A STUDY OF
SMOKE PREVENTION IN STEAM BOILER PLANTS;
WITH SPECIAL REFERENCE TO THE PROBLEM
IN THE CITY OF MINNEAPOLIS.

A THESIS

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PREFACE

In the preparation of this thesis I have studied the problem of smoke prevention from three standpoints, as follows.—

First, from a theoretical standpoint; I have endeavored to analyze, as thoroughly as possible, the underlying principles of smoke prevention. On this branch of the subject I have spent by far the most time and thought, and I believe it constitutes the most valuable portion of this thesis.

Secondly I have studied the problem from an experimental standpoint. - Besides a careful study of all available records of previous experiments along this line, especially those of the United States Geological Survey, I also experimented for myself, under the direction of Professor J. J. Flather, on the boilers of the University of Minnesota power plant. These experiments, due to lack of time, and means, had to be carried on in a rather superficial manner and hence in themselves do not afford data of much scientific value. Nevertheless they have been of great practical value to myself in connection with the theoretical studies just mentioned.

Thirdly I have studied the problem from an economic or social standpoint.- I have investigated the conditions in large cities of the United States, where of course the smoke problem is of the greatest economic importance. Finally, I have made a special study, although of necessity a limited one, of the local problem here in our city - Minneapolis.

The numbers in the footnotes, in the body of this thesis refer to corresponding numbers in the bibliography at the end (page 133). For instance the footnote 25:1-37 refers to to number 25 in the bibliography which is Kent's "Steam Boiler Economy"; the numbers 1-37 refer to corresponding pages in this book.

H. D. Frary

June 1909.

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I

PRINCIPLES OF SMOKE PREVENTION.

What is Smoke and what causes it?

The International Dictionary says that smoke is "the visible exhalation, vapor or substance that escapes from a burning body".

Smoke consists essentially of two elements; (1) Tarry vapors or hydrocarbons distilled directly from the fuel without burning, (2) small particles of unburned carbon wafted upwards by the gaseous products of combustion. From its very nature, then, SMOKE IS THE PRODUCT OF INCOMPLETE COMBUSTION.

Why should Smoke be prevented?

For four reasons:-- (1) Danger to public health, (2) Injury to the community in an aesthetic sense, (3) Damage to property, (4) Waste of fuel.

(1) With reference to the influence on the public health we quote from the report of the Cleveland Chamber of Commerce.[*]--

"It is difficult to estimate the effect upon health of the presence of any considerable quantity of smoke and gas in the air. It is known, however, that it acts as an irritant to the lungs and throat and nasal passages; that it is one of the predisposing causes of disease in these organs, and that it aggravates any existing disease. An inspection of the screens which are used in hospitals to purify the air drawn through the ventilating system shows, after twenty-four hours, astonishing results which are more eloquent than any description can be".

On this same question Wm. H. Booth says further.[**]-- "Smoke ought to be attacked, not only because it brings dirt and depression in its train but because its emission is accompanied by that of gases which are directly detrimental to the health of living beings". These poisonous gases,

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[*] 81:4 See also 27:14 (See preface for explanation of foot-notes)

[**] 21:38

namely carbon monoxide and various hydrocarbons, are invisible and hence are not smoke. They are, however, an inseparable accompaniment of smoke and result from the same cause. Hence the prevention of smoke means also the elimination of these gases and their deleterious effects.

(2) In regard to the aesthetic influence* on the community, the report of the Cleveland Chamber of Commerce makes the following statement.

"The presence of coal smoke in large quantities constitutes perhaps the greatest hindrance to the highest development of civic beauty and refinement. Its effect is seen in all plant life. It is well known that plants breathe much as do animals. The presence of large quantities of gas in the air and the coating of soot which settles upon all plant life have a definite effect, and in the smokier sections of the city this is noticed in a marked degree, in a form which is analogous to strangulation. The growth of green conifers is almost impossible, and only hardy and smooth-leaved trees are comparatively unaffected. No definite estimate has been made of the amount of loss of vegetation resulting directly from the presence of smoke in

* 81:3 158 27:13

the air, but the St. Louis Forestry Department[*] figures conservatively an annual loss of 4%, and these figures may doubtless be assumed for Cleveland. Ordinarily, flowering plants wither and die in smoky districts unless given especial care.

"To a considerable extent, the architectural effects of our buildings are destroyed by damage from this source. Buildings of almost every material are, in a few years, brought to a common level-- a grimy hue which robs them of their distinction. Painted buildings in a short time lose their color because of the coating of soot and the effect of chemical gases. Prevailing conditions make impossible the successful use of lighter or more cheerful colors without constant and expensive renewal".

A clean smokeless city, by virtue of the fact, would possess an attraction to outsiders far superior to any impression that a smoky city could make by beautiful parks, well lighted avenues or other artificial attractions.

(3) Damage to property.[**] In this connection we quote again from the report of the Cleveland Chamber of Commerce.

[*] 82:5

[**] 81:5 and 82:4

" The most tangible results of the smoke nuisance can be shown, perhaps in the financial loss to the community. There are approximately four hundred retail dry good stores in Cleveland, doing a business of from $10,000 to $4,000,000 a year. The owners of some of these stores estimate, and the same estimate is given in other cities, that on all white goods sold, a clear loss of at least 10% must be figured. Taking the single items of underwear, shirt waists, linens and white dress goods, for the eleven department stores, the proprietors conservatively estimate their combined loss at $25,000. Consider then the loss in all lines of light goods for all four hundred stores. The wholesale dry goods houses show a similar loss. There are in Cleveland, fifty-five men's furnishing stores, and the conservative estimate of loss to these stores is placed at $15,000 annually. It is a simple matter to distinguish between the soil from ordinary dust and that due to the presence of coal smoke and gas. The former is easily removed; the other, due to an air saturated with smoke, is absorbed, rendering the fabric practically beyond redemption, from the standpoint of the salesman. The stores mentioned represent only a small proportion of the trade directly effected. Aside from the damage to stock, an annual cost for cleaning, particularly among retail houses, must be included. Some conception of this loss may be had from a single instance. one retail establishment paid, in just a year after the painting and decorating of its walls and ceilings, $1,800 for repainting and decorating, made necessary entirely by the smoke. During the same year their bill for window cleaning was $2,000; for laundry purposes $1,500. This, in large measure, was due to the smoke nuisance. Multiply these figures by the thousands of business houses needing the same attention, in greater or less degree, and some estimate of the total cost in this direction may be obtained. To this should be added the cost of lighting, particularly in retail stores, factories and offices, made necessary by the smoky atmosphere. Some large houses charge several hundred dollars to this account.

" But a greater cost than all these must be considered in the loss to the one-hundred thousand homes of Cleveland. The constant need for cleaning of walls, ceilings,windows, carpets, rugs and draperies,for redecorating and renewing, can be realized only by the house owner or house keeper. To this add the increased laundry bills for household linen, the dry cleaning for clothing and the great additional wear resulting from this constant renovation, thus necessitating frequent renewals. Consider also the permanent injury to books, pictures and similar articles. Though impossible of computation, it will be seen that the total of these items aggregates millions of dollars. The annual tribute which Cleveland must pay to the smoke nuisance is a sum sufficient in a single year, to equip all plants not so provided, with smoke preventing devices."

(4) Waste of fuel.*--The common belief, supported by advertisers of so called smoke "consumers", that smoke issuing from a chimney represants a large waste of fuel is entirely erroneous. Prof. Benjamin says,** "Quite a number of experiments were made several years ago on very black, dense smoke. It was all collected and the solid matter was determined by weight. It was found to be in all, one third of one percent (.0033) of the weight of coal burned in that time. Probably one-half of this solid matter was carbon, showing that the amount of coal which is actually wasted in

* 80:27 90:9-12
** 60:164

soot is one six hundredth part of the coal burned" On the same point Prof. Breckenridge says,[**] " It takes but a small amount of soot to give a dense, black color to smoke. If it were to save only these soot particles, we could not afford expensive stoker and furnace settings. The appearance of black smoke is fortunately the signal of incomplete combustion and the losses due to this cause are many times the losses due to the carrying away of small soot particles".

It is not the smoke itself, then, which causes poor econony but the presence of unburned gases,[*] carbon monoxide and various hydrocarbons, which, as before indicated always accompany smoke. In other words, the presence of smoke indicates incomplete combustion and incomplete combustion means that more or less combustible gas is escaping unburned.

The tests made by the United States Geological Survey in the boiler testing plant at St. Louis corroborate these facts unmistakably. In the bulletin,[***] "The burning of coal without smoke in Boiler Plants", tables are given showing the relation between the percent of black smoke and the amount of carbon monoxide in the flue gases; and the rela-

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[**] 90:9

[*] This will be discussed from a chemical standpoint under the next heading.

[***] 7:13

tion between carbon monoxide and efficiency, as determined from the results of a large number of boiler tests. Using these two tables the writer has plotted the accompanying curves. Curve No. 1 shows that carbon monoxide (CO) varied almost directly with the amount of smoke. As the smoke increased from 0 to 52.9%, C O increased from.05 % to.35%. Curve No. 2 shows that as C O increased from .1% to .63% the boiler efficiency decreased from 72.73% to 52.96%.

Comparing these two curves

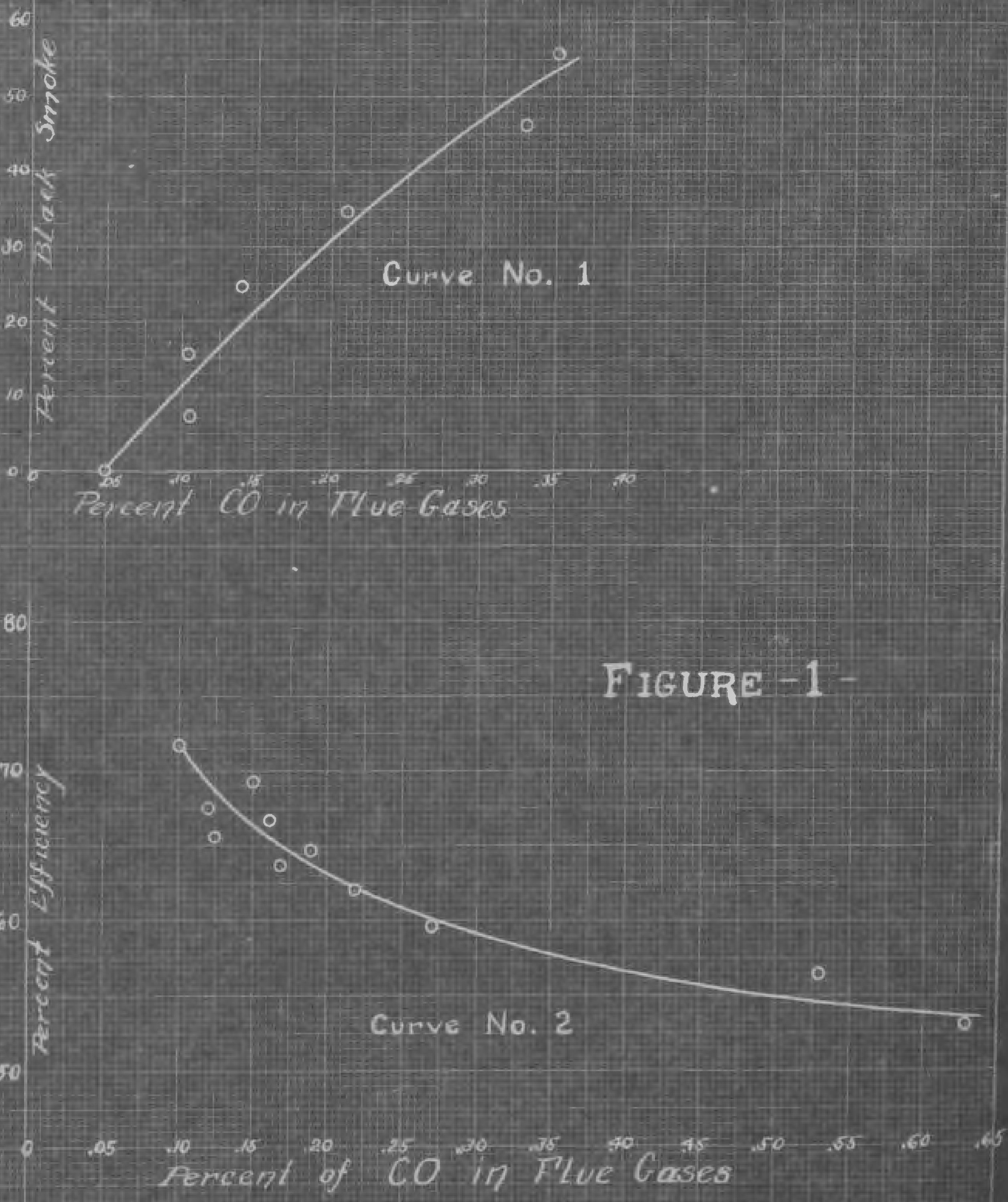
Percent Black Smoke
60
50
40
30
20
10
0
0
.05
.10
.15
.20
.25
.30
.35
.40
Percent CO in Flue Gases
Curve No. 1
Percent Efficiency
80
70
60
50
0
.05
.10
.15
.20
.25
.30
.35
.40
.45
.50
.55
.60
.65
Percent of CO in Flue Gases
Curve No. 2

FIGURE -1-

we see that as the smoke increases from 0 to 52% the boiler efficiency decreases from 73% to about 57.5%. Of course any one set of boiler tests might disagree greatly with these curves, or even partially contradict them; but the significant point about the curves is that they represent data from a large number of tests with different coals and different conditions, and hence give reliable average results. From these data Mr Randall concludes,- "It is evident that the prevention of smoke and the efficiency of the plant are very closely related."

The conclusion is,--THE EMISSION OF SMOKE MEANS INCOMPLETE COMBUSTION AND INCOMPLETE COMBUSTION MEANS WASTE OF FUEL.

What are the Requirements of Complete Combustion*?

In the first place we shall define combustion and discuss the chemical processes in the combustion of coal.

Combustion, in the sense used here, is the rapid chemical union of a combustible substance with the oxygen

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* 22:6-57 80:16 90:2-8 25:1-37 27:9-12 156 21:27-39 61:159-164

of the air.

Now, what is coal? what happens when it is burned? Coal is a compound of carbon and hydrogen, mixed with more or less free sulphur, moisture and ash. Although the carbon and hydrogen in coal are in a combined form the chemical formula is unknown. In fact there is probably no single chemical formula; that is, coal probably consists of a mixture of hydrocarbon compounds, which are present in varying amounts in different grades of coal.

When coal is burned the following events take place: First, as the coal is heated the moisture is evaporated. Secondly, the volatile matter in the coal is distilled off, that is, the hydrocarbons in the coal break up forming certain hydrocarbon gases and leaving behind so called fixed carbon. The most important gases formed in this way are methane and ethane. Numerous other hydrocarbon gases and hydrogen are also formed but in minute quantities . Thirdly, this volatile matter and the fixed carbon left behind, together with whatever free sulphur is present, are burned. The residue is ash.

The following table, though not rigidly exact, gives a general idea of the percents of fixed carbon , volatile gases and free sulphur obtained from different grades of coal. The remainder of the 100%, though not given in the table, consists of moisture and ash both of which increase as we go down from anthracite to lignite.

	Fixed Carbon	Volatile Matter	Free Sulphur
Anthracite Coal	80-95%	2-6%	0-1.5%
Semi-Anthracite	75-85%	6-15%	0-1.5%
Semi-Bituminous	70-80%	15-25%	0-1.5%
Bituminous	40-60%	25-35%	0-1.5%
Lignite	35-40%	35-45%	0-1.5%

In addition to the above there are two other combustible substances which are usually formed in appreciable quantities when coal is burned, namely carbon monoxide-$C O$- and hydrogen -H-. Carbon monoxide may be formed by the incomplete combustion of carbon ($2 C + O_2 = 2 C O$), or by the reduction of carbon dioxide, due to intimate contact with incandescent carbon when the air supply is insufficent

($CO_2 + C = 2\ CO$). Hydrogen may be formed by the breaking down of hydrocarbons, or by the decomposition of water in the presence of incandescent carbon ($H_2O+C=CO+H_2$).

We have then six combustible substances which are present, in appreciable amounts, during the combustion of coal; (1) carbon-C-, (2) sulphur -S-, (3) hydrogen -H-, (4) methane -CH_4-, (5) ethane -C_2H_4- and (6) carbon monoxide -CO-. The chemical reactions which take place inthe complete burning of the above six combustibles are are:-

(1.) $C + O_2 = CO_2$ (carbon dioxide)

(2.) $S + O_2 = SO_2$ (sulphur dioxide)

(3.) $2H_2+O_2 = 2H_2O$ (water or steam)

(4.) $CH_4+2O_2= CO_2+2H_2O$ (carbon dioxide and steam)

(5.) $C_2H_4+3O_2= 2CO_2+2H_2O$ (carbon dioxide and steam)

(6.) $2CO+ O_2=2CO_2$ (carbon dioxide)

The products of complete combustion of coal, then, are simply carbon dioxide, a colorless, odorless and harmless gas, and steam, together with a trace of sulphur dioxide.

As to just what reactions take place when combustion is incomplete we can not say. Suffice it to say that the following combustibles are commonly found in the products of incomplete combustion;--carbon, carbon monoxide, methane, hydrogen and ethane. (It is probable that minute traces of other hydrocarbons may be present also.) The amount of carbon as already stated is small. Carbon monoxide is the most prevalent constituent while methane probably comes next. Hydrogen and ethane are frequently present in small quantities. It is however worth noting that CH_4,H and C_2H_4, even when present in small quantities mean a considerable loss in heat due to their high calorific powers. The calorific powers of CO,CH_4,H and C_2H_4 are as follows.

C O --------------10,100 B.T.U. per lb.
CH_4--------------24,020 " " "
H --------------62,000 " " "
C_2H_4--------------21,930 " " "

In this connection Bulletin No. 325 *U.S. G.S. says:- "A mere trace of methane--for instance, to the extent of one tenth of one per cent in the flue gases--is sufficient to represent ordinarily a loss of 2% of the coal due to incomplete combustion."

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* 5:108

So much for the chemical processes of combustion. Now, these processes or reactions (that is, the reactions of complete combustion) will not occur unless certain physical requirements are fulfilled. In other words, in order that all the combustible elements of coal may be completely burned three things are necessary; (1.) SUFFICIENT AIR, (2.) PROPER TEMPERATURE, (3.) ADEQUATE MIXTURE OF GASES.

(1.) Amount of air. Air is a mixture of two gases; oxygen, the necessary supporter of combustion, and nitrogen, an inert gas and a mere diluent as far as combustion is concerned. The proportion of these gases in pure air is, by weight; oxygen 23.15%, nitrogen 76.85%. Now, from the reactions already given, together with the atomic weights of the reacting elements, we can calculate the amounts of oxygen and air which are chemically necessary for the complete burning of our six combustible substances. The results are given in the following table in which we have the respective amounts of oxygen and air necessary to burn one pound of the combustible:

		Pounds Oxygen	Pounds Air
(1.)	Carbon -C	2.33	11.52
(2.)	Sulphur-S	1.00	4.32
(3.)	Hydrogen-H	8.00	34.56
(4.)	Methane-CH_4	4.00	17.28
(5.)	Ethane-C_2H_4	3.43	14.82
(6.)	Carbon monoxide-CO	.57	2.47

It is evident that the amount of air chemically necessary to burn one pound of coal would vary somewhat depending upon the composition of the coal. As a matter of fact this requisite amount varies from about nine to twelve pounds with different grades of coal as may be readily determined from an analysis.*

This brings us to the most important point with regard to air supply, namely that IT IS BOTH THEORETICALLY AND EXPERIMENTALLY IMPOSSIBLE TO GET COMPLETE COMBUSTION WITHOUT AN EXCESS OF AIR ABOVE THAT WHICH IS CHEMICALLY NEEDED. This is due to two things; first, the impossibility of obtaining an absolutely uniform distribution of the air supply (this will be discussed under the heading "Mix-

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* See curves, fig. 4 page 50.

ture of gases"), and secondly the LAW OF MASS ACTION.*

The chemical law of mass action is such an important factor in the theory of combustion that we will endeavor, in a general way, to explain its fundamental principles. For convenience we will confine our attention to the combustion of hydrogen, but with the understanding that what is true of hydrogen is true in a similar way of carbon, carbon-monoxide and hydrocarbon compounds.-- Let one pound of hydrogen -H_2- and eight pounds of oxygen -O_2-, be thoroughly mixed and heated to the ignition temperature. Immediately the H_2 molecules will begin to combine with the O_2 molecules to form steam (H_2O) according to the reaction already given. By the law of mass action the rate at which the molecules will combine is proportional to the product of the masses of free H_2 and O_2 present in unit volume, (these masses being measured in gram molecules). This seems reasonable, for the fewer molecules of H_2 and O_2 we have in a certain volume the farther apart they will be, and the less likelihood there is that an H_2 molecule will strike an O_2 molecule and combine with it. As the combustion proceeds the free molecules of H_2 and O_2 decrease in number and become

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* 31:Ch.22 24:Ch9 5:61.170

more and more separated from each other by molecules of H_2O; hence the rate of combustion decreases proportionately. (It might be well to note here that when we burn a combustible in air, instead of oxygen, the rate of combustion is considerably decreased by the diluent effect of the nitrogen in the air.) To quote from Bulletin No. 325[*] U.S. G.S.; "The curve of chemical activity would drop off rapidly as the gases proceeded along their path in the combustion chamber, so that if the rates of combustion were plotted as ordinates along a base of travel of gases, the resulting curve would look much like the expansion curve of an engine-indicator diagram." Although these rates of combustion are unknown, it is evident from the above (in connection with experimental facts) that it is impossible, with only eight pounds of oxygen per pound of hydrogen, to get complete combustion or even practically completeecombustion in the time available. Therefore, in order that the reaction may take place within a reasonable length of time,(one second is probably the maximum time available in a furnace.) an excess of oxygen must be provided to increase the rate of mass action.

But this is not the whole story. If the temperature

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[*] 5:61

is high enough a counter reaction will take place, namely the decomposition of steam into hydrogen and oxygen ($2H_2O = 2H_2 - O_2$). We will then have the two reactions of opposite character going on at the same time. These two reactions will naturally strike a balance at which the same amount of H_2 will be dissociated as is formed, that is, the rates of combination and dissociation will be equal. This phenomenom is called equilibrium or balanced action. The point of balance depends upon at least two things; the amount of excess oxygen and the temperature. Increase of oxygen supply increases the rate of combination but does not affect the rate of dissociations; Hence increase of oxygen increases the completeness of combustion. Increase in temperature increase the rates of both combination and dissociation. But the rate of dissociation increase faster than the other so that rise in temperature tends somewhat to decrease the completeness of combustion. In this regard, Walker# says;"A rise of temperature is almost invariably accompanied by acceleration of chemical action. In a balanced action, therefore, both the direct and reversed actions are accelerated when the temperature is raised. The effect on the

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\# 31:258

opposed reactions is, however, not in general equally great, with the result that the point of equilibrium is displaced in one or other sense. This displacement is intimately connected with the heat evolved in the reaction. If the direct action gives out a certain number of calories per gram-molecule transformed, the reverse reaction will absorb an exactly equal amount of heat. Now rise of temperature always affects the equilibrium in such a manner that the displacement takes place in the direction which will determine the absorption of heat. If, therefore, the direct action is accompanied by evolution of heat, the action will not proceed so far at a high as at a low temperature." Granted then that increase in temperature theoretically decreases the completeness of combustion due to dissociation of H_2O and CO_2, is the amount of this dissociation an appreciable quantity? The accompanying curves obtained from results of recent experiments by Nernst and Wartenburg, which are given in Bulletin No. 325[#] U.S. G.S., determine this point. The Bulletin says concerning these curves; "These data are probably the most reliable extant. They indicate that many fears heretofore widely held, as to limitations

[#] 5: 154

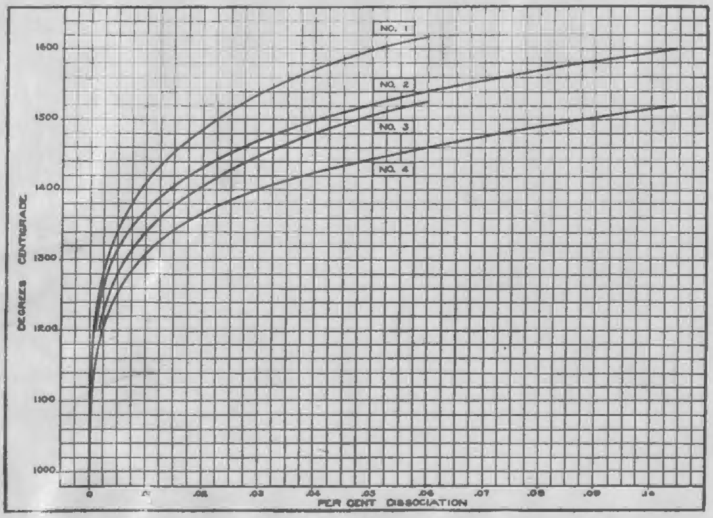

FIG. [illegible].—Dissociation curves of water vapor and carbon dioxide: Curve No. 1, H_2O at atmospheric pressure; No. 2, CO_2 at atmospheric pressure; No. 3, H_2O at 0.1 atmospheric pressure; No. 4, CO_2 at 0.1 atmospheric pressure. Data from Zeitschrift für physikalische Chemie, vol. 56, No. 5, 1906.

Figure -2-

in high temperature work due to dissociation, are almost groundless". From this it is evident that the affect of temperature on mass action is practically negligible as far as the burning of coal is concerned.

In conclusion we repeat:--THE LAW OF MASS ACTION SHOWS THAT IT IS THEORETICALLY IMPOSSIBLE TO GET COMPLETE

COMBUSTION WITHOUT EXCESS OF AIR ABOVE THAT WHICH IS CHEMICALLY NEEDED. Balanced action, due to dissociation of H_2O and CO_2, tends to decrease the completeness of combustion, but its affect is so slight as to be neglible.

(2) Temperature. In order that oxygen may unite with a fuel, that is, in order that combustion may occur we must first have a temperature at least equal to the ignition temperatures of the fuel. Moreover this temperature must be maintained throughout the entire period of burning, otherwise combustion will be incomplete and smoke will result. The cooling of gases to a point below their ignition temperature, before they have been completely burned, is a most common cause of smoke.

Now what are the ignition temperatures of coal and its various constituents? Albert A. Cary in an article in the Iron Age * (October 2,1902), gives a very thorough discussion of ignition temperatures as affecting the burning of coal under steam boilers. He says;-- "The critical temperature of combustion for various substances is a most important subject, which has received altogether too little attention by those interested in furnace development,

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smoke suppression and fuel economy". He goes on to discuss the ignition temperature of carbon as follows:--

"Few, if any, solid substances present so great a range of ignition temperatures as carbon, which occurs in many different forms, such as the diamond, graphite and charcoal. The ignition temperature of carbon in the form of the diamond is very high. As it has been burned in platinum without fusing the platinum its temperature is somewhat below the melting point of the metal, which is 3227 deg.F.

"I have found no reliable data concerning the ignition temperature of carbon in the form of graphite. There is no doubt that this temperature is less than that required to chemically combine oxygen with carbon in the form of diamond, but the ignition temperature is nevertheless very high, as we may infer from the extensive use of graphite for the manufacture of crucibles for use in highly heated furnaces and also for furnace linings where very high temperatures occur."

"There is a sharp contrast between the high ignition temperatures of these two forms of carbon and the third form mentioned--that is, charcoal, which is nearly pure carbon, containing but a few percent of impurities.

"The ignition temperatures of all charcoal are not the same, varying according to its density (there being both hard and soft charcoal), which difference is due to the kind of wood used in its preparation and also the temperature existing in the charcoal furnace when it was burned.

"Professor Thurston in his "Materials of Engineering" gives a table of ignition temperatures for charcoal as follows::

Temperatures of Preparation	Temperatures of Ignition
3,000 deg. Fahr.	2,500 deg. Fahr.
2,500 " "	1,300 " "
2,000 " "	1,100 " "
1,500 " "	900 " "
1,000 " "	800 " "
500 " "	650 " "

"We will see that the specific gravity of a substance (which is a measure of its density) has a material effect on its ignition temperature. Taking the above named forms of carbon and including with them anthracite coal (which runs from 92.5 to 97 percent of pure carbon aside from its ash), and also taking coke, which aside from its ash is within a few percent of pure carbon, and considering their specific gravities, we have the following interesting table.

	Av. Specific Gravity	Approx. Ignition Temp. Deg. Fahr.
Diamond, in small chips	3.53	about 2,900
Graphite, small flakes	2.5	possibly 2,700
Hard Charcoal	about 2.	2,500
Connelsville coke	1.875	about 1,500
Anthracite Coal	1.43	925
Soft Charcoal	about 1.3	650

"The table unfortunately, due to lack of sufficient data, is a very rough approximation, but is sufficient to show that the tmmperature of ignition of solids is governed by the state of density in which they exist."

Mr Cary apparently did not know of the experiments made by Henri Moissan, the distinguished French chemist. In his book[*] on the "Electric Furnace", Moissan gives some very carefully made determinations of the ignition tem-

[*] 26 Chap. 2

peratures of different forms of carbon. It is probable that these determinations are the most accurate as yet made. The temperatures given by Moissan, although they show in general the same relation to specific gravity are not nearly as high as those given by Cary. To show this we have compiled the following table from the results of Moissan:-

	Specific Gravity.	Ignition Temperatures	
		Deg. Cent.	Deg. Fahr.
Diamond (artificial)	3.-3.5	900	1652
Diamond (natural)	3.5	760-875	1400-1607
Graphite (artificial)	2.1-2.25	660	1220
Graphite (natural)	2.16-2.19	650-670	1202-1238
Carbon (lamp black)	1.87	476	888
Carbon (lamp black)	1.76	375	707

From this we see that the temperatures given by Cary and Thurston, which as stated were only rough estimates, were much too high. We conclude IT IS HIGHLY PROBABLE THAT NO FORM OF ORDINARY CARBON,-COAL, CHARCOAL, SOOT OR SMOKE PARTICLES, HAS AN IGNITION TEMPERATURE GREATER THAN 1200 DEGREES FAHRENHEIT. This conclusion is an exceedingly important one in its bearing on the smoke problem.

It shows that the statement, commonly made, that it is impossible or at least very difficult to burn smoke, is without foundation. It is probable that ordinary smoke would burn at 800 degrees F. It would be interesting to determine this experimentally and the write hopes to do this at some future time.

Another very important point in this connection, which is brought out by Moissan, is that all charcoal and common forms of carbon contain hydrogen in a combined form, as is shown by analysis, and that it is impossible to drive off this hydrogen except by very high temperature, and moreover that when this hydrogen is driven off we have no longer charcoal but graphite. Moissan quotes from Berthelot on this point as follows:[*] -- "In reality, the carbon cannot be regarded as a real element; on the contrary, it resembles a highly condensed hydrocarbon, with unusually little hydrogen and an unusually high molecular weight. In a certain measure, pure carbon means a border state that can be reached only by the highest temperature that we can produce",. It is probable then that free carbon exists

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[*] 26:41

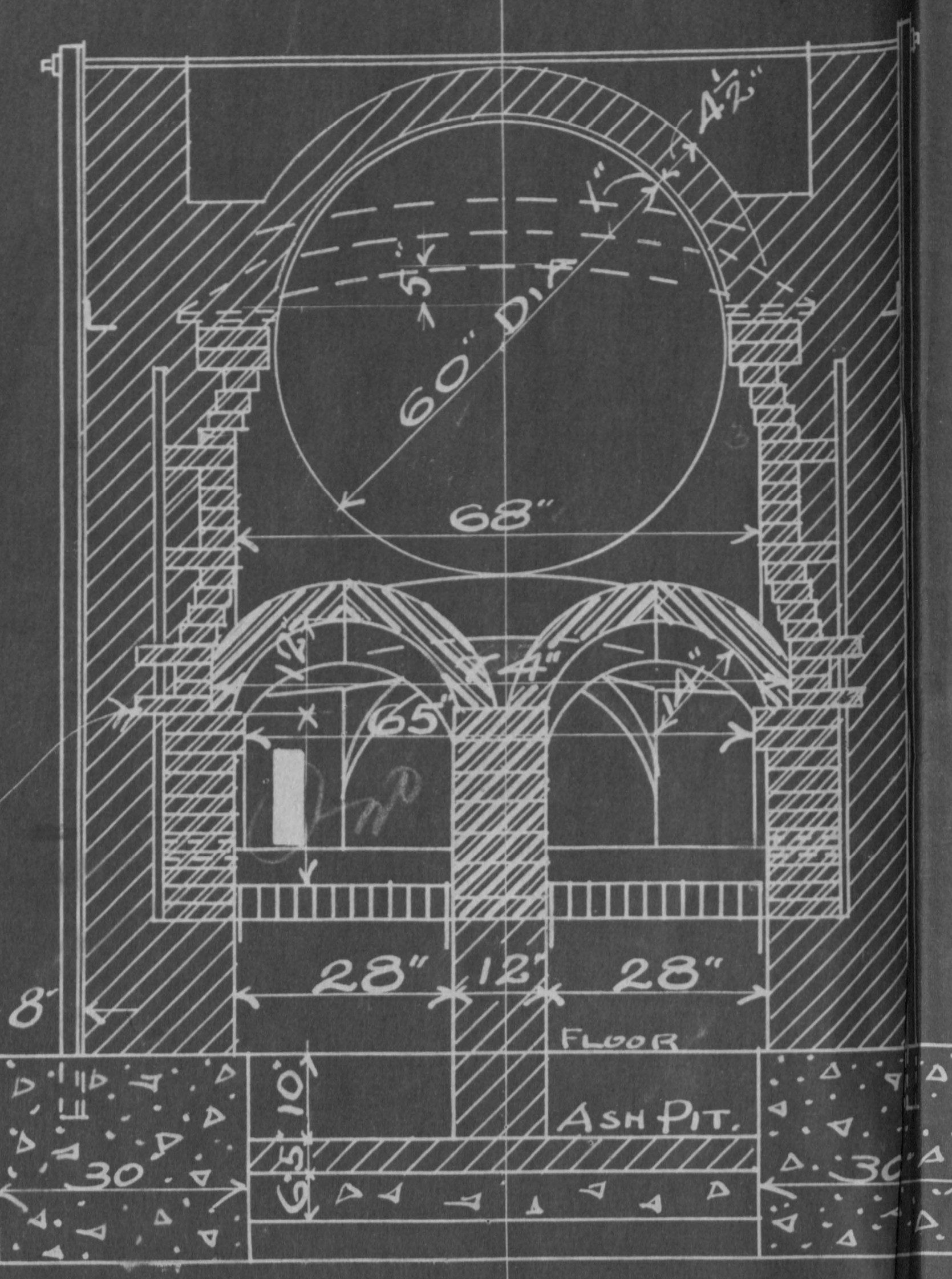
only in the forms of graphite or diamond and that charcoal and other common forms of carbon are not free carbon but hydrocarbons in which the amount of hydrogen is small. It is probable that this fact, as well as the varying density, has something to do with the variations in ignition temperatures of different forms of carbon.

So much for carbon. The other five combustibles, which we have been discussing, have ignition temperatures which are practically constant. The following table, condensed from one given by Cary, states these temperatures as obtained from seven different chemical authorities whom we have designated by letters A,B,C,D,E,F and G.

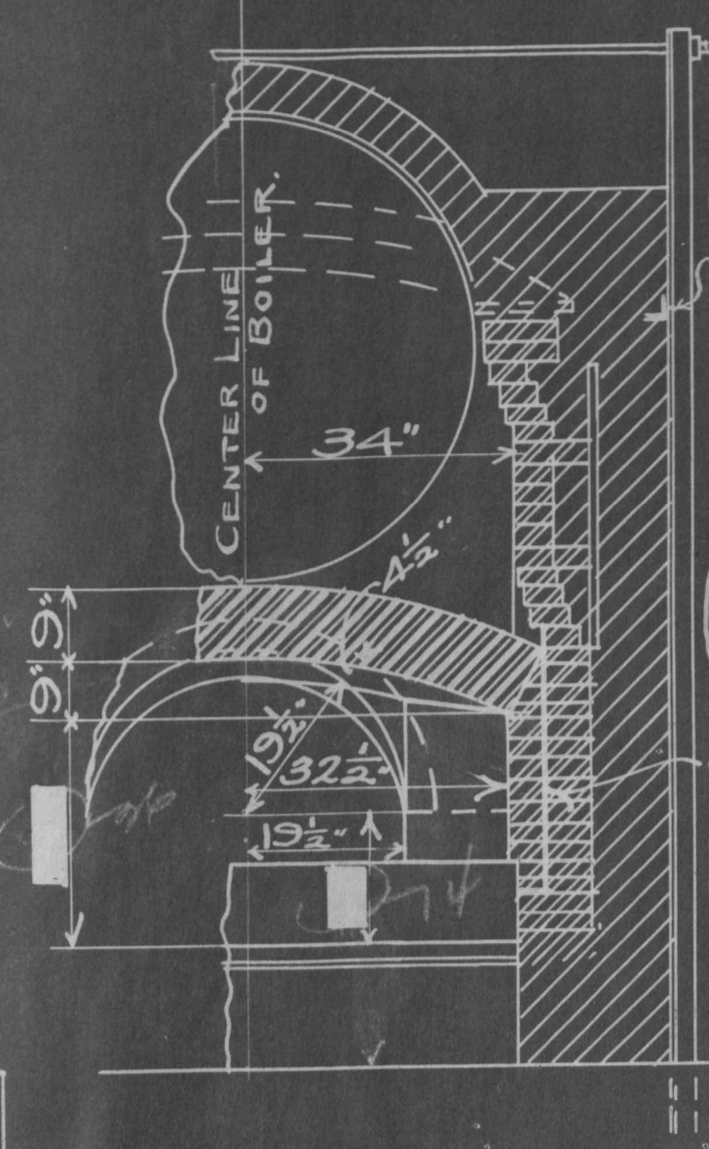
TABLE OF IGNITION TEMPS. UNDER ATM. PRESS. (In deg. Fahr.)

	A	B	C	D	E	F	G
Hydrogen	1130	1031	1071				
Methane	1313	1202	1436	1233	1200		
Ethane			1022				
Sulphur					470		
Carbon Monoxide		1211	1202		1211		

BOILER SETTER
NOTE ONE HEADER COURSE ABOVE LEDGE.



SECTION BACK OF FRONT WALL

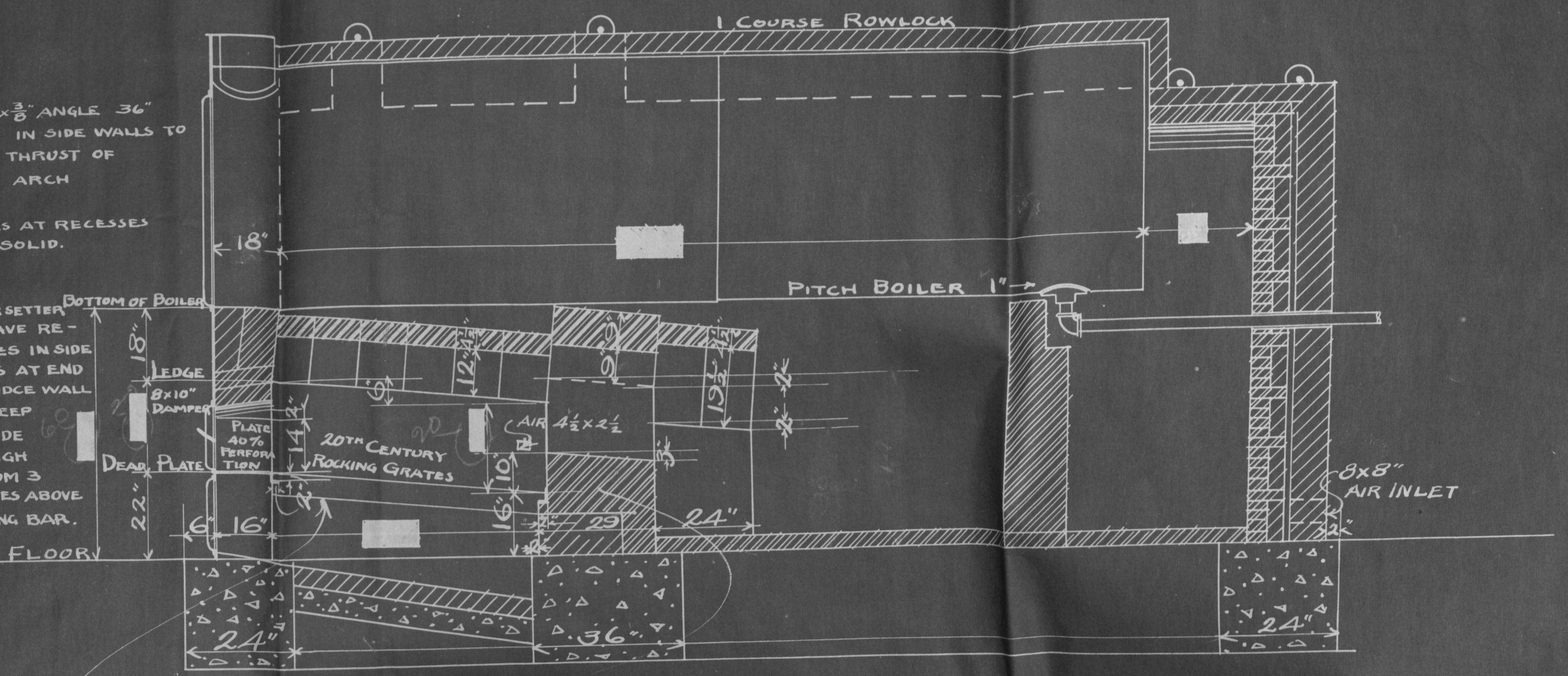


HALF SECTION AT BRIDGE WALL.

4"×4"×⅜" ANGLE 36" LONG IN SIDE WALLS TO TAKE THRUST OF BACK ARCH

WALLS AT RECESSES ARE SOLID.

BOILER SETTER TO LEAVE RECESSES IN SIDE WALLS AT END OF BRIDGE WALL 4½" DEEP 27" WIDE 36" HIGH BOTTOM 3 COURSES ABOVE BEARING BAR.



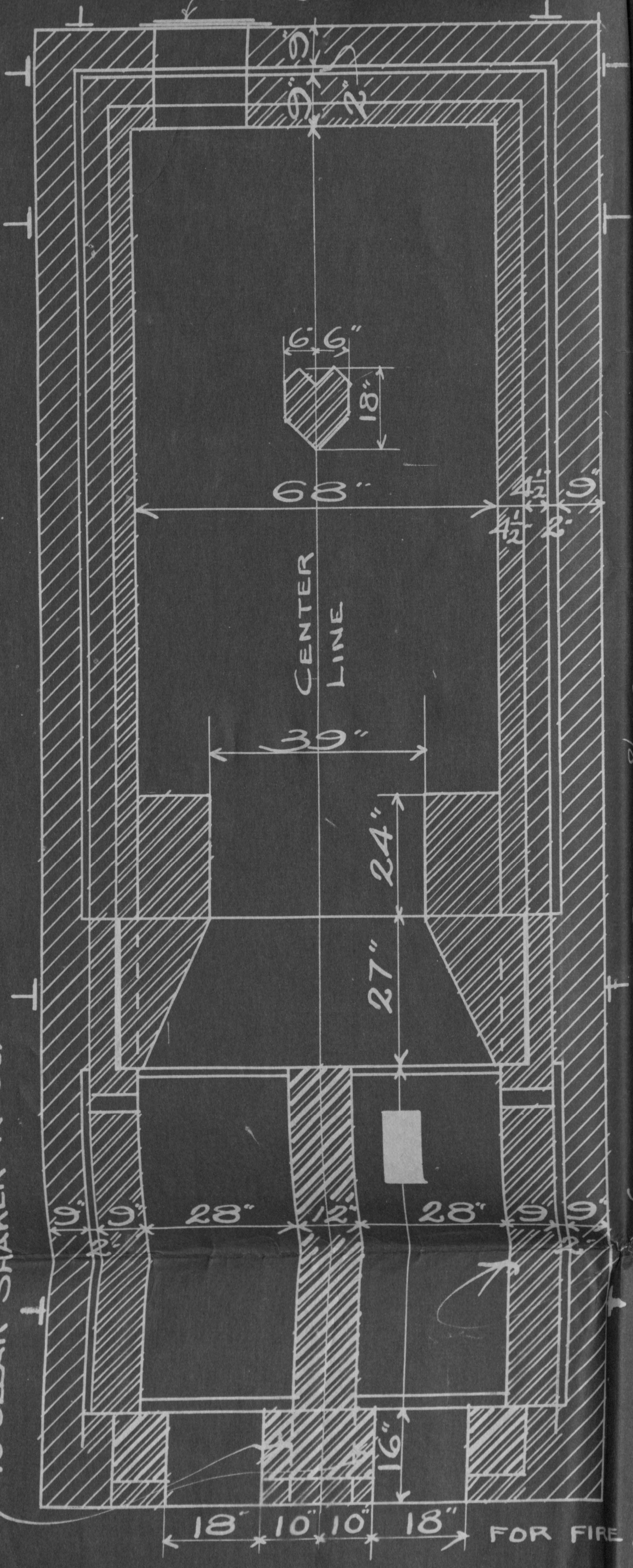
MAKE PITCH OUT OF COMMON BRICK
FIRE BRICK STARTS ON THIS LINE
2 COURSES BELOW THE GRATES

WATER ARCH FURNACE CO'S WORK ON BRIDGE WALL STARTS 3 COURSES ABOVE THE BEARING BAR.

LONGITUDINAL SECTION.

Boiler lowered 2"

18"×24" CLEAN OUT DOOR



FOR FIRE & ASH PIT DOORS

PIER UNDER DEAD PLATE 12" WIDE TO CLEAR SHAKER RODS.

SIDE WALLS OF FIRE BOX & 1 COURSE ABOVE LEDGE TO BE HEADERS.

PLAN AT TOP OF BRIDGE WALL.

HEADERS 4 COURSES APART
BOILER FRONTS TO BE SPLIT VERTICALLY & HORIZONTALLY BETWEEN FIRE DOORS
16 PIECES 10"×12"×4" FIRE TILE DOOR LINERS FURNISHED BY FURNACE CONTRACTOR & SET BY MASON CONTRACTOR.

SETTING PLAN FOR
1 – 60"× [illegible] H.R.T. BOILER.
EQUIPPED WITH THE
TWIN FIRE FURNACE &
20TH CENTURY ROCKING GRATES.
MANUFACTURED BY THE
WATER ARCH FURNACE CO.
1252 1ST NATL BANK BLDG.
SCALE ½"=1'-0" CHICAGO 10-17-10.

▨	▨	▨	▨
COMMON BR	FIRE BR	FIRE TILE	CONCRETE

210

NHC.

TABLE--CONCLUDED.

	A	B	C	D	E	F	G
Carbon monoxide in presence of large amount of CO_2			1292				
Cannel Coal						668	
Bituminous						766	
Semi bituminous						870	
Anthracite							925

From this table and our previous conclusion we see that A TEMPERATURE OF 1300 DEGREES FAHRENHEIT IS SUFFICIENT TO BURN ANY COMBUSTIBLE WHICH MAY BE PRESENT IN COAL OR WHICH MAY BE FORMED WHEN COAL IS BURNED.

(3) Mixture of gases. In order that the combustible gases distilled from a fuel may be completely burned, it is necessary that the molecules of gas shall be brought into intimate contact with the molecules of oxygen of the air. Streams of gas and streams of air may travel side by side through a furnace without combustion except where they touch each other, much of the interior of the gas

streams remaining unburned. In order to prevent this WE MUST PROVIDE SOME MEANS OF BREAKING UP THESE STREAMS AND MIXING THE GAS AND AIR MORE INTIMATELY. Of course it is impossible, in any practical case, to obtain an absolutely uniform mixture, but the more uniform mixture we have, the more efficient will the furnace be both as a heat generator and a smoke preventer. This problem of mixing is an exceedingly important factor in smoke prevention and fuel economy and deserves much more attention than it commonly receives in the design of a boiler furnace.

II

PRACTICAL APPLICATION.

Can Smoke be Prevented?

In the preceding pages we have endeavored to present, as thoroughly as possible, the underlying principles of smoke prevention. It remains now to apply these principles to the practical problems of existing boiler plants. The theory is comparatively simple. The application is much more difficult. Some affirm that the practical solution of the problem is impossible in many instances. With such persons we emphatically disagree. Moreover, after careful consideration of the problem and results obtained by numerous experiments, we do not hesitate to assert the following proposition. ALL OBJECTIONABLE SMOKE MADE BY BOILER FURNACES, REGARDLESS OF FUEL USED, CAN BE ABSOLUTELY PREVENTED BY MEANS WHICH ARE BOTH FEASIBLE AND PRACTICAL. In the remaining pages of this thesis we will attempt to give reasons and facts which will indicate the truth of this statement.

Principles of Smoke Prevention Applied to Steam Boiler Plants.

In the first place let us lay down four fundamental rules to be observed in the consideration of any smoke problem.

(1) The most important thing to remember is that, although in theory all problems in smoke prevention are exactly alike, IN PRACTICE EVERY PROBLEM IS DIFFERENT AND DEMANDS SEPARATE AND INDIVIDUAL TREATMENT. There is no such thing as a universal smoke preventer or "smoke con-

sumer" and there never will be.

(2) Smoke, as already indicated, is essentially due to one or more of three causes; INSUFFICIENT AIR, IMPROPER TEMPERATURE, INADEQUATE MIXING OF GASES. Every circumstance or condition, in an existing plant may be analyzed and classified under one or more of these three heads.

(3) ANY SMOKE PREVENTING DEVICE WHICH REQUIRES A LARGE AMOUNT OF SKILL, CARE OR ATTENTION, ON THE PART OF THE THE FIREMAN, IS SURE TO BE UNSATISFACTORY. The ideal smoke preventing apparatus should be entirely automatic and independent of the personality of the fireman.

(4) A FURNACE SHOULD BE DESIGNED TO BURN ONE GENERAL GRADE OF FUEL ONLY, and should not be expected to burn widely different grades of fuel satisfactorily. A furnace designed to burn hard coal will not burn the softer coals smokelessly or economically.

Now, applying rule (2), let us take up the following causes of smoke and analyze them.

(1) Too low temperature.
(2) Too high temperature.
(3) Too little air.
~~(4) Too much air.~~
(5) Too small draft. chimney
(6) Unburned gases come in contact with the water heating surfaces.
(7) Too small combustion space.
(8) Too much coal fired at once.
(9) Lack of mixing devices.
(10) Poor conditions in the fuel bed.
(11) Too high rate of combustion.
(12) Boiler overloaded.

In discussing these conditions we shall say a good deal about boiler economy+ and boiler efficiency+. That this is necessary and proper is evident from the fact, already made clear, that smoke prevention and boiler economy are inseparably related.

(1) Too low temperature. - As already explained, if at any time during combustion the temperature falls below the ignition temperature of the combustibles pre-

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+For definition of these terms as used in this thesis see page 40.

sent, smoke will be formed. We found that the ignition temperature would never exceed 1300 degrees fahrenheit. Hence we conclude that, in a boiler furnace EVERY PART OF THE COMBUSTION SPACE SHOULD BE MAINTAINED, AT ALL TIMES, AT A TEMPERATURE NOT LESS THAN ABOUT 1300 DEGREES FAHRENHEIT.

(2) Too high temperature.
(3) Too little air.

These two are so closely related that we shall take them up together:-

At first thought it would seem that the higher initial or furnace temperature we can obtain in a boiler, the better, provided the brick work will stand it. Indeed, this has been a common belief among engineers. Nevertheless the tests and investigations of the U.S. Fuel Testing Plant at St.Louis show that, although this is true in a slight degree, the common conception of the phenomenon is both experimentally and theoretically incorrect. In what follows we shall attempt to make this clear by showing the effect of high temperature upon combustion, smoke production and boiler economy.

We shall divide the problem into three phases as follows;- (a) the effect of temperature on mass action, (b) the relation between temperature and air supply, (c) the relation between temperature and boiler efficiency.

(a) The effect of temperature upon mass action has already been discussed. We showed that increase in temperature increased dissociation of H_2O and CO_2 in such a manner as to decrease the completeness of combustion. We concluded however that the effect was so slight, at the temperatures available in a furnace, that it was entirely negligible. Therefore we can disregard mass action in this connection.

(b) The relation between temperature and air supply.— The accompanying curves (fig 3), taken from

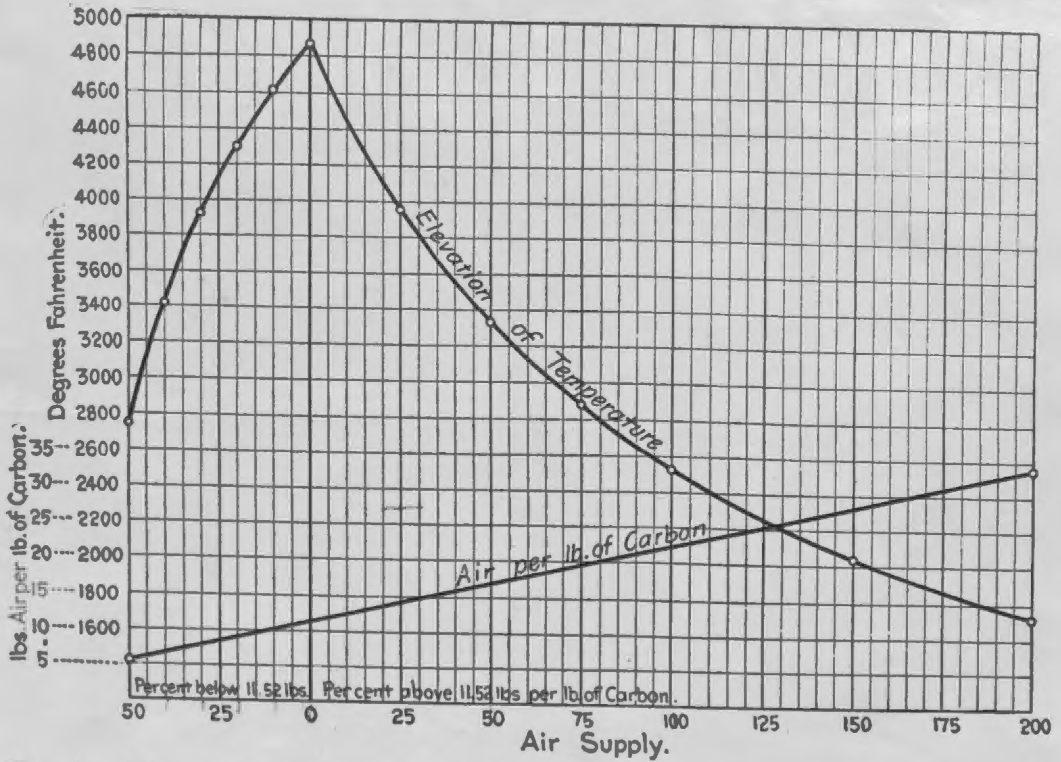

FIG. 1.—MAXIMUM THEORETICAL TEMPERATURE OF THE FIRE DUE TO BURNING CARBON WITH DIFFERENT QUANTITIES OF AIR.

Fig.-3-

Kent's "Steam Boiler Economy",+ show the theoretical relation between the combustion temperature of carbon and the air supply per pound, (assuming that the air is supplied at a constant temperature of 62 degrees F.) We note that the temperature is highest (4900 degrees F.) at the point where there is no excess air above the 11.52 pounds which is chemically necessary. Either to the left or to the right of this point the temperature decreases very rapidly, due to insufficient air on the left and excess air on the right.

The curves serve to illustrate the well known fact that an increase in furnace temperature can only be brought about by a decrease in the air supply, (We assume here that the temperature of the air supply is constant) Now the trouble is that, with an air supply less than about 100% excess, we always get more or less incomplete combustion. Moreover, as we decrease the air supply below this point (that is 100% excess) the amount of incomplete

+ 25:27 see also curves on page 50 of this thesis.

combustion increases. The result is that excessively high furnace temperatures are always accompanied by smoke and loss of heat due to the escape of unburned gases up the chimney. This was shown to be a fact experimentally in the tests made by the Geological Survey. To quote from Bulletin No.325# U.S.G.S. "Low efficiency is always accompanied by the highest per cent of CO in the flue-gas analysis, and the highest efficiency by the lowest per cent of CO. Moreover the high CO values always go with the highest combustion chamber temperatures. It is also found, as the combustion chamber temperature increases, that the per cent of black smoke increases".

Now there must be, for every boiler, an economical temperature and a corresponding economical air supply, at which the loss due to incomplete combustion just counterbalances the gain in boiler efficiency due to the higher initial temperature. This point of maximum economy will be constant for any single boiler and furnace but will vary

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5:64 See also 5:56,57,100-102,175.

somewhat with different boilers or different furnaces. (By the term boiler economy we mean the over all efficiency of boiler and furnace combined. By boiler efficiency we mean the efficiency of heat absorption, $\frac{t_1-t_2}{t_1}$) It is evident, then, that the maximum economy possible in any given case will depend upon the relation between temperature and completeness of combustion, and the relation between temperature and boiler efficiency.

As already explained, the completeness of combustion here depends upon two factors, (1) mass action and (2) mixture of gases. The effect of mass action is independent of the design of furnace and hence is unchangeable. But the effect due to mixture varies greatly in different furnaces depending upon the efficiency of mixing devices. Hence the more thorough the mixing is, the less will be the excess air necessary to give complete combustion, the higher will be the economical temperature, and the higher will be the maximum economy possible.

The staff at the St.Louis Fuel testing plant found that for the Heine boilers+ which they were using the economical temperature was about 2400 degrees F.++ It is probable that, if more efficient mixing devices had been used, a somewhat higher economical temperature would have been obtained.

(c) Relation between initial temperature of gases and boiler efficiency. - In this connection two questions present themselves, as follows, - We have seen that higher furnace temperatures cause smoke and incomplete combustion, but at the same time we have hinted that high temperatures increase the boiler efficiency. Now does the prevention of smoke mean that we must work a boiler below the economical temperature and thus sacrifice economy for smokelessness? Further, would it be worth while to preheat the air supply and thus get high temperature and plenty of air at the same time? The importance of these two questions depends largely upon a third question, namely; how much

+ see figure 11 page 98
++ 5:66

is the boiler efficiency increased by rise in initial temperature? This problem has been studied with great care both from an experimental and theoretical standpoint, by the fuel-testing branch of the Geological Survey.[#] In the following we shall give only the conclussions arrived at.

At first thought it seems almost axiomatic, that increase in the initial temperature of gases entering the boiler tubes should cause a corresponding and proportionate increase in boiler efficiency, in the same way that rise in initial steam temperature would increase the efficiency of a steam engine. Nevertheless the investigations at St.Louis show that this is both experimentally and theoretically untrue. We quote from Bulletin No.325[##]U.S.G.S. as follows:-

"Efficiency of a boiler as a heat absorber is $\frac{t_1-t_2}{t_1}$ where t_1 = initial temperature of gases above atmosphere, and t_2 = final temperature of gases above

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[#] 53; - 52; - 5.
[##] 5:107; See also 5:124, 125, 114, 115, 15.

atmosphere.

"Many of the staff believed at that time that if the air supply per pound of coal were reduced, without decreasing the completeness of combustion, (in consequence of which the initial temperature would rise) the final temperature t_2 would fall, or at least not rise proportionately with t_1. It is frequently stated by authorities on boiler testing that if the same number of heat units be liberated in a furnace per second in two cases - first, with a small air excess, and second with a large air excess — the final or flue temperature in the first case will be the lower. This assumption may be true with some boilers, or with most boilers, or even with those of this plant, but after careful investigations of large numbers of actual simultaneous readings, the staff has become convinced that such a theory is both practically and theoretically untrue; and that, on the contrary, a rise of furnace temperature usually causes a proportionate rise of flue temperature, the ratio between these temperatures being almost independent of the mass of gases passing. For a long time this conclusion was hard to believe, for on closing the stack damper a little, at times, the combustion-chamber temperature rose and the stack temperature fell; yet nothing appears more certain on observation than that the sun moves round the earth.

"It seemed almost axiomatic that the higher the initial temperature, the greater the amount of heat which would pass into the boiler, because of the greater temperature difference between gases and water, yet this proposition is only slightly true."

The bulletin goes on to develop the theory of boiler efficiency using equations given by Perry in his book on the "Steam Engine and Gas and Oil Engines".✦ The final equation thus derived indicates that, regarding only transmission of heat by covection, that is, neglecting

✦ 29:584-598 also 53.

radiation, the efficiency of a boiler tube depends only upon its length and diameter, and is absolutely independent of the initial temperature of the gases. (This theory is based on the assumption that the steam in the boiler is at the temperature of the atmosphere. This of course is not true in any case, but the steam temperature is so near to that of the atmosphere, as compared with the furnace temperature, that the error thus introduced is very slight under all possible working conditions.) This theory has been verified to a remarkable degree by the tests at the St.Louis boiler testing plant but especially by laboratory tests, made later, on miniature boilers constructed for the purpose. The results of these later tests have not yet been published by the government but may be found in a paper[+] which was presented before the Western Society of Engineers by W.T.Ray and H.Kreisinger.

Now of course some heat is transmitted by radiation, and the amount of radiation increases as the fourth

[+] 53.

power of the initial temperature. However the percent of heat transmitted by radiation is small compared with that due to convection. The result is that increase in furnace temperature causes a slight but in no way proportionate increase in boiler efficiency. This was shown to be true experimentally. To quote again from Bulletin No. 325.+ - "The most interesting showing is that the code 'boiler efficiency' rises only two percent as the combustion-chamber temperature rises from 1800 degrees to 2700 degrees F. This showing is in accordance with other charts and the theory of boilers, all being to the effect that a rise of about 1000 degrees F. in furnace temperature improves the efficiency of the boiler as a heat absorber only about ten per cent. Most of this gain, however, is offset by incompleteness of combustion chargeable to the restricted axygen supply required to get the high temperatures."

Theoretically then the gain in efficiency from

+ 5:23.

high temperatures, even when the completeness of combustion is maintained, is small. Practically two other considerations affect the problem. The best firebrick on the market will not endure a prolonged temperature much above 3000 degrees fahrenheit: this puts a practical limit upon temperature. Moreover the loss due to radiation from the furnace increases as the fourth power of the temperature and hence will be much greater at high temperatures.

To sum up all this, the advantages and disadvantages of high furnace temperatures are as follows:- Advantages; (a) small increase in boiler efficiency, (b) increase in boiler capacity:- Disadvantages; (a) more loss due to incomplete combustion, (b) increased loss from radiation, (c) deterioration of the furnace.

Now we are ready to consider the two questions proposed on page - 41. First, is it necessary, in order to prevent smoke, to use an excessive amount of air and thus sacrifice economy? We can not answer this question absolutely: we believe that in a well designed furnace with good mixing devices such a sacrifice would never be necessary; on the contrary however, in many actual boiler plants with furnaces of poor or improper design this may be, and often is, the only solution feasible. But the important point is this; the loss in boiler efficiency from excessive air (and corresponding low temperature) is not nearly as great as commonly believed and, moreover, in any practical case this loss will be partly offset by more complete combustion. The second question suggested was; would it be worth while to preheat the air supply and thus secure a high temperature with plenty of air at the same time? Under present conditions and limitations we believe this would not be worth while. Nevertheless, if a more refractory fire-brick should be made available, it seems quite probable that a boiler and furnace designed for high temperatures and preheated air would develop an economy (and also a capacity) superior to anything now attainable.

This, however, is foreign to the subject in hand.

We may now draw the following conclusions as to the effect of high temperatures and limited air supply upon combustion and economy.

HIGH FURNACE TEMPERATURES ARE UNECONOMICAL AND USUALLY ACCOMPANIED BY OBJECTIONABLE SMOKE.

TOO SMALL AN EXCESS OF AIR SUPPLY IS VERY DANGEROUS ECONOMICALLY, AND WILL CAUSE SMOKE AND INCOMPLETE COMBUSTION.

THE ADVANTAGES OF HIGH TEMPERATURE AND SMALL EXCESS AIR ARE COMMONLY OVER-ESTIMATED. THEY ARE ORDINARILY INSUFFICIENT TO OFFSET THE DISADVANTAGES, AND THE DANGER OF INCOMPLETE COMBUSTION, THEREBY ENCOUNTERED.

IN THE ORDINARY BOILER FURNACE A TEMPERATURE OF ABOUT 2400 DEGREES FAHRENHEIT (CORRESPONDING TO ABOUT 100% EXCESS AIR) IS SAFE AND ECONOMICAL. The accompanying curves (fig.4) taken from Bulletin No.325,[+] show that this would mean an air supply per pound of fuel of about ten pounds for

[+] 5:160

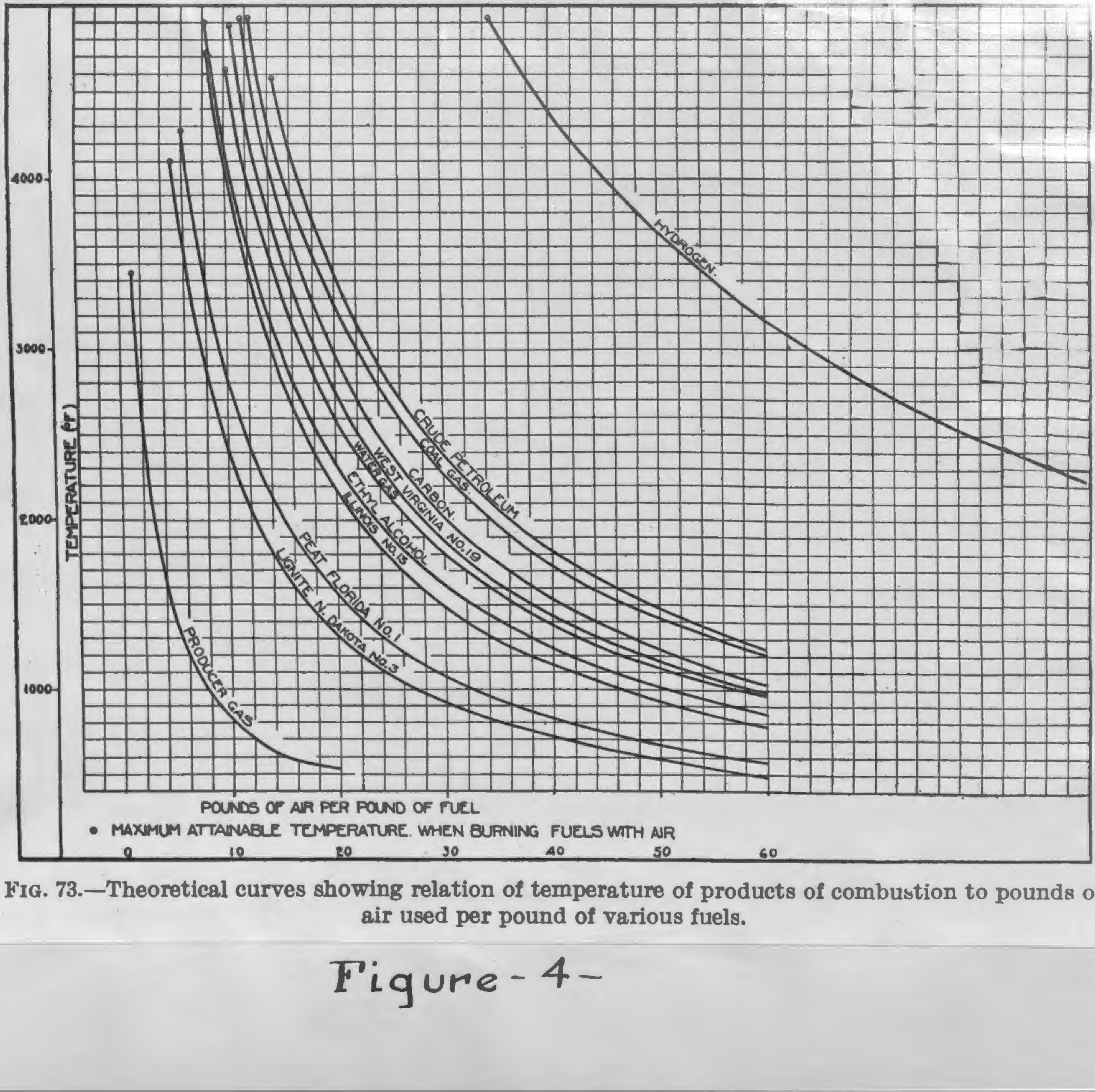

FIG. 73.—Theoretical curves showing relation of temperature of products of combustion to pounds of air used per pound of various fuels.

Figure - 4 -

North Dakota lignite No.3,+ eighteen pounds for Illinois bituminous No.13,+++ twenty-three pounds for West Virginia semi-bituminous No.19++++ and twenty-four pounds for pure carbon.

(4) We now come to the fourth heading suggested on page 34 as a cause of smoke and poor economy, namely, too much air. As we have already seen, plenty of air is a good cure for smoke. It is possible, however, to admit so much air as to cause incomplete combustion and smoke; that is the air may be admitted in such volume as to cool the combustion chamber down below the ignition temperature of the gases present. This seldom occurs in practice for it would require about 400% excess air+++++ which would shame even the most inefficient and poorly managed furnace. No, excessive air supply, in it self, seldom causes smoke. It is improbable that a total of 400% excess air would be admitted to any furnace, but it is quite possible, with

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++ For analysis see 3:138
+++ For analysis see 3:77
++++ For analysis see 3:216
+++++ See curves fig.4.

careless operation, to admit more than 400% excess air in certain spots. Such a condition may exist when there are holes or bare spots in the fire, when too much air is admitted through the fire-door, or when cold air is admitted into the combustion space through air ducts or other special devices. In any such case we are sure to have smoke unless the furnace is provided with very efficient mixing devices.

In regard to the effect of excess air on boiler efficiency much has been written. Many figures have been given showing that the ratio of the heat going up the stack to the total heat generated in the furnace increases greatly as the excess air increases. All these figures have been based on the assumption that the final or flue temperature would remain constant, or even rise somewhat, as the initial or furnace temperature was lowered. If Perry's theory of boilers, already presented, is correct (and it certainly has the advantage of being the most thoroughly and scientifically demonstrated theory at present known), this is not the case at all. From Perry's theory it is evident that, within reasonable limits of air supply, (that is, up to about 200% excess air, corresponding to a furnace temperature of about 1800 degrees fahrenheit; (see curves on fig. 4)) the final temperature t_2 varies almost directly with the initial temperature t_1, making the temperature difference $t_1 - t_2$ fairly constant. In other words when the furnace temperature is raised or lowered the flue temperature rises or falls correspondingly. The result is that the boiler efficiency $\frac{t_1 - t_2}{t_1}$ is fairly constant for different amounts of air supply within reasonable limits. To make this perfectly definite we have determined from the quoted statement on page 46 and with the use of the curves fig. 4 the following. - An increase in air supply from 80% excess to 200% excess causes a decrease in boiler efficiency of only about 10%. Moreover the actual decrease in economy obtained with the boilers used at St.Louis when the air supply was thus increased was only about 2%: the remaining 8% loss was offset by more complete combustion.

To emphasize these deductions we will quote again from Bulletin No.325+ U.S.G.S. as follows. -"If it be true that by raising the initial temperature of the gases entering a boiler by 1000 degrees fahrenheit the amount of heat put into the boiler for every pound of fuel is increased by only a few per cent, and if it also be true that the small amount of exygen present in case of high temperatures tends to reduce the speed and consequently the completeness of combustion, how, then, does it happen that (as is undoubtedly a matter of common abservation) a large air excess certainly lowers the over-all efficiency decidedly? The explanation probably is that when the air excess is large it is probably very large through the holes in the fire, and insufficient through the little hills and cakes of coal on the grate, especially if the latter are underlaid with clinkers; the result is that along with a general large air excess there may be much incomplete combustion. It comes

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+ 5:120

back to the old story that the fuel bed and combustion space are to blame. The remedy lies in a more even fuel bed and gas-mixing structures in the combustion chamber, rather than a low air excess or a thick fuel bed."

Our conclusions from the above are as follows.-

THE FIRE SHOULD BE KEPT UNIFORM OVER THE WHOLE GRATE IF POSSIBLE. NO HOLES OR BARE SPOTS SHOULD BE ALLOWED.

CARE SHOULD BE TAKEN NOT TO ADMIT TOO MUCH AIR OVER THE FIRE. MOREOVER AIR ADMITTED IN THIS WAY SHOULD BE MADE TO PASS AS CLOSE TO THE FUEL BED AS POSSIBLE IN ORDER THAT IT MAY BE HEATED BEFORE MIXING WITH THE GASES.

AIR ADMITTED IN FINE STREAMS OR THIN SHEETS WILL BE MUCH MORE EFFECTIVE THAN WHEN ADMITTED IN A SINGLE LARGE STREAM.

AIR SHOULD NEVER BE ADMITTED TO THE COMBUSTION CHAMBER UNTIL PREVIOUSLY HEATED TO A TEMPERATURE ABOVE 1000 DEGREES FAHRENHEIT.

BOILER EFFICIENCY IS NOT VERY GREATLY DECREASED BY INCREASE OF AIR SUPPLY UP TO 200% EXCESS.

(5) Too small draft. - Insufficient draft accounts for much of the smoke from boiler plants. TOO SMALL DRAFT MEANS INSUFFICIENT AIR SUPPLY AND INSUFFICIENT AIR SUPPLY MEANS INCOMPLETE COMBUSTION. The amount of draft necessary to furnish a required air supply to a boiler varies largely with different boilers, different fuels and different conditions of the fuel bed. In other words, with a constant draft in the chimney, the useful draft is decreased by friction in the breeching and boiler, by leakage through the boiler setting, and by friction in the fuel bed. The loss in the fuel bed depends upon the character of the fuel, the thinkness of the fuel bed and the condition of the fire (amount of clinker etc.).

Bulletin No. 325 says with regard to bituminous coal:- "The best thickness of fire ranges from five to ten

+ 10
++ 5:177

inches, varying with an intensity of draft of .5 to .7 inch under the stack damper." R.H. Kuss of the Chicago smoke department says that at least .25 inch of draft over the fire should usually be maintained with bituminous coal. This latter rule is more convenient for practical application because it is independent of the loss in the boiler itself and hence may be applied to any boiler.

With regard to the heights of chimneys for boiler plants Mr.Kuss gives the following rules. "Chimney heights of less then seventy-five feet above the grate line should not be permitted, and this height allowed only when the chimney is direct connected to the boiler uptake. In case of a breeching and detached chimney, add to the height of chimney computed by standard methods (never less than 75 feet) ten feet for every turn of the breeching and one foot for each foot in length of the breeching."

(6) Unburned gases come in contact with the water-

heating surfaces. - If a cold object is inserted in a gas flame the flame will become smoky and soot will be deposited, or the flame may be put out entirely. The explanation is simple:- The particles of unburned gas which come in comtact with the cold body are cooled down below the ignition temperature. The result is incomplete combustion. In a simillar way, if unburned gases are allowed to come in contact with the comparatively cold water-heating surfaces of a boiler, the result will be incomplete combustion and smoke.

(7) Too small combustion space. - By the term combustion space we mean space between the fuel bed and the water-heating surface of the boiler; that is, the space in which combustion may occur uninterruptedly. Now, if the combustion space is too small we shall have the condition under the previous heading, that is, the gases will come in contact with the cold boiler surfaces before they have been completely burned and smoke will result.

The volume of combustion space necessary for a given boiler depends on at least two things; the volatile matter in the coal used, and the efficiency with which the gases are mixed. - Anthracite coal, as already indicated, contains very little volatile matter and hence does not need much combustion space. As we go down the list of coals from anthracite to lignite, the amount of volatile matter increases: it is evident, then, that the volume of the combustion space necessary to give complete combustion with these coals will increase proportionately. Further, the more thorough the mixing, the more rapid will be the combustion of the gases and the smaller will be the necessary combustion space. (This will be discussed more fully under its proper heading,- number (9)).

The conclusion from (6) and (7) is:- THE DISTILLED GASES SHOULD BE BURNED IN A FIRE-BRICK CHAMBER OF SUFFICIENT CAPACITY TO GIVE COMPLETE COMBUSTION BEFORE THE WATER HEATING SURFACES ARE REACHED.

(8) Too much coal fired at once. - A large amount of coal fired at one time means a large volume of gases liberated at once. Unless the combustion chamber is very large or provided with very efficient mixing devices smoke will occur. The more uniform the distillation of the coal is, the smaller will be the required combustion space and the less will be the danger of smoke.

We conclude:- THE FEED OF FUEL SHOULD BE AS UNIFORM AS POSSIBLE: THE MORE UNIFORM IT IS THE MORE EASILY CAN SMOKE BE PREVENTED.

(9) Lack of mixing devices. - The necessity of good mixing and its efficacy in preventing smoke have already been referred to several times. If any one of the requirements for a good furnace is more important than the others, that one is good mixing devices. In the words of Bulletin No.325[#] U.S.G.S. "MIXING IS WHAT COUNTS".

+ 5:178

Strata of gases and air may travel side by side through a combustion chamber of almost any length without combining, unless they are brought into intimate contact with each other by the interposition of mixing devices. Bulletin No.325[#] U.S.G.S. says: - "Mere length of combustion chamber counts for little compared with some device for thoroughly mixing the gases of the flame stream; one good mixing wall or baffle is probably worth many feet of undisturbed flow."

Two obstacles to the use of mixing devices are encountered in practice. - First, they of necessity reduce the draft and hence, where extra draft is not provided, are apt to give dissappointing results. Secondly, many mixing devices tried have been found unable to withstand the heat to which they were subjected. They have deterior rated rapidly and had to be replaced frequently. We believe however that this difficulty may be entirely overcome by proper design.

Two rules may be laid down for the design of mix-

[#] 5:61

ing structures:-

(a) THE DEVICE SHOULD BE SO DESIGNED THAT IT DOES NOT GREATLY REDUCE THE AREA THROUGH WHICH THE GASES MUST FLOW. A reduction in area will not only choke the gases and reduce the draft, but will cause local high temperatures that will deteriorate the brick work,

(b) THE DEVICE SHOULD CONSIST OF LARGE MASSES OF BRICK RATHER THAN SMALL CHECKER-WORK, as they will more easily sustain the high temperatures.

(10) Poor conditions in the fuel bed. - This is a common cause of smoke.- Too thick a fire or the presence of clinker will result in insufficient air. A thin fire is difficult to keep free from air holes. If the coal is not uniform in size the air distribution will be irregular; very large lumps of coal are difficult to burn without smoke.

(11) Too high rate of combustion. - High rates of combustion ordinarily cause smoke, for two reasons:- First, the volume of gases distilled usually exceeds the capacity of the combustion chamber. Second, the draft is apt to be insufficient for the increased rate of combustion. Besides these two we wish to suggest a third reason which may or may not be a reality. - That is, the amount of air per pound of coal, at high rates of combustion, seems to be decreased even when there is plenty of draft. The experiments at St.Louis[#] seem to show that, as the draft is increased, consequently increasing the rate of combustion, the amount of air per pound of coal burned, at first increases until a certain critical rate of combustion is reached, but beyond that point decreases very perceptibly. This means that, above the critical point, the rate of combustion, with increased draft, increases faster than the air supply. (This may not be true for all furnaces or it may not be true at all. Nevertheless it sounds reason-

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[+] See 5:66.67,169.

able and, if it is true, presents an explanation for the fact often observed that high draft on a boiler is accompanied by high furnace temperature and high flue temperature).

(12) An overload on a boiler means high rate of combustion and hence is ordinarily accompanied by smoke. We believe, however, that this condition is largely amenable to better furnace design. - By making the combustion space large it is entirely possible to take care of a large overload in that respect. In order to insure sufficient air when the boiler is overloaded arrangements might be made to admit more air over the fire or to force heated air into the combustion chamber; or auxiliary grate surface might be provided so that, when the boiler was overloaded the grate surface could be increased, thus keeping the rate of combustion down to an economical value.

Special Methods and Appliances.

(1) Hand firing. - When boilers are fired by hand the amount of smoke emitted is dependent very largely upon the care and skill exercised by the fireman. This phase of smoke prevention has been discussed so often and so thoroughly that we will not dwell upon it here, but merely sum up some of the more important points.

There are three methods of hand firing, spreading coking and side firing. By the first method the coal is spread as evenly as possible over the whole fuel bed at each firing. This is the common method of firing.

By the coking method a charge of fresh coal is first placed on the front part of the grate where the volatile matter is gradually distilled off. The volatile matter in passing off must pass over the bed of hot coals on the back part of the grate where an excess of air is being admitted, thereby aiding combustion. When the pile of coal in front is coked it is spread over the back part of the grate and another charge of fresh coal put in its place. This method of firing presents large possibilities in the way of smoke prevention if all conditions are ideal but it is usually found in practice to be unsatisfactory. Some of the unsatisfactory features are:- It requires skill and care on the part of the fireman and is a "lot of bother". The coal should be one that cokes readily. The firedoor has to be kept open so long, while the charge is being pushed back and a new charge put on, that the furnace is chilled, causing smoke. When the boiler is carrying a good sized load the fresh charge does not have time to coke completely before it is necessary to push it back and fire again. It is practically impossible to use the coking method at all with high rates of combustion.

The third method, side firing or alternate firing is the most practical method for general purposes. By this method one side of the grate only, is fired at one time, the right and left halves of the grate being fired alternately. In this way we always have a hot bed of coals on one half the grate which will furnish a supply of hot air to burn the volatile matter distilled from the fresh coal on the other half of the grate. But this method is of very little value unless some means is provided for mixing the stream of hot air, from the one side, with the stream of volatile matter from the other side.

The proper care of hand fired furnaces is summed up in the following rules.#

(a) "Fire frequently in small quantities and at regular intervals.

(b) "Break up lumps to fist size.

(c)"Carry a level surface over entire grate.

(d) "Avoid thin and bare spots on grate.

(e) "Keep the fires clean.

(f) "Fire one door at a time and wait until the fire is in good shape before charging the other door.

+ 80:23.

(g) "Leave furnace door ajar for one minute after each firing."

Skillful firing as a solution of the smoke problem while it presents large possibilities, is in general unsatisfactory because of the great variableness of the personal element. Conscientious and skillful fireman command high wages and are extremely hard to find at any price. The ordinary fireman can never be depended upon of his own accord to prevent smoke. No, - as indicated in rule (3) on page 33 , THE PREVENTION OF SMOKE, IF IT IS TO BE A SUCCESS GENERALLY, MUST BE BROUGHT ABOUT BY MEANS WHICH ARE LARGELY INDEPENDENT OF THE PERSONALITY OF THE FIREMAN.

(2) Special kinds of fuel. - Anthracite coal, coke and charcoal are, of course, smokeless under almost any conditions because they contain very little bolatile matter.

Powdered coal,[#] blown into the furnace with air

+ See article by Sweeney J.W.S.E. Feb. 1904; also 25:182.

burns almost instantaneously and without smoke. Many experiments have been made during the last twenty-five or thirty years and much money spent, in efforts to make the burning of powdered coal a commercial success, but so far all attempts have failed. The trouble seems to be that the cost of powdering the coal and attendant machinery (coal can not be shipped in the powdered form; hence each plant has to do its own pulverizing) is too great to be offset by the saving due to cheaper coal used and the better combustion obtained.

Briquettes# made from powdered coal (they can be shipped without any trouble) present large possibilities but are at present commercially unsuccessful. Briquettes ordinarily burn with very little smoke.

(3) Steam jets. - The steam jet is a very common smoke preventing device and is the basis for many patented smoke preventers. The sole office of the steam jet is to mix the gases. It does not add heat to the furnace in any

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3:40-48; - 6:41-46; - 8; - 9.

way; in fact it abstracts heat, for the steam leaves the boiler at a much higher temperature than it enters. As a mixing device and consequently a smoke preventer the steam jet is fairly successful in many instances. It however involves a waste of steam which may or may not be offset by the saving due to more complete combustion. In short, the steam jet, although it should certainly have a place among smoke preventing devices, should be regarded ordinarily as a makeshift, to be used only when more efficient devices or methods are impracticable.

(4) Hawley down-draft furnace. - On the next page, fig (5), is a cut of the Hawley down-draft furnace applied to a return-tubular boiler. There are two grates, as shown, and three doors. The coal is charged through the top door on to the upper grate, which is made of water cooled tubes connected to the boiler as shown. The coke formed on the upper grate drops through on to the lower grate, which is of the ordinary type, where it is burned

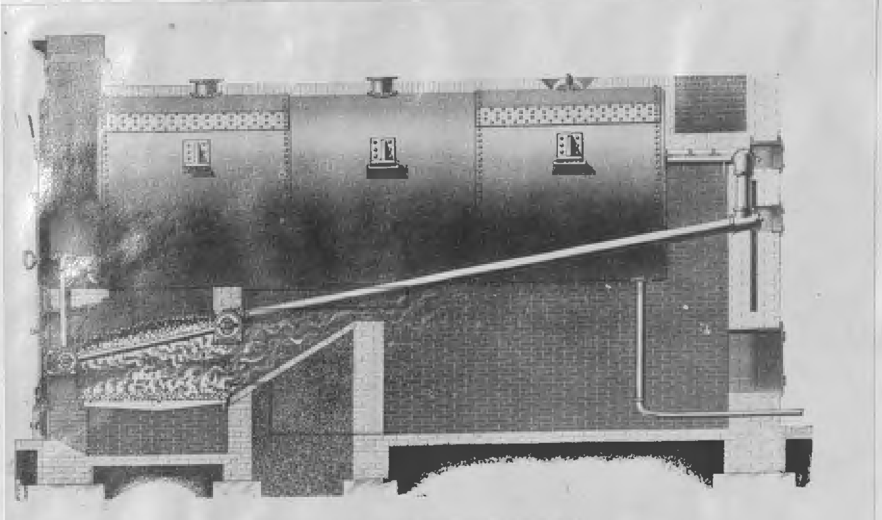
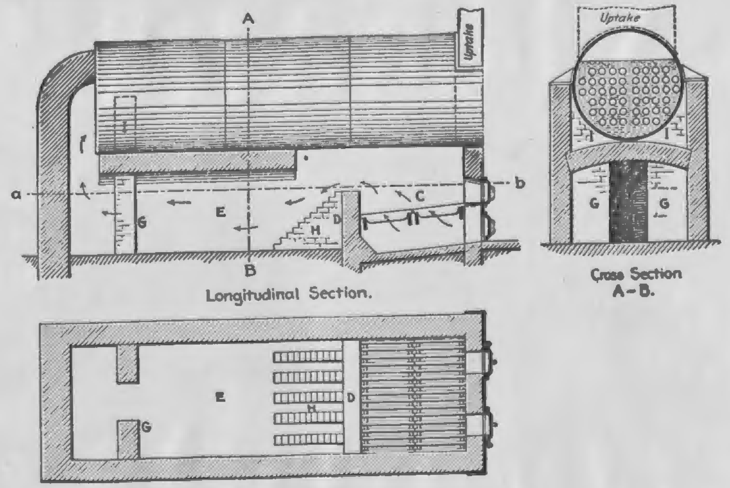


FIG. 2—HORIZONTAL TUBULAR SETTING

Figure-5-



Longitudinal Section.

Cross Section A-B.

Sectional Plan a-b.

FIG 19.—THE "WING-WALL" FURNACE APPIED TO A HORIZONTAL TUBULAR BOILER.

Figure-6-

The middle door is seldom opened. The main air supply is admitted through the upper door; the distilled gases, mingling with this air, are obliged to pass down through the hot fuel bed and thence to the boiler. A secondary air supply is admitted through the lower or ash-pit door and passes up through the lower grate in the ordinary manner.

The hot bed of coke on the lower grate keeps the combustion space always at a high temperature, thus aiding combustion. But the most important feature of the furnace is the thorough mixing afforded. - In passing down through the upper fuel bed the gas streams are broken up and mingled with the air: moreover, the upward stream of hot air and gas from the lower grate, meeting this downward stream, causes further mixture. The result is that a very rapid and thorough combustion is obtained and only a small combustion chamber is necessary. A common mistake however, in installing this furnace is not to provide any combustion chamber at all, in fact the design shown in the accompanying cut is faulty in this respect. A much better and more smoke-proof furnace would be obtained by cutting down the bridge-wall and putting in a short arch under the boiler as indicated by the dotted red lines.

The Hawley down-draft furnace, if properly installed, will be practically smokeless in the hands of the average fireman.

(5) The dutch-oven or fire-brick arch. - As we have already concluded a fire-brick chamber should be provided for every furnace using soft coal, in order to burn the volatile matter. A common method of producing such a chamber is by constructing a fire-brick arch over the grate or at some point between the grate and the boiler. Such an arch is a great aid to combustion and smoke prevention. It not only keeps the unburned gases from striking the cold boiler surfaces but helps greatly to keep the furnace temperature uniform. In this respect

it is like the flywheel of an engine; it stores up a large amount of heat and gives it out when it is most needed, as for instance, when the fire-door is opened and fresh coal is thrown on the fire.

In spite of these very excellent features, the dutch-oven furnace, as ordinarily constructed, lacks one thing which is really the most important requisite of a good furnace, - mixing devices. We have seen that the Hawley down-draft combined with the dutch-oven gives this added requirement of good mixture. The same effect or a similar effect may be obtained by inserting mixing structures in the combustion chamber. Under the following headings, (6) (7) and (8), we will take up several different furnaces designed in this way.

(6) Kent's wing-wall furnace. - First we will take up Kent's patented wing-wall furnace, a cut of which as applied to a return tubular boiler, is shown on page 71

(fig 6). This furnace provides, in addition to the firebrick arch, a mixing device in the shape of two wing walls as shown. Kent gives the following explanation of this furnace.[#]

"In operation with hand-firing, the alternate method is used. The fresh coal is spread alternately on the right and left sides of the grate at equal intervals of time. Immediately after firing on one side, dense, smoky gases arise on that side, while on the other side an excessive supply of very hot air is passing through the bed of partially burned coal or coke. These two currents, one of cool, smoky gas and the other of clear, hot gas with a large excess of air, pass side by side over the bridge wall D, but they are compelled to change their direction and mingle together on passing through the tall, narrow passage between the wing walls E E, and by so mingling, the gases are burned and the smoke prevented.

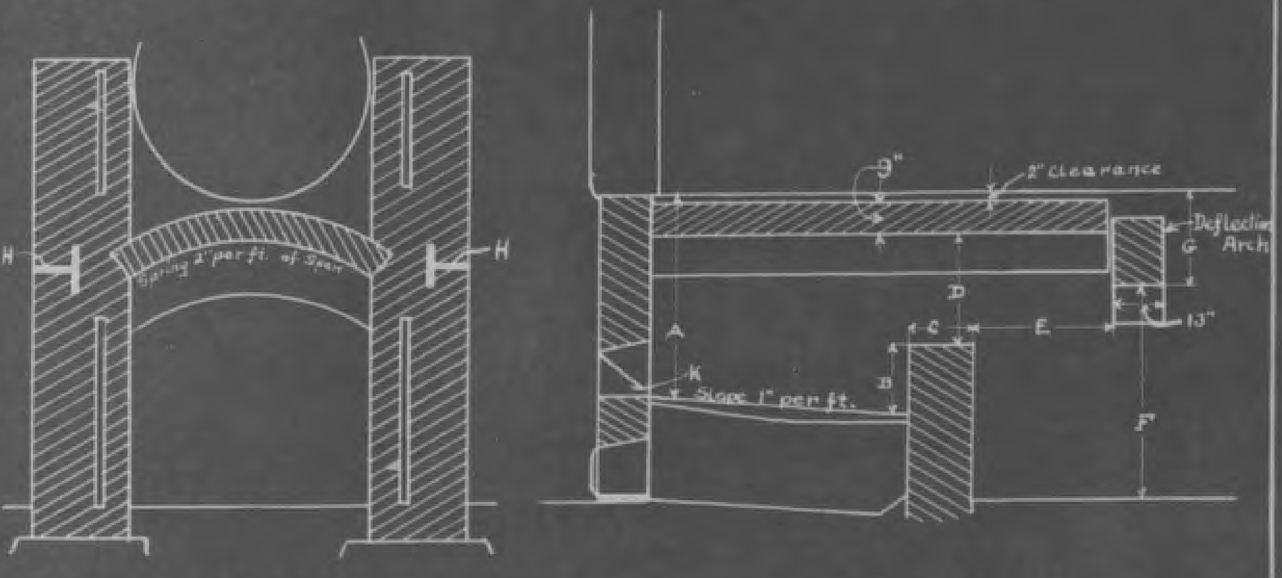
"The combustion is assisted by the heat radiated

[+] 25:162.

from the walls of the combustion chamber G and the piers H, which absorb heat during the time when the fire is hottest- that is, just before fresh coal is spread on the grate, and give out heat to the gases in the chamber G when the fire is coolest- that is, just after firing, when the smoky gases are escaping."

One other point about this setting is worth noting. The combustion chamber is located behind the bridge wall at some distance from the grate, while above the grate there is nothing to keep the gases from striking the cold boiler. Smoke is undoubtedly formed over the grate but is subsequently burned in the combustion chamber.—This furnace ought to give excellent results.

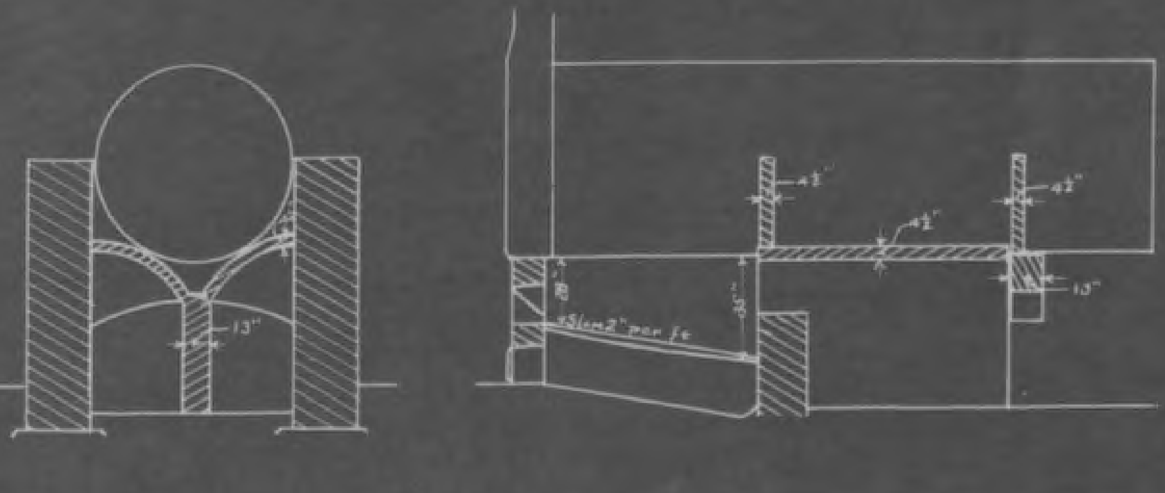
(7) The Chicago Smoke Department furnace. - The Chicago Smoke Department recommends, for return tubular boilers, a furnace containing the same two excellent features shown in Kent's furnace, namely a fire-brick chamber and mixing structures. Fig.7 on the next page is a sketch



Sketch of Setting for R. T. Boiler Recommended by Chicago Smoke Dept.

Not to Scale

Fig. 7.



Special Setting when Boiler is only 28" from Grates

Not to Scale

Fig. 8.

of this furnace. The dimensions of this furnace should be about as follows.-

The height of the boiler above the grates "A" should be about 51", so as to give 40" head room, but a somewhat smaller height may be allowed as a compromise.

The distance from the top of the bridge wall to the grate "B" should be equal to at least one fourth the length of grate. In order to get the required height here it may be necessary to increase the pitch of the grates somewhat in certain cases.

The width of bridge-wall "C" should equal about one fourth length of grate.

The height over the bridge wall "D" should be such as to give an area over the bridge wall equal to about 33% of the grate area.

The distance "E" from the bridge wall to the deflection arch should be about one half the length of grate.

The height "F" from the combustion chamber floor to the deflection arch should be such as to give an area equal to at least one half the grate area.

The distance "G" from the boiler shell to the crown of the deflection arch should be about the same as the height "D" above the bridge-wall.

In addition to these relative dimensions R.H.Kuss of the Chicago Smoke Department gives the following general rules with regard to the installation of this furnace.

"Doors should be of a type allowing the admission of excess air over the fire when so desired. If panels are cut in the fire doors for this purpose, the aggregate area of the openings should be not less than four square inches to each square foot of grate surface.

"Arches should be made of wedge brick or 'bull heads' and not laid in two courses of four and one half inch brick."

"The bridge-wall should be made of first grade fire brick above the grate line and with fire brick facing not less than nine inches in thickness on the combustion chamber side. The top row should be a rowlock course. Provision should be made in building the bridgewall for lateral expansion."

"The combustion chamber floor should be paved with fire-brick laid on edge."

"Facilities for taking up arch thrust should be provided in every case by suitable metal reinforcement extending horizontally throughout the length of the arches. No air space should intervene between the metal reinforcement and the skew-backs." (See "H" in figure (7)).

"For boiler 48" or less in diameter, special provision for the examination of girth seams must sometimes be made. This is because of the fact that with small boilers there is not sufficient room between the arch and shell for purposes of inspection."

"In the event of arch failures the boiler should be immediately taken out of service. This is to avoid failure of the boiler shell due to heat being supplied upon a portion of the heating surface over which a mud deposit has formed."

An examination of the sketch (fig.7) together with the above specifications brings out the following noteworthy features of this furnace.-

(a) A large, fire-brick combustion-chamber is provided. The height above the grates and the area over the bridge are both so large as to make the velocity of the gases through the combustion chamber low.

(b) Good mixing structures are provided in the shape of a high bridge-wall, with a square corner instead of a beveled corner as commonly constructed, and a deflection arch. The effect of these structures seems to be as follows. - The stream consisting of gases and air rising from the grate travels toward the bridge-wall. When it reaches the bridge-wall the lower part of the stream is deflected sharply upwards and thus is obliged to mix with the upper part. When the stream strikes the deflection arch the upper part is deflected sharply downwards thus completing the mixture.

(c) The areas over the bridge-wall and under the deflection arch are so large that the draft is not greatly reduced thereby.— It is quite common to make the area over the bridge-wall very small, with the idea that this will in some way prevent the smoke from getting out of the combustion chamber or else that high temperature will be obtained thus burning the smoke. Reducing the area over the bridge-wall certainly gives higher temperature in the furnace due to decrease in air supply, but this decrease in air supply will result in more incomplete combustion and smoke, thus giving the opposite effect to that sought.

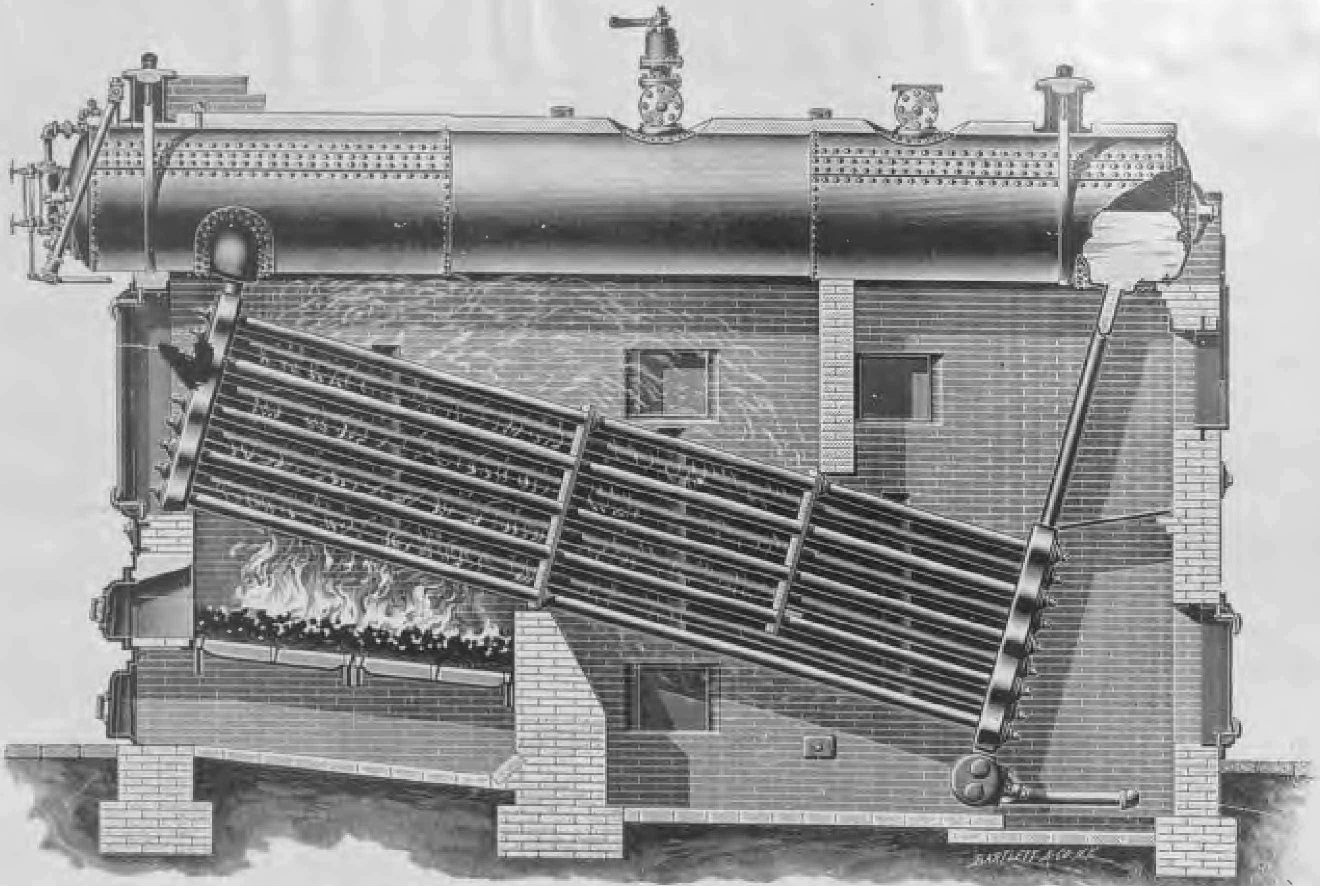
Now, in case the height of the boiler above the grates is small (28" for instance,- a very common value) and can not be increased in any way, the above furnace is impracticable. In such a case the Chicago Smoke Department recommends as a compromise a modified form of furnace something like that shown in figure eight, page 77 . This furnace may not give quite as good results as the other one but forms a good substitute under the circumstances.

(8) The Wooley[#] furnace consists of a fire-brick chamber in connection with several deflection arches, wing-walls and mixing piers. This presents a very tortuous path for the gases and provides very thorough mixing indeed. If these mixing devices do not choke the draft too much this furnace ought to be entirely smokeless.

(9) Water-tube boiler settings. - There are many different kinds of water-tube boiler settings, but the two most common types are the Babcock and Wilcox setting and the Heine setting.

The ordinary Babcock and Wilcox setting is shown

[#] 51:720



Side View of Babcock & Wilcox Boiler of Wrought Steel Construction.

Figure-9-

in figure 9 , page 84 . It is evident that, in this setting, very little combustion space is provided; the gases, on leaving the grate, strike the cold boiler tubes almost immediately. It is impossible to burn soft coal smokelessly with this setting.

The Heine setting is shown in figures 11+12 and on pages 98 and 99 . It has horizontal baffles, the lower baffle forming a dutch-oven or fire-brick chamber in which the gases may be burned. This type of setting is well adapted to the burning of soft coal smokelessly. As ordinarily installed, however, the furnace is deficient in mixing qualities and hence is not as efficient a smoke preventer as it might be. Wing-walls or a deflection arch or mixing piers[#] will add to the efficiency of this furnace as a smoke preventer.

(9) Mechanical stokers. - We have shown that uniformity of feed and uniform conditions in the fuel bed are

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+ 51:701.

great aids to smoke prevention. We have also seen that in hand fired furnaces these conditions are impossible. To give uniform such conditions in the fuel bed and eliminate the personality of the fireman is the object of the mechanical stoker. There are three types of mechanical stokers in common use in this country:- (a) the inclined grate stoker, (b) the underfeed stoker and (c) the chain grate or traveling grate stoker.

(a) There are two types of inclined grate stokers. First, there is the Roney type in which we have a single stepped grate sloping about fourty degrees to the horizontal, from front to rear. The coal is fed in automatically at the top of the grate in front and, by the slow rocking of the grate bars, is caused to decend slowly to the bottom. As it decends the coal is first coked and then burned, the ashes being discharged at the bottom. A short arch is provided over the upper part of the grate to aid the combustion of hydro-carbons. This stoker, when used with the return tubular boiler or the Babcock and Wilcox type of boiler with soft coal as fuel, smokes profusely. When applied to the Heine setting[+] it gives better results; if carefully manipulated it can be run up to 100% load without much smoke, but on an overload smokelessness or even an approach to smokelessness seems to be impossible.[++]

Second, we have the "V" type of inclined grate stoker, typified by the Murphy stoker. In this stoker there are two inclined grates sloping from the sides of the furnace to the center. The operation of the furnace is similar to that of the Roney. An arch covering the entire grate surface is provided, thus giving a large combustion space. This stoker, as a smoke preventer with bituminous coal, has given excellent results in some cases, but in other cases has proved unsatisfactory. Undoubtedly many of the troubles experienced have been due to defective installation. The stoker if properly installed ought to give smokeless combustion except perhaps when overloaded.

[+] 90:22

[++] 90:23.

Both the Roney and Murphy types of furnace might be improved by a judicious use of mixing structures.

(b) The underfeed stoker. - In the underfeed stoker, as is name indicates, the coal is fed from underneath the fuel bed. This is accomplished by means of a screw or plunger acting in a trough. The air supply,is introduced into the trough by forced draft. The principle is similar to the Hawley Down Draft furnace; the air and the hydrocarbons (which are distilled from the green coal underneath the fuel bed) are obliged to pass together up through the hot fuel bed where they are heated and thoroughly mixed. The result is a very rapid and intense combustion of the volatile matter. This stoker is well adapted for smokeless combustion even where the combustion space provided is small. Here again we see that mixing is what counts. The success of the underfeed stoker, we believe, is due almost entirely to this mixing of the gases.

(c) The chain-grate stoker.# -

See 50 and 11

The chain-grate stoker, as applied to the Heine boiler is shown in figure 12, page 99 . The stoker consists of a horizontal (or slightly inclined) traveling grate formed by heavy endless chains passing over sprockets. The sprocket shafts are driven at proper speed by an auxiliary engine. The coal is fed automatically on to the front part of the grate and, as it travels forward, is first coked, then burned and finally, being converted into ashes, is carried over the farther end into the ashpit. A combustion arch is provided which covers the front half of the grate.

The principle on which this stoker operates is similar to that of the inclined-grate stokers being about as follows. - In the first place, at the front of the grate where the fire is thickest only a small amount of air, insufficient to burn the volatile matter, is admitted, but at the back where the fire is thin and hot an excess of very hot air is supplied. The stream of volatile matter and distilled gases rising from the front part of the grate is kept hot by the combustion arch and deflected horizontally to the rear where it encounters the stream of hot air from the back part of the grate. These two streams of gas and air, rushing upon each other at right angles, become thoroughly intermingled thus affording ideal conditions for complete combustion.

Of all the stokers that have yet appeared on the market the chain-grate has without doubt given the greatest degree of success. It is recommended by many engineers as the best stoker made: many others state that it is the only stoker which can be relied upon to prevent smoke. Some argue that the chain-grate is smokeless only because it admits an excessive amount of air, hence that it is wasteful of fuel. Whether or not it admits an excessive amount of air, numerous tests have shown that the chain-grate is not or at least need not be wasteful of fuel. On the contrary it has often shown on economy superior to other stokers; the Twin City Rapid Transit Co., for instance, found, on replacing

Roney stokers by chain grates in their Minneapolis power station, a saving of 3% to 5% in the fuel. The chain-grate is especially well adapted to high volatile coals and will burn the poorest grade of soft coal successfully. The coal should be crushed to a uniform size; small sizes give best results. The best thickness of fire varies with different grades of coal but is usually five or six inches. Repairs on the stoker are few and in general the cost of maintenance is low.

Now what is the essential difference between the chain-grate and the inclined grate stoker (in principle as shown, they are the same) why then does the chain-grate give the better results? The advantage, we believe, is a mechanical one - namely the fact that the grate is horizontal. This fact gives two important advantages to the chain-grate. - (1) It insures an absolutely uniform feed of fuel; coal can not slide down the grate, bare spots are impossible. (2) The two streams of gas and air, as already shown, are forced to meet each other at right angles, thereby bringing about a thorough and rapid mixture; this is the important point for"mixture" is what counts".

(11) The locomotive problem. - Probably the most difficult problem in connection with smoke prevention is that presented by the steam locomotive. All sorts of adverse conditions are met with. - The firebox has to be small, space is at a premium. A very high rate of combustion is necessary. Sudden large changes of load occur frequently. Induced draft from a steam blower has to be used; this blower must be very carefully manipulated in order to supply a proper draft at all times and under widely varying conditions. Hand-firing seems to be necessary, a stoker being impracticable (the underfeed stoker, however, has been used on locomotives with some success).

There seem to be at present but two possible solutions of the smoke problem in steam locomotives: either (a) the training of skillful and conscientious firemen, supplemented by the installation of such beneficial appliances as steam jets and fire-brick arches, or (b) the use of smokeless fuel.

(a) In most cases where the abatement of the locomotive smoke nuisance has been attempted the first means has been used. All sorts of inducements have been employed to encourage firemen to do their best to prevent smoke. Some roads have installed special appliances steam jets and fire-brick arches to aid the firemen. The Chicago Smoke Department has been working along this line and has recently published a bulletin[*] on the subject. It contains careful instructions to firemen showing how locomotive smoke may be reduced to a minimum: it also gives data from experiments on locomotives equipped with various styles of fire-brick arches and steam blowers. The readings show that it is possible to eliminate all objectionable smoke from a locomotive if it is provided with such an arch and blower and a reasonable amount of care is exercised by the fireman.

(b) The use of smokeless fuel has been resorted to, in some cases, to prevent locomotive smoke. Among the fuels

#91

used are coke, petroleum and briquetted fuel. Coke is expensive and very bulky to carry, but it has been used to some extent where city ordinances have required it. Petroleum is being used with success in the oil regions where it is easily obtained, but its use is of necessity limited. Briquetts[+] made from cheap coal have been used successfully and may be extensively employed in the future; they give increased boiler capacity and burn with little smoke, but at present the expense of manufacture makes them cost more than ordinary coal.

Tests Conducted at the U.of M. Power Plant.

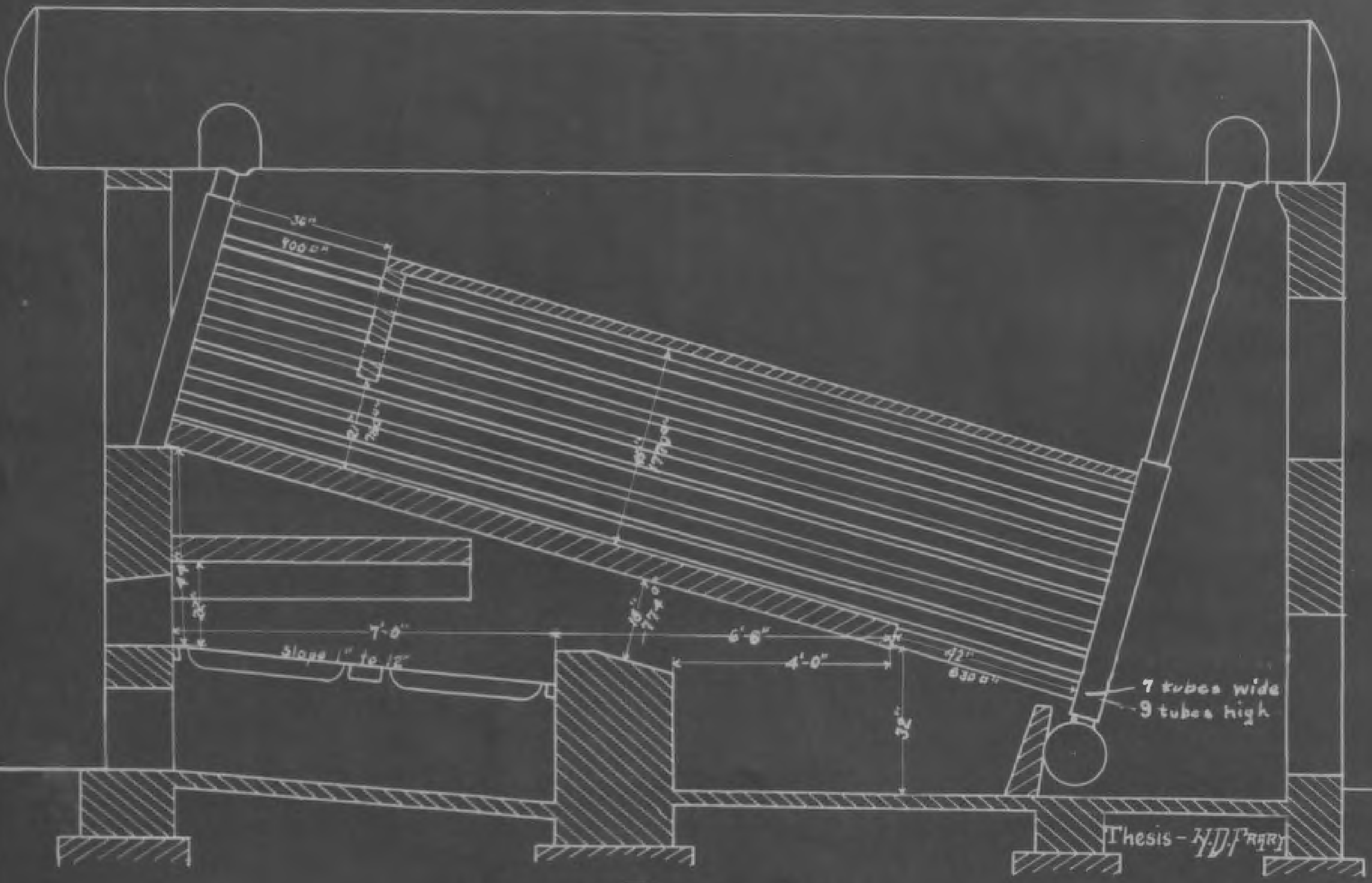
As stated in the preface the experimental work performed at the University power plant has been of a rather superficial character and much of the work done, although valuable to the writer personally, was not sufficiently thorough or scientific to be incorporated into this thesis.

#8

The boilers were in constant use to supply power and light for the University buildings so that it was impossible to obtain uniform conditions for comparative boiler tests: moreover the writer was obliged to do most of the experimenting by himself, and that, at odd hours when not occupied by other work. We shall therefore give simply a brief summary of some of the experiments made and the results obtained.

The apparatus used in these experiments consisted of the following. - Two boilers - one Cahall (B. and W. type), 132 horse power, water tube boiler and one 60 X 16, 80 horsepower return tubular boiler - with attendant apparatus; a chimney giving a draft of about six tenths of an inch, an exhaust fan capable of giving more than an inch of draft; means for weighing coal and measuring feed water; a Wanner optical pyrometer for getting furnace temperatures; an expansion pyrometer to get the flue temperatures; an Orsat's gas sampling apparatus. (A CO_2 recorder has recently been installed but was not ready in time for use in these experiments.)

First we will take up the experiments performed on the Cahall boiler. This boiler was originally provided with the ordinary Babcock and Wilcox setting as shown in figure 9, page 84. This setting, however, was subsequently changed, the vertical baffles being replaced by horizontal ones, so that when these experiments were begun the setting was arranged as shown in the sketch, figure 10, page 97. The boiler thus arranged gave results that were very disapointing. It smoked badly, for about three minutes after firing; the capacity attainable was low; the coal consumption was evidently more than it ought to be; moreover the furnace temperature was so high that the fire-bricks in the arch over the grates were gradually melted down. The fan was put on to try the effect of more draft but the smoke was only increased thereby. Something evidently was wrong. Finally the writer crawled into the boiler and took careful dimensions of the furnace, combustion chamber and all openings through which the gases must pass. From these dimen-


36"
400□"
42"
630□"
7'-0"
6'-6"
4'-0"
32"
Slope 1" to 12"
7 tubes wide
9 tubes high
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- Figure 10 -

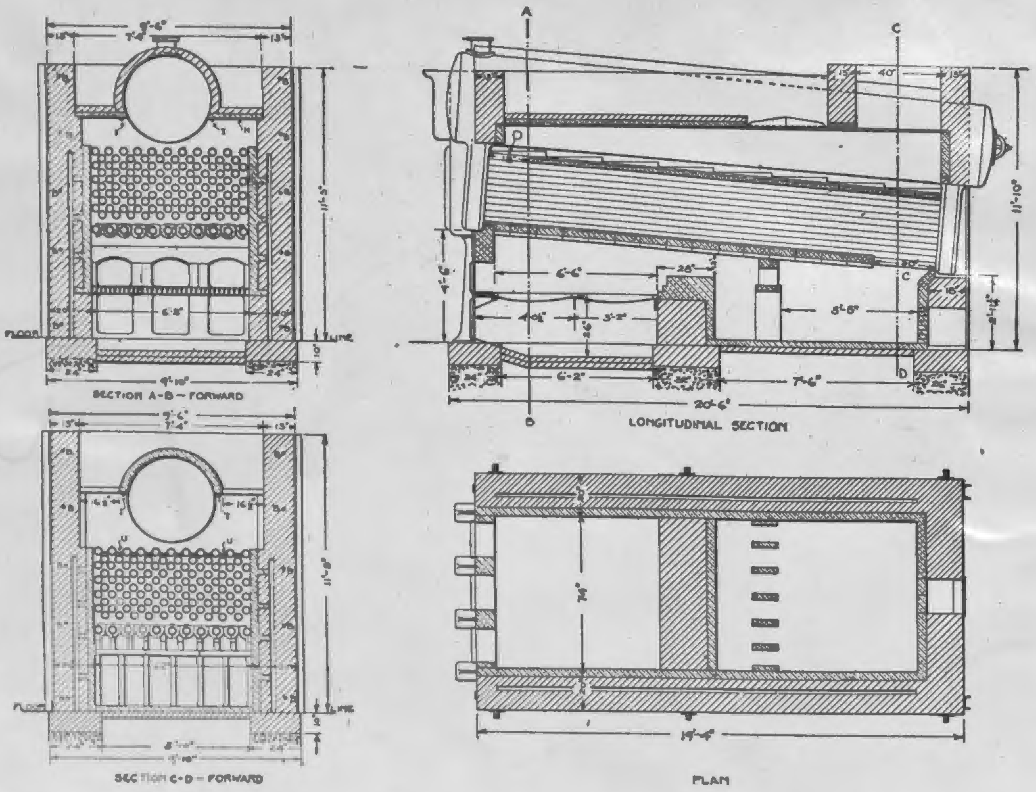


FIG. 76.—Dimensions and details of boiler setting.

Figure-11—

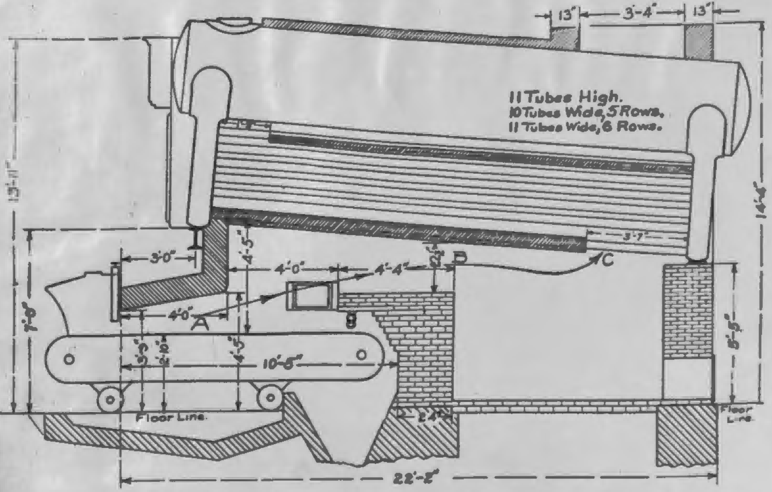
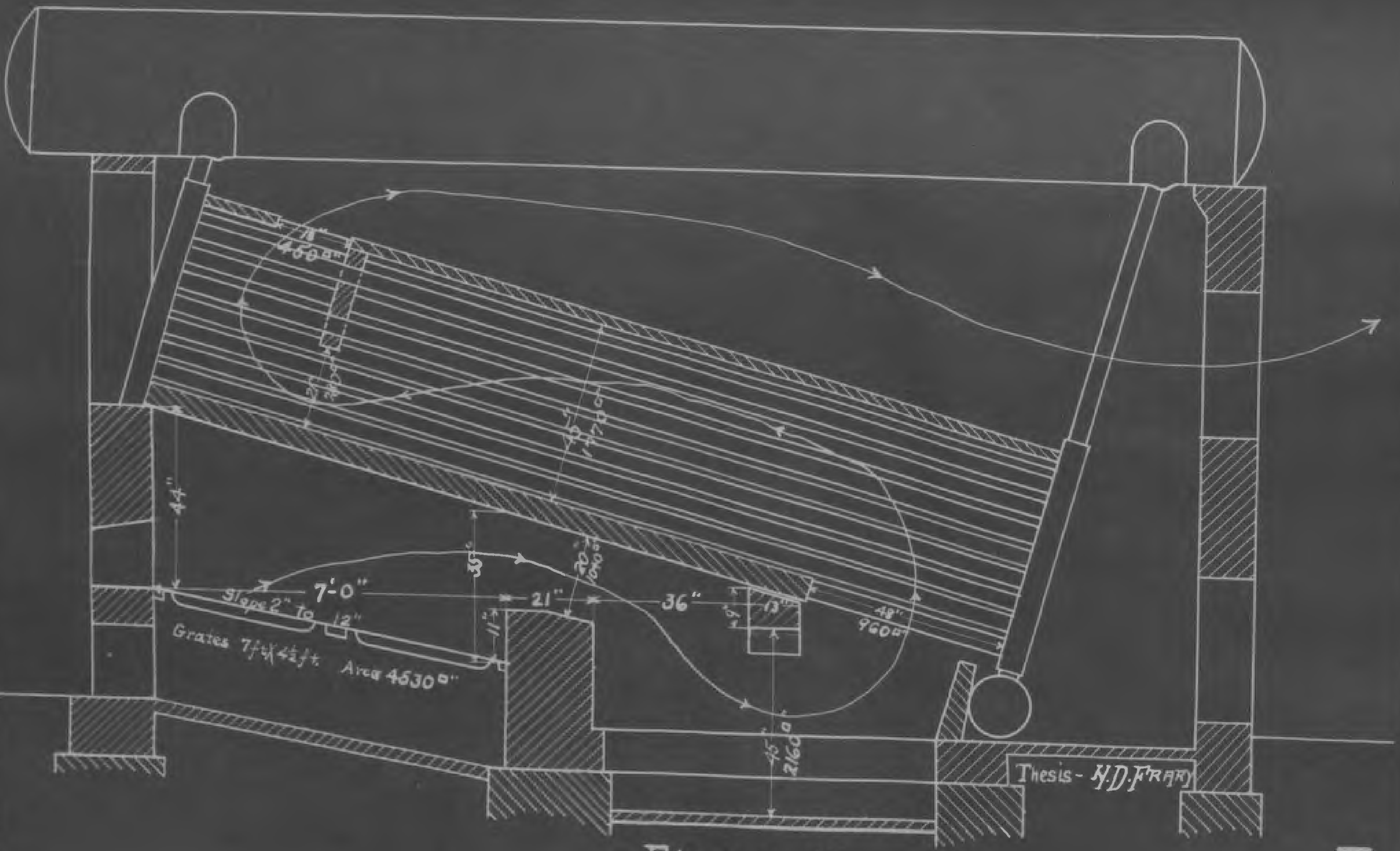


Fig. 7 HEINE STANDARD 210 H.: P. BOILER EQUIPPED WITH GREEN CHAIN GRATE, COMBUSTION ARCH, TILE ROOF FURNACE, ADJUSTABLE WATER-BACK AT BRIDGE WALL

This is the Engineering Experiment Station boiler furnished with induced draft., It can be run easily without smoke at capacities from 50 to 140 cent; almost impossible to make smoke with this setting under any condition of operation.)

Figure -12 —


18"
468□"
21"
380□"
49"
1470□"
20"
1040□"
35"
44"
7'-0"
21"
36"
13"
9"
11"
48"
960□"
45"
2160□"
Slope 2" to 12"
Grates 7ft×4½ft. Area 4630□"
Thesis - H.D. FRARY

-Figure 13-

sions, with the aid of a drawing of the original boiler setting, the accompanying sketch, figure 10, was made. This sketch shows first, that the combustion space was very small and secondly, that the areas through which the gases must pass, - especially the area at the entrance of the tubes, and the net area leaving the tubes, - were very badly proportioned. The openings where the gases leave the tubes was evidently much too large, for the volume of the gases at this point is less than half that at the entrance of the tubes, on account of the reduction in temperature. The openings over the bridge wall and at entrance of the tubes, although they evidently had been designed to give sufficient area for the passage of the gases, had been quite largely reduced by the laziness of the brick-layer who made the alterations; being obliged to re-line the combustion chamber with fire-brick he had built the new lining inside of the old lining (instead of tearing out the latter and putting fire-brick in its place), thereby reducing the width of the combustion chamber by about ten inches; this made the area over the bridge-wall and the net area at the entrance of the tubes respectively 774 square inches and 630 square inches instead of 970 square inches and 1090 square inches, as designed.

The first thing that was done was to knock out the arch over the grates; this arch seemed to be of no value, simply reducing the available combustion space over the grates which was not at all desirable. Next the writer attempted to determine what the correct proportions should be for the openings thru which the gases must pass. We were unable to find any literature on this subject; hence we tried to discover, by a comparison of settings in actual use, what proportions had given good results in practice. For this purpose the accompanying table, figure 14, was made, in which two Heine settings, - that used by the U.S.G.S.[#] at St. Louis (see fig.11) and that used by Prof.Breckenridge[##] at the University of Illinois (see fig.12) are analyzed on a basis of the velocity of the gases through the various open-

#5:173;174

##90:24

Boiler	H.P. of Boiler	Opening	Length of Opening	Depth of Opening	Gross Area of Opening	Subtract for Tubes	Net Area of Opening	Estimated Temp. of Air at Opening	Vol. of 1# of Air at Temp.	Lbs. Air* Necessary at Full Load	Velocity of Air
(1.) Heine Boiler Used by U.S.G.S. at St. Louis See Fig. 11.	210	Over Bridgewall	12"	74"	888 □"		888 □"	2800° F.	82.2 cu. ft.	280# per min.	3730 ft/min.
		Entering Tubes	30"	74"	2220 □"	1155 □"	1070 □"	2500° F.	74.5 " "	280# " "	2820 " "
		Leaving Tubes	18"	74"	1332 □"	692 □"	640 □"	650° F.	27.9 " "	280# " "	1760 " "
		Cross Section Thru Tubes	34"	74"	2507 □"	895 □"	1612 □"				
(2.) Heine Boiler Used by Prof. Breckenridge at U. of Ill. See Fig. 12.	210	Over Bridgewall	22½"	74"	1660 □"		1660 □"	2800° F.	82.2 cu. ft.	280# per min.	1990 ft/min.
		Entering Tubes	43"	74"	3180 □"	1650 □"	1530 □"	2500° F.	74.5 " "	280# " "	1960 " "
		Leaving Tubes	21"	74"	1550 □"	810 □"	740 □"	650° F.	27.9 " "	280# " "	1520 " "
		Cross Section Thru Tubes	34"	74"	2507 □"	895 □"	1612 □"				
(3.) U. of M. Boiler as First Installed — See Fig. 10.	132	Over Bridgewall	18"	43"	774 □"		774 □"	2800° F.	82.2 cu. ft.	176# per min.	2690 ft./min.
		Entering Tubes	42"	43"	1806 □"	1176 □"	630 □"	2500° F.	74.5 " "	176# " "	3000 " "
		Leaving Tubes	36"	53"	1908 □"	1008 □"	900 □"	650° F.	27.9 " "	176# " "	787 " "
		Cross Section Thru Tubes	45"	53"	2380 □"	630 □"	1770 □"				
(4.) U. of M. Boiler as Finally Installed — See Fig. 13.	132	Over Bridgewall	20"	52"	1040 □"		1040 □"	2800° F.	82.2 cu. ft.	176# per min.	2000 ft/min.
		Entering Tubes	48"	48"	2300 □"	1340 □"	960 □"	2500° F.	74.5 " "	176# " "	1970 " "
		Leaving Tubes	18"	53"	955 □"	505 □"	450 □"	650° F.	27.9 " "	176# " "	1570 " "
		Cross Section Thru Tubes	45"	53"	2380 □"	630 □"	1770 □"				

* Assuming 80# air per H.P. hr.

Thesis H.D. Frary

- Figure 14 -

ings. Both the Heine boilers (1) and (2) (see fig.14) were installed under the supervision of Prof. Breckenridge, yet their settings differ greatly in design as the table shows. Nevertheless, inasmuch as the setting of boiler No.2 was designed subsequently to setting No.1 and gave by far the best results in smoke prevention, it was decided to pattern our boiler after it.

The final result of this study and of experiments was the setting shown in figure 13. The changes indicated, however, were by no means all made at once, but, for the most part, one at a time so that the effect of each could be observed seperately. Smoke readings were taken after each change and in some cases boiler tests were made. The first changes consisted in knocking out the arch over the grates and reducing the opening where the gases leave the tubes to 18 inches. This gave a better boiler capacity and seemed to reduce the coal consumption; the amount of smoke emitted was also somewhat reduced although by no means to a satisfactory extent. During the Christmas vacation when the boiler could be cooled down, a bricklayer was engaged to re-line the sides of the combustion chamber. He also cut down the width of the bridgewall from thrity inches to twenty-one inches and, as an experiment, built up the top until the opening over the bridge-wall was 14 inches instead of 18 inches. This latter change, however, proved to be a mistake so the top bricks were knocked out again, leaving the opening 18 inches as before. Smoke readings taken at this time, the boiler being at about full load, showed 13% dense, 3% medium, 10% light and 74% clear; the smoke lasted from 1 1/2 to 2 1/2 minutes after firing. (Readings were taken in the same manner as explained on page 122.) Another set of readings taken at 64% overload (an induced draft of about one inch being used) showed 16% dense, 8% medium, 15% light and 61% clear.

Late in the spring the boiler was again shut down and further alterations made as follows. - The slope of the grates was increased from one inch to two inches per foot, thus giving more space above the grates and a higher bridge-wall; a deflection arch, as indicated in figure 13, was put in; the floor of the combustion chamber was lowered 18 inches, thereby greatly increasing the combustion space and giving a large area under the deflection arch. The openings over the bridge-wall and at entrance of the tubes still remained 18 inches and 42 inches respectively. When these alterations were completed the school term was about over; however a hurried test was made to ascertain the effect of the changes. The first thing noticed was that the draft over the fire had been reduced from 3/8 inch to 3/16 of an inch. This of course caused trouble immediately; the boiler smoked badly as soon as any considerable load was put upon it. The fan was then started up and a draft of about 3/8" over the fire obtained. The result was a big improvement. A little smoke appeared after each firing, being usually of a medium or light grade but occasionally dense for ten seconds. Smoke readings (taken for a period of 24 minutes only) showed 4% dense, 4% medium, 8% light, 84% clear. No further readings were possible at the time or thereafter since the plant was almost immediately shut down for the summer. Since shutting down the openings over the bridge-wall and at the entrance of the tubes have been enlarged to 20" and 48" respectively (see figure 13) with the hope that this may afford a better draft. Further experiments will be made on this boiler next fall.

With respect to the experiments on the return tubular boiler we will be very brief. - The boiler is set 36" above the grates. It was at first provided with an arch covering the grates and the top of the bridge-wall, the area over the bridge-wall being very small - less than 20% of the grate area. This gave fairly satisfactory results on ordinary loads but smoked rather badly when the load was heavy. Moreover the capacity attainable was not as great as it should be. This spring, the furnace was changed to conform to the setting recommended by the Chicago Smoke

Department (see page 77); the grates were sloped two inches per foot, the area over the bridge-wall was made about 33% of the grate area, the arch was extended to 27" beyond the bridge-wall and a deflection arch constructed as shown in figure 7. The results were highly satisfactory. The capacity of the boiler was increased; the boiler was run readily at 65% overload without the use of the fan. During an hours test at this load no dense smoke whatever was observed. The smoke readings showed 0% dense, 0% medium, 23% light and 77% clear. A very interesting circumstance noted was that this boiler smoked appreciably more on light loads than it did on the overload, at times emitting dense smoke when the load was small. This seems to show that the mixture brought about by the bridge-wall and deflection arch is the more thorough the greater the volume of gases passing.

Present Conditions in Large Cities.#

The smoke problem is not new. It has confronted our large cities for nearly a century. Yet it has been only during the last ten or fifteen years that serious and systematic attempts have been made to solve it. Today much progress is being made in many cities but much yet remains to be done in all of them.

In order to determine existing conditions, letters were sent to a number of the large cities of the United States and Canada asking for a copy of the city smoke ordinance (if any existed) and a statement as to what success had attended the efforts to abate the smoke nuisance. The results of the inquiries are summarized in what follows.-

The following eight cities to which letters were sent have no ordinances:-

New Haven, Conn.
Bridgeport, Conn.
Richmond, Va.
Savannah, Ga.

#See 7:7-10 and 11

Sioux City, Iowa
San Francisco, Cal.
Seattle, Wash.
Vancouver, British Columbia

The following twenty-three cities were found to have smoke ordinances of some sort.

Boston, Mass.
New York, N.Y.
Rochester, N.Y.
Syracuse, N.Y.
Buffalo, N.Y.
Philadelphia, Pa.
Pittsburg, Pa.
Baltimore, Md.
Washington, D.C.
Cleveland, O.
Cincinnatti, O.
Toledo, O.
Louisville, Ky.
Detroit, Mich.
Milwaukee, Wis.
Indianapolis, Ind.
Chicago, Ill.
Duluth, Minn.
Minneapolis, Minn.
St.Louis, Mo.
New Orleans, La.
Denver, Col.
Toronto, Canada.

We have made a careful study of the ordinances of these cities and shall endeavor to present in what follows, a brief, comparative analysis of their prominent features. These features, as we shall present them, are seven in number, as follows. -

(1) As to the color, appearance or amount of smoke which constitutes a nuisance. - Most ordinances define this in general terms as"dense black or gray smoke". The Rochester Philadelphia and Cincinnati ordinances establish a standard color scale and declare any smoke darker than this standard to be a nuisance. The Buffalo ordinance simply declares that smoke emitted in such quantities as to be injurious or annoying in any way is a nuisance. (It is almost impossible to enforce this ordinance due to the difficulty in obtaining actual evidence of such injury or annoyance.) The New Orleans ordinance declares that all plants must "consume not less than 75% of the smoke". (This is very indefinite and could not be enforced.)

(2) As to when the emission of such smoke is unlawful. - Seven cities prohibit dense smoke except for six

minutes in any one hour. Pittsburg allows dense smoke for eight minutes in an hour; Rochester, for only five minutes in four hours. Duluth merely prohibits the emission of dense smoke for more than five minutes at one time: (this clause makes the Duluth ordinance useless.) Ten cities make no such provisions but in general prohibit all dense smoke. A few of the above cities have, in addition, a special clause in their ordinances which provides that none of these rules shall apply to the hours between 4:00 and 7:00 A.M.

(3) As to what chimneys shall be excepted from compliance with the above. - Five cities make an exception of private residenses; three exempt locomotivies in continuous transit through the city. The Boston ordinance exempts power plants of public service corporations, (and these, says the Health Commissioner, are the worst offenders.) Toronto makes exceptions of furnaces used in smelting ores and in manufacturing establishments: (this, of course, renders the Baltimore ordinance practically useless.)

(4) As to who shall be liable for the violation of the above. - Most ordinances contain a clause like the following or to the same effect: The owner, agent, lessee or occupant of any building or the owner, manager, superintendent or other officer in charge of any plant, locomotive or steamboat from which dense smoke issues, or the engineer, fireman or operator of any furnace which emits dense smoke shall be liable for violating the above provisions.

(5) As to the penalty attached. - The penalty provided for violation of the smoke ordinance is ordinarily a fine of not less than $10.00 nor more than $100.00, although some cities make the maximum fine as high as $250.00 or $500.00.

(6) As to the authorities delegated to enforce the ordinance and how they are appointed. - Five cities place the enforcement in the hands of the Board of Health and its regular sanitary inspectors. Four cities put this in charge of the Department of Public Works (or its equivalent) and its regular building and boiler inspectors. Five cities provide

a Smoke Inspector who is either under the Board of Health or the Department of Public Works. New Orleans requires the City Engineer to see that its ordinance is enforced. Finally, seven cities - Denver, Pittsburg, Cincinnati, Cleveland, Milwaukee, St.Louis and Chicago - provide a separate Smoke Department with a Chief Smoke Inspector and (in most cases) several Deputy Smoke Inspectors. These seven cities are the ones which are getting by far the best results in smoke abatement. The cities of Chicago and Milwaukee have also an Advisory Board of smoke suppression. The Advisory Board of Milwaukee consists of the City Engineer, the Health Commissioner the Chief of Police, the Building Inspector and the Chief Engineer of the Waterworks. The members of this board themselves elect the Smoke Inspector and act as his advisors. In Chicago the Advisory Board consists of three consulting engineers (mechanical) who are appointed by a Smoke Abatement Commission, which in turn is appointed by the mayor. The twenty-nine members of the Chicago Smoke Department are appointed by civil service examination. A point worth noting in this connection is that the Smoke Departments of Milwaukee and Chicago are practically independent of political influences whereas in all the other cities the appointment of smoke inspectors is apt to be influenced largely by politics.

(7) As to special provisions with regard to the installation of new plants or the altering of old ones. - The ordinances of Cleveland, Milwaukee, Denver, Louisville, Indianapolis, Pittsburg and Chicago require that plants and specifications for all proposed new boiler plants or proposed alterations in old plants be submitted to the Smoke Inspector and his written permit obtained before these plans are carried out. This is a very important provision. It gives the Smoke Inspector the opportunity as well as the power to see that all alterations are made with a view to smoke prevention. As the old saying goes, "an ounce of prevention is worth a pound of cure". It is far easier to design a new boiler plant for smokeless operation than to change an existing plant

so as to eliminate the smoke. This, then, is an exceedingly important provision and should be a part of every city ordinance. - So much for the ordinances themselves.

In practically all of these cities which have ordinances, even, where the ordinances are invalid or ineffective, some progress has been made. In many of them this improvement has resulted from the arousing of public sentiment among business men and others by the newspapers and by various citizens organizations. In many cities the Chamber of Commerce or the Commercial Club or other organization has taken the matter in hand and has done a great deal to create public feeling in favor of smoke abatement. In at least eight cities a citizens' smoke abatement league or smoke abatement committee has been organized to study the problem. In some cases these organizations have hired an engineer to investigate the matter and instruct owners and operators of boiler plants to prevent smoke.

Now, in order that the suppression of smoke in any city may be successfully accomplished, four things are necessary.-

(1) First, a public sentiment favorable to smoke abatement. - Without such sentiment it is impossible to enforce any smoke ordinance. To arouse such a sentiment it is often necessary to conduct an educational campaign throughout the city by means of the newspapers, lectures, public meetings, etc.

(2) Second, a sound legal backing , that is, an efficient ordinance. - Just what an efficient ordinance should contain depends somewhat upon local conditions. A good general idea, however, of the essential elements of such an ordinance may be obtained, without further elaboration, from the preceding analysis of existing ordinances. The ordinance should of course be drawn up so as to stand the test of the courts.

(3) Third, an adequate and efficient inspection force. - Provision should be made for the appointment of the inspection force in such a manner as to eliminate political

influences. The number of inspectors necessary will of course depend upon the size of the city and the magnitude of the local problem.

(4) Fourth and most important of all, expert engineering information must be put at the disposal of power users. In order that this may be done a mechanical engineer should be employed who is thoroughly conversant with steam boilers and the problem of smoke prevention both from a theoretical and a practical standpoint. A power user may be really desirous of abating the smoke which issues from his plant, and yet be unable to do so through ignoerance of the means by which it may be accomplished. He is apt to become the victim of all sorts of patent schemes for smoke prevention or "smoke consumption". Many power users have spent large sums of money in installing smoke preventing devices which eventually proved either partially or wholly unsatisfactory. If the problem were the same in all plants there whould be little such trouble, for it could then be solved once for

all. But, as already pointed out, this is by no means the case. Scarsely any two problems are alike. An appliance or method which gives entire success in one plant may not succeed at all in another. Here is where the Mechanical Engineer must step in. He should be able to study and analyze each problem so as to determine where the trouble lies, redesign the furnace if necessary, or at any rate recommend such alterations or methods as will bring about smokeless operation.

The Problem in Minneapolis.

In our city a smoke ordinance has existed since 1894. The present ordinance, passed Sept. 25, 1895, is of an ordinary type, - a fairly good ordinance as far as it goes but inadequate for present needs. It declares the emission of dense smoke from any stack or chimney whatever to be a nuisance and therefore prohibited. It provides a penalty for the violation of the above in the shape of a fine not to exceed $100. It provides for a Smoke Inspector to be under the supervision of the Commissioner of health; said Inspector to be "a licensed chief engineer, who has been engaged in the active duties of his occupation for at least five years".

Now, in order to ascertain the actual conditions in Minneapolis with regard to the smoke nuisance, we have made the following (rather limited) investigations. -

First, letters were sent to forty-eight establishments of various sorts as follows; ten large office buildings and retail houses, eight wholesale houses, two hotels, seven machinery and manufacturing establishments, five lumber concerns, four milling companies, five grain elevators, three breweries, three power generating plants, one packing company. They were asked to indicate on an enclosed blank, the number, type and horsepower of their boilers, type of furnaces, and the kind of fuel used, also as to whether they were employing any special smoke preventing devices and if so with what success. The results which are given in detail in the first six columns of the accompanying table, fig.15, may be summarized as follows. - Fifteen plants did not reply; one had gone out of business; three others were using electric power exclusively. Of the remaining twenty-nine plants, five were using automatic stokers, three used the Hawley Down Draft furnace, six were employing steam jet smoke preventing devices, six more were using special furnaces or patented methods for preventing smoke, and the remaining nine had made no provision whatever for smoke prevention. Of these twenty-nine plants, then, about two-thirds were being operated with some attempt at smoke abatement.

Now, with regard to the actual amount of smoke emitted by these plants and others like them, data was obtained as follows. - On March 5th. smoke observations were made, from the top of the Guaranty Loan building, of some twenty-four of the surrounding chimneys, sixteen of which belonged to some of the above thirty-four plants from which data had already been obtained. Readings of each chimney were taken every two minutes for two hours, from 3:30 to 5:30 P.M. The appearance of the smoke was classified under four grades - dense, medium, light and clear - by comparison with color scales similar to those shown on page 123. On page 127 is a copy of one of the records taken showing the method employed. (One person can easily take six or eight of these records, from as many chimneys, at once.) Adding up the readings for any chimney and reducing them to a percentage basis gives a fairly accurate idea of its performance. This having been done for all the above chimneys, the results were tabulated in columns 7,8,9 and 10 of the table figure 15.

From an examination of these records it is evident that the smoke problem in Minneapolis is by no means a small one. The results show that more than two-thirds of the above chimneys were violating the smoke ordinance and half of them were making so much smoke as to be a decided ~~a~~ nuisance; this, in spite of the fact that conditions were very favorable to buildings which use their steam for heating, for the weather

Dense

Medium

Light

Milling District
Mar. 5, '09

Milling District
Mar. 12, '09

(126)

Figure-15 -

DATA FROM A FEW MINNEAPOLIS BOILER PLANTS

Smoke readings were taken from the Guaranty Loan Building, Mar. 5th, 3:30 to 5:30 P.M. (temp. 42°F.), with the exception of four readings taken Mar. 2nd as indicated below.

The 34 starred plants are those to which letters were sent and from which replies were received, giving the information tabulated. Other data shown was obtained by personal visits of the writer.

Name of Firm or Building		Total H.P. of Plant	Number and Type of Boilers	Type or Types of Furnaces	– Fuel Used –	Special Smoke Preventing Devices	Smoke Record				Remarks.
							Dense	Medium	Light	Clear	
* L. S. Donaldson & Co.		1000	6 R.T.	Hand-fired Grates	Pocohontas Screenings		8%	3%	40%	49%	
* Powers Mercantile Co.		600	4 R.T.	Hand-fired Grates	Yough. Dock Run	Kraig Automatic Steam Jet	25%	18%	13%	34%	
* Andrus Building		450	3 R.T.	Butman Furnace Built in front of Boiler	Pocohontas Screenings		0%	3%	15%	82%	Boiler is 5 ft. above grates. — Bridge wall is high. — A second bridge wall or deflection wall has been built 18" from end of boiler. — This acts as a mixing wall. — The results are excellent with almost any fuel.
* Guaranty Loan Building		700	4 Heine Water Tube	Hand-fired Grates	Anth. & Yough. Screenings	Mazey Door Attachment	8%	8%	34%	54%	
* Syndicate Block		600	4 R.T.	Hand-fired Grates	Anth. Dust & Smokeless Scrgs	K. & K. System — a water jet under grates with forced draft					
* Security Bank Building		450	3 R.T.	Hawley Down Draft	Yough. Screenings		0%	0%	33%	67%	
* Court House		1200	8 R.T.	Hawley Down Draft	Screened Yough. Lump		2%	2%	36%	60%	
* Chamber of Commerce		750	5 Scotch Marine Internally Fired	Hand-fired Grates	Yough. Screenings		10%	19%	75%	5%	
New York Life Building		about 450	4 R.T.	2 Hand-fired Grates 2 Chicago Patent Furnaces	Bituminous		0%	11%	56%	3%	
Bank of Commerce Building							6%	16%	63%	13%	
Minn. Loan & Trust Building							10%	17%	54%	19%	
Lumber Exchange							2%	11%	18%	69%	
* Wyman Partridge Building		450	3 R.T.	Hand-fired Grates	Coal	Sharf Automatic Steam Jet	6%	16%	7%	71%	
* Minn. Linseed Oil Co.		350	2 R.T	Hand-fired Grates	Yough. Screenings	Gregg Steam Jet					
* Geo. R. Newell & Co.		75	1 R.T.	Hand-fired Grates	Yough. Lump and Anth. Screenings						
* Deere & Webber Co.		80	1 R.T.	Hand-fired Grates	Bituminous						
Butler Bros.		about 200	3 Locomotive type	Hand-fired Grates	Bituminous						
* Jordan Bros. — Wholesale Grocers											A small plant for heating office only
Janey, Semple, Hill Co.		about 200	2 R.T.	Hand-fired Grates	Bituminous	Automatic Steam Jet	8%	8%	0%	84%	
* Nicollet Hotel		130	2 R T	Hand-fired Grates	Soft Screenings	Sharf Automatic Steam Jet					
Vendome Hotel		about 150	2 R.T.	Hand-fired Grates	Bituminous	K. and K. System					
* North Star Woolen Mill Co.		150	2 R.T.	Hand-fired Grates	Edgings						
* North Star Shoe Co.		320	4 R.T.	Hand-fired Grates	Shavings or Smokeless Screenings	Steam Jet					Steam jet found to be wasteful. Found it more economical to use smokeles coal than soft coal with steam jet.
* Diamond Iron Works											Use Electric Power only
* Mpls. Steel Mach. Co.		460	4 R.T.	Hand-fired Grates	Bituminous Slack						
* Wabash Screen Door Co.		450	3 R.T.	Hand-fired Grates	Mill Refuse						
* C.A. Smith Lumber Co.		1400	13 R.T.	Hand-fired – Dutch Oven Large Combustion Chamber	Mill Refuse						
* Shevlin Carpenter Co. — Lumber											
* Washburn Crosby Co.	Steel Stack	5000	9 Heine Water Tube 4 R.T. 2 Vert. Fire Tube	1 Murphy Stoker 2 Jones Underfeed 12 Hand-fired	Hocking, Yough. and smokeless Screenings		25%	20%	29%	26%	Intend to equip entire plant with stokers next year.
	Concrete Stack						8%	13%	23%	50%	
N.W. Consolidated Mill. Co.	Steel Stack						39%	8%	8%	45%	
	Concrete Stack			Detroit Stokers			2%	0%	10%	88%	
* Pillsbury Washburn Co.		1200	4 Heine – 2 R.T.	Roney Stokers	Coal		23%	32%	33%	10%	
Russell-Miller Milling Co.			Franklin Water Tube	Hand-fired			21%	42%	32%	5%	Smoke readings taken Mar. 2nd, from U. of M. Mech. Eng. B'ld'g
* Phoenix Mill Co.		150	1 R.T.	Hand-fired Grates	Coal						Used for heating only.
* Geo. C. Christian Mill Co.		525	3 Franklin W.T.	Murphy Stokers	Soft Screenings						
Elevator — Stirling Elevator Co.							24%	26%	35%	15%	Smoke readings taken Mar 2nd
* Elevator — Bagley Elevator Co.											Replied that they did not believe in smoke consumers.
* Elevator — Brooks Elevator Co.											Use Electric Power only.
* Elevator — Devereaux Elevator Co.											Use Electric Power only
Elevator — (In Milwaukee Yards — 6th Av. S. Wash. Av.)							10%	6%	13%	71%	
Elevator — (Near Russell-Miller Co.)							10%	27%	36%	27%	
Elevator — (Near Russell-Miller Co.)							37%	27%	23%	13%	Smoke readings taken Mar. 2nd
* Purity Malt Brewing Co.		300	2 R.T.	Hand-fired Grates	Coal	Sharf Automatic Steam Jet	7%	2%	34%	57%	Smoke readings taken Mar. 2nd
* Gluek Brewing Co.		450	2 R T	Hand-fired Grates	Shavings						
* T.C.R.T. Co.	Stack No. 1	13200	24 B.&W. Water Tube	Roney Stokers	Ill. Run of Mine and Screenings	Various forms of fire-brick Arch	69%	15%	13%	3%	Are now changing to chain grate stokers with great improvement as to smoke.
	Stack No. 2						87%	10%	3%	0%	
* No. East Mpls. Pumping Sta.		1000	4 Edge Moor W.T.	Hawley Down Draft	Screenings		Almost no smoke.				
* Gen. El. – River Sta.	Brick Stack	4150	10 Stirling W.T.	Hand-fired Grates	Bituminous		40%	19%	34%	7%	Very little power is now generated in Mpls. except when there is trouble on the line from Taylor's Falls. Hence Load is very small.
	Steel Stack						0%	16%	53%	31%	
* General Electric – 5th St. Station		500	2 Stirling W.T.	Hand-fired Grates	Bituminous		0%	5%	0%	95%	
U. of M. Heating Plant		1050	7 R.T.	Hand-fired Grates	Anth. & Bit. Screenings		Smokes badly.				A new plant is to be built in the near future
* Booth Packing Co.		425	3 R.T	2 Murphy Stokers 1 Hand-fired Grate	Screenings	Kraig automatic steam jet on one boiler					

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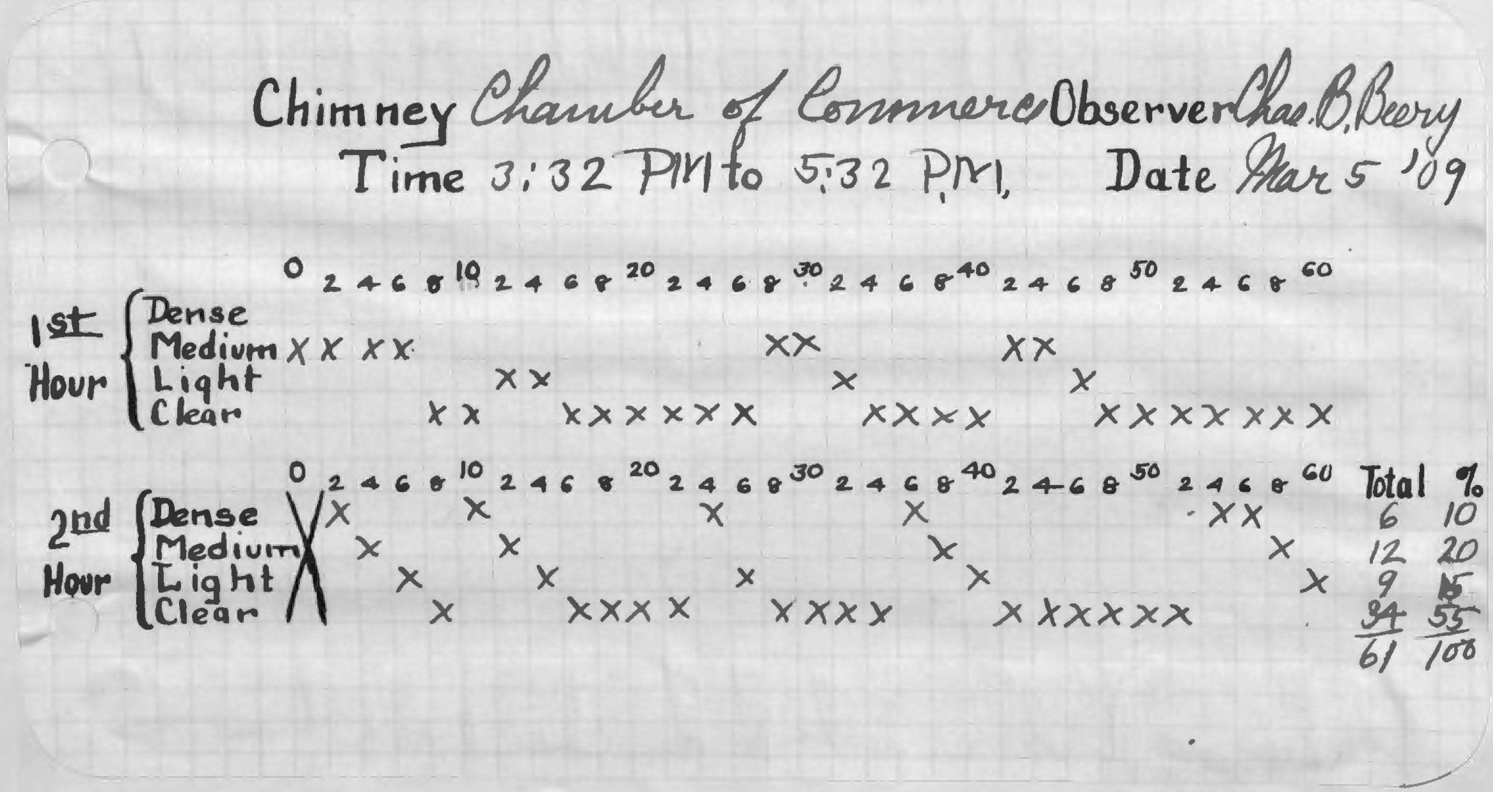


Chimney Chamber of Commerce Observer Chas. B. Beery

Time 3:32 P.M. to 5:32 P.M. Date Mar 5 '09

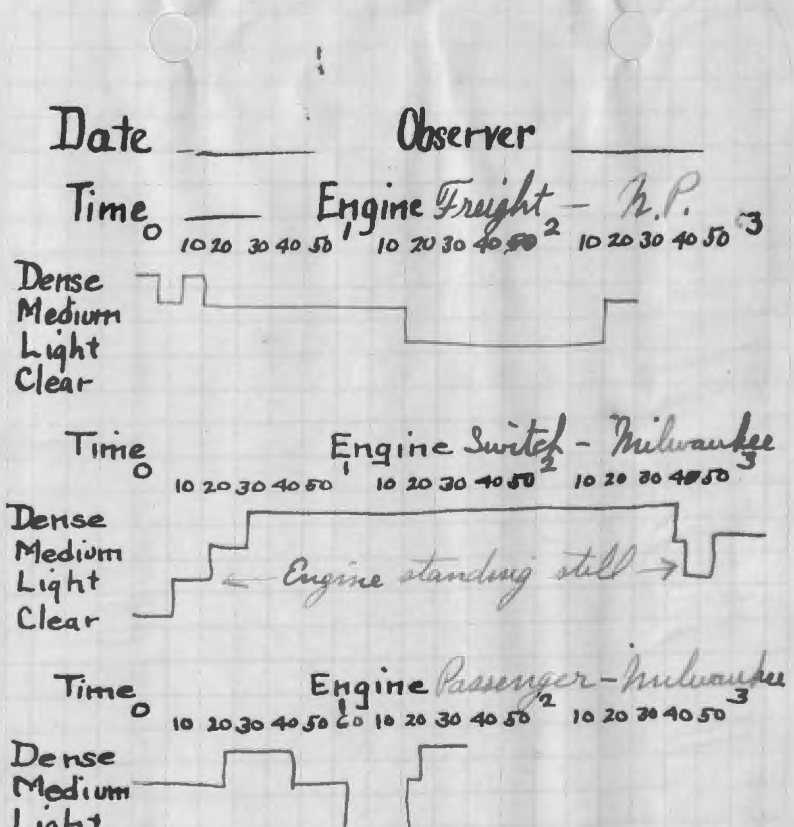
	Total	%
Dense	6	10
Medium	12	20
Light	9	15
Clear	34	55
	61	100

Figure-16 -

was mild (temperature 42 F.). On the contrary the readings also show some excellent performances from the Security Bank building, the Andrus building, the Court House, the New York Life building and the concrete stack of the N.W. Consolidated Milling Co. This shows conclusively that smoke prevention is entirely feasible.

The above records represent almost entirely plants of large horsepower. Besides these large plants (of which there are a good many more than those given) there are hundreds of small plants (from, say 30 to 100 horsepower) which commonly make more smoke for their size than the large ones. For instance the heating plant of Wilson's Book Store smoked almost as badly, last winter, as our own notorious U of M. Heating Plant.

Now with regard to the locomotive smoke problem in Minneapolis the following observations were made. On several different dates and from three different vantage points, the writer took smoke readings of passing locomotives. Continuous



Date ______ Observer ______

Time ____ Engine Freight - N.P.

Engine Switch - Milwaukee

Engine Passenger - Milwaukee

Engine Switch - N.P.

Engine Switch

Point of Observation ______

Figure-17 —

readings (see page 129) were taken for three minutes or as long as the locomotive remained in sight. Care was taken not to pick out those engines which were smoking badly, but simply to take them as they came regardless of the smoke which they were making. Forty-four locomotives were observed of which twenty-nine were switch engines, nine were passenger engines and six were freight engines. From an average of all these we get the following:-

	Passenger	Freight	Switch
Dense	2%	9%	23%
Medium	27%	18%	24%
Light	34%	28%	27%
Clear	37%	45%	26%

These results show that the switch engines are the chief offenders and since they are by far the most numerous of the three chasses we see that the locomotive smoke problem in Minneapolis is confined largely to this class. Much of the smoke emitted by switch engines is due to negligence on the part of the fireman. Witness, for instance, the engine from which the second set of readings page 129 was taken. This engine as indicated belched forth dense smoke continuously for over two minutes while standing idle and uncoupled in the Milwaukee yards.

It is time Minneapolis began to consider the smoke problem more seriously. Our city is growing very rapidly and the smoke problem is growing with it. To be sure, the condition here is by no means as bad as in some other cities; nevertheless there is much need for improvement. Minneapolis has the reputation of being a clean beautiful city - a wholesome place to live in. We can not afford to jeopardize such a reputation by neglect of the smoke nuisance.

A good deal has been accomplished in the past, but further progress seems to be impossible under present conditions. What then is to be done? Our present ordinance is, we believe, inadequate and should be revised. Smoke inspection should be taken out of the hands of the Board of Health and put under a separate Smoke Department. An Advisory Board of engineers should be provided to add dignity to the department. Besides a smoke inspector as at present and possibly two or three deputy inspectors, a mechanical engineer should be added who should give all his time to the redesigning of objectionable plants, inspecting the plans for new installations, and in general to conduct the technical end of the department. The ordinance should require plans and specifications for all proposed new boiler plants or alterations of existing plants to be submitted to him and his written approval obtained before they are carried out. Finally, provision should be made for the appointment of members of the Smoke Department in a manner independent of political influences.

Six thousand dollars a year spent in supporting such a department would bring about practical smokelessness in ten years and would eventually mean millions of dollars to our city.

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