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## CONDENSATION OF MOISTURE IN FLUES

A REPORT OF AN INVESTIGATION

CONDUCTED BY

THE ENGINEERING EXPERIMENT STATION  
UNIVERSITY OF ILLINOIS

IN COÖPERATION WITH

THE CLAY PRODUCTS ASSOCIATION

BY

WILLIAM R. MORGAN

SPECIAL RESEARCH ASSISTANT IN CERAMIC ENGINEERING



CIRCULAR No. 22

ENGINEERING EXPERIMENT STATION

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# CONDENSATION OF MOISTURE IN FLUES

## I. INTRODUCTION

1. *Purpose of Investigation.*—A consideration of the factors involved in the condensation of moisture in flues has become of especial interest with the advent and increasing use of gas-fired furnaces for the heating of residences, because of the possibility of seepage causing discoloration and damage to adjoining walls. Some conception of the magnitude of the condensation to be expected can be obtained by calculation of the quantity of moisture present in the flue gases and from a comparison of such values with the quantity of moisture required to saturate the flue gases at the temperature at which they emerge from the chimney under normal firing conditions.

Since moisture in flue gases originates from moisture in the fuel, from moisture in the air used for combustion, and from the combustion of hydrogen in the fuel, the amount of moisture in the flue gas can be calculated from the fuel analysis and the moisture content of the air for any given set of firing conditions.

Experimentally-determined flue-gas temperatures resulting from a fairly wide range of firing rates complete the necessary data, for the moisture in the flue gases in excess of that required to saturate them at the temperature at which they emerge from the chimney will be the condensate, the amount of which is to be determined.

2. *Scope of Investigation.*—The moisture content of flue gases resulting from the combustion of anthracite, semi-bituminous, and bituminous coals, oil, natural gas and manufactured gas has been calculated for a total of twenty-three individual fuels. The condensation to be expected with anthracite and soft coal and with manufactured gas has been computed using the calculated average moisture content of the flue gases for each type of fuel and the experimentally-determined flue-gas temperatures for a wide range of firing rates.

The important relationship between firing rates and flue-gas temperatures, with gas, will depend largely upon the type of gas furnace, or upon the relation between size of burner and area of heating surface, and also upon the presence or absence of baffling or checker work in the case of the conversion burner, etc. It is evident, then, that, while the installation studied is considered to be a typical modern residence and furnace, considerable variation may be expected

in other installations, and that the relations between firing rates, flue-gas temperatures, and condensation, which are given, cannot be applied indiscriminately to all residences and heating units.

An independent investigation has been conducted by A. C. ROBERTSON of the Engineering Experiment Station Staff on the effects of the products of combustion on the corrosion of various materials. The results are as yet unpublished.

3. *Acknowledgments.*—The data presented in this paper were obtained in an investigation which was conducted by the Engineering Experiment Station of the University of Illinois, of which M. S. KETCHUM, Dean of the College of Engineering, was Director, in cooperation with the Clay Products Association. This research was carried out in the Department of Ceramic Engineering of which C. W. PARMELEE, Professor of Ceramic Engineering, is the head.

Acknowledgment is made and thanks expressed to PROF. C. W. PARMELEE for his part in the initiation of the investigation and for his continued interest and coöperation, and to PROF. R. K. HURSH for his suggestions concerning the calculations.

## II. GENERAL PRINCIPLES

4. *Vapor Pressure, Humidity, and Dew Point.*—A liquid enclosed in a vessel from which all gases have been removed will evaporate until the pressure of the vapor over the liquid reaches a certain definite equilibrium value which is termed the vapor pressure of the liquid at the given temperature. If a liquid is enclosed in a vessel which also contains a gas, approximately the same amount of liquid will evaporate as though the gas were not present, if the gas has a low solubility in the liquid and the pressure does not exceed about one atmosphere. Thus the vapor pressure of water in contact with air is approximately the same as the vapor pressure of water in contact only with its vapor.

When the partial pressure of the water vapor in an air-water-vapor mixture is equal to the equilibrium pressure of water and its vapor at the same temperature, no more water can be taken up and the mixture is said to be saturated. Vapor pressure then is a measure of the degree of saturation which is commonly expressed as the ratio of the partial pressure of the water vapor in the mixture to the equilibrium pressure of water and its vapor at the same temperature, and is termed relative humidity or, when multiplied by 100, per cent relative



humidity. Thus the saturated mixture has 100 per cent relative humidity.

Such units, however, are not satisfactory\* for engineering calculations since there is no constant quantity on which to base the computations. If moisture is added at constant temperature to an air-water-vapor mixture, either the pressure or volume must increase; or if an air-water-vapor mixture is heated at either constant volume or constant pressure, the "relative" humidity will decrease although the composition expressed either by weight or volume remains unchanged.

For these reasons, the following terms and units have been generally adopted for engineering calculations:

**Humidity**—expressed as pounds of water-vapor per pound of dry air.

**Percentage Humidity**—expressed as the ratio of the pounds of water-vapor per pound of dry air at a given temperature, to the pounds of water-vapor per pound of dry air required for saturation at the same temperature.

The vapor pressure at equilibrium between a liquid and its vapor increases with increasing temperature, as evidenced by the fact that a liquid boils when the vapor pressure has been increased by heating until at equilibrium the vapor pressure is equal to the total pressure on the liquid. Since the partial pressure of the water vapor is a measure of the concentration and the vapor pressure increases with increasing temperature, it follows that saturated air-water-vapor mixtures at higher temperatures have a higher humidity than do saturated mixtures at lower temperatures and that in passing from one to the other water will be removed from the mixture as the temperature is lowered. As the saturated mixture is cooled, water will condense until under equilibrium conditions the partial pressure of the water vapor in the mixture is equal to the equilibrium pressure of water and its vapor at the temperature in question.

When an unsaturated mixture is cooled, condensation occurs at the temperature at which the partial pressure of the water vapor in the mixture is equal to the equilibrium pressure between water and its vapor at the same temperature, under which condition the mixture is said to be saturated. The saturation temperature, which obviously is the temperature below which the mixture cannot be cooled without causing condensation, is called the dew point.

\*Walker, Lewis, and McAdams, "Principles of Chemical Engineering," Pages 436-7, McGraw-Hill Book Company, Inc. New York, (1923)

## III. RESULTS

5. *Condensation Temperatures.*—The quantity of flue gas and the amount of water produced in burning a variety of fuels have been calculated from their analyses on the basis of normal firing conditions in which 100 per cent excess air was used with coal and 50 per cent with oil and gas. From these data the saturation temperatures of the flue gases and the amount of condensation at normal chimney temperatures for such fuels have been determined.

Johnstone\* has shown that the presence of sulphur trioxide in flue gases even in small amounts materially raises the dew point because of the formation of sulphuric acid. This is important in corrosion at relatively high flue-gas temperatures but has a negligible effect on the determination of the total condensation which will occur at relatively low flue-gas temperatures in dwellings.

The fuels† for which calculations were made include the following:

Bituminous Coal	Dew Point
1. Illinois, Franklin County, Orient Mine.....	92° F.
2. Indiana, Sullivan County, Vandalia Mine.....	96
3. Pennsylvania, Armstrong County, W. Kittaning Mine.....	91
Semi-Bituminous Coal	
4. Virginia, Tazewell County, Pocahontas Mine.....	84
5. Pennsylvania, Cambria County, St. Michael Mine.....	83
Anthracite	
6. Anthracite (typical).....	68
Manufactured Gas	
7. Coal Gas.....	136
8. Coke Oven Gas.....	136
9. Coke Oven Gas.....	137
10. Blue Water Gas.....	139
11. Carburetted Water Gas.....	131
12. Oil Gas.....	141
13. Blast Furnace Gas.....	135
Natural Gas	
14. Natural Gas, Follansbee, W. Va.....	124
15. Natural Gas, Follansbee, Residual.....	125
16. Natural Gas, McKean County, Pennsylvania.....	128
17. Natural Gas, Sandusky, Ohio.....	131
Oil	
18. Pennsylvania, 28 degrees Baume.....	112
19. West Virginia, 30 degrees Baume.....	113
20. Ohio, 28 degrees Baume.....	112
21. Bakersfield, California, 15 degrees Baume.....	108
22. Beaumont, Texas, 22 degrees Baume.....	109
23. Typical Fuel Oil, ‡ 38 degrees Baume.....	112

\*University of Illinois, Engineering Experiment Station, Circular No. 20, "An Electrical Method for the Determination of the Dew Point of Flue Gases."

†Fuel compositions were obtained from Haslam and Russel, "Fuels and Their Combustion," McGraw-Hill Book Company, New York, (1926)

‡U. S. Dept. Agr., Tech. Bull. No. 109, "A Study of the Oil Burner as Applied to Domestic Heating."

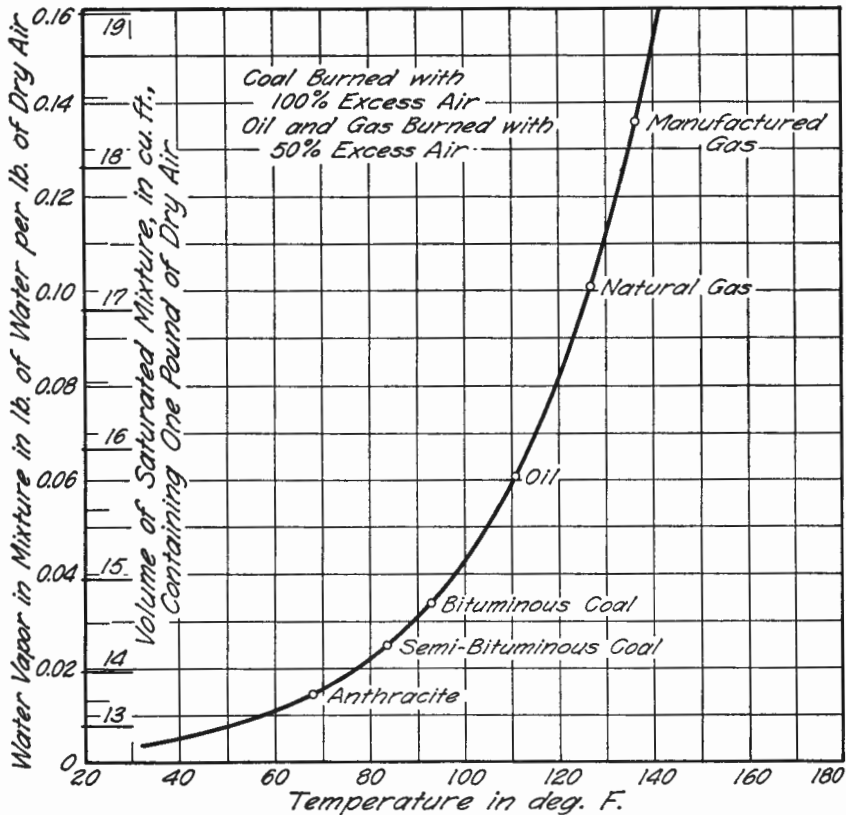


FIG. 1. SATURATION CURVE SHOWING DEW POINTS FOR COMBUSTION GASES FROM VARIOUS FUELS

Type of Fuel	Average Temperature at which Condensation will take place, deg. F.
Anthracite.....	68
Semi-Bituminous Coal.....	84
Bituminous Coal.....	93
Oil.....	111
Natural Gas.....	127
Manufactured Gas.....	137

The difference between the water content at saturation for a given flue gas and that of the mixture indicated by the curve of Fig. 1 for any lower temperature shows the amount of condensation which would occur if the flue gases were cooled over this range.

The amount of condensation possible at various flue-gas temperatures for the several types of fuel, with normal excess air for com-

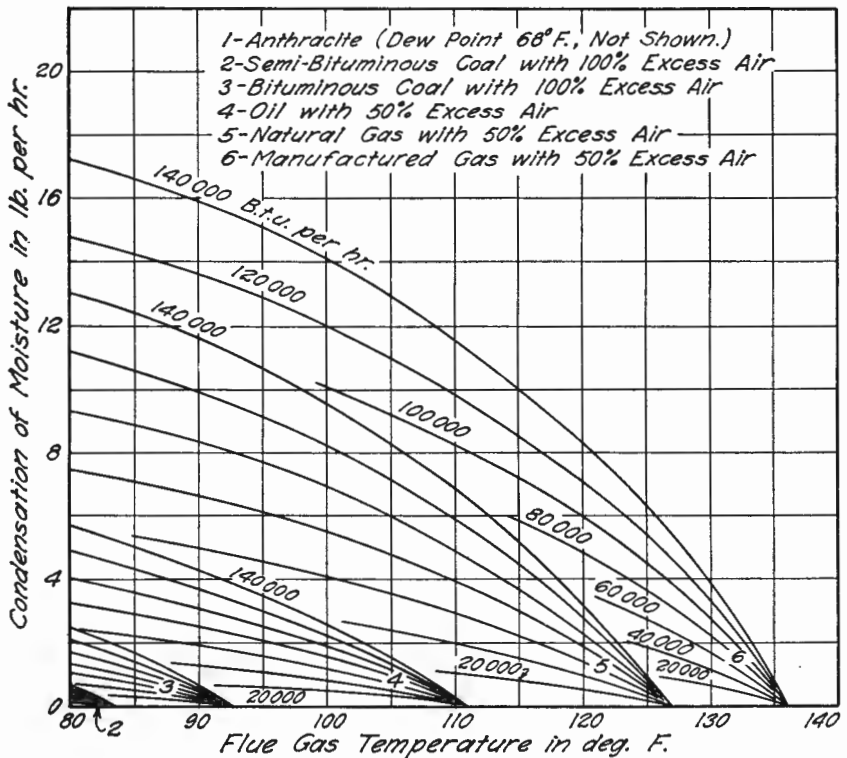


FIG. 2. CONDENSATION LIMITS WITH DIFFERENT FUELS FOR VARIOUS FIRING RATES AND FLUE GAS TEMPERATURES

bustion in each case, is shown in Fig. 2. The curves represent condensation for different firing rates from 20 000 to 140 000 B.t.u. per hour, the lowest condensation taking place at the lowest combustion rates. It is evident that, for any given firing rate and flue-gas temperature, condensation is highest for the fuel having the highest dew point and lowest for the fuel having the lowest dew point. Anthracite is not shown because of its extremely low dew point of 68 deg. F., which could not conveniently be plotted.

6. *Effect of Excess Air.*—Increase in excess air reduces the degree of saturation of the flue gases and, therefore, lowers the dew point (see Figs. 1 and 3). Hence an increase in excess air would tend to decrease condensation.

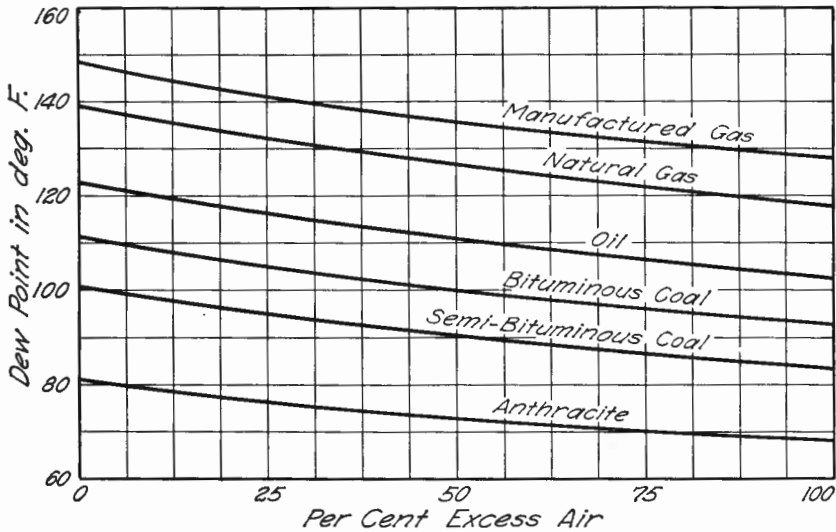


FIG. 3. AVERAGE RELATION BETWEEN DEW POINTS AND EXCESS AIR FOR TYPICAL FUELS

An increase in excess air also decreases the flame temperature but, contrary to what might be supposed, generally increases the exit temperature of the flue gases.\* This is explained partially by the fact that the radiant heat emitted by bodies, such as incandescent carbon particles, carbon dioxide, and water vapor, is a function of the fourth power of their absolute temperatures. Therefore, combustion products at a higher initial temperature transmit their radiant heat more effectively. In addition, heat transmission by convection is less efficient with large volumes of gas. The combination of these conditions produces higher flue-gas temperatures in the chimney when larger amounts of excess air are used for combustion.

7. *Relation Between Firing Rate and Flue-Gas Temperature.*—In order to determine actual condensation it is necessary to know the relation between firing rates and resulting flue-gas temperatures. Through the courtesy of the Department of Mechanical Engineering, in coöperation with the National Warm-Air Heating Association, it has been possible to obtain such data for anthracite and bituminous

\*U. S. Dept. of Agr. Tech. Bull. No. 109, "A Study of the Oil Burner as Applied to Domestic Heating." (1929)

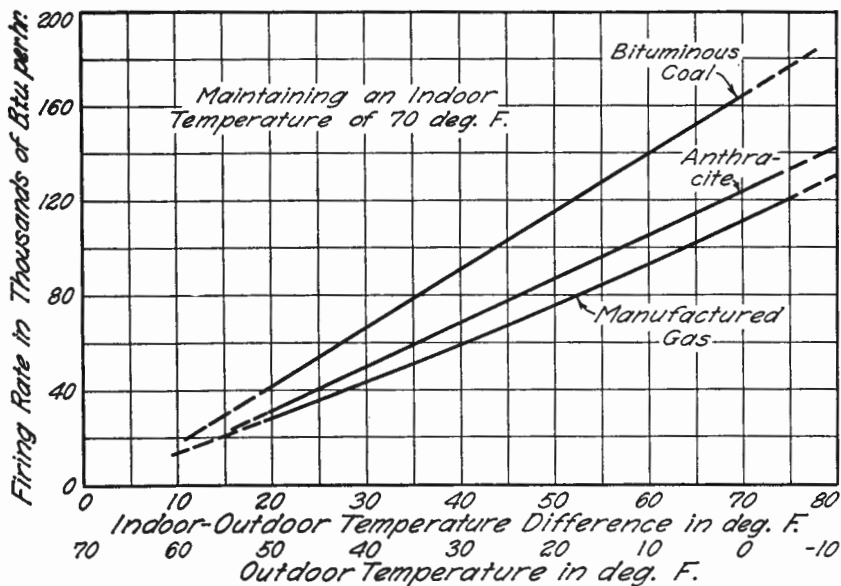


FIG. 4. RELATION BETWEEN INDOOR-OUTDOOR TEMPERATURE DIFFERENCE AND FIRING RATE

coal\* and for manufactured gas† under actual operating conditions.

The residence used for the tests was of standard three-story frame dwelling construction, heat being supplied to all three floors.

A gravity circulating warm-air heating plant of the common cast-iron type was used for all tests. The grate area for coal tests was 2.88 square feet. For gas tests, the furnace was equipped with a surface combustion burner.

The smoke pipe, which was 10 inches in diameter, and 10 feet long, was connected to a 12-inch by 12-inch fire-clay-lined flue 35 feet high. All flue-gas temperatures used in the calculations were measured at the roof line, 3 feet below the top of the chimney.

In Fig. 4 are shown the relations between firing rate and indoor-outdoor temperature difference (assuming indoor temperature of 70 deg. F.) for soft or bituminous coal, anthracite, and manufactured gas. It is readily seen that fuels cannot be compared on equal firing rates; that is, in zero weather the firing rates for soft coal, anthracite, and manufactured gas are 164 000, 124 000, and 112 000 B.t.u. per

\*"Investigation of Warm-Air Furnaces and Heating Systems, Part IV," Univ. of Ill., Eng. Exp. Sta., Bull. No. 189.

†"Investigation of Warm-Air Furnaces and Heating Systems, Part V," Univ. of Ill., Eng. Exp. Sta., Bull. No. 246.

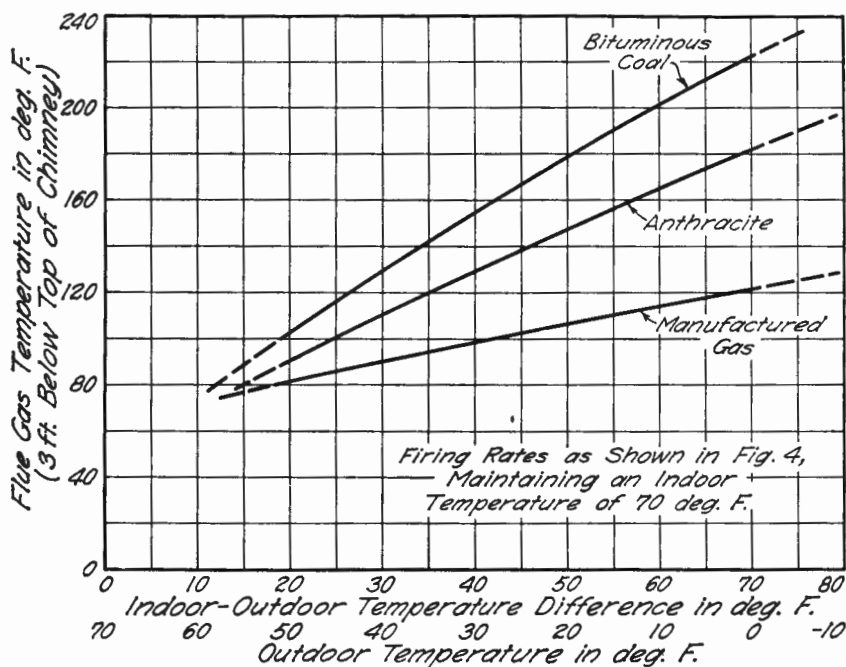


FIG. 5. RELATION BETWEEN INDOOR-OUTDOOR TEMPERATURE DIFFERENCE AND FLUE GAS TEMPERATURE

hour; respectively. In general, for equivalent indoor-outdoor temperature differences, and equal heating effects, higher firing rates are necessary in furnace operation with soft coal than with anthracite or gas, and correspondingly higher flue-gas temperatures result.

In Fig. 5 is shown the relation between indoor-outdoor temperature difference and flue-gas temperatures measured 3 feet below the top of the chimney. Flue-gas temperatures are highest with soft coal and lowest with manufactured gas.

8. *Condensation in Installation Studied.*—From the actual relation between firing rate and resulting flue-gas temperature shown in Figs. 4 and 5 it is possible to determine the condensation to be expected by plotting the intersections of the firing rate-flue-gas temperature relationships on the charts showing condensation limits for various firing rates. This has been done for soft coal in Fig. 6, and for manufactured gas in Fig. 7. The data have been replotted against indoor-outdoor temperature differences in Figs. 8 and 9.

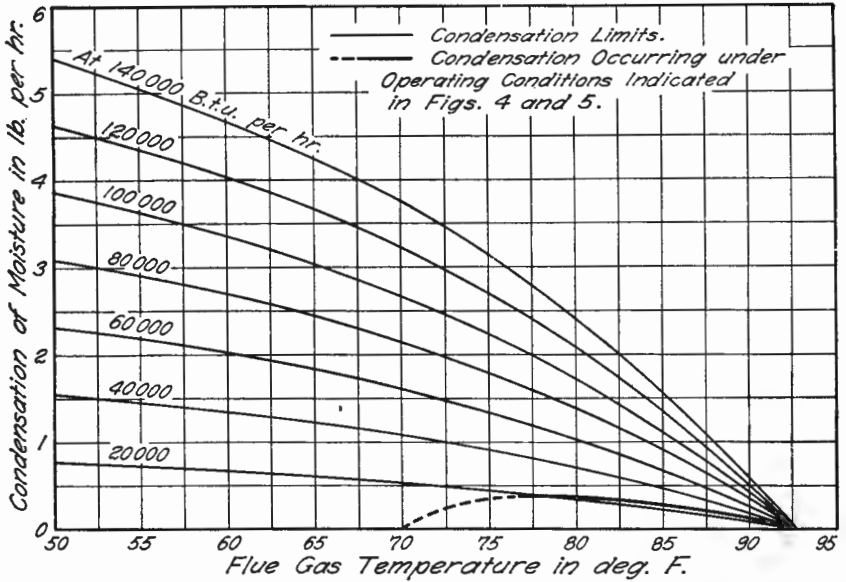


FIG. 6. CONDENSATION OF MOISTURE FROM FLUE GASES FOR BITUMINOUS COAL BURNED WITH 100 PER CENT EXCESS AIR

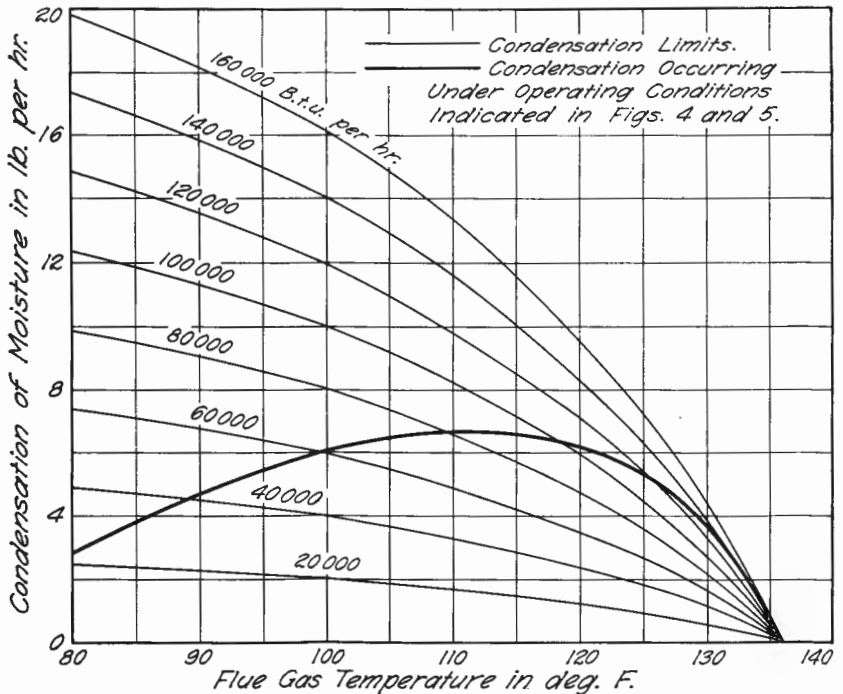


FIG. 7. CONDENSATION OF MOISTURE FROM FLUE GASES FOR MANUFACTURED GAS BURNED WITH 50 PER CENT EXCESS AIR



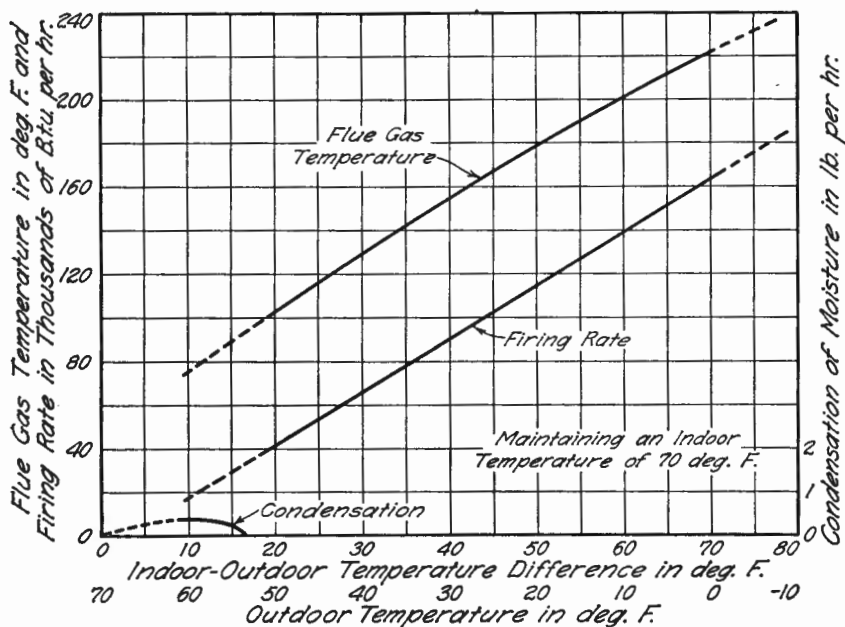


FIG. 8. FIRING RATE, FLUE GAS TEMPERATURE, AND CONDENSATION OF MOISTURE FOR BITUMINOUS COAL BURNED WITH 100 PER CENT EXCESS AIR

No condensation occurs with anthracite because the temperature of the flue gases is never below the dew point. A small amount of condensation may occur with soft or bituminous coal at low firing rates. The flue-gas temperatures in the low range have been obtained by extrapolation of the curves representing experimental data in the higher ranges. A maximum condensation of about 0.38 pound per hour would occur with a firing rate of 20 000 B.t.u. per hour, corresponding to an outdoor temperature of approximately 59 deg. F.

Extremely heavy condensation will occur with manufactured gas but under distinctly different conditions than with coal. With gas, a maximum condensation of about 6.75 pounds per hour would occur with a firing rate of 84 000 B.t.u. per hour, corresponding to an outdoor temperature of approximately 15 deg. F.

The maximum condensation for soft coal, then, will occur in mild weather, while for the gas the maximum condensation, approximately 18 times the maximum for soft coal, will occur when the outdoor temperature is about 15 deg. F. above zero.

Data for oil and for natural gas which would be directly comparable with the foregoing results are not available.

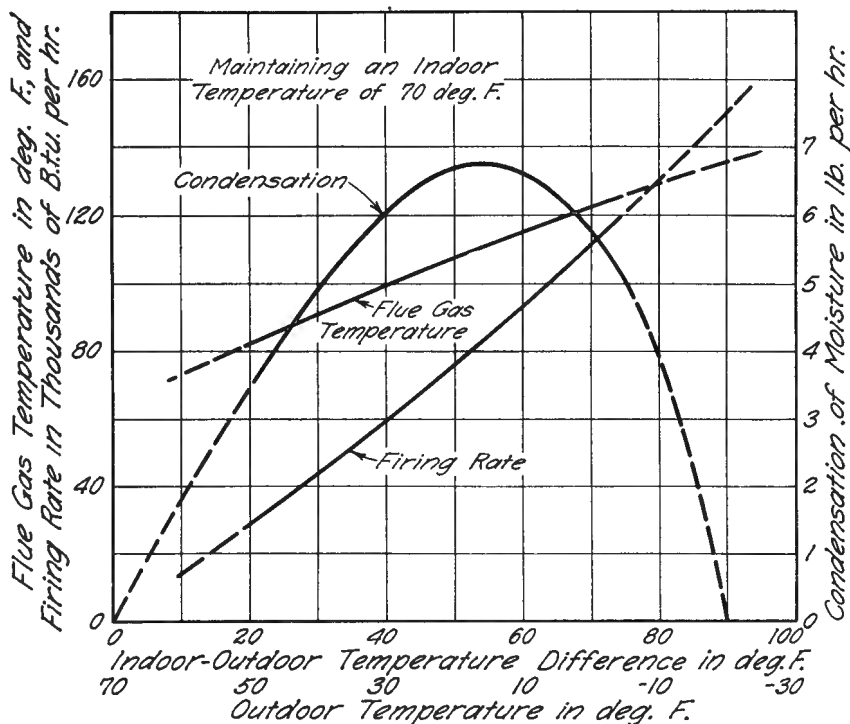


FIG. 9. FIRING RATE, FLUE GAS TEMPERATURE, AND CONDENSATION OF MOISTURE FOR MANUFACTURED GAS BURNED WITH 50 PER CENT EXCESS AIR

9. *Elimination of Seepage.*—Gas-fired furnaces are usually automatically operated and thermostatically controlled, so that large fluctuations in combustion rate and flue-gas temperature, such as would occur with hand-fired coal furnaces, are eliminated. Flue-gas temperatures with gas are also considerably lower than with coal. In zero weather the flue gas\* temperature at the smoke collar of the furnace was 570 deg. F. for anthracite, 780 deg. F. for soft coal, and 430 deg. F. for gas. At the roof line, 3 feet below the top of the chimney, the flue-gas temperature was 180 deg. F. for anthracite, 220 deg. F. for soft coal, and 125 deg. F. for gas.

Because of the less severe temperature conditions in the flue when gas is used as fuel, vitrified impermeable liners, provided possibly with sockets, could be used without much danger of breakage or disintegration. Such liners would eliminate seepage, and for this reason it would be necessary to make provision for drainage of the condensate from the chimney.

\*See Fig. 5, page 13.

## APPENDIX

### METHODS OF CALCULATION

1. *Weight-Volume Relationships for Gases.*—The unit of weight used in calculations is the pound mol which is the weight in pounds numerically equal to the molecular weight. The volume of one pound mol is the same for all gases and is equal to 359 cubic feet at 32 deg. Fahrenheit and a pressure of 29.92 inches of mercury.

The constituents of ordinary fuels are carbon, hydrogen, sulphur, oxygen, and nitrogen, which are converted respectively upon complete combustion of the fuel to carbon dioxide, water vapor, and sulphur dioxide, the oxygen having combined with the first three constituents during combustion, while the nitrogen remains unchanged.

2. *Volume of Combustion Products.*—The calculation of combustion products is greatly facilitated by use of certain constants as indicated below:

One pound mol of	Contains
Carbon dioxide (CO <sub>2</sub> ).....	12.005 lb. of carbon (C)
Sulphur dioxide (SO <sub>2</sub> ).....	32.06 lb. of sulphur (S)
Water Vapor (H <sub>2</sub> O).....	2.016 lb. of hydrogen (H <sub>2</sub> )
Nitrogen (N <sub>2</sub> ).....	28.02 lb. of nitrogen (N <sub>2</sub> )
Oxygen (O <sub>2</sub> ).....	32.00 lb. of oxygen (O <sub>2</sub> )
Air (Mixture).....	29.0 lb. of mixed gases

Since a pound-mol of gas at 32 deg. F. and 1 atmosphere pressure has a volume of 359 cubic feet, it follows that

One pound of carbon (C) forms  $\frac{359}{12} = 29.92$  cubic feet of carbon dioxide (CO<sub>2</sub>).

One pound of sulphur (S) forms  $\frac{359}{32} = 11.22$  cubic feet of sulphur dioxide (SO<sub>2</sub>).

One pound of hydrogen (H<sub>2</sub>) forms  $\frac{359}{2} = 179.5$  cubic feet of water vapor.

One pound of nitrogen (N<sub>2</sub>) has a volume of  $\frac{359}{28} = 12.82$  cubic feet.

One pound of oxygen (O<sub>2</sub>) has a volume of  $\frac{359}{32} = 11.22$  cubic feet.

From this it follows that, the analysis of a fuel being known, the volume of the products of combustion become for

Carbon (C),  $29.92 \times \text{lb. C} = \text{cu. ft. of CO}_2$  (also = cu. ft. O<sub>2</sub> required).

Sulphur (S),  $11.22 \times \text{lb. S} = \text{cu. ft. of SO}_2$  (also = cu. ft. O<sub>2</sub> required).

Hydrogen (H<sub>2</sub>),  $179.5 \times \text{lb. H}_2 = \text{cu. ft. of H}_2\text{O}$  (vapor)

Nitrogen (N<sub>2</sub>),  $12.82 \times \text{lb. N}_2 = \text{cu. ft. of N}_2$

Oxygen (O<sub>2</sub>),  $11.22 \times \text{lb. O}_2 = \text{cu. ft. of O}_2$

In the cases of carbon and sulphur the volume of the carbon dioxide and sulphur dioxide formed is also the volume of the oxygen required for combustion, since one mol of oxygen is required to form one mol of the gaseous product in each case.

In the case of hydrogen it will be noted that one mol of hydrogen combines with a half mol of oxygen to form one mol of water vapor. Therefore the volume of the oxygen required for the combustion of hydrogen is half of the volume of the hydrogen and also half of the volume of the resulting water vapor. Thus, for hydrogen

$$\frac{359}{2 \times 2} \text{ or } 89.75 \times \text{lb. H}_2 = \text{cu. ft. O}_2 \text{ required for combustion.}$$

The weight of water formed by the combustion of hydrogen is obtained by multiplying the weight of hydrogen, obtained from the chemical analysis, by 9, since the molecular weight of water is 18, or nine times the molecular weight of hydrogen.

3. *Air Required for Combustion.*—The total air, in pounds, required for combustion is obtained by multiplying the volume of oxygen required by the constant 0.384, thus

$$\frac{(\text{cu. ft. of O}_2) \times 29}{359 \times 0.21} = 0.384 (\text{cu. ft. of O}_2) = \text{lb. of air,}$$

where division of the volume of oxygen by 359 gives the number of mols of oxygen; division by 0.21 gives the equivalent mols of air; and multiplication by 29, the approximate molecular weight of air, gives the weight, in pounds, of air required.

4. *Nitrogen in Flue Gases.*—Oxygen for combustion is obtained from the air, which has an approximate composition of 21 per cent oxygen and 79 per cent nitrogen, by volume. Therefore nitrogen is introduced in the combustion gases in proportion to the amount of air used, or in the ratio of  $\frac{79}{21}$ , or 3.76, times the volume of oxygen required.

5. *Sample Calculation.*—A sample calculation for Illinois bituminous coal from Franklin County is given below.

All air used for combustion is considered to have a relative humidity of 55 per cent at 60 deg. F.; under this condition approximately 0.006 pound of water vapor will be introduced into the combustion gases for each pound of dry air used for combustion.

## (a) Analysis of Coal

Ash.....	8.1 per cent
Sulphur.....	1.0
Hydrogen.....	5.4
Carbon.....	69.0
Nitrogen.....	1.6
Oxygen.....	15.0
B.t.u. per pound (as received).....	12,164

All calculations are based on one pound of fuel.

## (b) Sulphur (1.0 per cent)

The sulphur, which is never completely burned, is present in such small quantities that the air required for its partial combustion can be neglected in the present calculations.

There will be  $0.01 \times 11.2 = 0.11$  cu. ft. of oxygen required, which is also the volume of sulphur dioxide formed.

## (c) Hydrogen (5.4 per cent)

There will be  $0.054 \times 89.76 = 4.8$  cu. ft. of oxygen required, and  $9 \times 0.054 = 0.486$  lb. of water-vapor formed.

## (d) Carbon (69.0 per cent)

There will be  $0.69 \times 29.92 = 20.6$  cu. ft. of oxygen required, which is also the volume of carbon dioxide formed.

## (e) Oxygen (15.0 per cent)

There are  $0.15 \times 11.22 = 1.68$  cu. ft. of oxygen in the fuel, which must be subtracted from the total oxygen required, the remainder being obtained from the air.

The oxygen to be obtained from the air becomes, therefore,  
 $(4.8 + 20.6) - 1.68 = 23.7$  cu. ft.

## (f) Nitrogen (1.6 per cent)

There are  $0.016 \times 12.82 = 0.21$  cu. ft. of nitrogen in the fuel.

The nitrogen introduced in the air for combustion is 23.7 (cu. ft.  $O_2$  to be obtained from the air)  $\times 3.76 = 89.11$  cu. ft.

The total nitrogen then is  $89.11 + 0.21 = 89.32$  cu. ft.

## (g) Volume of Dry Combustion Products

The volume of the dry combustion products will be the sum of the carbon dioxide and the nitrogen or  $20.6 + 89.32 = 109.92$  cu. ft., which is equivalent to 8.87 lb. of dry air.  $\left( \frac{109.92}{359} \times 29 = 8.87 \text{ lb. equivalent dry air} \right)$ .

## (h) Moisture in Air for Combustion

The volume of air required for combustion is obtained by dividing the volume of the oxygen obtained from the air by the percentage present in air. Thus the air required for combustion is  $\frac{23.7}{0.21} = 112.8$  cu. ft. which, of course, should check with the sum of the oxygen and nitrogen required, already calculated.

From the volume of air required, the weight required is obtained by using the factor designated, so that there are

$$\frac{112.8}{359} \times 29 = 9.10 \text{ lb. dry air required.}$$

Since the assumption was made that the air used contained 0.006 lb. moisture per pound of dry air, the total moisture introduced in this manner will be

$$9.10 \times 0.006 = 0.0546 \text{ lb. moisture.}$$

## (i) Total Moisture

The total moisture in the combustion gases will include the water in the fuel, which has been included in the hydrogen and oxygen shown in the analysis, the water formed by the combustion of the hydrogen in the fuel, and the water introduced in the air for combustion. The first two items amounted to 0.486 lb. and the last to 0.0546 lb. so that the total moisture in the flue gases would be 0.5406 lb. per pound of fuel burned.

## (j) Dew Point

For each pound of fuel burned combustion gases equivalent to 8.87 lb. of dry air will be formed which will contain 0.5406 lb. of water vapor, or 0.061 lb. per pound of dry air equivalent. From the psychometric chart it is seen that such a mixture has 100 per cent relative humidity, or is completely saturated, at 111 deg. F., which is the dew point. Below this temperature moisture will be condensed.

6. *Effect of Excess Air on Moisture Content and Dew Point.*—It has been shown in the sample calculations that for the coal in question

TABLE 1

	Weight of Dry Air Required	Weight of Water in Combustion Products	Weight of Dry Air Equivalent of Combustion Products	Values in Column (2) ÷ Values in Column (3)	Dew Point
	lb.	lb.	lb.		deg. F.
	(1)	(2)	(3)	(4)	(5)
Theoretical quantities.....	9.10	0.486	8.87	.....	....
No excess air.....	.....	.....	.....	.....	.....
Water in air.....	.....	0.0546	.....	.....	.....
Totals.....	9.10	0.5406	8.87	0.0609	111.0
100 per cent excess air.....	9.10	.....	9.10	.....	.....
Water in air.....	.....	0.1192	.....	.....	.....
Totals.....	18.20	0.6052	17.97	0.0336	92.5

9.10 lb. of dry air were required for theoretical combustion (no excess air); that 8.87 lb., equivalent of dry air, of combustion products were formed; and that 0.486 lb. of water vapor was formed when one pound of coal was burned. To the moisture thus formed, 0.006 lb. of moisture per pound of dry air was introduced in the air for combustion, or 0.0546 lb. of water per pound of fuel burned, making a total of 0.5406 lb. of water in the flue gas per pound of fuel burned.

The effect of excess air on moisture content and dew point of flue gases is shown, and the method of calculation indicated, in Table 1.

Obviously, increased excess air tends to lower the moisture concentration in the flue gases and to lower the dew point.

### 7. Condensation of Moisture.—

#### (a) Convenient Units—Moisture per 1000 B.t.u. Fired

Since firing rates frequently are expressed in B.t.u. per hour rather than pounds of fuel per hour, it will be convenient to express moisture contents on the basis of 1000 B.t.u. fired. Thus,

$$\frac{\text{Pounds of water in flue gas per 1000 B.t.u. fired}}{\text{Pounds of water per lb. dry air equiv. at saturation}} = \frac{\text{Total water in flue gases per lb. fuel fired} \times 1000}{\text{B.t.u. per lb. of fuel}}$$

$$\text{Pounds of water per 1000 B.t.u. producing saturation} = \frac{(\text{Pounds of water per lb. dry air equiv. at saturation}) (\text{Pounds of dry air equiv. of combustion products}) \times 1000}{\text{B.t.u. per lb. of fuel}}$$

## (b) Method of Calculation

The moisture concentration in the flue gases and the moisture required for saturation at the temperature at which the gases leave the chimney will determine the amount of condensation to be expected.

Flue gas temperatures at the top of the chimney, when bituminous coal is used, normally will lie between 80 and 120 deg. F.

Saturated air at 80 deg. F. (Fig. 1) contains 0.0222 lb. of water vapor per pound of dry air. With no excess air, 8.87 lb. dry air equivalent of combustion products were formed, which, if saturated at 80 deg. F., would contain a total of  $8.87 \times 0.0222 = 0.197$  lb. of water per pound of fuel fired, or

$$\frac{0.197 \times 1000}{12\ 164} = 0.0162 \text{ lb. of water per 1000 B.t.u. fired.}$$

With no excess air, there was 0.5406 lb. of water in the combustion products, or 0.0444 lb. per 1000 B.t.u. fired.

The condensation at 80 deg. F., then, would be the difference between the actual water content of the flue gases and that required for saturation, or  $0.0444 - 0.0162 = 0.0282$  lb. of water per 1000 B.t.u. fired. This figure multiplied by the firing rate in 1000 B.t.u. per hour gives the pounds of water condensed per hour.

Condensation for any given set of conditions can be calculated, but in order to show the effects of excess air, variation in firing rates, flue gas temperatures, etc., the condensation under various conditions is best calculated (Fig. 3) and from these theoretical quantities values corresponding to actual conditions can be selected.



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