

Feb. 10, 1959

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2,873,099

APPARATUS FOR BURNING FUEL

Filed June 16, 1954

3 Sheets-Sheet 1

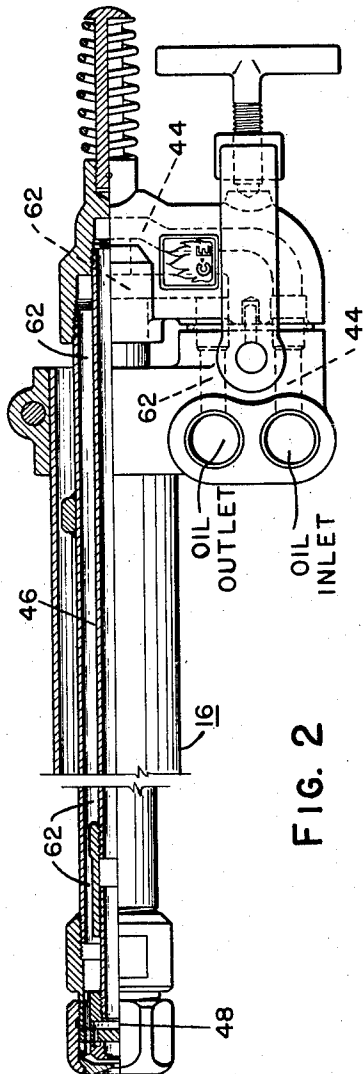


FIG. 2

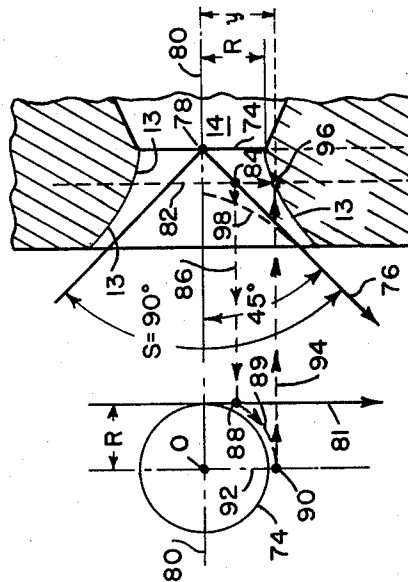


FIG. 1

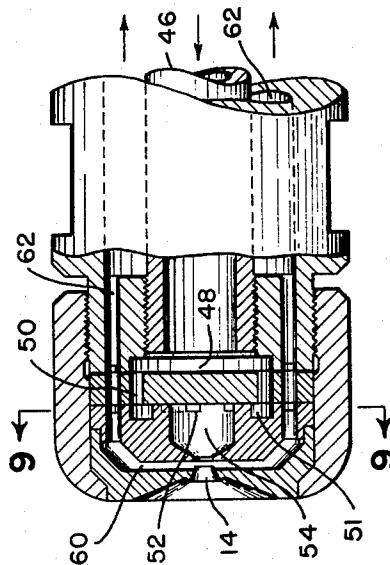


Fig. 3

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3 Sheets-Sheet 2

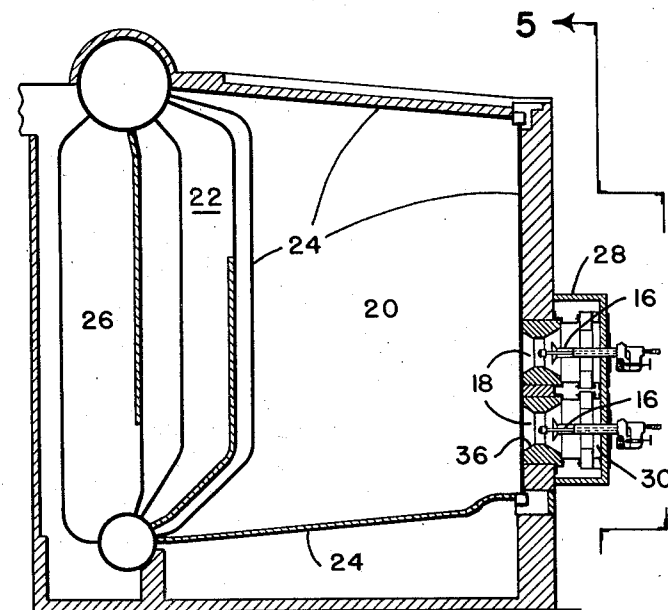


FIG. 4

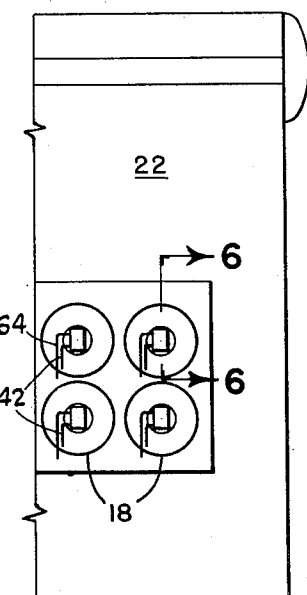


FIG. 5

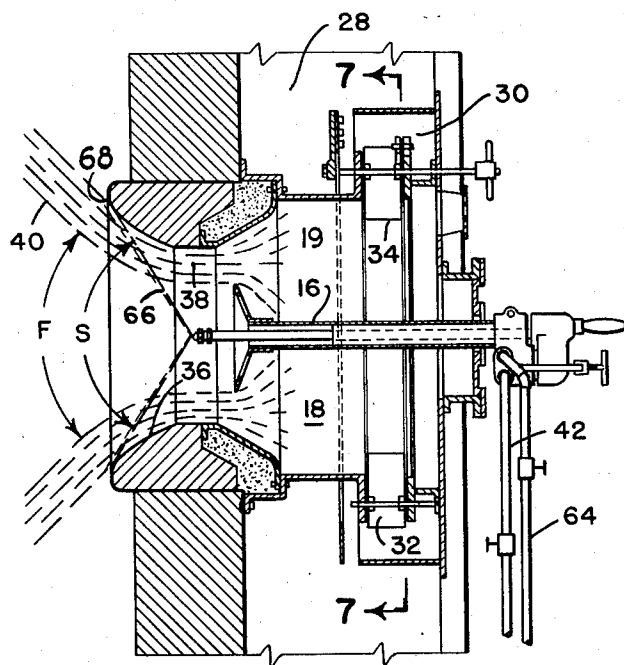


FIG. 6

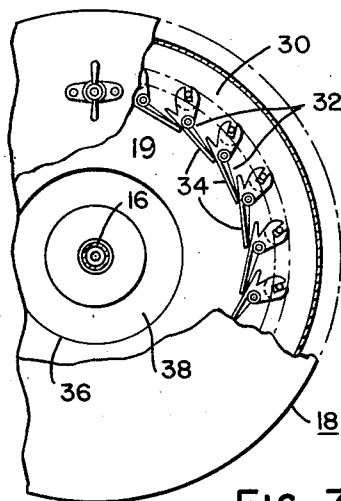


FIG. 7

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Filed June 16, 1954

3 Sheets-Sheet 3



1

2,873,099

APPARATUS FOR BURNING FUEL

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Application June 16, 1954, Serial No. 437,155

3 Claims. (Cl. 158—73)

This invention relates to an improved method and apparatus for atomizing liquid fuel mechanically or by means of centrifugal force without the use of steam or other atomizing medium, and for burning said fuel or other finely divided or gaseous fuel efficiently within a furnace chamber over a wide range of loads. More particularly the invention relates to a liquid fuel burner in which the fuel is being mechanically atomized in such a manner as to maintain a predetermined constant spray angle over a wide capacity range of the fuel burning apparatus, and to a fuel burner in which the air for combustion is discharged with said liquid, gaseous or other finely divided fuel into the furnace chamber in such a manner as to maintain a flame shape having a predetermined constant flame angle over a wide capacity range of the fuel burner.

In liquid burners of the foregoing type the fuel is conducted under pressure into an atomizer tube having one or more whirling ports or channels arranged tangentially to a circular whirlchamber into which the fuel is discharged near an outer wall thereof. The fuel moves in a more or less spiral path toward the center line of the chamber with a progressively increasing angular velocity. The rotating fuel finally leaves the chamber through the spray nozzle orifice passes through the orifice in the form of a hollow or annular jet which is subsequently converted into a conical spray of fuel the apex angle of which is called the spray angle of atomization.

To support combustion of the fuel, air is introduced into the furnace through the burner throat surrounding the spray nozzle. This air is first conducted into an annular chamber, the central portion of which is occupied by the atomizer, by way of air ports spacedly arranged around the periphery of said chamber. Adjustable dampers may cooperate with these ports to direct the air into the chamber tangentially to impart a spiral whirl to the air so that it leaves the burner throat in the form of a hollow cone. The apex angle of this cone controls the shape of the flame and is called the flame angle.

In the operation of such burners burning liquid, gaseous or other comminuted fuels it is very desirable to maintain a predetermined flame angle so as to avoid impingement of the flame on the furnace walls. At the same time it is also desirable to maintain the spray angle of the atomizer constant and in the proper relation to the flame angle so as to achieve complete and efficient combustion of the fuel through adequate mixing of the fuel with the combustion air.

It has been found in the operation of burners not equipped with my inventive improvement that a change in load, that is, a change in quantity of fuel fired and air supplied, may alter both the flame angle and the spray angle by unequal amounts thereby upsetting a previously established efficient relationship between the flame angle and the spray angle. This makes it necessary for the operator upon change of load, to reset the axial position of the atomizer nozzle with respect to the burner throat in order to re-establish the earlier found favorable

2

relationship with the flame angle so as to again provide optimum conditions for efficient combustion. It is often also necessary to correct the flame angle by means of the adjustable burner vanes.

- 5 Adjusting the nozzle position of the several burners used in a large steam generator, for instance, is not only time consuming but wasteful in fuel consumption and lowers the overall efficiency of the power plant. My invention as herein disclosed eliminates the necessity for burner adjustment due to load changes by holding both the flame angle and spray angle constant at all loads thereby achieving optimum burner performance independent of variations in load.

- 15 It is accordingly one object of the invention to provide in a burner for burning comminuted, liquid or gaseous fuels a burner throat which will yield a flame shape the angle of which is held constant over a wide capacity range of the burner.

- 20 It is another object of the invention to provide in liquid burners an atomizer nozzle which enables the atomization of liquid fuel over a wide capacity range of the atomizer while a constant spray angle is being maintained without adjustment of the nozzle position with respect to the burner throat.

- 25 It is a further object of the invention to provide a liquid fuel burner in which the relationship between the flame angle and the spray angle, once having been established as the most efficient one for maximum capacity will remain intact and yield equally comparable efficiency at any other capacity of the fuel burner.

- 30 Still another object of the invention is to provide a liquid fuel burner in which the aforesaid relationship between the flame angle and the spray angle is a built-in predetermined feature of the burner, designed to give optimum performance independent of load without adjustment of the nozzle position, and air vane angle.

- 35 With these and other objects in view, which will become apparent from the following description, reference is made to the accompanying drawings forming a part of this specification and illustrating my invention as applied to the oil fired furnace of a steam generator, without intention of limiting the invention to any particular form or application or use.

In the drawings:

- 45 Fig. 1 is a diagram showing the basic method herein disclosed of geometrically constructing the contour of a burner throat or of the orifice of an atomizer, which method forms the basis of my invention. In Fig. 1 this method is applied in such a manner that a relatively wide flame angle or spray angle, such as 90° is produced.

- 50 Fig. 2 is an atomizing oil gun shown partially in section having an atomizing nozzle which is equipped with the herein disclosed orifice contour.

- 55 Fig. 3 is an enlarged sectionalized portion of the oil gun tip of the gun shown in Fig. 2.

- 60 Fig. 4 is a sectional elevation of a steam generator the oil fired furnace thereof being equipped with several liquid fuel burners embodying my orifice and burner throat contour.

- 65 Fig. 5 is a partial elevational view of the burner wall of the furnace taken on line 5—5 of Fig. 4.

- Fig. 6 is a vertical cross section through the burner wall and burner taken on line 6—6 of Fig. 5 and showing the improved burner with the atomizing oil gun in an enlarged scale.

- Fig. 7 is a fragmental front view of the burner taken on line 7—7 of Fig. 6 and shows a cutaway view of the air ports and dampers.

- 70 Fig. 8 is an enlarged section through the atomizing tip shown in Fig. 3 and taken on line 8—8 of Fig. 9.

- Fig. 9 is a section through the oil gun taken on line 9—9 of Figs. 3 and 8.

Fig. 10 indicates the oil gun movement required for variations in spray angle in a burner organization not equipped with my inventive improvement.

Fig. 11 is a section through the orifice showing the forces acting on the straight and inclined portions thereof.

Fig. 12 is another form of the herein disclosed nozzle contour and illustrates the geometric method of construction as applied to the orifice of a mechanical atomizer designed for a relatively narrow spray angle, such as 60°.

In the following description my invention is presented as being applied to the atomizing orifice of a liquid fuel burner and to the burner throat thereof.

My invention as herein disclosed is however equally well applicable to the burner throat of a fuel burner burning gas, pulverized fuel or other finely divided fuel instead of liquid fuel, since the geometric construction of the burner throat contour as herein disclosed is entirely independent of the type of finely divided fuel used.

In Fig. 1 is represented, in greatly enlarged form, the inner contour 13 of the orifice 14, illustrated in Figs. 3 and 8, of the mechanical oil atomizing gun 16 shown in Fig. 2. For purposes of illustration gun 16 forms a part of oil burner 18 shown in detail in Fig. 6 and also in Figs. 4 and 5 as being mounted in the front wall of furnace 20 of a steam generating boiler 22.

In a boiler of the type illustrated in Fig. 4 steam generating tubes 24 line the walls, bottom and roof of the furnace chamber 20 and additional steam generating surface is provided in the tube bank 26. Fuel oil and air for combustion are fed into furnace chamber 20 through burners 18. The mixture burns with a hot bushy flame the temperature of which may reach 3000° F. It is therefore very important that the shape of this flame be controlled to prevent impingement thereof upon the furnace walls, bottom or roof.

The burners 18 are surrounded by a windbox 28 through which air is supplied from a source not shown. This air enters an annular chamber 30 (see Figs. 6 and 7) and passes through air ports 32 spacedly arranged around the periphery of said air chamber 30 at the outlet end thereof. Air dampers 34, see Fig. 7, direct the air tangentially into chamber 19 causing the air to move in a spiral path as it advances toward the burner throat 36 forming a hollow cylinder 38 which is subsequently transformed into a hollow cone 40 as the air leaves the burner throat 36. The angle F formed by the imaginary apex of this cone is called the flame angle. The angularity of this angle is held normally between 45 degrees and 90 degrees depending upon the location of the burner with respect to other burners or with respect to the furnace walls.

In the operation of a furnace of the kind hereinabove described it is very desirable that the flame angle F be held constant at all loads independent of the quantity of air discharged from chamber 30 through burner throat 36. The reasons for this will become evident as the description hereof proceeds.

The fuel oil is conducted to the oil gun 16 through pipe 42 (see Figs. 6 and 5) under pressure from a source not shown. Referring now to Figs. 2 and 3 the oil passes through conduit 44 into inner tube 46 wherein it proceeds in an axial direction and enters chamber 48. At the periphery of this chamber openings 50 are provided through which the oil passes and enters annular chamber 51 and slots 52. This is more clearly shown in Fig. 8. These slots direct the oil flow in a direction tangential to the periphery of a circular whirl chamber 54 thereby causing the oil entering said chamber to spin at a high tangential velocity.

Centrifugal force created by this velocity causes the oil to form a hollow cylinder 56 as indicated in Fig. 8. The hollow core of this cylinder increases slightly in diameter as the whirling oil advances toward the outlet 58 of whirl chamber 54. Having passed through outlet or orifice 58 of the whirl chamber the oil enters return cham-

ber 60 before a portion thereof passes through atomizing orifice 14. Centrifugal force causes part of the oil entering chamber 60 to return through conduits 62 and pipe 64 to an oil tank not shown.

The oil leaving the orifice 14 forms a frustum-like hollow cone 66 (Fig. 6) similar to cone 40 formed by the air leaving the burner throat 36. The oil cone 66 has an apex angle or spray angle S the angularity thereof being determined by the relative magnitude of the tangential and axial velocities of the oil leaving the discharge orifice 14.

As earlier stated herein it is very important that the spray angle S remain as constant as possible at all loads if optimum burner performance is to be achieved. In a wide range mechanical atomizer not equipped with my improved orifice contour the spray angle S increases at least 20 degrees as the load is changed from full load to minimum. When employing an atomizer of the aforesaid type in conjunction with a burner that discharges fuel into the furnace in a horizontal direction the variation in spray angle requires that the oil gun be repositioned as the load is changed in order to either prevent impingement of the spray on the burner throat 36 at low loads, or prevent by-passing of the air around the oil at high load.

Fig. 10 diagrammatically shows the above mentioned repositioning. The atomizing gun 16 shown in solid lines indicates the position taken when operating at top load the oil being discharged at a spray angle S. The atomizing gun 16' shown in dotted lines indicates the position to which the burner tip must be adjusted at low loads when the spray angle increases to S' due to a change in axial velocity with respect to the tangential velocity of the oil as it leaves the orifice.

The relationship which must be maintained between the spray angle S and the flame angle F is clearly illustrated in Fig. 6.

Thus, in order to achieve complete dispersion of the sprayed oil particles throughout the air stream, which takes the form of air cone 40, the oil must traverse the full thickness of the air stream 40. This is accomplished by an oil cone 66 having the proper spray angle S so that the cone is tangent to the curvature of the burner throat at point 68. In this manner as the sprayed oil transverses the air stream it is picked up by the air little by little and dispersed within the entire air cone 40. Maximum availability of oxygen for combustion is thereby assured for each droplet of oil leaving the atomizer 16.

If the load is increased above a given value in a burner which is not equipped with my inventive improvement the spray angle S decreases causing some of the air to by-pass the oil cone 66 if the nozzle 16 is not shifted to compensate for the change in spray angle.

On the other hand, if the load is decreased the spray angle S increases causing undesirable impingement of the oil spray on the inner contour of the burner throat 36, which again necessitates a repositioning of the oil gun to avoid such impingement.

However in a burner organization designed in accordance with my invention it is now possible to maintain a desirable efficient relationship between the spray angle S of the mechanical atomizing gun 16 and the flame angle F of the burner throat 36 over the entire operating load range of the burner without requiring that the burner gun 16 be repositioned for each load change.

This is accomplished according to the invention by designing and forming the inner contour of the discharge orifice 14 of the atomizing gun 16 in conformity with design principles which will establish and maintain a predetermined desired spray angle S.

Although the present description deals in detail with the contour of the oil atomizing orifice 14, it should be understood that these same design principles also apply to the inner contour of the burner throat 36 making it

possible to establish and maintain a constant flame angle F over the entire operating load range of the burner.

As earlier stated herein the angularity of the spray angle S depends on the relative magnitude of the axial and tangential velocities of the oil spray when leaving the discharge orifice. Or, to express it differently, if the spray angle is too large, it is too large because the tangential velocity is too large with respect to the axial velocity. In accordance with the invention therefore, the contour of the discharge orifice 14 is designed and formed in such a manner as to convert the excess tangential velocity into additional axial velocity, essentially without loss of energy, until the relative values of the two components assume the correct relationship to produce the desired spray angle. At this point the conversion of tangential velocity to axial velocity will cease.

The invention discloses therefore a discharge orifice contour which—provided the tangential velocity is too large—will act to reduce the tangential velocity of the oil stream and increase the axial velocity until the ratio of the tangential to the axial velocity is such that the desired spray angle results, and then ceases to act. Thus, as long as the initial ratio of tangential to axial velocity is too great the spray angle S will be determined by the inherent characteristic of the herein disclosed orifice contour and will not be subject to variations in atomizer dynamics.

Considering now the cylindrical portion 70 of the orifice contour shown in Fig. 11 the tangential velocity of the oil experienced in the discharge orifice 14 causes the oil to exert an outwardly radial or centrifugal force P on the inner surface of the orifice. Conversely, the surface of the orifice exerts an inwardly radial or centripetal force Q on the oil. It is a well known fact that a surface can only exert a force on a fluid in a direction which is normal to the surface. Therefore, by inclining the surface of the orifice so that the diameter thereof is largest at the exit as illustrated at 72 the centripetal force Q creates a force component A which acts on the oil in an axial direction thereby increasing the axial velocity of the oil stream. This increase of the axial velocity takes place at the expense of the tangential velocity, which increase theoretically reduces the spray angle. It can thus be seen that the spray angle S can be reduced, substantially without loss of energy, by means of an inclined surface on the discharge orifice.

According to the invention the inclination of the orifice surface changes gradually, forming a curve which continuously reduces the theoretical spray angle as the oil is guided along the orifice contour until a point is reached when it becomes necessary to prevent reduction of the theoretical spray angle below a desired predetermined value. This is accomplished by providing an orifice the shape of which is the solid of rotation generated by the paths of oil particles leaving the orifice throat or the so-called break circle at the desired angle S .

To bring out the above with more clarity and to describe the geometric method by which the orifice contour is constructed reference is now made to Fig. 1.

For purposes of illustration it is assumed that a wide spray angle such as $S=90^\circ$ is desired. Accordingly draw reference line or base line 76 through point 78 so as to form an angle of one half of the spray angle or 45° with the axis 80, point 78 being the intersection point between axis 80 and the projection of break circle 74. Normal to axis 80 draw a line 81 a distance R from center O , R being the equivalent of the radius of break circle 74. Also draw an arbitrary line 82 (shown in dash) normal to axis 80 intersecting base line 76 at 84. Draw a line 86 parallel to axis 80 intersecting line 81 at 88. Carry point 88 along an arc 89 struck about center O to a point 90 on the diameter 92, thence along a line 94 drawn parallel to axis 80 intersecting the original arbitrary line 82 at 96 which represents one point of the orifice curve 13. Proceed to do the same for as many

points as are required to plot the entire contour of orifice 14.

It was found that an orifice designed according to the above relationship results in substantially perfect spray angle control (without measurable variation) with orifices of fairly short axial lengths (length not more than half of diameter) when the spray angle is above 80° . However when the spray angle is appreciably less than 80° the performance of the orifice begins to fall off. This is due to the fact that the angle between the orifice curve 13 and the axis 80 becomes smaller making available a smaller axial component for theoretical spray angle correction. With a spray angle S of 70° and less the ratio of length to diameter of the orifice becomes so great as to cause considerable spray deterioration at reduced ratings.

According to the invention this difficulty is overcome by changing the shape of a portion of base line 76 (see Fig. 1) from a straight line to a curved line 98 indicated in dotted lines.

This is shown more clearly in Fig. 12 which illustrates the method of constructing a wide range orifice having a relatively narrow spray angle such as 60° as is generally utilized in tangentially fired burners.

It will be noted that a base line starting out with a curved portion, as illustrated by line 98 of Fig. 12, makes use of a large theoretical spray angle at the beginning of the line which angle gradually decreases to the desired smaller spray angle at the end of the base line. This differentiates from base line 76 (see Fig. 1) which line is represented as a straight line maintaining a constant angle (of 90°) throughout its length.

Providing line 98 with a curve at the starting end as shown in Fig. 12 is the equivalent of moving the break circle 74 forward thereby in effect shortening the length of the orifice. This will eliminate deterioration of the spray experienced with orifices constructed for a narrow spray angle (less than 70°) but using the straight base line of Fig. 1.

Having assumed a proper particle path or base line the geometric steps of constructing the orifice contour of a narrow spray angle orifice are exactly the same as those earlier set forth in describing the method shown in Fig. 1.

Thus having determined the desired narrow spray angle which in the case illustrated in Fig. 12 is $S'=60^\circ$, a base curve 99 is selected which has a curved portion 98 the curvature of which is determined by the desired length L of the orifice establishing the location of the break circle 100 and break point 101 on axis 102.

Similar to the description earlier given in connection with Fig. 1 draw a line 103 a distance R' from center O' and normal to axis 102. Also draw an arbitrary line 104 normal to axis 102 intersecting base line 99 at 105. Draw a line 106 parallel to axis 102 intersecting line 103 at 107. Carry point 107 along an arc 108, struck about center O' , to a point 109 on the diameter 110, thence along a line 112 drawn parallel to axis 102 intersecting the original arbitrary line 104 at 115 which represents one point of the orifice curve 116.

Proceed in like manner to determine as many points of curve 116 as may be required to establish the desired contour.

From the above it can readily be seen that any number of base lines or assumed particle paths can be used, from a straight line such as line 76 in connection with a wide spray angle to an inwardly curved line as indicated by line 99 which latter is more suitable for a relatively narrow spray angle such as 60° . The common denominator of these throat shapes resides in the fact that for a short distance before the end of the orifice the generating particle path or base line (such as 76, 99) must have an inclination to the orifice axis equal to one half of the desired spray angle. Thus this inclination is 45° for line 76 and 30° for line 99. It was found when de-

signing wide range orifices that the axial length of this straight portion of the base line should be at least about 5% of the smallest diameter of the orifice. The length of this straight portion may obviously be increased up to the full length of the base line, such as exemplified by line 76, depending on the magnitude of the spray angle S, the length L of the orifice, and other operating conditions. It is however important that the final portion of the base line be made a straight line inclined to the orifice axis at an angle of one half of the desired spray angle.

When applying my invention to the throat contour (such as 36, Fig. 4) of a burner firing gaseous or pulverized fuel wherein a spray nozzle is not required the same basic steps for the geometric construction of the contour are used as those set forth hereinabove in connection with description of Fig. 1. In a burner throat designed in this manner in accordance with my invention, a desired flame angle can be determined to suit furnace heating surfaces and shape and can be maintained over a wide range of load.

In a burner firing a liquid fuel such as oil which utilizes a spray nozzle my invention as herein disclosed makes it possible to select and maintain a suitable flame angle and a suitable spray angle cooperating therewith by properly designing the contour of the burner throat and that of the spray nozzle in accordance with the invention.

While I have shown and described herein above a graphical method of determined various points of the curve 13, forming the basic contour of the atomizing orifice or burner throat of my invention, the location of these points or the shape of the curve can also be determined by the use of the formula

$$y = \sqrt{R^2 + (x \cdot \tan S/2)^2}$$

wherein R is the radius of the throat at the smallest diameter thereof and S is the spray angle (see Fig. 1), x represents the distance of any point of the curve from a line representing the diameter of the so-called break circle 74, said circle defining the point of transition of the orifice curvature, and y represents the distance of the curve point from axis 80.

Thus for a desired spray angle S the location of any point on curve 13 can be determined by assuming a distance x and calculating the corresponding distance y. By repeating this procedure for several points curve 13 can be plotted.

The same method can be followed to plot the outlet end of curve 116 which is based on the straight portion of base line 99 having the desired spray angle S. When plotting the inlet portion of curve 116—that portion which is based on the curved section 98 of line 99—the angle S of the formula must be increased gradually with a decrease of x.

While I have shown and described herein some forms of my invention, it will be understood that minor changes in construction, combination and arrangement of parts may be made without departing from the spirit and scope of the invention as claimed.

What I claim is:

1. In a liquid fuel burner operating under variable load requirements and having a burner throat and a fuel nozzle of the mechanical atomizing type located centrally of said burner throat, said nozzle having an orifice at the outlet end thereof for atomizing and discharging said fuel passing through said burner for combustion in a furnace, means for causing a spiral flow of said fuel through said orifice at a predetermined maximum fuel discharge capacity, said spiral flow having tangential and axial velocity components of sufficient magnitude to produce at the end of said orifice a spray cone having a desired spray angle within the limits of 45° and 120°, said orifice having an inner surface of revolution pro-

duced by revolving a curved line about the longitudinal axis of said orifice said curved line having an outlet end a substantial portion thereof being defined by the formula

$$y = \sqrt{r^2 + (x \cdot \tan S/2)^2}$$

wherein the variable y is the distance of each curve point from the longitudinal axis of said orifice, the variable x is the distance of each curve point from a line perpendicular to said longitudinal axis, said line constituting a diameter of the so-called break circle, r is the minimum internal radius of said orifice and S is the desired spray angle in degree within said limits, whereby said desired spray angle and the positioning of said nozzle with respect to said burner throat can be maintained over a relatively wide range of burner load.

2. A liquid fuel burner according to claim 1 wherein said burner throat is of bell mouth shape for discharging combustion air into said furnace, means for causing a spiral flow through said burner throat of a quantity of said air corresponding to said predetermined maximum fuel discharge capacity, said spiral flow having tangential and axial velocities of sufficient magnitude to produce a flame cone having a desired flame angle within the limits of 45° and 120°, said burner throat having an inner surface of revolution produced by revolving a curved line around the longitudinal axis of said burner throat, said curved line having an outlet end, a substantial portion thereof being defined by the formula

$$y = \sqrt{R^2 + (x \cdot \tan F/2)^2}$$

wherein the variable y is the distance of each curve point from the longitudinal axis of said orifice, the variable x is the distance of each curve point from a line perpendicular to said longitudinal axis, said line constituting a diameter of the so-called break circle, R is the minimum internal radius of said burner throat and F is the desired flame angle in degree within said limits.

3. In a fuel burner operating under variable load requirements, burning finely divided fuel and having a burner throat of bell mouth shape for discharging air and fuel for combustion into a furnace, means for causing a spiral flow through said burner throat of a quantity of air and fuel corresponding to a predetermined maximum fuel discharge capacity, said spiral flow having tangential and axial velocity components of sufficient magnitude to produce a flame cone having a desired flame angle within the limits of 45° and 120°, said burner throat having an inner surface of revolution produced by revolving a curved line around the longitudinal axis of said burner throat, said curved line having an outlet end, a substantial portion thereof being defined by the formula

$$y = \sqrt{R^2 + (x \cdot \tan F/2)^2}$$

wherein the variable y is the distance of each curve point from the longitudinal axis of said orifice, the variable x is the distance of each curve point from a line perpendicular to said longitudinal axis, said line constituting a diameter of the so-called break circle, R is the minimum internal radius of said burner throat and F is the desired flame angle in degree within said limits; whereby said flame angle can be maintained substantially constant at the desired value over a wide load range.

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