

THE DEVELOPMENT AND USE OF THE MODERN CHAIN GRATE

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After discussing the need of progressive combustion of the several constituents in coal, and the variations in grate design to handle different coals, the author takes up the improvement of chain-grate practice as regards airtightness, cooling, size of combustion space, etc. He shows how greater boiler capacity can be obtained by increasing grate size or by more intense natural or forced draft (0.50 to 0.60 in. for a combustion rate of 40 to 45 lb. per sq. ft. of grate per hour), but states that high and sudden overloads are best met by forced-draft chain grates burning 55 to 60 lb. bituminous coal per sq. ft. per hour, with air at 2 in. pressure distributed through compartments between the runs of chain. He describes such equipment, and states that 200 per cent of rating can be reached in 8 min., from a short-banked fire, or in 52 min. from a cold grate. The paper concludes with a table of results obtained in a number of stations equipped with chain grates.

ANY STUDY of the adaptability of various stoker types and their proper functioning as fuel burners must start with an analysis of four constituents in coal, namely, moisture, volatile, fixed carbon, and ash; or roughly, water, tar, coke and dirt. These constituents are so dissimilar that each must be differently treated in the combustion process, and specific provisions for burning them in proper sequence must be provided in stoker and furnace design. These facts at once determine as fundamentally correct those types of stokers embodying the principles of progressive combustion, by which is meant in practice a continuous movement of coal through the furnace and the providing of definite treatment at proper time and place for the burning of each constituent of the fuel.

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2 Chain grates embody the principles of progressive combustion. As coal is fed into the furnace, the moisture is vaporized; then the volatiles are distilled and burned in suspension, followed by the burning of fixed carbon. Finally the ash is discharged over the rear, and the air space of the grate is automatically cleaned for a repetition of the process.

3 Variations in the proportions of these constituents are seen in coal from different sources. Some coals are more free-burning, others tend toward coking. Some have high percentages of ash, others less. Differences as to clinkering or non-clinkering are noted. Such variations at once emphasize the fact that no one stoker and furnace can be suitable for all coals. Stokers and furnaces adapted for progressively burning certain coals must be modified if they are to be used for burning other coals having widely different proportions of characteristic constituents.

4 Free-burning coals burn best when the fuel bed is undisturbed; coking coals demand fuel-bed agitation. High-ash coals demand continuous scavenging of refuse from the grate; with low-ash coals this is not necessary. Clinkering coals must not be agitated, or clinker formations will result. With non-clinkering coal, agitation has a less detrimental effect.

5 Chain grates were first developed to burn high-volatile, free-burning, high-ash, clinkering coals. For such coals they offer in best form the specific combustion treatment demanded by the characteristics of such coals. The fuel bed is undisturbed, making this stoker type suitable for free-burning and clinkering fuels. The ash is continuously discharged from the grates, which is necessary for continuous operation with high-ash coals.

6 The development resulting in the modern chain grate has been gradual but definite, and has involved the successful burning of many coals having far different characteristics. All successes, however, have been dependent upon the application of the principles of progressive combustion. Coal burning in any practical process involves some losses: a total conversion of the heat in coal into heat in steam is impossible. Costs of operation must also be considered. These facts determine that every combustion process must finally operate with a common-sense balance between the three important factors in steam generation economy: namely, maintenance, efficiency, and capacity.

MAINTENANCE

7 Maintenance and reliability are closely related. The chain grate, with two-thirds of the grate surface out of the furnace and with a simple driving mechanism, was always low in maintenance costs. In the earlier design, however, some parts were exposed both to heat and wear. Parts necessarily exposed to wear or strain often did not have sufficient resistance.

8 The modern chain-grate designer recognizes that the functions of stoker parts fall into three classes: Supporting the fuel, actuating the mechanism, or furnishing the necessary support for coördinating the first two. Parts performing any one of these functions must be protected as far as possible from failure due to being called upon to perform any of the other functions. Actuating mechanism is accordingly removed from heat, and is subject only to wear. The chain, which is the fuel-carrying part, is now subjected to but slight heating as a result of adequate ventilation. Stoker frames are not subject to wear and are not exposed to heat. When exposed to heat or wear, replaceable parts are provided.

EFFICIENCY

9 The high fuel costs of recent years, combined with a broader knowledge of combustion principles, have led to the development of features for improving efficiency. Inasmuch as chain-grate stokers have always involved very low auxiliary power consumption — about 0.5 hp. per stoker — all results obtained are practically net, and little improvement could be hoped for in that direction. Efforts were therefore directed toward the elimination of other losses, such as excess air, and to the reduction of furnace and ashpit losses.

IMPROVEMENTS IN GRATE DESIGN

10 *Air Leakage.* A grate surface moving through a furnace presents the problem of air seals along the sides of stoker and at the rear. The reduction of air leakages at these places has contributed materially to modern economy.

11 Overhanging bridge walls and water backs are necessary. All attempts to approach efficient combustion without water backs have failed. Many designs of water backs were tried, resulting

finally in the modern water back connected into the pressure circulation of the boiler. Water backs are successful only to the extent that they close the openings and eliminate air leakage between the bridge wall and the fuel bed.

12 Ledge plates or seals along the sides of the stoker went through a similar development, resulting in the modern adjustable ledge plates for making a proper rubbing seal with the stoker chain, and including means for adjustment to keep this seal intact.

13 The development of the ledge-plate flange adjustable against the side of the upper chain made it possible to raise and lower the stoker to vary the discharge opening under the water back in order to meet broad changes in fuel conditions. The improved results thus obtained indicated the desirability of a water back adjustable as to height, and several designs were developed. These were for the most part difficult to construct or to maintain. From such designs the modern fuel retarder was developed. This is an adjustable member in connection with a fixed water back and bridge wall. The fuel retarder can be raised or lowered to make a definite air seal with the fuel bed.

14 Sifting of coal through the grate was an objectionable feature of early chain grates. This often amounted to from 5 to 10 per cent of the coal fired. The most important item in reducing this sifting has been the use of longitudinal skids to carry the chain in place of the cross-rollers employed in the earlier designs. Skids reduced the siftings to 1 or 2 per cent, and in addition to labor saving a more uniform fuel bed results.

FURNACE DESIGN

15 Simultaneous with the development of the stoker has been that of furnace design. Furnace volumes have been quadrupled during the last 10 years. Modern chain-grate furnaces have 2 cu. ft. of furnace per developed horse power. Losses due to unburned hydrocarbons have been greatly reduced.

16 Early chain-grate furnaces had arches of limited height and length, and with insufficient draft could burn fuels at rates which modern practice would consider as low. A rating of 150 per cent was exceptional. Modern high-set arches with ample draft and adequate furnaces permit high combustion rates and high ratings from boilers.

17 Improved furnaces, proper draft, longer arches, water backs, and fuel retarders have all contributed to the reduction of ashpit losses. High stoker and furnace efficiency is dependent, not on a minimum of any one loss, but on a minimum sum of the losses due to excess air, ashpit loss, and unburned hydrocarbons. The modern chain grate and furnace permit adjustment and continuous operation, with the aggregate of these losses a minimum.

18 Chain grates are ideally adapted for producing smokeless combustion, due to the uniform feed, uniform fuel bed, and the arch. With modern furnaces and proper air control, smokelessness within the capacity of the furnace can be assured even with the high-volatile smoky coals of the Middle West.

CAPACITY

19 Modern steam turbines called for greater capacities from boilers. This demand was met in the chain-grate field by development along three general lines:

- a Higher drafts
- b Larger grate surfaces
- c Forced draft.

20 *Higher Drafts.* Chimney heights for natural draft were increased to 200, 250, and even in excess of 300 ft. Many plants installed induced-draft fans. Furnace drafts of 0.50 to 0.60 in. were obtained, and combustion rates reached figures of 40 to 45 lb. per sq. ft of grate surface per hour.

21 *Larger Grates.* This rate of combustion seems to be about the limit of natural-draft performance. Efforts to obtain higher ratings have led to larger stokers. Stokers were built up to 18 ft. long, with ratios of grate to heating surface increased to 1 to 30. With such grates, and high draft, boiler ratings up to 200 per cent were possible.

22 *Forced Draft.* The need of still higher ratings, particularly with low-grade coal, brought the application of forced draft to the chain grate. Early installations applied forced draft at uniform pressure under the entire grate surface. This increased capacity, but did not control excess air. Forced draft under a fuel bed with the slightest tendency toward thin spots caused excess-air losses, chilled the furnace, and reduced capacity.

FORCED DRAFT WITH COMPARTMENTS

23 The logical development for air control was to divide the stoker into compartments and control the air supply to each compartment.

24 In the early forced-draft chain grates difficulty was experienced in obtaining uniform air distribution laterally. This was obviated by some designers by reducing the air space in the grate surface to a very small amount and depending on the resulting chain resistance to equalize the pressure under the grate surface. This produced the desired results, but the required higher pressure in the air compartment entailed higher auxiliary power for fans. Small air spaces greatly reduce boiler ratings when operating on natural draft.

25 Other manufacturers solved the problem of obtaining uniform air distribution by the use of more air space, more liberal air ducts, lower velocity, and lower air pressures.

26 The forced-blast chain-grate stoker has been in commercial use for some twenty-five years, and in successful use for approximately ten or twelve years in the anthracite-coal regions, but it was not until five or six years ago that any really successful installations were made for burning bituminous coal.

27 Several chain-grate manufacturers had applied forced blast to their natural-draft stokers, and had increased the amount of coal burned per square foot of grate by so doing, but it was not until uniform air distribution was obtained and blast compartments between the runs of chain had been arranged for the control of the blast, that the performance of this type of stoker began to attract the attention of the bituminous-coal user.

28 The general design of the forced-blast chain-grate stoker is quite similar to that of the natural-draft chain grate with which every one is more or less familiar.

29 This stoker consists of a continuous or endless chain of links or grate bars, traveling over front and rear sprockets. Side girders are used in some cases, but in others are entirely omitted and transverse members forming compartment sides and wall supports substituted therefor. Above the front sprockets is a sizeable coal hopper, and at the back of this hopper a stoker gate which can be raised or lowered to vary the thickness of the fuel bed on the grate.

30 The stoker is usually set in an extension or Dutch-oven furnace, the arch of which radiates its heat on the incoming fuel under the stoker gate and causes it to ignite, the fire gradually burning down through the fuel bed until it reaches the grate. The thickness of the fuel bed is governed by the character of the coal burned, the length of the stoker grate, and the capacity at which the stoker is to be operated. With the same grate, and with different grades of coal or different capacities, the fuel bed may vary between 5 in. and 9 in. in thickness.

SIZE OF FORCED-DRAFT STOKERS

31 The length of the stoker, which should be taken as the distance between the inner face of the stoker gate and the sealing plate of the rear blast compartment, is varied somewhat to conform with the type of boiler under which the stoker is installed, and with the rate of combustion which is desired. Very few forced-draft chain grates are less than 12 ft. in length, but only in exceptional cases do they exceed 20 ft.

32 The width of the stoker is usually made slightly less than the boiler-furnace width, so as to afford column protection. Single stokers practically the full width of the furnace have been built, even for the wide central power-station boilers now so popular. There are forced-blast chain-grate stokers in operation today that are 24 ft. in width, and widths of 27 ft. to 30 ft. are under consideration.

33 Various types of links are used with the forced-blast chain-grate stoker, some of which are held in place with steel link rods, while others are strung on malleable-iron dovetails, which in turn are bolted to carrier bars extending the full width of the stoker, and attached to forged conveyor chains. Regardless of the type used, however, the design of the link is such that relatively fine jets of air are admitted through the grate, and a uniform air distribution is applied to the fuel bed from any given blast compartment.

34 The forced blast is usually admitted into five or six compartments formed between the runs of the chains. These compartments are sealed from one another, and dampers or slides are arranged so that the blast to any one compartment may be regulated independently of that in any other compartment. Some

designs are so constructed that any compartment can be operated on forced or natural draft, or closed off entirely, and so that the change from one to either of the other conditions of air supply can be made simply by the operation of a single adjustment lever.

35 As the coal is burned, the resistance of the fuel bed decreases toward the rear end of the grate, and the air pressure is varied in the different compartments to meet the requirements and effect proper combustion at any given point, with least excess air. It is possible to use only half or three-quarters of the grate length when operating the stoker at low capacities, and still maintain a comparatively high rate of combustion on the front portion of the stoker.

36 The blast pressure in any one compartment rarely exceeds 2 in. water pressure, even at a combustion rate of 55 to 60 lb. of coal per sq. ft. of grate surface. Low-pressure designs obtain similar combustion rates with about one-third of this pressure. The highest pressure is usually carried in the second and third compartments from the fronts of the stoker, as it is at these points that the fuel bed on the grate is completely ignited and the maximum rate of combustion takes place.

37 The blast to each compartment is regulated by hand control. The dampers or slides to these compartments, however, may be set in a definite relation to each other, after once determining the requirements of blast for a given fuel; and the rate of combustion is regulated by varying the speed of the fan or by operating a single damper at the forced-blast-fan discharge, or in the main air duct, and by adjusting the boiler damper and fuel fed to correspond. The amount of blast used under the grate and the speed at which the stoker chain travels usually determine the capacity at which the stoker may be operated with a given thickness of fuel bed.

38 The small amount of fine coal and ash siftings that falls through the upper run of the grate into the blast compartments is handled in different ways by different manufacturers. With some, the siftings are raked from the blast compartments through doors on the boiler-room floor; others arrange steam jets to blow these siftings to the end of the blast compartments, where they are removed by steam ejectors. Still others construct the stokers in such a manner that the siftings fall on to the lower or return run of the grate, and are carried forward to the front end of the stoker,

where they are deposited into a hopper, from which they are conveyed to the coal bunker or ash pit.

COMBUSTION ARCHES

39 Stokers installed for the burning of the Central States high-volatile coals have ignition or combustion arches set about four feet above the grate at the front end, and somewhat higher at the inner end. These arches cover approximately 50 per cent of the length of the stoker, are of the suspended type, and are made from high-grade refractory material.

40 Stoker installations for the burning of the low-volatile high-carbon bituminous coals of the Eastern States use a shorter arch, covering about 30 per cent of the stoker length, but set at practically the same height above the grate as for the high-volatile coals. Arches set at this distance above the grate require a short ignition arch, 12 to 18 in. in length, at the stoker gate, and set 18 to 24 in. above the grate. The increased rate of combustion obtained with forced-blast chain grates necessitates a better grade of refractory for the entire furnace lining.

41 Various schemes are being considered today for cooling the furnace side walls of all the different types of stokers operating at high rates of combustion, with the purpose of reducing furnace maintenance costs. Of these various schemes, those employing water-cooled members will undoubtedly prove the most successful, because of positive functioning.

42 Prevention of the formation of clinkers at the fire line on the side walls is a problem separate and distinct from reducing side-wall maintenance. Some manufacturers are using specially designed firebrick blocks at the fire line, through which blast from the blast duct enters the furnace. The air passing through these blocks keeps them cool and prevents clinker from adhering to them. Other manufacturers are using side-wall water boxes at this point, some of which are connected into the boiler circulation, while others are independently connected.

43 The bridge-wall water back is a part of the standard stoker equipment with several of the forced-blast chain-grate stokers. This water back is carried transversely across the rear end of the stoker 3 to 7 in. above the grate, and acts not only as an air seal at this point, but protects the bare links of the stoker from the reflected heat of the bridge-wall brickwork.

RESULTS SECURED

44 The forced-blast chain-grate stoker is particularly adapted to the use of free-burning coals that require agitation of the fuel bed to break the crusting or caking action so often encountered with the slower-burning coking coals.

45 With free-burning coals, which usually run high in sulphur, and have an ash with a low fusing point, results are being obtained, with uninterrupted operation, that equal the results obtained with other types of stokers using the low-volatile high-carbon coals.

46 When burning No. 3 buckwheat or coke breeze, fires 3 to 6 in. in thickness are carried on the grate and sufficient blast is carried in the first and second blast compartments to cause a gentle boiling or dancing of the fuel bed. Care must be taken, however, to regulate the thickness of fire and the blast so that excess carbon monoxide is not produced and continued combustion carried through the boiler to the chimney.

47 The forced-blast chain grate may be operated at continuous high overload capacities for days at a time with only slight variations in the steam output of the boiler. This operation is made possible by the uniform thickness of the fuel bed, the uniform blast pressures carried, and the uninterrupted disposal of ash and refuse from the grate. Such stokers may be operated efficiently under natural draft when burning as little as 10 lb. and as high as 35 lb. of coal per sq. ft. of grate per hour. Forced-draft combustion ratings reach 55 to 60 lb. of coal per sq. ft. of grate per hour.

48 The forced-blast chain grate is simple to operate and flexible in handling varying load conditions. If properly handled it can be brought from banked fires to full load in time to meet any ordinary power-plant requirements. A cold boiler can be put on the line in 45 min. from the time of lighting fires. The boiler can be operating at 150 per cent of rating in 5 min. from the time it goes on the line, or it can be operating at 200 per cent of rating in 7 min.

49 With the ordinary short-banked fire, which consists of a bed of coal three to four feet in from the stoker gate, the remainder of the grate being bare, the boiler can be brought up to 200 per cent rating within 25 min., while with the long bank, in which 50 per cent of the grate is covered with fire, the boiler can be brought up to 200 per cent rating within 6 to 8 min.

50 Automatic control has been successfully applied to both natural- and forced-draft chain grates. With natural-draft chain grates the usual control is by means of a steam-pressure or steam-flow regulator controlling the boiler damper and the speed of the stoker engine or motor. With forced-draft chain grates several control systems are in successful service. The electrical control is applicable on motor-driven installations. The steam-flow regulator controlling the air supply to the stoker and the speed of the grate is giving successful results.

51 The steam-pressure regulator controlling the air supply to the stoker and speed of the grate is also giving excellent service. In case constant furnace draft is desired, the balanced control can also be applied, as is frequently done with the two latter-mentioned systems.

DESIRED FEATURES

52 Among the features that it is desirable to embody in modern forced-draft chain grates and furnaces are included the following items:

Reliability. A rugged, heavy stoker with simple parts protected from heat effects and accessible for inspection and repairs

Maintenance. Heavy construction; all parts accessible; small parts exposed to heat easily replaceable; side walls protected by water-cooled members connected into the boiler circulation

Efficiency. Continuous fuel feed and ash discharge. Each part of the combustion process carried out in a definite manner, and a place designed therefor. Excess air excluded by definite seals in contact with the fuel bed. Ashpit losses low

Capable of control and adjustment, and of continuation in service under such adjustments. Low banking loss

Low labor of operating due to continuous process

Low air pressures so that auxiliary power may be at a minimum when forced draft is used

All compartments tight initially, and capable of being maintained tight, due to design and accessibility of dampers

TABLE 1 FUELS USED AND RESULTS OBTAINED IN ELEVEN BOILER PLANTS EQUIPPED WITH CHAIN GRATES

Description of Station	Location	Name of Coal Used	Moisture, per cent	Ash, per cent	Volatile, per cent	Fixed Carbon, per cent	Sulphur, per cent	B.t.u. per lb., Commercial Basis	Average Rating, per cent	Maximum Rating, per cent	Banked Boiler Hours, per cent	Economizers	Combined Efficiency of steam-generating-unit, per cent	Time covered
Central station ¹	Middle West	Illinois	14.5	16			4	10000	225	275	8	Yes	73.6	3 months
Central station	Middle West	Illinois	14.5	16			4	10000			30	50 %	69.4	3 months
Central station	Southwest	Kansas	4.66	11.7	33.05	50.62	4.2	10561				No	69.4	24 months
Central station	West	Iowa	16.51	18.72				8891	180		32	No	73	12 months
Central station	Middle West	Indiana	9.8	17.7	33.3	49	4.2	10000	170	230	30	No	70	12 months
Steel plant	Middle West	Indiana	18	12.2	35.2	52.6	2.20	10150	140			No	71	12 months
Steel plant	Pittsburgh district	Pennsylvania	2.09	10.5	33.7	55.8	1.60	13250	107			No	69.4	12 months
Central station	West	Colorado	23	12.5	32.5	32	0.20	8865				Yes	72	1 month
Central station	West	Kansas	6	19	27	48		10700	130	200	49	50 %	69	1 month
Central station	Middle West	Ohio&Penn.						11766	145	225	6	Yes	73.8	5 months
Central station ²	Middle West	Illinois	14.5	16			4	10000	271			Yes	78.7	1 month

¹ Part of the stokers in this plant are forced-draft units.² All of the stokers in this plant are forced-draft units.

The fuel bed surrounded on its active sides by water-cooled members.

Capacity. Capable of reaching high ratings by increasing combustion rates rather than by increasing effective grate surface in service. A stoker capable of operating on natural draft at ratings of 150 to 175 per cent and at higher capacities when forced draft is applied.

NATURAL DRAFT VS. FORCED DRAFT

53 The above specifications for an ideal forced-draft chain-grate stoker are such as produce best economy in steam production.

54 Whether natural- or forced-draft chain grates should be installed depends upon conditions in the individual plant. The station load, banking periods, boiler absorption with or without economizers, and the limits of the draft available, are all involved.

55 Natural-draft chain-grate stokers, within the limits of the draft available, produce cheap steam. Low auxiliary power requirements, low maintenance, and controlled loss in the combustion process, make low cost of steam inherent.

56 Natural-draft stokers should be installed:

- a Whenever the capacities demanded to meet the station load are within range of the natural draft available
- b Whenever the load demand is steady or where peaks can be anticipated sufficiently far ahead to permit building up furnace conditions to meet them
- c Within the limits of the above two conditions, whenever induced draft and economizers are used.

57 In Table 1 the author submits some long-period operating figures from chain-grate power stations. While the compiling of such figures by power stations is subject to variations in the methods employed for that purpose, the figures in question nevertheless must be accepted as part of the operating records of large and reliable companies having engineering departments competent to compile such records.