

March 17, 1942.

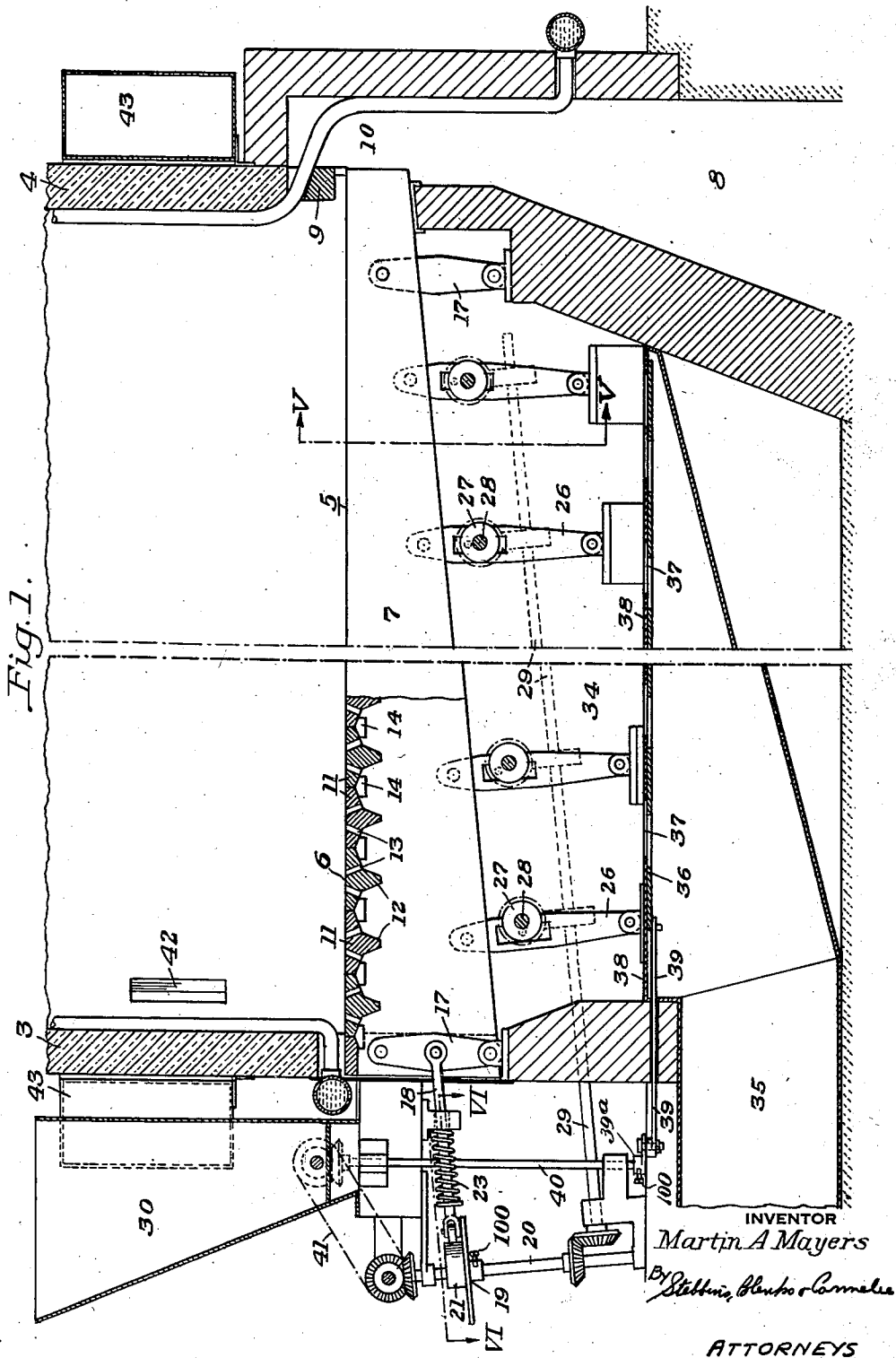
M. A. MAYERS

2,276,327

METHOD OF AND APPARATUS FOR BURNING FUEL

Filed Sept. 28, 1939

4 Sheets-Sheet 1



March 17, 1942.

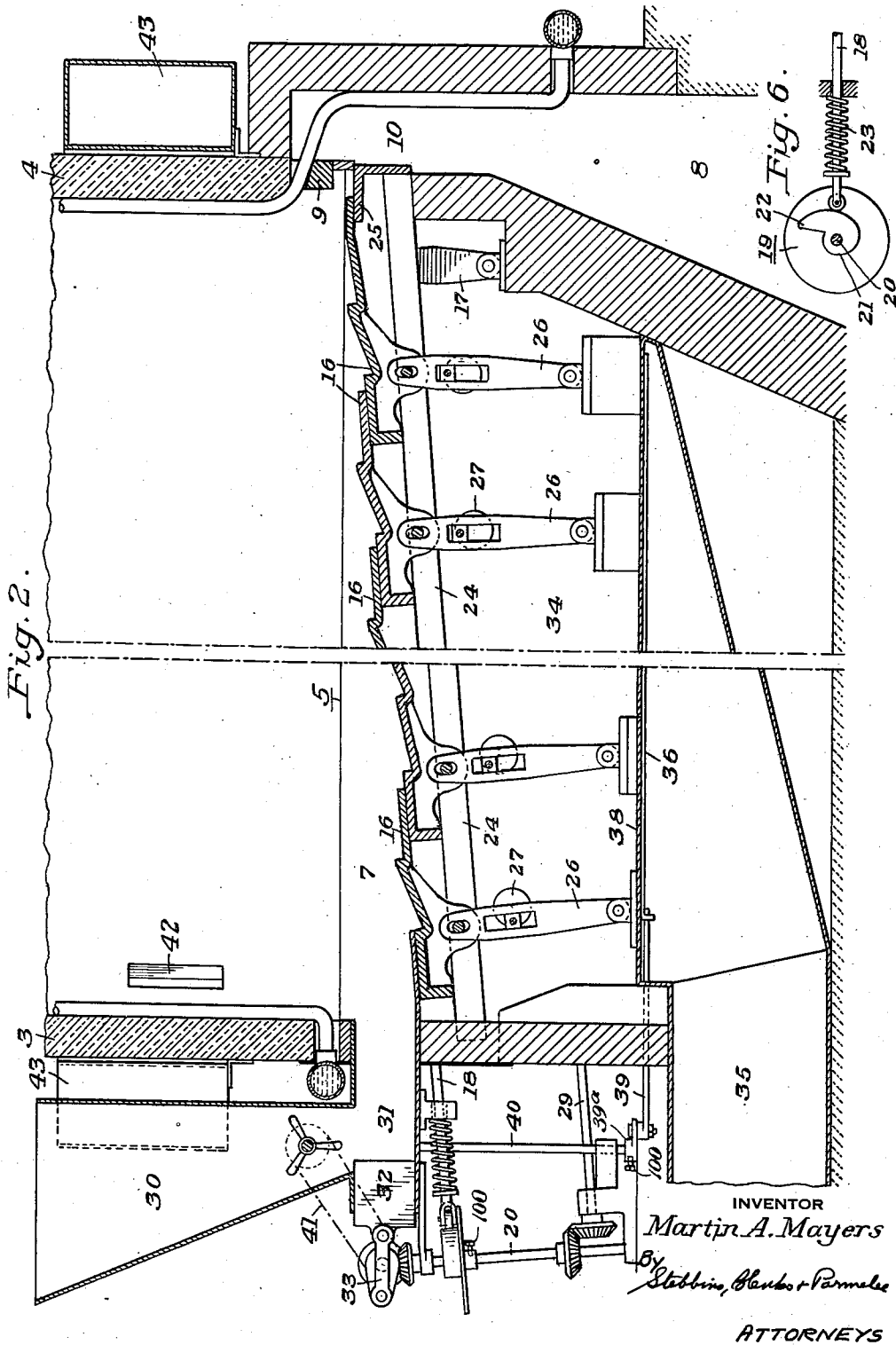
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4 Sheets-Sheet 3

Fig. 3.

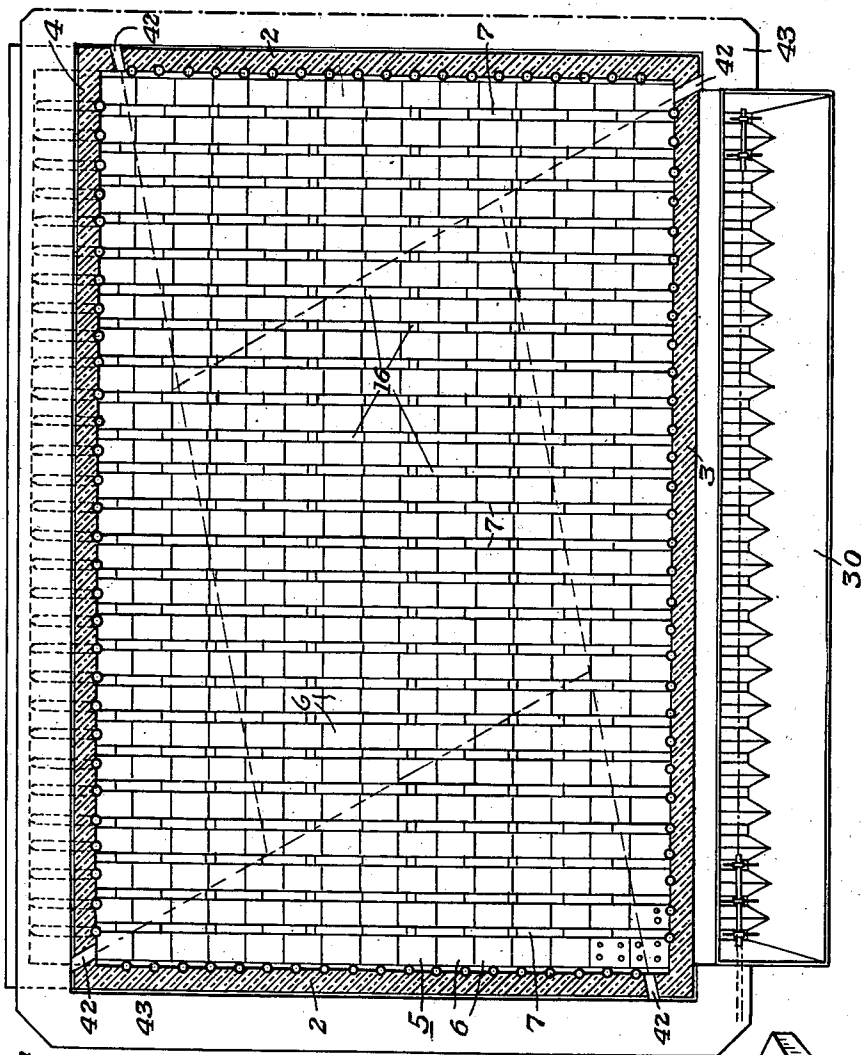


Fig. 5.

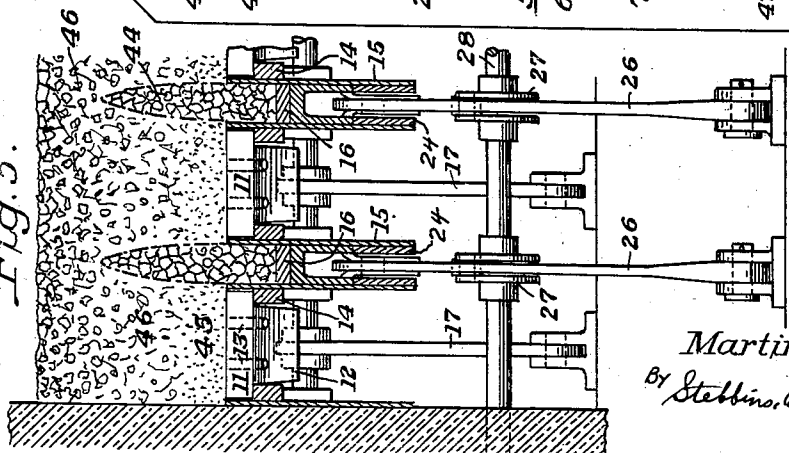
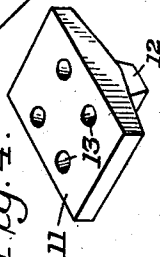


Fig. 4.



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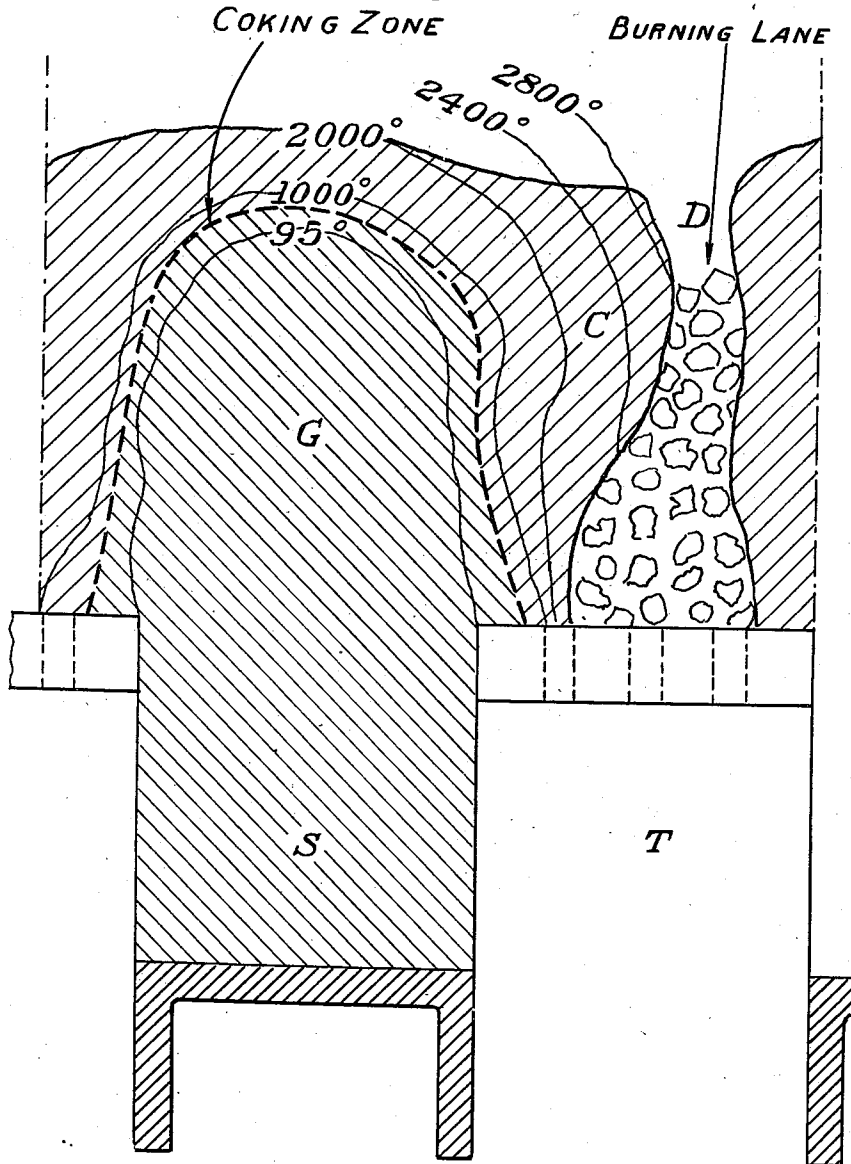
2,276,327

METHOD OF AND APPARATUS FOR BURNING FUEL

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4 Sheets-Sheet 4

Fig. 7.



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UNITED STATES PATENT OFFICE

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METHOD OF AND APPARATUS FOR
BURNING FUEL

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Application September 28, 1939, Serial No. 296,934

17 Claims. (Cl. 110—44)

My invention relates in general to a method of and apparatus for burning fuel and is particularly applicable to underfeed stokers and especially to large, multiple retort underfeed stokers such as are used in connection with steam boilers which use coal as the fuel.

The grate in a multiple retort underfeed stoker is made up of a number of fuel retorts and tuyère stacks arranged in parallel lines side by side and extending from the front of the grate to the rear thereof. My invention consists in the arrangement of apparatus and a method of burning coal in such a manner that the rate of burning of the fuel per unit of grate area is substantially greater than that heretofore obtained. I have discovered how to determine the correct width of the tuyère stack and of the retort for any desired combustion rate of a desired fuel. Stokers constructed following the teachings of my invention have retort sections, the width of which is much less than that of existing stokers and is of much greater efficiency and capacity.

In the accompanying drawings I have shown for the purposes of illustration only the preferred embodiment of apparatus suitable for the practice of my invention. In the drawings:

Figure 1 is a longitudinal view partly in section and more or less diagrammatic of a stoker embodying my invention, the section being taken through a tuyère stack and air-admission section;

Figure 2 is a vertical longitudinal section similar to that shown in Figure 1 but taken through a retort;

Figure 3 is a horizontal section partly diagrammatic showing the grate area;

Figure 4 is a view in perspective of a tuyère;

Figure 5 is a vertical section to an enlarged scale along the line V—V of Figure 1 showing two retorts and associated tuyères;

Figure 6 is a view along the line VI—VI of Figure 1 showing a detail of the apparatus; and

Figure 7 is a view largely diagrammatic showing a partial section through a retort and tuyère and a part of the overlying fuel bed of a conventional stoker.

It has heretofore been thought by those skilled in the art that fuel beds of underfeed stokers were essentially uniform all the way across the stoker and divided into substantially horizontal strata and that the green coal which is pushed up into the coking zone is gradually coked by the heat from the fire above. I have discovered that such is not the case, but, on the contrary, (1) that the fuel bed is not continuous but is divided into sub-

stantially vertical strata which extend longitudinally of the grate and consist of a multiplicity of parallel channels extending along the grate immediately above the tuyère stacks in which active burning of the fuel occurs, the channels being separated by elongated heaps of coal and coke in the retorts in which almost no burning occurs; (2) that the coal is not heated appreciably from above; (3) that the air for combustion passes up directly above the tuyère stacks and does not spread appreciably in the region above the retorts; (4) that the passage of heat into the coal leading to its coking and ignition is mainly in a horizontal direction from the hot walls of the channels in which rapid combustion is occurring and, lastly, (5) that the level of the fuel bed is seldom more than one to two feet deep above the level of the tuyères.

These discoveries can best be visualized by reference to Figure 7, which represents a cross section of a portion of a conventional stoker taken through a tuyère section T and a stoker retort S. On this diagram, which it is understood represents only a portion of the cross section and is repeated as many times as there are tuyère stacks in the stoker, are shown contour lines representing regions of equal temperature. These contour lines are the traces on a vertical plane of surfaces extending parallel to the axes of the retort and tuyère stack and bounding the regions of equal temperature throughout the length of the stoker. It will be observed that the coal in the center of the retort is not heated, excepting in a small region at the top of the retort. Passing from the center line of the retort toward the center line of the tuyère stack the temperature increases through the coking range of the fuel and finally reaches very high values in the channel above the center line of the tuyère stack through which the air for combustion passes, maintaining very rapid burning on the walls of this channel. The region within the heavy line shown is a compact mass consisting of green coal G within the dash line between the contours at 95° and at 1000° F. and of massive, nearly monolithic walls of coke C between the dash line and the heavy outline. The dash line represents the approximate locus of the coking region. The channel D through which air flows up through the bed is nearly empty and most of the combustion takes place on the walls of this channel.

By means of these discoveries, I have been able to analyze the conditions underlying the flow of heat into the coal which is being prepared for combustion in the retorts of the under-

feed stoker, and I can show that this heat flow must obey laws similar to those governing the flow of heat into the charge of a slot-type by-product coke oven. For, as shown in Figure 7, the steepest temperature gradients and hence, the most rapid heat flow, appear in a horizontal direction across the retort so that the principal flow of heat resulting in coking green coal takes place from the burning lanes on either side of the retort toward the center of the retort. This results in setting up a "plastic layer" so called, or region of coke formation on either side of the retort, which is substantially vertical and which travels across the retort full of coal from the burning lane toward the center of the retort. This is exactly analogous to what takes place in a byproduct coke oven, as shown by the researches of D. W. Wilson (Proc. Am. Gas. Assoc., vol. 1923, pp. 952-64), W. P. Ryan (Ibid., vol. 1925, pp. 861-78) and others except that in the byproduct coke oven the source of heat is the confining brick wall of the oven which is heated by the combustion of gas in flues passing through it. This difference in structure can obviously have no effect on the laws governing heat penetration within the mass of coal and coke.

Now it has been found empirically by Dr. H. H. Lowry (unpublished data communicated privately) from the correlation of many data published by the U. S. Bureau of Mines in Monograph No. 5 (1934) by A. C. Fieldner and J. D. Davis, and checked against other published data (e. g., Coke for Blast Furnaces by R. A. Mott and R. V. Wheeler (1930) Table 88, page 215) that the time required for coking a charge of coal in a byproduct coke oven, *ceteris paribus*, varies as the 1.6 power of the oven width or diameter. This is an empirical fact whose explanation is not yet understood, but which we are now seeking. Making use of this fact, and the analogy shown above to exist between heat flow in an oven and in the retort of an underfeed stoker we may write that the time required to coke the coal in a retort of width *w* is given by $mw^{1.6}$ where *m* is a parameter depending on the coal characteristics, the temperature of the source, and other such quantities and need not be more exactly specified since it will be eliminated during this derivation. Now, the amount of coke formed in such a retort per unit length is proportional to the width of the retort and may be written as *nw*, where *n* depends on the coal characteristics and the height of the retort. Hence, it is evident that the average rate of coking per unit length of retort is given by the quotient of these expressions or

$$\frac{n}{mw^{0.6}} = \frac{B}{w^{0.6}}$$

where *B* is a constant depending on the character of the coal (fixed carbon, ash and moisture content), the height of the retort, the temperature in the burning lane and perhaps upon other factors. The constant *B* may be defined as the rate of coking per foot of retort length for a retort one foot wide.

In view of the discussion of the operation of such underfeed stokers which will be given later, it is evident that on the average each tuyère stack must burn coke at the rate at which it is prepared and delivered to it by the retorts on either side of it. Now the rate of burning on the tuyère stacks referred to unit area of the stack may be measured for any particular coal and any particular installation, as hereinafter

pointed out or it may be calculated from the formula for *U** given below, which was derived by me in a paper presented before the American Society of Mechanical Engineers (Trans. A. S. M. E., vol. 59, pp. 279-288 (1937); see particularly page 281, equation 15).

$$U^* = GMP_1 \left[\left(1 - e^{-\frac{u_1}{G}f} \right) + \left(1 - \frac{e^{-\frac{u_2}{G}f} - \frac{u_2}{u_1} e^{-\frac{u_1}{G}f}}{1 - \frac{u_2}{u_1}} \right) \right]$$

where:

G=rate of air flow, lbs./sq. ft./hr.

M=stoichiometric factor, 0.414

*P*₁=oxygen partial pressure, atm. (in air=0.21)

*u*₁=rate of reaction $C + O_2 \rightarrow CO_2$, lbs./cu. ft./hr.

*u*₂=rate of reaction $CO_2 + C \rightarrow 2CO$, lbs./cu. ft./hr.

f=depth of ignited fuel bed in feet

e=base of natural logarithms

Hence, the rate of burning on a tuyère stack whose width is *d*, will be, per unit length of tuyère *U*d*. Since this must, as shown above, be equal to the rate at which coke is delivered to the tuyère stack, we may, for a correctly proportioned stoker, set

$$\frac{B}{w^{0.6}} = U^*d$$

which results in the first proportioning formula

$$dw^{0.6} = \frac{B}{U^*} \quad (1)$$

The quantity *B* depends on the properties of coal as a heat conductor, the temperature obtaining at the face of the heap of coke, and the height of this face through which heat is conducted into the coking coal. I have determined by experiments suitable values of this quantity *B* for typical high and low volatile bituminous coals coking in a region that extends one foot above the level of the tuyères. For these conditions, a suitable average value of *B* is 90, when *U** is expressed in pounds of coal per hour per square foot of air admission surface. For higher or lower coking faces, the quantity *B* must be increased or decreased respectively in proportion to the depth. Because of variations in the properties of different coals, *B* is not a true constant, but may be expected to vary over a range of 25% greater or less than the value stated, say, from about 65 to about 120 per foot height above the level of the tuyères.

The effect of coal characteristics on the value of *B* can be estimated as follows: *B* is inversely proportional to the sum of ash plus fixed carbon in the coal and is decreased approximately 3% for each per cent of moisture content. It depends upon the temperature in the burning lane of the stoker in which the value of *B* is being determined or applied. It increases with the temperature approximately as indicated by the equation

$$\log B = \log B_0 - \frac{1800}{T}$$

where *T* is the temperature in degrees C. plus 273.

There are various ways in which the value for *B* for any given coal may be determined.

Method 1

Measurement is made of the rate of the transverse flow of coal in an underfeed stoker of any suitable type by the method described in the article by M. A. Mayers, W. H. Dargan, J. Gersh-

berg, B. C. Dalway, M. J. Williams and E. R. Kaiser, the article being entitled "The Fuel Bed Tests at Hell Gate Generating Station," and read in 1938 before the American Society of Mechanical Engineers (to be published in their Transactions shortly). In these tests, motion pictures of the bed were taken from the rear wall of the furnace from which the transverse velocity of the fuel flow could be estimated. The tests were made while the furnace was in a steady condition and the transverse velocity of fuel across retorts 11' in width, in which the coke mass was estimated to be 16' wide was 0.7 foot per hour. Since under the conditions of the test the fuel bed was in a relatively steady state, the rate of transverse flow of the fuel was equal to the rate of coking, so that these data can be inserted in the expression for the rate of coking

$$\frac{B}{w^{0.6}}$$

with the factors necessary to change from linear velocity to fuel flow in pounds per foot of retort length giving the following:

$$2 \text{ (factor)} \times 0.7 \text{ (transverse velocity of fuel)} \times 1 \text{ (height in feet of coke above tuyères)} \times 45 \text{ (pounds per cubic foot of coal)} =$$

$$2 \times 0.7 \times 1 \times 45 = \frac{B}{(16/12)^{0.6}}$$

$$B = 75$$

In this equation, the factor 2 appears because the retort delivers coke on both sides. The expression $2 \times 0.7 \times 1 \times 45$, it will be noted, is the number of pounds of coal which is coked.

Method 2

A second method of determining B for any particular coal is as follows:

The coal is burned in an underfeed stoker of any suitable type and the burning rate of the coal in the stoker is determined. This burning rate can be determined by a weighed coal test, or when the boiler efficiency is known, can be calculated from the rate of steam production.

Assume that the stoker used in determining the burning rate of the coal had the following dimensions and that the rate of burning coal was 12,200 lbs./hr.:

1. Total stoker area = 382 square feet
2. Total air admission area = 182 square feet
3. Width of tuyère stack (d) = $10\frac{1}{2}$ in.
4. Width of coking mass (w) = 16 in. (estimated)

The average rate of burning of the coal in pounds per hour per square foot of air admission area equals $12,200/182 = 67.1$. This value of 67.1 is a measured value of U^* . Therefore,

$$U^*d = 67.1 \times \frac{10\frac{1}{2}}{12} = 58.7 \text{ lbs./ft. length of tuyère}$$

Referring now to the first proportioning formula,

$$dw^{0.6} = \frac{B}{U^*}$$

and transposing in order to solve for B, we have the formula

$$B = U^*d \times w^{0.6} \\ = 58.7 \times \left(\frac{16}{12}\right)^{0.6} = 69.8$$

These discoveries lead to another formula which determines the average burning rate U for any given values of U^* , d , and w . The av-

erage burning rate U in pounds of coal per hour per square foot of the entire stoker area will bear the same ratio to U^* as the area of the tuyère stacks bears to the total area of the stoker. But, since the retorts and tuyères have the same length, the ratio of the areas is given by the ratio

$$\frac{d}{d+w}$$

so that

$$\frac{U}{U^*} = \frac{d}{d+w}$$

which results in the second proportioning formula

$$U = U^* \frac{d}{d+w} \quad (2)$$

An examination of this formula will show that the average rate of burning increases more and more as w is decreased by comparison with d . Thus it will be seen that it is advantageous to make w as small as possible in view of the practical requirements set by the necessity of feeding coal.

By the use of these formulas it can be shown that the maximum coal burning rates that are possible with conventional designs of stokers have been reached. In conventional stokers, as marketed by the principal manufacturers of such equipment, d is equal to about 11 inches and w is usually about 10 inches. There are slight variations in the designs of different manufacturers, but these variations do not exceed an inch or two greater or less than the dimensions given. Using these dimensions in Formula 1, it will be seen that U^* has a value of 110, which, using Formula 2 corresponds to a value of U of about 60 pounds/square foot/hour. The maximum coal burning rates that have been attained on multiple retort underfeed stokers are reported in the paper "Ten Years of Stoker Development at Hudson Avenue," John M. Driscoll, W. H. Sperr, Trans. A. S. M. E., 57, 49-58 (1935) as about 75 pounds/square foot/hour. This figure is referred to the projected area of the furnace and includes the area occupied by the ash pit. Correcting for the width of the ash pit and for the slope of the stoker furnace, this corresponds to the same value of about 75 pounds per hour when referred to one square foot of actual stoker surface, which it is seen is larger than the value of 60 pounds determined by Formulas 1 and 2. The reason for this discrepancy arises from the fact that the stokers on which this high coal burning rate was attained include a section on which overfeed burning takes place, namely, the so-called extension grates immediately ahead of the ash pit. Overfeed burning permits the attainment of higher combustion rates, but does so at the risk of inefficient combustion and the production of smoke. If the average figure of 75 pounds/square foot/hour given above were corrected for the high combustion rate developed on the extension grate, the quantity $U = 60$ pounds/square foot/hour for the underfeed section would not be materially exceeded.

By the use of the proportioning Formulas 1 and 2 given above, it is possible to design stokers for values of U^* much greater than the value of 110 which is found to be the limit for conventional stokers. Thus, my discoveries and the use of the proportioning formulas permit the extension of U^* to values greater than 150. There is, however, an upper limit to attainable values of

U^* , which is set by the necessity of operating at air flow rates below those which will disrupt the fuel bed. This upper limit becomes effective at values of U^* in the neighborhood of 250 to 300, depending on the size of the particles of coked fuel delivered by the retorts. In order to show the advantages that may be gained by the use of these formulas, a single example will suffice. Setting $w=3$ inches and $d=10$ inches in Formula 1 and solving for U^* we obtain $U^*=250$. Putting this value and the values of w and d in Formula 2, we obtain $U=200$. This is a 300% increase over the maximum combustion rate attainable on the underfeed section of multiple retort stokers as they are now built. It is seen that the width of the retort which I propose is only a fraction of the width which has heretofore been used and considered necessary.

The dimensions of the stoker can be determined as follows: Using the Formulas 1 and 2, calculate U for the fuel to be used and the conditions of firing, that is, the air pressure available, size consist of fuel, depth of fuel bed; divide the load to be carried in pounds of coal per hour by U and this will give the required stoker area. It is desirable to make the grate as nearly square in cross section as possible, although this proportioning is not essential.

It is understood that this example is merely typical of the results that may be attained by the use of the proportioning formulas given above.

In order to understand the functional meaning of the improvements about to be described, it will be necessary to bear in mind the operation of existing types of underfeed stokers. The explanation will be confined to a description of the process occurring between the center line of a retort and that of the next adjacent tuyère stack in any of the common types of multiple retort underfeed stokers, from which the entire stoker can be built up by simple multiplication of units. In such a stoker, raw coal is fed into the retort and is pushed along the retort until it rises above the level of the tuyère stack which slopes down to meet the level of the bottom of the retort. From the burning lane over the middle of the tuyère stack (which, however, may be displaced from side to side across the width of the tuyère stack by uncontrolled variations of the properties of the fuel or of the feeding or burning action of the stoker) which acts as a source of heat, heat is conducted into the coal in the retort and a coking zone travels across the retort from the burning lane, reaching the center of the retort by the time the coal has reached the end of the retort immediately adjacent to the ash pit or extension grate, if any, when the stoker is properly operated. On the cold side of the coking zone, i. e., toward the center of the retort, the coal remains substantially unheated, even when it has passed almost all the way down to the ash pit extension grate. On the hot side of the coking zone, the semi-coke continues to be heated until, by the formation of shrinkage cracks and the agitating action of the secondary rams, portions of the coke wall formed by the passage of the coking zone break off and fall down into the burning lane producing a more or less continuous porous fuel bed through which the air stream introduced through the tuyères may pass. Since the fuel falling into the burning lane has already been heated to ignition temperature, the air stream causes it to burn, releasing heat. In this manner, the self-supporting fuel bed is set

up and it continues to burn so long as fuel is supplied to the retorts and air is supplied to the tuyères. I have found that the limiting factors in this operation are (1) the slow rate of heat penetration into the raw coal supplied to the retorts; (2) channeling of the fuel bed over the tuyère stack causing the appearance of marked burning lanes which may contain very little fuel; and (3) general instability of the fuel bed causing large areas of the bed over the tuyère stack to be blown clear of fuel thus allowing large amounts of air to enter the furnace without being made to support combustion and thus be heated, and exposing the grates to dangerous heating by radiation from the surrounding active fuel bed.

The most serious of these shortcomings is the first which in itself limits the attainable rating on most existing stokers and is the principal reason for the existence of the other two which occur principally because of the failure of a sufficient supply of prepared coke for the burning lanes. It may also be noted that operation according to this scheme involving the overfeed of fuel to the burning lanes permits the attainment of extremely high temperatures, between 2800° and 3100° F. in the burning lanes. At such temperatures any small particles of ash released in the burning lane will be immediately melted; if the particles are large enough to remain in the fuel bed they will inevitably come in contact with other particles forming clinkers, while if they are small enough to be carried out of the lane by the fuel bed gases, they are likely to be carried up to the boiler heating surface producing slagging of the tubes.

The improvements suggested here, and therein lies my invention, are aimed at all of these limiting factors as follows:

1. The retort is to be made as narrow as conveniently possible considering the size of coal which it is desired to burn. This step will, as explained in more detail above, increase considerably the rate of heat penetration into the cold fuel.

2. Violent agitation is to be applied to the fuel in the region between the retort and the tuyère stack to break up the coke wall as rapidly as formed into small uniform pieces. In this way, the width of the coal mass is maintained substantially equal to the width of the retort. This step is aimed at the third limit mentioned above. It does, however, introduce a difficulty due to the very rapid release of volatile substances from the coking coal which is, in turn, taken care of by improvement 4, *infra*.

3. The active grates or tuyère stacks are to be made just wide enough so that the coke formed at the rate of which the retort is capable can be burned with a deficiency of air when the air is introduced at a rate high enough to cause the bed to have the consistency termed by Hirst (*Trans. Institute of Mining Engineers*, 79, 463, *ibid* 85, 236) "just moving."

Under these conditions the bed is sufficiently fluid so that it will flow to a uniform level. When this condition of "just moving" is maintained by the use of an interrupted stream of air, the uniform level of the bed can be maintained without any tendency toward channeling. In order to maintain a deficiency of air with the type of flow described, it would be necessary to maintain a bed very much deeper than is now in use over the tuyère stack. This method of air admission will introduce the difficulty that dust, finer than about 50 mesh, is likely to be blown out of the

bed. This difficulty is also met by improvement 4, *infra*.

4. A large proportion of the air for combustion is to be applied over the fire, either in the form of jets under high pressure, or air introduced tangentially under pressure so as to cause a vortex just above the burning fuel. By a large proportion is meant from 25% to 70% of the total quantity of air supplied, depending on the proportion of volatile matter in the coal, the reactivity of the coke formed from the coal, and the thickness of fuel bed it is desired to carry.

5. The ash is to be removed from the bottom of the fuel bed at the foot of the burning lane in much the same way as refuse is removed from a coal-cleaning table. This is possible because of the classification by density that occurs in a fluid bed such as that in the "just moving" condition.

It is apparent that the air flow rate will not affect the penetration of heat into the fuel in the retort because the heat flow depends only on the thickness and cross sectional area of the coal layer and on the temperature maintained at its face. This temperature does not change appreciably in the lower part of the bed adjacent to the coking zone since it is determined largely by the heat of reaction of the fuel and its direction of flow. The fuel flow in this region will continue to be overfed as in existing stokers, so the temperature will rise to about 2700° F. Only beyond this region will the temperature, which in existing stokers reaches 3100°, decrease because of the increased importance of the endothermic reduction reaction $C + CO_2 \rightarrow 2CO$ which absorbs about 5800 B. t. u./pound of carbon. Since there will be no flow of air through the retort, the increased air flow through the stoker will not affect the rate of heating of the coal. Maintenance of the area necessary to permit the required amount of heat to flow will be automatic because if it tends to become too small, the action of the agitating mechanism will raise the uncoked coal in the retort thus increasing the area exposed. This process of heating in underfed stokers produces the characteristic that renders them independent of the restrictions on the rate of ignition present in "pure underfeed burning." See the article by P. Nicholls and M. G. Eilers, in Transactions of the American Society of Mechanical Engineers, vol. 56, p. 321, 1934. The term "pure underfeed burning" is here used as burning in which the flow of air and the flow of fuel through the fuel bed takes place in the same direction, or alternatively in which the ignition of fresh fuel proceeds in a direction opposite to the flow of air. Thus, the rates of ignition in existing stokers are above those that could occur in pure underfeed burning, and by the improvements described herein they are increased still further.

The consistency of the fuel bed required by improvement No. 3 is obtained at a forced draft pressure that depends only on the density of the bed and its depth. More specifically the forced draft pressure should approximately equal the product of the bulk density times the depth of the bed so that a pressure gradient is maintained through the bed equal to its bulk density. For a bed of coal, this pressure gradient (Hirst, previously cited) has been determined as 0.67" water column per inch of bed thickness. Since the bed in this case will be coke of somewhat lower density than coal, the factor will be somewhat lower than that quoted. In addition, the ex-

pansion of the bed gases, due to their rise in temperature, may effect this quantity, although it seems more likely that its effect will be solely on the rate of air flow associated with the pressure required to produce "just moving" conditions. The latter quantity depends only on the size of the fuel particles. For closely sized beds, the "just moving" condition is reached at higher gas velocities than with unsized beds, although the pressure applied is nearly the same, but there are no definite figures available on the flow velocity in unsized beds.

In the drawings, there is shown a multiple retort underfeed stoker suitable for use in connection with a steam boiler, the side walls of which are designated by the numeral 2, the front wall by the numeral 3, and the back wall by the numeral 4. The grate 5 is made up of a number of units, each consisting of a tuyère 6 and a stoker retort 7, arranged side by side and extending from the front wall 3 of the boiler to a point adjacent the rear wall 4. The number and length of the units depend on the desired capacity of the boiler. The length of the grate and the rate of fuel feed would be adjusted to insure that the fuel will be coked by the time it reaches the end of the unit. The depth of the fuel bed is such that it may extend to the rear wall 4 of the furnace and the ash alone is forced over the end of the tuyère stack into the ash pit. The grate 5 terminates below a stop 9 and short of a jog in the rear wall 4, thus leaving a space 10 leading to the ash pit 8. The stop 9 extends into contact with the bottom 25 of the fuel retort.

The tuyère 6 consists of a plurality of tuyère sections 11, each arranged end to end from the front of the grate to the back of the grate. One of the sections is shown in perspective in Figure 4. The section 11 is made from a suitable material such as cast iron, is rectangular in shape and has a tongue 12 depending from the sloping bottom of the section. The tongue is shorter than the width of the tuyère and both ends of the tongue terminate a short distance from the sides of the section. A number of suitable holes 13 are provided extending from the bottom of the section to the top. The section illustrated shows four holes which incline toward one another upwardly and terminate on opposite sides of the tongue 12. The sections 11 are laid end to end and the sloping bottom portions rest on lugs 14, which are secured to the partition plates 15 which separate the tuyères 6 from the retorts 7. The plates extend from a position adjacent the top of the tuyère downwardly past the bottoms of the secondary rams 16.

The partitions 15 are supported by and pivoted to the upper ends of links 17. The lower ends of the links are pivoted on supports in the boiler adjacent the front and rear of the grate 5. The links are hingedly secured both to the partition plates and to the boiler supports so as to allow a reciprocating motion of the partition plates lengthwise of the grate. The links 17 are moved back and forth by the rod 18, which has a quick return motion connection 19 with the shaft 20. The quick return motion connection 19 comprises a cam 21 having a projecting tongue 22 and a cut-away portion which allows the rod 18 to be forced rapidly backward by the spring 23 after the completion of the forward stroke. The cam 21 is secured to the shaft 20 and is rotated by it. The rotation of the shaft 20 causes the partition plate 15 and the tuyères supported thereon to be reciprocated relatively slowly in a direction toward

the rear of the grate and relatively quickly toward the front of the grate on the return movement.

The stoker retorts 7 lie between the tuyères 6 and each is composed of a number of secondary rams 16, the top surfaces of which are stepped or saw-toothed, as illustrated in Figure 2. A portion of each secondary ram overlaps the secondary ram immediately in the rear of it and the lower front part of the secondary rams rest on a pilot bar 24, which is supported at its ends in the furnace structure and slopes upwardly from the front of the grate to the rear. The secondary rams are thus prevented from tipping and are compelled to move in a generally straight line which is upwardly inclined. The upper surfaces of the secondary rams slope upwardly from the front of the grate to the rear of the grate and at the rear of the grate the top of the adjacent secondary ram is substantially level with the top of the tuyère section and overlies a plate 25 which extends between the partition plate 15 forming the side of each tuyère section and closing off the end thereof.

The secondary rams 16 are each driven by a lever 26 associated with each section, which lever, in turn, is driven by an eccentric connection 27 which is driven by a shaft 28 geared to shaft 29. The shaft 29 is gear connected with the shaft 20. It will be observed by inspection of Figures 1 and 2 that the secondary rams 16 are so arranged that they are moved in a step-like motion relative to each other with a quick return motion so that the fuel thereon is forced along the grate from the front toward the rear. Fuel is fed from the hopper 30 into the retort 31 whence it is forced by the main ram or plunger 32 into the stoker retort 7. As explained above, the fuel is moved through and along the stoker retort by the step-like motion of the secondary rams. The main ram 32 is reciprocated back and forth by the link 33, which is gear connected with the shaft 20. The rate of movement of the secondary rams depends on the operating conditions of the stoker.

Combustion air under pressure is admitted to the plenum chamber or wind box 34 from an air duct 35 to which air is supplied under temperature and pressure from a suitable source (not shown). The flow of air from the air duct 35 to the plenum chamber 34 is controlled by slide valves 36, which open and close the ports 37 in the plate 38 which divides the wind box 34 from the air duct 35. The slide valves 36 are reciprocated by the connecting rod 39, which is moved through a crank connection 39a by the shaft 40. The shafts 20 and 40 are connected together by a drive 41, indicated in chain lines, and are driven by a prime mover (not shown). The slide valves 36 are opened and closed at the same frequency as the tuyère stacks 6 are reciprocated. The mechanism for reciprocating the tuyère stacks 6 and the mechanism for operating the slide valves are so arranged that the phase of operation of each relative to each other may be adjusted. To make the parts adjustable, set screws 100 as shown in Figs. 1 and 2 may be provided to adjustably connect the crank 39a to the shaft 40 and to adjustably connect the cam 21 to the shaft 20. In general, the tuyère stacks 6 are being moved toward the ash pit at the rear of the grate at the same time as air is being admitted through the slide valve 36. The rate of operation of the main ram 32 and the secondary rams 16 are adjustable and the fuel feed and air feed are so disposed and adjusted that the rate of flow of the fuel and of

the ash bed along the grate can be regulated as operating conditions may require.

At each corner of the furnace walls, there are provided openings or ports 42 through which air for combustion is supplied from the bustle pipe 43, which extends around the sides and back wall of the furnace and which contains air under a suitable temperature and pressure supplied from a suitable source (not shown). The ports 42 are located above the fuel bed and directed across the grate surface and above the fire, as shown in dotted lines. This causes a vortex over the fire and insures thorough mixture of the gases of combustion with the air and complete combustion of the gases.

In the operation of my apparatus, fuel such as coal is forced into the retort 31 by the plunger 32 and is fed along the length of its upwardly sloping bottom by the reciprocating rams 16, which rams also by their reciprocation force the green coal up into the coking zone 44 (Figure 5) and break up the semi-coke adhering to the hot side of the coking zone. Air passes through the holes 13 in tuyères 6 through the layers of ash 45 on the tuyères and into the fuel 46. Ash is discharged continuously to the ash pit 8 from the top surface of the ash pit end of the tuyère stack 5, underneath the layer of fuel, by the reciprocating action of the tuyère stack 5.

Secondary air is admitted through the ports 42 in close proximity to the top of the fuel bed where the thorough mixing of the rich gases rising from the bed by the tangential firing of the overfire air burns up the combustible gases and any fine dust that is blown through the bed.

Following the teachings of my invention, it is possible to obtain very much higher burning rates than are possible with conventional designs of stokers and an additional increase in capacity available within a given space is possible because of the small space required for ash removal. Boilers equipped with stokers made according to my invention will have a capacity considerably greater per square foot of grate area than that obtained with any stoker of similar grate area heretofore made. The rate of burning per unit of grate area is increased and the cost of installation is reduced, due to the lower cost of grates or tuyères. Maintenance cost of the grates or tuyères is lowered because replacement of grates will be reduced by the improved cooling due to the high rates of air flow required and because the layer of ash on the grates will protect them from heat radiated downwardly toward them from the burning fuel. Slagging of the tubes in the boilers by molten ash carried up to the tube by the hot gases rising from the fuel bed will be reduced because ash will not be subjected to high temperatures when it is liberated in the upper part of the bed, because the uniformity and depth of the bed will permit the endothermic reaction $C + CO_2 \rightarrow CO$ to be completed to a considerable extent. This will materially cool the upper parts of the bed to temperatures well below the fusion point of most ash.

It must also be observed that this method of firing lends itself to the use of highly preheated air with stoker firing. It would be necessary where such practice is desired to preheat only the secondary, overfire air while the air for combustion supplied through the tuyères 11 would be air at normal atmospheric temperature. Since the secondary overfire air is not passed through the grates, the increasing maintenance costs found with increasing air temperature where all

the air is passed through the grates would not limit the preheat temperature that might be used. Of course, the air supplied through the tuyères could also be heated, if desired; however, if such air were heated to a high temperature, say above the order of 300° F., this would tend to materially decrease the life of the grates.

While I have set forth a preferred embodiment of my invention, it is to be understood that my invention is not limited to this embodiment, but may be practiced within the scope of the following claims.

I claim:

1. A multiple retort underfeed stoker for burning coal having alternate parallel fuel retorts and tuyère stacks in side by side relationship wherein the width of the retorts does not exceed 50% of the width of the tuyère stacks, each of said fuel retorts having a plurality of secondary rams, the ends of which are in overlapping relationship, means for reciprocating the secondary rams in a step-like motion relatively to each other so that fuel thereon is moved from the front toward the rear of the grate and means for reciprocating the tuyère stacks relatively slowly in a direction toward the rear of the stoker and relatively quickly from the rear toward the front.

2. A multiple retort underfeed stoker for burning coal having alternate parallel fuel retorts and tuyère stacks in side by side relationship wherein the width of the retorts does not exceed 50% of the width of the tuyère stacks, said fuel retorts having a plurality of secondary rams, the ends of which are in overlapping relationship, means for moving the secondary rams in a step-like motion relatively to each other so that fuel thereon is moved from the front to the rear of the grate, means for supplying combustion air through the tuyère stacks, valves for controlling the flow of combustion air, and means for opening and closing the valves in synchronism with the movement of the tuyère stacks.

3. A multiple retort underfeed stoker for burning coal having alternate parallel fuel retorts and tuyère stacks in side by side relationship wherein the width of the retorts does not exceed 50% of the width of the tuyère stacks, said fuel retorts having a plurality of secondary rams, the ends of which are in overlapping relationship, means for moving the secondary rams in a step-like motion relatively to each other so that fuel thereon is moved from the front to the rear of the grate, means for supplying combustion air through the tuyère stacks, valves for controlling the flow of combustion air, and means for opening and closing the valves in synchronism with the movement of the tuyère stacks, the valves being open for at least a portion of the time the tuyère stacks are being moved toward the rear of the grate.

4. An underfeed stoker for burning coal having alternate fuel retorts and tuyère stacks in side by side relationship, the width of the retorts and the tuyère stacks having a relationship expressed by the formula

$$dw^{0.6} = \frac{B}{U^*}$$

where d is the width of the tuyère stack in feet, w is the width of the retort in feet, B is a constant whose value lies between 65 and 120 per foot depth of fuel bed, and U^* is the theoretical combustion rate of coal per pound per square

foot per hour of actual air-admitting surface determined by the formula:

$$U^* = GMP_1 \left[\left(1 - e^{-\frac{u_1}{d}f} \right) + \left(1 - \frac{e^{-\frac{u_2}{d}f} - \frac{u_2}{u_1} e^{-\frac{u_1}{d}f}}{1 - \frac{u_2}{u_1}} \right) \right]$$

Where:

G = rate of air flow pounds/square foot/hour

M = stoichiometric factor 0.414

P_1 = oxygen partial pressure atm. (in air = 0.21)

u_1 = rate of reaction $C + O_2 \rightarrow CO_2$ pounds/cubic foot/hour

u_2 = rate of reaction $CO_2 + C \rightarrow 2CO$ pounds/cubic foot/hour

f = depth of ignited fuel bed in feet

e = base of natural logarithms,

and wherein the values of G and f are such that they produce a value of U^* substantially greater than 110.

5. A method of burning coal in a multiple retort underfeed stoker which comprises moving the coal along a plane in parallel rows and introducing air through the bed between said rows, agitating the coal on the bed so as to prevent the formation of solid coke walls between the rows of green fuel, and partially suspending the fuel bed by an intermittent stream of air flowing through it.

6. The method of burning coal in a mechanical stoker, which comprises intermittently passing combustion air through coke beds lying between separated green coal masses, continuously supplying overfire combustion air over the fuel bed, and introducing the last mentioned air over the fuel bed in intersecting streams under pressure so as to cause the air to swirl above the fuel bed.

7. In a multiple retort underfeed stoker for burning coal, a stoker area composed of alternate parallel fuel retorts and reciprocable tuyère stacks in side by side relationship, the width of each of the retorts not exceeding 50% of the width of each of the tuyère stacks, each of said retorts having a plurality of secondary rams disposed lengthwise of the retorts, means for moving the secondary rams in a step-like motion relatively to each other so that fuel thereon is moved from the front to the rear of the stoker area, means for supplying combustion air through the tuyère stacks, means for reciprocating the tuyère stacks, valves for controlling the flow of combustion air, and means for opening and closing the valves in synchronism with the movement of the tuyère stacks.

8. In a multiple retort underfeed stoker for burning coal, a stoker area composed of alternate parallel fuel retorts and reciprocable tuyère stacks in side by side relationship, the width of each of the retorts not exceeding 50% of the width of each of the tuyère stacks, each of said retorts having a plurality of secondary rams disposed lengthwise of the retorts, means for moving the secondary rams in a step-like motion relatively to each other so that fuel thereon is moved from the front to the rear of the stoker area, means for supplying combustion air through the tuyère stacks, means for reciprocating the tuyère stacks, valves for controlling the flow of combustion air, and means for opening and closing the valves in synchronism with the movement of the tuyère stacks, the valves being open for at least a portion of the time the tuyère stacks are being moved toward the rear of the grate.

9. In a multiple retort underfeed stoker for burning coal, a stoker area composed of alternate parallel fuel retorts and reciprocable tuyère stacks in side by side relationship, the width of each of the retorts not exceeding 50% of the width of each of the tuyère stacks, each of said retorts having a plurality of secondary rams disposed lengthwise of the retorts, means for moving the secondary rams in a step-like motion relatively to each other so that fuel thereon is moved from the front to the rear of the stoker area, means for supplying combustion air through the tuyère stacks, means for reciprocating the tuyère stacks, valves for controlling the flow of combustion air, means for opening and closing the valves in synchronism with the movement of the tuyère stacks, and means for supplying from 25% to 70% of the air for combustion over the fire.

10. In a multiple retort underfeed stoker for burning coal, a stoker area composed of alternate parallel fuel retorts and reciprocable tuyère stacks in side by side relationship, the width of each of the retorts not exceeding 50% of the width of each of the tuyère stacks, each of said retorts having a plurality of secondary rams disposed lengthwise of the retorts, means for moving the secondary rams in a step-like motion relatively to each other so that fuel thereon is moved from the front to the rear of the stoker area, means for supplying combustion air through the tuyère stacks, means for reciprocating the tuyère stacks, valves for controlling the flow of combustion air, means for opening and closing the valves in synchronism with the movement of the tuyère stacks, and means for supplying from 25% to 70% of the air for combustion tangentially over the fire and under pressure.

11. In a multiple retort underfeed stoker for burning coal, a stoker area composed of alternate parallel fuel retorts and tuyère stacks in side by side relationship, the width of each of the retorts not exceeding 50% of the width of the tuyère stacks, said retorts extending substantially the full length of the stoker area, means closing the ends of the fuel retorts, means in each of said retorts for urging the fuel therein upwardly and toward the rear of the retort, means for imparting reciprocatory motion to the tuyère stacks, and means for intermittently supplying combustion air through the tuyère stacks.

12. In a multiple retort underfeed stoker for burning coal, a stoker area composed of alternate parallel fuel retorts and tuyère stacks in side by side relationship, the width of each of the retorts not exceeding 50% of the width of the tuyère stacks, said retorts extending substantially the full length of the stoker area, means closing the ends of the fuel retorts, means in each of said retorts for urging the fuel therein upwardly and toward the rear of the retort, means for imparting reciprocatory motion to the tuyère stacks, means for intermittently supplying combustion air through the tuyère stacks, and means for supplying from 25% to 70% of the air for combustion over the fire.

13. In a furnace, in combination, a multiple retort underfeed stoker for burning coal, comprising a stoker area composed of alternate parallel fuel retorts and reciprocable tuyère stacks in side by side relationship wherein the width of the retorts and the tuyère stacks have a relationship expressed by the formula

$$dw^{0.8} = \frac{B}{U^*}$$

where d is the width of the air-admitting surfaces in feet, w is the width of the green coal masses in feet, B is a constant whose value lies between 65 and 120 per foot depth of fuel bed and U^* is the theoretical combustion rate of coal per pound per square foot per hour of actual air-admitting surface determined by the formula:

$$U^* = GMP_1 \left[\left(1 - e^{-\frac{u_1}{G}f} \right) + \left(1 - \frac{e^{-\frac{u_2}{G}f} - \frac{u_2}{u_1} e^{-\frac{u_1}{G}f}}{1 - \frac{u_2}{u_1}} \right) \right]$$

where:

G = rate of air flow, lbs./sq. ft./hr.

M = stoichiometric factor, 0.414

P_1 = oxygen partial pressure atm. (in air = 0.21)

u_1 = rate of reaction $C + O_2 \rightarrow CO_2$, lbs./cu. ft./hr.

u_2 = rate of reaction $CO_2 + C \rightarrow 2CO$, lbs./cu. ft./hr.

f = depth of ignited fuel bed in feet

e = base of natural logarithms

and wherein the values of G and f are such that they produce a value of U^* substantially greater than 110, said fuel retorts having means extending lengthwise of the retorts for moving the fuel upwardly and toward the rear of the retorts, means for supplying a portion of the combustion air through the tuyère stacks, and means for reciprocating the tuyère stacks.

14. In a furnace, in combination, a multiple retort underfeed stoker for burning coal, comprising a stoker area composed of alternate parallel fuel retorts and reciprocable tuyère stacks in side by side relationship, wherein the width of the retorts and the tuyère stacks have a relationship expressed by the formula

$$dw^{0.8} = \frac{B}{U^*}$$

where d is the width of the air-admitting surfaces in feet, w is the width of the green coal masses in feet, B is a constant whose value lies between 65 and 120 per foot depth of fuel bed, and U^* is the theoretical combustion rate of coal per pound per square foot per hour of actual air-admitting surface determined by the formula:

$$U^* = GMP_1 \left[\left(1 - e^{-\frac{u_1}{G}f} \right) + \left(1 - \frac{e^{-\frac{u_2}{G}f} - \frac{u_2}{u_1} e^{-\frac{u_1}{G}f}}{1 - \frac{u_2}{u_1}} \right) \right]$$

where:

G = rate of air flow, lbs./sq. ft./hr.

M = stoichiometric factor, 0.414

P_1 = oxygen partial pressure atm. (in air = 0.21)

u_1 = rate of reaction $C + O_2 \rightarrow CO_2$, lbs./cu. ft./hr.

u_2 = rate of reaction $CO_2 + C \rightarrow 2CO$, lbs./cu. ft./hr.

f = depth of ignited fuel bed in feet

e = base of natural logarithms

and wherein the values of G and f are such that they produce a value of U^* substantially greater than 110, said fuel retorts having means extending lengthwise of the retorts for moving the fuel upwardly and toward the rear of the retorts, means for supplying a portion of the combustion air through the tuyère stacks, means for reciprocating the tuyère stacks, valves for controlling the flow of combustion air through the tuyère stacks, and means for opening and closing the valves in synchronism with the movement of the tuyère stacks.

15. An underfeed stoker for burning coal having alternate fuel retorts and tuyère stacks in side by side relationship, the width of the retorts and the tuyère stacks having a relationship expressed by the formula

$$dw^{0.5} = \frac{B}{U^*}$$

where d is the width of the tuyère stack in feet, w is the width of the retort in feet, B is a constant whose value lies between 65 and 120 per foot depth of fuel bed, and U^* is determined by the formula

$$U = U^* \frac{d}{d+w}$$

and the quantities d and w are to be so chosen that U has a value substantially in excess of 75.

16. An underfeed stoker for burning coal having alternate fuel retorts and tuyère stacks in side by side relationship, the width of the retorts and the tuyère stacks having a relationship expressed by the formula

$$dw^{0.5} = \frac{B}{U^*}$$

where d is the width of the tuyère stack in feet, w is the width of the retort in feet, B is a constant whose value lies between 65 and 120 per foot depth of fuel bed, and U^* is determined by the formula

$$U = U^* \frac{d}{d+w}$$

and the quantities d and w are to be so chosen that U has a value substantially in excess of 75 but not greater than the value of U^* determined by the formula:

$$U^* = GMP_1 \left[\left(1 - e^{-\frac{u_1}{G}f} \right) + \left(1 - \frac{e^{-\frac{u_2}{G}f} - \frac{u_2}{u_1} e^{-\frac{u_1}{G}f}}{1 - \frac{u_2}{u_1}} \right) \right]$$

where

G = rate of air flow, lbs./sq. ft./hr.

M = stoichiometric factor, 0.414

P_1 = oxygen partial pressure atm. (in air = 0.21)

u_1 = rate of reaction $C + O_2 \rightarrow CO_2$, lbs./cu. ft./hr.

u_2 = rate of reaction $CO_2 + C \rightarrow 2CO$, lbs./cu. ft./hr.

f = depth of ignited fuel bed in feet

e = base of natural logarithms

17. An underfeed stoker for burning coal having alternate fuel retorts and tuyère stacks in side by side relationship, the width of the retorts and the tuyère stacks having a relationship expressed by the formula

$$dw^{0.5} = \frac{B}{U^*}$$

where d is the width of the tuyère stack in feet, w is the width of the retort in feet, B is a constant whose value lies between 65 and 120 per foot depth of fuel bed, and U^* is determined by the formula

$$U = U^* \frac{d}{d+w}$$

and the quantities d and w are to be so chosen that U has a value substantially in excess of 75 but not greater than the value of U^* determined by the formula:

$$U^* = GMP_1 \left[\left(1 - e^{-\frac{u_1}{G}f} \right) + \left(1 - \frac{e^{-\frac{u_2}{G}f} - \frac{u_2}{u_1} e^{-\frac{u_1}{G}f}}{1 - \frac{u_2}{u_1}} \right) \right]$$

where

G = rate of air flow, lbs./sq. ft./hr.

M = stoichiometric factor, 0.414

P_1 = oxygen partial pressure atm. (in air = 0.21)

u_1 = rate of reaction $C + O_2 \rightarrow CO_2$, lbs./cu. ft./hr.

u_2 = rate of reaction $CO_2 + C \rightarrow 2CO$, lbs./cu. ft./hr.

f = depth of ignited fuel bed in feet

e = base of natural logarithms

and in which G has the maximum value at which the coke bed is in the just-moving condition.

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