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## AN ELECTRICAL METHOD FOR THE DETERMINATION OF THE DEW- POINT OF FLUE GASES

BY

HENRY FRASER JOHNSTONE



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HENRY FRASER JOHNSTONE  
SPECIAL RESEARCH ASSOCIATE IN CHEMICAL ENGINEERING

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# AN ELECTRICAL METHOD FOR THE DETERMINATION OF THE DEW-POINT OF FLUE GASES

## I. INTRODUCTION

1. *Importance of Determination of Dew-point of Flue Gases.*—In studying the corrosion of metals by flue gases, one of the questions of great importance is what is the highest temperature at which a liquid phase will exist on the metal surface in equilibrium with the gas. Such a liquid phase would influence the rate of corrosion not only because of the presence of a film of acid, but also because other corroding agents, such as a sulphate scale, will be brought into close contact with the metal, with a consequent better chance for reacting. In all probability the rate of corrosion would be greatest at the temperature of the dew-point, because of the combined action of the acid film and of the better contact of the scale. At higher temperatures there is probably some reaction between the gas and the metal, with the scale acting as an intermediate agent. At temperatures below the dew-point the action probably decreases due to the ordinary temperature coefficient of chemical reactions.

2. *Previous Estimates of Dew-point of Flue Gases.*—Various estimates of the dew-point of furnace gases have been made. Unfortunately, most writers have not realized that a trace of sulphuric acid vapor materially affects the temperature at which liquid will first be formed.

J. N. Waite\* has calculated the dew-point temperatures for furnace gases resulting from the complete combustion of typical coals and oils for various percentages of excess air. He defines the dew-point temperature as the temperature at which water vapor begins to be deposited as liquid water, a definition which is too specific when acid vapor is present. For Waite's purposes, however, viz., the effect of the dew-point on boiler efficiency, no great error is introduced by the use of this definition.

B. M. Thornton† also disregards the effect of acid vapor on the dew-point, and calculates the temperature at which liquid will first form from the percentage of carbon dioxide in the gases, basing his result on the percentage of moisture and hydrogen in the original fuel, and on the humidity of the outside air. Both of these writers undoubt-

\*J. N. Waite, "The Dew-point of Gases from Combustion," Elec. Rev. 94, pp. 954, 994, 1924.

†B. M. Thornton, "Economizer Corrosion and the Dew-point of Flue Gases," Power 61, p. 460, 1925.

edly obtain results which are from 20 to 200 deg. F. too low, according to the type of fuel considered.

J. F. Barclay,\* on the other hand, takes into consideration the effect of the presence of sulphuric acid vapor in the gases on the dew-point. He states that, as the flue gas temperature drops the sulphur trioxide gas begins to unite with the water vapor, forming sulphuric acid vapor, until at the boiling point of concentrated sulphuric acid (about 620 deg. F.) practically all of it is united. This acid vapor condenses in the same way as water vapor. "On condensation," he writes, "it first appears as an acid of 98.3 per cent concentration, which becomes diluted by the absorption of water upon further cooling." Using the data of Thomas and Barker† for the partial pressures of sulphuric acid vapor over 98.3 per cent sulphuric acid he calculates the temperature at which liquid will begin to form from the partial pressures of sulphuric acid in the gases as determined by analysis.

According to the laws of physical chemistry the vapor in equilibrium with a liquid composed of two or more components must contain the same components in a definite ratio for each temperature. For any definite ratio in the gas phase, therefore, there will be a temperature at which a liquid will be in equilibrium with the gas. The concentration of the liquid will depend upon the value of this ratio and on the sum of the partial pressures of the components. The liquid condensed from flue gases containing sulphuric acid vapor will not be 98.3 per cent sulphuric acid, therefore, except for one definite concentration of sulphuric acid and water vapor in the gases. Actually the concentration of the acid which first forms varies between 60 and 90 per cent according to the gas analyses from several different coals. The dew-points, as well as the concentration of acid first condensed, as calculated by Barclay, are somewhat too high. Furthermore, the values of the sulphur trioxide concentration in the gases as given in Barclay's paper, unfortunately, are also in error because of inaccuracies in the method used for the analysis of the flue gases.

In a later section of this circular a method of calculating the dew-point of the flue gases from the concentrations of sulphur trioxide and of water vapor in the gases will be described. For this calculation data are required for the partial pressures of water and of sulphuric acid over acids of high concentrations for temperatures between 100 and 500 deg. F. Unfortunately, measurements for the entire range have not been made.

\*J. F. Barclay, "The Sulphur Problem in Burning Coal," Bureau of Mines Tech. Paper No. 436, 1928.

†J. S. Thomas and W. F. Barker, "The Partial Pressures of Water Vapor and of Sulphuric Acid Vapor over Concentrated Solutions of Sulphuric Acid at High Temperatures," J. Chem. Soc. (London) 127, p. 2820, 1925.

3. *Difficulties in Determining Dew-point of Flue Gases.*—For the determination of the dew-point of flue gases the ordinary psychometric method is useless. As previously stated in a gaseous system containing two or more condensable components the temperature at which the liquid phase will first appear depends upon the partial pressures of each of the condensable components and also upon the nature of these components. If the ordinary method of determining the dew-point were used, based on the heat of evaporation of a sufficient quantity of liquid to saturate the gas in the immediate neighborhood of the wet bulb, not only the composition of the liquid and of the gas phases would be required, but also a large amount of data on the heats of vaporization of the solutions. In most cases, therefore, the psychometric method cannot be used, and a more direct method for determining the dew-point must be sought.

Of the methods for the direct determination of the dew-point that have been described in the literature, the one most likely to be useful for flue gases is based on the observation of a highly polished metal surface,\* the temperature of which can be adjusted until the dew forms, and over which the gaseous mixture is passed. This method has been used for gasoline vapor-air mixtures. The difficulties in observing the formation of the liquid phase from flue gases are apparent. Furthermore, since the dew-point varies with the boiler operation, some method of recording is greatly desirable. In this circular a method will be described that is based on new principles. It has been used successfully for flue gases, and probably can be used for other vapors. Furthermore, since it is an automatic recording device it may find uses as a method for the control of humidity and of the dew-point.

4. *Acknowledgment.*—The apparatus and relationships described here are some results of a study being carried on in the Engineering Experiment Station of the University of Illinois on the prevention of corrosion by flue gases. The problem has been under the administrative direction of Dean M. S. KETCHUM, Director of the Experiment Station, and of Prof. D. B. KEYES, Head of the Division of Industrial Chemistry. The work is a coöperative investigation in conjunction with the UTILITIES RESEARCH COMMISSION OF CHICAGO. The Commission represents the Commonwealth Edison Company, the Public Service Company of Northern Illinois, the Middle West Utilities Company, The People's Gas, Light and Coke Company, the Chicago Rapid

\*W. A. Gruse, "Direct Determination of Dew-points of Gasoline-Air Mixtures," Ind. Eng. Chem. 15, 796, 1923; cf. also

O. C. Bridgeman, Amer. Pet. Inst.-Refining Tech., Jan., 1929, for a description of other methods and references to the literature.

Transit Company, the Chicago North Shore and Milwaukee Railroad Company, the Midland United Company, and Sargent and Lundy.

## II. AN ELECTRICAL METHOD FOR DETERMINING DEW-POINT OF FLUE GASES

5. *Principle of Method.*—When a liquid condenses on the surface of a dielectric, the electrical conductivity of the surface is increased if the resistance of the liquid is less than that of the surface on which it condenses. If two platinum electrodes are imbedded in a glass surface and a potential difference of 100 volts is placed across the gap, a noticeable deflection of a sensitive galvanometer included in the circuit can be obtained when the breath is blown on the surface in such a way that dew is formed. The galvanometer returns to zero simultaneously with the disappearance of the film across the gap. If, now, the current is amplified by means of a thermionic tube, a relay of high resistance can be operated by the formation and disappearance of the dew. This relay in turn can be made to operate a less sensitive relay that will make and break a lighting or heating current.

It is realized, of course, that a glass surface will adsorb gases, and that, for a given concentration of the condensable vapors, the adsorption increases as the temperature is lowered. There is no distinct boundary between the state of adsorbed vapor and that of condensation. It is known, however, that, in the adsorption of gases, after the first layer of molecules is formed the other layers adhere quickly, so that there is only a small temperature range between the state of the monomolecular layer and that of saturation. Since the adsorbed film is removed only by heating to a high temperature, it might be expected that the dew would form more quickly on a surface on which it had formed before. This was found to be true in the determinations to be described. In this connection the question may also be raised as to the exact definition of the dew-point. Since for all substances it is conceded that there is a gradual transition from the gaseous to the liquid state rather than an abrupt line of demarcation between the two states, the dew-point must correspond to the zone of transition between the two phases rather than to any definite temperature for which it can be said that liquid first forms.

6. *Accuracy of Electrical Method.*—In order to determine the availability of the method for the accurate measurement of the dew-point the conductivity of a glass surface between two platinum electrodes was measured at different temperatures. For this purpose a

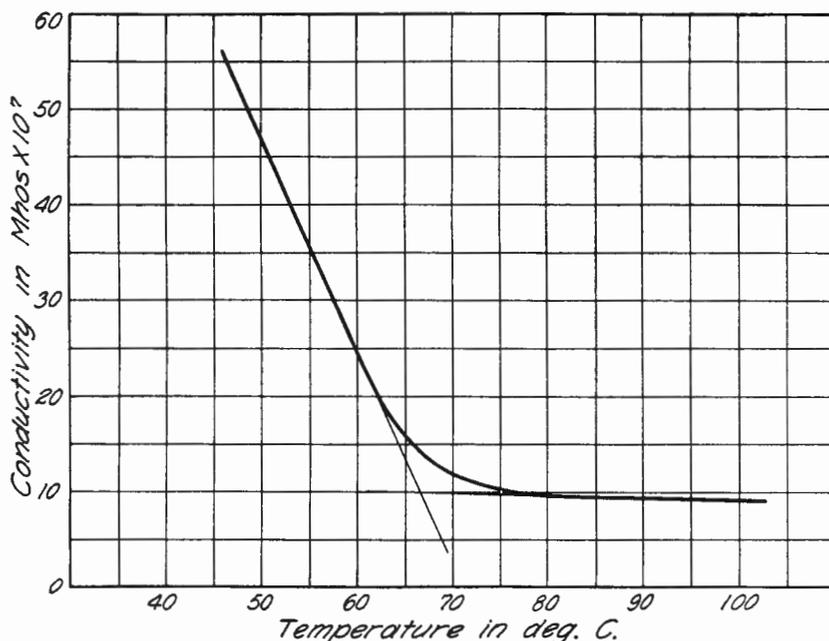


FIG. 1. CONDUCTIVITY TEMPERATURE CURVE FOR GLASS SURFACE

cabinet containing gases of a definite constant composition was used. The composition of the gas was approximately that found in furnace gases, containing 9.1 per cent  $\text{CO}_2$ , 6.0 per cent  $\text{O}_2$ , 72.1 per cent  $\text{N}_2$ , 12.6 per cent  $\text{H}_2\text{O}$ , 0.21 per cent  $\text{SO}_2$ , and 0.004 per cent  $\text{SO}_3$ , by volume. (The composition of this gas corresponds to a normal dew-point, in the absence of  $\text{SO}_3$ , of 50.8 deg. C., or 123.6 deg. F.) The electrodes were sealed on the outer surface of a glass tube. Adjacent to these there was sealed a chromel-alumel thermocouple. The surface of the tube could be heated or cooled at any desirable rate by a jet of air directed against the inner surface. The temperature was obtained from the potential of the thermocouple as determined with a potentiometer and a low resistance galvanometer. The conductivity of the gap was determined by applying a constant potential of 85 volts from a cell and measuring the current with a sensitive milliammeter. The resistance of the cell and of the meter was negligible compared to that of the gap. The values obtained for the cooling curve are plotted in Fig. 1. Those for the heating curve were not reproducible, evidently because equilibrium was not established in the evaporation-adsorption process. The curve in Fig. 1 shows that as the temperature

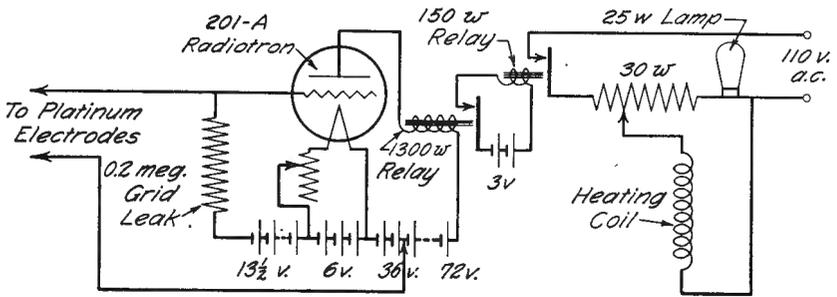


FIG. 2. ELECTRICAL CONNECTIONS FOR DEW-POINT APPARATUS

falls the conductivity of the glass remains approximately constant until the neighborhood of the dew-point is reached. Here the adsorption of the gas by the glass surface increases the conductivity gradually until saturation is reached. Then the conductivity increases rapidly, and the slope of the curve again becomes constant.

As predicted, there is a transition zone in the neighborhood of the dew-point in which the properties of the adsorbed vapor are closely related to and rapidly approaching those of the new liquid film. It is difficult to state just when the new phase appears. Undoubtedly the same conditions exist on all surfaces near the saturation point, and no definite temperature can be said to be that at which the properties of the liquid first appear. The transition zone evidently depends on the adsorption of the vapor. For substances which are only slightly adsorbed by glass there should be a more pronounced break between the state of adsorption and that of the liquid film.

For present purposes it is satisfactory to assume an arbitrary point in the transition zone as the dew-point. If tangents are drawn to the two branches of the curve at points where the slope becomes approximately constant they will intersect at a point which should closely correspond to the dew-point if there were no adsorption. In the present case this point is between 67 and 70 deg. C., and corresponds to a conductivity of  $10.0 \times 10^{-7}$  mhos. Using the electrical set-up shown in Fig. 2 it is now possible to determine what conditions give the maximum amplification for a conductivity of  $10.0 \times 10^{-7}$  mhos. With this arrangement errors due to a lag in the instrument will be reduced to a minimum. The values indicated in Fig. 2 have been found to give good performance. Small variations from these values do not affect the accuracy of the instrument. The 1300-ohm relay was set to operate between 1.5 and 2.0 milliamperes. For the gas mixture considered this represents a range of between 67 and 70.5 deg. C.

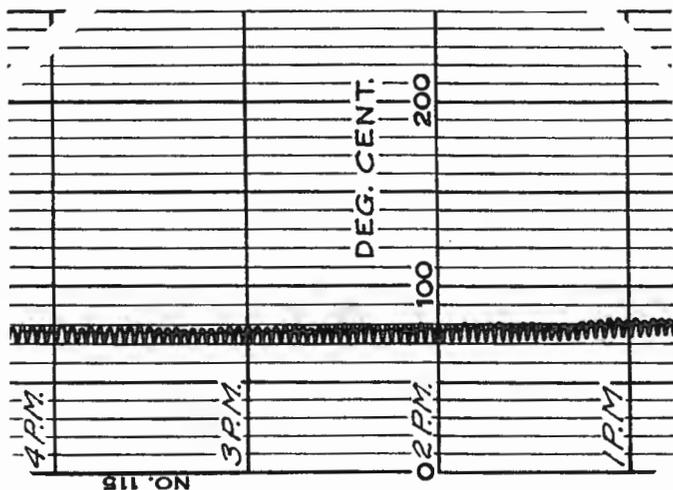


FIG. 3. RECORDED DEW-POINT OF GAS MIXTURE

The dew-point apparatus was now used to determine the dew-point of the constant gas mixture. Figure 3 shows a reproduction of the actual chart produced on the temperature recorder. The results are evidently closely reproducible.

In order to further check the accuracy of the instrument the dew-point of a gas containing water vapor with no other condensable component was determined. The humidity of the gas was determined by analysis. The calculated dew-point from the humidity was 41.1 deg. C. The instrument recorded the appearance of the new phase at 41 deg. This agreement is perhaps fortuitous, and is probably better than that corresponding to the accuracy of the instrument, especially if sulphur trioxide were present.

7. *Apparatus for Determination of Dew-point.*—The apparatus used for the determination of the dew-point of flue gases is shown in Fig. 4. Figure 2 is a diagram of the electrical connections.

As shown in Fig. 4, the flue gases are drawn directly from the furnace setting at a point where the temperature of the gases is such that no condensation can take place before they reach the apparatus. The gases enter a 1½ x 6-in. nipple and pass through a thick layer of glass wool, which acts as a filter for any solid material carried by the gases. They then pass around the glass thimble, on the outer surface of which are imbedded the two platinum electrodes and the thermo-

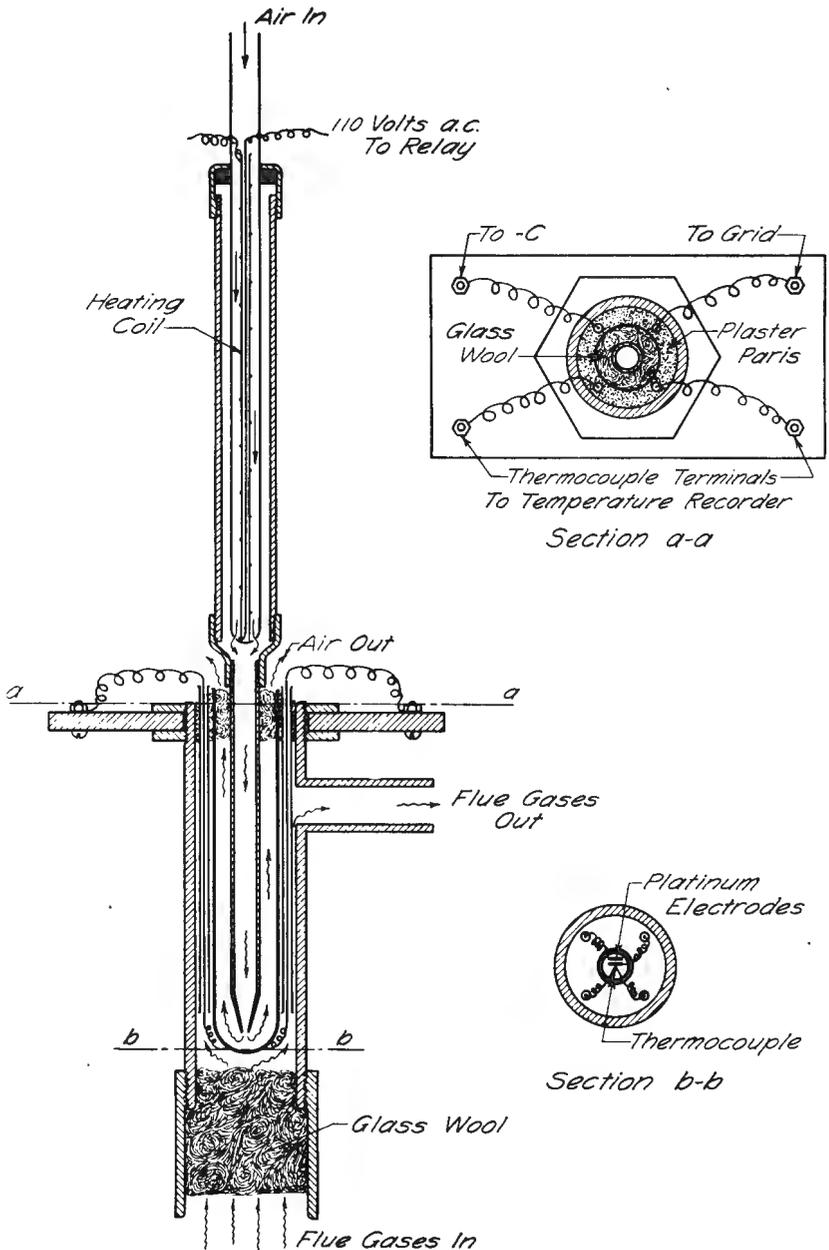


FIG. 4. APPARATUS FOR DETERMINING DEW-POINT OF GASES

couple. A jet of cold air cools this surface from the inside. In entering the apparatus this air passes through a large glass tube (12 mm. Pyrex) and around a smaller glass tube (4 mm. Pyrex). On the smaller tube is wound 15 ft. of "Chromel A" resistance wire, B. and S. gage No. 26. One end of the wire passes up through the small glass tube, so that both the terminals are brought out of the larger tube by sealing them through the glass. A section of  $\frac{1}{2}$ -in. pipe serves as a case for the glass tube. Air passes through holes in the end of the larger tube and into the nozzle at the lower end of the pipe.

When the temperature of the surface of the glass thimble has been lowered to the dew-point the large increase in conductivity of the gap causes a much greater increase in the plate current through the relay. The closing of this relay in turn causes the second relay to close the circuit of the heating coil. The heating coil then heats the air so that the surface of the glass is no longer being cooled, but the dew is being driven away by an elevation of the temperature. As soon as the liquid film breaks, the contacts are opened and the air again begins to cool the surface.

The temperature of the surface on which the dew forms is recorded by the thermocouple imbedded beside the electrodes in the glass, and attached to a temperature recorder. For obtaining the results discussed in the following section a chromel-alumel couple of No. 22 B. and S. gage was used. The temperature recording instrument was a Leeds and Northrup potentiometric type with scale reading from 0 deg. to 1000 deg. C. An instrument with a shorter range would probably give better results.

During the operation of the apparatus the temperature recorder shows a minimum at the dew-point. When the dew forms, the current in the heating coil is momentarily turned on and the temperature rises until the film breaks. The rise in temperature shown by the recorder during the evaporation will depend on the rate of the heating of the air and the velocity with which the flue gases sweep the glass surface. The rate of heating was adjusted by means of a 30-ohm rheostat in series with the heating current. The velocity of the flue gases was controlled by means of the air aspirator used to create the suction. For the best performance a rise of about 30 deg. C. was used. At this rate about twenty cycles of the instrument an hour were obtained. For convenience, a small lamp bulb of 25 watts was shunted across the heating coil to indicate when the instrument was operating correctly.

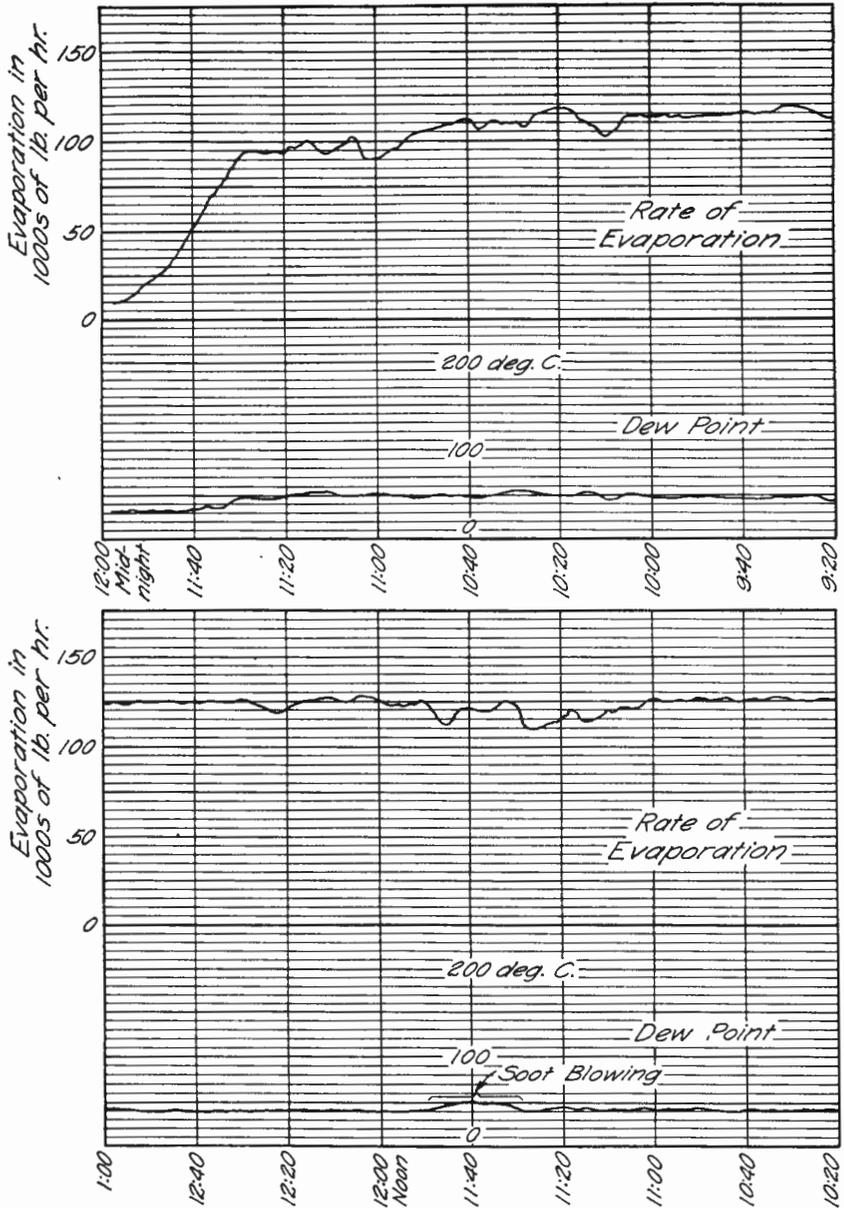


FIG. 5. FLUCTUATIONS OF DEW-POINT AND BOILER EVAPORATION—  
 LOW SULPHUR COAL

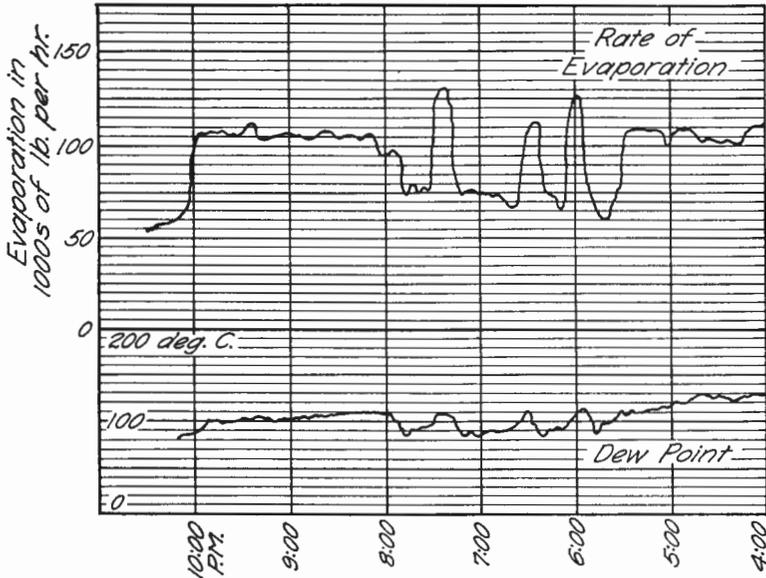


FIG. 6. FLUCTUATIONS OF DEW-POINT AND BOILER EVAPORATION—  
HIGH SULPHUR COAL

8. *Results Obtained by Electrical Method.*—The apparatus as described has been used to determine the dew-point of the furnace gases at two large central power stations. In both cases the boilers were about 1700 h.p., and were equipped with economizers and preheaters. The evaporation varied from 100 000 to 150 000 lb. per hr. during the day to 30 000 to 50 000 at night. Both boilers were stoker fired. In one case the coal used had an average sulphur content of 2.7 per cent, whereas in the other case the average sulphur content was 4.2 (as fired basis). The points of sampling were between the economizers and preheaters at the middle of the setting. The gas temperature at this point was 150-170 deg. C. (300-350 deg. F.). A continuous flow of flue gases through the apparatus was brought about by an air aspirator.

Figures 5 and 6 show typical variations of the dew-point with time for the two plants. (The dew-point curves have been plotted from the minima of the recorder readings.) For comparison, the evaporation during the same period of time has been plotted on the same chart. The values plotted were taken from Bailey Boiler Meter records. As might be expected, the dew-point fluctuations agree with those of the

TABLE 1  
DISTRIBUTION OF THE FORMS OF SULPHUR IN THE COALS

	Coal A Per cent	Coal B Per cent
Sulphate sulphur.....	0.08	0.26
Pyritic sulphur.....	1.76	1.40
Organic sulphur.....	0.42	2.58
Total sulphur.....	2.26	4.24

rating. This is particularly noticeable in the case of the higher sulphur fuel. Here a variation from 137 to 87 deg. C. (270 to 190 deg. F.) was caused by a drop in the evaporation from 110 000 to 60 000 lb. of steam per hour. The changes are undoubtedly due to a decrease in the sulphur trioxide concentration in the gases, which is determined by the amount of coal fired and the excess of air used. Fluctuations of the dew-point with the lower sulphur coal are not so noticeable as with the higher sulphur coal. The effect of the addition of moisture to the gases during the soot-blowing operation, however, causes a noticeable increase in the dew-point.

9. *Discussion of Results.*—The relation of the dew-point to corrosion has already been mentioned. For the plant using the high sulphur fuel it has been noticed that the corrosion in the economizer and preheater has been particularly severe at points where the metal temperature ranges from 175 to 300 deg. F.

Emphasis should be placed on the fact that no great concentration of sulphur trioxide is required to raise the dew-point over a considerable range. The effect of the acid vapor on the dew-point may be gathered from the following: A complete survey of the gases for sulphur dioxide and trioxide was made at each plant. Samples of gas were drawn at various points from the first pass in the boilers through the economizers and preheaters. In the case of the plant using the higher sulphur coal the average sulphur trioxide concentration was approximately 0.010 per cent, while in the other plant the average was 0.002 per cent. A difference of 0.008 per cent, therefore, is sufficient to cause a difference in the dew-point of 125 deg. F.

In this connection it is interesting to note that the sulphur trioxide concentration in the gases can be accounted for by assuming that this gas is derived from the sulphate sulphur in the coal, and without

TABLE 2  
DISTRIBUTION OF THE SULPHUR IN COAL IN COMBUSTION

	Coal A	Coal B
<u>Sulphate sulphur</u> Total sulphur—sulphate sulphur (in coal) .....	0.037	0.065
<u>Sulphur trioxide</u> <u>Sulphur dioxide</u> (in gas).....	0.015	0.028
Percentage of sulphate sulphur as SO <sub>3</sub> in gases.....	41	43

assuming any oxidation of sulphur dioxide in the furnace gases. The distribution\* of the forms of sulphur for the two coals are given in Table 1. The primary combustion of the pyritic and organic sulphur in coal results in the formation of sulphur dioxide. At high temperatures no further oxidation of the dioxide can take place. On the other hand, the temperatures at which decomposition of iron sulphate and calcium sulphate begins are 750 and 2200 deg. F., respectively. These temperatures are considerably lowered by the presence of silica and iron oxides. Evidently the temperatures in the furnace are sufficiently high for these decompositions, which yield sulphur trioxide and the metallic oxide, to take place. The sulphur trioxide concentration in the gas can be increased only by the oxidation of sulphur dioxide in the cooler parts of the system, i.e., in the economizer and preheater. If the velocity of the gases is sufficiently great in these parts, however, so that the rate of reaction is slow compared to the time of passage from the furnace to the stack, no increase in sulphur trioxide concentration will be noticed. The gas analyses actually show that this state of affairs exists. The sulphur trioxide concentration does not tend to increase at the lower temperatures. Furthermore, the sulphur trioxide/sulphur dioxide (SO<sub>3</sub>/SO<sub>2</sub>) ratios for both gases are lower than the sulphate sulphur/total sulphur — sulphate sulphur ratios in the coals. These data are summarized in Table 2.

This question opens a fruitful field for research, for if the small amount of sulphate sulphur in coal is responsible for a high dew-point an entirely different light is thrown on the problem than if the total sulphur content of the coal is responsible. Further work is being carried on to confirm these relationships if possible.

\*See "A Study of the Forms in which Sulphur Occurs in Coal," Univ. of Ill. Eng. Exp. Sta. Bul. 111, 1919.

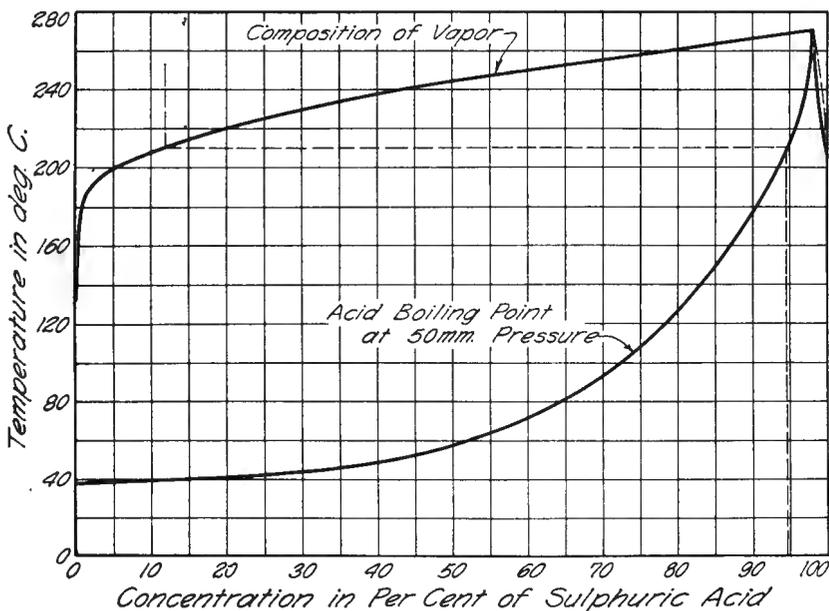


FIG. 7. BOILING POINT—VAPOR COMPOSITION CURVE FOR SULPHURIC ACID SOLUTION AT 50 MM. PRESSURE

### III. CALCULATION OF DEW-POINT FROM SULPHUR TRIOXIDE AND WATER VAPOR CONTENT OF FLUE GASES

10. *Relation between Sulphur Trioxide and Water Vapor Concentration in Gases and Dew-point.*—The relation between the sulphur trioxide and water vapor concentration and the dew-point has been shown in a preceding section. If the concentration of sulphur trioxide in the gas is accurately known it is possible to estimate the dew-point roughly by calculation from the ordinary flue gas analyses. Conversely, if the dew-point and the humidity of the gases are known it is possible to estimate the sulphur trioxide concentration.

So far as the condensable substances are concerned the gases may be considered as a two component system, viz., water and sulphuric acid. The other gases have no effect on the dew-point except in so far as dilution is concerned. The dew-point will depend, therefore, on the partial pressures of these two components. From the data of Thomas and Barker,\* and that given in the International Critical Tables,† the boiling-point-composition diagrams for solutions of sulphuric acid may be constructed for any pressure. Figure 7 shows such a diagram for

\*Thomas and Barker, *loc. cit.*

†International Critical Tables, Vol. III, p. 303.

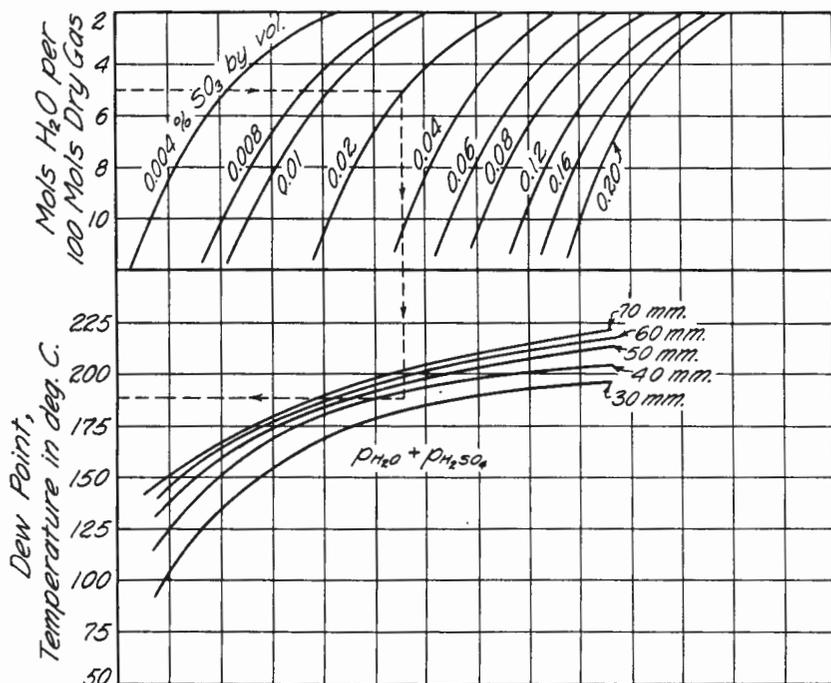


FIG. 8. DEW-POINT OF FLUE GASES FROM GAS ANALYSIS

a total pressure of 50 mm., a pressure which is approximately the sum of the partial pressures of water vapor and of sulphuric acid vapor in the gases. In this diagram the lower curve represents the boiling points of acids of various concentrations from zero to 100 per cent, i.e., the temperature at which the sum of the partial pressures of water vapor and sulphuric acid equals 50 mm. Corresponding to each point on the lower curve there is a point on the upper curve which shows the composition of the vapor in equilibrium with the acid of each concentration at its boiling point. (At the maximum point the liquid and vapor phases have the same composition; in order to have 98.3 per cent acid forming, the vapor phase must have this same composition.)

If the concentration of water vapor and sulphuric acid vapor in the vapor phase is known the temperature at which the first droplet of liquid is formed when the gases are cooled can be found. This will be the dew-point. The broken line shows what will happen when gases containing water vapor and sulphuric acid vapor in the ratio of 88:12 are cooled. At 215 deg. C. the vapors will exist in equilibrium with a liquid of the composition of 94.5 per cent sulphuric acid. Since the

liquid is much more concentrated in acid than the vapor, in a closed system the vapor will lose some of its acid due to the condensation, and the temperature of condensation will gradually decrease. At the same time the liquid condensing will become less and less concentrated. In the end, if the temperature is sufficiently low, the concentration of all the liquid condensed, of course, will be that of the original vapor, i.e., 12 per cent sulphuric acid. In an open system, such as in flue gases, the composition of the gases is constant, and the dew-point remains the same.

This is what would happen if the sum of the partial pressures of water vapor and sulphuric acid vapor were exactly 50 mm. Actually, in the flue gases this sum varies from 30 to 70 mm. By drawing several curves similar to those of Fig. 7, interpolations can be made for any value. Figure 8 represents such a diagram with the curves at 30, 40, 50, 60, and 70 mm. The upper curves are plotted from calculations\* and make it possible to find the composition of the gases in terms of water and sulphuric acid from the concentration of sulphur trioxide and of water vapor in the gases. The concentration of sulphur trioxide is determined by analysis. The concentration of water vapor is calculated from the formula:

Mols.  $H_2O$  per 100 mols. dry gas

$$y = \frac{0.66 M + 12 H}{C} \times CO_2 + 0.0144 N_2$$

\*The calculations are made as follows: The molecular ratio ( $R$ ) of  $H_2SO_4$  to  $H_2O$  in the gases is given by

$$R = \frac{\text{Per cent } SO_3}{\text{mols } H_2O \text{ per } 100 \text{ mols dry gas } (y) - \text{per cent } SO_3}$$

The weight ratio ( $r$ ) of  $H_2SO_4$  to  $H_2O$ :

$$r = R \times \frac{98}{18}$$

If  $x$  equal the weight of  $H_2SO_4$  per 100 parts of acid and water together, then

$$\begin{aligned} x &= \frac{100 r}{1 + r} \\ &= \frac{544 SO_3}{y + 4.44 SO_3} \end{aligned}$$

Expressed logarithmically,

$$\log x = \log 544 + \log SO_3 - \log (y + 4.44 SO_3)$$

For each value of  $SO_3$  (as per cent) curves may be constructed showing the variation of  $\log x$  with  $y$ . These are the curves represented.

Partial pressure of  $H_2O$ ,

$$p_{H_2O} = \frac{y \times \text{atmospheric pressure in mm. of mercury}}{100 + y}$$

Here,  $M$  = per cent moisture in coal as fired

$H$  = per cent hydrogen in coal as fired

$C$  = per cent carbon in coal as fired

$CO_2$  = per cent carbon dioxide in gases

$N_2$  = per cent nitrogen in gases

The factor 0.0144 represents a relative humidity of 66 per cent, and an air temperature of 60 deg. F.

Since the partial pressure of sulphuric acid vapor is always very small, it may be neglected in estimating the sum of the partial pressures of the acid and water vapor.

For convenience the lower curves are plotted on a logarithmic scale. An example will illustrate the use of the chart. Suppose the analysis of the gas shows a concentration of sulphur trioxide of 0.02 per cent, and the calculation shows 5 mols of water per 100 mols of dry gas. Beginning with the upper set of ordinates at the point 5 and following this ordinate through to the curve corresponding to 0.02 per cent  $SO_3$ , then down to a partial pressure of 36.2 mm. ( $5 \times 750 \div 105$ ) and then to the left to the lower set of ordinates, the dew-point is found to be 185 deg. C. (365 deg. F.).

Conversely, if the dew-point and concentration of water vapor are known it is possible to begin with the lower set of curves and proceed to the upper set to the correct ordinate and find the sulphur trioxide concentration.

Unfortunately, the vapor pressure data used in constructing the lower curves in Fig. 8 are not sufficient to allow extrapolation to the dew-points found for the combustion gases from certain low sulphur coals. With additional knowledge of the vapor pressure of sulphuric acid solutions more accurate estimations of the dew-point can be made.

#### IV. SUMMARY

11. *Summary of Conclusions.*—As the result of the investigation the following summary is made:

(1) It is possible to record the dew-point of furnace gases by means of an electrical device based on the conductivity of a glass

surface. The accuracy of the instrument is probably within 2 deg. C. for low concentrations of sulphur trioxide and 10 deg. C. for high concentrations.

(2) The concentration of sulphur trioxide greatly affects the temperature at which liquid will form.

(3) Data are presented to show that the sulphur trioxide in the furnace gases does not originate by oxidation of sulphur dioxide, but by the decomposition of the sulphates in the coal.

(4) A rough estimate of the dew-point may be made if the sulphur trioxide concentration, together with the usual Orsat data, is known for the gases.

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