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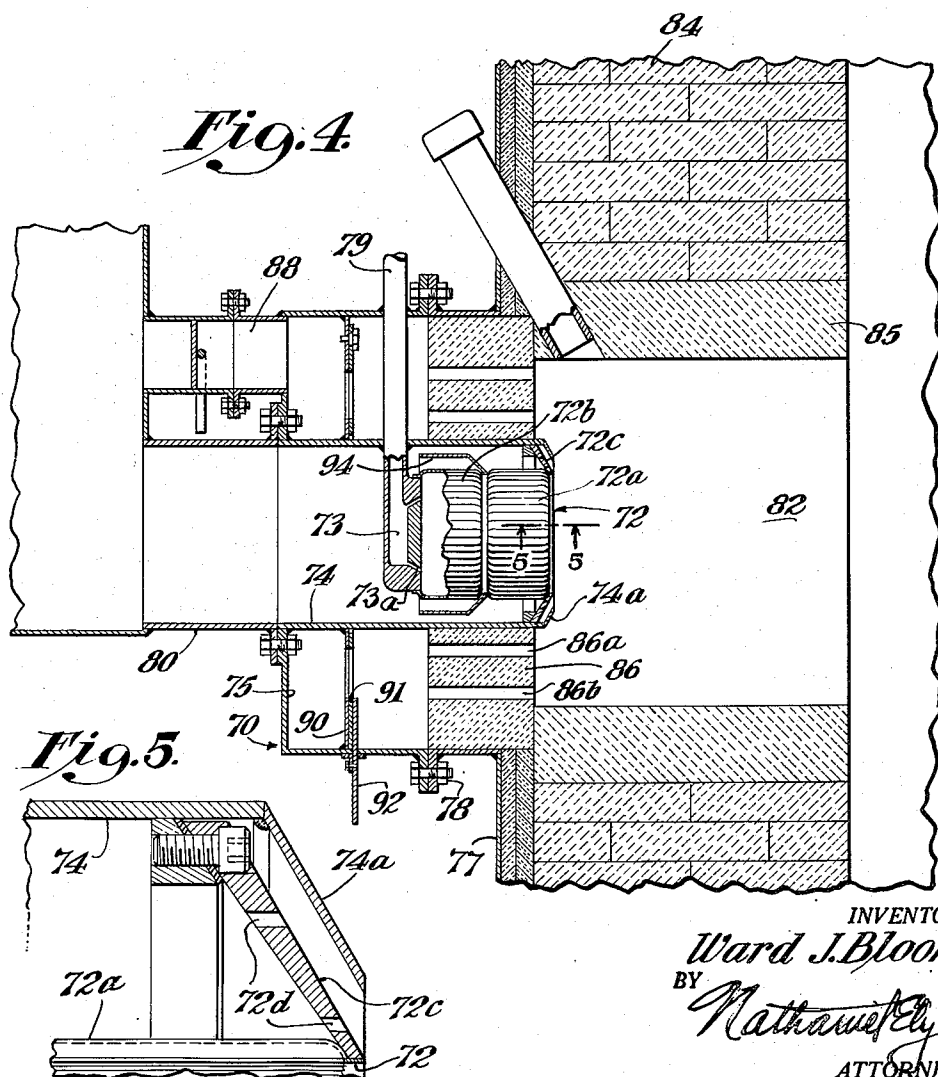
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METHOD AND APPARATUS FOR BURNING FUEL

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METHOD AND APPARATUS FOR BURNING
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This invention relates to fuel burning, and in particular to the provision of a new and improved fuel burner, and a new and improved method of burning fuel. It is a continuation-in-part of my prior copending application Serial No. 580,804, filed March 2, 1945, and entitled Positive Pressure Centrifugal Type Burner and Method of Operation, now abandoned.

It is an object of this invention to provide such a burner and such a method, wherein a high efficiency and completeness of combustion is achieved through entrainment or injection of the fuel into a swirling annular layer or hollow column of combustion air in which the fuel is mixed thoroughly with the air to form a combustible fuel-air mixture which is supplied to a combustion zone totally outside and spaced from the fuel burner, whereby the temperature of the burner and/or the mixing temperature is totally independent of the combustion temperature, and whereby the burner and associated equipment are thus relieved of the necessity for withstanding high, destructive temperatures in operation.

It is a further object of this invention to provide such a burner and such a method, wherein all of the air utilized to entrain liquid fuel and break, separate or atomize it into a mixture or suspension comprising small air-borne fuel particles is utilized also as combustion air, i. e., wherein a column of low-pressure air is made to perform the multiple functions of breaking the fuel into discrete particles of such size as are readily combustible, of entraining the aforesaid particles and suspending them uniformly therein, and conveying the aforesaid particles in uniform suspension to a burning zone, separated or spaced from the zone or zones wherein they are entrained and mixed while also supplying the greater portion, at least, of the air necessary for combustion.

It is a further object of this invention to provide a burner particularly adapted to the method of this invention and possessed of features whereby it may be adjusted to accommodate varying types and grades of fuel and varying air pressures and whereby the burner may be cleared of "slugs" or obstructions impairing the efficiency thereof during its operation.

This application is also a continuation-in-part of my copending application Serial No. 66,445, filed December 21, 1948, for improvements in Method and Apparatus for Burning Fuel. In that application the mixing zone inside the bladed tuyère was surrounded by the entrainment zone which was disposed outside the tuyère, fuel being

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entrained in air by its passage through the blades or vanes of the tuyère into the mixing zone within the tuyère. According to this invention the entrainment zone is disposed at or in the lower end of the mixing zone formed by the hollow, swirling outwardly moving fuel-air column. In other words, the entrainment zone is within the tuyère, and the fuel is introduced or injected directly into the inner end or lower end portion of the swirling air column, without passage through the blades or vanes whence it passes outwardly through the mixing zone formed by the swirling fuel-air mixture representing, so to speak, the main wall portion of the hollow column within the tuyère, passing thence to the combustion zone which is spaced outwardly from the tuyère.

It is a further object of this invention to provide such a burner and such a method which in addition to being adapted to gaseous and finely divided or comminuted solid fuels or combinations thereof is particularly adapted to liquid fuels wherein the aforesaid breaking of liquid fuel into the small readily combustible particles is followed by a shearing action on the particles whereby a high combustion rate is accomplished in a small volumetric space.

A further object of the invention is to provide a commercial burner assembly including associated wind box, primary air controls, fixed cylindrical tuyère and mounting plate whereby the entire assembly can be readily attached to and/or detached from a furnace.

These and other objects and advantages of the invention will clearly appear from the following description thereof taken in conjunction with the drawings in which:

Fig. 1 is a diagrammatic view in elevation, with parts in section, of apparatus adapted to burn liquid fuel;

Fig. 2 is a horizontal section taken substantially on the plane indicated by the line 2—2 in Fig. 1;

Fig. 3 is a fragmentary section taken substantially on the plane indicated by the line 3—3 in Fig. 1;

Fig. 4 is a substantially central vertical section through a part of a furnace setting showing a horizontally mounted burner;

Fig. 5 is a vertical section on the line 5—5 of Fig. 4 of the modified form of tuyère having a supplementary air feed and shield.

Referring to the drawing in detail, and as shown particularly in Figs. 1 to 3, the burner comprises a tuyère generally designated 10, surrounded by a shell or casing generally designated 11, the space between the shell and tuyère being

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closed at its outer end by an annular, substantially frusto-conical end plate 12 provided with an orifice closely fitting the tuyère 10. The end plate 12 is fixed, in a suitable manner, both to the upper or outer ends of the blades of the tuyère 10, and to the outer end of the shell or casing 11.

At its lower end, the shell or casing 11 is provided with a flange 14 which is bolted or otherwise secured at 16 to a flange 17 in which the delivery duct 19 of the blower 20 terminates. The blower 20 is provided with an inlet duct 21 through which air is drawn and forced through the blower 20 upwardly through the delivery or outlet duct 19 and axially into the shell or casing 11, whence it passes inwardly through the blades or vanes of the tuyère 10 to form a swirling, hollow column of air for a purpose hereinafter described in detail.

The tuyère 10 comprises a plurality of spaced substantially tangential blades or vanes 22, having their upper or outer ends fixed to the above described end plate 12, and their lower or inner ends fixed to a seat 23 provided on the tuyère base plate 25. The series of tangential blades form the sidewall of the tuyère 10, the slots or spaces therebetween, which are designated 24, providing a plurality of elongated substantially rectangular air inlets, spaces or air paths, through which the low-pressure air from the interior of the casing 11 passes into the interior of the tuyère 10 to form the above described swirling, outwardly moving hollow column of air.

The base plate 25 is provided internally with a fuel chamber 26 disposed substantially coaxially with respect to the tuyère 10 and communicating with a frusto-conical seat 27 leading thereto. The base plate 25 is also provided with a centrally arranged packing gland generally designated 28, through which extends the threaded stem 29 of a mushroom-type valve member 30 having the periphery of the head portion thereof substantially complementary with the above described frusto-conical seat 27. This valve member 30 may be moved rotatably and/or axially with respect to the gland 28 by means, and for a purpose, hereinafter fully explained.

The space between the periphery of the valve 30 and the seat 27 forms an annular inlet or injection orifice 26a through which fuel from the fuel chamber 26 may pass upwardly and outwardly directly into the swirling, hollow column of air formed by passage of the low-pressure air from the interior of the casing 11 through the air inlets, spaces or air paths 24 into the interior of the tuyère 10. By axial adjustment of the valve 30, with respect to the seat 27, as hereinafter described, the area or size of the injection orifice 26a may be varied to accommodate fuels of various grades or types.

Fuel is supplied to the fuel chamber 26 by means of the pipe-like inlet 32 extending radially from the base plate 25 and preferably formed integrally therewith, as shown, through the wall of the shell or casing 11 to which it is secured in fluid tight manner, as by means of welding 33, as shown. The outer end of this inlet 32 is preferably secured in suitable manner as by a union 34 with the delivery 35 of fluid supply means under suitable pressure. Thus, fuel from the delivery pipe 35 passes into the fuel chamber 26 and is then supplied or injected upwardly and outwardly through the orifice 26a defined by the seat 27 and the periphery of valve 30 directly into the lower end portion of the swirling outwardly moving hollow column of air, as

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shown in Fig. 1, being broken up into fine particles and thoroughly mixed with the air to form a uniform fuel-air mixture or suspension, which is readily combustible.

As will be readily understood, by varying the size of the orifice, by adjusting the valve 30, the rate of feed of a given fuel may be varied according to the pressure of air in the shell or casing 11, and the variation thereof likewise permits of the use of liquid fuels of widely varying properties in the burner system.

The means for accomplishing the above described rotary and/or axial adjustment of the valve 30, with respect to the base plate 25 and the seat 27, comprises the worm wheel 39 screw threadedly attached to the threaded stem 29 of the valve 30 and a cooperating worm 40. The worm wheel 39 is supported at its upper end by a suitable bearing or seat provided for that purpose in the base plate 25 and at its lower end by a seat or bearing surface provided in the supporting bracket 41 which has the legs thereof fixedly secured, as by means of bolts 42, to the inner side of the base plate 25 in such manner that it is rigidly secured thereto. A pair of aligned similar supporting brackets 43 spaced axially with respect to the worm 40 support the worm for rotation without axial movement, and the shaft 44 extending from one end of the worm 40 is supported by a fluid tight bearing 45 supported in the wall of the shell or casing 11 through which the shaft 44 extends, the shaft 44 being provided at its outer end with suitable manually operable means such as the crank 46.

The pitch of the screw threads in the worm wheel 39 and the valve stem 29 is sufficiently steep to prevent relative rotation therebetween when the worm wheel 39 is revolved through the crank 46. The valve member 30, however, is provided with means such as the sockets 31 which may be engaged by a suitable tool such as a spanner to hold the valve 30 stationary when the worm 40 is revolved whereby rotary movement of the worm wheel 39 is transmitted into axial movement of the valve 30 to increase or decrease the size of the feed or injection aperture. Likewise, the spanner or other tool may be revolved, without actuation of the crank 46 to cause relative rotary movement with respect to the worm wheel 39 and the valve 30 which is, of course, converted into axial movement of the valve 30 for the same purpose. The nature of the worm and wheel is such that the worm thus acts as a locking member, preventing such rotation of the valve 30 from revolving the worm wheel 39.

If the orifice between the valve 30 and the seat 27 becomes plugged up, or if the fuel causes the deposition of gum or other solid matter therein, revolution of the valve member 30 through the crank 46 may be accomplished to free the orifice of the obstruction without shutting down the burner, and without changing the adjustment of the valve 30.

While the above description relates to liquid fuel, and while the source of liquid fuel is shown in Fig. 1, it is, of course, to be understood that the above structure may be readily modified for use with gaseous or fluidized powdered or comminuted solid fuel by connecting the inlet 32 or 52 to such a source, in a manner which will be readily understood by those skilled in the art.

Operation

An important feature of this invention is the production of a fuel-air suspension in the form of

an open, swirling vortical fuel-air column designated 60 in Fig. 1. As a result of the high velocity of air passing through the blades, this column 60 is unclosed, or open, throughout its length and has a reduced pressure center. The setting up of forces acting in opposition to the vertical or outward linear velocity component of the fuel particles is obviated so that the fuel particles travel freely and generally spirally outwardly through the tuyère. They are thus thoroughly mixed with or suspended in air from the entrainment zone adjacent the junction of the injection orifice with the interior of the tuyère 10, through the adjacent mixing zone 62 extending substantially throughout the length of the tuyère, to the burning zone 63. This latter zone is so spaced from the casing or shell 11, and other parts of the burner, as to relieve these parts of the necessity for withstanding combustion temperature.

While this column 60 is herein described as "generally cylindrical," as hollow and open throughout its length, which is necessary in such a fuel-air column to achieve the objects and advantages of this invention, it might, perhaps, more accurately or mathematically be described as parabolic or truncated parabolic the inner surface being defined by a parabola of revolution with its theoretical vertex lying below or outside the end wall of the tuyère 10, which is formed by the valve 30 described above.

Because of the spacing of the burning zone or combustion zone from the mixing zone and entrainment zone, the separate particles of fuel pass, generally speaking, in spiral or helical paths in fully dispersed air borne condition, whereby substantially complete combustion thereof is achieved in the burning zone.

If forces in opposition to the outward or linear velocity of the fuel column (which are herein obviated) did exist, there would be a tendency for these separate fuel particles to fall out of suspension, which would materially impair the efficiency of the combustion, since the uniformity of the fuel-air suspension supplied to the burning zone 63 would be impaired or destroyed, resulting in periodic fluctuations which would produce, intermittently or periodically, incomplete combustion.

Closing of the column 60 at the bottom of the tuyère 10, would result in the production of such deleterious forces in opposition to the aforesaid outward or linear velocity of the component of the swirling fuel-air column, and consequent impairment of the uniformity of the suspension and the uniformity of the outward component of this velocity which are the factors upon which uniformity of combustion is dependent.

I find that it is not only necessary to provide the previously described column of helical moving air-fuel mixture, but that great care must be used to prevent a premature discharge of the fuel from the mixture which may occur from a sudden change of velocity as the mixture moves out of the restricted tuyère area. As one effective manner of accomplishing this, I provide a curb or refractory chamber 65 adjacent the end of the tuyère such chamber being adapted to embrace and be mounted upon the top plate 12 of the tuyère.

In small furnaces with relatively low heat input, and with air pressures and velocities near the minimum that will successfully operate with this type of burner, I consider it especially desirable to form the inner wall 66 of the curb as

a surface generated by rotation of a parabola about an axis perpendicular to the base so that the increase in cross sectional area is comparatively slow as compared with the outward movement of the column of the fuel-air mixture to the flame of combustion. In such a construction unusually good combustion results.

The refractory curb or combustion chamber permits a stable sustained combustion in part also apparently because of the re-radiation of the heat back from the curb to the burning fuel particles or vapors and because the whirling action of the air-combustion gas mixture maintains these burning fuel particles in suspension until combustion is complete. The whirling flame will serve to re-ignite the mixture if the tendency were for the burning flame to be quenched with the admission of greater amounts of air.

In starting the burners illustrated, operation is begun by starting the air blower 20 to produce an annular air current of suitable low pressure in the shell or casing 11 which will pass upwardly toward the upper end of the casing 11, thence through the air inlets 24, between the blades 22 of the tuyère, into the tuyère 10, and thence outwardly as a vortex or helical path from the open end of the tuyère 10. The fuel pump, or other fuel supply means, as the case may be, is then started, and fuel is supplied at a suitable rate to the fuel chamber 26 whence it passes upwardly and outwardly through the frusto-conical orifice provided by the seat 27 and the valve 30 into the tuyère and thus into the air vortex by which it is entrained, and thence through the mixing zone 62, through which it travels in a substantially helical path, being thoroughly broken up and mixed or suspended in the current of air in the column 60, passing thence outwardly within this column 60 to the burning zone 63 where combustion occurs. Such combustion may be initiated by a torch or flame.

The vortical movement of the fuel and air within the mixer also causes a low pressure central region in the central region of the combustion zone in which the pressure is so low as to induce into the central path a body which is held over the center of the tuyère. This vortical movement tends to induce some of the hot gases from the combustion chamber as well as a portion of the flame itself into the tuyère so that the heat from the combustion chamber thus heats the fuel and air within the burner for some preheating. This results in highly efficient combustion.

From the above description, it will clearly appear that I have provided a new and improved fuel burner adapted to burn fuel of widely varying properties and characteristics, which burner is extremely self-contained and compact, and which contains no moving parts except, of course, the valve adjustment means of Figs. 1, 2 and 3.

It will further appear that I have provided a new and improved method of burning fuel wherein fuel, either in gaseous, liquid or finely comminuted solid form, is entrained in a vortical generally cylindrical hollow column of air, and thoroughly mixed or broken up therein, being carried by the outward or linear component of the fuel-air column to a point or zone spaced from the entrainment and mixing zones. The distance of the aforesaid spacing of the combustion, entrainment and mixing zones, is controllable through the linear velocity of the vortical, hollow fuel-air column, which is, of course, a function of air pressure in the casing 11 which may be adjusted by damper 11a and of the ini-

tial velocity of the air column impressed upon the burner. It is also dependent upon the ratio of the diameter of the tuyère 10 to the length of the blades or vanes 22. For example, doubling the tuyère diameter, and halving the blade length, while providing the same blade area, pressure drop and air capacity in the burner provides four times the cross-sectional area in the orifice defined by the outer end of the tuyère 10. For this reason, the net axial discharge velocity would be reduced and the pattern of the combustion zone would thus be varied accordingly by variation of the diameter-height ratio.

The term "air" as used herein is to be broadly construed, i. e., it is used broadly, to designate combustion supporting media including gases other than air and mixtures of such gases with air.

The angle of the blades and their relative length and the effective opening will vary for different results, but in general I find it desirable to keep the blades about 0.39 inch in width, with an opening of $\frac{3}{32}$ ". Generally a blade angularity of about $13^{\circ} 55'$ on a 7" diameter tuyère is appropriate. The essential element, however, is the relatively high velocity of air required to pick up the fuel. While I have operated at as low as 30 feet per second, usually I find a minimum of 50 feet per second to be necessary for uniform operation and the top range may be 100 feet per second or more. Higher ranges of 150 feet per second have been used but the pressure drop is excessive and if such a large capacity is required, then a larger tuyère should be used. For practical purposes the range of my burner is about 70% of design capacity to 140% of design capacity. The pressure drop in such case will vary from about 3" of water to about 12" of water. With one pound per sq. in. gauge which is equal to 27.7" of water, I obtained 216% of designed working range.

The following table gives the approximate size of burners heretofore constructed and tested:

	1 MM ¹	4.8 MM	7.2 MM	10.6 MM	12 MM
Tuyère diameter . . .	3	7 $\frac{1}{8}$	7 $\frac{1}{8}$	10	8.7
Tuyère length	3	6	9	9	12
Fuel, gals per hr.					
Bunker C	7 $\frac{1}{2}$	32	48	72	80

¹ NOTE.—MM equals 1 million B. t. u./hr. of heat release.

The following table gives the details of a particular burner:

Length of tuyère—3 $\frac{1}{4}$
Diameter of tuyère—3
Number of blades—18
Width of blades—0.525 inch
Area of inlets, total—4.08 sq. in. or 0.0284 sq. ft.
Gross sectional area of tuyère—7.06 sq. in. or 0.049 sq. ft.
Ratio inlet area to cross sectional area—0.58
Diameter of casing 11—6 inches
Diameter of fuel pan—4 inches
Air pressure in casing 11—0.58 lb. per sq. in.
Air feed rate—200 cu. ft. per min.
Fuel gas heating value—550 B. t. u./cu. ft.
Fuel rate—44.5 cu. ft./min.
Combined feed—244 cu. ft./min.
Volumetric ratio of air to gas—4.5 to 1
Combined feed velocity—8640 ft. per min.
Combined vertical feed velocity—5000 ft. per min.
Pressure drop through tuyères—16 inches of water

Minimum pressure drop for satisfactory operation—3 inches of water

Heat release—1,468,000 B. t. u. per hour

In the above case, the ratio of inlet area to cross sectional area of 58% will result in a low forward component of the fuel-air vortex. My experience has been that with ratios of from 120% to 130%, a much greater forward velocity could be obtained which in certain cases, provides a better flame pattern.

The same burner, under the same conditions using 41.3° A. P. I. kerosene weighing 6.818 lbs. per gal. and having a heat value of 19,810 B. t. u. per lb. burned 8.8 gal. per hour equal to a heat release of 1,128,600 B. t. u. per hour.

The same burner, when charged with powdered coal of 12,000 B. t. u. per lb., supplied at the rate of 64.5 lbs. per hour, the other conditions being the same, gave a heat release of 769,000 B. t. u. per hour.

A further example of capacity is illustrated by a somewhat larger tuyère. In this case a tuyère of 5 $\frac{3}{4}$ inches in height and 5 inches in diameter mounted in an 8 inch casing was supplied with a gas of 550 B. t. u. per cu. ft. heat value of the rate of 181.7 cu. ft. per min. to release 6,000,000 B. t. u. per hour.

While, as above described, the low pressure air which entrains the fuel becomes combustion air, i. e., all of it takes part in fuel combustion, other, secondary air may be added to this low pressure air where the combustion air requirements are greater than this low pressure air.

The application of the foregoing general principles may also be applied to a horizontal type of burner. While it could be expected that a fluid fuel would normally tend to drain away from the high point of the tuyère, with a non-uniform flame, this was not a fact if the feed head closely fit the end of the tuyère. In such a case the feed of fuel is suitably accomplished at only sufficient head to maintain the feed pan full and by starting the air first, the flame is uniform.

The advantage of this discovery is of major importance for many furnace installations require a wall burner, not only for accessibility but also for uniformity of heating. A commercial burner mounting of this type which is adaptable to a furnace side wall is shown in Fig. 4. The burner mounting 70 in this case includes the tuyère 72, its feed pan 73, the primary air duct 74, the wind box 75 and the controls all in an integral unit. Fuel is fed from pan 73 into the tuyère 72 through a substantially annular slot 73a. In this manner, the entire burner mounting 70 may be bolted to the furnace plate 77 as by bolts 78 and the entire unit is in place.

It is only necessary to connect the fuel line at 79 and the air intake at 80 and the unit can be placed in operation at once. A fixed position of the burner from the combustion chamber 82 is assured and operating variables are reduced to a minimum.

It will also be noted that the forward end of the primary air casing 74 in which the tuyère 72 is mounted, extends to the outer edge of the combustion chamber 82 formed in the furnace wall 84 by the lining 85. The diameter of the combustion chamber 82 is preferably from one and a half to three times the diameter of the tuyère opening and it should be about as long in front of the tuyère as it is in diameter. The tuyère 72 itself is thus actually outside of

the furnace and in a zone of relatively low temperature. It is generally surrounded with refractory at 86 which may have a plurality of rows of secondary air ports 86a and 86b connecting the wind box 75 with the combustion chamber.

The secondary air may be brought into the windbox through port 88 and I prefer to use a louvred member 90 with a movable louvred valve plate 91 to vary the air. This plate 91 may have a handle 92 to permit adjustment during operation, if necessary, bringing more or less of the fixed louvre openings into coincidence with the movable openings.

The tuyère 72 may have two sets of blades 72a and 72b and be provided with a generally cylindrical skirt 94 which closely embraces the blades near their center line and is secured in position by suitable means. The skirt has an effective diameter such that approximately equal amounts of air passing through the main air duct 74 go through the respective blade banks. In large type units, operating under high air velocity, there might otherwise be a tendency to channel the air which may easily be corrected by this device.

Although this very intimate mix carries the fuel particles in a number of turns in a helical path through the tuyère, the path itself is substantially smooth and uniform with a minimum of pressure drop. The air undoubtedly moves faster than the fuel particles however, causing a shearing of the fuel particles so that there is a complete dispersion of the fuel particles in a highly atomized or mixed form. After the desired amount of mixing, the air-fuel mix is thrown out into the combustion chamber 82 in which combustion is completed within a very short distance.

As in the prior case the blades may be struck out of a suitable metal which need not be completely heat resistant itself. I find that although temperatures of several thousand degrees Fahrenheit are generated in front of the burner, the rapid passage of air tends to keep the blades relatively cool. Long life of blades has been attained by using the various alloy steels such as 18% nickel, 8% chrome, and others. Preferably the blades are straight throughout their length to simplify their fabrication.

When preheated air is used to aid in reducing the viscosity of the fuel, as for example use of 450° F. preheated air on asphalt or 250° F. air on Bunker C, to establish a fuel viscosity having from 20 to 30 centipoises and thus exceptionally high heat release, the tuyère face 72c unless covered by refractory as in Fig. 2 becomes excessively hot. This is of course due to the radiation from the furnace and as the blades of the tuyère extend from the face plate to the fuel feed pan 73, some premature coking may take place.

As shown in Fig. 5, I have found that the mounting of a face plate shield 74a extending from the casing 74 to be especially effective. This shield which may be of a suitable heat resisting alloy such as 25% chrome and 12% nickel extends substantially parallel to the face plate 72c and to a position not beyond the plane of the end of the tuyère so that it does not interfere with the discharge of the fuel-air column. It may be provided also with two rows of apertures or air ports 72d.

The air which passes through ports 72d under the shield tends to cool not only the shield but also tends to cool and insulate the face plate 72c. In operation, I have found that the temperature

at the end of the tuyère 72 may be reduced from approximately 1500° F. to approximately 450° F. and thus avoid any coking.

The principal advantage of the internal or inside fuel feed is that the pressure drop of the blades is materially reduced so that either more fuel is delivered or less pressure drop is taken for the same size of tuyère. In addition, the presence of the fuel within the tuyère tends to reduce wetting of the blades and reduces any tendency of the fuel to coke. With solid comminuted fuels, there is no attrition on the blades which might otherwise be objectionable. In each case of inside feed the fuel is distributed to a zone between the inside and outside walls of the air column whereby entrainment is readily accomplished. If the fuel is introduced to the center of the tuyère, it is resisted by the high speed rotation and centripetal resistance of the internal wall of the air column. With an increased velocity of the inlet air, the column 60 tends to become more nearly cylindrical and the fuel should be introduced closer to the tuyère wall to avoid a central unburned jet which otherwise results.

It is, of course, to be understood that the above description is merely illustrative and in nowise limiting, and that I desire to comprehend within my invention such modifications as are included in the scope of the following claims.

Having thus fully described my invention, what I claim as new and desire to secure by Letters Patent is:

1. A method of burning fluid fuel utilizing a cylindrical mixing chamber open at its outer end and closed at its inner end, and having an annular side wall formed with a plurality of circumferentially spaced tangential air inlet slots extending to the closed inner end, and a casing surrounding the mixing chamber and closed at the outer end, said method comprising feeding air axially of said casing and over the length of the slotted side wall of the mixing chamber to direct the air through the slots and tangentially into the mixing chamber, said air being fed at such rate and angular relation to the axis of the mixing chamber that there is formed an outwardly moving rotating column of air with a partial vacuum in the center thereof, supplying fuel annularly to the inside of the mixing chamber adjacent the side wall at the closed inner end thereof and entraining said fuel by contact with the portion of air entering the inner end parts of the slots with said fuel being intimately mixed into and moved outwardly with the rotating column of air as an annulus along the wall of the tuyère, discharging the fuel-air mixture as a vortical column into a combustion zone of elongated restricted circular cross section spaced outwardly from said mixing chamber, constraining the fuel-air mixture discharged into said combustion zone to a rotating outwardly moving hollow column and burning said fuel-air mixture in said combustion zone as a continued rotating annulus.

2. In a fluid fuel burner, a tuyère having its side wall formed by a plurality of fixed generally tangentially disposed blades extending substantially throughout the length of the tuyère and forming inwardly directed air inlets therebetween, said tuyère being open at one end and having fuel feeding means within the interior thereof adjacent its opposite end, said fuel feeding means forming an airtight end for the tuyère, means for supplying fuel through said fuel feed-

ing means axially into said last named end of said tuyère adjacent the inner edges of at least some of said air inlets, means for supplying air through said air inlets between said blades for forming a hollow swirling outwardly moving column adjacent the inner wall of said tuyère and an inwardly moving central core, said column comprising a combustible fuel-air mixture, means at the inner end of the last-mentioned means and directed axially of the tuyère for supplying air under pressure, and an elongated combustion chamber registering with the outlet of said tuyère, said chamber having a refractory wall larger than the tuyère outlet but small enough to restrict the lateral component of the fuel-air mixture as it discharges from the tuyère, said combustion chamber having a diameter of from $1\frac{1}{2}$ to 3 times the diameter of the tuyère opening.

3. In a fluid fuel burner, a tuyère for mixing air and fuel and for discharging the combustible fuel-air mixture into an adjacent combustion chamber said tuyère having its side wall formed by a plurality of fixed, annularly-spaced blades projecting from the wall throughout substantially the entire length of the tuyère and forming inwardly directed converging air inlets therebetween, said tuyère being open at one end and being closed on the other end, a fuel feeding inlet orifice extending through the closed end of the tuyère, means for supplying fuel through said fuel feeding inlet orifice into the closed end of said tuyère adjacent the inner edges of at least some of the said air inlets, an enclosure surrounding said tuyère and fixedly secured to the open end, air supply means in communication with said enclosure whereby air under pressure will pass through said inwardly directed air inlets to form an outwardly moving vortical column of air within the tuyère and adjacent the wall thereof, said column entraining fuel discharged into the tuyère to form a combustible air-fuel mixture, said column inducing an inwardly directed flow of gas from the combustion chamber into the central part of the column, and an elongated combustion chamber comprising a chamber of revolution having a minimum diameter at least as great as the tuyère outlet and a maximum diameter approximately equal to its length and not more than three times the diameter of the tuyère outlet whereby vortical mixing in the tuyère is continued as vortical burning in the combustion chamber, said combustion chamber registering with the outlet of said tuyère.

4. A fluid fuel burner as claimed in claim 3 in

which the combustion chamber has a truncated paraboloidal shape.

5. In a fuel burner, a tuyère having its side wall formed by a plurality of generally tangential blades with inwardly convergent air inlets therebetween, said tuyère being open at its outer end and having a wall at its inner end, said wall having a coaxially disposed frusto-conical valve seat therein, an axially and rotatably adjustable valve member cooperating with said seat to form an adjustable annular fuel injection orifice adjacent the inner ends of said air inlets, means for continuously supplying fuel through said orifice, means for manually rotating said valve without changing the axial adjustment thereof to clear said orifice of obstructions and means for supplying air under pressure through said air inlets between said blades for forming a hollow swirling axially outwardly moving fuel-air column in said tuyère.

WARD J. BLOOMER.

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