

THE DETERMINATION OF RELATIVE HUMIDITY OVER WHEAT  
AND MILL STOCKS

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## TABLE OF CONTENTS

INTRODUCTION . . . . .	3
Importance of Controlled Humidity in the Flour	
Milling Process . . . . .	3
Definitions of Terms . . . . .	4
Causes for Variation in Relative Humidity . . . . .	5
Effects of Variation in Humidity and Methods	
of Humidity Control . . . . .	6
Application of Controlled Humidity to Other	
Industries . . . . .	6
REVIEW OF LITERATURE. . . . .	7
THEORY . . . . .	16
Discussion . . . . .	16
APPLICATION OF THEORY . . . . .	20
Application to Wheat Tempering . . . . .	23
EXPERIMENTAL WORK . . . . .	28
Description of Instruments . . . . .	28
Set Up of Apparatus and Development of a	
Method for Measuring the Aqueous Vapor Pressure	
Over Wheat . . . . .	31
Some Factors Which Influence the Aqueous Vapor	
Pressure Over Wheat . . . . .	45
The Influence of Moisture Content and Tempering	
Time on Relative Humidity . . . . .	48
Effects of Temperature on the Rate of	
Absorption . . . . .	49
The Effect of Scouring on the Rate of	
Absorption . . . . .	50
The Equilibrium Relative Humidities Which	
Exist Over Mill Stocks . . . . .	51
Effect of Temperature on Relative Humidity . . . . .	54
Comparison of Results from the Crova Hygrometer	
and the Working-Anderson Apparatus . . . . .	57
A Comparison of the Relative Humidities Obtained	
from the Crova Hygrometer and the Sling	
Psychrometer . . . . .	58
SUMMARY AND CONCLUSIONS . . . . .	60
ACKNOWLEDGMENTS . . . . .	62
LITERATURE CITED . . . . .	64

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## INTRODUCTION

### Importance of Controlled Humidity in the Flour Milling Process

Controlled humidity in flour milling may prevent the excessive changes in the moisture content of the grain and mill stocks which ordinarily take place under natural conditions of humidity.

During the harvest months the existing relative humidity on dry days may be as low as 20 per cent, while during a rain the relative humidity approaches saturation. The results are a rapid evaporation at the low humidity and likewise a rapid absorption of moisture at the high humidity. The drier atmospheric conditions are much more prevalent for this region, while a more even and a higher humidity may exist nearer the coast. Sudden changes of temperature also create wide variations in the degree of relative humidity.

Rapid loss of moisture from tempered wheat produces a brittle bran much the same as existed before moisture was added. This lowers the efficiency of the milling process resulting in a poorer grade of flour with less desirable color and higher ash.

High humidity, while less prevalent, causes condensation in the cooler spouts of the mill. It also

necessitates resetting of the different machines as far as it is possible to make adjustments. By equalizing the conditions of relative humidity, a more uniform process is maintained and a more uniform product is produced. Controlled humidity when properly maintained should improve the color and ash content of the flour. Also a more uniform and desired moisture content of the products should be obtained. It is also possible that maintaining the optimum condition of the bran and the endosperm for milling will increase the yield of flour.

#### Derinitions or Terms

The important terms used in this paper have the following meanings:

Absolute humidity or simply humidity- The amount of aqueous vapor in a given volume expressed as grains per cubic foot.

Relative humidity- The degree of saturation of the aqueous vapor expressed in per cent.

Equilibrium humidity- The relative humidity that is maintained when the moisture in a given material has reached equilibrium with the moisture in the surrounding atmosphere.

Dew point- The temperature at which the aqueous vapor is saturated. Below this temperature condensation occurs.

Vapor- An element or compound in a gaseous state which exists below the boiling point and which may be condensed under ordinary conditions of temperature.

Vapor pressure- The pressure exerted by a vapor.

Vapor tension - Same as vapor pressure.

Saturated vapor - A vapor which contains the maximum amount of vapor per unit volume and if cooled condensation immediately occurs.

Unsaturated vapor - A vapor which is of such condition that more vapor of the same kind may be introduced into the volume occupied without condensation taking place.

Absorption - The taking up of a liquid by a solid which holds the liquid with the weaker forces which may be overcome by heating to near the boiling point of the liquid.

Adsorption - The tendency of gaseous or liquid particles to condense upon the surface of a solid on which the gas or liquid is held with forces which may be great enough to ionize the deposited substance.

Imbibition - The entrance of water into a solid with the subsequent swelling and gel formation.

#### Causes for Variation in Relative Humidity

Causes of variation in relative humidity may be classed as climatic and environmental. Climatic conditions

which influence relative humidity are temperature and air currents. Environmental conditions include the relation of bodies of land and water such as lakes, inland seas, and coastal regions. Water bodies equalize conditions while the wider variations are found in far inland regions as in Kansas and the surrounding states.

#### Effects of Variation in Humidity and Methods of Humidity Control

Varying conditions of humidity produce varying rates of evaporation. Humidity may be controlled by several means. One method of control is through the control of the moisture content of the material. Another method is the use of humidifiers such as the Carrier air conditioner or by blowers which produce mists for adding moisture to the air. Steam may also be used. An aid in maintaining humidity in the mill is the return of as much air as possible from the dust collectors after it is freed of dust.

#### Application of Controlled Humidity to Other Industries

Air conditioning or controlled humidity has made possible the manufacture of textiles in the South near the source of raw material. Not less important is controlled humidity in ceramics, tobacco curing and paper making.

It is as applicable to flour milling. It has not been applied to flour milling to the same extent as to textile manufacturing because it is possible to mill flour without controlled humidity. The milling process is a somewhat closed system which builds up its own humidity under normal conditions. In many cases however the benefits from tempering and conditioning of the grain are to a large degree undone by the unsuitable conditions of humidity.

#### REVIEW OF LITERATURE

Carrier (1911, 1918, 1921) states the following principles:

When unsaturated air comes in contact with water three changes take place.

1. The temperature of the vapor is reduced to a definite temperature known as the wet bulb temperature.
2. A definite amount of water is evaporated increasing the amount of water vapor and the vapor pressure.
3. The air is cooled as the latent heat of evaporation is taken from the air as the only source of heat.

Water vapor has a definite weight and volume relation at a definite temperature, has a definite vapor pressure, and obeys the gas laws with reference to temperature, vapor pressure and density. The combined pressure is equal to the total or atmospheric pressure. The total weight of

pure air in a cubic foot of a mixture of air and water vapor is less than the weight contained in a cubic foot of dry air.

Evaporation is increased by increased air velocity but the increase in the rate of evaporation is not so great as the increase in velocity of the air. In air traveling 4000 ft. per min. the rate of evaporation is only 3.5 times as great as in air traveling 1000 ft. per minute.

All evaporation is due to the difference of the vapor pressure of the moisture in the material corresponding to its temperature and the vapor pressure of the moisture in the surrounding atmosphere, corresponding to the dew point.

In still air and at constant velocities the rate of evaporation from a water surface is proportional to the above stated difference regardless of temperature.

Rate of evaporation in addition to the two conditions of vapor, is influenced by air velocity and the physical and chemical nature of the material.

The three general mechanisms of drying are according to Sherwood (1929):

1. Evaporation of the liquid at the solid surface: resistance to the internal diffusion of the liquid, small as compared to the resistance of removal of vapor from the surface.



2. Evaporation at the solid surface: resistance to the internal diffusion of liquid, great as compared with the resistance to the removal of vapor from the surface.

3. Evaporation in the interior of the solid: resistance to internal diffusion of the liquid, great as compared to the total resistance to the removal of vapor.

Under constant drying conditions all very wet solids show a constant rate of drying over a definite period. This condition exists until the amount of liquid is reduced to the critical liquid content. The first period is called the constant rate period of evaporation. The period of drying following is called the variable rate period. If the liquid content is below the critical liquid content, no constant drying rate appears. Unless the air is absolutely dry, the solid will retain some moisture.

Adjoining dry surfaces may affect evaporation by giving off heat to furnish energy for evaporation. Rate of drying does not decrease in proportion to decrease in surface area due to covering with an impervious membrane.

In the first zone the rate of diffusion of the liquid is equal to the diffusion of vapor from the surface. The falling rate zone deals with or is controlled by the rate of diffusion of water to the surface of the solid. When this rate of diffusion is less than the possible rate of vapor removal, internal liquid diffusion controls the rate of drying.

When drying takes place with internal liquid diffusion controlling, the plane of evaporation tends to recede or move into the solid so that vapor removal is impeded until the rate of diffusion is again equal to the rate of vapor removal.

The third zone of drying is due to the insulating action of the dry outside layer against heat.

Macleod (1925) states that at a given temperature some molecules move at a faster rate and are able to escape from the liquid. This determines the numerical values for the various factors. There is no definite minimum velocity of the molecules at the critical temperature.

The work done in expansion is:

$$P(V - v)$$

When  $V$  is the volume of vapor,  $v$  is the volume of liquid, and  $P$  the pressure. Near the critical temperature  $V$  becomes comparable to  $v$ , and  $PV$  equals  $RT$ . The external work is proportional to the absolute temperature.

The total kinetic energy of 1 gm. of escaping molecules minus the total kinetic energy of 1 gm. of liquid is equal to the latent heat of vaporization.

According to Hederstrandt (1924) rate of evaporation of water is only slightly affected by a thin (one or two molecules thick) surface of oil. The rate of evaporation is not affected by a change in surface tension.

Greene (1923) proves that for non associated liquids, the ratio of the boiling point to the critical temperature is a constant (0.66). The heat of vaporization is a function of the temperature which is the same function for all non associated liquids but differs in the values of constants.

Boswell and Dilworth (1928) show that  $\text{Al}_2\text{O}_3$  containing 4.0 per cent moisture has each particle completely enveloped in a covering of alternating  $\text{H}^+$  and  $\text{OH}^-$  ions. The water at the surface is completely dissociated and exists as charged particles. It is also very firmly held, being able to pull  $\text{H}^+$  and  $\text{OH}^-$  ions out of the ethyl alcohol molecule.

The stability of the film indicates that these particles are several layers thick, and removed with increasing difficulty as the temperature is raised and the outer layers removed as free water. That is, as water molecules through union of  $\text{H}^+$  and  $\text{OH}^-$  ions.

Experiments by Nelson and Hulitt (1925) indicate that the critical decomposition temperature for cereals is about  $190^\circ\text{C}$ . When heated for four hours under high vacuum, the maximum moisture content is obtained with only slight decomposition.

Gortner (1923) believes that proteins may exist in colloidal solution and still be in the colloidal state due to the fact that the water of imbibition swells the protein molecule so as to bring it well within the limits of size which determine the colloidal realm, and that such bound water must be differentiated from free water.

Two different plant tissues may contain exactly the same amount of dry matter and have entirely different physiological processes going on. Enzyme actions are equilibria. Emulsin hydrolyzes glucosides in dilute solutions and synthesizes them in concentrated solutions. The direction of enzyme action is regulated by the ratio of bound water to free water.

Something of the ratio of combined and free water may be learned from freezing point determinations. (The method could possibly be modified to suit the study of water in grains).

Bailey (1918) states that respiration rate in wheat increases sharply above 14.5 per cent moisture. Moisture in grain may be assumed to exist as imbibed water in loose combination with the organic colloids. The organic colloids which form the principal constituents of the wheat kernel have the property of imbibing considerable water and forming elastic gels. The gel swells as the water is increased although the total volume of the dry colloid plus

the added volume of water is diminished. The water imbibing capacity of the colloids differs widely, that of starch being much lower than the water imbibing power of wheat gluten. There is no fixed amount which a dry colloid will imbibe. Thus gels of varying viscosity can be produced, depending upon the proportion of water present, temperature, mineral salts, and other substances.

The rate of diffusion in a gel varies with viscosity. In dilute gels diffusion takes place as in water, while in concentrated gels the rate is slower.

In dry grain the imbibed water is not sufficient to produce a gel in the endosperm structure. The colloidal matter does not have a continuous structure. The possibilities for diffusion are decidedly reduced. The exact percentage of moisture is not known below which the structure becomes discontinuous. It probably varies with the percentage of gluten in the wheat since gluten possesses a greater water imbibing capacity than starch. Increasing the moisture content above the maximum at which discontinuity exists results in the formation of a gel through which diffusion can occur. Further increase in moisture content up to maximum imbibition produces progressively less viscous gels and correspondingly increases the rate of diffusion. Since respiration doubtless depends upon the rate of diffusion, it follows that the less viscous

the gel, the more rapid will be the production of heat through respiration.

Gortner (1929) states that the time factor affects all colloidal systems but particularly gels. Micelles may aggregate into larger units. Crystal growth may be a factor and the larger particles grow at the expense of the smaller ones due to unequal distribution of surface energy forces. Imbibition capacity decreases with age in bio colloids. The constituents of the living organism are:

1. Proteins
2. Carbohydrates
3. Fats and lipoids
4. Inorganic salts
5. Water

The proteins belong to the class of lyophylic colloids. They possess the power of becoming strongly hydrated. The large amount of water present in living organisms is probably held mainly through the affinity of proteins for water.

Thoenes (1925) presents the following technic for differentiating between free and bound water. Hypothesis was made to show that bound water would not freeze at  $-20^{\circ}\text{C}$ . The samples were cooled to  $-20^{\circ}\text{C}$ . for several hours and the amount of water crystallized as ice was determined calorimetrically by observing the amount of heat

necessary to thaw the ice and bring the temperature to equilibrium.

The mathematical calculation is as follows:

$$X = \frac{C(T-T) - as (T_1 + T_0)}{80 - \frac{T}{2}}$$

X = the quantity of water crystallized as ice.

T<sub>0</sub> = the temperature of the gel when placed in the calorimeter.

T<sub>1</sub> = the equilibrium temperature of the water in the calorimeter.

T = the initial temperature of the water in the calorimeter.

a = the weight of the gel.

s = the specific heat of the gel.

C = the constant of the calorimeter system.

The moisture content of the sample minus X equals the amount of water not frozen or the bound water.

Newton (1922) has shown that wheat leaves which are acclimated to cold weather have less dry matter than those gathered before cold weather. After freezing for several hours, very little sap can be extracted under four hundred atmospheres of pressure. Sap was extracted under less pressure before cold hardening.

McClatchie and McBain (1932) state the following facts: An attraction between the solvent and the super molecule is necessary before a gel will form. Polarization or else

adsorption takes place.

Two reasons for the swelling of a gel are:

1. Penetration of the solvent between molecules to relieve tension.
2. Swelling due to physical structure, that is, attraction of water for itself.

When the temperature is raised:

1. Attraction of solid for water increases.
2. Attraction of solid for solid decreases.

## THEORY

### Discussion

The factors influencing evaporation are:

1. Temperature
2. Duration of exposure to the atmosphere.
3. Moisture content of the material
4. Moisture content of the atmosphere
5. Physical nature of the material
6. Chemical nature of the material

Basically temperature affects kinetic energy.

Molecular activity is directly proportional to the absolute temperature.

In order to maintain a constant relative humidity or degree of saturation over a range of temperature it is



necessary to raise or lower the density of the aqueous vapor with the increase or decrease of temperature.

If from a moist solid evaporation occurs in an atmosphere of constant humidity, the process continues at a decreasing rate with time and decreases the moisture content of the material. The rate is much more affected in still air than in moving air. The rate of air flow also affects evaporation as shown by Carrier (1911). These conditions are governed by the rate at which moisture can disperse from the interior to the surface of the material. The system approaches equilibrium in still air by increasing the moisture content of the air and approaches equilibrium in flowing air by removing moisture from the solid. Even in dry air some moisture may remain in the material unless the temperature is far above the boiling point of water, that is,  $190^{\circ}\text{C}$ . (Nelson and Hulett 1920). The water may be held with such force that only  $\text{H}^+$  and  $\text{OH}^-$  ions are present. These ions when driven off reunite to form water.

Moisture content of the material affects the rate of evaporation. The rate of evaporation of moisture from the material being dried should indicate something of the way in which the water is held.

Evaporation rate is affected by the humidity of the surrounding atmosphere. Normal humidities vary from a very low degree of saturation to saturated aqueous vapor. For different localities there are prevailing conditions of humidity and corresponding moisture contents of grain and similar materials. The condition which we term relative humidity is that of unsaturated water vapor. This is little affected by the presence of air. The vapor independently exerts its own pressure, but disperses at a slower rate when mixed with air.

Physical characteristics of the material affect evaporation by influencing the rate of escape or dispersion of water molecules from the material. Size of particle, density or hardness, all influence the ability of water molecules to move through the material. The organization of a living body such as a kernel of grain probably affects its water holding power. Once this living organization is destroyed, its ability to hold moisture may be decreased. If such a condition exists, grain which has been ground should show a more rapid evaporation rate. This is in addition to an increase in the specific surface from which absorbed water may disperse into the surrounding atmosphere. When the size of the particles has been decreased to such an extent that the specific surface is great, forces of adsorption may increase to such an extent that the dis-

persion of water particles is decreased.

The chemical nature of the material exerts a very decided effect upon evaporation. The affinity of the material for water varies widely among gluten, starch, and inorganic materials. The nature of the colloidal system may greatly increase or diminish the amount of water which can be held. Water may be the continuous or discontinuous phase. It may be held by forces so great that the hydrogen and hydroxyl ions are separated, uniting and escaping as water only after sufficient energy has been supplied to pull away the ions.

Osmotic pressure may also affect the water holding power. Imbibitional forces are active to some extent at high moisture contents. The protein present in wheat is highly lyophilic, while starch has less affinity for water. The enzyme activity may synthesize or decompose certain compounds with the taking up or liberation of water as the case may be depending upon concentration, moisture content, and temperature. There may be conditions under which the enzymes will cause larger amounts of water to be held with greater force, or even combine water chemically. This process is probably very slow at fifteen per cent moisture if such a condition exists. The reversible reaction may be represented as follows:



### APPLICATION OF THEORY

Vapors form because of the ability of molecules to escape from the mother substance, whether the substance be in the form of a solid or liquid, or held by some other material. Vapor pressure is due to kinetic molecular energy. Collectively speaking all molecules have the same kinetic energy at the same temperature. But for very short periods of time, one molecule may be given greater kinetic energy by elastic impact through the loss of energy from one or more other molecules. If this occurs in the interior far from the surface, no molecules will escape. The excess energy will be dispersed among other molecules through impact and energy again equalized. But if one molecule is given additional energy near to and directed toward the surface, it may overcome the forces of surface tension and escape into the atmosphere. Being far out of the realm of forces of attraction, no great forces are acting upon it to cause its return. The space between molecules even in solids and liquids is great as compared to the size of the molecule. In the vapor state the molecules are still more widely separated. In a vapor there are fewer collisions of molecules with each other. The molecules continue to escape until the density of the vapor is such that the number of molecules in the gaseous phase causes as many

molecules to return to the surface of the solid as are escaping from it. At this point equilibrium exists though the interchange of molecules continues.

At this point a definite pressure is exerted. If the vapor is in equilibrium with a free water surface, the aqueous vapor is said to be saturated. When the water is absorbed in a solid equilibrium will be established but at a lower vapor density. The vapor pressure at the lower vapor density or dew point temperature divided by the pressure at the saturated vapor density for the existing temperature of the vapor represents the relative humidity or the degree of saturation.

Kinetic energy is directly proportional to absolute temperature. If the temperature increases, the kinetic energy increases and produces greater molecular movement. The water held in the material and the water vapor will receive equal increases in energy when at the same temperature. If the water holding forces of the desiccant remains proportional to the tendency of water molecules to escape, the vapor density will increase but the degree of saturation or relative humidity will remain constant. That is, if the desiccant holds back a definite fraction of the molecules which would escape from a free water surface, a definite part will escape. Let  $K$  represent this fraction which escapes. Let  $P_1$  represent the pressure of the vapor at

temperature  $T_1$ , and  $P_2$  the pressure of the vapor at  $T_2$ , a higher temperature.

The relative humidity at temperature  $T_1$  is  $\frac{KP_1}{P_1}$

The relative humidity at temperature  $T_2$  is  $\frac{KP_2}{P_2}$

Considering  $K$  as a constant,  $\frac{P_1}{P_1}$  equals 1.

$\frac{P_2}{P_2}$  equals 1.

$K$  equals  $K$

$\frac{KP_1}{P_1}$  equals  $\frac{KP_2}{P_2}$

When equilibrium is reached the vapor pressure of the water in the material is equal to the vapor pressure of the water in the vapor state in the surrounding atmosphere. If the material is surrounded by an atmosphere of water vapor which exerts a pressure equal to that of the water in the material, no evaporation can occur.

Velocity of water particles cannot affect a loss of moisture, for while water may leave the material, an equal amount of water molecules moving with an equal velocity will return to the material. The vapor may continually change, but there is a constant supply of the vapor exerting its pressure to maintain the equilibrium. Change

of temperature can affect the desiccating power of the water holding solid to produce a change of equilibrium since equal amounts of energy will be radiated to the water existing in the two different states. However if evaporation is occurring, the material will exist at a temperature lower than that of the air and corresponding to the wet bulb temperature of the air. (Carrier 1918) If the aqueous vapor pressure of the atmosphere is less than the vapor pressure of the water in the material, evaporation will occur. If the aqueous vapor pressure of the atmosphere is greater than the vapor pressure of the water in the material, the material will absorb moisture. If the desiccating power of the material remains constant, a constant relative humidity will be maintained in the atmosphere by the water in the material over a range of temperature. This will prevent evaporation, keep the rate of evaporation constant, or add moisture to the material depending upon the ratio of the vapor pressures of the water in the vapor state to the water in the material.

#### Application to Wheat Tempering

The common practice in the milling of wheat is to temper the grain with sufficient water and allow time for the kernel to acquire the proper consistency for the most efficient separation of the bran from the endosperm.

Primarily this process toughens the bran and improves the friability of the endosperm. No consideration has been made of the fact that possibly to acquire the best separation of the bran requires a moisture content of the whole kernel sufficient to too greatly soften the endosperm. There is the possibility of conditioning to some extent the endosperm during the milling process after it has been separated from the bran by causing it to give up moisture to the air. The bran may be kept in a tougher state by maintaining its original moisture content, or by increasing its moisture content after the kernel is broken open. These conditions can be maintained in practice if the required relative humidity over the various streams is not above practical limits.

The following are some conditions which vapor pressure measurements may aid in identifying:

The magnitude of the force with which the grain holds its moisture is probably very greatly influenced by the condition of the water in the kernel. Water may be held as free water or as bound water. Free water exists in the spaces between the particles as water is held by a sponge, being easily forced out or removed by dispersion from the surface.

Bound water is held by the much stronger forces of adsorption, imbibition, electrical attraction or chemical



combination. Adsorption and electrical attraction are probably most closely related. Adsorption is selective or specific. (Getman 1928.) This may be due to the nature of the charge carried by the adsorbent and the adsorbed material. The amount of the adsorbed material might also be influenced by the number of stray valences existing on the adsorbent. In the latter case a greater concentration of the adsorbed material would occur at the surface while in the former case, alternate layers of positive and negative charges would probably form until the forces of attraction and dispersion are in equilibrium.

Adsorption is directly proportional to the specific surface. (Getman 1928.) As the separation of individual particles progresses in the milling process, the specific surface is increased. From this it appears that if the conditions are such that the material will absorb moisture from the atmosphere, such adsorption will follow but probably takes place at a slower rate.

The ripening of the wheat kernel is a process of dehydration or desiccation. The sprouting or growing process is a reversal of this process, a hydration and synthesis of different compounds. It is known that respira-

tion under ordinary temperatures does not increase rapidly until the moisture content is 14 to 16 per cent, yet it seems that any increase in the moisture content of the kernel after it has once dried would tend to change the chemical reaction in the kernel toward the formation of new compounds. At the lower moisture contents this probably takes place very slowly, but to a marked degree if allowed to proceed through long periods of time. It is possible that some of the products formed are used up by the enzymes as rapidly as they are produced. But any change of this nature would produce simultaneously the chemical combination of water with the other compounds, and the production of water through the oxidation of carbohydrates.

Protein hydrolysis and the synthesis of soluble carbohydrate are probably the major changes which take place and require water as one of the substances reacted. The process is chiefly one of hydration until respiration becomes active.

In consideration of the facts just mentioned, it appears that storing of grain at a higher moisture content, 12 to 13 per cent, may increase the forces with which water is held. In this case wheat containing 12 per cent moisture which has been stored for several months should show

a lower vapor pressure of the surrounding aqueous vapor than wheat which has been brought to this moisture content and allowed to remain for only a few hours or even several days. The same condition would hold true for wheat containing 15 per cent or more moisture, but above 12 per cent other factors enter in which make it impossible to store the grain at the higher moisture content.

Drying of other solids indicate a definite relation of moisture content and evaporation rate. If this holds true for wheat, it should be possible through vapor pressure measurements of the aqueous vapor surrounding the grain and equilibrium with the moisture in the grain to determine the optimum moisture content for the milling of wheat. Tempering to the same moisture content is not satisfactory for all lots of grain even though it be of the same variety. This difference may be more pronounced among varieties. Measurements of aqueous vapor pressure over grain and mill stocks at equilibrium with the pressure of the moisture in the materials should indicate the degree of saturation which must be maintained to prevent evaporation. If different varieties of wheat or different lots of the same variety grown under different conditions hold water with forces differing in magnitude, there should be a corresponding difference in the degree of saturation of the aqueous vapor pressure at equilibrium, and a corresponding

difference in the optimum moisture contents for milling. Wheats showing a lower vapor pressure of their moisture must hold water more tenaciously. This might be due to the protein content as well as to physical characteristics of the grain.

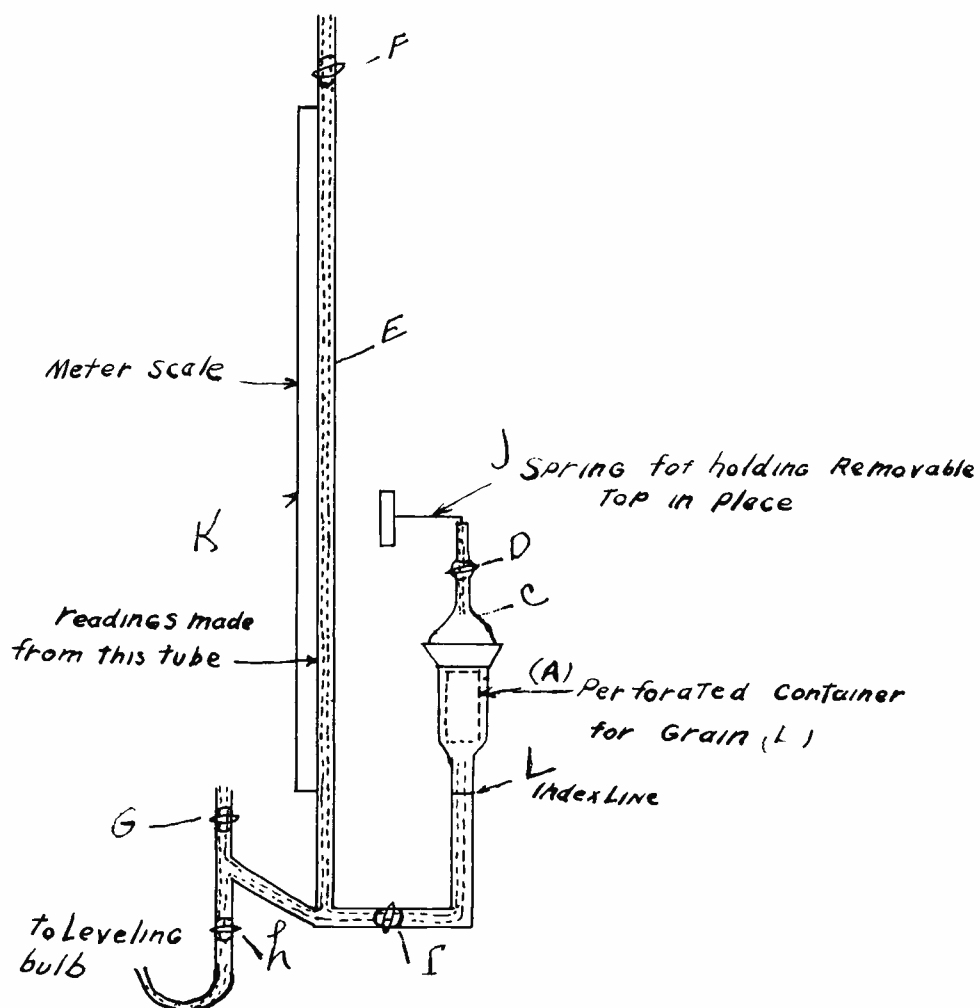
By measuring the vapor pressure of the aqueous vapor over bran and endosperm containing equal amounts of moisture there should be possible some interpretation of the comparative water holding capacity of the two materials. By making a collective study of these conditions as applied to the milling process, some knowledge should be gained as to the proper control of humidity and moisture content to produce the previously mentioned improvements in the finished products, and possibly raise the efficiency of the process of flour milling.

## EXPERIMENTAL WORK

### Description of Instruments

The Working-Anderson Vapor Pressure Apparatus. The apparatus (Plate I) for direct measurement of vapor tension consists of chamber (A), a glass cylinder drawn to a small tube at the lower end and closed at the top by means of a

Plate I Apparatus for measuring the vapor pressure of moisture over grain.



hollow glass stopper (C) drawn to a small tube at the top and closed by pet cock (D). A ground glass joint forms the union of chamber and stopper.

Tube (E) is a manometer tube closed at the top by stopcock (F). Petcock (G) is used to remove air that might enter the apparatus through the rubber tubing used to connect the apparatus to the leveling bulb. Petcock (I) closes off the chamber (A). The spring clamp (J) is used to keep in place the glass stopper which might otherwise be lifted out by the mercury. (K) is a meter stick mounted against tube (E) on which the barometric height is measured. The index line (L) corresponds to zero reading on the meter scale when the instrument is properly leveled. This should be checked and the instrument kept level or some correction applied if the instrument is not level.

If a manometer tube be completely freed from gases and filled with mercury, there will be supported by the atmosphere a column of mercury which just balances the pressure exerted by the atmosphere on the exposed surface of the mercury. If in another identical tube a vapor be introduced, the height of the second column will be lowered by an amount corresponding to the vapor pressure measured in millimeters of mercury. Wheat contains much adsorbed

air which if introduced into the chamber will affect the pressure in addition to the vapor effects. For this reason the air must be extracted as completely as possible. The apparatus was designed to provide a means of conveniently introducing the sample and ridding it of adsorbed air.

The column of mercury will stand at a height above the leveling bulb equal to the barometric pressure. The column in the tube containing the grain will be lowered by an amount equal to the pressure of the aqueous vapor above the grain.

Vapors under high vacuum rapidly approach equilibrium. It is probable that there is always some air left in the grain. For this reason the vapor pressures observed will be above the true values. But the differences of vapor pressures obtained from a series of samples should show a true relationship. Variations of temperature will affect the vapor pressures. But if all are calculated to the degree of saturation, the results are comparable, neglecting temperature effects.

#### Set Up of Apparatus and Development of a Method for Measuring the Aqueous Vapor Pressure Over Wheat

The apparatus is built in three separate pieces which require two air tight joints. These joints being somewhat

flexible lessen the danger of breakage. A good grade of nitrometer tubing was used for the inside of these joints, and also to connect the leveling bulb to the apparatus. In making the joints a No. 6, one hole, rubber stopper was slipped onto the tubes to be joined. On one stopper was placed a short section of rubber tubing in which the stopper fits snugly. With the stoppers and large tube pushed onto the glass tube as far as possible, the connection was made with the smaller nitrometer tubing which fits tightly on the glass tubes. This tube was wired at either end with iron wire. The lower stopper carrying the larger tubing was slipped up against the lower end of the nitrometer tubing. The space between the two tubes was then filled with mercury leaving just sufficient space to insert a stopper which had been placed on the upper glass tube. This forms a joint which is practically air tight, but some time is required to remove the air already absorbed by the tubing and stoppers. The apparatus was then securely mounted on an upright panel and leveled. The points at which the mercury stood in the two tubes was marked and the scales set to correspond to these points. The apparatus was filled with mercury and the air and moisture extracted from the apparatus. This requires several hours and is greatly speeded up by introducing small amounts of Dehydrite or other good desiccating agent into the apparatus.



A barometer was mounted on the panel with the apparatus to make convenient the determination of the existing barometric pressure. This pressure is used as a check in determining when the manometer tube has been completely extracted. The column in this tube should stand within 2 to 3 mm. of that in the barometer. There seems to be material in the mercury, impurities collected from the grain and desiccant that give a pressure equal to this difference. The difference however remains constant. Difficulty is sometimes experienced in getting a good vacuum above the mercury in this tube. Usually the introduction of fresh desiccant aids, but this contains adsorbed air which in turn must be removed. The most careful extraction of this tube is necessary to secure correct values.

When tube (E) is ready, an 8 to 10 gm. sample of wheat is placed in the perforated steel container. The container is then inserted in chamber (A) and stopper (C) inserted. Petcock (D) is open. The spring clip (J) is brought to bear on the top of stopper (C). Petcock (H) is opened full. Petcock (I) is opened and used to control the flow of mercury into chamber (A). The flow should be decreased as the chamber fills to prevent overflowing. When a small

amount has passed petcock (D), petcock (I) is closed. Then close petcock (J). Lower the leveling bulb until the mercury column in tube (E) falls to a point opposite chamber (A). Then open petcock (I) and allow the mercury to flow out of chamber (A). Sometimes there is a layer of mercury which remains on top of the steel container. This may be removed by shaking the apparatus. Allow the mercury to flow from the chamber but do not let it flow from the horizontal tube. This requires careful adjustment of the leveling bulb which should be suspended from a strap or thong or leather or other strong material. Contact of the hands with the bulb increases the temperature of the mercury above that of the room, and should be avoided.

Allow the mercury to flow back into the chamber by raising the leveling bulb. This traps the extracted air above the mercury where it may be released through petcock (D). This process is repeated until no air can be drawn from the grain. Tube (E) is again checked and if holding the proper vacuum, the columns are drawn down until the column under chamber (A) is on the scale. The height of both columns are read. The difference is the aqueous vapor tension over the grain. Duplicate readings should be made by repeating the extraction of air. If the extraction of air is complete, consecutive readings will check. The

difference in height of the two columns is recorded as the vapor pressure of the water in the material.

After making readings on any one sample and before the next sample is introduced, the apparatus is dried by introducing into chamber (A) a perforated tube containing dehydrite. The chamber is then closed and vacuum partially drawn. Dehydrite is also introduced into the manometer tube to rid it of moisture, when the column of mercury did not closely correspond to that of the barometer. This difference was kept below 0.4 cm. The temperature of the material and of the apparatus is also recorded.

The degree of saturation or the relative humidity is calculated by dividing the aqueous vapor tension over the grain by the vapor tension which would be exerted by saturated water vapor at the temperature which existed when the vapor tension over the grain was measured.

The moisture content, length of tempering time, protein content, variety and kernel characteristics were recorded for each of the samples.

Sources of Error. With very moist samples there is a tendency for vapor to condense on the walls of the chamber containing the grain, but this disappears in a few minutes. This would tend to produce a degree of saturation above that which existed at equilibrium. This occurs when the vacuum is lowered, but disappears rapidly when the vacuum

is again raised, or when the columns of mercury are lowered and balanced against atmospheric pressure to take the readings.

The measurements of temperature introduce some error. With rapid formation of vapor, the chamber is cooled below the existing temperature. However the coefficient for vapor is small as compared with the mercury which warms the grain and chamber each time the air is extracted.

Some adsorbed air may still have been retained by the grain. Some water vapor constituting a small moisture loss from the grain also escapes with the extracted air. This source of error is negligible since the loss of such amounts of moisture cannot be determined by the ordinary moisture measurements. Moreover the amount of moisture lost is small as compared with the amount of moisture contained in the 10 gm. sample of grain used.

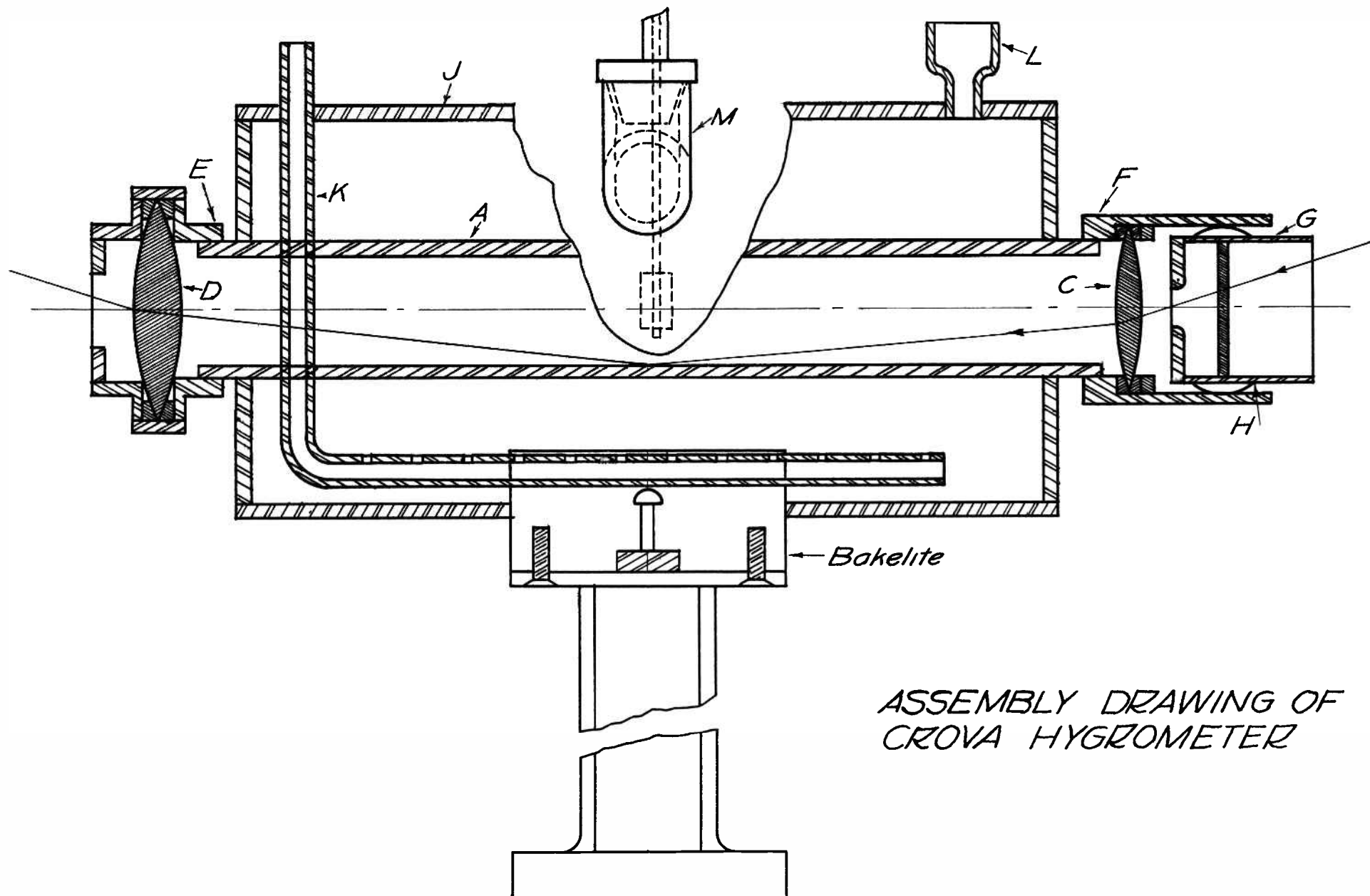
The readings of vapor pressure could be made to 0.5 mm. but the other factors probably lower the accuracy below this point.

The apparatus requires frequent cleaning and drying. The joints are very difficult to make air tight. Good technique is necessary to prevent air entering from the tube leading to the leveling bulb. Much time is consumed in keeping the apparatus in working condition.

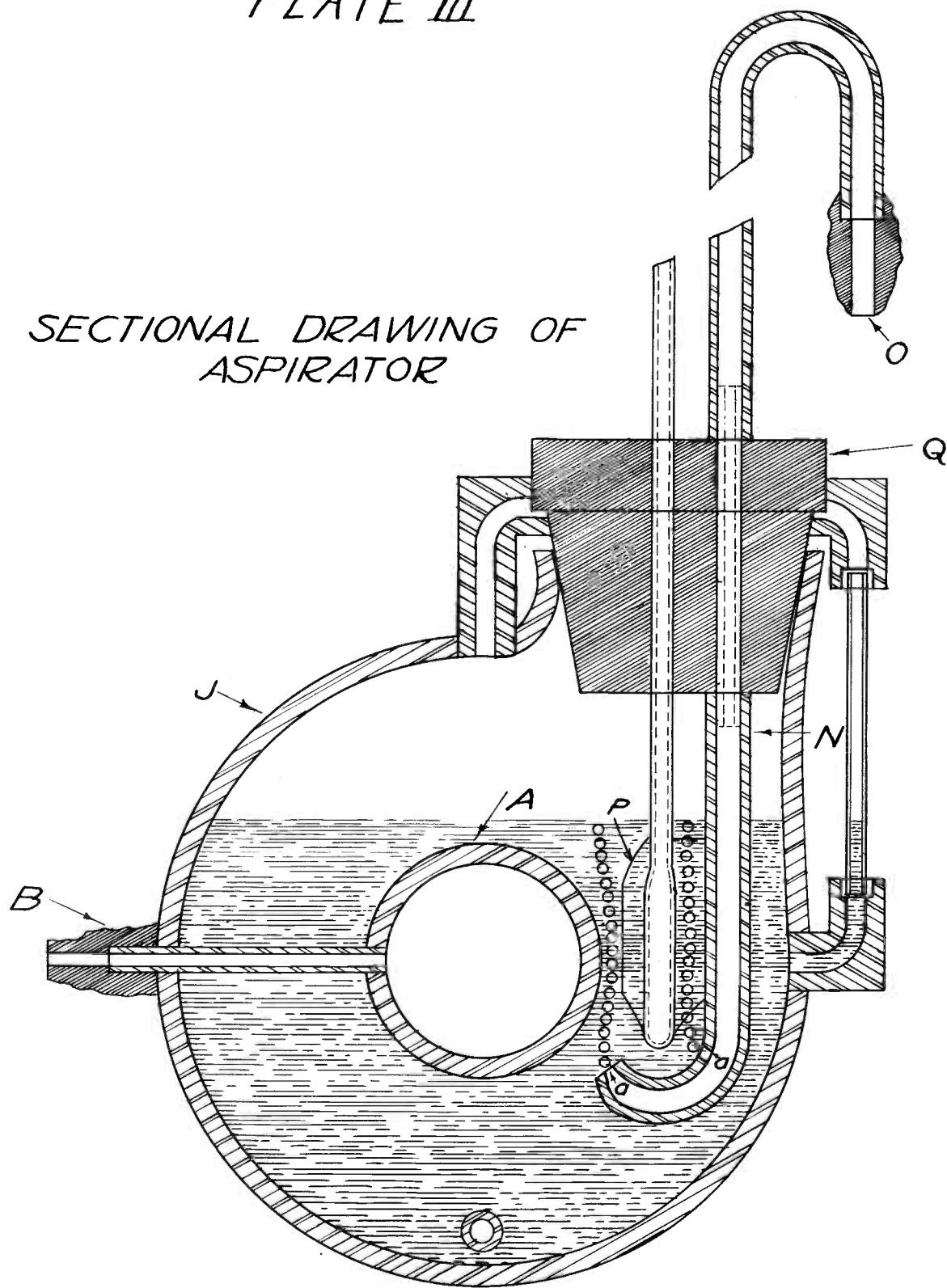
The Crova Hygrometer with Floyd-Anderson Modifications.

Plates II and III show respectively an assembly drawing of the instrument and a detailed assembly drawing of the aspirator used for cooling the instrument. Tube (A) (Plate II.) is the tube into which the sample of air is drawn. The smaller tubes (B) connect tube (A) with the exterior of the instrument. The objective lens (C) has a focal length of approximately 8 inches. The ocular lens (D) has a focal length slightly greater than one half the length of tube (A). The lenses are set in rubber gaskets to make air tight joints and to protect the glass against breakage. The lens carriages (E and F) are fitted onto tube (A) with slip joints cut to a bevel of 0.5 degrees. The objective extends beyond the lens about 3 cm. and tube (G) is fitted inside and held in place by spring (H). The inner end of tube (G) is fitted with a disc in the center of which is an aperture 3 mm. in diameter. Inside tube (G) is placed a green translucent disc which diffuses the light and prevents the formation of images on the highly polished inner surface of tube (A). The green light seems to bring out the darkness of the condensed moisture in tube (A) and also lessens the amount of light which enters the tube. A gauge (I)

## PLATE II

ASSEMBLY DRAWING OF  
CROVA HYGROMETER

## PLATE III

SECTIONAL DRAWING OF  
ASPIRATOR

made of glass cemented into brass ferrules provides a convenient check on the level of cooling fluid contained around tube (A) and inside tube (J), which acts as a container for the fluid. (K) is an auxiliary cooling or aspirator tube through which air is pumped to evaporate the cooling fluid. This is used in determining very low humidities when the dew temperature is far below the temperature of the air surrounding the instrument. (L) is used as a funnel for filling the instrument with cooling fluid (carbon disulfide or ether) and also provides a means of escape for the air pumped into the instrument. A tube may be attached to carry away the fumes of carbon disulfide or ether if they are offensive to the observer. It is well to provide this means of carrying away the fumes if the measurements are being made in a small closed room. Tube (M) is fastened over an opening in tube (J). Through this opening is inserted the aspirator and thermometer.

Plate III shows the construction of the aspirator used in cooling the instrument and in determining the dew point temperature as already stated. Tube (N) is constructed of copper tubing 2 mm. in diameter and bent in the form shown. Air jets (a,a) spray air into the fluid and create rapid evaporation when the air is forced in from some form of pump attached at (O). (P) is a thin shield of brass attached to (N) and fitting snugly around the bulb of the



thermometer. This aids localization of cooling and makes easier the observation of condensate on the inner surface of tube (A) opposite the point where the air bubbles come in contact with tube (A). (Q) is constructed of brass and fits securely into tube (M).

The Crova hygrometer is the dew point type of apparatus. When a mixture of air and water vapor is cooled, the water vapor reaches a condition of saturation at some definite temperature below which condensation of water vapor occurs. This is slightly affected by the presence of air, but the difference is within the experimental error of the determinations. If some means is provided to accurately determine the temperature at which condensation occurs, this may be taken as the dew point of the vapor or the point at which the vapor is saturated. The pressure of the saturated vapor corresponds to the pressure of water vapor at the same temperature. From this and the temperature at which the vapor existed may be calculated the degree of saturation. This may be expressed by the ratio of the amount of water vapor in a given volume to what it could hold in an equal volume, but it sometimes is expressed as the ratio of the vapor pressure at the dew point to the vapor pressure of saturated water vapor corresponding to the temperature at which the vapor existed. Since the difference in results from the two methods is less than the experimental error,

the latter means was used in calculating relative humidity from the hygrometer readings. The following figures illustrate the methods of calculation:

Vapor temperature . . . . .	81°F.
Saturated vapor pressure in inches of mercury at 81°F. . . . .	1.056
Saturated vapor pressure when dew point is 70°F.	.732
$\frac{.732}{1.056} = 69.5\% \text{ Relative Humidity.}$	

Vapor temperature . . . . .	81°F.
Dew point . . . . .	70.
Grains water per cubic foot when saturated at 81°F. . . . .	11.275
Grains water per cubic foot when dew point is 70° . . . . .	7.98
$\frac{7.98}{11.275} = 70\% \text{ Relative Humidity.}$	

Directions for the use of the Crova Hygrometer. Pour enough cooling fluid into the instrument through the attached funnel (L) to cover tube (A). This is insured if the fluid stands well above halfway up in the gauge. Attach the vessel containing the air to be sampled to the instrument by slipping rubber tubes over the ends of tubes (B) and connecting the other ends of the rubber tubes to the two connections provided on the vessel. A bulb pump is inserted in the tube leading from the instrument to the vessel. This provides

a means of circulating air through tube (A). Fifteen to 20 strokes of the bulb are sufficient to remove residual air and insure proper sampling of the air to be examined. By means of small rubber tubing a similar pump bulb is attached to tube (O). With the aspirator and thermometer properly inserted, and the instrument pointed at a good light, the instrument is ready to make the dew point determination.

Force air into the aspirator by means of the bulb attached to tube (O), at the same time watch through the objective for the condensation of water vapor. The light as seen through the ocular inside tube (A) will appear as a small disc surrounded by a dark unlighted area outside of which is a brightly illuminated ring or circular band of light. In the right hand side of this ring and equidistant between the top and bottom, the condensate will appear as a dark blot. As soon as condensation occurs the temperature should be observed. Continue forcing air into the cooling solution until the thermometer readings are constant. This requires some experience and technique on the part of the operator. The rate of cooling or forcing air into the cooling solution should be decreased until the blot is barely perceptible, but is neither increasing or decreasing. By proper manipulation of the cooling device, the thermometer and tube are brought to the same temperature and held there.

The condensation will be difficult to control but when the conditions just mentioned are met, immediately read the temperature. As a further check, readings may be made for the appearance and disappearance of condensation. This also requires some experience in handling the instrument. As soon as condensation is observed read the temperature, and again note the temperature when condensation has disappeared. Alternate cooling and reading the temperature will give a series of temperature readings which decrease much the same as the wet bulb readings of the psychrometer. Temperatures will be found which are constant for both appearance and disappearance of condensation. The sample of air should be changed frequently during a series of readings. The air may be circulated through the instrument continuously (through tube A) without altering the readings to any appreciable degree. Sharper readings may be made by this means. The readings for disappearance and appearance of condensate will under properly regulated conditions check within 0.2 degrees.

The most likely source of error in the determination of relative humidity with the Crova hygrometer is the failure of the samples to have attained equilibrium with the surrounding atmosphere. Changes in temperature immediately

destroy the equilibrium. However, if the bottles containing the samples are placed in a box in which the temperature is controlled, the time required to reach equilibrium seems to be much greater than when they are left where they may be shaken and thoroughly mixed with the air. In order to measure the pressure as it exists under the conditions which correspond to those in the mill, the measurements should be made as soon as possible after the samples are taken. As to the accuracy of the instrument, it is with recently added improvements able to show more accurate results than the readings from the Sling psychrometer. The Crova hygrometer is unaffected by dust, and is an instrument for the direct determination of the dew point. Since the readings for appearance and disappearance can be regulated to within  $0.1^{\circ}\text{C}$ . it appears that the deviation from the true value cannot be greater than this amount. The results from the Crova are lower than those from the Sling psychrometer, about 2.3 per cent relative humidity. The Sling psychrometer is a standard instrument checked and standardized by the manufacturer.

Some Factors Which Influence the Aqueous Vapor  
Pressure Over Wheat

Any variation in the aqueous vapor tension over the grain, the moisture content and temperature being constant,

would indicate that the rate of gain or loss of moisture from the grain had changed. That is if the vapor tension decreased, then the moisture would be held more tenaciously by the grain thereby lowering the amount of moisture per unit volume of air. This would mean a lower absolute humidity and also a lower relative humidity. The converse of this would also be true.

In order to bring about this change there must be a rearrangement in the distribution of the moisture in and at the surface of the kernel. It is not possible to state what this change is, but it is apparent that if the tension of the aqueous vapor in the space over the grain has decreased, the vapor pressure of the moisture in the grain has decreased, which will reduce the rate of evaporation. Also that differences of behavior in the decrease of vapor tension will indicate something of the power of the grain to absorb moisture, the length of time required for absorption, and the tenacity with which moisture is held by the grain. In this work it is assumed that any change in the moisture content of the air over the grain is due to an altered condition of the moisture in the grain.

To test the above the vapor pressures were measured over wheats tempered to different moisture contents for

various periods, the temperature being constant. In another experiment the moisture was constant, but the time and temperature varied. In a third experiment the influence of scouring the grain was studied. The vapor pressures were measured by the Working-Anderson apparatus previously described, and from the figures obtained the relative humidities were calculated.

From a uniform lot of hard red winter wheat weighed samples were placed in glass bottles and tempered at 14, 15, 16, and 18 per cent moisture. The temperature of the grain and water was 27°C. The samples were kept in the sealed bottles for the periods of time indicated in the data ranging from  $\frac{1}{4}$  to 24 hours. Ten gram samples were taken from the bottles at the end of these periods, placed in the apparatus and the vapor pressures measured as described in the directions for the operation of the apparatus. The temperatures of the wheat as well as the vapor when measured were recorded with the corresponding pressures. The relative humidities shown are the ratios of the measured aqueous vapor pressures to the pressures which would have been exerted by saturated aqueous vapor at the temperature under which the vapor existed when the pressure measurements were made.

### The Influence of Moisture Content and Tempering Time on Relative Humidity

The data obtained on the aqueous vapor pressures exerted over wheat as influenced by moisture content and the length of time after the grain had been wetted are found in Table I.

Table I Relative humidities as affected by moisture content and time after tempering.

Moisture : in temp- :		Tempering time hours									
ered wheat:		$\frac{1}{4}$	$\frac{1}{2}$	1.3	2	3.5	4.5	5.5	24	48	72
14	: 86:		:77.5		:78.0:		:	:		: 69 :	67
15	: 90:	91	:83.0:	78.5	:83.6:	76	: 75	:73		: 77 :	72.5
16	: 93:	94.3	:83	:83.5:	85		: 78	: 78	:76.5:	80	: 79
18	: 95:		:93		:94.5:		:	:		: 86 :	89

A comparison of the relative humidities in the table will show the following: The relative humidity increases several per cent for each increase of one per cent in moisture content of the wheat in the range measured. For tempering periods of less than 4 hours the relative humidities decrease with increasing time due to absorption of the water by the grain. After 4 to 5 hours after the grain was wetted the relative humidities became nearly



constant showing complete absorption.

### The Effects of Temperature on the Rate of Absorption

Several samples of wheat were tempered at 15 per cent moisture but at different temperatures of either the wheat or the water before mixing. The procedure, apparatus, and calculations were the same as mentioned in the preceding. The data obtained are given in Table II.

Table II Relative humidities as influenced by varying temperature and time. Moisture being 15 per cent for all samples.

Temperature of grain or water before mixing. (°C.)		::	Tempering time in hours.			
Grain	: Added water	::	2	:4.5 to 5.5:	24	
27	: 27	::	83	: 73	: 73	
30	: 75	::	82	: 70.5	: 70.5	
75	: 31	::	75	: 77	: 74.5	
75	: 75	::	67	: 67	:	

The slowest absorption took place when both the wheat and the water were at 27°C. Heating only the water to 75°C. did not increase the rate of absorption for the first two hours, but did increase it after that time. When the wheat

only was heated the absorption was complete in 2 hours, but the vapor pressure continued on a higher level than when the water only was heated. The most rapid and thorough absorption took place when both wheat and water were heated to 75°C.

#### The Effect of Scouring on the Rate of Absorption

In obtaining the data for effects of scouring the two samples were tempered to the same moisture contents and kept under like conditions of temperature. One sample was scoured before tempering, the other was unscoured. The wheat used, method of sampling, apparatus, and calculations are the same as those used in the preceding. The data obtained are given in Table III.

Table III Relative humidities over scoured and unscoured wheat.

Description of samples.	Tempering time hours.			
	: 2	: 4.5 to 5.5	:	24
Unscoured grain tempered to 15 per cent moisture.	83	: 73	:	73
Scoured grain tempered to 15 per cent moisture.	84	: 71	:	69

The data in Table III show a lower relative humidity over scoured wheat after a tempering period of 4.5 to 5.5 hours. This indicates that scouring increases the water absorption of the wheat kernel. The exact reason for this is not apparent, but it is probably due to the thinning and bruising of the bran coat making the entrance of water easier.

Investigations of other factors which may affect the relative humidity over wheat have been attempted but the results are too meager to warrant presentation at this time. Some of the factors studied were the effects of kernel characteristics, protein content, and the addition of salts and mineral oil emulsions to the tempering water.

#### The Equilibrium Relative Humidities Which Exist Over Mill Stocks

It is known that evaporation is affected by the relative humidity maintained in the mill room and in the machines or that which surrounds the mill stocks. There is a degree of saturation which if maintained in the mill or machines will prevent losses of moisture from the stocks. The required degree of saturation or relative humidity will be equal to that which is built up in the atmosphere due to the vapor pressure of the moisture in the material, when equilibrium has been established between the vapor pressure

of the atmospheric moisture and moisture in the material. By placing samples of the stocks in suitable containers, allowing time for the establishment of the equilibrium just mentioned, measuring the dew point of the vapor surrounding the samples and calculating from the dew point the relative humidity, we are able to determine the humidity necessary to prevent evaporation from the different stocks. For these measurements the Crova hygrometer is eminently adapted, and was used.

A 6 kilogram sample of hard red winter wheat was tempered to 16.7 per cent moisture and milled under ordinary humidity conditions, 30 to 40 per cent, on the experimental mill. The stocks were graded according to size or particle. Small samples were taken for moisture determinations, and the larger remaining portions were sealed in one gallon glass bottles, where they were kept at a constant temperature for the lengths of time designated in Table IV, in order to allow the moisture in the atmosphere to build up and to reach equilibrium with the moisture in the material. In doing this some moisture is lost from the materials, but the size of sample and the volume in which the humidity is built up are so adjusted that the amount of moisture lost from the stocks is negligible. After equilibrium is reached each of the bottles in turn was connected to the Crova hygrometer for the sampling of the vapor inside the bottle.

The procedure for the use of the instrument has been described under the discussion of apparatus. The dew point of the vapor was determined and recorded together with the temperature of the vapor before sampling. The relative humidities shown in Table IV were calculated by dividing the saturated aqueous vapor pressures at the dew point temperature by the saturated aqueous vapor pressures at the temperature of the vapor as it existed over the materials before sampling of the vapor.

Table IV Relative humidities over mill stocks.

Sample	Mois- ture: per cent:	Time after milling.		
		24 hours:	48 hours :	144 hours
Over 20 W	:15.6:	81.7 :	84.7 :	85.0
Over 30 G.G.	:15.3:	81.7 :	76.1 :	81.5
Over 50 G.G.	:15.5:	82.5 :	80.0 :	83.0
Over 70 G.G.	:15.7:	85.6 :	76.2 :	84.0
Over 12 XX	:15.6:	84.6 :	76.2 :	81.5
Through 12 XX	:15.2:	83.1 :	75.8 :	79.2
Bran	:15.7:	85.7 :	79.7 :	81.5

The figures in Table IV show the relative humidities necessary to prevent evaporation from the various mill stocks at the moisture contents shown. The moisture percentages in these samples were higher than is usually found in the streams of the long process mill. It is seen that the relative humidity necessary is between 80 and 85 per cent. Since the moisture contents are near the maximum, this humidity is as high as it should ever be necessary to maintain. The optimum humidity will probably be found to be below this figure. The mill stocks are shown to contain one per cent less moisture than the tempered wheat. This decrease occurred in the short period of time necessary to grind the wheat according to the short flow sheet of the experimental mill. The process requires only 20 minutes. Under low humidity it is seen that the rate of evaporation of moisture is rapid.

#### The Effect of Temperature on Relative Humidity

In the mill rooms there may be a temperature variation of 40° F. or more during the year. The influence of these changes on humidity will now be considered. As stated in a preceding paragraph, if the desiccating power of the wheat

remains constant, the equilibrium relative humidity in a closed system is the same for different temperatures. However it is not known that the desiccating power of the grain and stocks remains constant, nor is there any information concerning the effect of temperature on the humidities which it is necessary to maintain to prevent evaporation.

In making a study of the temperature effects on relative humidity, uniform samples of hard red winter wheat were placed in one gallon glass bottles and tempered to the moisture contents shown in Table V. The bottles were then sealed and kept at constant temperature for 24 hours. At the end of this time the dew points of the vapors in the bottles over the grain were determined by means of the Crova hygrometer, and the relative humidities calculated as already described. These measurements on the various samples were repeated at the different temperatures shown in Table V.

Table V Relative humidity over wheat in a closed system at different temperatures.

Sample	: Per cent : moisture	Relative Humidity			
		36°C.	: 30°C.	: 26°C.	: 23°C.
1	: 15	: 73.6	: 72.0	: 73.2	: 71.0
2	: 15	: 74.0	: 72.8	: 73.0	: 70.5
3	: 16	: 77.0	: 76.5	: 75.0	: 73.0
4	: 16	: 76.5	: 75.2	: 76.2	: 74.3
Average:	15	: 73.8	: 72.4	: 73.1	: 70.8
Average:	16	: 76.8	: 75.9	: 75.6	: 73.7

From these figures it is seen that there may be a slight increase in relative humidity with rise in temperature. The highest temperature,  $36^{\circ}\text{C}.$ , is probably the maximum temperature which may exist in the mills during the summer months. During the winter season the temperatures may be below the lowest temperature studied. The range in values for relative humidity due to variation in temperature are small in comparison with the range in temperature changes. Since the change in humidity due to variation in temperature is so small, the relative humidities may be considered independent of the temperature of the vapor for which the relative humidity is determined. That is, temperature need not be considered a variable in comparing relative humidities which have been measured at different temperatures. The absolute humidities will vary with the temperature as will also the dew points, but the degree of saturation remains nearly constant for different temperatures. To illustrate, a mill stock which requires a relative humidity of 60 per cent to prevent evaporation at  $25^{\circ}\text{C}.$  will require only a slightly higher relative humidity to prevent evaporation at  $35^{\circ}\text{C}.$  However the absolute humidity at the higher temperature would be greater and the dew point would also be found to be higher. The relation of the vapor pressure at the dew point to the pressure of saturated vapor for the temperature at which the vapor



existed before cooling would remain practically constant.

### Comparison of Results from the Crova Hygrometer and the Working-Anderson Apparatus

To compare the values obtained from the vapor pressure measurements made with the Working-Anderson apparatus and the dew point determinations made with the Crova hygrometer data were taken with both instruments. Four identical samples were tempered 2 to 15 per cent moisture and the other 2 to 16 per cent moisture. Readings with each of the instruments were taken and the relative humidities calculated according to the methods previously stated. Table VI gives the observations and the calculated relative humidities obtained by use of the Crova hygrometer, and Table VII the data from the Working-Anderson vapor pressure apparatus. Both sets of data are for 4 hour tempering periods.

Table VI Data from the Crova hygrometer.

Sample	:	Dew Point	:	Temperature of vapor and grain	:	Relative humid- ity (Calculated).
11	:	20.5	:	26.8	:	69.0
12	:	20.6	:	26.8	:	69.5
13	:	22.5	:	26.8	:	77.3
14	:	22.3	:	26.8	:	76.6

Table VII Data from the Working-Anderson Apparatus.

Sample:	Vapor pressure millimeters of Hg.	:Temperature: of vapor and grain °C.	Vapor tension of saturated vapor for tem- perature of grain and va- por millimeters Hg.	:Calcu- lated relative humidi- ties
11 :	16	: 25	: 23.5	: 68.0
12 :	16	: 25	: 23.5	: 68.0
13 :	19	: 25.6	: 24.4	: 78.0
14 :	18	: 25.6	: 24.4	: 77.8

A comparison of the humidities in Tables VI and VII for any one sample shows the agreement between the two instruments. The agreement in relative humidities over identical samples may be seen from a comparison of the humidities over samples 11 and 12 which contain 15 per cent moisture or that over samples 13 and 14 which contain 16 per cent moisture. The variations in both cases are less than the usual experimental error.

#### A Comparison of the Relative Humidities Obtained from the Crova Hygrometer and the Sling Psychrometer

The values for relative humidity as determined by means of the Crova hygrometer and the Sling psychrometer are

shown in Table VIII. The readings were made alternately with the two instruments in a closed room. The relative humidity values for the Sling psychrometer were obtained from Tables prepared for wet and dry bulb readings. Relative humidities from the Crova hygrometer were calculated from the ratio of the pressure of water vapor at the dew point temperature to the pressure of saturated aqueous vapor at the temperature of the vapor when sampled as it existed before it was cooled.

Table VIII Relative humidities obtained from the Sling psychrometer and the Crova hygrometer.

Values obtained from the : Sling psychrometer.		Values obtained from the Crova hygrometer.	
42.25	:	44.8	
44.50	:	46.25	
45.25	:	47.5	
45.25	:	47.8	
44.3	:	46.6	
Mean	:	46.6	
Maximum deviation from mean for the Sling psychrometer 1.04			
Maximum deviation from mean for the Crova hygrometer 1.06			
Difference in the values of the means . . . . . 2.3			

The maximum deviations as shown in Table VIII may be considered equal which indicates that one instrument is as accurate as the other. However there is a difference of 2.3 per cent relative humidity in the figures obtained from the two instruments. The lower percentages shown by the Sling psychrometer are probably due to contamination of the cloth bag which covers the bulb of the wet thermometer. The maximum rate of evaporation may not have been reached in the wet wick or cloth due to the removal of a part of the water by centrifugal force. This agreement is closer than that for other types of apparatus for determining relative humidity.

#### SUMMARY AND CONCLUSIONS

1. When water is absorbed by a solid such as wheat, the vapor pressure of the absorbed water is lowered due to the decreased rate of escape of water molecules. The extent to which the wheat affects the pressure which can be exerted by the vapor from the water which it contains is a measure of the intensity with which the wheat retains water, and indicates the capacity of the wheat for holding water. Evaporation is greatly affected by this capacity. The benefits from the tempering of wheat are to a large degree undone by the evaporation which takes place in the milling process.

2. Measurements were made to determine the effects of certain factors on the vapor pressure exerted by the water in the grain. The factors studied were length of tempering time, moisture content of the grain, temperature of the grain and temperature of the tempering water. The effect of temperature on relative humidity in a closed space was also studied. The results obtained from the different instruments used in these studies were compared.

3. Vapor pressure measurements indicate that the water added to the wheat in tempering is completely absorbed in 1 to 3 hours. Longer tempering periods may produce desirable changes in the grain which aid in the milling process. The rate of evaporation increases with increased moisture content of the grain due to the higher vapor pressure of the water in the materials. Heating the wheat and tempering water before mixing increases the rate at which water is absorbed by the wheat. Scouring the wheat before tempering also increases the rate of water absorption by the grain.

Dew point determinations show that the maximum relative humidity needed to prevent evaporation in the flour mills is below 85 per cent. More work is needed to establish this more accurately. Relative humidities which exist under equilibrium conditions in closed systems remain the same under different temperatures, if the moisture content of the material remains constant.

The results obtained by the use of the different instruments are comparable when calculations have been made to show the corresponding relative humidities.

4. The results show that it is possible to maintain the relative humidities which are necessary to prevent evaporation in the mill. They also serve as a guide to what range of humidities should be maintained in a study of the effects of relative humidity on the milling process. It has also been shown that the data obtained under different temperatures are comparable when calculated to relative humidities. This eliminates the consideration of temperature as a variable. If the proper humidity to prevent evaporation is maintained over the mill stocks the initial moisture content of the wheat need not be so high or it may be desirable to maintain the higher humidity over only some of the streams in the mill. This work should be considered preliminary. Much more extensive investigations are needed in this field of air engineering in the flour mill.

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