatomaceous earth, glue, starch or lime may be included.

b. Porous Cellulosic Derivative Mixtures      George Schneider (17),  
Reginald O. Herzug and Hellmut Hoffmann (7), and George A. Fletcher (6)  
have made porous products with the aid of cellulosic derivatives. Schneider used a derivative such as the acetate and mixed it with sodium carbonate or bicarbonate which would decompose under the influence of heat alone and at a temperature below the fusion point of the cellulosic derivative. Herzug and Hoffmann used a viscose solution beaten into a foam and poured into molds where it was coagulated by treatment with an acid gas. Molds having gas permeable walls were used. Fletcher used particles of a metal that would react with sodium hydroxide evolving hydrogen and mixed these particles with a solution of viscose to form a porous mass. On coagulation and regeneration it forms a porous solid structure. The evolution of hydrogen may be retarded by the use of castor, Turkey red or other oil before addition to the viscose. Flax, hemp, cotton, jute, or other fibers may be added to the viscose.

## B. Drying

### 1. Principles of Drying

a. Mechanism of Drying      The air drying of a solid involves the vaporization of the liquid contained by the solid, followed by the removal of the vapor in a stream of air. The outstanding questions in the drying of solids are those concerning the method in which water travels through the solid up to the surface; how and where evaporation takes place; and how these factors affect the moisture distribution in the solid, the temperature of the material and the rate of evaporation under different conditions of the drying air such as its temperature, humidity and velocity. (18)

The process of drying falls into either or both of two stages; the constant rate and the falling rate periods. (26). For the sake of definiteness, conditions such as the following will be assumed. A sheet is to be dried which is so large in comparison to its thickness that drying from the edge of the sheet may be assumed to be negligible. Assume also that the initial moisture concentration is uniform and sufficiently high so that the surface of the sheet is thoroughly wet. As soon as the sheet is brought into contact with the warmer air, the water on the surface begins to evaporate and the vapor flows through the air film into the surrounding air and is carried off by the air stream. The decrease in the moisture concentration at the surface causes liquid water to flow to the surface from the interior of the solid, depleting the total water content of the sheet. So long as the surface remains sufficiently wet, the evaporation proceeds at a constant rate.

If the evaporation is continued, the surface concentration of the liquid eventually becomes so low that the surface no longer behaves as though it were thoroughly wet, and hence the evaporation rate decreases and the so-called falling rate period begins. The moisture content at which the drying rate starts to decrease is called the critical moisture content.

The flow of liquid from the interior of the sheet to the surface is by diffusion (9). The two processes, diffusion and evaporation from the surface go on simultaneously until the drying operation has been suspended or the sheet has come to equilibrium with the drying air. In some cases the resistance to surface evaporation is the controlling factor in drying, while in others the resistance to diffusion is the controlling factor.

b. Drying Hygroscopic Solids      The vapor pressure of water over a very wet solid is that of liquid water at the temperature of the solid. If the water is progressively removed, a moisture concentration will be reached where the aqueous vapor pressure over the solid begins to decrease and becomes less than that over water at the same temperature. Materials that have a considerable water content at this point are hygroscopic solids. This suggests that the total water content of a solid may be divided into two classes, free and bound water. Free water may be defined as water which exerts its full vapor pressure and is held in the voids of the solid. Bound water is water which exerts less than its normal vapor pressure and may be liquid in very fine capillaries, water with salts dissolved in it in cell or fiber walls,

or water in chemical or physical combination. The relation between the vapor pressure of water over the solid and the water content of the solid is determined by experiment and is generally given as a curve of moisture content versus the relative humidity of the air in equilibrium with the material. The moisture content corresponding to 100 per cent relative humidity divides the free and bound water areas. Absorption and desorption curves do not coincide, the desorption curves being higher in water content for a definite humidity and are the ones used when drying a solid. By assuming that only free water diffuses through the solid as water vapor, to show the difference in rates of diffusion between free and bound water, and that water vapor diffusing through the solid is at any point in equilibrium with the solid as shown by the desorption curve of the material, the mechanism of drying may be represented in the following way: Since the drying rate decreases after the critical moisture content, the partial pressure gradient in the air adjacent to the solid decreases; and since the heat requirement also decreases, the temperature gradient in the air decreases. Up to the critical point the air at the air-solid interface is saturated. If the humidity decreases and the temperature increases at the air-solid interface, a condition arises where the air at the interface is no longer saturated. This indicates that free water must have been vaporized before it reached the surface or if vaporization is occurring at the surface it must be from bound water, and that at the critical point the concentration of moisture at the surface is equal to the equilibrium moisture content corresponding to saturated air at the temperature of the solid at the air-solid interface. During the

constant rate period the temperature at the air solid interface is the wet bulb temperature of the air. As the drying process continues, the temperature at the surface continues to rise and the partial pressure to fall. This indicates that if vaporization of free moisture is occurring, such vaporization is taking place at a continually retreating plane. Free moisture vaporizes from the center line of the solid to that plane and bound water from the plane to the air solid interface. At any point in this latter zone, the air is in equilibrium with the solid. If the substance is non-hygroscopic, the vaporization ~~the vaporization~~ is confined to a narrow zone inside the solid, and if hygroscopic, a considerable portion of the evaporation takes place between the vaporization plane and the air solid interface. For hygroscopic solids, all of the heat is not used to vaporize free water as a good deal is retained in the zone of vaporization to vaporize bound water.(11)

c. Constant Rate Period      In the constant rate period,

Sherwood (20) has stated that the surface is completely wet with water and that the rate of drying is similar to the evaporation of water from a free surface. Carrier (2) has discussed this type of evaporation and has shown that that the rate of drying depends upon the following:

1. The vapor tension of the moisture in the material corresponding to its temperature.
2. The vapor tension of the moisture in the air corresponding to its absolute humidity or dew point temperature.

3. The effective velocity of the air over the surface.
4. The physical and chemical properties of the material being dried.

He has shown that the rate of evaporation at any instant per unit surface is proportional to the difference in vapor pressure between the liquid and the vapor of that liquid in the immediate vicinity.

This relationship is shown by the following equation:

$$dw/dt = x(e' - e)$$

This holds only for the following:

1. For a free liquid surface or for the vapor pressure of the liquid at the surfaces of a wet material.
2. When the total pressure is greater than the vapor pressure of the liquid.
3. Constant conditions of air velocity and its direction.
4. Whether the liquid is above or below the temperature of the surrounding atmosphere.
5. The quantity  $x$  is probably independent of the latent heat of evaporation, but varies directly as the molecular weight of the evaporating liquid.

Carrier has also found that the rate of evaporation increases directly with an increase in the velocity of the air. The effect of the velocity is apparently to increase the rate of diffusion of liquid to the wetted surface. There is undoubtedly a surface film of vapor saturated at the liquid temperature which is admixed with the air, broken up and removed in direct proportion to the velocity or square root of the surface-frictional-head-effects by atmospheric movement.

This may be expressed as follows:

$$dw/dt = (a - bv)(e' - e)$$

where  $a$  is the rate of evaporation in still air.

$b$  is the rate of increase in the evaporation with the velocity

$e'$  is the vapor pressure of the liquid in the solid

$e$  is the vapor pressure in the atmosphere

A free wetted surface tends to assume a definite minimum temperature of evaporation with a corresponding vapor pressure  $e'$ . The temperature is dependent upon the latent heat and the specific weight of the saturated vapor, the specific heat and the density of the atmosphere and the degree of initial saturation with the vapor. It is known as the wet bulb temperature. In becoming saturated with moisture, the atmosphere cools down to the wet bulb temperature and the latent heat of the water or other liquid evaporated is equal exactly to the loss of sensible heat of the atmosphere. When the air passing over a moist surface drops towards the wet bulb temperature, its vapor pressure and dew point rise towards the wet bulb condition. It follows that the wet bulb temperature remains constant, although the dry bulb temperature drops. If the material is evaporating freely, the temperature is therefore substantially constant at the wet bulb value. The rate of evaporation may be shown to be directly proportional to the wet bulb depression as well as to the difference in partial pressures, and it can in turn be shown that the wet bulb depression is proportional to the partial pressure difference. Sherwood (20) has confirmed the views of Carrier as applied to the constant rate period of drying in solids stating that the driving force causing the heat flow is the wet bulb

depression and the driving force causing vapor diffusion is the difference between the partial pressure of the water vapor in the air and of the water in the solid. This is upset if heat from other sources than the air (radiation), the temperature tending to be decreased and the partial pressure difference increased. The liquid temperature is therefore increased above the wet bulb value and the rate of evaporation is increased. Another way to supply heat to a very wet solid is by conduction through the dry edges or other dry surfaces of the solid. In the case of a block or slab, one or more of the faces are covered or water proofed and the heat inflow through these adjoining dry surfaces raises the liquid temperature and thus the rate of evaporation.

d. Falling Rate Period In dealing with the falling rate period, Sherwood (19, 20) noted that it might be divided into two distinct divisions; one of unsaturated surface drying in which the resistance to surface evaporation controls, and the other in which the resistance to diffusion of the liquid controls the drying process. In the case of unsaturated surface drying, the effective wetted surface is lower since the surface is no longer completely wetted and thus causes a reduction in the rate of evaporation. The effective wetted surface is usually a straight line function of the water content so that the rate of drying curve is a straight line in this region. The mechanism of drying is similar to that during the constant rate period and is therefore independent of the thickness of the specimen. Water is evaporated as fast as it diffuses to the surface and the resistance to internal diffusion is small as compared to the resistance of surface evaporation. The rate of water diffusion to the surface decreases,

however, with the water content of the material, so that a second critical point is reached beyond which the resistance to internal diffusion controls the drying process.

Experiments by Chang (19) showed that a difference in humidity affected the rate of drying during the zone immediately following the first critical point but did not affect it after the second critical point. It was therefore concluded that the internal diffusion did not control during the first zone but did after the second critical point. Sherwood tested some whiting, and showed that in the first zone the drying process was unaffected by the thickness of the sample. This further supported the contention of the possibility of two distinct zones occurring during the falling rate period.

e. Overall Coefficient of Heat Transfer It is instructive to measure the temperature of the midplane of the slab as the drying run progresses in the falling rate period. (19, 20). If the overall coefficient of heat transfer  $U$  decreases considerably during the falling rate period as compared to the constant rate period, it is clear that the thermal resistance of the interior is increasing owing to the retreat of the plane of vaporization. During the zone of unsaturated surface drying, the overall coefficient of heat transfer is substantially the same as that during the constant rate period, showing that evaporation is occurring essentially at the surface of the slab. In the second zone, where the rate of diffusion is the controlling factor, since the evaporation of water is more rapid than the arrival of moisture at the surface, the plane of evaporation tends

to retreat into the solid due to depletion of water from the surface. This probably only takes place in porous or fibrous solids and not in colloidal materials. When evaporation takes place within the solid, the vapor formed must diffuse not only through the surface air film but also through the relatively dry surface layer of the solid. The actual evaporation takes place at such a distance from the surface that the rate of diffusion of the vapor through the solid and the air film resistances will equal the rate of internal liquid diffusion. It can readily be seen therefore why a drop in  $U$  occurs during the second zone of the falling rate period. The plane of vaporization was shown to be distributed through a relatively dry pulp in experiments carried out by Sherwood (20) and showed an evaporating zone of apparently large thickness.

f. Capillarity in Drying In the drying of highly porous solids capillarity plays a considerable part (23); while in the drying of non-hygroscopic solids containing grains of non-uniform size, the movement of moisture is controlled by capillarity and not by moisture gradients. In the drying of a granular solid, the capillaries are neither circular nor straight, but the water is drawn through the passages in a manner similar to the movement through a tapered capillary. Water evaporates from the small menisci exposed at the surfaces. The small curvature of these menisci exert sufficient capillary pull to draw water through any passages ending in air water interfaces of larger curvature. The water drawn to the surface is necessarily replaced by air which enters the solid through the larger passages connected with the larger openings at

the surface. Because of the complicated interconnecting passages beneath the surface, it is possible for the necessary air to enter through a relatively few surface openings and thus for the water concentration at the surface to remain relatively high. The water continues to rise to the surface through any system of interconnecting passages until all of the various menisci at the lower ends of the columns have the same radii of curvature as the small menisci at the surface from which evaporation is taking place. At this point, a small amount of evaporation from the surface menisci may result in a retreat of these surface menisci into passages of smaller cross section and the increased capillary tension is sufficient to draw additional water to the surface. It is possible for this increased tension to draw some of the menisci at the lower ends through narrow constrictions into larger cavities and thus reduce the tension required to cause movement to the surface. The menisci in the passages at the surface can then rise to their former position and the process continue. As this process continues, the menisci at the lower ends of the water columns become about the same size as the smallest menisci at the surface, and water will no longer be drawn through these passages to the surface. Evaporation will continue through the surface menisci and the water will be depleted in these passages thus causing the retreat of the surface menisci into the solid. The rate of drying will consequently be retarded because of the necessity of the diffusion of the vapor formed through the air filled passages to effect removal from the solid. As a solid dries, the tension exerted by a capillary results in a corresponding compression of the solid structure and a consequent

strong tendency for the material to shrink.

N. H. Seaglske and O. A. Hougen have investigated the effect of capillarity on the drying of various granular solids. (5).

## 2. Drying Equations

a. H. K. Lewis (9) By assuming a linear moisture gradient during the drying process because the diffusion law gave a complicated function, Lewis derived approximate equations for the drying rate during the falling rate period. The equation he derived is the following:

$$\ln(W_0 - E / W - E) = K\theta \quad \text{where } K = 8AR/L(4A + RL)$$

$W_0$  is the initial free water content at the critical point

$E$  is the equilibrium water content

$\theta$  is the time

$A$  and  $R$  are constants.

The drying coefficient  $K$  varies with the rate of diffusion and the surface evaporation and also with the thickness of the material being dried. If surface evaporation is the controlling factor in the drying process, then  $RL$  may be neglected  $K$  being equal to  $2R/L$ . If diffusion controls the process, then  $4A$  may be neglected  $K$  being equal to  $8A/L^2$ . When the rate of diffusion is the controlling factor, it is to be noted that the rate of drying depends upon  $A$  which in turn depends upon the temperature increasing rapidly with it. This is made use of in drying substances which harden and shrink but must not be permitted to

It is best to crack in the process. ~~XXX~~ dry at the highest possible temperature to permit the highest rate of liquid diffusion to the surface, and also at a high humidity in order to prevent to rapid an evaporation setting

up strains and stresses in the solid and causing rupture of the surface.

b. T. K. Sherwood Sherwood has proposed an equation for the falling rate period (19). In order to get a simpler equation proposed so that it might be used for approximations, he assumed the rate of drying to be a linear function of the total moisture content per unit weight of dry solid with a rate of zero at  $T$  equals  $T_c$  and a rate of  $S_c$  at  $T$  equals  $T_e$ . The following is the equation:

$$\ln E' = \theta' S_c / (T_c - T_e) ADR$$

where:

$T$  is the water content, weight of water/weight dry solid

$T_c$  is the critical water content

$T_e$  is the equilibrium water content

$E'$  is the free water content/free water content at the critical point

and is given by  $(T - T_c) / (T_e - T_c)$

$\theta$  is the time after the falling rate period begins

$R$  is one-half the slab thickness

$A$  is the surface area

$D$  is the density

$S$  is the rate of drying, loss of weight/unit time

$S_c$  is the rate of drying at the critical point and equals the rate during the constant rate period

Sherwood has also derived equations for the zone of the falling rate period in which the resistance to internal diffusion is the controlling factor as compared to the surface evaporation resistance. (18)

He assumes a negligible surface evaporation resistance which corresponds to a negligible free water concentration at the surface, since no moisture gradient is required to cause the water to diffuse through the surface air film. The slope of the moisture gradient line is then proportional to the rate of diffusion of water at any point within the solid, and falls off from the surface to the center line when drying at two faces and approaches zero at the center line. The following is the equation:

$$E = \frac{8}{\pi^2} \left[ e^{-\left(\frac{\pi}{2}\right)^2 r} + \frac{1}{9} e^{-9\left(\frac{\pi}{2}\right)^2 r} + \frac{1}{25} e^{-25\left(\frac{\pi}{2}\right)^2 r} + \dots \right]$$

A. B. Newman has derived similar equations for solids of various shapes. (13)

Between the limits of E equals 0.9 and 0.5 Lewis's approximate equations have been shown to be fairly accurate. The above equation is based on the constance of K, the diffusion constant; a uniform liquid concentration throughout the solid at the start; diffusion taking place wholly normal to the plane; evaporation taking place at the surface and  $R_s$ , the resistance to surface evaporation being negligible; and the validity of the diffusion equation:

$$dv/d\theta = Kd^2v/dx^2$$

where:

v is the moisture concentration per unit volume

$\theta$  is the time

x is the distance of the point from the surface of the sheet

K is the diffusion constant

The theoretical relation for the drying of an infinite slab where

the resistance to internal diffusion controls the process is given above. It is applicable, however, only to materials where the initial moisture distribution throughout the solid is uniform at the start of period where the resistance to internal diffusion controls. Frequently as in the drying of wood and clay, the period of internal resistance controlling follows the constant rate period, and the moisture distribution at the end of the constant rate period is more nearly parabolic than uniform. The above equation does not hold for this case. It would appear that an equation similar to the one above, but based on the assumption of an initial parabolic moisture distribution would be useful. Sherwood developed the following equation for this purpose:

$$E' = \frac{24T_m}{W^2(T_s - 2T_m)} \left[ e^{-p} + \frac{1}{9} e^{-9p} + \frac{1}{25} e^{-25p} + \dots \right] + \frac{192(T_m - T_a)}{W^2(T_s - 2T_m)} \left[ e^{-p} + \frac{1}{81} e^{-9p} + \frac{1}{625} e^{-25p} + \dots \right]$$

where:

$E'$  is the ratio of total free water to free water content at the critical point.

$K$  is the diffusion constant of water through the solid with concentration as weight per unit volume.

$p$  is equal to  $Kw^2/4R^2$

$R$  is one-half of the slab thickness

$T_m$  is the free moisture concentration per unit weight of dry solid at the center of the slab while at the critical point

$T_s$  is the same as that above except that it is at the surface of the slab

$\theta'$  is the time after the critical point.

c. A. B. Newman As has been mentioned before, Newman has derived equations for the drying of solids of various shapes where internal diffusion controls the drying process throughout and the moisture distribution is uniform in the solid at the start of the drying period. (13). He has lately derived equations based on the resistance to internal liquid diffusion and to surface evaporation, with the rate of drying being influenced by a continuously decreasing liquid concentration at the surface. At any instant the rate of drying is directly proportional to the free liquid concentration at the surface at the time, the laws of diffusion being valid, and the diffusion equations must be consistent with the varying surface concentration. (14). T. K. Sherwood and E. W. Comings (22) investigated Newman's equations both for initial uniform concentration of liquid in the solid and for initial parabolic moisture distribution. They concluded that Newman's theory of changing importance of the resistance to internal liquid diffusion and the resistance to surface evaporation failed to explain experimentally determined rate of drying curves.

d. Evaporation at the Surface An equation is derived in Walker, Lewis, McAdams and Gilliland (27) for the drying of a solid

by evaporation at the surface during the falling rate period. It is based upon the diffusion laws and the assumption that the falling rate period is preceded by a constant rate period such that the moisture distribution curve will have approached a parabolic form. The equation derived is the following one:

$$\ln T_1 - E / T - E = \theta / L (r_1 + r_s) = K\theta$$

where:

$$r_1 = L/3D$$

$$r_s = (T_{sc} - E)p/a = (T_{sc} - E)p/k'(H_{sc} - H)$$

Either or both of the resistances may be important during the drying process. The terms above are defined as follows:

$T, T_1, T_{sc}$  is the total moisture content, weight per unit weight of bone dry solid,  $T$  corresponding to time  $\theta$ ,  $T_1$  to any time in the falling rate period,  $T_{sc}$  to the critical point value at the surface.

$E$  is the equilibrium water content, weight per unit weight of bone dry material corresponding to the temperature and humidity of the air.

$\theta$  is the time

$L$  is one-half the thickness

$r_1$  and  $r_s$  are the resistances to internal diffusion and to surface evaporation respectively.

$K$  is the drying coefficient in units of reciprocal time

$D$  is the diffusivity of the liquid

$p$  is the weight of bone dry stock per unit original volume

$a$  is the weight evaporated per unit time per unit of wet surface in the constant rate period.

$H$ ,  $H_{s0}$  is the absolute humidity, weight per unit weight of bone dry air,  $H$  corresponding to the main body of air,  $H_{s0}$  corresponding to saturation conditions at the surface temperature during the constant rate period.

$k'$  is the evaporation coefficient, based on humidity difference, weight per unit time per unit wetted surface.

### III EXPERIMENTAL

Purpose of Investigation. This investigation concerns the drying and warping properties of Scherer Insulation and its purpose is to determine the proper drying conditions so that the product would neither warp nor crack.

#### Plan of Procedure.

Mixing. The following methods of mixing were proposed:

1. Lime, gypsum plus aluminum added to viscose.
2. Viscose added to lime, gypsum plus aluminum.
3. Gypsum plus lime added to viscose and then incorporate aluminum.

Forming. The following methods of forming were proposed:

1. Casting.
2. Rolling.
3. Extrusion.
4. Heat treatment to set the structure.

Drying. It was proposed to dry the above specimens at different temperatures, humidities and air velocities.

#### Materials.

Sulphite Pulp. Sulphite pulp manufactured by the Brown Co., New Hampshire was used for the manufacture of viscose. Its properties as determined by chemical analysis were:

moisture ----- 4.5 per cent

alpha cellulose ----- 95.5 per cent (dry basis)  
 ash ----- 1.3 per cent (dry basis)  
 copper number ----- 0.9

Lime. Masons Hydrated Lime made by the Ripplemeade Lime Co.,  
 Ripplemeade, Virginia was used for the preparation of Scherer Insulation.

Gypsum. Ben Franklin Agricultural Gypsum made by the U. S. Gypsum  
 Co., Plasterco, Virginia was used.

Caustic. Technical grade sodium hydroxide, about 96 per cent  
 purity, made by the General Chemical Co. was used to prepare the  
 18 per cent caustic solution required for the production of viscose.

Carbon Bisulphide. Reagent grade carbon bisulphide made by the  
 General Chemical Co. was used for the xanthation process in the  
 preparation of the viscose solution.

Aluminum. Guaranteed Chemically Pure Aluminum + Bronze Powder  
 made by the U. S. Bronze Powder Works, Inc., New York, N. Y. was used  
 for the production of Scherer Insulation.

Grease. Socony Motor Grease No. 3 was used as the lubricating  
 agent for the pans in which the insulator was formed.

#### Apparatus.

Hydraulic Press. A Watson-Stillman Co., New York press Job 41421  
 was used for pressing the dipped pulp to the desired weight.

Xanthation Drum. The xanthator was manufactured by the Max Am...

Chemical Engineering Corporation of Bridgeport, Conn. It is 12 inches in diameter and 12 inches high. It is shown in Figure 1.

Pfleiderer

Mixer. A Werner-Pfleiderer mixer, 10 by 11.5 by 8.5 inches was used for the disintegration of the pulp in the preparation of the viscose and also for the mixing of the powders with the viscose for the preparation of Scherer Insulation. Figure 2 shows the mixer very clearly. It is made for a capacity of 600 grams of dry sulphite pulp.

Motors. In order to dissolve the xanthated cellulose for the production of the viscose solution, a Sears-Roebuck motor was used. It was a type SIC 61614, 0.25 HP., 1725 rpm, 110 volts, 4.9 amperes, 50 cycle, 1 phase motor.

Forming Apparatus. The product was cast into galvanized sheet metal containers 15 by 15 by 2 inches riveted at the four corners. A sheet metal plate 14 by 14 inches was used for application on the top surface of the specimens after its formation. The specimens were leveled off by a strip of sheet metal nailed to a wooden guide which was run along the edges of the sheet metal container. These are shown in Figure 3.

Drier. A tray drier manufactured by the Proctor & Schwartz Co., Inc. of Philadelphia, Pa. series no. H 8122 was used for drying the specimens. It is illustrated in Figure 4.

Modulus of Rupture Test. Figure 5 shows the testing apparatus used. A lever arm with weights at various points provides the required force

XANTHATOR



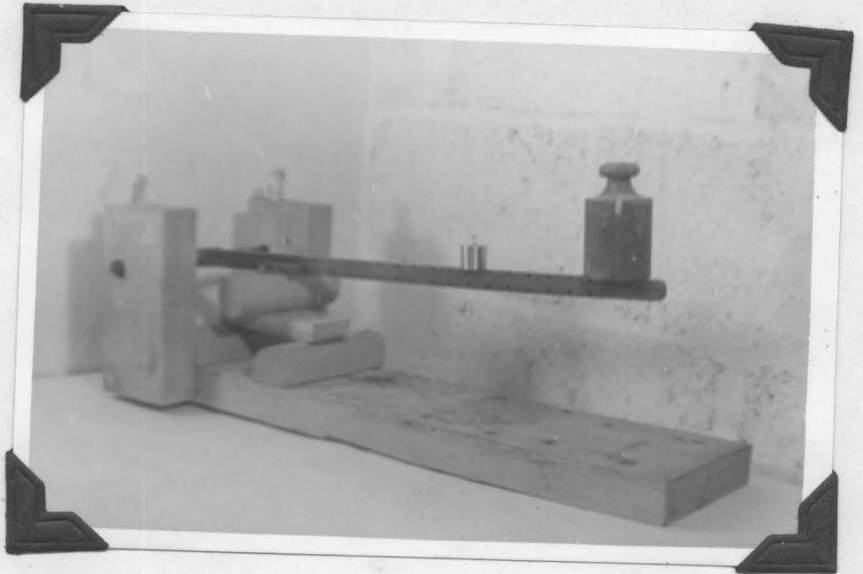
FIGURE 1

WERNER-PFLEIDERER MIXER



FIGURE 2.

FORMING APPARATUS.FIGURE 3.

PROCTOR-SCHWARTZ TRAY DRIER.FIGURE 4.MODULUS OF RUPTURE TEST.FIGURE 5.

to rupture the specimens.

Crushing Strength Test. These were performed in a standard Tinius-Olsen machine set for a 1000 pounds maximum load.

Thermal Conductivity Test. Tests of thermal conductivity were made by Mr. C. B. Ruehr on equipment designed by and constructed by Dr. G. M. Johnston of the Mechanical Engineering Department of the Virginia Polytechnic Institute and is described in a departmental thesis.

#### Method of Procedure.

Preparation of Viscose. The viscose solution was prepared in the following manner:

1. Dip sulphite pulp in 18 per cent sodium hydroxide for one hour.
2. Press to 3.35 times the alpha cellulose content.
3. Grind in Werner-~~Blender~~<sup>Pfleiderer</sup> mixer until the Bulk No. is 190 to 200.
4. Age at 18°C. for 48 hours.
5. Xanthate with carbon bisulphide using carbon bisulphide in an amount equal to 37 per cent of the alpha-cellulose content of the crumbs.
6. Dissolve the xanthated crumbs preparing a 7 per cent cellulose and a 3.5 per cent alkali solution of viscose.
7. Ripen for 24 hours at 18°C.
8. Mix with powders the composition of the mix being in parts by weight:

viscose -----100

gypsum -----24

lime -----50

aluminum -----0.2

9. The actual procedure in handling the specimens will be discussed more fully in the next section.

10. Drying in the Proctor-Sewartz tray drier at desired conditions of temperature, humidity and air velocity. The high air velocity is 474 feet per minute, and the low air velocity is 273 feet per minute.

#### Preparation of Specimens and Results.

All specimens are prepared on the basis of, in parts by weight, 100 viscose, 30 lime, 24 gypsum and 0.2 aluminum.

Preliminary Experiments - Run 1. All the specimens were mixed by hand in a bell jar.

a. Specimen 1A. A dry mix of aluminum, lime, gypsum was added to viscose and placed into a pan which it filled. It was dried at 105°C. overnight in an oven. In the morning it was seen to have risen above the pan's top level with a domed top like bread. The top surface was smooth but had several wide cracks and a shrinkage of about 14 per cent along the length and width had occurred. The color of the sides and the top were green while the bottom was white, the sides and bottom having flat surfaces. The specimen had a sulphide odor and was warped so that the entire specimen was concave on the bottom. The color distribution was not uniform on a cross sectional area, most of the color being concentrated at the top of the specimens. Large pores were at the bottom of the specimens while small ones were at the top surface. The specimens broke easily with crumbling and showed lots of strains as evidenced by large cracks in the interior structure.

b. Specimen 1B. A dry mix of lime and gypsum was added to the viscose and after dispersion of the powders, the aluminum was incorporated. The specimen was placed into a pan with high sides and dried at 105°C. overnight. In the morning the top of the specimens was slightly concave, greenish in color and had myriads of cracks. The sides and bottom were smooth, the bottom being convex in nature. About 15 per cent shrinkage along the width and length had occurred. The specimen broke easily and showed a greenish segregation at the bottom. The porosity was quite uniform, but occasional pockets of lime and gypsum comparable in size to the size of the pores were noted. On a cross-sectional area, the top and bottom were greenish, the center colorless.

Upon soaking in water, the specimen softened slightly, sulphides being leached out and the greenish color spread throughout the mass.

Upon prolonged heating over a bunsen flame, the specimens became lighter, becoming fragile and crumbly and turning a greyish-black color due to the carbonization of the cellulose. Continued heating turned it to a white color and produced a very porous structure of lime and gypsum. The cellulose was completely driven off. No burning had occurred.

-Pfleiderer

Use of Poor Viscose - Run 2. The Werner-~~Blender~~ mixer was used with lime and gypsum being added to the viscose and after incorporation of these powders the aluminum was added. Five minutes of mixing time before the addition and five minutes after the addition of the aluminum were the conditions of the run. The mix could neither be cast nor rolled, as it jelled into a rubber like spongy mass and was worthless as an insulator. The viscose solution prepared for this run had appeared to

be very thick and almost jelly like in nature.

Two Procedures of Mixing.- Run 5. In this run two methods of mixing were attempted; that of adding the lime, gypsum and aluminum to the viscose and that of adding the lime and gypsum to the viscose and then incorporating the aluminum.

a. Series 3A. The powder mix of lime, gypsum and aluminum were added to the viscose, five minutes of mixing time, starting with zero time after the addition of the powders being used. All runs from this one on were mixed in the Werner-Pfleiderer mixer. The powders dispersed rapidly and gave a smooth mix, being tacky in nature and definitely could not be rolled. The first specimens formed proved the inability of the rolling process to prove successful. Specimen 3A-1 was set in a pan filling it to the top and permitted to stand thus for one hour at room temperature. During this time it rose 25 per cent and caused the material to flow over the sides and thus crack the top surface. After drying overnight at 105°C., the specimens color was greenish and it showed a 50-75 per cent rise. It was all broken and cracked in the pan and had shrunk away from the sides. There was a green segregation at the bottom of the specimen concentrated mainly at the central portion and extending half the depth of the specimens. No powder pockets were noticed and despite hollows and cracks in the interior of the specimen, it showed considerable strength.

Specimen 3A-2, while mixed in a manner similar to 3A-1 was, however, placed into a pan filled to the top with a cardboard sheet placed on top of the specimens surface. It rose 25 per cent during a one hours standing period at room conditions. The cardboard collapsed in

the center. After drying at 105°C. for one hour, it was removed to make room for another specimen and then air dried overnight. The next morning the cardboard was cemented to the top of the specimen and gave a smooth flat top. Under the cover, the specimen was still damp and soft. The porosity was not uniform but was not different at different levels of the specimen except for a thin top layer of extremely small pores.

b. Series B. For this series lime and gypsum were added to the viscose and mixed for two minutes. Aluminum was then added for a total mixing time of five minutes. The specimens formed were put into a high sided pan not completely filling it. The specimens formed were tacky and handled in lumps but flowed together forming ~~x~~ good specimens upon juggling.

Specimen SE-1 was air dried for 0.75 hours and then dried overnight at 105°C. The specimen rose over 100 per cent having a greenish top with a damp green core. The porosity was uniform except for the usual surface skin. There were many cracks and hollows in the specimen but it showed good strength. A slight segregation of lime, gypsum particles were apparent.

Specimen SE-2 was air dried overnight and then dried at 105°C. It had a green top with a perfectly smooth flat surface after air drying though it was still damp and soggy. It was firm enough to support its own weight but could not be removed from the pan in which it was formed. After drying the surfaces of the specimen were green, but had a white interior. The porosity was uneven and had some cracks in the interior which were fewer in number than for most of the other specimens previously

formed. The sides and the bottom were even and the top slightly domed. A skin effect occurred at all of the surfaces.

Order of Addition, Powders to Viscose, Viscose to Powders - Run 4.

For these specimens a dry mix of lime, gypsum and aluminum was mixed with viscose and formed in pans 15 by 15 by 2 inches which were coated with grease to facilitate removal of the specimens from the pans. The specimens were formed 0.5 inches high by cutting across the top surface with a sheet of galvanized metal attached to a board and using the pan sides as guides. Series 1 was dried at high air velocity, series two at low air velocity, being 474 and 275 feet per minute respectively. The specimens were dried from all six surfaces, where previously they had been dried from only one. 175°F and 50 per cent <sup>humidity</sup> were the temperature and humidity conditions.

a. Series 1. For series 1 the powders were placed on top of the viscose in the mixer. Times of mixing were as follows:

4A-1 ----- 4 minutes  
 4B-1 ----- 8 minutes  
 4C-1 ----- 12 minutes  
 4D-1 ----- 16 minutes.

Specimens A and B showed some rise but were very warped and cracked. Specimens C and D showed no rise whatever and also warped and cracked. The specimens were dried in the Proctor-Schwartz tray drier from all six surfaces.

b. Series 2. For series 2 the viscose was added to the powder with mixing times as follows:

4A-2 ----- 4 minutes  
 4B-2 ----- 6 minutes  
 4C-2----- 12 minutes  
 4D-2 ----- 18 minutes

These specimens had the same defects as the series 1 and in addition the dispersion of the powders was extremely poor. Powders in the bottom of the mixer and in the corners were not incorporated into the mix. These were dried in a manner similar to series 1 but at a lower air velocity.

Change of Proportion of Aluminum in Mix - Run 5. For these specimens a dry mix of lime, gypsum and aluminum were added gradually to the viscose. The amount of aluminum used was halved and doubled to see the effect on the rate of evolution of gas.

a. Series 1. One-quarter the normal amount of aluminum was used and the mixing times were as follows:

5A-1 ----- mixed six minutes  
 5B-1 ----- mixed nine minutes  
 5C-1 ----- mixed twelve minutes

They were formed in the pans 15 by 15 by 0.5 inches as before and air dried for 18 hours, after which they were removed from the pans and dried in the Procter-Schwartz tray drier at 175°F and 50 per cent humidity. After forming a thin mass of fluid rose to the top of the specimens surface and formed in a very short while a hard surface. The specimens were dried at the low air velocity and were completely warped after three hours of drying. Specimen 5A-1 is shown in Figure 6. These specimens showed no porosity whatsoever.

WARPING DUE TO SKIN FORMATION.

0.25 normal amoynt of aluminum used.



FIGURE 6.

b. Series 2. These specimens were formed with four times the normal amount of aluminum. After two minutes of mixing time, the mass was completely blown up and porous and became rubber like after five minutes of mixing time. The temperature due to evolution of heat was 122°F. The temperature rise jelled the viscose solution. It was of course impossible to form.

Time of Mixing to Incorporate Aluminum - Run 6. For this run the powder mix of lime and gypsum was added to the viscose and after ten minutes of mixing time, the aluminum was added. It was attempted to wet the aluminum with water to facilitate incorporation into the mix but this proved to difficult and the aluminum was added dry. The specimens were again formed 15 by 15 by 0.5 inches.

a. Series 1. Mixing times after the addition of the aluminum were as follows:

6A-1 ----- 3 minutes

6B-1 ----- 5 minutes

6C-1 ----- 7 minutes

All these specimens were air dried. A skin formed on the top surface of the specimens after forming and after 67 hours of air drying, the specimens were warped into almost a pipe shape.

b. Series 2. The times of mixing were as follows:

6A-2 ----- 3 minutes

6B-2 ----- 5 minutes

6C-2----- 7 minutes

The specimens were then treated with live steam for 18 hours and then air dried. No warping had occurred during the steaming period. The

specimens were very soggy and damp, however and upon drying they shrunk and cracked and warped.

Steam Setting - Run 7. Lime and gypsum were well mixed and then added to viscose, the latter mixing time taking five minutes. The aluminum was then added. The same pans, size and forming method were used. All were dried in the Proctor-Schwartz tray drier at 175 °F. and 50 per cent humidity. Series 1 was dried at high air velocity, and series two at low air velocity.

a. Series 1. The mixing times after addition of the aluminum were as follows:

7A-1 ----- 5 minutes

7B-1 ----- 5 minutes

7C-1----- 7 minutes

It was then air dried for two hours to attain full rise, steamed four hours, air dried twelve hours, removed from the pans and dried in the tray drier from six surfaces. The steam treatment blew the specimens up giving a billowing surface, but it did not warp on steaming or drying. The "C" specimen was tacky, hard to form and unsuitable due to its high density. Specimen 7B-1 is shown in Figure 7.

b. Series 2. Mixing times after the addition of the aluminum were as follows:

7A-2 ----- 5 minutes

7B-2 ----- 5 minutes

7C-2 ----- 7 minutes

These were air dried for 18 hours and then dried in the tray drier from all six surfaces. These specimens were almost flat, but a bit cracked

STEAMING WITHOUT TOP PLATE - BILLOWY SURFACE.



FIGURE 7.

in one spot on the side. They were still green at the end of the drying run. In drying they first warped toward the top and later straightened out and warped toward the bottom. The skin effect was again noted. Specimen TC-2 is shown in Figure 8.

Introduction of Top Plate - Run 8. For this run a mix of lime and gypsum was added to the viscose for a total five minutes of mixing time (powders to viscose) and then the aluminum was incorporated. Immediately after forming a smooth plate of galvanized sheet metal with grease on it was placed on top of the specimen. These plates were 14 by 14 inches.

a. Series 1. The mixing times were as follows:

8A-1 ----- 3 minutes after adding aluminum

8B-1 ----- 5 minutes after adding aluminum

They were air dried for 18 hours after applying the top plate and then dried at low air velocity in the tray drier at 175°F. and 50 per cent humidity. The specimens had a good porous top surface except that trapped air caused pocket formation to occur. The specimens warped in two directions.

b. Series 2. The mixing times were as follows after the incorporation of the aluminum.

8A-2 ----- 3 minutes

8B-2----- 5 minutes

After applying the top plate, the specimens were air dried for 2 hours, steamed 4 hours, air dried 12 hours and then dried in the tray drier at low air velocity and 175°F. and 50 per cent humidity. It was still soft

WARPING DUE TO SKIN FORMATION.



FIGURE 8.

after long drying but it retained its shape in the drier, however, and had a good structure.

Steaming With or Without a Top Plate - Run 9. The same mixing conditions were used. Lime, gypsum mix was added to viscose for five minutes of mixing time and then the aluminum was incorporated.

a. Series 1. The times of mixing after the addition of the aluminum were:

9A-1 ----- 3 minutes

9B-1 ----- 5 minutes

The top plate was applied immediately after forming the specimens, then air dried 18 hours, steamed 4 hours, removed from the pans and dried from 6 surfaces at 175°F. and 50 per cent humidity in the tray drier. These specimens warped in two directions again proving the skin formation theory. No skin appeared in these specimens except those due to air pocket formation on the top surface. The B specimen is denser and a portion of its rise was cut off during the forming and some even squeezed out during the mixing operation.

b. Series 2. The times of mixing after the addition of the aluminum were as follows:

9A-2 ----- 3 minutes

9B-2 ----- 5 minutes

The top plate was not applied here. After formation the specimens were air dried 18 hours, steamed 4 hours, and then dried from 6 surfaces at 175°F. and 50 per cent humidity in the tray drier. A skin formed during the air drying period and the specimens warped during the steaming period and then cracked during the drying period.

Steaming vs Air Set - Runs 10, 11. The same method of mixing as in Run 9 was used. The plate on the top surface was, however, placed on one hour after formation of the specimens.

a. Run 10, Series 1. The time of mixing after the addition of the aluminum was:

10A-1 ----- 3 minutes

10B-1 ----- 5 minutes

After one hour the top plate was put on, the specimens were then air dried overnight and then dried in the tray drier at 175°F. and 50 per cent humidity and high air velocity. The top was not satisfactorily porous, a skin formation having occurred. There was, however, a negligible amount of trapped gas pockets. The dried edges on the specimens were cut off before drying and the specimens were almost entirely flat. In the first few hours of drying they warped to the top of the specimen, then later straightened out and finally warped towards the bottom of the specimen. They cracked at one point on the edges during the drying operation.

b. Run 10, Series 2. The mixing times here were as follows:

10A-2 ----- 3 minutes

10B-2 ----- 5 minutes

The top plate was put on one hour after the formation of the specimens, air dried a total of 2 hours after forming, steamed 3 hours, air dried 13 hours, removed from the pans and dried from 6 surfaces at high air velocity and 175°F. and 50 per cent humidity. These had the same top surface as Series 1. They warped towards the bottom, however, during the steaming operation. In the drier the shape did not alter.

c. Run 11, Series 1. The mixing times after the addition of the aluminum were as follows:

11A-1 ----- 3 minutes

11B-1 ----- 5 minutes

The top plate was put on 1 hour after forming, it was then air dried a total of 18 hours after its formation, steamed 3 hours, and then dried at low air velocity and 175°F. and 50 per cent humidity from 6 surfaces. On forming the skin was produced and in the steaming operation the specimens were blown up. It held its shape during the drying operation, however. The B specimen was poor. The edges of the specimens appeared case hardened prior to the actual drying process.

d. Run 11, Series 2. The times of mixing after the addition of the aluminum were as follows:

11A-2 ----- 3 minutes

11B-2 ----- 5 minutes

The specimens were formed without a top plate, air dried for 18 hours, steamed 3 hours, then dried at low air velocity and 175°F. and 50 per cent humidity. A skin formation occurred during the air drying period and the specimens warped considerably and were unsuitable. Again the B specimen showed a lower porosity than the A specimens. The edges of the specimens appeared to be case hardened, prior to the actual drying operation.

Time of Application of Top - Runs 12, 13. From Run 12 on the same method of mixing was used throughout. A dry mix of lime and gypsum was incorporated into the viscose in five minutes and then the addition

of the top plate was in 5 minutes

12-2 - Place top plate 15 minutes

of the aluminum, three minutes being allowed to incorporate the aluminum.

a. Run 12. The treatments were as follows:

12-1 -- Place top on in 5 minutes

12-2 -- Place top on in 15 minutes

The specimens were air dried 2 hours, steamed 3 hours, air dried 13 hours and the dried in the tray drier at high air velocity, 175°F. and 50 per cent humidity from 6 surfaces. Specimen 12-1 was slightly warped with a moderately porous top surface, which was however, unevenly blown up. No gas trapping occurred. Specimens 12-2 was warped and had a non-porous surface which was also unevenly blown up. No gas trapping occurred. These specimens were trimmed to remove dried edges before the actual drying operation.

b. Run 13. The treatments for these specimens were as follows:

13-1 -- Place top on in 5 minutes

13-2 -- Place top on in 15 minutes

The specimens were then air dried 15 hours, steamed 3 hours, and then dried from 6 surfaces at high air velocity and 175°F. and 50 per cent humidity. Before drying the specimens were trimmed to remove case hardened edges. Again as in Run 12, the 2 specimen had a poorer structure than the number 1 specimen. The specimens both warped and cracked with some gas trapping occurring in both specimens.

Air Setting With and Without a Top - Runs 14, 15. The same method of mixing as was used in Runs 12 and 13 was repeated here, this method being adopted for all future runs.

a. Run 14. The treatments were as follows:

14-1 -- Place top on in 5 minutes

14-2 -- Place top on in 15 minutes

The specimens were air dried 18 hours and then the top plate removed. The air drying was then continued for a total of 66 hours. At this point, the specimens had warped considerably and during the drying at an intermediate air velocity and 175<sup>o</sup>F. and 50 per cent humidity warped and cracked wide open.

b. Run 15. The treatments were as follows:

15-1 -- Place top on in 5 minutes

15-2 -- Place top on in 15 minutes

The specimens were then air dried to 66 hours with the top plate and then dried after trimming at an intermediate air velocity and 175<sup>o</sup>F. and 50 per cent humidity. The specimens both warped, specimen 15-2 more than 15-1. The 15-2 specimen was less porous than the 15-1. The phenomenon of double warping is shown by specimen 15-2 in Figure 9.

Reduced Time of Steaming - Runs 16, 17, 18, 19. The method of mixing used was the same as that used in Runs 12 and on. It was attempted in this series of runs to determine the optimum time required for the steam treatment to obtain the desired setting action.

a. Run 16. The treatments were as follows:

16-1 -- Place top on immediately

16-2 -- Place top on in 5 minutes

These were then air dried 2 hours, steamed 1 hour, air dried 15 hours, and then dried at high air velocity and 175<sup>o</sup>F. and 50 per cent humidity from 6 surfaces after trimming. These specimens did not warp; both tops were satisfactorily porous and gave good specimens.

USE OF TOP PLATE - DOUBLE WARPING.

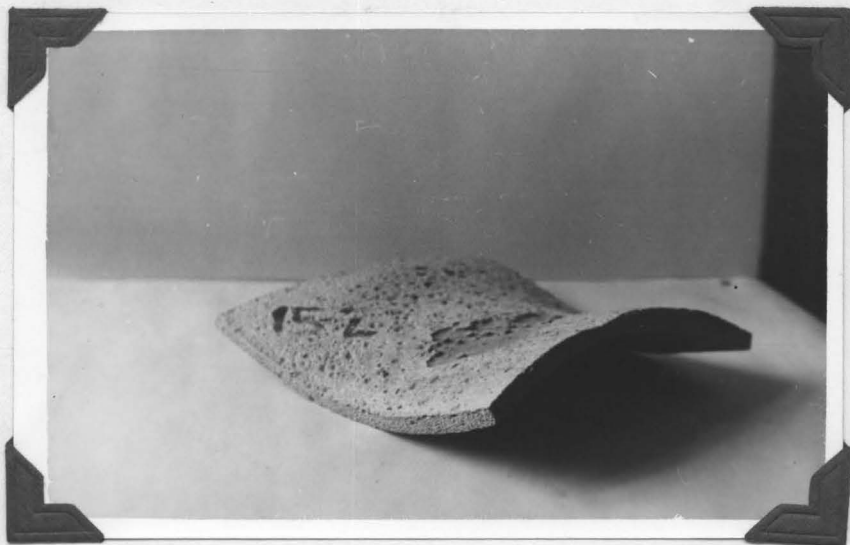


FIGURE 9.

b. Run 17. The treatments were as follows:

17-1 -- Place top on immediately

17-2 -- Place top on after five minutes

These were then air dried 17 hours, steamed 1 hour, then removed from the pans, trimmed and dried from 6 surfaces at low air velocity, 175°F., and 50 per cent humidity. The top surfaces of the specimens were satisfactory but the specimens warped nevertheless. The warping occurred during the steaming operation and this structure was maintained during the drying period.

c. Run 18. The treatments were as follows:

18-1 -- Place top on immediately

18-2 -- Place top on in 5 minutes

The specimens were then air dried 2 hours, steamed 2 hours, air dried 14 hours, and then removed from the pans and dried from 6 surfaces after trimming at high air velocity, 175°F. and 50 per cent humidity. Specimen 18-1 had a good porous surface with a flat top but was cracked at one edge. Specimens 18-2 developed a skin and warped in two directions.

d. Run 19. The treatments were as follows:

19-1 -- Place top on immediately

19-2 -- Place top on in 5 minutes

The specimens were then air dried 16 hours, steamed 2 hours, removed from the pans, trimmed, dried from 6 surfaces in the tray drier at low air velocity, 175°F. and 50 per cent humidity. Both of these specimens warped during the steaming operation, but showed no appreciable change during the drying operation.

Rate of Cooling After Steaming - Runs 20, 21. This series of runs attempted to find the effect of slow cooling of the specimens after the steaming treatment. The method of mixing was similar to that of Runs 12 and on.

a. Run 20. The plate on top of the specimens formed was put on within 5 minutes after the formation.

20-1 -- Air dry 2 hours, steam 1 hour, cool slowly in steaming apparatus, air dry 15 hours, remove from pan, trim, dry from 6 surfaces at high air velocity, 175°F., 50 per cent humidity.

20-2 -- Same conditions as above, except that the specimen was cooled rapidly after the steaming operation.

Both specimens were similar as to structure, surfaces and general appearance which were good.

b. Run 21. The top plate was put on within 5 minutes after the specimens were formed.

21-1 -- Air dry 17 hours, steam 1 hour, cool slowly in steamer, remove from pans, trim, dry at high air velocity in tray drier, 175°F., and 50 per cent humidity, 6 surfaces exposed.

21-2 -- Same conditions as the above, except that the specimen was cooled rapidly after the steaming operation.

Specimen 21-1 was fairly flat with a good structure and surface, but was at several of its edges. Specimens 21-2 warped during the steaming treatment and maintained this shape during the drying process.

High Temperature Dry Heat Set - Run 22. The same method of mixing as Run 12 and on was used. The top plate was put on within 5 minutes after the formation of the specimens. It was attempted to set the structure of Scherer Insulation by a dry heat treatment. The method of treatment was as follows:

22-1 -- Air dry 2 hours, dry heat treatment in tray drier at 220°F for 1 hour, air dry 15 hours, trim and dry from 6 surfaces at low air velocity, 175°F. and 50 per cent humidity.

22-2 -- Air dry 17 hours, dry heat treatment at 220°F. for 1 hour in tray drier, trim and dry from 6 surfaces at low air velocity, 175°F., and 50 per cent humidity.

The specimens were flat and generally satisfactory. Specimen 22-2 warped slightly. During the dry heat treatment the specimens cracked wide open and considerable trimming had to be done before drying them.

Prolonged Air Setting - Run 23. It was attempted here to set the structure of the insulator by a prolonged air setting period. The same method of mixing as used in Runs 12 and on was repeated. The top plate was put on within five minutes after the formation of the specimens.

23-1, 23-2 -- Air dried 6 days, trim and dry from 6 surfaces in the tray drier at high air velocities, 175°F., 50 per cent humidity.

After 6 days of air setting, the specimen was firmly set and the edges were hard to trim. The specimens had shrunk away from the sides of the pans. The specimens had a good surface after drying, but warped considerably.

Drying at 175°F., 50 per cent Humidity - Runs 24, 25, 26, 27. The

same method of mixing as used in Runs 12 and on was repeated for these runs. The top plate was put on within 5 minutes after the formation of the specimens.

a. Run 24. The methods of treatment were as follows:

24-1 -- Air set 2 hours, steam 1.5 hours, air dry 15 hours, remove from pans and trim, dry from 6 surfaces at high air velocity.

24-2 -- Same as above, except to dry at low air velocity.

These specimens proved to be good flat specimens with good structure and surfaces except for cracks occurring on the edges. Specimen 24-2 is shown in Figure 10.

b. Run 25. The methods of treatment were as follows:

25-1 -- Air set 16 hours, steam 1.5 hours, dry in tray drier from 6 surfaces at high air velocity.

25-2 -- Same as above except that it was dried at the low air velocity.

These specimens were good but were slightly warped, and in this respect inferior to the specimens of run 24.

c. Run 26. The methods of treatment were as follows:

26-1 -- Air set 2 hours, dry heat treatment 1.5 hours, the treatment carried out at 175°F., air dry 14 hours, dry from all 6 surfaces in the tray drier after trimming at high air velocity.

26-2 -- Same as above except that it was dried at the low air velocity.

Both specimens were slightly warped, specimen 26-1 being partly ruined

STEAMING THE DAY FORMED - TOP PLATE.



FIGURE 10.

by accidental loading on the center of the top plate during the dry heat treatment.

d. Run 27. The methods of treatment were:

27-1 -- Air set 16 hours, dry heat treat 1.5 hours at 175<sup>o</sup>F., dry from 6 surfaces in tray drier after trimming at high air velocity.

27-2 -- Same treatment as the above except that it was dried at the low air velocity.

Specimen 27-1 was flat and had a good top. Its structure appeared dense. Specimen 27-2 was warped and cracked and ruined because the edges of the top plate were trapped by the specimen causing warping when the specimen was shrinking during the dry heat period. Both specimens showed cracking after the dry heat period and required trimming before actual drying.

Drying at 200<sup>o</sup>F., 50 per cent Humidity - Runs 28, 29. The same method of mixing as used in Runs 12 and on was repeated. The top plate was again applied within 5 minutes after the formation of the specimens.

a. Run 28. The methods of treatment were as follows:

28-1 -- Air set 2 hours, steam 1.5 hours, air dry 14 hours, remove from tray, trim and dry from 6 surfaces at high air velocity.

28-2 -- Same as above except that it was dried at the low air velocity.

The specimens were flat but cracked considerably at the edges.

b. Run 29. The methods of treatment were as follows:

29-1 -- Air set 16 hours, steam 1.5 hours, remove from pan

trim and dry from 6 surfaces at high air velocity.

29-2 -- Same treatment as the above except that it was dried at low air velocity.

The steaming operation warped these specimens, but gave them a permanent set and they retained this shape in the drier. See Figure 11 of Specimen 29-1.

Air Drying - Runs 30, 31. The same method of mixing as used in Runs 12 and on were again repeated. The top plate was applied within 5 minutes after the formation of the specimens.

a. Run 30. The method of treatment was as follows:

30-1 -- Air set 2 hours, steam 1.5 hours, remove from pan, trim, and air dry at room conditions from 6 surfaces.

30-2 -- Air set 16 hours, steam 1.5 hours, remove from pan, trim, and air dry at room conditions from 6 surfaces.

Specimen 30-1 was flat with good structure and surfaces, while specimen 30-2 was slightly warped. Specimen 30-1 is shown in Figure 12. No cracking occurred in either of the specimens.

b. Run 31. The method of treatment was as follows:

31-1 -- Air set 2 hours, dry heat treatment at 150°F. for 1.5 hours, remove from pans, trim, air dry completely from 6 surfaces.

31-2 -- Air set 16 hours, dry heat treat 1.5 hours at 150°F., remove from pan, trim, dry at room conditions completely from 6 surfaces.

Both specimens were trimmed, case hardening with no cracking occurring at the exposed edges during the dry heat period. A very slight warpage during the drying operation.

STEAMING THE DAY AFTER FORMING.

TOP PLATE.



FIGURE 11.

AIR DRYING SPECIMENS STEAMED ON FORMING.



FIGURE 12.

Drying at 150°F. and 50 per cent Humidity. - Runs 32, 33, 34, 35. The same method of mixing as used previously in Runs 12 and on were repeated for this series. The top plat was applied within 5 minutes after the specimens were formed.

a. Run 32. The method of treatment was as follows:

32-1 -- Air set 2 hours, steam 1.5 hours, air dry 15 hours, trim and dry from 6 surfaces at high air velocity.

32-2 -- Same treatment as the above except to dry at low air velocity.

The specimens were flat and had a good surface structure but cracked at the edges on drying.

b. Run 33. The method of treatment was as follows:

33-1 -- Air set 17 hours, steam 1.5 hours, trim and dry from all 6 surfaces at high air velocity.

33-2 -- Same treatment as above except to dry at the low air velocity.

Both specimens were warped after the drying operation. Initial warping occurred in the steaming operation.

c. Run 34. The method of treatment was as follows:

34-1 -- Air set 2 hours, dry heat treat for 1.5 hours at 150°F., air set 15 hours, trim and dry from all 6 surfaces at the high air velocity.

34-2 -- Same treatment as the above except to dry at the low air velocity.

Specimens 34-1 was very slightly warped and gave a good structure. Specimen 34-2 was a bit warped also.

d. Run 35. The method of treatment was as follows:

35-1 -- Air set 15 hours, dry heat treatment at 150° F. for 1.5 hours, trim and dry from 6 surfaces at high air velocity.

35-2 -- Same treatment as above except that the drying is at the low air velocity.

Specimen 35-1 was flat while 35-2 warped a bit. The structure of both was good and the surfaces were also good. Specimen 35-1 is shown in Figure 13.

Structure of Scherer Insulation. Figures 14, 15 and 16 are illustrative of various internal structures of Scherer Insulation. Figure 14 shows an example of poor structure caused by segregation of aluminum. This caused the blowholes to form. The specimens produced was weak and brittle.

Figure 16 represents a specimen prepared without any thermal treatment, while Figure 17 is a steamed specimen. The steamed specimen has larger pores than the one which did not receive a thermal treatment. The thermal treatment caused greater expansion of the structure of the product.

DRY HEAT TREATED SPECIMEN.FIGURE 13.Figure 14EFFECT OF SEGREGATION OF ALUMINUM ON  
INTERNAL STRUCTURE.

STRUCTURE OF SPECIMEN NOT SET  
BY THERMAL TREATMENT



FIGURE 15.

STRUCTURE OF SPECIMEN SET BY  
STEAM TREATMENT.

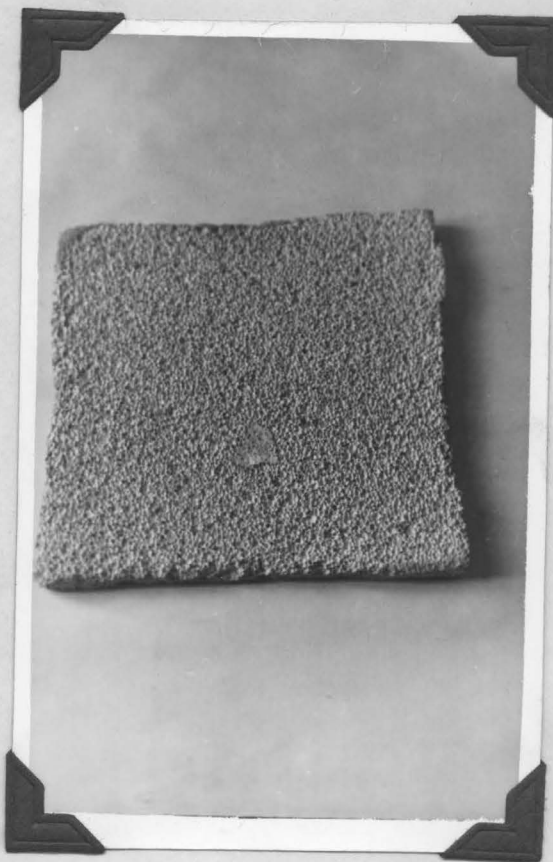


FIGURE 16.



### Test Data and Results.

General Properties of Scherer Insulation. The properties of Scherer Insulation are listed in Table 1.

The per cent shrinkage is the average change in length of the specimen based on the length before drying.

The modulus of rupture is defined by the equation:

$$s = Mc/I$$

where:

s is the maximum unit stress lb./sq. in.

M is the maximum bending moment, lb. in.

c is one-half the height in inches.

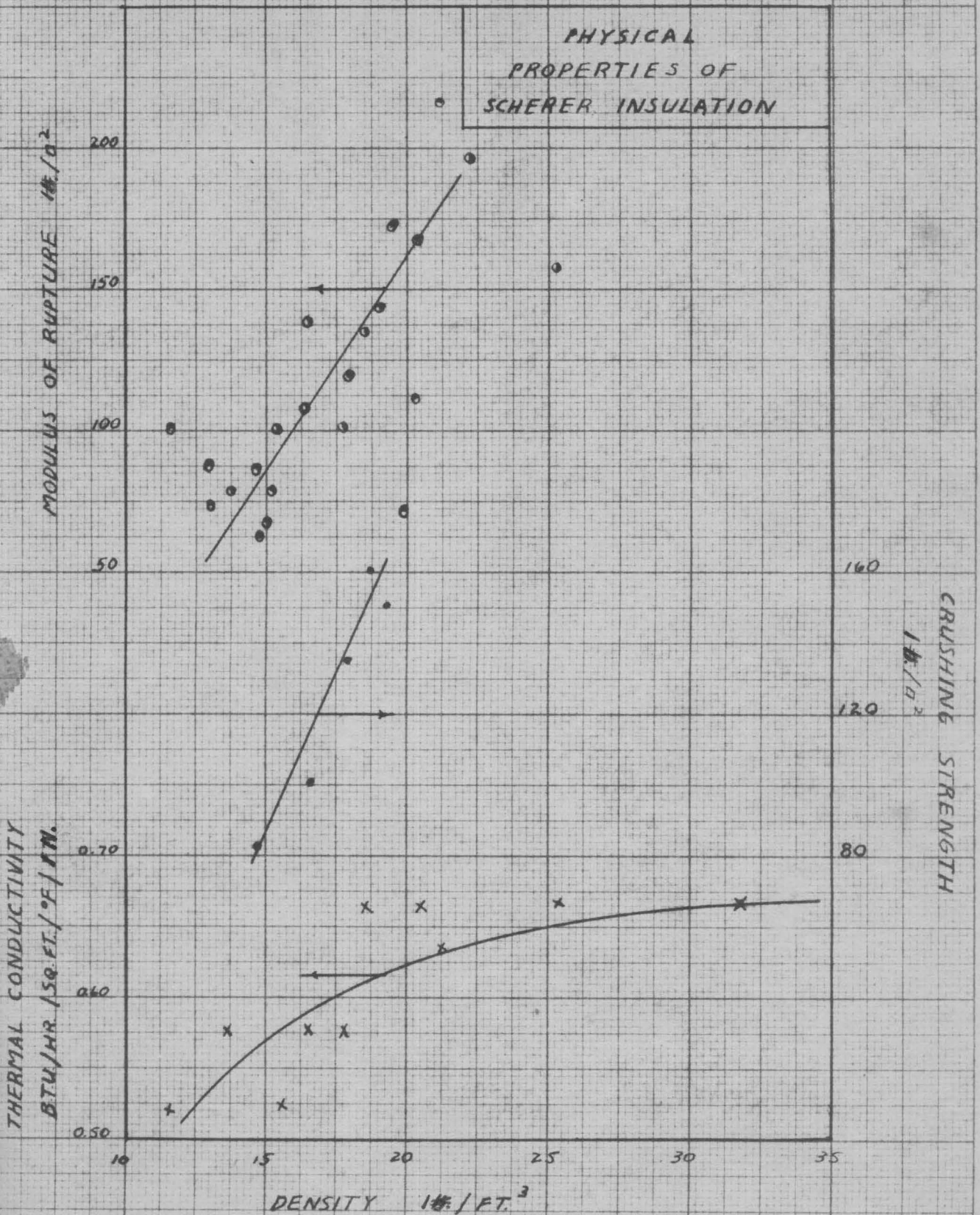
I is the section modulus (inches)<sup>4</sup>.

The values of thermal conductivity, modulus of rupture and crushing strength from Table 1 are plotted against the density of Scherer Insulation in Graph 1.

Table 2 - Properties of Scherer Insulation.

Specimen	Rise per cent	Shrinkage per cent	Density lb./ft <sup>3</sup>	Modulus of Rupture lb./in. <sup>2</sup>	Crushing Strength lb/in. <sup>2</sup>	Thermal Cond. BTU/hr. ft <sup>2</sup> per °F/Inch
10A-1	200	11.6	16.5	157		0.575
10B-1	175	6.5	21.2	215		0.656
12-1	275	9.4	15.7	77		0.575
12-2	225	21.7	17.7	100		0.575
13-1	225	13.4	19.3	171	149	
16-1	325	9.6	13.0	73		
17-1	325	10.2	17.9	118	136	
18-1	200	13.5	18.5	134		0.663
19-1	200	13.7	20.3	110		0.663
19-2	225	13.8	22.3	194		
20-1	175	12.4	14.9	65.5		
20-2	200	13.7	19.8	68.3		
21-1	225	12.5	20.4	165		
22-1	200	9.8	14.6	86		
24-1	300	16.0	14.6	62.8		
24-2	500	10.9	15.1	77.0	82.2	
27-1	250	9.2	25.3	156		0.665
30-1	275	12.3	11.6	99		0.521
30-2	325	13.0	15.3	100		0.521
34-1	225	15.7	18.8	143	160	
35-1	175	15.0	31.7	232		0.665
32-1						
With skin	325	10.2	16.6	107	100	
Without	325	10.2	12.8	86		

GRAPH 1



Air Drying Steamed Specimens. The data for specimens 30-1 and 30-2 is given in Tables 3 and 4. Graphs 2 and 3 are plotted for this data, the former for moisture content vs time and the latter for drying rate vs moisture content.

Specimen 30-1.

moisture content on forming ----- 57.8 per cent

average drying area -----396 sq. cm.

specimen steamed 2 hours after forming

Specimen 30-2.

moisture content on forming ----- 57.8 per cent

average drying area -----399 sq. cm.

specimen steamed 15 hours after forming.

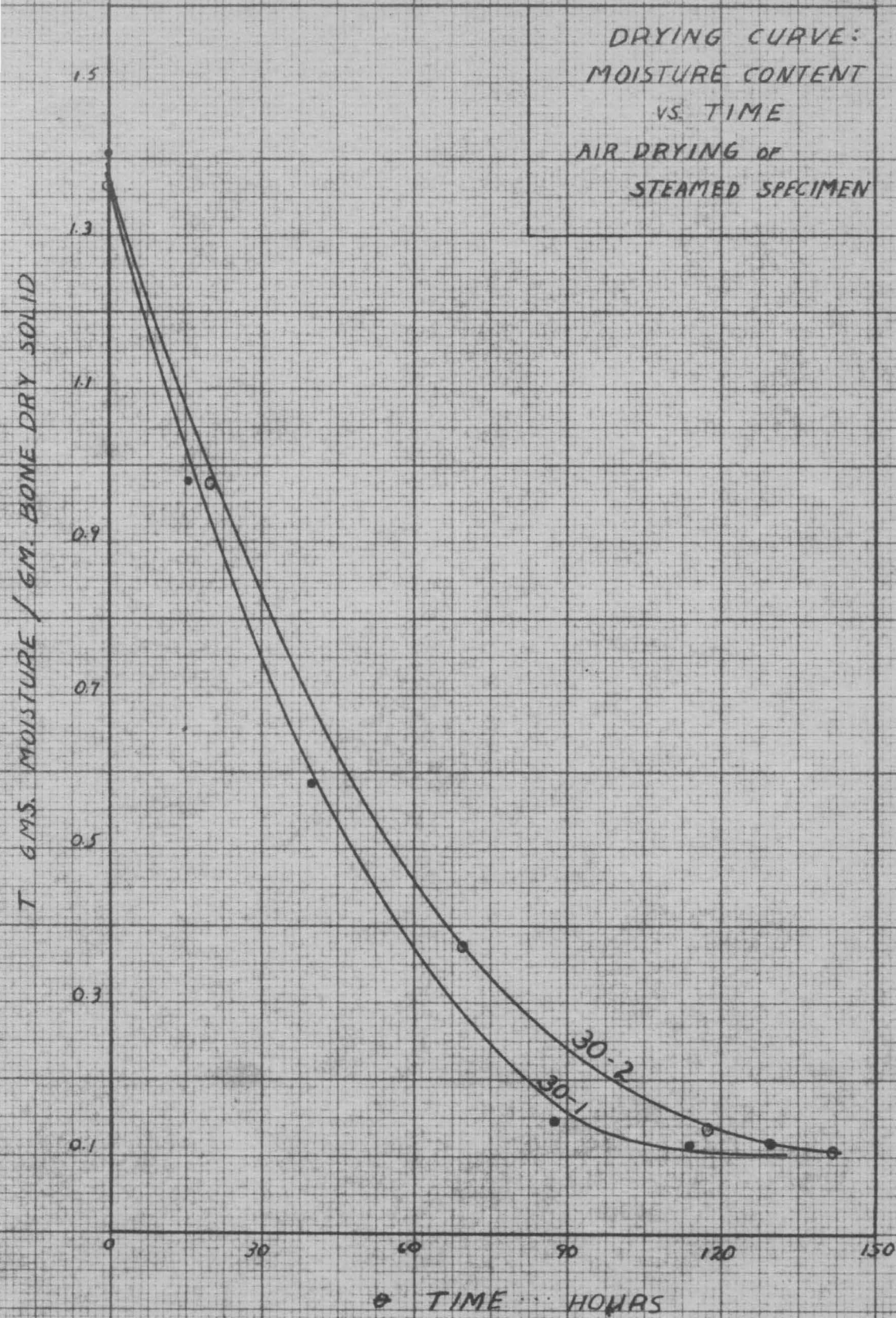
Table 3.Moisture Content vs Time - Air Drying Steamed Specimens.

Specimen 30-1			Specimen 30-2		
Time	Weight	Moisture Content	Time	Weight	Moisture Content
hours	gms	gm. H <sub>2</sub> O/gm solid	hours	gms.	gm. H <sub>2</sub> O/gm solid
0	1620	1.410	0	2216	1.566
16	1334	0.982	21.5	1850	0.976
40	1066	0.586	69.5	1292	0.371
88	770	0.145	96.5	1127	0.202
116	750	0.116	116	1067	0.133
186.5	753	0.120	142	1056	0.108

Table 4Drying Rate vs Moisture Content - Air Drying Steamed Specimens.

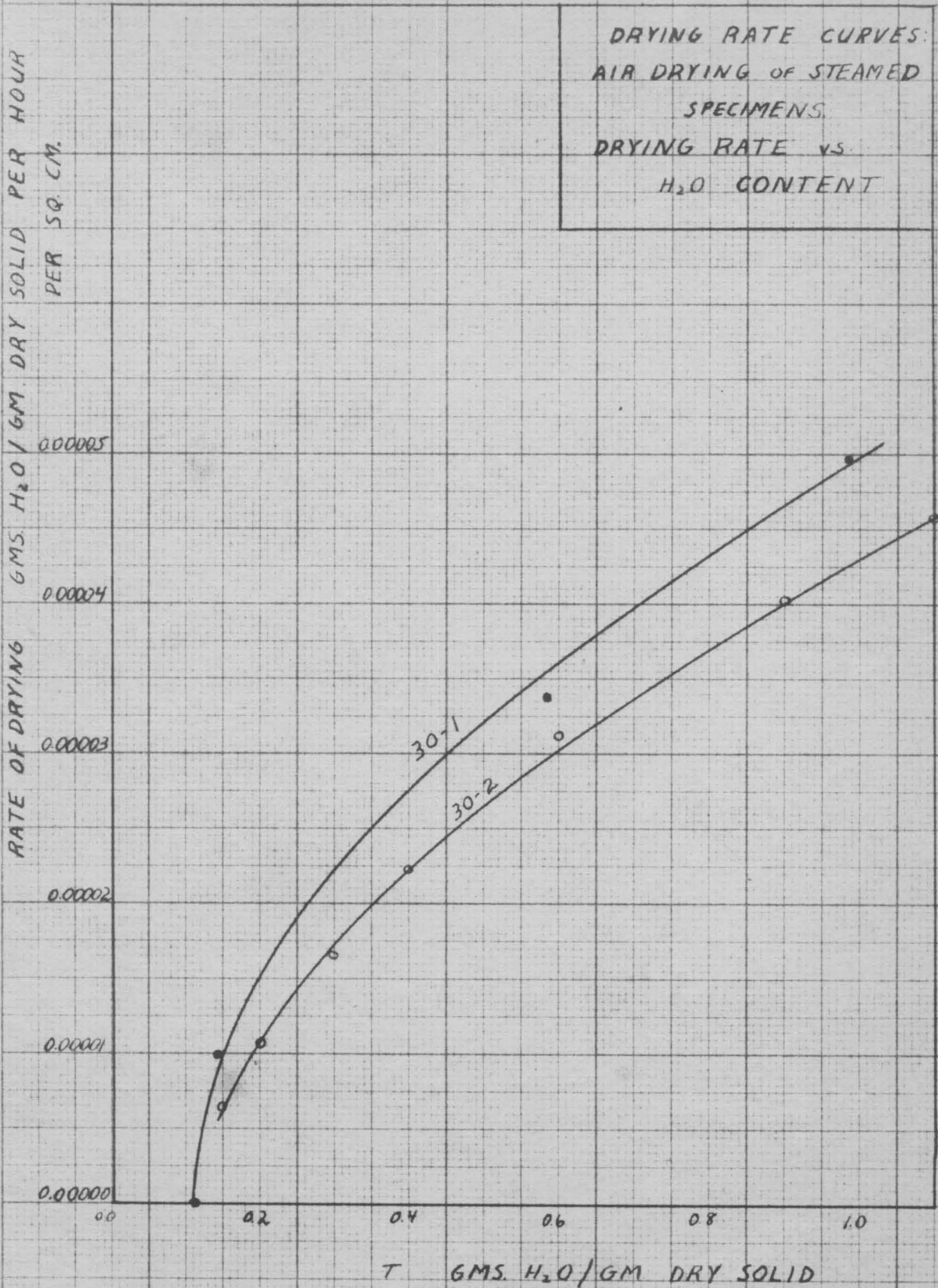
Specimen 30-1		Specimen 30-2	
Moisture Content	Drying Rate	Moisture Content	Drying Rate
gm. H <sub>2</sub> O/gm solid	gm. H <sub>2</sub> O/gm solid per hr. per sq. cm.	gm. H <sub>2</sub> O/gm solid	gm. H <sub>2</sub> O/gm solid per hr. per sq. cm.
0.982	0.0000498	1.1	0.0000457
0.586	0.0000356	0.9	0.0000402
0.145	0.0000099	0.6	0.0000312
0.116	0.00	0.4	0.0000223
		0.3	0.0000165
		0.2	0.0000109
		0.15	0.0000069

GRAPH 2



GRAPH 3

DRYING RATE CURVES:  
AIR DRYING OF STEAMED  
SPECIMENS.  
DRYING RATE vs.  
H<sub>2</sub>O CONTENT



Air Drying Dry Heat Treated Specimens. The data for specimens 31-1 and 31-2 is given in Tables 5 and 6. Graphs 4 and 5 are plotted for this data, the former for moisture content vs time and the latter for drying rate vs moisture content.

Specimen 31-1

moisture content on forming ----- 57.8 per cent  
average drying area ----- 295 sq. cm.  
specimen dry heat treated 2 hours after forming.

Specimen 31-2

moisture content on forming ----- 57.8 per cent  
average drying area ----- 309 sq. cm.  
specimen dry heat treated 16 hours after forming.

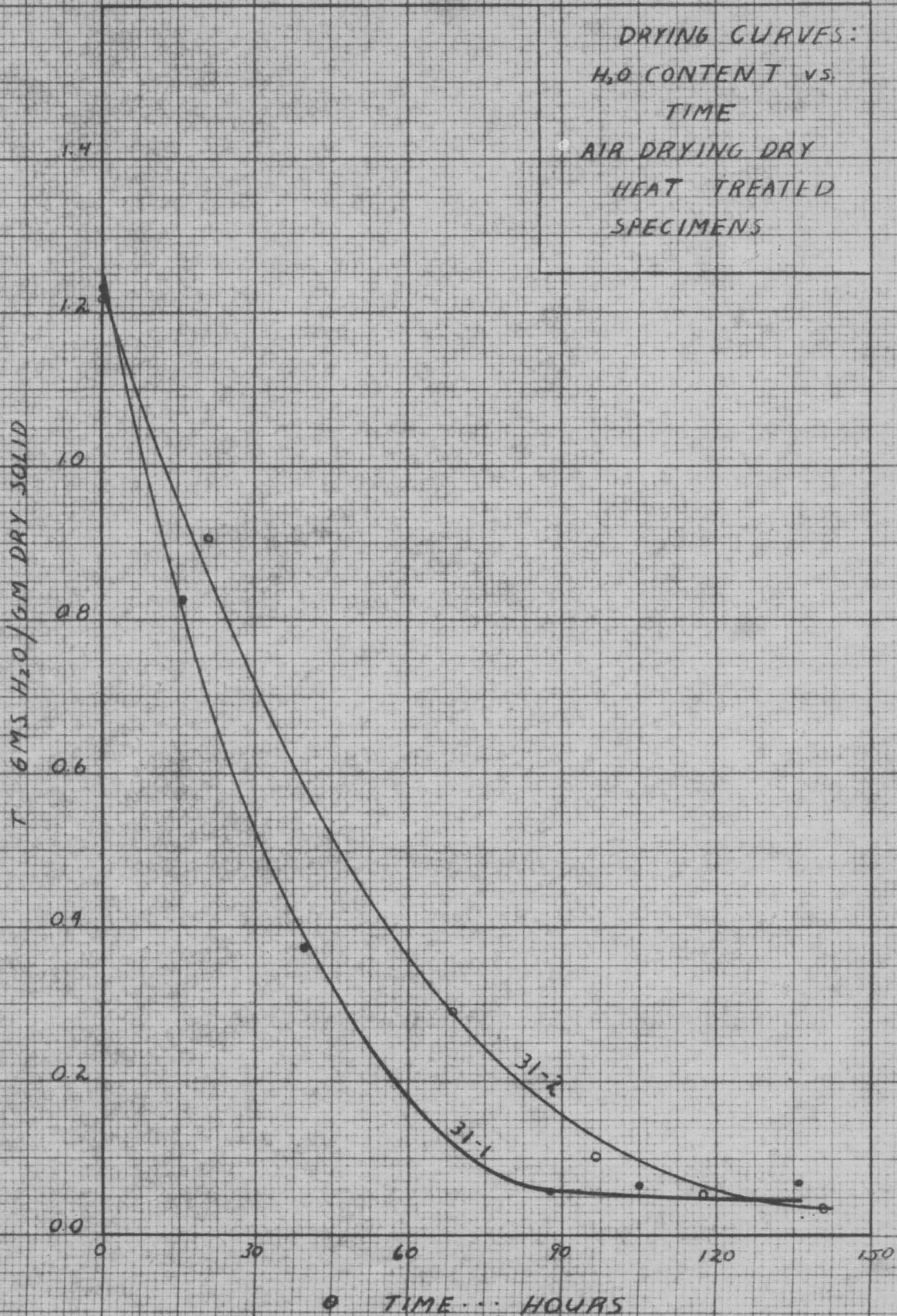
Table 5.Moisture Content vs Time - Air Drying Dry Heat Treated Specimens.

Specimen 31-1			Specimen 31-2		
Time hours	Weight gms.	H <sub>2</sub> O Content gm. H <sub>2</sub> O/gm solid	Time hrs.	Weight gms.	H <sub>2</sub> O Content gm. H <sub>2</sub> O/gm solid
0	903	1.230	0	1643	1.220
16	735	0.821	21.5	1370	0.853
40	554	0.371	69.5	955	0.290
68	427	0.0565	96.5	819	0.106
115	429	0.062	118	781	0.0556
158.5	429	0.062	142	767	0.0565

Table 6.Drying Rate vs Moisture Content - Air Drying Dry Heat Treated Specimens.

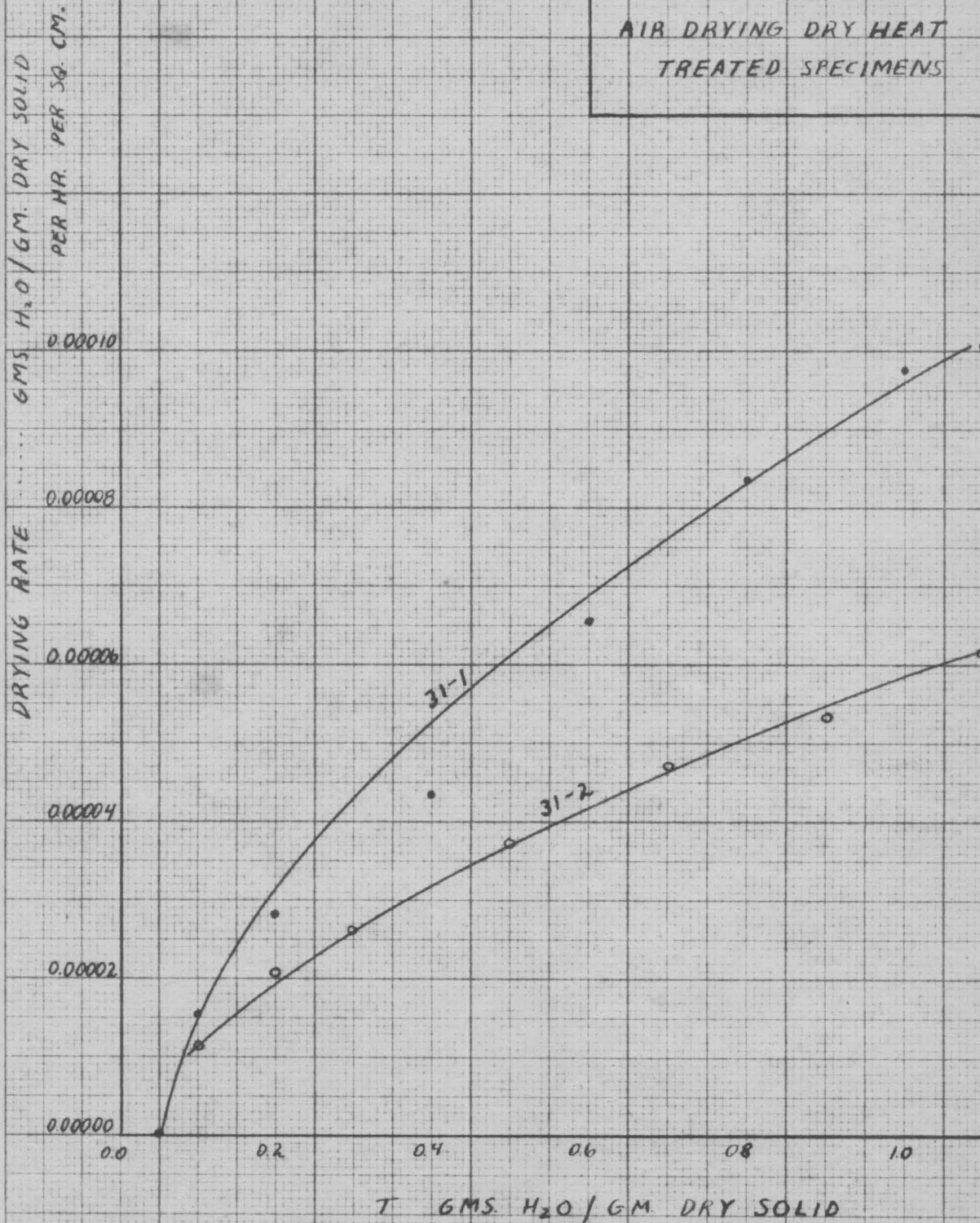
Specimen 31-1		Specimen 31-2	
Moisture Content gm. H <sub>2</sub> O/gm solid	Drying Rate gm. H <sub>2</sub> O/gm solid per hr. per sq. cm.	Moisture Content gm. H <sub>2</sub> O/gm solid	Drying Rate gm. H <sub>2</sub> O/gm solid per hr. per sq. cm.
1.1	0.0001050	1.1	0.0000613
1.0	0.0000973	0.9	0.0000552
0.8	0.0000834	0.7	0.0000472
0.6	0.0000655	0.5	0.0000371
0.4	0.0000433	0.3	0.0000268
0.2	0.0000280	0.2	0.0000202
0.1	0.0000157	0.1	0.0000113
0.05	0.0		

CURVE 3



GRAPH 5

DRYING RATE CURVES:  
 DRYING RATE vs  
 H<sub>2</sub>O CONTENT  
 AIR DRYING DRY HEAT  
 TREATED SPECIMENS



Drying at 150°F., 50 per cent Humidity, 273 Feet per Minute

Air Velocity. The data for specimens 32-2 and 34-2 is given in Tables 7 and 8. Graphs 6 and 7 are plotted for this data, the former for moisture content vs time and the latter for drying rate vs the moisture content.

Specimen 32-2.

moisture content on forming ----- 57.3 per cent

average drying area ----- 458 sq. cm.

Specimen steamed 2 hours after forming.

Specimen 34-2.

Moisture content on forming -----50.6 per cent

average drying area ----- 272 sq. cm.

specimen dry heat treated 2 hours after forming at 150°F.

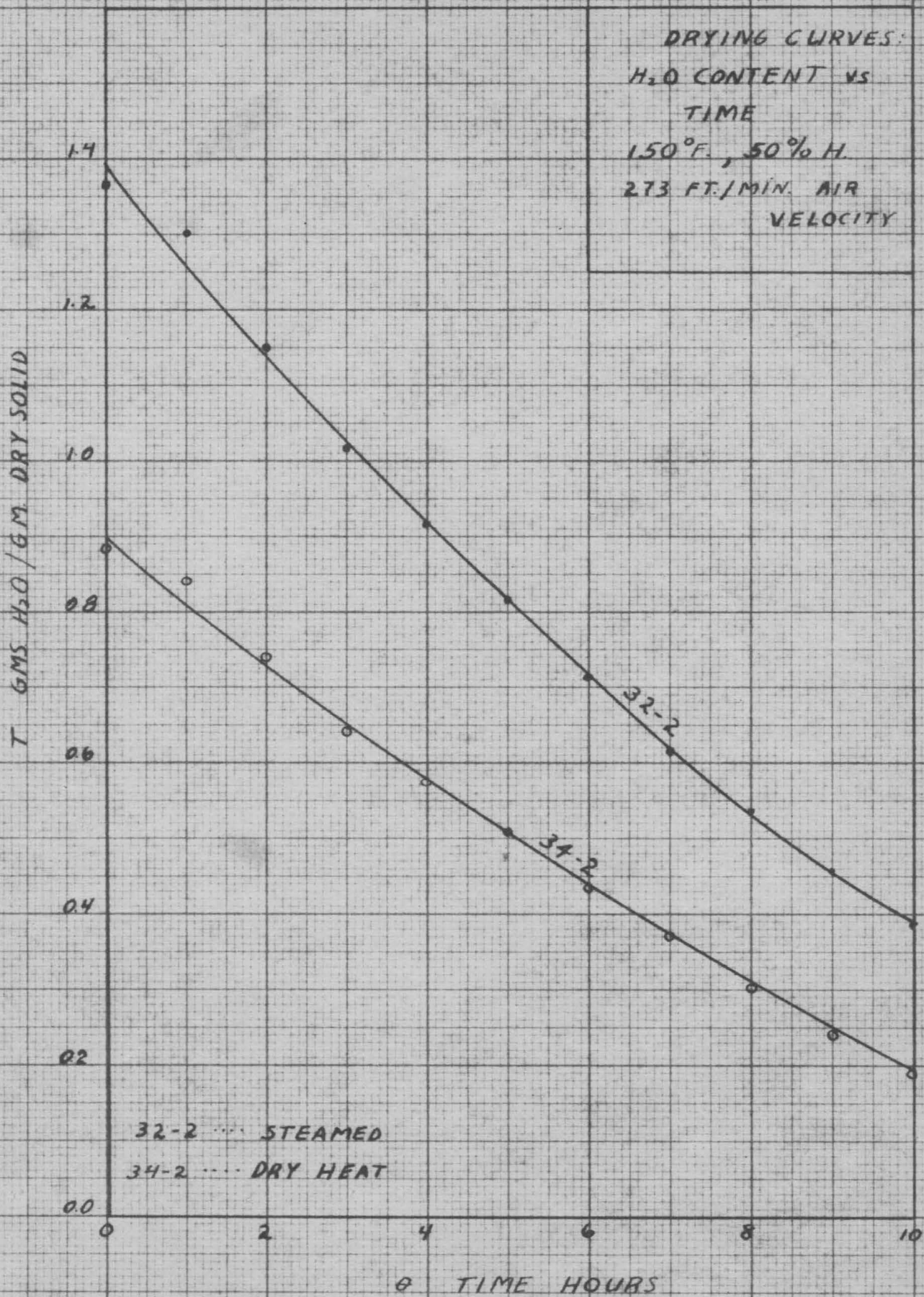
Table 7.Moisture Content vs Time - 150°F., 50 per cent Humidity.

Specimen 32-2			Specimen 34-2		
Time hrs.	Weight gms	H <sub>2</sub> O Content gm.H <sub>2</sub> O/gm.solid	Time hrs.	Weight gms.	H <sub>2</sub> O Content gm.H <sub>2</sub> O/gm solid
0	2070	1.365	0	2000	0.888
1	2010	1.300	1	1981	0.840
2	1882	1.150	2	1846	0.741
3	1761	1.015	3	1745	0.645
4	1675	0.914	4	1674	0.576
5	1585	0.816	5	1600	0.509
6	1500	0.716	6	1524	0.437
7	1414	0.616	7	1454	0.371
8	1342	0.534	8	1380	0.302
9	1276	0.459	9	1319	0.245
10	1213	0.387	10	1251	0.180

Table 8.Drying Rate vs Moisture Content - 150°F., 50 per cent Humidity.

Specimen 32-2		Specimen 34-2	
Moisture Content gm.H <sub>2</sub> O/gm solid	Drying Rate Gm.H <sub>2</sub> O/gm solid per hr.per sq.cm.	Moisture Content gm.H <sub>2</sub> O/gm.solid	Drying Rate gm.H <sub>2</sub> O/gm solid per hr.per sq.cm.
1.365	0.000281	0.840	0.000311
1.150	0.000264	0.741	0.000297
1.015	0.000244	0.645	0.000285
0.914	0.000233	0.576	0.000273
0.816	0.000220	0.509	0.000265
0.716	0.000211	0.437	0.000257
0.616	0.000199	0.371	0.000245
0.534	0.000176	0.302	0.000236
0.459	0.000152	0.245	0.000219
0.387	0.000129	0.180	0.000209

GRAPH 6



GRAPH 7

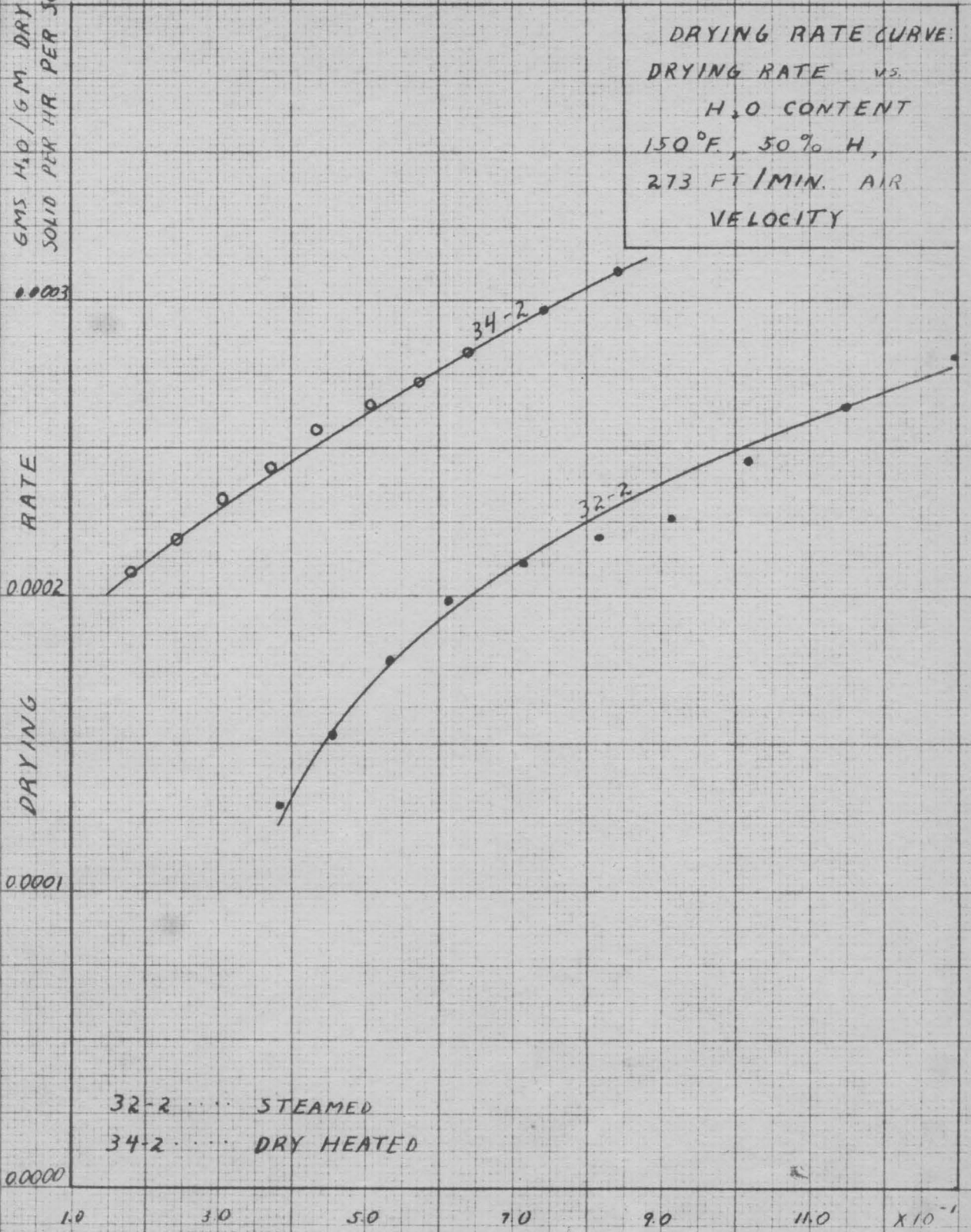
DRYING RATE CURVE:  
 DRYING RATE VS.  
 H<sub>2</sub>O CONTENT  
 150°F, 50% H,  
 273 FT/MIN. AIR  
 VELOCITY

GMS H<sub>2</sub>O / GM DRY  
 SOLID PER HR PER SQ CM.

0.0003  
 RATE  
 0.0002  
 DRYING  
 0.0001  
 0.0000

1.0 3.0 5.0 7.0 9.0 11.0 X 10<sup>-1</sup>  
 T GMS H<sub>2</sub>O / GM DRY SOLID

32-2 ····· STEAMED  
 34-2 ····· DRY HEATED



Drying at 175°F., 50 per cent Humidity. The data for specimens 24-1 and 24-2 is given in Tables 9 and 10. Graphs 8 and 9 are plotted for this data, the former for moisture content vs time and the latter for rate of drying vs moisture content.

Specimen 24-1.

Moisture content on forming ----- 56.7 per cent  
 average drying area ----- 433 sq.cm.  
 specimen steamed 2 hours after forming.  
 dried at 474 feet per minute air velocity.

Specimen 24-2.

Moisture content on forming ----- 56.7 per cent  
 average drying area ----- 431 sq.cm.  
 specimen steamed 2 hours after forming.  
 dried at 273 feet per minute air velocity.

Table 9.Moisture Content vs Time - 175°F., 50 per cent Humidity.

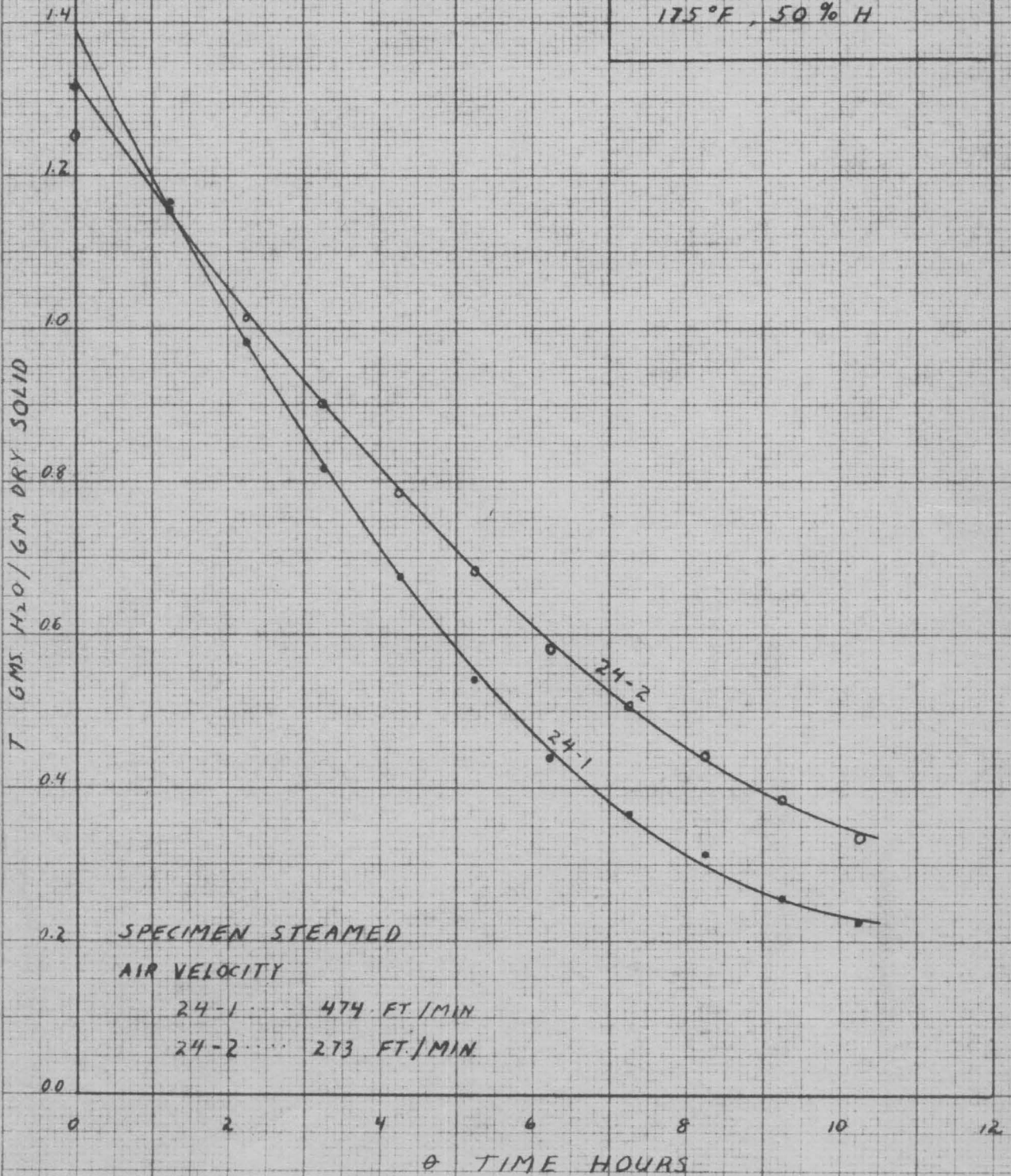
Specimen 24-1			Specimen 24-2		
Time hrs.	Weight gms.	H <sub>2</sub> O Content gm.H <sub>2</sub> O/gm solid	Time hrs.	Weight gms.	H <sub>2</sub> O Content gm.H <sub>2</sub> O/gm solid
0.00	1894	1.511	0.00	1897	1.250
1.25	1685	1.165	1.25	1824	1.165
2.25	1450	0.961	2.25	1698	1.015
3.25	1332	0.819	3.25	1600	0.900
4.25	1227	0.676	4.25	1503	0.785
5.25	1117	0.540	5.25	1422	0.682
6.25	1055	0.442	6.25	1331	0.582
7.25	998	0.363	7.25	1269	0.509
8.25	960	0.312	8.25	1219	0.447
9.25	927	0.253	9.25	1166	0.385
10.25	894	0.221	10.25	1124	0.335

Table 10.Drying Rate vs Moisture Content - 175°F., 50 per cent Humidity.

Specimen 24-1		Specimen 24-2	
Moisture Content gm.H <sub>2</sub> O/gm solid	Drying Rate gm.H <sub>2</sub> O/gm solid per hr.per sq.cm.	Moisture Content gm.H <sub>2</sub> O/gm solid	Drying Rate gm.H <sub>2</sub> O/gm solid per hr.per sq.cm.
1.2	0.000420	1.2	0.000315
1.1	0.000405	1.1	0.000302
1.0	0.000387	1.0	0.000280
0.9	0.000365	0.9	0.000263
0.8	0.000354	0.8	0.000253
0.7	0.000325	0.7	0.000240
0.6	0.000286	0.6	0.000211
0.5	0.000244	0.5	0.000172
0.4	0.000197	0.4	0.000122
0.3	0.000123		
0.25	0.000072		

GRAPH 8

DRYING CURVES  
 H<sub>2</sub>O CONTENT VS.  
 TIME  
 175°F, 50% H



GRAPH 9

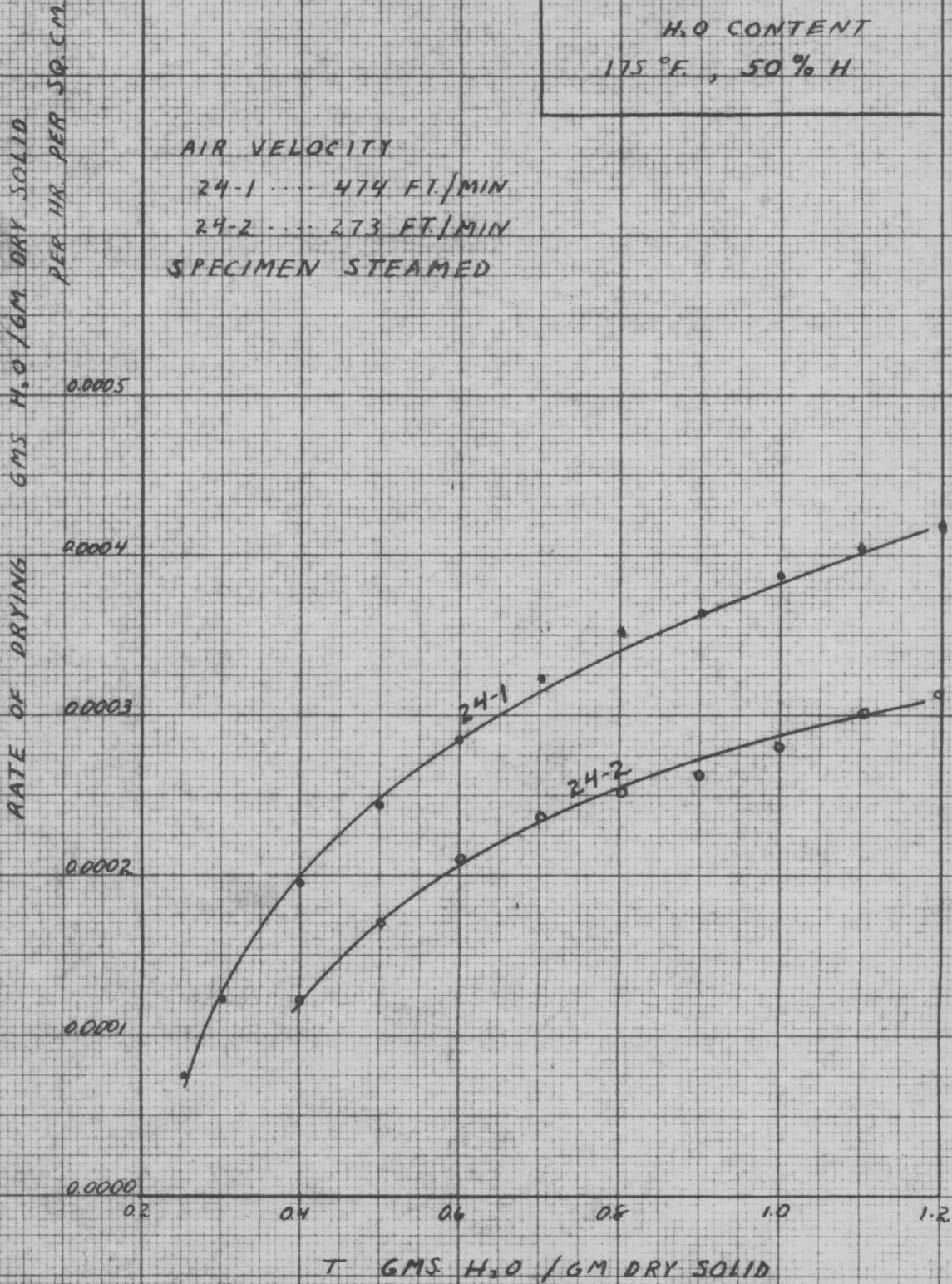
DRYING RATE CURVES:  
 DRYING RATE vs.  
 H<sub>2</sub>O CONTENT  
 175 °F., 50% H

AIR VELOCITY

24-1 ..... 474 FT./MIN

24-2 ..... 273 FT./MIN

SPECIMEN STEAMED



Drying at 200°F., 50 per cent Humidity, 273 feet per minute Air Velocity. The data for specimens 28-2 and 29-2 is given in Tables 11 and 12. Graphs 10 and 11 are plotted for this data, the former for moisture content vs. time and the latter for drying rate vs moisture content.

Specimen 28-2.

Moisture content on forming ----- 57.4 per cent

Average drying area ----- 374 sq. cm.

Specimen steamed 2 hours after forming.

Specimen 29-2.

Moisture content on forming -----57.4 per cent

Average drying area ----- 409 sq. cm.

Specimen steamed 16 hours after forming.

Table 11.Moisture Content vs Time - 200°F., 50 per cent Humidity.

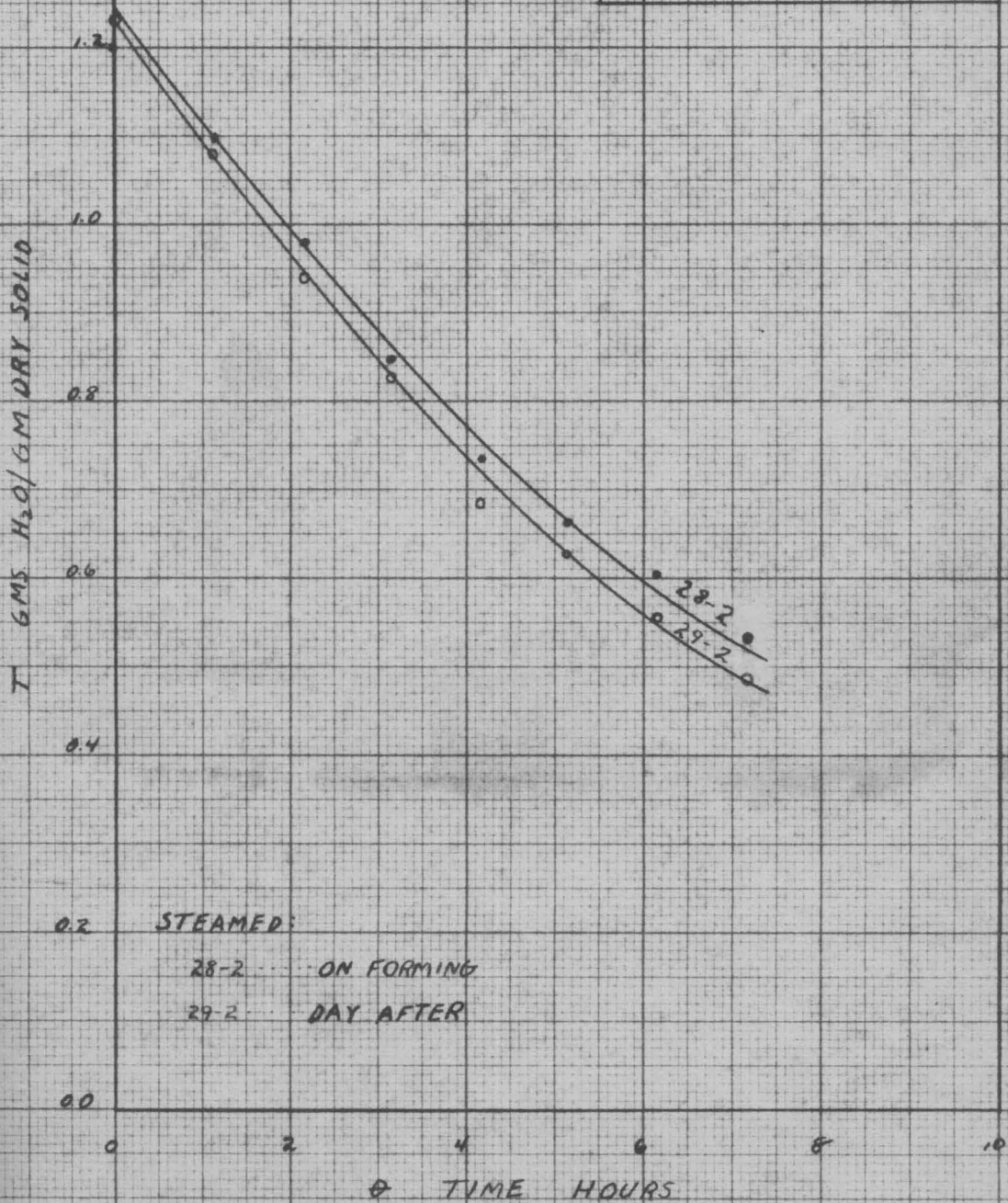
Specimen 28-2			Specimen 29-2		
Time Hrs.	Weight gms.	H <sub>2</sub> O Content Gm. H <sub>2</sub> O/gm. solid	Time Hrs.	Weight Gms.	H <sub>2</sub> O Content Gm. H <sub>2</sub> O/gm solid
0.00	1780	1.200	0.00	1942	1.280
1.17	1681	1.100	1.17	1814	1.070
2.17	1549	0.970	2.17	1700	0.940
3.17	1484	0.880	3.17	1600	0.827
4.17	1384	0.734	4.17	1480	0.689
5.17	1308	0.666	5.17	1425	0.626
6.17	1260	0.602	6.17	1360	0.553
7.17	1205	0.533	7.17	1300	0.484

Table 12.Drying Rate vs Moisture Content - 200°F., 50 per cent Humidity.

Specimen 28-2		Specimen 29-2	
Moisture Content gm. H <sub>2</sub> O/gm. solid	Drying Rate gm. H <sub>2</sub> O/gm solid per hr. per sq. cm.	Moisture Content gm. H <sub>2</sub> O/gm solid	Drying Rate gm. H <sub>2</sub> O/gm solid per hr. per sq. cm.
1.1	0.000343	1.1	0.000324
1.0	0.000318	1.0	0.000302
0.9	0.000302	0.9	0.000294
0.8	0.000278	0.8	0.000265
0.7	0.000248	0.7	0.000245
0.6	0.000203	0.6	0.000196
0.55	0.000160	0.5	0.000153

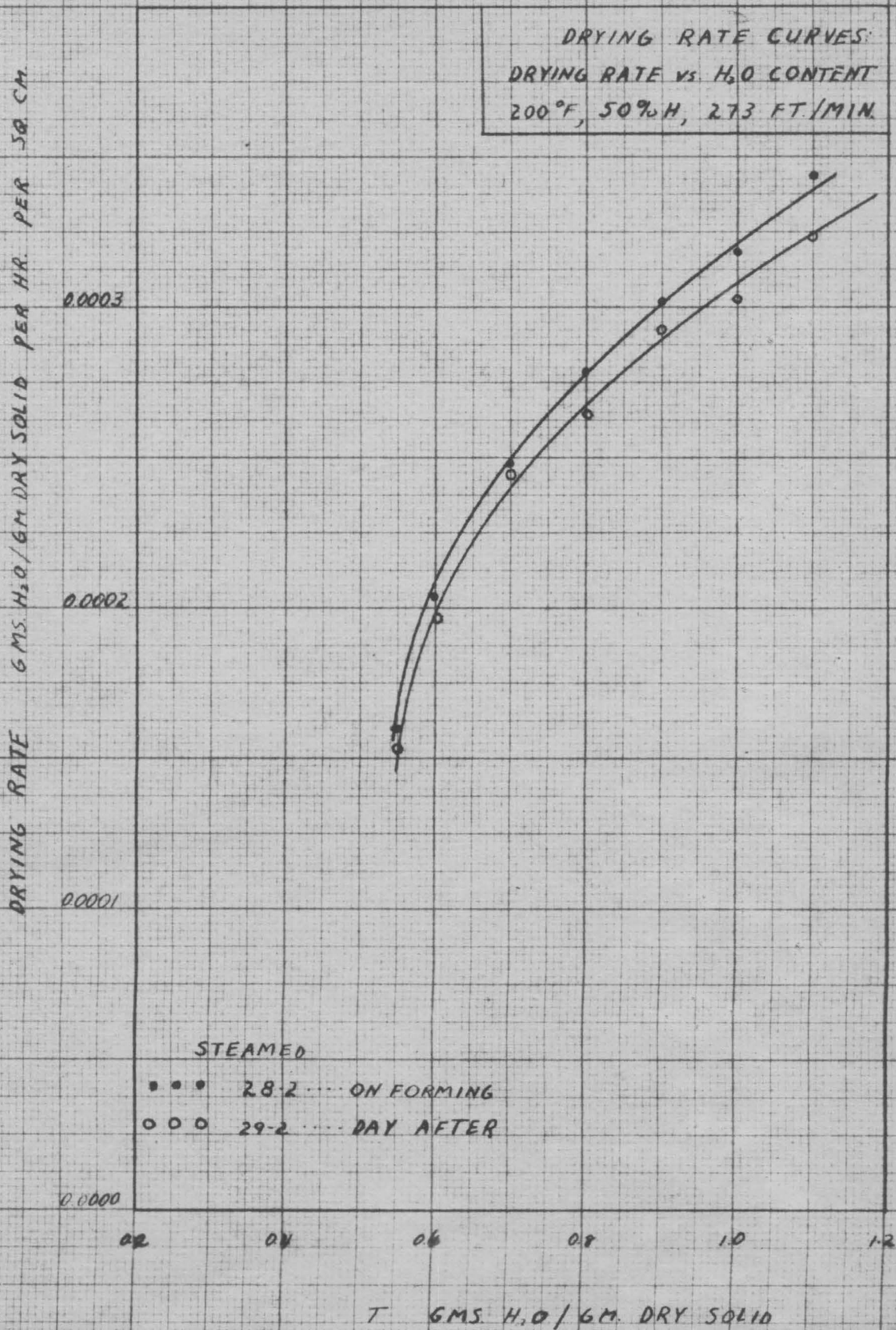
GRAPH 10

DRYING CURVES:  
 H<sub>2</sub>O CONTENT vs.  
 TIME  
 200°F, 50% H,  
 273 FT./MIN AIR  
 VELOCITY



STEAMED:  
 28-2 ON FORMING  
 29-2 DAY AFTER

GRAPH II



## IV DISCUSSION

Mixing. By the experiments carried on from runs 1 to 12, it was found that in order to best incorporate the powders into the viscose the lime and gypsum were mixed first. Five minutes was then found to be sufficient time to incorporate these powders into the viscose, the powders being added to the viscose. At the end of this period, the powdered aluminum was added for an additional three minutes of mixing time. This procedure afforded sufficient time to incorporate the powders into the viscose and permit the forming of the specimens by casting before any appreciable reaction between the aluminum and the alkali of the viscose solution occurred.

Drying Difficulties. The colloidal nature of the mix offers the major difficulty to drying. The specimens shrink considerably during the drying operation, averaging about 12 per cent as seen in Table 2. Should the rate of drying be different at different surfaces of the solid, then the shrinkage would not be uniform and strains are set up in the specimen. If the tension produced by unequal shrinkage is great enough, the specimens would then warp or crack or do both.

In order to produce as far as possible, uniform drying, the specimens were removed from the pans in which they were formed and dried from six surfaces. Also, for specimens of small height, such as the one inch high, as an average, specimens prepared during the course of the investigation, the edge and corner effects play an important part in the drying operation.

Excessive drying occurs at these points producing excessive shrinkage there. The tension thus set up will effect warping and cracking if great enough.

The problem therefore was to determine conditions such that drying should occur as uniformly as possible from all surfaces and also to determine conditions such that edge and corner drying will not cause cracking.

Skin Effects. Immediately after forming, a thin wash of liquid rose to the top of the specimen which hardened in a very short while. The case hardened surface offered considerable resistance to the passage of moisture which had diffused from the interior of the solid to the surface out into the main air stream. As a result drying occurred at a greater rate from the sides and the bottoms of the specimens which in turn caused excessive shrinkage at these points. The tension set up by this unequal shrinkage caused the specimens to warp towards its bottom surface due to insufficient rigidity of structure. The phenomenon of skin formation was noted as early as the first run, when an examination of the structure showed small pores at the top surface while larger ones existed at the center and the bottom of the specimens. Runs 2 and 3 showed the tendencies of the specimens to warp towards its bottom surface, considerable cracking occurring because at that time no grease was being used to lubricate the sides of the forming apparatus and thus permit free shrinkage of the specimens. Also in several instances, cracking occurred because the pans were filled to the brim and overflowed when the specimens began to rise. Later runs used high sided pans and were well greased. Run 4 was the first of these runs. All specimens which

permitted a skin formation caused warping or cracking to occur.

Skin Elimination. In Run 8 a sheet of galvanized metal was used being applied to the specimen's top surface after formation. As noted in the experimental section the phenomenon of double warping occurred upon application of this top plate. That is the specimens warped in two directions. Also trapped gas pockets were evident on the specimen's top surface. The skin formation had, however, been eliminated by the use of this sheet metal plate.

Runs 8 through 19 show that the optimum conditions for the application of this top plate, so as to produce a minimum of trapped gas pockets and to prevent a skin formation, was to apply the plate within five minutes after the formation of the specimens. This permits time for the escape <sup>which</sup> of gas evolves in the reaction and prevents a skin formation. The plate must be applied slowly and carefully so as not to trap any air underneath it.

Despite the skin formation elimination, the specimens still warped. This was caused by the insufficient rigidity of the specimen's structure which permitted warping to occur as a result of excessive edge and corner drying. The problem remained, at this point, one of determining a method of setting the structure of the specimen so that it would not warp.

Effect of Steam Treatment on Setting. One method of setting the structure of the specimens was to give them a live steam treatment either after forming or 16 hours after forming. Although the setting by steam 16 hours after forming was carried out throughout this work, it

is not recommended. Since time can be substituted for temperature, an initial setting action occurs while standing overnight before actual steam treatment and then when actually applying the steam treatment the specimen blows up and warps considerably. Specimen 29-1, whose picture is shown in the experimental section (Figure 11), is illustrative of this type of action. The specimens steamed the same day gave flat surfaces and had good structure. The time of steaming was found to be 1.5 hours, too long a treatment giving poor specimens with poor surfaces.

Runs such as the 11-2 series proved that it was essential to use a top plate within five minutes after forming even when steaming. If this is not adhered to, the specimens form a skin and then warp in the steam chest.

Runs 20 and 21 showed that it was not necessary to cool down the specimens slowly after the steaming treatment, both slow and rapid cooling for specimens steamed on forming giving good, flat products, while those steamed the following day gave poor, warped products on both slow cooling on both slow cooling and rapid cooling.

Effect of Dry Heat Treatment on Setting. The method of setting the structure of the product by jelling the viscose binder with a thermal treatment at 150°F. was also found to be suitable. This operation permits some drying to occur during the treating period and necessitates the use of the top plate to prevent skin formation and excessive drying which would cause cracking and warping.

Runs 22, 26, 27, 31, 34, and 35 involved the dry heat treatment. Run 22 attempted the treatment at 220°F, Runs 26 and 27 at 175°F. , both attempting the treatment the same day and after setting in air overnight.

The high temperature caused considerable drying at the exposed edges of the specimens and caused them to crack wide open. Runs 31, 34 and 35 attempted the treatment at 150°F. and this proved to be satisfactory, setting the structure without causing warping or cracking to occur. The length of treatment is 1.5 hours.

Effect of Air Ageing on Setting. Upon attempting to substitute time for temperature and cause the setting action to occur by merely permitting the specimens to stand at room conditions for several days, unsatisfactory results were obtained. Run 6, attempting complete air drying proved unsuccessful; series 1 because it was formed without a top plate and a skin formation caused warping, and series 2 because of a similar skin formation plus excessive steaming time. Series 2 had been steamed overnight and the structure of the specimens was impaired by the leaching action of the condensing steam in the steam chest.

In Runs 14 and 15 a three day setting period and in Run 23 a six day setting period, prior to actual drying a Proctor-Schwartz tray drier, proved unsuccessful. The three day period was not long enough to set the structure of the specimens firmly, while the six day period did. However, the six day period did not make the structure sufficiently rigid to overcome the effects of edge and corner drying and they warped and cracked upon drying.

Effect of Trimming on Drying. It was found advisable to trim the specimens before actual drying. During the steaming operation and the dry heat treatment, the edges become case hardened and would produce

difficulties in drying. The top plate exposes about 0.25 inches on each side. It was made thus to prevent it from catching at the corner and being trapped there while the specimens are in the process of rising due to the evolution of gas.

Surface Evaporation. The rate of drying curves with the rate of drying plotted against the moisture content show that the resistance to surface evaporation is the controlling factor in drying. That is the resistance to diffusion of the liquid from the interior of the solid to the surface is negligible in comparison to the resistance to surface evaporation. This is logical when the structure of the specimen is noted. For practically every specimen noted, the porosity was greater in the interior of the solid than at the surfaces. Also on examining the surface structures, it is noted that the skin formation is common to all of the surfaces. The six sheet metal contact surfaces in the forming, produces the same surface on all sides permitting as uniform drying as possible, all the surfaces having the same skin formation.

Edge and Corner Effects. The actual controlling factor in determining the optimum conditions of drying is the edge and corner drying phenomenon. Excessive drying occurs at these points, and in turn causing excessive shrinkage and then cracking at the edges. Conditions were sought so that the drying would proceed from as rapid a rate as possible and yet not causing cracking of the edges to occur. For the steamed specimens, drying must be carried out as an air drying operation in order to insure production of specimens which do not crack. Once steamed the specimens do not warp in drying. Drying at higher temperatures

causes excessive edge and corner drying in comparison to the drying from the center of the specimens and thus causing cracking. Dry heat treated specimens can best be handled by air drying or drying at 150°F. and 50 per cent humidity without causing cracking.

Drying of Steamed and Dry Heated Specimens. Dry heat treated specimens dry at a higher rate than the steamed specimens as evidenced by the air dried specimens and also specimen 34-2 as compared 32-2. This is probably caused by the difference in treatment. The dry heat treated specimens evidently have a lower resistance to surface evaporation than the steamed specimens and dry at a more rapid rate. Also because of its ability to resist cracking at 150°F. it may be assumed that the difference between the rate of drying at the edges and corners as compared to that from the center of the specimens is less for the dry heat treated specimens than for the steamed ones. Another possibility is that the denser structure of the dry heat treated specimens makes it more resistant to cracking.

Effect of Time of Setting. Specimens treated the same day dry at a faster rate than those treated the day after. The air dried specimens and the ones dried at 200°F. show this effect. The tendency decreases when drying at higher temperatures. This difference in the rates of drying depending upon the time of treatment may be explained as follows. Upon standing overnight, the surfaces may tend to harden in the partial time setting which is always proceeding, and then during the actual thermal treatment a different surface is exposed than were the specimens treated immediately after forming. As a result the resistance to surface evaporation

is greater and the rate of drying lower for specimens whose structure is by the treatment the day after its formation than if it were treated immediately after forming.

Effect of Air Velocity. At a higher air velocity, the drying rate is considerably higher than at the low air velocity. Specimens 24-1 and 24-2 show this clearly. The effect of air velocity appears to be greater than that of temperature. Specimens 24-1 dried at a high air velocity has the highest drying rate of all of the specimens. While being dried at 175°F. and 50 per cent humidity, it has a higher rate of drying than the specimens dried at 200°F. and 50 per cent humidity.

Effect of Temperature. Air drying, of course, shows the lowest rate of drying. Little difference in drying rate is seen by drying at 150, 175 or 200 degrees F. all at 50 per cent humidity. What does occur, however, is a steeper curve; a more rapid fall in the drying rate occurring as the run progresses as the temperature of the drying process increases. This may be explained as follows. At the higher temperature, the surfaces of the specimens are effected so that contraction and shrinkage occurs increasing the resistance to surface evaporation progressively, more so than at the lower temperatures. This explains the greater drop in the drying rate curves for specimens dried at the higher temperatures, as the run proceeds. Why the rates do not differ appreciably is due very likely to the change in the surface evaporation resistance with the temperature. If this rises appreciably with the temperature, it is very possible that the drying rate will not be changed very much by a rising temperature.

## Physical Properties.

General Properties. Graph 1 shows that the density of the specimens when increasing, causes the modulus of rupture, the crushing strength, and the thermal conductivity to increase. The insulating value decreases because a denser product, while stronger, traps less air. The skin effect makes the specimens considerably stronger as shown by the tests made on specimen 32-1.

Structure. Different structures are obtained depending upon the treatment of the specimens. Figures 14, 15 and 16 show various structures. The specimens have a uniform structure with each pore being segregated and independent of the others. It takes a nail cleanly without cracking. Steamed specimens, because of the higher temperature treatment have a greater porosity than the dry heat treated ones. Concurrently, the steamed specimens have a lower strength and thermal conductivity than dry heat treated ones.

## Recommendations.

Among the recommendations for future work are the following:

1. Investigate different compositions of ingredients.
2. Use other metallic agents for gas evolution.
3. Use inhibitor like Turkey Red or castor oil to coat aluminum and prevent rapid reaction
4. Use fiber fillers to increase the strength
5. Further drying investigation, varying the humidities.
6. Preparation of various sizes and shapes of specimens.

### Limitations.

The limitations in this investigation were the following:

1. Use of only one composition.
2. Use of only one mixer, the Werner-~~and~~<sup>Pfleiderer</sup> kneader type mixer.
3. Size of equipment permitted the manufacture of 0.5 inch high specimens only.

## V. CONCLUSIONS.

1. The best method of mixing is to add a dry mix of lime and gypsum to the viscose for five minutes. After this time add the aluminum for an additional three minutes of mixing time.
2. The best type of mixer is a Werner-Pfleiderer ~~Rfixudax~~ sigma-bladed kneader type mixer.
3. The specimens are best formed by casting, to be carried out immediately after the mixing time of eight minutes is over.
4. The pans used for the forming must be greased to permit the free shrinkage of the specimens.
5. A galvanized sheet metal plate, also greases, must be applied to the top surface of the specimens within five minutes after their formation to prevent warping.
6. The structure of the specimens may be set by a live steam treatment for 1.5 hours 2 hours after their formation.
7. The structure may also be set by a dry heat treatment at 150°F. for 1.5 hours, 2 or 16 hours after its formation.
8. The dry heat treated specimens are best air dried or dried at 150°F., 50 per cent humidity, and 273 feet per minute air velocity.
9. The steamed specimens are best air dried at room conditions of temperature and humidity.
10. The specimens must be trimmed before drying to remove dried edges and then dried from all six surfaces.
11. Steamed specimens have a lower density, strength and thermal conductivity than the dry heat treated ones.

## VI. SUMMARY.

Scherer Insulation is composed of 100 parts by weight of viscose, 30 lime, 24 gypsum and 0.2 aluminum. It was proposed to dry this product so that it would not warp or crack.

The colloidal nature of the mix offers the major difficulty in drying. The product shrinks considerably upon drying with unequal shrinkages causing cracking and warping. Also upon casting, a skin formation occurs which is resistant to the passage of moisture into the main air stream. Another factor involves the edge and corner drying effects. Excessive drying at these points causes cracking to occur.

In order to produce as uniform a rate of drying as possible, the specimens were dried from all six surfaces in the Proctor & Sewartz tray drier or air dried. To prevent the skin formation, a sheet of galvanized sheet metal was applied to the top surface of the specimens within five minutes after its formation. To contend with the edge and corner effects, the specimens were set either by a steam treatment for 1.5 hours, 2 hours after its formation, or given a dry heat treatment at 150°F. for 1.5 hours either 2 or 16 hours after its formation. Time setting proved unsatisfactory. This setting treatment must be carried out with the top plate on and as a result of exposure of edges, the specimens must be trimmed before drying.

Suitable drying conditions involved air drying of steamed specimens and either air drying or drying at 150°F., 50 per cent humidity and 273 feet per minute air velocity for the dry heat treated specimens. This is

limited to these conditions because of edge and corner effects.

Steamed specimens have a lower thermal conductivity, strength and density than the dry heat treated specimens.

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