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UNIVERSITY OF LOUISVILLE

HUMIDITY MEASUREMENTS IN PRESENCE OF
WATER-SOLUBLE SALTS

A Thesis

Submitted to the Faculty
Of the Graduate School of the University of Louisville
In Partial Fulfillment of the
Requirements for the Degree
OF MASTER OF CHEMICAL ENGINEERING

Department of Chemical Engineering

By

Robert O. Schmitt

Year

1944

HUMIDITY MEASUREMENTS in PRESENCE
of
WATER SOLUBLE SALTS

Robert O. Schmitt

Approved by the Examining Committee

Director G. C. Williams

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Date Oct. 21, 1944.

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LIST OF SYMBOLS

A	=	Interfacial area (Sq. ft.)
C	=	Heat evolved by crystallization of salt from solution per unit weight of water evaporated (Btu./lb.)
H	=	Absolute humidity of air (lb./lb. dry air)
H_s	=	Adiabatic saturation humidity corresponding to t_s , (lb./lb. dry air)
h	=	Air film heat transfer coef. Btu./ (hr) (sq.ft.) ($^{\circ}$ F.)
k_g	=	Diffusion film coefficient (gas phase)
k_g^1	=	29 k_g /18
p_g	=	Partial pressure of water in the air
p_1	=	Partial pressure of water at wet-bulb temperature
p_s	=	Partial pressure of water at saturated salt solution wet-bulb temperature
q_c	=	Heat evolved by crystallization per unit of time
q	=	Heat transferred per unit of time
t_g	=	Dry-bulb temperature
t_1	=	Water wet-bulb temperature
t_w	=	Water wet-bulb temperature
t_s	=	Salt solution wet-bulb temperature
W	=	Quantity of water vaporized per unit of time
λ_1	=	Heat of vaporization of water per unit of weight at t_1
λ_s	=	Heat of vaporization of water per unit of weight at t_s
λ_w	=	Heat of vaporization of water per unit of weight at t_w

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

The author wishes to acknowledge the kind assistance and helpful guidance of Dr. G. C. Williams, who directed this research.

ABSTRACT

A theory is presented for the observed rise in wet-bulb temperatures when salt solutions are used as the bulb wetting liquid, and an equation is derived for determining the humidity of air using salt solution wet-bulb temperatures. Humidity charts are included for saturated solutions of NaNO_3 , NH_4NO_3 , and $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$.

Experimental data are presented on three water-soluble salts. These data show substantial agreement with the salt solution wet-bulb temperatures calculated from the postulated equation.

INTRODUCTION

Wet-and-dry bulb psychrometry is one of the most important methods for the determination of humidity. It is commonly used in industrial applications for controlling the moisture content of the air in buildings, constant humidity rooms, and various air drying operations. If the air used in making a humidity determination is contaminated with a water soluble salt, some of the salt particles will dissolve in the water maintained on the wet-bulb thermometer. The salt solution will then have a different vapor pressure-temperature relationship than pure water and will continue to change until a saturated solution is obtained on the wick of the wet-bulb thermometer. Since saturated salt solutions have a lower vapor pressure than pure water, a higher wet-bulb temperature would be obtained in order to attain equilibrium conditions. Thus, the wet-bulb reading would indicate an erroneously high humidity in the air stream.

In making heat and moisture balances for drying water soluble salts, the effect of the salt may be considerable and give entirely false results. Hence, the purpose of this work is to determine how different saturated salt solutions affect the wet-bulb temperature readings and to develop a modified psychrometric equation that can be applied to all salt solutions used for or present in humidity determinations.

HISTORICAL

Prior to 1911 no accurate method of determining absolute humidity by means of wet- and dry-bulb thermometry had been developed, nor had any relation, other than empirical, been established between humidity and wet- and dry-bulb temperatures. In 1911 W. H. Carrier (4) presented the basic psychrometric principles of the present-day practice for humidity determinations.

The psychrometric chart presented by Carrier (4) was based upon calculated values of adiabatic saturation. His test data showed that the observed wet-bulb temperatures, with a sling psychrometer, were in close agreement with the calculated adiabatic temperatures. Radiation corrections were indicated when the unshielded wet-bulb and the shielded wet-bulb readings were compared. The radiation-shielded wet-bulb readings gave lower temperature readings. It was also noticed that there was a difference between the reading of a radiation-shielded wet-bulb and the observed temperature of adiabatic saturation, where the radiation-shielded wet-bulb apparently gave the lower reading of the two. Later experimental work by Arnold (1) and by Dropkins (5) has shown that this variation is in accordance with already established physical laws. It has been proven that there is a definite air velocity where there is practical agreement between an unshielded wet-bulb temperature and the actual temperature

of adiabatic saturation, but there is some disagreement (1, 4, 6, 10) as to the actual velocity where this condition exists.

In 1943 Williams, G. C. and Williams, R. J. (12) published an approximate correction to the original psychrometric equation to be used when saturated salt solutions are used for the bulb wetting liquid in place of pure water. The resultant lowering of the water vapor pressure by the salt, produced a higher wet-bulb temperature reading. In applying this new correction an empirical relationship corrected the saturated salt solution wet-bulb temperature to a water wet-bulb temperature by isobaric readings on the respective vapor pressure curves for the saturated salt solution and pure water. The corrected wet-bulb temperature obtained by this method was substituted for t_w in the basic psychrometric formula. The revised humidity equation postulated from this work included the heat of crystallization, but the data was correlated without applying the correction as it was assumed to be negligible for the salts used.

T H E O R E T I C A L

Psychrometric formulae are based upon the assumption that adiabatic conditions exist around the wet-bulb and that heat balances may be arranged. On one side heat is removed from the wet-bulb by vaporization of the water; on the other hand heat is gained by convection and radiation from the surrounding air and walls. It has been shown that, with a sufficiently high air velocity, the radiation effect on an unshielded bulb is negligible (1, 4, 6, 10) and will be neglected in this derivation.

In the case of a bulb wet with pure water, the heat transferred by vaporization of the water,

$$q = \lambda_1 W \quad (1)$$

Where λ_1 is the heat of vaporization and W = wgt. of water vaporized. Under equilibrium conditions this must equal the sensible heat transferred to the wet-bulb from the air:

$$q = h A (t_g - t_1) \quad (2)$$

Where h = heat transfer coefficient, A is the area involved and t_g and t_1 are the temperatures of the gas and water respectively.

Therefore (2, 11)

$$\lambda_1 W = h A (t_g - t_1) \quad (3)$$

As W is the rate of vaporization, the following relation may be set up according to Fourier's law (8)

$$W = k_g A (p_1 - p_g) \quad (4)$$

Where k_g is the diffusion coefficient and p_1 and p_g are the

pressures of water vapor at the interface and in the gas.

The heat relation would then become

$$1 (p_1 - p_g) k_g A = h A (t_g - t_1) \quad (5)$$

Suppose that a water soluble salt is being dried, and the bulk of the air contains some entrained particles of salt. If these particles of salt come in contact with the wet-bulb of the thermometer, the standard humidity equations will not be valid until corrections have been made for the effect of the salt. (12) The first effect to be considered is the transfer of sensible heat from the particles of salt to the wet-bulb. Since the sensible heat in the salt striking the wet-bulb is such a small percentage of the total sensible heat transferred by convection from the air stream, it can be neglected or considered as being a part of the air. In either case the total heat, q , transferred to the wet-bulb will be such that adiabatic conditions are maintained.

The second effect to be considered is the heat of solution. As the particles of salt impinge on the wet-bulb, they tend to dissolve as long as the bulb-wetting liquid is not saturated. The dissolving salt changes the equilibrium conditions because each concentration of solution has its own vapor pressure-temperature relationship and is different from that of pure water. It also adds the heat of solution for the salt. The equilibrium conditions will continue to change until the bulb-wetting liquid becomes saturated with salt. At

this point a new equilibrium condition exists at an entirely different wet-bulb temperature which shall be called a saturated salt solution wet-bulb temperature, t_s . If the solution on the wet-bulb is not saturated, its composition will change steadily as evaporation proceeds. An equation for this condition would be too difficult to use because the salt concentration and vapor-pressure for that solution would have to be known for each wet-bulb temperature reading.

If wet-bulb measurements are made with a saturated salt solution, diffusion of water-vapor into the air stream will cause part of the salt to crystallize out of solution. This crystallization is a continuous equilibrium process when measuring a salt-bulb temperature and must be considered in the heat balance as the heat of crystallization, q_c .

$$\lambda_1 W = q + q_c \quad (6)$$

$$\text{or } \lambda_1 k_g A (p_1 - p_g) = h A (t_g - t_1) + q_c \quad (7)$$

The quantity of q_c is dependent upon the rate of evaporation of the water and is related to the rate of evaporation as follows:

$$q_c = C k_g A (p_1 - p_g) \quad (8)$$

Where C = heat evolved by crystallization per pound of water evaporated from the saturated solution. The equation then becomes

$$\lambda_1 k_g A (p_1 - p_g) = h A (t_g - t_1) + C k_g A (p_1 - p_g) \quad (9)$$

$$\text{or } (\lambda_1 - C) (p_1 - p_g) = \frac{h}{k_g} (t_g - t_1) \quad (10)$$

Since the interface conditions p_i , t_i and λ_i are for saturated salt solutions, they shall be indicated as p_s , t_s , and λ_s . Therefore, the final form of the equation becomes

$$(\lambda_s - C) (p_s - p_g) = \frac{h}{k_g} (t_g - t_s) \quad (11)$$

When pure water is used as the bulb-wetting liquid, the partial pressure of water vapor at the interface, p_i , is greater than the partial pressure of water vapor in the main body of the air stream except at one hundred percent saturation where the two partial pressures are equal. Under less than saturated conditions water vaporizes from the wet-bulb thermometer continually, p_i is always greater than p_g and t_g will always be above t_i .

If, however, a saturated salt solution is used as the bulb-wetting liquid, the partial pressure of water vapor at the interface, p_s , is lower than when pure water is used as the bulb-wetting liquid. With the lower partial pressure for the saturated salt solution (p_s), the partial pressure of the water vapor in the air stream (p_g) becomes equal to and finally greater than p_s as the air approaches one hundred percent saturation. Simultaneously, the equilibrium temperature of the saturated salt solution wet-bulb thermometer, t_s , becomes equal to and finally greater than the temperature of the air, t_g .

When p_s is less than p_g , water vapor diffuses from the air stream to the salt solution wet-bulb thermometer. There-

fore, with an excess of salt on the wet-bulb and water vapor diffusing to the wet-bulb, part of the excess salt must dissolve if the bulb-wetting liquid is to remain saturated. This introduces the heat of solution effect on the wet-bulb thermometer instead of the heat of crystallization. However, all other heat effects and weight effects are also in the reverse direction and an examination of equation 11 will show that it holds for diffusion in either direction as the signs of the quantities mutually cancel.

Since humidity, H , has been defined (2, 11) as pounds of water vapor per pound of dry air, it follows that

$$H = \frac{18p}{29(1-p)} \quad (12)$$

"Under ordinary temperature conditions, p is small in comparison to unity and equation (12) becomes, approximately,

$$H = \frac{18}{29} p \quad (12a)$$

Within a small error, humidities are proportional to partial pressures, and humidity differences are proportional to partial pressure differences." (2)

In the condition of this work, p_g will be lower than p_w and this substitution will be even more accurate.

Replacing the partial pressures, p_g and p_s , by the corresponding humidities H and H_s equation 11 becomes

$$H_s - H = \frac{h(t_g - t_s)}{k'_g(\lambda_s - C)} \quad \text{Where } k'_g = \frac{29}{18} k \quad (13)$$

Using equations 11 and 13 it is possible to calculate data for

constructing humidity charts for various saturated salt solutions.

Actual substitution of equation (12) in equation (11) results in the following:

$$\frac{H_s}{\left(1 + \frac{29}{18} H_s\right)} - \frac{H}{\left(1 + \frac{29}{18} H\right)} = \frac{h (t_g - t_s)}{k_g (\lambda_s - C)} \quad (14)$$

EXPERIMENTAL

A forced circulation dryer was used to produce a high air velocity for the wet- and dry-bulb temperature readings. The dryer was equipped with steam heat so that the temperature could be adjusted to the desired range. To vary the vapor pressure of water in the air stream, water was sprayed upon the surface of a steam heated preheater located at the air intake of the dryer. Thus the humidity of the air as well as the temperature could be adjusted.

Three thermometers for measuring the dry-bulb, water wet-bulb, and the salt solution wet-bulb temperatures were mounted in the end of the six inch diameter exhaust air duct of the dryer. To protect the thermometers against radiation, sheet metal plates were soldered in the duct between each thermometer and parallel to the air stream. The air velocity was maintained at approximately 2100 feet per minute which also minimized radiation effects as conduction is the major method of heat transfer at this velocity. (2, 4, 5.)

The water wet-bulb was wet with distilled water at the wet-bulb temperature. The solution wet-bulb was wet with a solution of a reagent grade salt that had been saturated at a higher temperature than the solution wet-bulb temperature and then cooled to the solution wet-bulb temperature.

The salt solutions used in this research were sodium nitrate, ammonium nitrate, and magnesium chloride hexahydrate.

In taking the experimental data the dry-bulb, water wet-bulb, and the saturated salt solution wet-bulb temperatures were determined simultaneously and under the same heat and air conditions. Before a solution wet-bulb temperature was taken, the bulb was wetted several times and the salt solution allowed to evaporate until free salt was present. This insured excess salt present when the temperature determination was made. When the salt solution wet-bulb temperature was above the exhaust air temperature, it was impossible to maintain an excess of salt for any long period of time on the wet-bulb by this method because water condensed on the bulb. Thus readings for the salt solution wet-bulb temperatures that were above the exhaust air temperature may be slightly low because of the difficulty of maintaining saturated conditions.

DATA AND RESULTS

RESULTS WITH NaNO_3 SOLUTION

In order to compare this work with the previous investigation using saturated salt solutions (12), experiments were repeated using saturated NaNO_3 solutions as the bulb wetting liquid for wet-bulb temperature measurements. This salt solution exerts a vapor pressure lower than that of pure water, and the heat of crystallization amounts to approximately five percent of the latent heat of evaporation of water. No hydrates of sodium nitrate are formed over the temperature range used in obtaining the experimental data.

The experimental data are given in Table I and correlated in Figure 1. The data cover a dry-bulb range from 71°F. to 128°F. and a corresponding wet-bulb range from 64°F. to 112°F. The wet-bulb temperature depressions varied from 1°F. to 26°F. , and the temperature rise of the salt solution effect varied from 6.1°F. to 12.6°F. Sample calculations are shown in the Appendix.

Excellent agreement was obtained in the correlation of the experimental salt solution wet-bulb temperatures with the values derived by using equation No. 11. The agreement was good when the salt solution wet-bulb temperatures were both above and below the air stream temperatures. When the experimental salt solution wet-bulb temperatures were below the air temperature, the values were 0.1°F. to 1.7°F. above

those calculated from equation No. 11. With the salt solution wet-bulb temperatures above the air temperature, the experimental values were from 1.4°F. lower to 0.45°F. higher than the calculated ones. This correlation is good and tends to substantiate the correctness of the postulated equation.

These data were further correlated by the empirical method proposed by Williams, G. C. and Williams, R. J. (12) (See Fig. 7). Good agreement was obtained with the empirical results being from 0.1°F. to 3.6°F. lower than the experimental water wet-bulb temperatures. In this correlation the heats of crystallization were neglected because the heat produced by salt crystallization was considered to be negligible when compared to the latent heat of vaporization for water. This assumption is applicable to salts having low heats of crystallization, but it does not apply when the heat of crystallization is large in comparison to the latent heat of water.

The empirical relationship (12) for converting the experimental salt solution wet-bulb temperatures to water wet-bulb temperatures by isobaric readings from the respective vapor pressure curves is a satisfactory approximation for salt solutions that have small vapor pressure lowerings, but is not satisfactory when the salt solution vapor pressure lowering is large.

A humidity chart, Fig. II, was constructed for saturated solutions of NaNO_3 using the derived equation No. 11 as

the basis of calculation. This new humidity chart will be of considerable value if it becomes necessary to make heat or moisture balances when drying NaNO_3 . If there is considerable salt dust entrained in the air stream that will come in contact with a water wet-bulb thermometer, the salt will dissolve on the wick and raise the wet-bulb temperature above the true wet-bulb temperature of the air. This will give a high humidity reading and make it impossible to obtain a good heat or moisture balance. By making wet-bulb measurements with saturated salt solutions instead of water, higher wet-bulb temperatures will be obtained and radiation losses can be minimized. This factor becomes very important at very low air velocities because the radiation correction becomes greater with decreasing velocities.

TABLE I
DATA FOR NaNO_3 SOLUTIONS

		$^{\circ}\text{F.}$		P_w	P_g	λ_w	λ_s	P_s	C	T_s Calc.
Run No.	T	T_w	T_s	mm. H_g	mm. H_g	Btu/lb.	Btu/lb.	mm. H_g	Btu/lb.	$^{\circ}\text{F.}$
1	71.2	67.5	73.8	17.2	16.75	1054.1	1050.7	16.1	53.9	73.7
2	70.9	63.7	69.8	15.1	13.26	1056.1	1052.8	14.2	52.8	69.0
3	73.2	65.6	71.8	16.1	14.18	1055.1	1051.7	15.1	53.4	71.1
4	73.2	67.2	73.4	17.1	15.51	1054.3	1050.9	15.9	53.8	72.9
5	72.5	68.4	74.6	17.8	16.69	1053.6	1050.2	16.5	54.1	74.0
6	71.9	69.4	75.7	18.4	17.74	1053.1	1049.7	17.1	54.4	75.2
7	73.2	67.1	73.6	17.0	15.44	1054.3	1050.8	16.0	53.9	72.8
8	79.5	72.1	79.1	20.2	18.31	1051.5	1047.8	18.9	55.2	78.3
9	80.1	75.9	83.0	22.9	20.85	1049.6	1045.6	21.4	56.4	81.6
10	81.1	77.5	84.7	24.1	23.35	1048.7	1044.7	22.5	56.8	84.7
11	86.7	84.9	92.8	30.7	30.28	1044.7	1040.3	28.8	59.1	92.6
12	83.1	81.3	89.0	27.4	26.91	1046.6	1042.4	25.7	58.0	88.6
13	88.2	86.7	94.8	32.6	32.18	1043.6	1039.2	30.6	59.5	94.6

Run No.	°F.			mm. Hg		Btu/lb.		mm. Hg		Btu/lb.		°F.
	T	T _w	T _s	P _w	P _g	λ _w	λ _s	P _s	C	T _s	Calc.	
14	92.1	91.0	99.9	37.3	37.03	1041.3	1036.4	35.1	61.0	99.7		
15	91.9	90.9	99.5	37.1	36.62	1041.4	1036.5	34.7	60.8	99.2		
16	94.5	93.5	102.7	40.2	40.98	1039.9	1034.8	37.8	61.8	102.6		
17	99.1	98.2	108.0	46.4	46.17	1037.3	1035.9	43.2	63.3	108.4		
18	98.3	94.3	104.2	41.3	40.96	1039.5	1034.0	39.3	62.2	103.6		
19	101.7	95.5	105.6	42.9	41.29	1038.8	1033.1	40.7	62.5	105.3		
20	105.8	96.8	107.1	44.6	42.20	1038.1	1032.4	42.2	63.0	106.8		
21	107.8	90.5	100.9	36.7	32.09	1041.6	1035.8	36.1	61.3	99.2		
22	106.7	92.3	102.7	38.8	35.08	1040.6	1034.8	37.8	61.8	101.4		
23	109.4	107.4	118.9	61.2	60.69	1032.2	1025.7	58.2	66.6	118.9		
24	106.5	102.9	113.9	53.6	52.64	1034.7	1028.6	50.6	65.0	113.9		
25	107.8	106.3	117.7	61.8	58.93	1032.8	1026.4	56.3	66.1	117.7		
26	116.0	108.3	120.4	62.8	60.79	1031.7	1024.9	60.7	67.0	119.8		
27	118.8	106.7	118.8	59.9	56.80	1032.6	1025.7	58.0	66.4	118.1		
28	122.2	108.9	121.5	63.8	60.37	1031.4	1024.3	62.5	67.8	120.5		

Run No.	° F.			mm. H _g		Btu/lb.		mm. H _g	Btu/lb.	° F.
	T	T _w	T _s	P _w	P _g	λ _w	λ _s	P _s	C	T _s Calc.
29	122.2	105.1	117.5	57.1	52.80	1033.5	1026.5	56.0	66.1	116.5
30	121.5	100.8	112.6	50.2	45.99	1035.9	1029.3	48.8	64.6	111.7
31	120.7	94.8	106.5	41.9	37.56	1039.2	1032.7	41.7	62.8	106.4
32	122.2	110.7	123.3	67.2	64.28	1030.4	1023.3	65.8	67.8	122.6
33	75.0	68.2	74.7	17.6	15.91	1058.3	1050.2	16.6	54.1	73.9
34	125.4	102.0	113.4	52.2	46.07	1035.2	1028.9	49.8	64.9	113.2
35	127.9	106.0	117.7	58.7	53.05	1033.0	1026.4	56.8	66.1	117.5
36	124.0	111.7	123.4	69.3	65.13	1029.8	1023.2	66.0	67.9	123.1
37	126.0	104.8	112.8	50.2	44.85	1033.6	1029.2	49.1	64.7	112.5

EXPERIMENTAL TEMPERATURE - T_s - °F

130

120

110

100

90

80

70

60

50

50

60

70

80

90

100

110

120

130

CALCULATED TEMPERATURE - T_s - °F

FIG. 1

COMPARISON OF DERIVED AND EXPERIMENTAL WET BULB TEMPERATURES WITH SATURATED NaNO_3 SOLUTION

○ $T_s > T_g$
△ $T_s < T_g$

RESULTS WITH NH_4NO_3 SOLUTION

In studying the effect of salt solutions on the wet-bulb temperatures, one having a high heat of crystallization and a low vapor pressure-temperature relationship would give results showing the effect of two variables simultaneously. Ammonium nitrate solutions have these two properties. Its vapor pressure-temperature relationship, Fig. 9, is much lower than that of water or NaNO_3 solutions, and the heat of crystallization, Fig. 10, is very high, amounting to approximately twenty percent of the latent heat of vaporization for water. Also NH_4NO_3 forms no hydrates over the temperature range used in obtaining the experimental data.

The experimental data are given in Table II, and the correlation with values calculated by using equation No. 11 (See Appendix) is shown on Fig. 3. These data cover a dry-bulb temperature range from 70.5°F . to 109.5°F . and a corresponding wet-bulb temperature range from 57.4°F . to 106.9°F . with depressions varying from 1.7°F . to 18.0°F . The range for the simultaneously determined salt solution wet-bulb temperatures varied from 65.1°F . to 127.8°F ., and the temperature rise due to the salt solution effect varied from 7.7°F . to 20.9°F . It will be noticed that the salt solution wet-bulb temperatures varied from less than the air temperature

to as much as 18.3°F . above the air stream temperature, t_g . If a wet-bulb thermometer becomes coated with NH_4NO_3 while taking psychrometric measurements in NH_4NO_3 bearing gases, the wet-bulb temperature would indicate an absolute humidity which would be in error by approximately 300% for the lowest wet-bulb temperature reading, and it would be impossible to determine the humidity for the maximum wet-bulb temperature because it would read 18.3°F . above the dry-bulb temperature of 109.5°F . For the air stream to be completely saturated with water vapor, the water wet-bulb temperature will be the same as the dry-bulb temperature. If the wet-bulb temperature reads 18.3°F . higher than the dry-bulb temperature, a new theory would have to be developed to account for this unusual phenomenon.

By applying the theory developed in the theoretical section, a correlation of the experimental salt solution wet-bulb temperatures with the corresponding derived values gave a very good agreement as indicated in Fig. 3. The agreement was good when the salt solution wet-bulb temperatures were both above and below the corresponding dry-bulb temperatures. When the experimental salt solution wet-bulb temperatures were below the air temperature, they ranged from 0.2°F . less than to 0.9°F . greater than the values calculated from the theoretical equation. With the salt solution wet-bulb temperatures above the air temperature, t_g , the experimental

values varied from 0.3°F. greater than to 3.8°F. less than the corresponding derived values. The greatest deviations occurred at higher wet-bulb temperatures when t_s was greater than t_g . It is supposed water vapor condensing on the wet-bulb faster made it more difficult to maintain a saturated salt solution on the wet-bulb thermometer. If the salt solution on the wet-bulb is not saturated, it will give a higher vapor pressure and consequently the salt solution wet-bulb temperature will be too low as is shown on Fig. 3.

When these data were correlated by the method of the previous investigators (12), the results were not satisfactory. In this correlation (see Fig. 7) the empirical results were from 3.7°F. to 7.4°F. lower than the corresponding experimental water wet-bulb temperatures. When correlating the data as proposed in this report, the variation was from 0.2°F. less than to 0.9°F. greater than the calculated theoretical values when t_s was less than t_g . When t_s was greater than t_g , the experimental values varied from 0.3°F. greater than to 3.8°F. less than the values calculated from the theoretical equation No. 11. By comparing the two correlations it is seen that the greatest deviation, 3.8°F. , indicated by the new theory is approximately the same as the minimum deviation of 3.7°F. shown by the method used by the previous investigators (12). This shows a substantial improvement in the correlation.

In order to make this work of some practical value a

humidity chart, Fig. 4, was constructed for saturated solutions of NH_4NO_3 using the derived equation No. 11 as the basis of calculation. If it is necessary to dry NH_4NO_3 crystals in a rotary dryer, a certain amount of salt dust may become entrained in the air stream. In order to obtain correct heat and moisture balances under such conditions, it will be necessary to use NH_4NO_3 solutions as the bulb wetting liquid for wet-bulb temperature measurements, and this chart would be useful in reading humidities directly.

TABLE II
DATA FOR NH_4NO_3 SOLUTIONS

Run No.	° F.			mm. Hg		Btu/lb.		mm. Hg		Btu/lb.		° F.	
	T	T _w	T _s	P _w	P _g	λ _w	λ _s	P _s	C	T _s	Calc		
1	100.8	90.1	105.8	36.3	33.41	1041.8	1033.1	30.4	219.5	107.2			
2	100.0	89.2	104.9	35.3	32.47	1042.3	1033.5	29.8	218.0	106.1			
3	105.0	93.8	110.3	40.3	37.44	1039.5	1030.6	33.3	226.0	112.6			
4	107.5	95.2	112.1	42.4	39.18	1039.0	1029.6	34.6	229.0	114.8			
5	108.0	95.7	112.9	43.1	39.94	1038.7	1029.1	35.1	230.2	115.8			
6	104.7	95.2	112.7	42.4	39.90	1039.0	1029.3	35.0	229.5	114.9			
7	103.6	90.0	106.7	36.1	32.55	1041.8	1034.6	30.9	220.3	107.2			
8	106.5	104.2	123.3	55.6	52.42	1034.0	1023.2	44.1	255.4	125.2			
9	106.7	104.5	123.8	56.2	55.64	1033.8	1022.9	44.6	246.3	127.7			
10	106.7	104.7	124.5	56.5	56.99	1033.7	1022.5	45.3	247.5	127.9			
11	70.5	57.4	65.1	12.1	8.74	1059.6	1055.4	10.3	156.0	65.3			
12	70.9	57.8	65.7	12.2	8.88	1059.5	1055.1	10.5	156.6	65.6			
13	71.8	59.6	67.8	13.1	10.98	1058.4	1053.9	11.2	160.5	67.8			

Run No.	° F.			mm. H _g		Btu/lb.		mm. H _g		Btu/lb.		° F.
	T	T _w	T _s	P _w	P _g	λ _w	λ _g	P _g	C	T _s	Calc	
14	72.0	60.3	68.9	13.4	10.51	1058.0	1053.4	11.5	162.0	68.8		
15	72.2	61.0	69.5	13.7	10.88	1057.6	1053.0	11.7	163.0	69.5		
16	72.3	60.5	69.1	13.5	10.45	1057.9	1053.3	11.6	162.3	68.9		
17	100.5	95.0	111.7	42.2	40.75	1039.1	1029.8	34.3	228.0	114.2		
18	108.6	106.9	127.8	60.2	59.78	1032.4	1020.6	48.5	252.5	131.0		
19	103.5	98.6	117.1	47.1	45.79	1037.1	1026.8	38.6	236.6	119.2		
20	103.3	98.4	106.6	46.8	45.54	1037.2	1027.0	38.2	235.8	119.0		
21	88.3	71.6	83.6	19.8	15.55	1051.9	1045.3	17.8	185.5	82.8		
22	84.7	70.9	82.6	19.3	15.82	1052.3	1045.9	17.2	183.8	81.7		
23	91.8	77.0	90.0	23.8	20.96	1048.9	1041.8	21.1	195.0	89.3		
24	93.8	77.7	90.7	24.3	20.20	1048.6	1041.4	21.5	196.4	90.3		
25	97.3	79.3	93.0	25.7	21.03	1047.7	1040.2	22.8	200.0	92.7		
26	90.7	77.2	90.0	23.9	20.44	1048.8	1041.8	21.1	195.0	89.6		
27	89.4	82.6	95.8	28.5	26.73	1045.8	1038.7	24.3	204.0	96.2		
28	89.2	84.6	98.5	30.4	29.21	1044.8	1037.1	25.8	208.0	99.0		

		° F.		mm. H _g		Btu/lb.		mm. H _g		Btu/lb.		° F.
Run	T	T _w	T _s	P _w	P _g	λ _w	λ _s	P _s	C	T _s	Calc.	
No.												
29	89.4	84.8	98.8	30.6	29.37	1044.7	1037.0	26.0	208.8	99.1		
30	108.6	103.6	124.8	54.7	53.44	1034.2	1022.4	45.5	246.7	126.5		
31	108.5	95.0	113.5	42.2	38.68	1039.1	1028.8	35.7	231.0	114.7		
32	109.5	100.0	120.0	49.2	46.70	1036.3	1025.1	41.2	240.8	121.6		
33	109.2	102.0	121.9	52.2	50.29	1035.2	1024.1	42.7	243.5	124.3		
34	86.5	76.8	89.1	23.6	21.05	1049.0	1042.9	20.6	193.8	88.7		
35	86.1	77.0	88.9	23.8	21.42	1048.9	1043.0	20.5	193.5	88.9		
36	71.6	64.8	73.4	15.7	13.83	1055.5	1050.9	13.2	169.3	73.6		
37	73.6	67.8	76.8	17.3	15.83	1054.0	1049.0	14.6	174.4	77.2		
38	75.4	69.8	79.5	18.7	17.22	1052.8	1047.6	15.8	179.0	79.7		
39	78.1	74.4	85.1	21.8	20.83	1050.4	1044.5	18.5	187.8	85.2		
40	80.8	77.5	89.2	24.2	23.34	1048.7	1042.3	20.7	194.0	89.2

FIG. 3.
COMPARISON OF DERIVED AND EXPERIMENTAL WET BULB TEMPERATURES WITH
SATURATED NH_4NO_3 SOLUTION

ABSOLUTE HUMIDITY LBS. H_2O PER LB. DRY AIR

0.10
0.08
0.06
0.04
0.02
0.00

60 70 80 90 100 110 120 130 140

TEMPERATURE °F

ADIABATIC WET BULB LINES WITH SATURATED NH_4NO_3 SOLUTION
FIG. 4.

90%
80%
70%
60%
50%
40%
30%
20%
10%

160

150

140

130

120

110

100

90

80

70

RESULTS WITH $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ SOLUTIONS

In order to check the validity of the empirical relationship used by the previous investigators (12), it was necessary to choose a salt with saturated solution vapor pressures very low compared to water or saturated NaNO_3 solutions and also one that had a very low heat of crystallization. Solutions of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ meet these requirements because the vapor pressures at various temperatures, Fig. 9, are much lower than for water or solutions of NaNO_3 and NH_4NO_3 . The heat of crystallization, Fig. 10, is on the order of 10 B.T.U. per pound and will have no practical effect if it is ignored in psychrometric calculations. Over the temperature range used in the experimental work magnesium chloride is in the form of a hexahydrate. If research work is done with this salt, in other temperature ranges, it will be necessary to check the hydrates that are formed before it can be assumed that the heat of crystallization has a negligible effect upon the psychrometric measurements.

The experimental data for $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ solutions are given in Table III, and the salt solution wet-bulb temperatures are correlated with the theoretical values, Fig. 5, calculated by using equation No. 11. The data covers a dry-bulb temperature range from 77.4°F . to 130.8°F . and a corresponding wet-bulb temperature range from 58.6°F . to 115.0°F . with depres-

sions varying from 5.0°F. to 42.2°F. The range for the simultaneously determined salt solution wet-bulb temperatures varied from 76.6°F. to 152.8°F. , and the temperature rise above t_w varied from 18.0°F. to 36.8°F. The data for t_g varied from 16.9°F. below to 24.7°F. above the air stream temperature, t_g . It would be impossible to obtain accurate water wet-bulb temperatures if $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ impinged on the wick while taking readings. Assuming that the water on the wet-bulb became saturated with this salt, the lowest wet-bulb temperature data recorded in this work would cause an error of approximately 325% in the absolute humidity. Using such data any heat or moisture balances being determined would be greatly in error. Since the maximum salt solution wet-bulb temperature was 24.2°F. above the corresponding dry-bulb temperature, it would be impossible to estimate this error.

The results were correlated as experimental salt solution wet-bulb temperatures with the corresponding salt solution wet-bulb temperatures derived from equation No. 11. This correlation is shown in Fig. 5 and good agreement was obtained. When the salt solution wet-bulb temperatures, t_g , were lower than the air temperature, t_g , an excellent correlation resulted with the variation ranging from 1.2°F. less than to 0.9°F. greater than the theoretical values. Two-thirds of these temperatures were practically equal to the calculated values showing that the correlation was better than the above range of

temperature variations has indicated. When the salt solution wet-bulb temperature, t_s , was above the air temperature, t_g , the experimental values varied from 0.8°F. to 6.5°F. less than the corresponding derived values. The variation of t_s from the derived values of t_s increased slightly with increasing temperatures. This is to be expected because water vapor will condense on the wet-bulb at an increasing rate with an increasing salt solution wet-bulb temperature making it more difficult to maintain the wick saturated with $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ solution. As the salt solution concentration decreased, it gave an increased water vapor pressure and simultaneously t_s approaches t_w , the water wet-bulb temperature. It is the slight change in salt concentration with the corresponding change in the solution vapor pressure that makes the experimental values of t_s lie below the derived values of t_s as is shown in Fig. 5.

These data were correlated by the method of the previous investigators (12) and the results were far worse. In this correlation shown on Fig. 7 the empirical results were from 6.4°F. to 14.4°F. less than the corresponding water wet-bulb temperatures. In this case the heat of crystallization amounted to less than 10 B.T.U. per pound of water vapor transferred and had no practical effect upon the temperatures. This indicates that vapor pressure lowering caused by the salt solutions is the primary factor to be considered in the derivation of a new theory, and definitely shows that the empirical rela-

tionship (12) for converting the experimental salt solution wet-bulb temperatures to water wet-bulb temperatures by isobaric readings from the respective vapor pressure curves for the salt solution and pure water is in error.

The empirical correlation of the experimental t_s values by the method of Williams, G. C. and Williams, R. J. (12) gave a variation of from 6.4°F. to 14.4°F. less than corresponding water wet-bulb temperature, t_w . When correlating the data as proposed in this report, the variation was 1.2°F. less than to 0.9°F. greater than the calculated t_s values when t_s was less than t_g . When t_s was greater than t_g , the experimental values of t_s varied from 0.8°F. to 6.5°F. less than the values of t_s calculated by using equation No. 11. By comparing variations from the two methods of correlation, it is seen that the maximum deviation of 6.5°F. shown by the new theory is approximately equal to the minimum deviation of 6.4°F. obtained by the method used by the previous investigators (12). When t_s is less than t_g , the proposed method is very accurate, but it becomes less accurate at high humidities. In either case considerable improvement is obtained in the correlation.

A humidity chart, Fig. 6, was constructed for saturated solutions of $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ using equation No. 11 for calculating the adiabatic wet-bulb lines. The curves showing the percent relative humidity are the same as for the standard air-water vapor humidity chart.

TABLE III
DATA FOR $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ SOLUTIONS

Run No.	° F.			mm. Hg			Btu/lb.			° F.	
	T	T _w	T _s	P _w	P _g	P _s	λ _w	λ _s	C	T _s Calc.	
1	112.1	92.0	120.6	38.5	32.30	27.3	1040.7	1024.8	8.5	123.3	
2	108.5	93.4	123.3	40.1	36.21	29.4	1040.0	1023.3	8.5	126.0	
3	114.3	93.6	123.3	40.3	35.98	29.4	1039.9	1023.3	8.5	126.3	
4	114.4	93.9	122.9	40.8	35.49	29.1	1039.7	1023.5	8.5	126.8	
5	111.2	96.8	126.0	44.6	40.83	31.6	1038.1	1021.7	8.5	130.8	
6	110.8	96.6	126.7	44.3	40.64	32.2	1038.2	1021.3	8.5	130.6	
7	110.1	96.4	126.3	44.1	40.54	31.9	1038.3	1021.6	8.5	130.3	
8	111.6	102.0	132.4	52.2	49.68	37.2	1035.2	1018.0	8.6	138.5	
9	110.8	102.4	133.2	52.8	50.60	37.8	1035.0	1017.5	8.6	139.1	
10	77.4	58.6	76.6	12.6	7.87	7.6	1059.0	1048.2	8.2	77.5	
11	84.6	69.4	88.5	18.4	14.56	11.2	1053.0	1042.7	8.3	92.6	
12	94.3	73.8	96.1	21.3	16.09	13.8	1050.9	1038.5	8.3	99.0	
13	94.6	81.5	104.4	27.5	24.18	17.6	1046.5	1033.9	8.4	109.7	

Run No.	° F.			mm. Hg			Btu/lb.			° F.	
	T	T _w	T _a	P _w	P _g	P _s	h _w	h _g	C	T _a	Calc.
14	92.5	81.0	104.4	27.1	24.10	17.6	1046.7	1033.9	8.4	108.8	
15	92.8	83.3	107.2	29.2	26.73	19.0	1045.5	1032.3	8.4	112.1	
16	94.8	86.2	111.4	32.0	29.79	21.4	1043.9	1030.0	8.4	116.2	
17	95.7	85.8	111.4	31.6	29.08	21.4	1044.2	1030.0	8.4	115.7	
18	98.2	92.3	118.4	38.8	37.24	25.7	1040.6	1026.0	8.5	124.5	
19	96.8	91.6	117.9	37.9	36.58	25.4	1041.0	1026.3	8.5	123.6	
20	110.1	70.0	93.2	18.8	8.53	12.7	1052.7	1040.1	8.3	93.4	
21	98.1	65.7	87.1	16.2	7.91	10.7	1055.1	1043.4	8.2	87.2	
22	108.0	68.9	92.1	18.1	8.12	12.3	1053.4	1040.6	8.3	91.9	
23	113.5	96.3	124.3	43.8	39.62	30.2	1038.4	1022.6	8.5	130.3	
24	114.1	88.5	106.1	34.5	27.88	24.2	1042.7	1027.4	8.5	119.5	
25	113.0	86.9	114.1	32.7	25.71	22.9	1043.5	1028.5	8.4	116.9	
26	112.5	87.3	114.1	33.1	24.04	22.9	1043.3	1048.5	8.4	114.9	
27	109.0	84.7	111.0	30.6	24.05	21.1	1044.7	1030.2	8.4	113.9	
28	106.3	84.0	109.8	29.9	24.13	20.4	1045.0	1030.9	8.4	113.2	

Run No.	° F.			mm. Hg			Btu/lb.			° F.
	T	T _w	T _s	P _w	P _g	P _s	λ _w	λ _s	C	T _s Calc.
29	100.0	73.0	97.9	20.8	13.90	14.5	1051.1	1037.5	8.3	97.8
30	130.8	95.0	129.2	42.2	32.91	34.3	1039.1	1019.8	8.6	128.3
31	130.6	94.5	128.3	41.5	32.12	33.6	1039.3	1020.3	8.5	127.6
32	130.5	101.4	135.7	51.2	43.63	40.0	1035.6	1016.1	8.6	137.6
33	129.7	107.2	141.1	60.9	55.00	45.3	1032.3	1013.0	8.7	146.0
34	129.9	108.5	141.4	63.1	57.54	45.7	1031.6	1012.7	8.7	147.8
35	127.2	93.7	126.3	40.6	31.91	31.9	1039.8	1021.5	8.5	126.5
36	125.6	102.4	134.8	52.7	46.69	39.2	1035.0	1016.6	8.6	139.1
37	127.0	105.6	139.3	58.0	52.46	43.4	1033.2	1014.0	8.6	143.7
38	127.4	106.0	138.4	58.7	52.08	42.5	1033.0	1014.5	8.6	143.4
39	121.5	103.5	135.3	54.4	49.76	39.7	1034.3	1016.3	8.6	140.5
40	119.8	96.4	127.4	44.1	38.02		1038.3	1020.9	8.5	130.4
41	119.3	94.1	124.5	41.0	34.50	30.4	1039.6	1022.5	8.5	127.0
42	90.0	70.0	92.5	18.8	13.67	12.3	1052.7	1040.5	8.3	93.4
43	85.6	76.2	98.8	23.1	20.71	14.9	1049.4	1037.0	8.3	102.2

Run No.	° F.			mm. Hg			Btu/lb.			° F.	
	T	T _w	T _s	P _w	P _g	P _s	λ _w	λ _s	C	T _s Calc.	
44	83.8	78.3	101.1	24.8	23.34	15.9	1048.3	1035.7	8.3	105.1	
45	82.8	63.9	83.7	15.2	11.38	9.5	1056.1	1045.3	8.2	86.4	
46	82.8	69.6	90.3	18.5	15.18	11.7	1053.0	1041.7	8.3	92.8	
47	81.7	70.7	91.2	19.2	16.43	12.0	1052.4	1041.2	8.3	94.6	
48	79.7	73.6	95.0	21.2	19.89	13.4	1050.9	1039.1	8.3	99.0	
49	81.1	74.0	94.8	21.5	19.70	13.3	1050.6	1039.2	8.3	99.2	
50	84.1	72.0	93.6	20.1	19.52	12.8	1051.6	1039.9	8.3	100.0	
51	83.5	76.5	99.1	23.3	21.54	15.0	1049.2	1036.9	8.3	102.6	
52	82.9	77.9	100.2	24.5	23.18	14.7	1048.5	1036.2	8.3	104.5	
53	83.3	74.4	96.6	21.8	19.50	14.0	1050.4	1038.2	8.3	99.7	
54	128.1	115.0	152.8	76.0	72.60	58.7	1027.9	1006.0	8.8	157.5	
55	130.3	88.1	118.9	34.0	23.15	26.1	1042.9	1025.7	8.5	118.9	

EXPERIMENTAL TEMPERATURE - T_s - °F

150

140

130

120

110

100

90

80

70

70

80

90

100

120

120

130

140

150

CALCULATED TEMPERATURE - T_s - °F

FIG. 5.

COMPARISON OF DERIVED AND EXPERIMENTAL WET BULB TEMPERATURES WITH
SATURATED $MgCl_2 \cdot 6H_2O$ SOLUTION

○ $T_s > T_G$
△ $T_s < T_G$

ABSOLUTE HUMIDITY LBS. H₂O PER LB. DRY AIR

0.10
0.08
0.06
0.04
0.02
0.00

60 70 80 90 100 110 120 130 140

TEMPERATURE °F

ADIABATIC WET BULB LINES WITH SATURATED $MgCl_2 \cdot 6H_2O$ SOLUTION
FIG. 6.

GENERAL DISCUSSION OF RESULTS

The results obtained with the three saturated salt solutions correlated excellently when t_s was less than t_g . (i.e. low humidities) When t_s was greater than t_g the correlations with the values of t_s calculated by using equation No. 11 were good but inferior to the previous case. In general where t_s was greater than t_g , it was observed that the quality of the results decreased as t_s increased. This decrease in accuracy is suspected to be due to the difficulty of maintaining a saturated salt solution on the wick of the wet-bulb thermometer. With water condensing rapidly it was extremely difficult to maintain a saturated solution on the wick. Furthermore, the greater the temperature difference for isobaric readings obtained from the water and salt solution vapor pressure curves when t_s is greater than t_g , the greater the condensation of water vapor becomes because the vapor pressure of the salt solution is lower and a greater driving force ($p_g - p_s$) for diffusion is set up.

There are two factors which change the wet-bulb temperatures when using salt solutions. The most important factor is the change in vapor pressure of water caused by the addition of soluble salts. The lower the salt solution vapor pressure, the greater the difference between t_w and t_s becomes in order to maintain equilibrium adiabatic conditions. This fact is

readily observed by comparing the experimental data or the humidity charts for the three salt solutions. The second factor to be considered is the heat of crystallization or solution. This heat must be considered for all salt solutions if adiabatic conditions are to be used. The heat evolved per pound of water evaporated is shown in Fig. 10 for saturated solutions of NaNO_3 , NH_4NO_3 , and $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$. Comparison of the heats of crystallization with the latent heat of vaporization shows that the heat of crystallization can not be neglected for any salt solution if accurate salt solution wet-bulb temperatures are to be obtained. A comparison of the heats of crystallization and the latent heat of vaporization for water indicates that the error caused by neglecting the heat of crystallization amounts to approximately 1% for $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, 6% for NaNO_3 , and 20% for NH_4NO_3 . Thus it would be practical to neglect the heat of crystallization for $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ solutions but not for NH_4NO_3 solutions.

A comparison of the two methods of correlation for NaNO_3 show very little difference in the results but the data correlated by this later theory appears to be better. There is further evidence of an improved method of correlation when NH_4NO_3 data is observed. This salt introduces a large correction for the heat of crystallization and has a relatively low vapor pressure. This heat of crystallization is neglected in the earlier method of correlation (12). The third salt stud-

ied, $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, has a low vapor pressure and practically no heat of solution effect. Comparison of the two methods of correlation indicate that the last proposed method is far superior. This is particularly noticeable when t_s is less than t_g . Thus the comparisons of t_s calculated by using equation No. 11 with the simultaneously determined value of t_s indicates that the postulated equation, No. 11, is substantially correct, and the correlation used by Williams, G. C. and Williams, R. J. (12) is insufficient.

In order to compare the effects of various saturated salt solutions on the wet-bulb temperatures a humidity chart, Fig. 8, has been constructed with adiabatic wet-bulb temperature lines shown for water and saturated solutions of the three salt solutions studied at temperatures of 80°F . and 120°F . This chart shows the tremendous differences between the wet-bulb temperatures for pure water and the saturated salt solutions at given air temperature and humidity conditions. If 130°F . wet-bulb readings are obtained for water and solutions of NaNO_3 , NH_4NO_3 , and $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$ at 100% relative humidities for the air, the corresponding dry-bulb temperatures are 130°F ., 117°F ., 106°F ., and 96.3°F . Thus under these conditions of equal wet-bulb temperatures and 100% relative humidity there is a variation of 33.7°F . between corresponding dry-bulb temperatures. This increase in wet-bulb temperature could be very important if it were necessary to obtain an accurate mois-

ture content in air at a very low humidity and low air velocity. Using water as the bulb wetting liquid under these conditions would be difficult and inaccurate because radiation would effect the results showing a high humidity. By the proper choice of a salt solution the temperature difference between t_g and t_s could be much smaller with a resultant decrease in radiation effect.

FIG. 7.
RELATION OF MEASURED WET BULB TEMPERATURES AND VALUES CALCULATED
FROM SALT SOLUTIONS BY THE METHOD OF WILLIAMS (12)

COMPARATIVE EFFECT OF BULB WETTING LIQUID ON ADIABATIC WET BULB TEMPERATURE
FIG. 8.

CONCLUSIONS
AND
RECOMMENDATIONS

The experimental results indicate the following conclusions concerning the effect of water soluble salts on the wet-bulb temperature.

1. The lowering of the vapor pressure of water by the addition of a water soluble salt is of primary importance because it produces an adiabatic temperature above the normal water wet-bulb temperature.
2. The salt solution wet-bulb temperature becomes equal to the dry-bulb temperature at a vapor pressure below that of saturated air. As the vapor pressure at the salt solution wet-bulb interface approaches the pressure required for saturated conditions, the salt solution wet-bulb temperature becomes greater than the dry-bulb temperature.
3. The effect of the heat of crystallization is important if the heat of crystallization is considerable as in the case of NH_4NO_3 . When the effect of the heat of crystallization is very small, i.e. $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$, it has no appreciable effect on the wet-bulb temperature.
4. A revised psychrometric formula is postulated as follows:

$$(\lambda_s - G)(p_s - p_g) = \frac{h}{k_g}(t_g - t_s)$$

RECOMMENDATIONS

In this work it was assumed that the value of $\frac{h}{k_g}$ was the same for saturated salt solutions as for pure water. It is recommended that the following work be done to check the postulated equation.

1. Experimentally determine values for $\frac{h}{k_g}$ for various salt solutions.
2. Extend the salt solution wet-bulb temperature range obtaining t_g values less than and greater than t_g for the salts studied.

A P P E N D I X

SAMPLE CALCULATIONS

The following experimental data for NH_4NO_3 will be used to demonstrate the method of calculation used in comparing the experimental saturated salt solution wet-bulb temperature with the calculated temperature using the modified psychrometric formula.

$$t_g - - - - - 108.6^\circ\text{F.}$$

$$t_w - - - - - 103.6^\circ\text{F.}$$

$$t_s - - - - - 124.75^\circ\text{F.}$$

Using equation No. 5 the partial pressure of the water vapor in the bulk of the air is

$$\lambda_w (p_w - p_g) k_g A = h A (t_g - t_w)$$

$$\text{or } p_g = p_w - \frac{h}{k_g \lambda_w} (t_g - t_w)$$

$$\text{Where } \lambda_w = 1034.2 \text{ Btu. per pound}$$

$$p_w = 54.737 \text{ mm. H}_g$$

$$\frac{h}{k_g} = 0.354 \quad (9)$$

$$p_g = 54.74 - \frac{0.354 \times 760}{1034.2} (108.6 - 103.6) = 53.44 \text{ mm. H}_g$$

Solving equation No. 11 for t_s

$$t_s = t_g - \frac{(\lambda_s - C)(p_s - p_g)}{\frac{h}{k_g}} = t_g + \frac{(\lambda_s - C)(p_g - p_s)}{\frac{h}{k_g}}$$

$$\text{Where } p_s = 45.45 \text{ mm. H}_g \text{ (Fig. 9) at } 124.75^\circ\text{F.}$$

$$\lambda_s = 1022.55 \text{ Btu. per pound}$$

$$C = 246.7 \text{ Btu. per pound (Fig. 10)}$$

Solving this equation by trial and error assuming 124.75°F.
data

$$t_s \text{ Calc.} = 108.6 + \frac{(1022.35 - 246.7)(53.44 - 45.45)}{0.354 \times 760} = 131^\circ\text{F.}$$

Since t_s , calculated, is greater than the experimental temperature, it indicates that the experimental t_s is low. Assuming a new t_s the above calculation is repeated.

Assuming $t_s = 126.5^\circ\text{F.}$

$$p_s = 47.23 \text{ mm. H}_g$$

$$t_s \text{ Calc.} = 108.6 + \frac{(1022.5 - 246.7)(53.44 - 47.23)}{0.354 \times 760} = 126.46^\circ\text{F.}$$

Since the assumed temperature, $t_s = 126.5^\circ\text{F.}$, is approximately equal to the calculated temperature, $t_s = 126.46^\circ\text{F.}$, the result is considered as a calculated solution.

Using the same data the effect of neglecting the heat of crystallization will be examined.

$$t_s = 108.6 + \frac{1022.35 (53.44 - 45.45)}{0.354 \times 760} = 139.0^\circ\text{F.}$$

Since t_s , calculated, is greater than the experimental temperature, the experimental temperature, t_s , is too low and a new value will have to be assumed:

Assuming $t_s = 127.7^\circ\text{F.}$

$$p_s = 48.4 \text{ mm. H}_g$$

$$\lambda_s = 1020.7 \text{ Btu. per pound}$$

$$t_s = 108.6 + \frac{1020.7 (53.44 - 48.4)}{0.354 \times 760} = 127.7^\circ\text{F.}$$

In this case the calculated equilibrium temperature, 127.7°F. is 1.2°F. greater than the equilibrium temperature obtained when the heat of crystallization is considered.

DETERMINATION OF C

The values of C were obtained in the following manner:

$$\frac{\text{Heat of solution (kg. Cal./gm. mol. salt) (1800)}}{\text{Mol. wgt. salt}} =$$

Heat of Solution(Btu./lb. salt dissolved)

$$\frac{\text{Btu.}}{\text{lb. salt dissolved}} \times \frac{\text{lbs. salt}}{\text{lbs. water}} = \text{Btu./lb. water}$$

The solubility data was obtained from the International Critical Tables (7) and the heat of solution data was obtained from Thermochemistry of Chemical Substances (3) by taking the difference between the heat of formation for crystalline salt and the heat of formation at various dilutions.

C - B.T.U. PER LB. H₂O EVAPORATED

280

240

200

160

120

80

40

0

-40

 NH_4NO_3 NaNO_3 $\text{MgCl}_2 \cdot 6\text{H}_2\text{O}$

TEMPERATURE °F

HEAT OF CRYSTALLIZATION FOR AQUEOUS SOLUTIONS
FIG. 10.

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He attended the elementary schools at Greencastle and later moved to Indianapolis, Indiana, where he attended Arsenal Technical High School.

He received a Bachelor of Science degree in Chemical Engineering at Purdue University in June, 1936. Attending the University of Louisville, he obtained the degree of Master of Chemical Engineering in October, 1944. His thesis, "Humidity Measurement in Presence of Water Soluble Salts", was performed under the direction of Dr. G. C. Williams.

From June, 1936, to July, 1944, he was employed as a Chemical Engineer by Joseph E. Seagram & Sons Company, and in July, 1944, he joined the Louisville Drying Machinery Company as Chemical Engineer.