SMOKE PREVENTION

...BY...

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THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

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ENTITLED SMOKE PREVENTION

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OF Bachelor of Science in Mechanical Engineering

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INTRODUCTION

The subject of "Smoke Prevention" is important, because the suppression of dense clouds of smoke, which have become a nuisance in our cities, will lead to a more healthful condition of the atmosphere.

In the treatment of this subject, the writer begins at the origin- "coal."

Section I discusses coal and its occurrence, and points out the fact that bituminous coals are most extant.

Section II treats with the present state of the art.

Section III explains in detail what methods and appliances have been used successfully to prevent smoke.

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1.- DEFINITION OF COAL.- Coal is the name applied to a relative group of massive crystalline black or brown bedded minerals or rocks, which are composed largely of carbon with some oxygen and hydrogen and a few other elements, which are economically unimportant as fuels.

2.- COMPOSITION OF COAL.- Coal is by some writers treated as a mineral, by others as a rock. As a coal lacks the definite chemical composition which minerals are generally considered to have it may be treated as a rock. Coal is a mixture of certain elements or compounds of these elements. The principal element being carbon, a common form of which is charcoal. The diamond and graphite are other forms of the same element. Oxygen and hydrogen, the two gases which combined form water are the next most abundant elements. With these are traces of the elements nitrogen and sulphur, and more or less of other substances that will not burn and are grouped together as ash. The ash will include traces of silica, potash and soda, sometimes alumina and iron, and in impure coal some shale or dirt. The way these elements differ in different coals is shown in the following table.

Table Showing Composition of Different Coals

		CARBON	HYDROGEN	OXYGEN	NITROGEN	SULPHUR	ASH	ANALYSIS
1	Coal, Eastern Pa.	90.45	2.43	2.45			4.67	Regnault
2	Coal. Clay Co., Ind.	82.70	4.77	9.39	1.62	0.45	1.07	Cox
3	Coal, Ohio	73.80	5.79	16.58	1.52	0.41	1.90	Wormley
4	Coal, Breck'nrg, Ky.	68.13	6.49	5.83	2.27	2.48	12.3	Peters
5	Coal, Bovey	66.31	5.63	22.86	0.57	2.36	2.27	Vaux
6	Peat	59.47	6.52	31.51	2.51			Websky

In studying coal it is found that while some of the matter is in the elementary stage, much of it is in the form of compounds. Thus, part of the carbon is uncombined, when it is known as "free carbon" or "fixed carbon", while the rest of it is combined, partly with the hydrogen, making the hydro carbons as marsh gas, tar, etc., and partly with the oxygen making the gas carbon monoxide. The hydro-carbons are gases or become so on heating. Part of the hydrogen and oxygen will be found combined in the form of water. The sulphur occurs principally as a simple compound with iron, forming the mineral known as pyrite, a mineral closely resembling gold in its yellow color. The sulphur balls frequently noticed in the coal are an impure form of the same mineral.

The elements and compounds may then be grouped as :-

1.- Fixed Carbon.

2.- Gases that will burn or the volatile combustible Material.

3.- Water, will not burn.

4.- Sulphur, considered by itself for reasons given below.

5.- Ash.

PROXIMATE ANALYSIS.

An analysis of the coal which shows the proportion of the above parts of the coal is known as a proximate analysis. It is easier to make than an ultimate analysis. or one which determines the proportions of the elements, and is much better for determining the value of coal for fuel purposes.

The subjoined table will give an idea of the variation of the above constituents in different coals.

Table Showing Proximate Analysis of Different Coals

		FIXED CARBON	GAS	WATER	SULPHUR	ASH	ANALYSIS
1.	Coal, Eastern Pa.	86.38	3.08	4.12	0.50	5.92	McCreath
2.	Coal, Clay Co. Ind.	55.25	39.85	3.40		1.50	Cox
3.	Coal, Pittsburg, Pa.	54.56	37.74	1.79	1.50	4.47	McCreath
4.	Coal, Fountain Co Ind	47.50	47.00	4.50		1.00	Cox
5.	Coal, Carbon City, Colo.	41.25	46.00	3.50		9.35	Cox

Section 2.- Chemical and Physical Properties of Coal.

COMBUSTION.- The most valuable property of any coal is its power to produce heat by the oxidation or burning of its constituent parts. If these parts are examined it will be found that two of them will not unite with oxygen or burn, as they are already practically burnt substances, or highly refractory. the water and the ash. The weight of ash in any coal is that much unburnable matter and reduces the heat value of the coal that much. The water not only reduces the heat value by not burning, but absorbs a part of the heat produced by the other components while being evaporated. The sulphur yields a small amount of heat, but its value in this direction is more than offset by the injurious effects in the commercial use of coal, as will be shown further on.

The combustible volatile matter yields the most heat for its weight, but in the ordinary usage of coal much of this is lost. For most of the purposes to which coal is put the fixed carbon is the most valuable element. Future practice may modify or change the truth of this statement.

IGNITING OF COALS.- In general it may be stated that those coals containing a large proportion of gas ignite readily, while those containing a small proportion ignite with difficulty.

CAKING.- Some coals when heated have a property of becoming vicid and running together into a solid mass. Coals are sometimes classed on the basis as "caking or cementing coals," and as "non-caking" "free burning," or "splint coals." The former coal is generally preferred by the blacksmith on account of its forming a "hollow fire" and hense is referred to as "blacksmith coal." "Blacksmith coal" is often used in speaking of a part bed of caking coal on account of its freedom from sulphur and other impurities. In parts of Indiana a caking coal is spoken of as a "bituminous" in contrast to "black coals."

A caking coal is a bright coal while the non-caking or splint coal has a dull fracture; second, the non-caking coal splits more readily parallel to the plane of the bedding, and if these planes along which it splits be examined they will be found to resemble sheets of charred shavings still showing the fibre, like charcoal, and if one of these sheets be examined chemically it is found to resemble charcoal further in having a very high percentage of carbon.

COKING.- By heating a caking coal out of contact of air, the volatile parts are driven off leaving a mass somewhat larger, lighter but very valuable as a fuel for certain purposes. Practically all caking coals are "coking" coals, but not of the same commercial value.

HARDNESS.- Coals vary in hardness from 1.2 to 1.8. That is a little harder than talc which can be scratched with the finger nail and is 1 in the table of hardness. The hardness influences largely the value of a coal. A soft coal crumbles readily in mining, entailing some loss; there is further loss in screening and handling and a still further loss in shipping and delivering. Often coals of excellent quality cannot be shipped for the above reasons, and are used in local trade. Such coals may be improved by washing. Often coals which appear hard and firm will soften and crumble to a fine coal when exposed to the weather. This is due to the presence of sulphur and other impurities.

The hardest coals break often with a conchoidal or shell like fracture. More common are the coals breaking into more or less cubical blocks sometimes with bright faces, often with dull, but more commonly with bright and dull bands. Such coal tends to cleave along the dull lines when struck. Examined in the mine, it is found that the laminations agree with the bedding.

VARIETIES OF COAL

Coals may be divided into classes determined by the amount of fixed carbon and volatile matter.

Anthracite or "stone coal" is coal No. 1 of the above analysis. It has 78 to 88 % fixed carbon; from 3 to 7 % volatile matter, usually some sulphur, and from 4 to 12 % ash. Its hardness is from 2 to 2.5. and it burns with a feeble blue flame.

Bituminous.- This is the most abundant coal and is well known as soft coal burning with a yellow flame and usually with much smoke. (This thesis will endeavor to show what efforts have been made and what can be done to avoid smoke when bituminous coal is used as fuel.)

Coals Nos. 2 and 3 in the above tables are bituminous coals. They contain a large percentage of volatile matter, often 40 to 60 %, ash one to eight per cent, usually less than anthracite, sulphur one to three per cent. The coal used at the University of Illinois in 1903 - 1904 was mined in Sangamon County, Illinois. It is "pea" size and clean analysis showed as follows:-

Water	7.9
Volatile combustible	35.3
Fixed carbon	39.7
Ash	17.1
	100.0

B.T.U. by Parr calorimeter 10268.

Sulphur - 5.2%.

It has been found that volatile combustible ran high and fixed carbon low. Bituminous coals are usually divided into the three following groups:-

(1).- Caking coal, as above defined.

(2).- "Non-Caking" or free burning splint coal.

(3).- Cannel coal.

"Cannel" is applied to coal in which a regular system of joints is developed in a high degree. Cannel is lustreless compact and of an even texture with a conchoidal fracture. It is very similar to ordinary bituminous coal, but usually with a larger percentage of gas, as shown in coal (4). It burns like a candle, whence its name, burning with a yellow flame without melting. Its difference from bituminous seems to be due to a difference in origin.

Lignite or "brown coal" varies from brown to black in color, often shows woody structure, contains a large amount of moisture and other volatile matter.

Coal (5) in tables.

Peat is the name given to thick mass of vegetable matter occurring in swampy places and believed to represent the first stages of vegetable growth. Coal (6) of the first table. In northern Indiana peat beds are known to have a thickness of fifty feet.

Graphite is a carbonaceous deposit practically nothing but fixed carbon and is not used as fuel. The intermediate grades of coal are semi-anthracite between anthracite and bituminous or semi-bituminous as they approach more nearly the anthracite or bituminous.

IMPURITIES IN COAL

Sulphur is the most important impurity in coal, and occurs chiefly in the form of iron pyrites of a bright yellow color.

Pyrite tends to take up oxygen from the air or from water, changing to iron sulphate , which readily crumbles. Sulphur in coal tends to make the coal clinker and stick to the grate bars.

Phosphorus in coal proves a detriment for metallurgical purposes. Nitrogen adds its own weight without assisting combustion. Oxygen might be classed the same as nitrogen in that the air will supply the necessary oxygen for combustion.

Water is an impurity when the coal is viewed from the use as fuel.

OCCURRENCE OF COAL IN THE U. S.

Map.- The accompanying map shows the developed coal fields west of the 97th meridian, as shown by the 1890 census report.

The long field extending from Pennsylvania to Alabama is known as the Great Appalachian field. A narrow strip on the eastern border contains semi-bituminous coals, and west of this strip the best varieties of bituminois gas stream and coking coals.

Several small detached field lie east of these. The most important are three anthracite fields in Pennsylvania. The Michigan coal field contains a poor quality of bituminois coal.

To the west is the Illinois, or central, extending into Indiana and Kentucky, and containing a great variety of bituminous coals, most of which are inferior to the Appalachian field. West of the Mississippi is the great Missouri field covering several states. The coals found here are mostly of a poor quality. West of the 97th meridian there are a great number of detached fields, mostly of small areas, with every grade of coal from anthracite to lignite. The quality of coal and its location will be further considered below.

FIG-I-

COAL-FIELDS OF THE UNITED STATES EAST OF THE NINETY-EIGHTH MERIDAN.

Anthracite Coal-beds of Pennsylvania

These coal beds are all in the eastern part of the state. They are three in number, known as the First, Second, and Third. The coal in all the fields follows the general law of increasing in percentage of volatile matter and decreasing in hardness towards the western portion of the fields. In fact this is true more or less of all the coal in the United States. We find the Anthracite in Pennsylvania, and as we go westward the coal decreases in hardness and increases in percentage of volatile until west of the Mississippi we find the lignites. The operators in the anthracite region met January 1, 1891 in Wilkesbarre and adopted the following sizes to secure uniformity of product.

Egg, through 2-3/4 inches and over 2 inches.

Stove, through 2 inches and over 1-1/4 inches.

Chestnut, through 1-1/4 inches and over 3/4 inches.

Pea, through 3/4 inch and over 1/8 inch.

Buckwheat, through 1/2 inch and over 1/4 inch.

No. 2 Buckwheat, through 1/4 inch and over 1/8 inch.

Anthracite is also found in Virginia, Colorado and New Mexico. Pennsylvania anthracite was known as early as 1766, but was not used much because of the lack of knowledge of how to burn it.

1.- A very hot fire of wood must be first established.

2.- The coal should be laid several inches deep.

3.- The bed must not be disturbed while beginning to burn.

4.- A constant supply of air must be maintained through the grate.

Bituminous and Semi-bituminous Coals in the United States.

The Triassic Area comprises, Richmond basin, Chesterfield and Henrico counties, Virginia, and the Deep River and Dan River fields in North Carolina. The first coal mined in the United States was taken from the Richmond basin.

The Bituminous coals of the Carboniferous formation (not including the more recent coals of the Western States) are shown in the map.

1.- The Appalachian field, extending from Pennsylvania to Alabama. 50,000 square miles. The eastern portion of the Appalachian field contains the semi-bituminous coals which are found in a narrow strip running from northern Pennsylvania through portions of Maryland, Virginia, West Virginia and Tennessee.

2.- The Illinois basin extending into the western part of Indiana and northwestern Kentucky. 47,188 square miles.

3.- The Michigan basin, 6,700 square miles.

4.- The Missouri or Western basin, 90,343 square miles, covering portions of Iowa, Nebraska, Missouri, Kansas, Indiana Territory and Arkansas with an extension into Texas. The coal in this basin is not very pure and contains a large amount of sulphur.

West of Missouri are still softer coals of the lignites and lignitic coals (some of them are transformed into bituminous and anthracite) of the Rocky Mountain field, containing the coal areas in the States and Territories lying along the Rocky Mountains and the Pacific coast field embracing the coal districts of Washington, Oregon and California. Pennsylvania- The Appalachian coal field extends over 12,302 square miles.

The difference between the semi-bituminous and the bituminous coals is an important one economically. The former have on the average a heating value per pound of combustible about six per cent higher than the latter, and burn with much less smoke in ordinary furnaces. Volatile matter increases smokiness. For this reason the western coals five off a large amount of smoke.

Maryland Semi-bituminous Coal,-

Cumberland coal-field in Alleghany County, Maryland is thirty miles long and average four and one-half miles in width. It is one of the best steam coals mined in the United States. It is jet black and glossy; is friable and becomes pulverized in transportation and handling, showing a large percentage of sulphur.

Elk Garden and Upper Potomac Fields.

The northern end of this field passes through the western part of Alleghany County and a portion of the eastern part of Garrett County, Maryland, and from it the entire coal product of Maryland is obtained.

Virginia:- The Appalachian Semi-bituminous coals are found in the southwestern part of the state, in Tazewell County, on the West Virginia border. The famous Pocahontas coal field which embraces parts of Buchannan, Dickinson, Lee, Russell, Scott, Tazewell and Wise Counties, at the southern edge of the Flat Top region, including the church valley field, containing the lower productive measures of the Appalachian field. The Pocohontas Flat Top coal measures contain thirty square miles. The region was opened in 1881 and is a prominent factor in United States coal production.

North Carolina:- Semi-anthracite is found in two unimportant beds in 200 square miles.

West Virginia:- Semi-bituminous in the eastern and bituminous in the western. Here are found excellent steam, coking and gas coals, also cannel and hard splint coal.

Eastern Kentucky furnishes a good coal although it contains a large per cent of volatile matter. Area 8983 square miles.

Tennessee:- About 5100 square miles are contained in this coal area. It furnishes a good grade of coke.

Georgia:- 150 to 170 square miles. This coal is similar to that of Tennessee.. The Dade County analysis gave moisture 1.20; volatile matter 23.05; fired carbon 60.50; ash 15.16; sulphur 0.84.

Alabama:- The Appalachian coal field extends into this state, as seen by the map, and covers about 3,500 square miles, and is a good coal.

Ohio:- The Appalachian field covers more than 10,000 square miles. The coals are of a bituminous variety, are known in general terms as block coal, gas coal, cannel coal, etc. Block coal is found here and is known for its excellence. Area, 6,700 square miles. One analysis gives moisture 2.; volatile matter 49; fixed carbon 45; ash 2; sulphur 2.

Michigan:- Coals are of an inferior quality compared with those shipped by rail into the state and the imported coals are sold cheaper than for what the domestic coals can be produced.

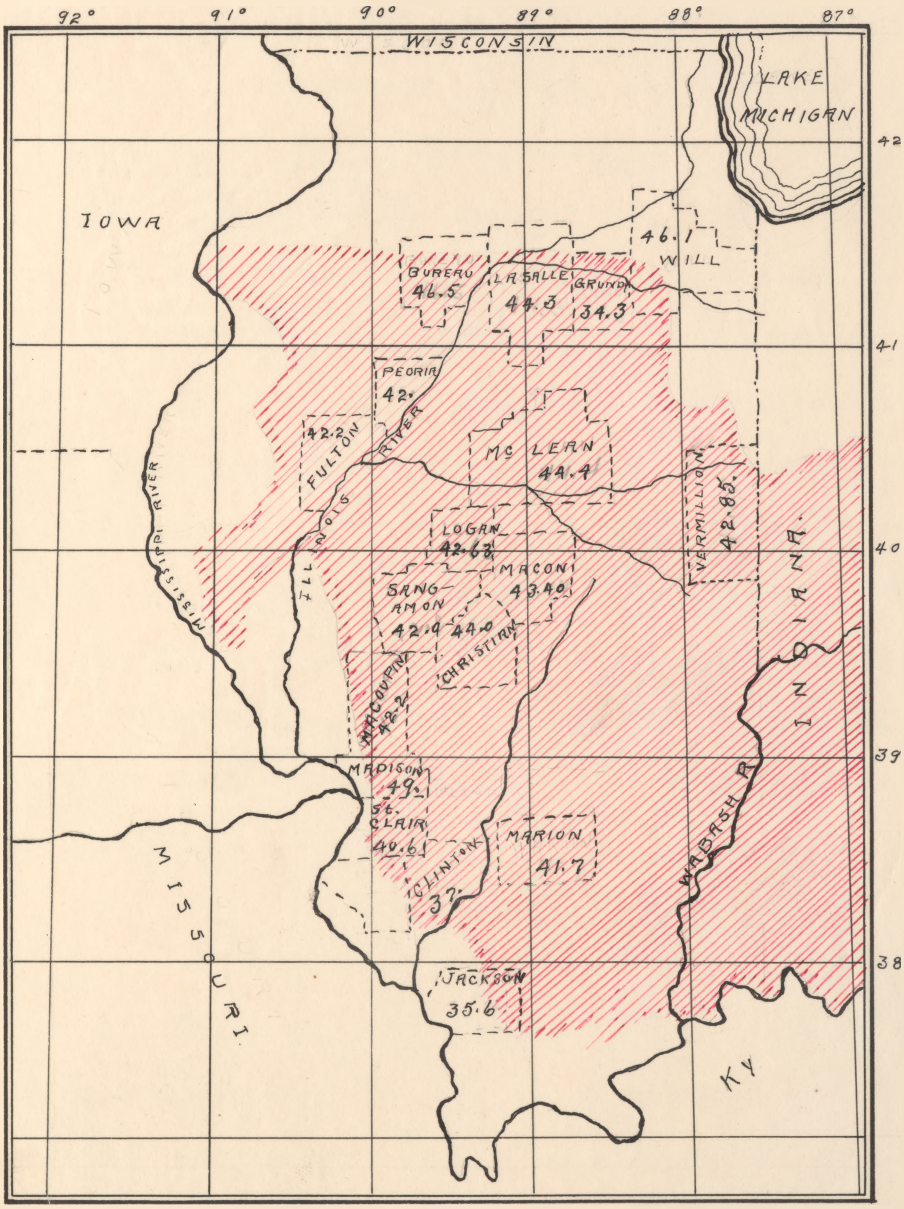
THE ILLINOIS COAL BASIN

This basin is very interesting because of its extent and central location and the fairly good value of the coal. The only serious objection is its smokiness and this can be overcome by the proper kind of a combustible chamber.

Indiana:- Area of coal belt, 6,500 square miles. Here are found caking coals and block coals. The volatile matter varies from 31 to 45 per cent.

MAP OF ILLINOIS COAL AREA.

FIG II



REF'S.- "KENT STEAM BOILER ECONOMY", "BULLETIN 20TH ANNUAL ILLINOIS COAL REPORT".

Western Kentucky:- Coal area. 3,888 square miles. The volatile matter averages about 35 per cent.

Illinois:- The coal-field of Illinois occupies an area of 36,800 square miles, or nearly two-thirds of the area of the state. The coal measures contain six beds of workable size, with a total thickness of 24 feet, but the beds are irregular, often wanting and often containing an inferior quality of coal. In the DuQuoin district, Perry county, two seams, V and VI, 6 to 7 feet thick are worked within 75 feet of the surface. In the Big Muddy district in Jackson county, the coal occurs near the surface. The lower seams produce a good block coal. From the Belleville district, St.Clair county, St.Louis obtains most of its bituminous coal. Coal seam VI, 5 to 7 feet thick, is principally worked. The lower seams contain more sulphur and the quality varies. Other large producing districts are Neelysville, Danville, and LaSalle. The latter is of importance from its proximity to Chicago. There are three workable beds:-

VI.-	4-1/2 - 5 feet
V .-	3 - 9 feet
II.-	4 feet.

The coal of the upper bed, No. VI, is light, dry, and free-burning. No. V is a purer coal. No. II is most highly bituminous, cakes in burning, is high in sulphur, and throws off heavy soot.

WILMINGTON DISTRICT

In the Wilmington district, Will county, there is a workable seam which is largely used for household and steam purposes. The coal is high in moisture and is often very high in sulphur and ash. When burned in ordinary furnaces it produces dense volumes of black smoke.

CHEMICAL ANALYSES OF ILLINOIS COALS

The Bureau of Labor statistics in 1902 issued a bulletin of chemical analyses of Illinois coals. The following table contains some of the analyses for average samples. This report was made by Professor Parr, Applied Chemistry, University of Illinois.

c 4

TABLE CONTAINING PROXIMATE ANALYSIS OF ILLINOIS COALS

	Moisture	Volatile matter	Fixed carbon	Ash	Sulphur	B.T.U. per pound	Analysis
1: Wilmington, Will	dry	36.80	49.90	13.30		12180	Carpenter
2: Lombardville, Bureau	9.42	31.38	51.74	7.46	2.46		Rudy
3: Streator, LaSalle	12.01	35.32	48.78	3.89	2.38	11420	Eng. Club. St. L.
4: Morris, Grundy	7.10	32.12	49.74	11.04	2.75	10684	Forsythe
5: Elmwood, Peoria	8.70	43.63	41.30	6.37	3.98	12420	Wolcott
6: Farmington, Fulton	11.12	35.93	36.50	16.25	1.97	10530	"
7: Bloomington, McLean	7.90	34.02	53.12	4.96		12318	Rudy
8: Danville, Vermilion	4.78	43.70	45.37	6.15		12506	McConney
9: Mt. Pulaski, Logan	7.68	35.82	46.53	9.97		11360	"
10: Divernon, Sangamon	8.69	34.72	38.59	18.00	6.03	10262	Koch
11: Niantic, Macon	7.9	36.3	47.4	8.5		42.9	
12: Pana, Christian	8.55	35.45	39.35	16.65	4.77	9810	Koch
13: Mt. Olive, Macoupin	9.63	38.33	40.22	11.82	6.78	11072	"
14: Glen Carbon, Madison	7.85	39.13	40.66	12.36	4.87	11539	"
15: Trenton, Clinton	13.30	30.40	52.00	4.30	.90	10588	Eng. Club. St. L.
16: Vulcan, St. Clair	7.44	30.86	45.09	16.61	1.30	9450	"
17: DuQuoin, Perry	7.02	35.02	44.56	13.39		10989	Parr
18: Carbondale, Jackson	6.08	39.78	46.22	2.92		11070	"

Taken from table of proximate analyses made at the University of Illinois since 1878.

DETERMINATION OF HEAT VALUE

An accurate means of determining the calorific value of coal has been devised in the Parr calorimeter which is simple and accurate. The following is based on the ultimate analysis and is more difficult. The values of the constituents being known we may compute by means of Dulong's formula, the actual heat value:-

$14600\ c + 62000\ (H\ \frac{O}{8})$ C H and O are carbon, hydrogen and oxygen respectively.

CONSTITUENT PARTS OF ILLINOIS COALS

The term "moisture" means the amount contained in the coal when taken from the mine and is ascertained by weighing before and after the process of heating at a temperature at or above that of boiling water. This water varies greatly with different coals, being rarely below three or four per cent and sometimes reaching as high as 12 per cent, the average being perhaps seven or eight per cent water. The average for anthracite is less than 3 per cent moisture. Lignites average about 15 per cent. The coals of Illinois and the Mississippi and the Mississippi valley stand midway between the anthracite coals of the East and the lignites of the South and Northwest in per cent of moisture.

ASH

The ash is an inert waste material carrying away heat and also carrying away, mechanically, unburnt material.

COMBUSTIBLE MATERIAL

Combustible material consists distinctly of two parts; volatile matter and fixed matter. The latter burns as coke.

VOLATILE MATTER AND ITS BEHAVIOR IN THE FURNACE

The volatile matter is liberated in great volumes when when fresh fuel is added to the fire. The admission of air is regulated for the average conditions and if this be so an insufficient supply of oxygen is present, allowing much of the gaseous product to pass off unburned.

It is evident that a low efficiency and a great deal of smoke occurs with Illinois coals if not properly handled in the furnace. The volatile constituents begin passing off at about 700 degrees Fahrenheit, and the process when once started is very rapid for the major part of the gaseous constituents. It is just at this time when insufficient oxygen results in incomplete combustion, which is evident by volumes of smoke. However, an excess of air must be avoided as this will cause a waste of heat.

Section II.- SMOKE ABATEMENT

Introduction

When used to a great extent in cities, bituminous coal becomes a nuisance and cities have passed laws prohibiting smoky chimneys. The following is the smoke ordinance as passed by the Chicago City Council:-

Legislative Action

Chicago City Smoke Ordinance

Reference, - Section 10, page 8:- Ordinance governing the department for the inspection of Steam Boilers and Steam plants,- City of Chicago. In effect, May 1,1903.

Section 10, pp 8. The emission of dense smoke from the smoke stack of any boat or locomotive, or from any chimney anywhere within the city, shall be deemed, and is hereby declared to be, a public nuisance: but no prosecution for the emission of dense smoke shall be commenced unless within ten days prior thereto at least three notices shall have been mailed to the offender that dense smoke has been seen emitted from his premises.

The owner or owners, lessee, agent, or manager of any boat or locomotive, and the proprietor lessee, or agent of any building, factory, mill, works, or other establishment having smoke-stacks or chimneys, who shall permit or allow dense smoke to issue or to be emitted from the smoke-stack of any building factory, mill, works or other establishment having smoke-stacks or chimneys within the corporate limits to exceed three minutes (excepting in cases where the fire box is being cleaned out or a new fire built therein, in which cases, the limit shall be six minutes) in any hour of the day or night, shall be deemed and held guilty of creating a nuisance, and shall for every such offence be fined a sum of not less than ten dollars ($10.00) nor more than one hundred dollars ($100.00).

It shall be the duty of the board to see that the boiler or boilers, boiler setting, means of producing draft, smoke connections and furnace or fire-box or each boiler inspected by it are of sufficient capacity and so constructed as with proper management to avoid the emission of dense smoke.

Prosecutions for all violations of this ordinance shall be brought by the Chief Inspector or Supervising Mechanical Engineer and Chief Deputy Inspector of Steam Boilers and Steam Plants, in the name of the City of Chicago.

PROVIDED, That no prosecution under this ordinance shall be commenced against the owner, or owners, lessee, agent, or manager of any boat, locomotive, or the proprietor, lessee or agent of any building, factory, mill, works or other establishment having smoke-stacks or chimneys, the plant of which shall have been installed prior to the passage of this ordinance, until the expiration of one year after the passage of this ordinance within which to rebuild and re-equip the same in accordance with the provisions of this ordinance;

PROVIDED, further, that no such owner, owners, lessee, agent or manager shall be entitled to said one year unless he shall at once commence his plans for the rebuilding and re-equipping of such plant and shall proceed with said work to the satisfaction of the board upon inspection at intervals of three months during said period of one year.

(b) THE MISSOURI STATE LEGISLATURE.

Provisions of the act of the general assembly of the state of Missouri relating to smoke abatement in cities of one hundred thousand inhabitants, approved, March 21, 1901

(c) EXPERT OPINION ON SMOKE PREVENTION

St.Louis Committee Report

(a).- A committee appointed by the Engineers Club of St.Louis in 1891 investigated various smoke consuming devices upon the market. The following ten requirements were laid down by them.- Any smoke-consuming or preventing device must satisfy these in order to fully meet the varying conditions in ordinary practice.

1.- It should develop such high temperature and oxidizing action as to insure the combustion of the free or separate carbon which forms visible smoke.

2.- It should insure regularity of action under the varying conditions induced by charging fresh coal, cleaning fires, inattention of firemen, etc.

3. - It should not be susceptible to derangement under the conditions likely to obtain in use, such as carelessness of firemen, inferior water, bad clinkers, etc.

4.- If there is any increase in the cost of operation it should be small.

5.- The capacity of the apparatus should be such that efficient action will be secured not only when the boiler is working up to its full rated capacity, but even when forced in order to meet extraordinary demands.

6.- The apparatus should be readily adjustable to all forms of boilers and boiler settings.

7.- It should be susceptible of application to boiler-settings where the space is already limited.

8. - It should be of comparatively low first cost.

9. - Repairs should be small in amount, easily made and low of cost.

10.- The apparatus should operate without injury to boiler or other accessories.

The following classifications were also made for smoke;-preventing devices,-

1.- Steam jets

2. - Fire-brick arches or checker work.

3. - Hollow walls for pre-heating air.

4. - Coking arches or chambers.

5. - Double combustion furnaces.

6. - Downward draught furnaces.

7. - Automatic stokers..

The following is taken from a report by C. H. Benjamin, Cleveland, Ohio.

(b).- SMOKE ABATEMENT IN LARGE CITIES.

Nature of Soft Coal Smoke

"The smoke from bituminous coal owes its offensive character to the presence of hydro-carbons in that grade of fuel. Coals such as anthracite and semi-bituminous which are free from hydrogen or nearly so, cause little offense. When bituminous coal is first put upon a hot fire the heat distills from the fresh fuel the volatile hydro-carbons which would pass off as an almost colorless gas if unburned. The heat and the presence of a certain amount of oxygen causes these gases to burn with a yellow flame. If sufficient air is supplied, and the temperature is not allowed to fall, they will be almost completely burned, and no objectionable smoke will result. If, however, the quantity of air is insufficient or if the gases be chilled by coming into contact with the comparatively cold surface of the boiler, combustion is retarded, and fine particles are set free, which either collect on the cold surface as soot or pass off through the chimney as black smoke. It is extremely difficult to burn this soot after it is once formed, and the better remedy is prevention.

The peculiar oily consistency of the soot from this class of coals is probably due to the presence of hydrogen with the carbon."

Section III. METHOD OF FIRING

(A).- Hand Firing. There are three methods of hand firing.

(a).- Side firing.

(b).--Spreading

(c).- Coking.

(a). - Side firing is used often used in the so-called "Dutch Oven" furnace. By this method coal is fed alternately first to one side and then to the other in such a manner that one side is continually at a high heat, say 2400 degrees Fahrenheit. In this way the volatile matter from the side freshly fed passes over and is immediately consumed and the furnace is kept at a constant heat.

(b).- Spreading. This method involves the practice of spreading the fuel over the fire in a thin layer at certain regular intervals.

(c).- Coking. To some extent coking occurs in side firing but the method to which this term is applied is the practice of feeding the coal from the front of the fire and gradually forcing it back as the volatile matter is driven off.

The best and most practical method of hand firing by any of the methods mentioned is to feed the fire at regular intervals a certain number of shovel fulls at definite intervals of time. This has been tried in foreign countries and resulted in absolutely no smoke

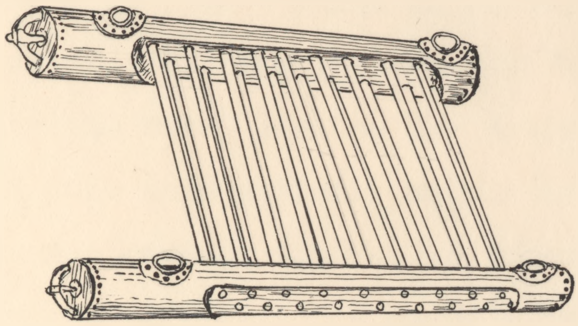
(d). MECHANICAL DEVICES USED IN HAND FIRED BOILERS

1. - Preheating Air . - This has been tried to prevent smoke, but unless apparatus is of a rather complicated nature it will not be very successful. Hollow walls, pipes, passages in the bridge wall, etc., can at best add but a few degrees of heat to the air passing through them at a high velocity.

2.- Down Draft Furnaces. The original down draft furnace was invented by Watt. This is a very simple device for preventing smoke. A blower may be used to furnish the air and a pipe located above the fire conveys the air to the fire. A steam jet is sometimes used to effect the same results and may be attached to existing boilers giving very good results with low cost of operating. Smoke has been prevented by lowering the duty on a boiler introducing steam jets and brick arches.

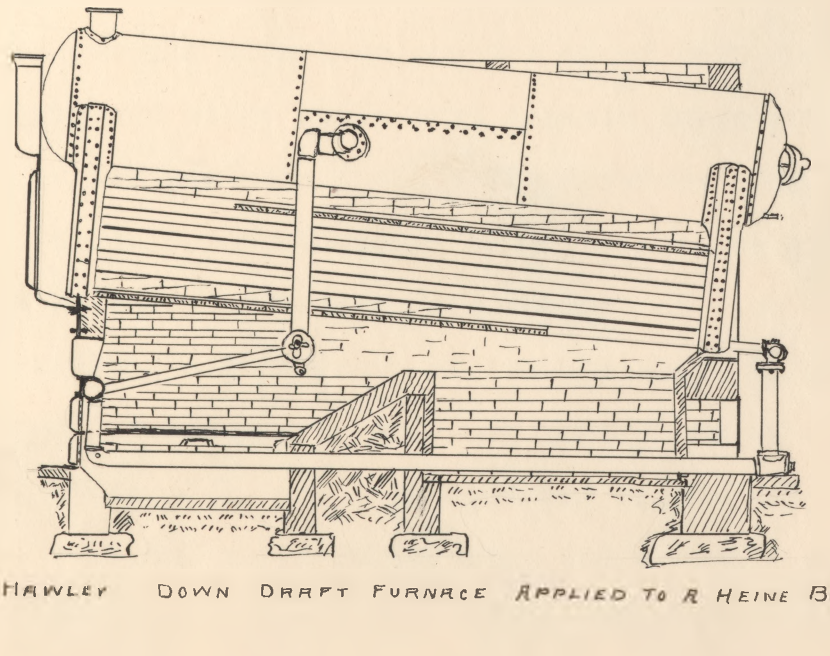
3. - Hawley Down draft Furnace. This is a form of the down-draft furnace which has within the past few years been

FIG. III.



WATER-GRATE USED IN HAWLEY FURNACE.

FIG. IV.



HAWLEY DOWN DRAFT FURNACE APPLIED TO A HEINE BOILER.

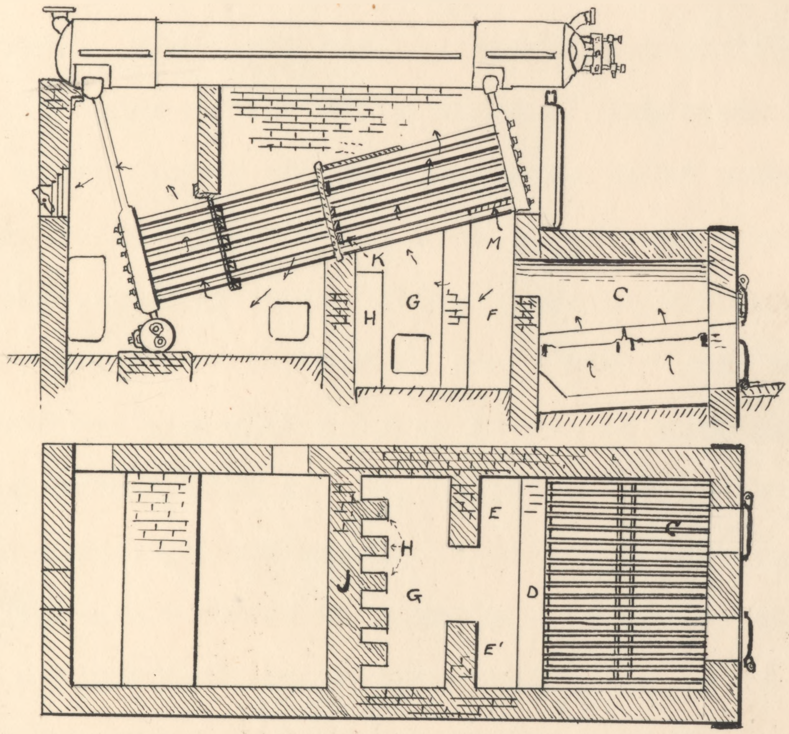
KENT

widely introduced in the United States, and has given excellent results both in smoke - prevention and in economy of fuel. Besides the water grate upon which the coal is fed, there is a lower or common grate, upon which is burned the coke that falls through the water grate. The greater part of the air supply is admitted above the fresh coal on the water-grate, passing through the coal, and an additional supply is admitted below the lower grate, passing upwards through it to burn the coke and to assist in burning the gases. The space between the two grates forms part of the combustion chamber in which the gases are burned. Figure (III) shows a view of the water grate and figure (IV) shows a Hawley furnace as applied to a Heine water-tube boiler. The pipe connections by which a circulation of water is insured through the grate are also shown in figure (IV).

The Wing Wall Furnace

This furnace was patented by William Kent, May 17, 1898. It is adapted for the smokeless combustion of soft coal, plant, wood, tan bark, and other fuels that contain large proportions of volatile matter and moisture. The drawings (Fig. V) taken from Kent's "Steam Boiler Economy" show the furnace applied to a water tube boiler. "C" is a fire chamber or oven built of brick and extending out in front of the boiler. In it the fuel is burned, either on the ordinary grate-bars or by means of a mechanical stoker. "D" is an ordinary bridge wall. "EE' " are two tall vertical walls called wing walls, built some distance in the rear of the bridge wall. "G" is a combustion

FIG. V.



THE "WING-WALL" FURNACE APPLIED TO A WATER-TUBE BOILER.

KENT'S STEAM BOILER ECONOMY PP. 161.

chamber. "HH" are several piers of fire-brick projecting into the chamber "G" from the rear wall "J". "K" is the ordinary partition wall built across the boiler-tubes, and "M" is a tile roof to the chamber "F" to prevent the gas in that chamber from reaching the tubes until after they have passed through the narrow vertical passage between the wing walls "E E' ".

In operation with hand firing the alternate method of firing is used. The first 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 at "D", but they are compelled to change their direction and mingle together on passing through the tall narrow passage between wing walls E E' and by so mingling the gases are burned and smoke prevented.

The combustion is assisted by the heat radiated 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. They act on the principle of the Siemen's regenerative furnace, commonly used in steel-works.

B. - THE MECHANICAL STOKER.

This device with or without draft, is a good solution of the smoke problem. There are many devices of this kind on the market, a few of which will be described by diagrams. In large plants mechanical stokers give a marked economy due to their regularity of action and convenience in handling fuel and disposing of the ash.

(a).- Types of Mechanical Stokers The mechanical stokers may be divided into four classes.

(1). In this class the coal is carried on the grate-bars either horizontal or inclined more or less, the individual bars, or sometimes alternate bars, being given a reciprocating to and fro, up and down, or rocking motion, by which the coal is gradually advanced along the grates.

(2).- The grate is steeply inclined, and the coal is pushed onto its upper end, and slides down slowly as it burns. Example,- Murphy Automatic Furnace.

(3).- The grate forms an endless chain of short bars, on which the coal travels horizontally into the furnace, the chain passing over a sprocket wheel at the end and returning through the ash-pit. Example,- Heine Boiler; B. & W. Boiler.

(4).- The fish coal is fed in underneath the burning coal, and the gases distilled from it pass through the bed of hot coke above, the action being exactly the reverse of that of the Hawley down-draft furnace, in which the fresh coal is fed on top of the bed. and the gases pass down through the bed of hot coke beneath.

FIG. VI.

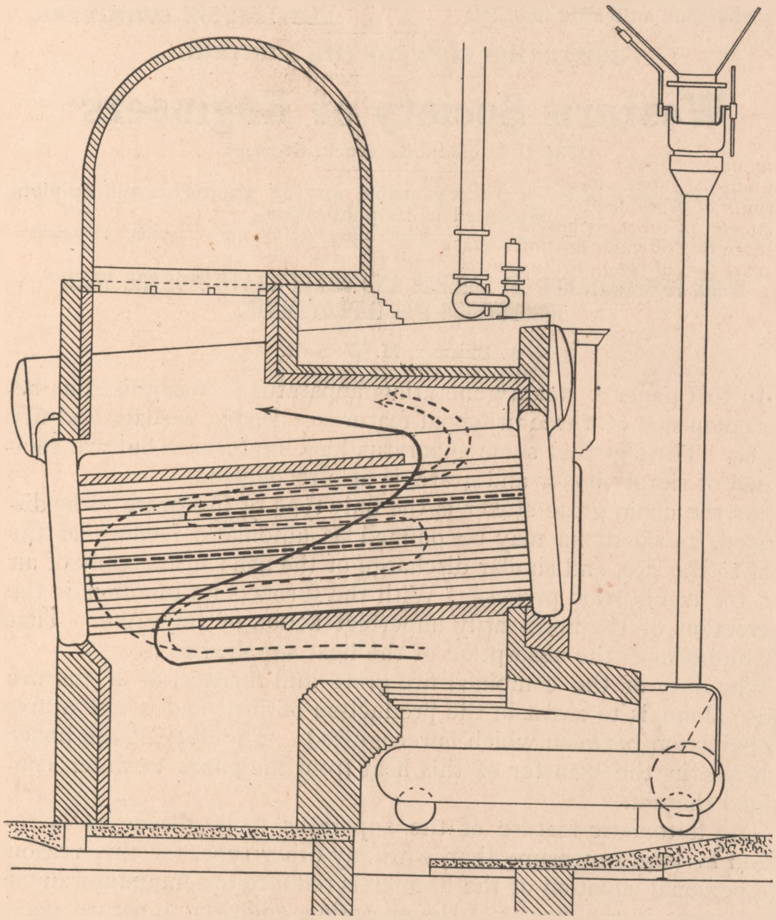


Fig. 1. Vertical Longitudinal Section of ~~Nos. 1 and 2~~ and Improved Heine Boilers with Tile Roof Furnace.

I. - THE HEINE BOILER

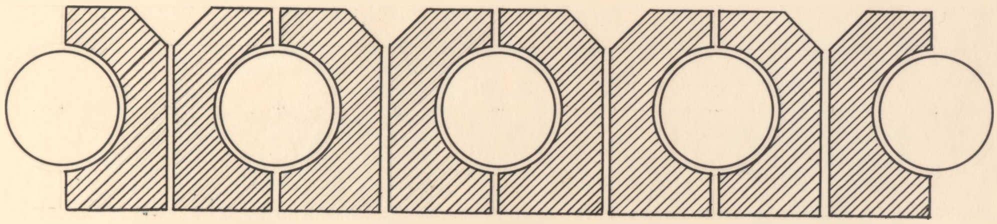
The Heine boiler is shown in the figure VI and resembles the Babcock and Wilcox boiler in general arrangement, but differs in that the tubes are expanded into one large header at each end, made of plate, properly stayed and provided with hand holes. Also, the gases from the fire are constrained to pass along the tubes instead of across them, for which purpose there are floors or nearly horizontal bridges of tiles, shown in detail in figure VII and VIII. These tiles are laid on two or three layers of tubes, instead of the nearly vertical bridges of tiles used in the Babcock and Wilcox boiler.

Figure (IX) is taken from an article by A. Bement, presented before the Western Society of Engineers, 1904. It shows an improved form of the Heine boiler fitted with a chain grate. This form of apparatus proved smokeless and gave a very high efficiency (86.6%).

Referring to figure (IV) we see four tall chimneys which serve 24 Heine boilers fitted with the tile-roof furnace; equipped with Babcock and Wilcox chain grate stokers of a total grate area of 1,732 square feet, and having a total of 104,930 square feet of boiler heating surface. The draught over the fire ranges from 0.15 to 0.45 inches of water. The character of the coal being burned at the time the photograph was taken is given as follows:-

Ash	15 per cent.
Moisture	13.5 per cent.
Heating power	9652 B.T.U.per pound.

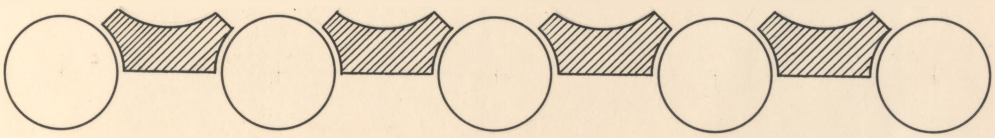
FIG. VII.



SECTION OF TILES ENCIRCLING LOWER ROW OF BOILER TUBES,

TILE ROOF FURNACE.

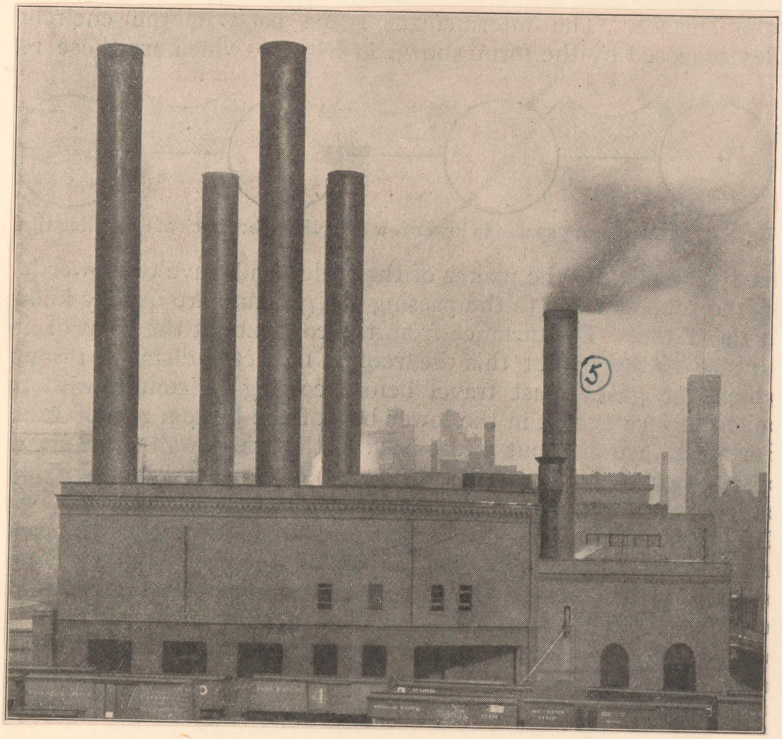
FIG VIII



TILES CLOSING SPACES IN LOWER ROW OF BOILER TUBES

BACK OF ENCIRCLING TILES.

FIG IX



which is an average for laboratory records, and like all Illinois coal, it will make smoke when conditions are favorable.

The appearance of the four chimneys which serve the tile roof furnaces proves that their capacity to produce an effective mixture is ideal when uniformly supplied with fuel, which the chain grate does. It should be said that this photograph was taken when all the furnaces which discharge into these four chimneys were in service and working at a maximum capacity, burning about forty tons of coal per hour, and the chimneys discharging more than 1,000 tons of gases in a like period. The grates under the Babcock and Wilcox boilers were working at a corresponding rate, and the smoke from this chimney (15) was not due to lower draft because the strength of the draft measured over the fires shows that a portion of the tile roof furnaces have less than the Babcock and Wilcox boiler grates.

2. THE BABCOCK AND WILCOX CHAIN GRATE STOKER

This stoker is an endless chain grate. It has been used with much success in the West with bituminous coals. The grate may be removed from the furnace by rolling it out on a permanent track made for the purpose. The figure No. X shows the stoker. The large vertical pipe is the coal feeder, which delivers coal from an overhead bin into the hopper. It is driven by a worm-wheel, the power being delivered to the worm from an independent engine through a lever and ratchet-wheel.

3.THE RONEY MECHANICAL STOKER

This stoker was first brought out in 1885. The present construction is shown in figure (XI). It receives the fuel in

FIG. X.

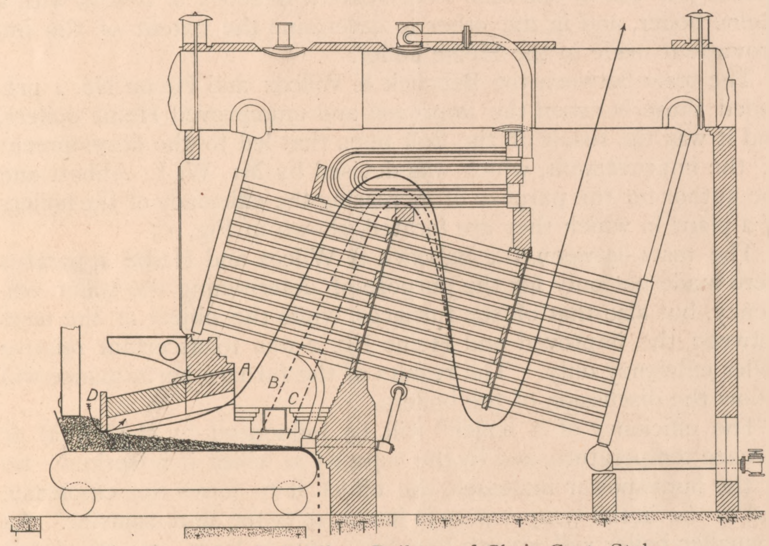
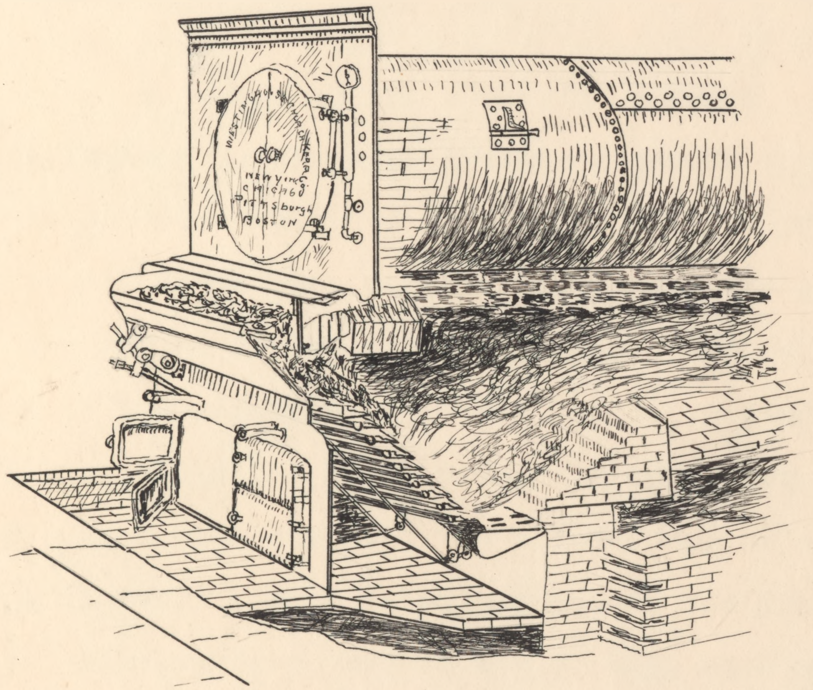


Fig. 2. Babcock & Wilcox Boiler, and Chain Grate Stoker.

bulk, and, without further handling, feeds it continuously and at any desired rate to the furnace, burns the combustible portion and deposits the ash and cinder in the ash pit ready to be removed. In the bottom of the coal hopper is located a sliding pusher, which gradually feeds the coal over the dead plate and on to the grate. The latter consists of horizontal flat-surfaced over lapping bars, extending from side to side of the furnace, and inclined at an angle of 37 degrees from the horizontal. In the wider furnaces two or more sets of grate-bars are placed side by side, provided with independent actuating connections. The grate-bars rock in unison, assuming alternately a stepped and an inclined position the burning coal tends to work down in a body, but before it can move too far the bars rock back to the stepped position, checking the downward motion, breaking up the bed of fuel and freely admitting air through the fire. This alternate starting and checking motion keeps the fire constantly stirred and opened up from beneath and finally lands thecinder and ash on the dumping grate from which it is discharged into the ash-pit. The depending webs of the grate bars are ferforated with longitudinal slots, so placed that the condition of the fire can be seen at all times and free access had to all parts of the grate without the opening of doors. These shots also serve to furnish an abundant supply of air for combustion. The motion of the grate-bars and the feeding device is regulated by two simple adjustments, by which the action of the stoker is controlled and the fires are forced, checked or banked at will.

FIG. XI.



THE ROONEY MECHANICAL STOKER.

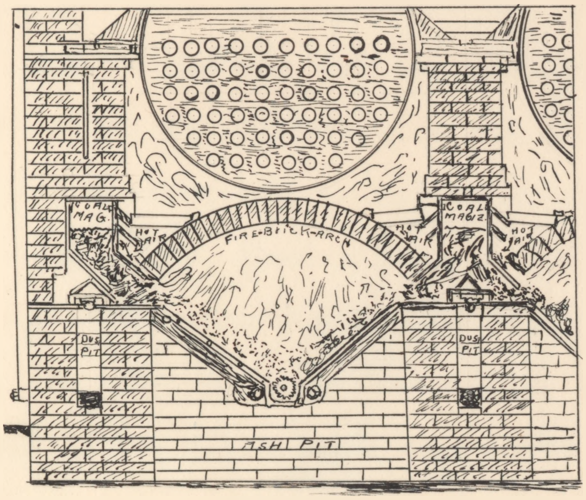
A coking-arch of fire brick is sprung across the furnace covering the upper part of the grate and forming a gas-producer whose action is to coke the fresh fuel and release its gases, which, mingling with the heated air, and supplied in small streams through the perforated tile above the bed of incandescent coke on the lower part of the grate. This stoker burns all kinds of coal, from lignite to anthracite, and also waste products, such as tan-bark, saw-dust, cottonseed hulls, and coke "breeze" without change of grate bars..

4. - THE MURPHY AUTOMATIC FURNACE.

This furnace is shown in cross-section in figure XII as applied to a horizontal tubular boiler. The furnace is also applicable to all forms both of fire tube and water tube boilers. The grates are of a "V" form and in pairs, the upper ends resting on the magazine bed plate, which is also the feed or coking plate, while the lower ends rest in niches on the grate-beams, which also contains the clinker bar or clinker-breaker. A fire-brick arch is sprung across the furnace covering the grate-surface, and on top of each side of the arch there is an air-flue from which hot air is supplied through the series of small openings at the bases of the arch where the brick rests on the ribbed surface of the arch plates on either side of the furnace. This gives a double side feed and coking plate. The coal magazines are provided with stoker-boxes, which are connected by means of pinion-gears to the stoker shaft, which is automatically moved back and forth, stoking the coal into the furnace.

One grate of each pair of grates is fixed, while the other is movable up and down by a rocker motion at the lower or center end, thus keeping the fire free from ashes while the coarse refuse and clinker is worked down the center, where a rotating clinker-bar grinds it into the ash pit. The entire operating mechanism is attached to a flat iron bar running across the outside of the front, and operated by a little automatic upright engine set at the corner of the setting which uses about one horse-power per furnace operated. Each revolution of the driving gear stokes a given byt variable quantity of coal into the furnace on each side, moves half of the grate-bars on each side up and down, and turns the clinker bar partly around. Thus the coal is fed and the fires cleaned constantly. The teeth on the clinker-bar are prevented from becoming hot and worn off by means of a current of air passing through the open center of the bar and piped to the flue or stack beyond the damper. The clinker is kept brittle and prevented from sticking by a spray of exhaust steam distributed through a pipe cast into either side of the grate-bearer.

FIG. XII.



THE MURPHY AUTOMATIC FURNACE.

KENT

C. - POWDERED COAL BURNING SYSTEM.(Cyclone).

The system briefly described is to reduce any gaseous coal (those containing 25% of volatile matter are suitable) to a powder of about 100 mesh (or 10,000 holes per square inch); to mix this with air in the correct theoretical proportion, and pass the mixture either by natural, induced or forced draught into the combustion chamber of the boiler or other heating apparatus. All fire-bars, dead-plates , etc. are removed from the boilers, and a combustion chamber is built of fire bricks, to receive the coal and air, in a similar manner to burning gas. The brick-work attains a white heat, and keeps up the combustion. In starting all that is necessary is a little oily waste, or wood fire and the coal powder catches immediately, the charge gradually being increased to the full or necessary consumption, all being regulated by the dampers in stoke hole. The chief advantages claimed, are,-

1. The abolition of all smoke.

2. The ability to burn all common, cheap, and small coals.

3. The increase in efficiency obtained by complete combustion regularity in burning and no waste heat due to escess of air.

4. The utilization of the greatest possible quantity of heat of the coal.

5. Easy manipulation starting and stopping.

6. Quickness of raising steam.

7. Abolition of fire bars and clinkers.

8. Reduction in labor.

SECTION IV

A. - S M O K E   O B S E R V A T I O N S

TAKEN IN CONNECTION WITH

B O I L E R   T E S T

UNIVERSITY OF ILLINOIS   MECHANICAL ENGINEERING DEPARTMENT

J a n u a r y 1 4 - 1 5 - 1 9 0 4   A. E. L o g e m a n '04

FIG. XIII

The University of Illinois Plant.
Back View.

BOILER TEST SMOKE OBSERVATIONS January 14 - 15,'04

Name of observer, - A. E. Logeman

PURPOSE

These smoke observations were taken during the day time while a twenty-four hour boiler test was in progress. The purpose was to get results under ordinary working circumstances. These results are more comprehensive than was desired because it was necessary to run other boilers besides those being tested.

Apparatus

The boilers tested were Nos. 5 and 6 Babcock and Wilcox type fitted with Roney stokers. Boilers 1, 2, 3, 4, 5, and 6 were served by the same stack. No. 1 was used only January 15, and was hand fired. The smoke was compared with the standard charts.

The smoke observations were made in the following manner:- Professor Ringelmann's smoke charts were reproduced on cards one foot square with black lines as described below. These charts were placed upon the chimney in a straight row and observations were made at a distance of some 100 feet, but always from the same location every ten minutes. The smoke issuing from the chimney was compared with the charts. The number of the chart that nearest resembled the smoke was recorded. The charts were made as follows:-

Card 0, All white

Card 1, Black lines 1 mm. thick, 10 mm. apart, leaving spaces 9 mm. square.

Card 2, Lines 2.3 mm. thick, spaces 7.7 mm. square

Card 3, Lines 3.7 mm. thick, spaces 6.3 mm. square

Card 4, Lines 5.5 mm. thick, spaces 4.5 mm. square.

Card 5, All black.

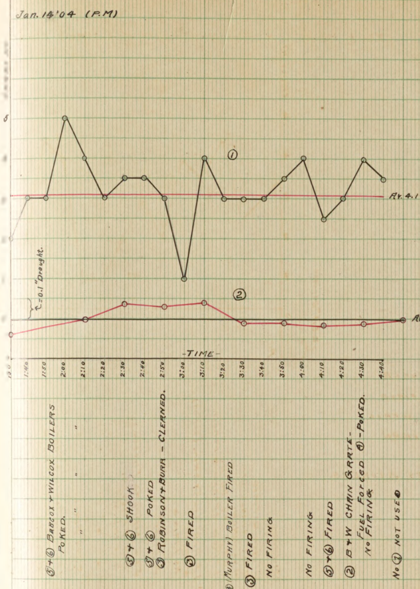
The results obtained are fully shown on the chart, (Plate I), and a curve (1) plotted, also a curve (2) was plotted on the same chart to show the draught gauge readings. These curves are both plotted with the same time base. Notes were taken referring to conditions of fire, and manner of stoking, and these are shown on the chart.

The average curves were found by averaging the results for each curve.

From the average results we may conclude- a better draught was obtained, and less smoke was visible the second day than was the first, because the steam jets were used more freely. The better draught also obtained less smoke when the hand fired boiler was used than when visible the first day when the hand fired boiler was not used.

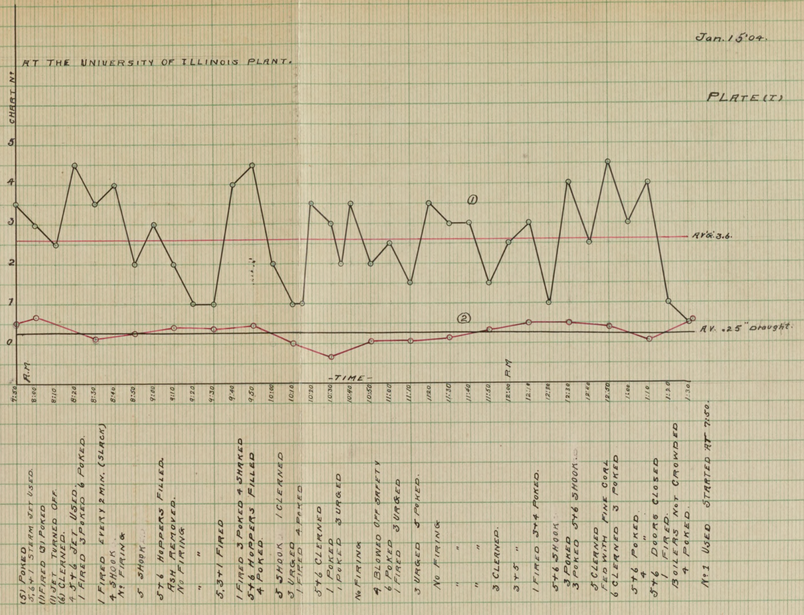
TEST MADE AT THE UNIVERSITY OF ILLINOIS PLANT.

PLATE (I)



No	NAME	STOKER
1	BABCOX + WILCOX	HAND FIRED
2	" "	CHAIN GRATE
3	ROBINSON + BURR	BRIGHTMAN
4	MURPHY FURNACE	
5	BABCOX + WILCOX	RONEY STOKERS
6	" "	" "

5+6 ONLY WERE TESTED.



B SMOKE OBSERVATIONS

TAKEN IN CONNECTION WITH

BOILER TEST

DANVILLE, URBANA & CHAMPAIGN ELECTRIC COMPANY

CHAMPAIGN, ILLINOIS

APRIL 18, 1904

A. E. LOGEMAN

SMOKE OBSERVATIONS

Observers :	
A. E. Logeman:	Smoke

PURPOSE

The purpose of making these observations was to obtain results showing the amount of smoke visible under the existing conditions.

DESCRIPTION OF APPARATUS

The apparatus tested in the boiler room consisted of two hand fired water tube Stirling Boilers, each being 260 H.P. Brick arches were sprung across the combustion chamber and extended nearly to the back of the furnace. The purpose of these arches has been previously described in Section III of this thesis. The stack served these two boilers alone, and was 150 ft. high, 8 ft. diameter, and made of 7/8" steel unlined.

MANNER OF CONDUCTING TEST

While the regular boiler test was in progress, standard charts were placed on a line with the chimney, and the smoke issuing was compared with the charts. The number of the chart nearest resembling the smoke was recorded.

During the morning, readings were taken every 15 minutes. In the afternoon readings were taken every minute for each alternate period of 15 minutes for the intervening periods conditions in the boiler room were carefully observed.

DATA

The data was plotted in the form of a curve as shown in plate (II).

The method of plotting was this:

The ordinates 0, 1, 2, 3, 4, 5, represent the chart referred to. The abscissa is time as indicated.

The results show that on an average more smoke was produced when a thick fire was used than when the fire was thin.

When the fire was thick the boilers were not fired so often, but when fired an insufficient supply of air caused the hydro-carbons to escape only partly burned.

Smoke was prevented to a large extent, showing that some success was attained in this plant to prevent smoke by the application of the brick arch and care in firing.

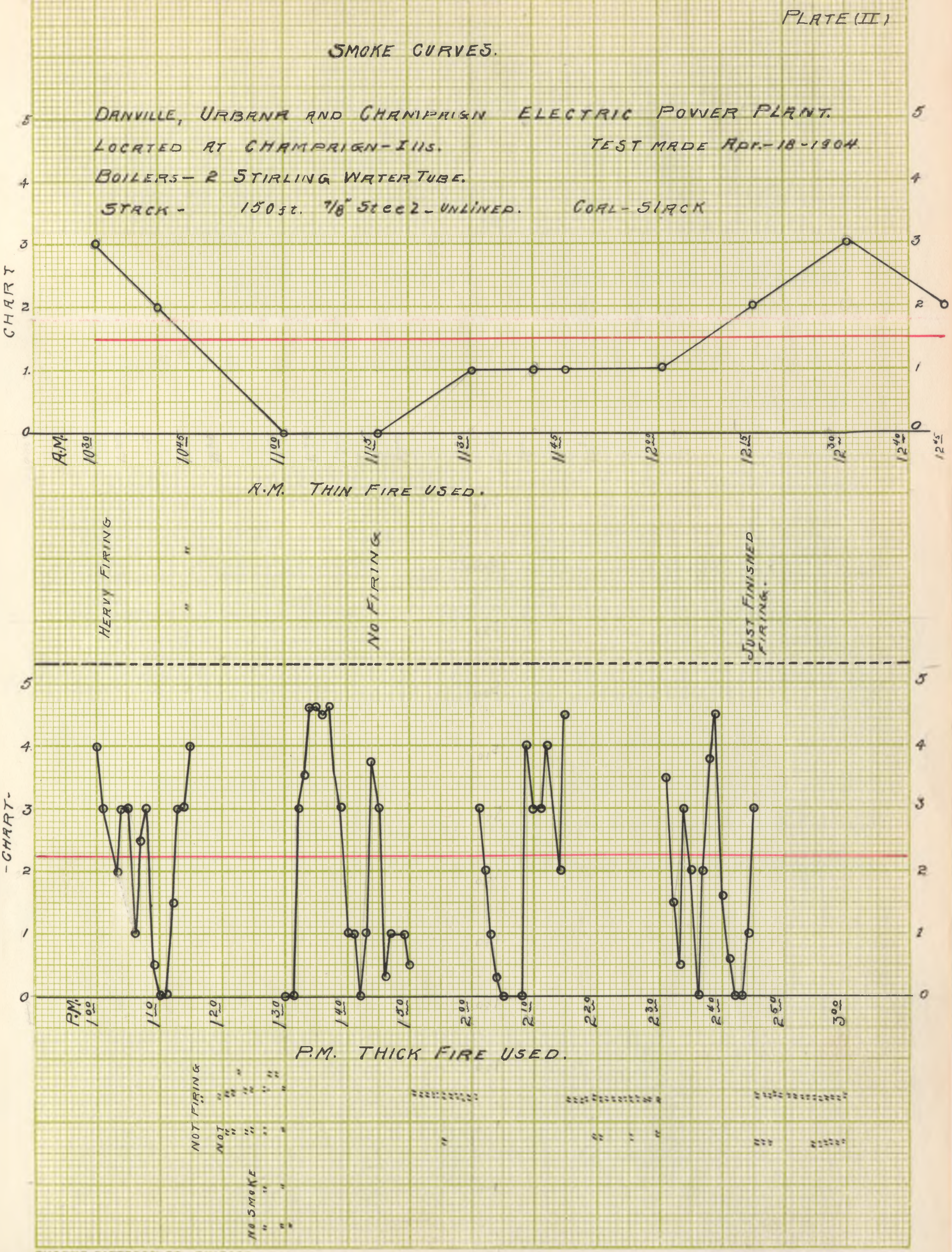


PLATE (II)
SMOKE CURVES.
DANVILLE, URBANA AND CHAMPAIGN ELECTRIC POWER PLANT.
LOCATED AT CHAMPAIGN - ILLS.
TEST MADE Apr.-18-1904.
BOILERS - 2 STIRLING WATER TUBE.
STACK - 150 ft. 7/8" Steel - UNLINED.
COAL - SLACK
CHART
A.M. THIN FIRE USED.
HEAVY FIRING
NO FIRING
JUST FINISHED FIRING.
-CHART-
P.M. THICK FIRE USED.
NOT FIRING
NOT
NO SMOKE

SECTION V

CONCLUSION OF THESIS

In conclusion, it may be said that smoke can be prevented.

The first cause is the coal. Anthracite coal is comparatively scarce, if used generally the supply would soon become exhausted. Hence, bituminous coal is used, which although not so good as anthracite is cheaper, can be easily obtained, and exists in vast fields which lie in close proximity to some of the largest manufacturing cities in the country.

A study of the constituents and practical experience show bituminous coals, and especially Illinois coals, to be smoke producers, if not treated properly. An intelligent fireman can prevent smoke if he will observe these three conditions.

(a) Supply enough air.

(b) Sustain a high furnace temperature.

(c) Obtain a thorough mixture of the gases.

These conditions may be obtained without the use of arches, steam jets, stokers, etc., but these appliances have shown themselves to be efficient and economical fuel savers and smoke preventers.