United States Patent [19]

Shular

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[54] **BURNER APPARATUS FOR FLAME PROPAGATION CONTROL**

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[52] **U.S. Cl.** **431/9**, 431/185, 431/188

[51] **Int. Cl.** **F23b 11/00**

[58] **Field of Search** 431/9, 182, 185, 186, 187, 431/188, 351, 353

[56] **References Cited**

UNITED STATES PATENTS

1,953,590	4/1934	Cone	431/185
2,368,178	1/1945	Turpin	431/284
3,378,206	4/1968	Poe et al.	431/8
3,481,680	12/1969	Kohn	431/182
3,671,172	6/1972	Chedaille et al.	431/182
3,676,048	7/1972	Sellors, Jr. et al.	431/187

Primary Examiner—William F. O'Dea
Assistant Examiner—William C. Anderson
Attorney, Agent, or Firm—Meyer, Tilberry & Body

[57] **ABSTRACT**

A burner apparatus comprising a fuel burner and flame tunnel in combination. The tunnel is of a suitable refractory material and is substantially trumpet-shaped in cross section, comprising a first substantially cylindrical section and a second, flared section. The first, substantially cylindrical section preferably diverges in the direction of fuel and air flow at an angle of not more than about 3° and preferably about 1 ½° from a cylindrical surface. The length of the substantially cylindrical first section is at least two and one-half and preferably four times as great as the inlet diameter thereof, and the diameter of the large, furnace end of the flared second section is at least two and one-half and preferably four times as large as the inlet diameter of the first section.

Combustion air and fuel are injected with a rotational motion into the flame tunnel. Combustion takes place in the flame tunnel, and a high kinetic energy is imposed upon the burning gas and air mixture within the comfines of the first, substantially cylindrical section. The high velocity attained causes the flame to cling to the tunnel walls, forming a substantially hollow flame. The reduced pressure at the center of the flame facing the furance draws in furnace atmosphere and enhances the formation of a flat, hollow flame even at high firing rates.

9 Claims, 8 Drawing Figures

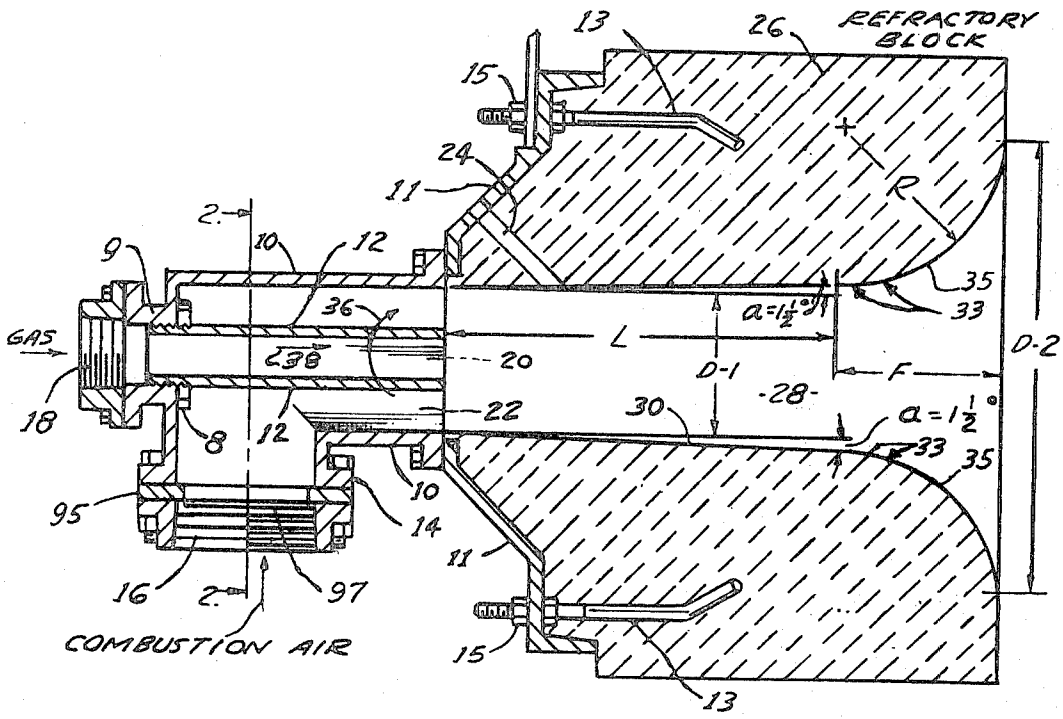
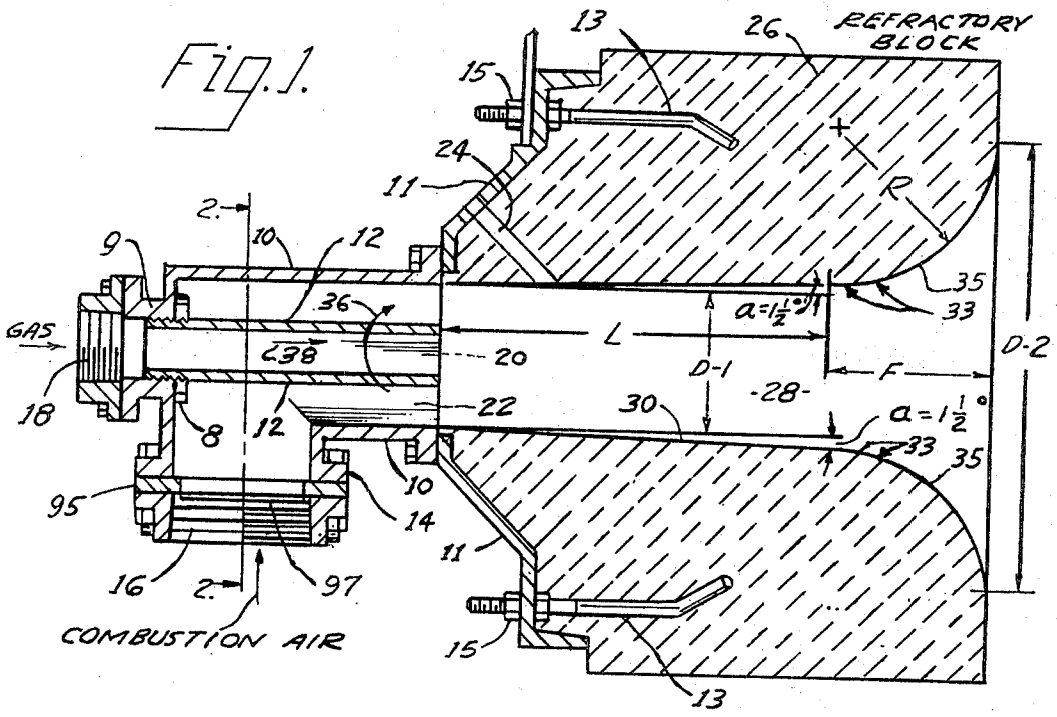


Fig. 1.


13
26
REFRACTORY BLOCK
15
24
11
R
2
10
12
9
35
33
36
a=1½°
GAS
L
20
D-2
D-1
F
18
22
30
-28-
a=1½°
8
12
33
35
95
10
14
11
16
2
97
COMBUSTION AIR
15
13

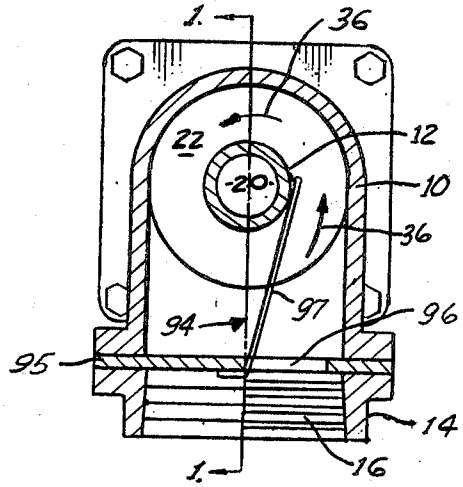
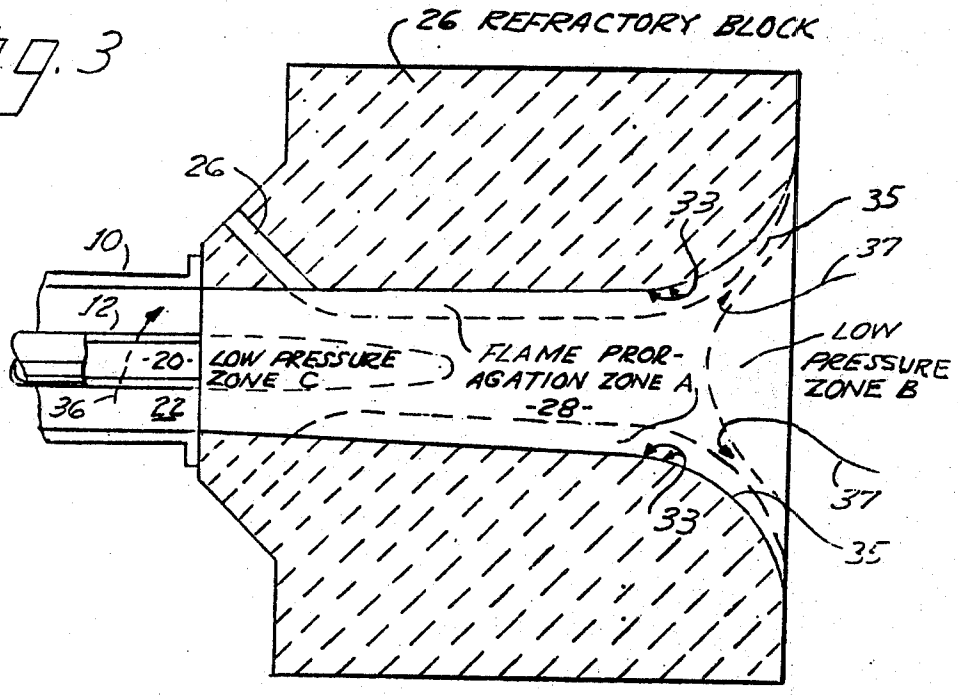

1
36
22
12
20
10
36
97
96
94
95
14
16
1

Fig. 2.

Fig. 3


26 REFRACTORY BLOCK
26
33
35
37
10
12
20
LOW PRESSURE ZONE C
FLAME PROPAGATION ZONE A
28
LOW PRESSURE ZONE B
36
22
37
33
35

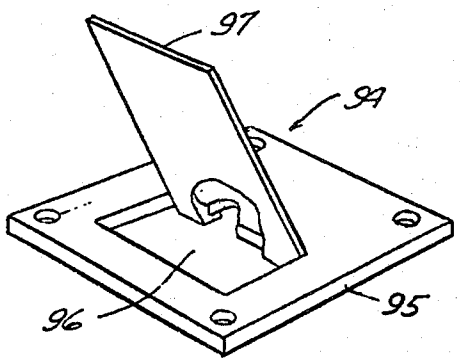
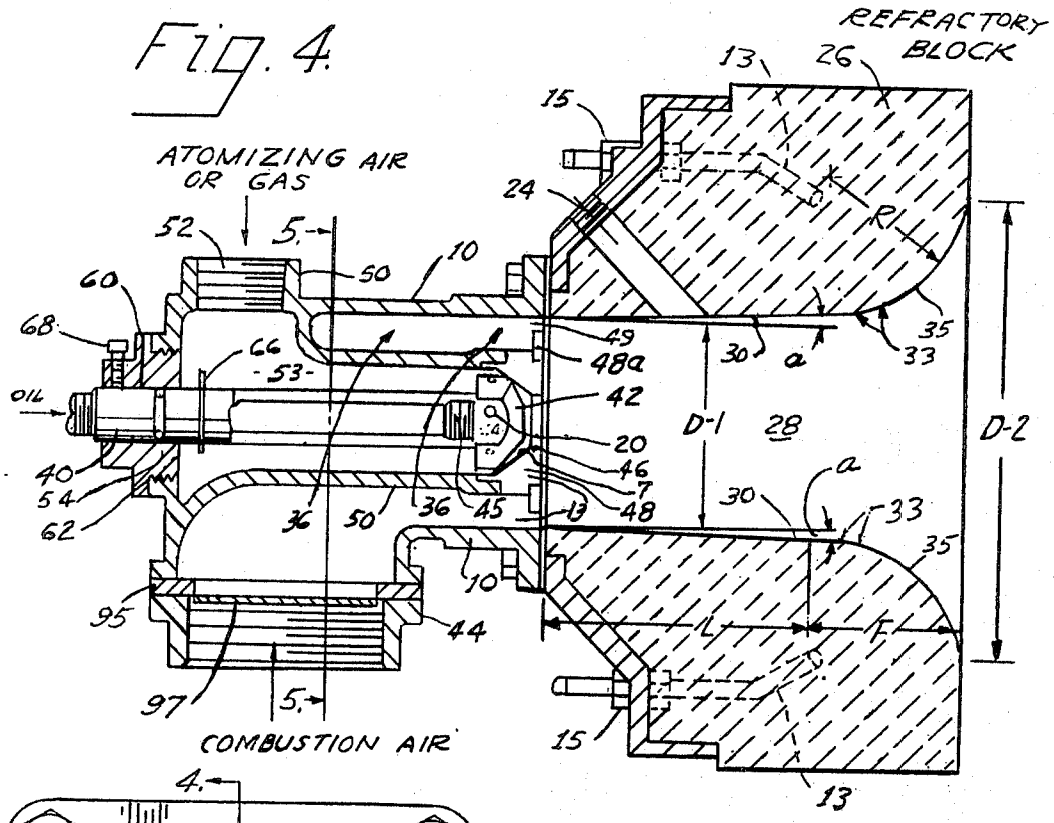

97
94
96
95

Fig 7.

Fig. 4


REFRACTORY BLOCK
ATOMIZING AIR OR GAS
COMBUSTION AIR
OIL
D-1
D-2
28
13
26
15
24
52
5
50
10
60
68
66
53
49
48a
42
20
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54
62
36
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18
30
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44
95
97
R
L
F

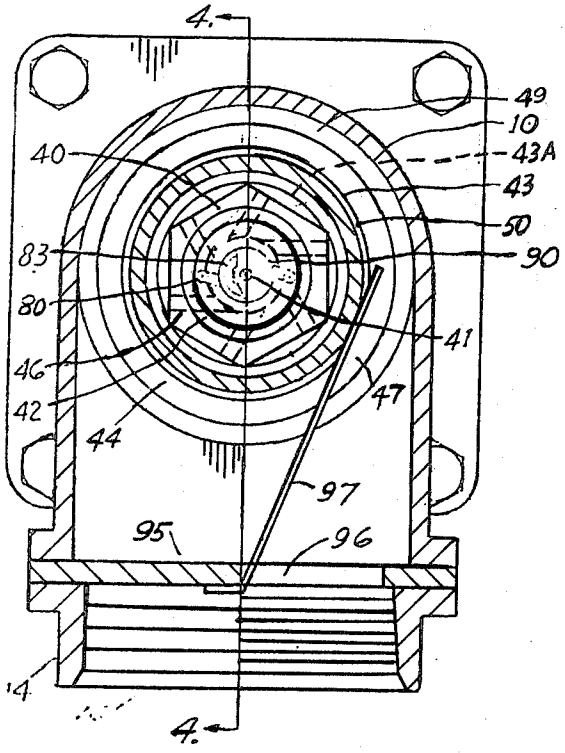

4
49
10
43A
43
50
90
40
83
80
46
42
44
41
47
97
95
96
14

Fig. 5

Fig. 6.

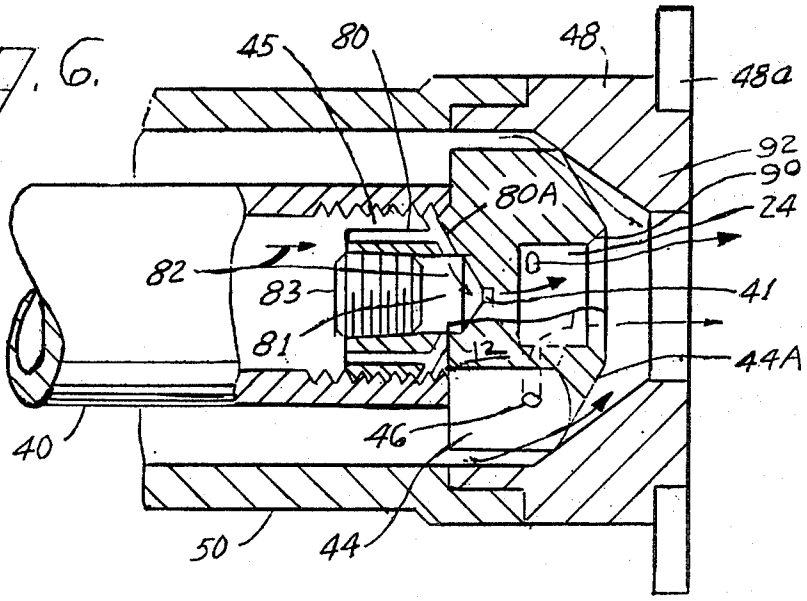
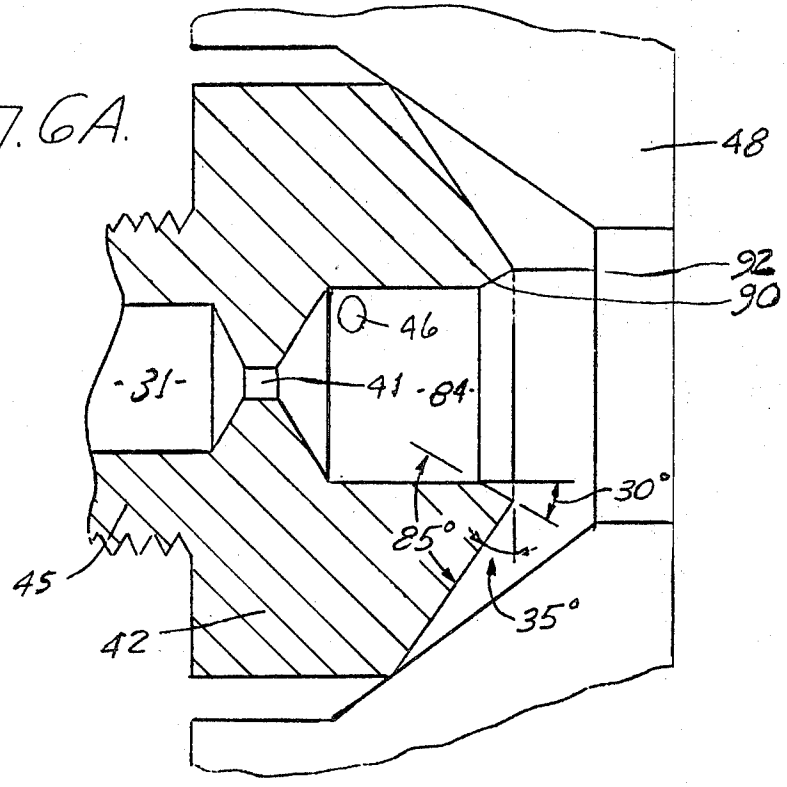

45
80
48
48a
92
90
80A
24
82
83
41
81
44A
40
46
50
44

Fig. 6A.


48
92
90
46
31
41
84
30°
85°
35°
45
42

BURNER APPARATUS FOR FLAME PROPAGATION CONTROL

The present invention pertains to burners for the combustion of fuels, and more particularly, to burners adapted to burn either gaseous or liquid hydrocarbon fuels. The invention is particularly applicable to gas or oil burners such as are employed for a wide variety of commercial process heating applications. Hydrocarbons which are normally liquid at ambient temperature and pressure are hereinafter referred to as "oil" and gaseous fuels such as natural gas, propane gas and the like, which are normally gaseous at ambient temperature and pressure are hereinafter referred to as "gas".

Such burners generally comprise in combination with a flame tunnel, a substantially cylindrical member containing a fuel inlet, an air inlet and a mixing nozzle. The fuel and air are admixed and injected into the flame tunnel, which is formed within a refractory block. In prior art burners the fuel and air are premixed. That is, they are admixed prior to entering the flame tunnel, to insure complete and thorough mixing of combustion air and fuel. Generally, at least a portion of the total combustion air to be used is premixed with the fuel at the fuel inlet into the burner body. Oil is broken up into tiny droplets to form a fine mist prior to combustion, usually by imparting a high velocity to the oil by injecting it through fine nozzles or by impacting it with a gaseous medium, such as air or steam. Combustion air is then admixed with the vaporized oil. The vaporization, sometimes referred to as nebulization of the oil, is necessary in order to attain efficient and complete combustion of oil. Prior art mixing nozzles usually comprise a nozzle through which the oil is sprayed and around which a portion of atomizing air is flowed to impact the oil spray emerging from the nozzle. The atomizing air is flowed through a passageway formed between the outer surface of the nozzle and the inner surface of an adjustable cap surmounting the nozzle, so that the size of the passageway can be varied to attain efficient nebulization of oil at different oil flow rates. Varying the size of the passageway to accommodate different oil flow rates is required because the flow rate of atomizing air usually is constant regardless of the firing (oil) rate of the burner.

Gas, being already in a gaseous state, need only be thoroughly mixed with combustion air, usually by forcing the gas or the air, or both, through restricted passageways and injecting one into the path of the other in order to obtain a rapid and complete mixing and combustion.

Burners and flame tunnels are designed to provide different flame configurations because of the differing demands of different heating processes. For example, it may be desired to have a short, relatively compact "short burst" flame, or an extended "long burst" flame. Heating may be accomplished by direct radiation from the flame to the surface being heated, by convection of hot gases from the flame over the object being heated and, most often, by a combination of the two. Accordingly, it is important to control flame propagation without, however, interfering with nebulization of the oil when it is used as the fuel.

Co-pending patent application Ser. No. 189,447, filed Oct. 14, 1971, and assigned to the assignee of this application, discloses a burner apparatus which includes a refractory block which is cup-shaped in cross-section and has other features as described therein in order to provide a full cross-section, highly radiating flame. The present invention provides a burner apparatus including a refractory block which is substantially trumpet shaped in cross-section and has other features, described in detail hereinbelow, designed to provide a flat, hollow flame over a wide range of firing rates.

The present invention contemplates a new and improved burner and flame tunnel combination and method of operation thereof, which permits control of flame propagation without sacrificing excellent combustion characteristics.

In accordance with the present invention, there is provided a burner having a flame tunnel comprising a first longitudinal section which is substantially cylindrical in shape, and a second longitudinal section, the diameter of which increases from the inlet end thereof so as to describe a flared, toroidal shape. The outlet end of the first section is connected to the inlet end of the second section, with the first and second sections having a common longitudinal axis.

Combustion air and fuel are admixed and injected into the inlet end of the flame tunnel with a rotational motion about the common longitudinal axis of the first and second sections. Combustion takes place within the flame tunnel. The length of the first section of the flame tunnel is long relative to its diameter and consequently, a high rotational velocity is imparted to the burning gas and air mixture passing therethrough. The high rotational velocity of the air and gas mixture provides excellent mixing of the fuel and air and the first section of the flame tunnel thus serves as an extended fuel mixing throat.

Further, the high velocity attained by the combustion mixture in the substantially cylindrical portion of the flame tunnel causes the combustion mixture to reach the second section of the flame tunnel at an earlier stage of combustion than it otherwise would. In those cases where air is present in the furnace atmosphere, this feature makes such furnace air available to assist in completing the combustion of the fuel.

Because the flame/combustion mixture is traveling along the surface of the flared portion of the flame tunnel at a high velocity, the air pressure at the surface of the flame is reduced and a vacuum or zone of reduced pressure is formed at the central portion of the flared, outlet end of the flame tunnel, i.e., at the outlet end of the second section thereof. The reduced pressure zone thus formed causes a portion of the furnace atmosphere to be drawn into and to commingle with the flame traveling along the surfaces of the flared, outlet end of the tunnel. The circulating flow caused thereby tends to trap and reintroduce into the flame any unburnt fuel particles which might otherwise escape, and more importantly, it maintains the hollow, flattened shape of the flame even at increased firing rates. As the firing rate increases, the vacuum formed at the center of the hollow flame increases, the circulating flow of furnace atmosphere likewise increases, and this circulating flow helps to maintain the flat, clinging flame attained in accordance with the invention. By a "flat" flame, it is meant that the "walls" of the cylindrical, hollow flame lie substantially flat against the flame tunnel surfaces, and do not converge to form a conventional, pointed-tip flame.

A very gradual increase in the cross sectional area (in the direction of the flame travel) of the first section of the tunnel of the invention has been found to be advantageous both from the point of view of flame propagation and of ease of manufacture of the flame tunnel. It has been found that by forming the substantially cylindrical portion with a slight divergence in the direction proceeding from the inlet to the outlet portion thereof, the small additional volume which is thereby provided for the expanding, heated combustion gases facilitates the transfer of the growing flame to the flared surfaces of the second section of the flame tunnel. The slightly divergent cross section also facilitates manufacture by permitting easy withdrawal of the mandrel around which the refractory material is cast. Therefore, in accordance with a more limited aspect of the invention, the substantially cylindrical section of the flame tunnel diverges slightly in proceeding from the inlet to the outlet portion thereof. A maximum divergence of not more than about 3° between the surface of the flame tunnel and the surface of a theoretical cylinder concentric therewith is provided, since a divergence larger than about 3° will unduly slow the progress of combustion gases through the flame tunnel, and no divergence at all may create manufacturing problems and may result in too-high a velocity being imparted to the combustion gases. A divergence of between about ½° and 3° is most preferred.

As the flame emerges from the first, substantially cylindrical section of the flame tunnel, it is important that the flame cling to the flared surfaces of the second section of the flame tunnel to form a hollow flame with a reduced pressure area at the center thereof, and not project ahead in a direction parallel to the surfaces of the first section. It has been found that a smooth, clinging transition of the flame from the first to the second section of the flame tunnel is enhanced if the flared section is formed so that the inner surfaces thereof, when viewed in cross section, substantially describe segments of a circle. Therefore, in accordance with a more limited aspect of the invention, the surface of the flared second section of the flame tunnel comprises a substantially circular toroid. The term "substantially circular toroid" as used in this specification and claims, means a flared shape which is substantially circular in any cross section taken perpendicularly to its longitudinal axis, and substantially describes opposed, convex-facing segments of a circle in any cross section taken through its longitudinal axis, and is continuously increasing in diameter from the inlet to the outlet end thereof.

The substantially circular toroidal shape is easier to manufacture than the "teardrop" shapes previously employed and yields satisfactory results in accordance with the invention which results are not attained by the teardrop shapes heretofore employed.

As used in the specification and claims, the "length" of the first and second and transition sections of the flame tunnel refers to the length along their respective segments of their common longitudinal axis; "inlet" and "outlet" used to describe the several diameters or ends of the sections, refer to the movement of fuel and combustion air therethrough.

In accordance with another aspect of the invention, travel of the flame from the first to the second section of the flame tunnel, while maintaining the flame in clinging relationship to the surfaces of the second section, is enhanced by providing a smooth transition surface to which the flame can cling in moving from the surfaces of the first to the second section. The small (in length) transition surface is provided between the substantially cylindrical surface of the first section to the flame tunnel and the substantially circular toroid surface of the second section of the flame tunnel.

Maintaining the flame in clinging relationship along the surfaces of the second section is also enhanced, when oil is employed as the fuel, by insuring complete conversion of the oil to a gaseous state. If the oil is not gasified, the weight of liquid oil droplets will tend to propel liquid droplets, because of their greater mass relative to gas, straight ahead from the first section, rather than causing the fuel to cling to the flaring, diverging surfaces of the second section.

Attainment of a surface-clinging flame is also enhanced by introducing the combustion air into the flame tunnel with a rotational velocity about the longitudinal axis of the tunnel. The centrifugal force thus imparted tends to hold the flame against the surfaces of the flame tunnel.

In order to attain the hollow, flat flame desired, the first section of the flame tunnel must be of a certain minimum length as compared to its diameter, and as compared to the outlet diameter of the second section of the flame tunnel. Therefore, in accordance with another aspect of the invention, the length of the first section of the flame tunnel should be at least about two and one-half times as great as the inlet diameter thereof, and preferably four times as great as the inlet diameter thereof. Similarly, the outlet diameter of the second section of the flame tunnel should be at least about two and one-half times as great and, preferably, about four times as great as the inlet diameter of the first section of the flame tunnel.

The present invention, accordingly, contemplates a new and improved burner and method of operation thereof which provides a controlled, hollow flame which clings to the flame tunnel surfaces and provides complete fuel combustion without interferring with nebulization of oil or proper mixture of fuel and air.

In accordance with the present invention, there is provided a burner in which combustion air admixed with fuel is passed into a flame tunnel which is substantially trumpet-shaped and comprises first and second sections. The first section is substantially cylindrical in shape and the second section is a substantially circular toroid in shape, increasing in diameter from the inlet to the outlet end thereof.

In accordance with another aspect of the invention, the substantially cylindrical first section diverges slightly in the direction of flame travel, preferably, so that the walls of the first section diverge at an angle of between about ½° and 3°, more preferably at an angle between about 1° and 2°, from the walls of a theoretical cylinder placed concentric with the first section, and of a diameter equal to the inlet diameter of the first section.

In accordance with another aspect of the invention, the combustion air is introduced through a slotted, baffled entryway wherein a high velocity and rotational movement is imparted to the air by means of a restricted slotted opening and baffle. The rotation and higher velocity aid in obtaining the clinging, hollow flame.

The invention is applicable to gas burners, to oil burners and to burners adapted to burn either oil or gas.

When the fuel employed is oil which must, as aforesaid, be nebulized into fine particles in order to assure good admixtures with air and complete combustion, a nebulizer nozzle is employed.

In accordance with yet another aspect of the invention, an improved oil nebulizer nozzle is provided which passes fuel oil with a first portion of atomizing air over a knife-edge into a second portion of atomizing air to assist in breaking up the oil into fine particles.

The oil is sheared by the nozzle knife-edge and first portion of atomizing air into fine filaments or sheets which break into small particles upon being impacted by the second portion of atomizing air. The oil particles, in admixture with combustion air, are introduced into the first section of the flame tunnel wherein the high velocity sustained through the length of the section completes nebulization of the oil, and the heat vaporizes the oil droplets into a gas, assuring that no liquid drops persist.

The invention may take physical form in certain parts and arrangements of parts, an embodiment of which is described in detail in the following portion of the specification, and illustrated in the accompanying drawings, wherein:

FIG. 1 shows a longitudinal section view of a burner and flame tunnel in accordance with the invention, adapted to burn gas.

FIG. 2 is a section view taken long lines 2—2 of FIG. 1.

FIG. 3 is a schematic representation of the flame propagation and low pressure zones created by a burner in accordance with the invention.

FIG. 4 is a longitudinal section view of another burner and flame tunnel in accordance with the invention, adapted to burn either gas or oil.

FIG. 5 is a section view taken along lines 5—5 of FIG. 4.

FIG. 6 is an enlarged view in partial section of a nebulizer in accordance with the invention, which is also employed in the burner of FIGS. 4 and 5.

FIG. 6A is a schematic enlarged view of the face of the nozzle shown in FIG. 6.

FIG. 7 is a perspective view of an embodiment of combustion air rotation means comprising a seal plate containing a slot and baffle, which means may be employed in connection with the burner of the invention.

The burner of the apparatus of the invention may comprise a conduit for introducing fuel into the burner, the conduit being positioned within and substantially concentric to a combustion air inlet conduit. Combustion air enters the combustion air conduit via a branch section which joins the conduit at substantially a right angle thereto. The fuel conduit enters the combustion air conduit through an opening provided in the base thereof, the fuel conduit being seated snugly in the opening so that opening is air-tight with respect to air passing through the combustion conduit. The flow of combustion air through the combustion air conduit and the flow of fuel through its conduit are thus maintained isolated one from the other up to the respective exits therefrom, at which point the fuel and combustion air are commingled at the entrance to the first section of the flame tunnel.

It should be noted that the fuel and combustion air are not premixed, that is, they are separately conducted to the entrance of the flame tunnel and mixed at this point, not before. By employing this "nozzle-mixing" technique rather than premixing the fuel and combustion air, the danger of flash-back, i.e., premature combustion of the fuel-air mixture which is always present with premixed feeds, is eliminated.

A secondary conduit to introduce atomizing air when oil is the fuel, or to serve as the conduit for introducing fuel into the burner when gas is the fuel, may be employed in addition to the fuel and combustion air conduits in embodiments of the invention adapted to burn oil as well as gas. In such case, the secondary conduit may be positioned substantially concentrically with respect to the first conduit and combustion air conduits, so that the three substantially concentrically positioned conduits are maintained isolated from flow communication between one another except at the respective exits therefrom, at which point the admixed air and fuel are commingled at the entrance to the first section of the flame tunnel.

The outlet end of the fuel conduit preferably comprises a fuel nozzle of the nebulizer type wherein oil is sprayed into a fine stream and passed into the path of a gaseous medium, e.g., atomizing air, in order to disperse the oil into fine droplets. When it is desired to burn gas as a fuel, the secondary conduit may be employed to carry the gas, in which case the secondary conduit serves as the conduit for introducing fuel into the burner, atomizing air not being required for a gas fuel. (For uniformity, the secondary conduit is always referred to as such, even when it serves to conduct gas in a dual-fuel burner. The fuel conduit is also always referred to as such even though in gas burners it conducts only gas, in oil burners it conducts only oil and in dual-fuel burners it normally serves to conduct only oil. The term "conduit for fuel" as used in the specification and claims is a general term which includes fuel conduit and secondary conduit in a dual-fuel burner.)

In a dual-fuel burner, it is advantageous to seat the fuel conduit adjustably within the burner so that the opening of the secondary conduit into the flame tunnel may be varied in size by adjusting the position of the fuel conduit. In such a case, the nozzle of the fuel conduit serves in effect as a plug or nozzle for the gas introduced into the flame tunnel via the secondary conduit. In this manner, the use of low pressure gas is enhanced since the secondary conduit outlet may be increased in size to accommodate low pressure gas transmitted therethrough.

Referring now to FIG. 1, the gas burner shown is seen to consist substantially of two concentrically positioned conduits 10 and 12, the base 7 of conduit 12 being screwed into the base 9 of combustion air conduit 10. A locknut 8 serves to hold fuel conduit 12 in place.

Branch conduit 14 comprises a conduit of substantially circular cross section meeting conduit 10, also of substantially circular cross section, at substantially a right angle. Combustion air is introduced, as described hereinbelow, via inlet 16 of branch conduit 14.

A mounting plate 11 is employed to hold the burner assembly in place in refractory block 26 by means of lugs 13 and nuts 15, the lugs 13 being molded within refractory block 26.

Combustion air rotation means (indicated generally at 94 in perspective view in FIG. 7) may consist of a

seal plate **95** with a slotted opening **96** cut therein adjacent to a baffle plate **97.** As is best understood by referring to FIGS. **1, 2** and **7** jointly, seal plate **95** is positioned within branch conduit **14** so that baffle **97,** which is substantially as wide as the inner diameter of branch conduit **14,** substantially completely blocks the opening of branch conduit **14** into the lower portion (as viewed in the drawings) of combustion air conduit **10.**

As best seen in FIG. **2,** the opening **22,** of combustion air conduit **10** is substantially doughnut-shaped and concentric to the substantially circular opening **20** of fuel conduit **12.** Openings **20** and **22** lead into flame tunnel **28,** formed within refractory block **26.** The method of forming the flame tunnel within the refractory block forms no part of the present invention and it suffices to state the block is usually cast around a mandrel, the outer surface of which is shaped to form the inner surfaces of the flame tunnel.

A channel **24** leading into flame tunnel **28** contains a pilot light (not shown) which serves to ignite the fuel-/air mixture passing through flame tunnel **28.**

Flame tunnel **28** comprises a first, substantially cylindrically shaped section, the surfaces of which are designated by the numeral **30.** The surfaces **30** are seen to diverge in the direction of flame travel at an angle a of about 1½° from the surface of a theoretical cylinder placed concentrically therewith, and of equal diameter with the inlet diameter of the first section of flame tunnel **28.** The second section of flame tunnel **28** is defined by surfaces **35** which flare outwardly in a substantially circular path from the outlet end of the first section of the flame tunnel **28.** A transition surface indicated by the arrows **33** connects the outlet portion of the first section with the inlet portion of the second section of flame tunnel **28.** Transition surface **33** is shaped to provide a smooth connecting surface between the two sections of the flame tunnel without abrupt changes in direction.

Referring particularly now to FIG. **1,** the inlet diameter of flame tunnel **28** is shown as the dimension D-**1,** and the outlet diameter of the flame tunnel **28** is shown as dimension D-**2.** The length of the first section of the flame tunnel is indicated by the dimension L, and the length of the second section of flame tunnel **28** is shown by the dimension F. The length of transition surface **33** is quite small compared to the dimensions L and F, and is included in the dimension F.

In operation, combustion air enters conduit **10** via branch **14** and passes through slotted opening **96.** Because of the small size of opening **96** a high velocity is imparted to the air passing therethrough. A rotational motion about conduit **12** is imparted to the air by baffle **97** (as best seen in FIG. **2**) which deflects the incoming air, as indicated by the arrows in FIG. **2,** over and around conduit **12.** The combustion air progresses through conduit **10** as shown by the arrows **36** in FIG. **1** and emerges through outlet **22** thereof.

Gas is introduced via inlet **18** of fuel conduit **10,** passes therethrough as shown by arrow **38** and emerges via opening **20.** Gas and combustion air are admixed as they enter the first substantially cylindrical section of flame tunnel **28** in high velocity, rotational motion which tends to force the mixture against the surfaces **30** of the first section of the flame tunnel **28.**

The pilot light (not shown) positioned within channel **24** of refractory block **26** serves to ignite the gas/air mixture, and combustion takes place within the flame tunnel **28.**

As the admixed gas and combustion air mixture enters the first section of flame tunnel **28,** the rotational velocity of the mixture along the length of flame tunnel **28** is maintained and enhanced as the mixture combusts and expands in the relatively long and narrow first section. The length of the first section provides room for thorough admixture of the air and gas; the flame formed tends to cling to the surfaces **30** of the first section, forming thereby a hollow flame as best seen with reference to FIG. **3,** which is a schematic representation of the cross sectional view of the flame. As the flame, shown in cross section as flame propagation zone A, progresses along flame tunnel **28,** it passes over transition surface **33** and enters the second section of flame tunnel **28.** Transition surface **33** connects the first and second sections of flame tunnel **28** with a smooth, gradually diverging surface and the expanding flame clings to the surfaces **35** to provide the hollow, flaring flame desired in accordance with the invention.

A low pressure zone B as indicated schematically in FIG. **3** is formed at the center of the outlet end of the second section of flame tunnel **28.** This low pressure zone is formed by the high velocity along the surface of flame propagation zone A in the second section of flame tunnel **28,** and tends to draw atmosphere from the furnace as indicated by the arrows **37** in FIG. **3.** This aspiration of furnace atmosphere increases as the firing rate increases and thus the velocity of the combustion gases emerging from the flame tunnel increases. The circulating atmosphere helps to hold the flat, clinging flame even at higher firing rates — a feat not attainable by prior art flat flame burners which tend to flare into tipped flames at high firing rates because of the increased velocity of the gases.

As shown in FIG. **3,** the rotational velocity of the combustion air introduced into the first section of the flame tunnel **28** causes a vortex or low pressure zone C to be formed in front of the outlet **20** of fuel conduit **12.** Thus low pressure zone C helps to aspirate fuel out of fuel conduit **12** and is helpful when the available fuel pressure is low.

The relatively long length and small diameter of the first section of flame tunnel **28** advances the gas/air mixture into the second section of flame tunnel **28** at an earlier stage of combustion than it would in the case of a conventionally shaped flame tunnel. This results in a greater proportion of combustion being carried out in the second section of flame tunnel **28,** at a distance removed from the nozzle, which is therefore less severely affected by heat.

As aforesaid, it has been found to be preferable that the dimension L should be at least 2½ times as great as the dimension D-**1,** and, more preferably, at least 4 times as great as the dimension D-**1.** In addition, the dimension D-**2** is preferably at least 2½ times, and, more preferably, at least 4 times as great as the dimension D-**1.** Generally, although not necessarily, the dimension D-**2** will be substantially equal to the dimension L.

The divergence of the first section of flame tunnel **28** from a true cylindrical shape is conveniently measured by the angle a shown in the preferred embodiment of FIG. **1** at the most preferred value of 1½°. Angle a may range up to 3° and is preferably between 1° and 2°. The

divergence of the surfaces 30 of the first section of flame tunnel 28 and the provision of smooth transitional surface 33 tend to direct the flame to cling along the surfaces 35 of the flaring second section of the flame tunnel rather than shooting directly ahead. The surface 35 may be described in cross section as a circle of radius R, as shown in FIG. 1. The dimension F is not critical, except in the sense that it must be large enough to provide a sufficient distance along the surfaces 35 to complete combustion of the fuel, i.e., the distance along the surfaces 35 must be long enough to accommodate the flame. With this in mind, the radius R is determined once the dimensions L, F and D-2 are set. The position of the center of the circle of radius R, the arc of which describes — in cross section — the surface 35, is selected to establish the smoothest possible transition surface between the first and second sections of the flame tunnel.

The embodiment of the invention illustrated in FIGS. 1 and 2 shows a burner adapted to burn only gas. FIGS. 4 and 5 show a burner in accordance with the invention adapted to burn either gas or oil. (It should be noted that similar elements of the various embodiments illustrated are identically numbered in the various FIGURES and their description not repeated, except insofar as is necessary to describe the various embodiments illustrated. The low pressure and flame propagation zones of FIG. 3 apply in general, and are thus applicable also the embodiment of FIGS. 4 and 5.)

Referring now to FIGS. 4 and 5, combustion on air conduit 10 has a branch 14, inlet 16 of which has a combustion air rotation means 94 positioned therein. As best seen in FIG. 5, baffle plate 97 and slotted aperture 96 are provided in a manner similar to that shown with respect to the embodiment of FIGS. 1 and 2.

Secondary conduit 50 is positioned within combustion air conduit 10, and substantially concentrically thereto. Air inlet 52 to secondary conduit 50 serves to introduce either atomizing air (when oil is introduced through conduit 40) or gas (when the burner operates on gas fuel), all as more fully explained hereinbelow. An air deflector 48, with a conical inner surface 47 is positioned at the outlet end of secondary conduit 50.

A combustion air deflector lip 48A is mounted on air deflector 48 and serves to restrict the size of opening 49, through which combustion air enters the first section of flame tunnel 28.

An oil spindle or fuel conduit 40, through which oil is fed to the burner, is equipped with a suitable oil control valve (not shown). Fuel conduit 40 is shown in partial section and is fitted near its outlet end with a nozzle 42, the outer surface 44 of which is polygonal in shape. As best seen with reference to FIG. 6, nozzle 42 is seated within air deflector 48, the inner surface of which is substantially conical in shape. A passageway 43 (FIG. 6) is thereby provided between polygonal surface 44 and beveled surface 44A of nozzle 42 on the one hand, and the conical inner surface 47 of air deflector 48. Dotted line 43A is a section line passing through the inner surface 47 of air deflector 48 to clearly indicate the shape of the passageway formed between the surfaces 44, 44A and 47.

The chamber 53 formed within secondary conduit 50 is seen to be air tight with respect to fuel conduit 40 and combustion air conduit 10. Chamber 53 is in flow communication with passageway 43 and, via opening 20, with the first section of flame tunnel 28. Thus, passage of gas, or of atomizing air and oil, as the case may be, into the flame tunnel is accommodated.

Fuel conduit 40 is seated snugly but slidably in an opening 60 in base 62 of conduit 10. An O-ring 64 serves to seal the opening and make it air tight in respect to atomizing air or gas in chamber 53. A stop ring 66 is affixed to fuel conduit 40 which serves to limit the rearward movement of conduit 40 so that it is not withdrawn an excessive amount. Set screw 68 serves to hold the conduit in any desired, preselected position. It will be seen that by moving fuel conduit 40 to the left, (as viewed in the drawing) passageway 43 between the surfaces of nozzle 42 and air deflector 48 is increased accordingly. Movement to the right, (as viewed in the drawing) will decrease the size of opening 43.

Referring now particularly to FIGS. 4 and 6, the stem 45 of nozzle 42 is seen to be threaded on both its outer and inner surfaces. The wall of the stem contains one or more small inlet passageways 80 which are substantially L-shaped in their effective dimensions, and adapted to introduce oil tangentially into receiving chamber 81, formed within nozzle 42 by plug 83. (It will be noted that the branch portion 80A of conduit 80 is drilled through the wall of stem 45, in a direction such that branch 80A enters receiving chamber 81 tangentially to the walls thereof.) This tangential entry, and the small size of the passageways enhance the energy input to the oil. The upper portion of branch 80A is sealed during operation by oil conduit 40, and the hollow end of stem 45 is similarly sealed by plug 83 to define receiving chamber 81. The open end construction of stem 45 is a manufacturing convenience to permit drilling out of receiving chamber 81 and nozzle aperture 41.

Nozzle aperture 41 of nozzle 42 is a small, substantially cylindrical opening connecting the center of receiving chamber 81 with the center of mixing chamber 84. Atomizing air inlet ports 46 enter mixing chamber 84 substantially tangentially to the walls of the mixing chamber as best seen in FIG. 5. Each face of polygonal surface 44 has an atomizing air inlet port 46 drilled therethrough (FIG. 5).

The outlet side of mixing chamber 84 has a chamfered surface 90 which terminates in a circular, knife-edge rim 92. Knife-edge rim 92 is thus positioned near the outlet end of opening 43 between nozzle 42 and air deflector 48.

Referring particularly to FIGS. 6 and 6A, it is seen that mixing chamber 84 comprises a cone-shaped inlet section and a substantially cylindrical-shaped main section. Further, the diameter of the cylindrical main section is approximately equal to the length of the mixing chamber 84. Chamfered surface 90 is at an angle of about 30° from the horizontal, i.e., 30° from the wall of the cylindrical section, and the cross sectional trace of beveled surface 44A is at an angle of about 35° with the vertical. These angles fix the angle included between the faces forming knife-edge rim 92 at about 85°. Knife-edge rim 92 should form approximately a right angle, preferably slightly less than a right angle, so that substantially right angle impaction between oil filaments and air is attained, as explained below. Accordingly, an 85° angle is preferred.

The dimensions of the nozzle as described have been found to promote efficient nebulization of the oil when the proper proportion of atomizing air is maintained

between injection ports **46** and passageway **43**, as described hereinbelow. The dimensions of the mixing chamber promote good entrainment and filamentation of the oil, and the approximately right angle knife-edge insures good impact fractionation. Further, when these dimensions are employed for the nozzle, the need for an adjustable cap, as required for nozzles of prior art oil burners, is eliminated and air deflector **48** may be fixedly mounted with respect to nozzle **42**. That is to say, it is not necessary to provide for adjustment of the size of passageway **43** to accommodate different oil firing rates, even though the overall atomizing air flow rate remains constant. (In the dual fuel embodiments illustrated, the size of passageway **43** may be adjusted for operation with gas, in order to assist the flow of low pressure gas. For operation with oil burners, the position of nozzle **42** and the size of passageway **43** is fixed. In the case of a burner to burn oil only, the nozzle **42** would be permanently fixed with respect to air deflector **48**.)

In operation, oil introduced via fuel conduit **40** enters small passageway **80** as shown by arrows **82**, and is sprayed into receiving chamber **81** in a tangential fashion, emerging via nozzle aperture **41** into mixing chamber **84** as a fine, cone-shaped stream of oil. The small size of aperture **41**, the high velocity imparted to the oil by passage through it and small passageway **80** and the smooth, tangential entry into mixing chamber **84**, all assist in injecting the oil into mixing chamber **84** with high kinetic energy as a fine stream.

Atomizing air is introduced through secondary conduit **50** via inlet **52** as shown by the arrow in FIG. **4**. Atomizing air enters inlet ports **46** contained in nozzle **42** which direct the air tangentially into mixing chamber **84** and into oil emerging via aperture **41** from receiving chamber **81**. Within mixing chamber **84**, the fine stream of oil is entrained by the air entering via inlet ports **46** and expelled outwardly over chamfered surface **90** and knife-edge rim **92**, as fine filaments or sheets of liquid. Of the total amount of atomizing air employed (which is usually constant), between about 50% and about 70% enters through inlet ports **46** to entrain the oil in mixing chamber **84**. Since the atomizing air usually comprises about 10% of the total (combustion air plus atomizing air) air input to the burner at full firing capacity, atomizing air passed through inlet ports **46** comprises about 5% to 7% of the total air to the burner. The remainder of the atomizing air, about 3% to 5% of the total air input, passes through passageway **43**. The portion of atomizing air passing though passageway **43** impacts the fine filaments of liquid at an angle substantially transverse, i.e., substantially a right angle, to the direction of oil flow, as shown by the arrows in FIG. **6**, thus insuring the complete nebulization of the oil into fine droplets. Thus, although the overall atomizing air rate remains constant at about 10% of the full firing capacity total air rate, the respective proportions of atomizing air passed through passageway **43** and inlet ports **46** respectively may be set within the limits described. For a given burner nozzle, the proportion is set by the size of inlet ports **46** as compared to the size of passageway **43**.

It will be understood that some of the oil may have been broken up into fine droplets prior to streaming over knife-edge **92**. Nonetheless, the unnebulized oil reaching knife-edge **92** has been reduced to exceedingly fine filaments of liquid and is impacted by the atomizing air passing through passageway **43** into extremely fine droplets by virtue of the thinness of the filaments and the substantially transverse angle of the high velocity atomizing air with respect to the direction of oil travel. At increased oil supply rates, the oil increases in proportion to atomizing air passed, respectively, through passageway **43** and inlet ports **46**. The oil supply rate may be measured in gallons of oil per hour per linear inch of circumference of knife-edge rim **92**. The burner of the invention employing the fixed cap and substantially right angle knife-edge face, described above, operates with efficient oil nebulization at oil rates of between about 3 to about 8 gallons/hour/inch. The atomized oil passes into first section of flame tunnel **28**.

By diverting a portion of the atomizing air via inlet ports **46** through mixing chamber **84** in the same direction of flow as the oil spray therethrough, disruption of the oil spray by atomizing air passing through passageway **43** and into mixing chamber **84** in a direction counter to or transverse to the direction of oil entering from aperture **41** is prevented. The diverted air injected into mixing chamber **84** thus insures entrainment of the oil in droplets or fine filaments past chamfered face **90** and knife-edge **92** into transverse flow contact with the air passing through opening **43**, as aforesaid.

Combustion air introduced via inlet **16** of branch conduit **14** has imparted to it a high rotational velocity by passing through slot **96** and around baffle **97** substantially as described with respect to the embodiment of FIGS. **1** and **2**. The rotating combustion air passes through opening **49** between air deflector lip **48A** and the inner surface of conduit **10** (as best seen in FIG. **4**). The nebulized oil and atomizing air are thus admixed with combustion air at the inlet to the first section of flame tunnel **28**.

The admixed, nebulized oil and combustion air mixture is ignited by a pilot light (not shown) positioned within pilot light channel **24**. Thereafter combustion and attainment of the hollow flame provided in accordance with the invention is as described with reference to the embodiments of FIGS. **1** and **3**.

The dimensions of flame tunnel **28** in the embodiments of FIGS. **4** and **6** may be different from those shown with respect to the embodiments of FIGS. **1** and **2**, but preferably they will meet the criteria that the dimension L is at least two and one-half (and preferably four) times as great as the dimension D-**1**, and the dimension D-**2** is at least two and one-half (and preferably four) times as great as the dimension D-**1**.

When oil is employed as a fuel, the relatively long length of the first section of flame tunnel **28** provides an opportunity for complete gasification of the nebulized fine droplets of oil so that by the time the fuel/air mixture reaches the end of the flame, the oil fuel is present in the form of a gas. This not only insures complete combustion but eliminates relatively heavy liquid droplets which would tend to shoot ahead and not cling to the surfaces **35** as they emerged from the first section of flame tunnel **28**. The distance between the fuel nozzle **42** and the point of ignition, which is generally some distance downstream of the point at which the pilot light meets the mixture, keeps the nozzle some distance removed from the heat of the flame which helps to prevent carbonization of the oil within the fine conduits of the nebulizer nozzle.

The ability to position fuel conduit 40 to adjust the size of the passageways 43 permits regulation of the flow of atomizing air therethrough, and when the dual fuel burner is operating with gas as a fuel, permits regulation of the amount of gas flow. When gas is employed in the embodiment of the invention shown in FIGS. 4 and 5, the oil flow through fuel conduit 40 is closed off by a valve (not shown) and the gas is introduced into the burner via inlet 52 of secondary conduit 50. The gas flows through chamber 53 and follows the same path that is followed by the atomizing air, that is, the gas passes through passageway 43 and through inlet 46 of fuel nozzle 42. The gas is admixed with combustion air passing through conduit 10 as shown by the arrow 35, and thence into flame tunnel 28. The passageways 43 are increased in size when the gas supply is at low pressure so as to facilitate the passage of low pressure gas through the burner.

Introducing combustion air in rotation into the first section of flame tunnel 28 has the added advantage, as explained above, of creating a low pressure zone B directly in front of outlet 20, as shown in FIG. 3. The low pressure zone helps the injection of fuel into the first section of flame tunnel 28, and, like the adjustable nature of passageway 43, is particularly helpful when gas is available only at low pressure. The same low pressure zone is useful in aspirating residual oil from nozzle 42 after a changeover is made from oil to gas fuel. It is important that no residual oil remains in the nebulizer nozzle 42 after a change from oil to gas fuel, because such residual oil will tend to become carbonized by the heat of the flame. The passage of gas through atomizing air injection ports 46 also assists in purging the nozzle 42 of residual oil after a changeover from oil to gas fuel.

Fuel burners in accordance with the invention are capable of operating with a large excess of air, that is, the amount of fuel introduced may be reduced to lower the firing rate while the air supply remains constant. A reduction in fuel supply from 100% to 10% of fuel capacity rate is attainable without disruption of the desired flame configuration. The dual fuel burners may be switched from one fuel to the other, without significant interruption of service and the burner of the invention may operate efficiently with very low pressure gas.

Control of flame propagation and other advantages of the invention will be apparent to those skilled in the art upon reading and understanding the foregoing.

While the invention has been described with respect to preferred embodiments thereof, it will be apparent that many modifications and alterations to the embodiments shown will occur to those skilled in the art upon reading and understanding of the specification. It is intended to include all such modifications and alterations within the scope of the appended claims or the equivalents thereof.

What is claimed is:

1. A burner apparatus comprising a fuel burner including ignition means and a flame tunnel in combination, said fuel burner comprising a conduit for fuel and a combustion air conduit, said conduits being structurally associated one with the other to pass admixed fuel and air into said flame tunnel, the improvement comprising,

said flame tunnel comprises first and second sections arranged along a common longitudinal axis,

said first section is substantially cylindrical in shape, and has its inlet adjacent said fuel burner and its outlet adjacent said second section,

said second section is substantially a circular toroid in shape, having its inlet adjacent the outlet of said first section and its outlet adjacent the outlet end of said flame tunnel,

the diameter of the outlet of said second section is larger than the diameter of the inlet of said second section,

said conduit for fuel is positioned within said combustion air conduit,

combustion air deflection means are structurally associated with said combustion air conduit to impart a rotational velocity about said longitudinal axis to combustion air entering said flame tunnel,

said combustion air deflection means comprise a seal plate with an aperture therein, said seal plate being positioned substantially transversely to the flow of combustion air thoough said combustion air conduit so that substantially the entirety of said flow passes through said aperture, and a baffle plate positioned adjacent to said aperture, said baffle plate being positioned with respect to said combustion air so that substantially the entirety of said flow is directed in rotational motion about said conduit for fuel.

2. The burner apparatus of claim 1 wherein the length of said first section along its longitudinal axis is at least about two and one-half (2½) times as great as the diameter of the inlet of said first section, and the diameter of the outlet of said second section is at least about two and one-half (2½) times as great as the diameter of the inlet of said first section.

3. The burner apparatus of claim 1 wherein the length of said first section along its longitudinal axis is at least about four (4) times as great as the diameter of the inlet of said first section, and the diameter of the outlet of said second section is as least about four (4) times as great as the diameter of the inlet of said first section.

4. The burner apparatus of claim 1 further including a secondary conduit for the passage of atomizing air or gas therethrough, and a fuel conduit for the passage of oil therethrough.

5. The burner apparatus of claim 1 wherein said first section diverges from its inlet towards the outlet end thereof, at an angle of divergence of not more than about three degrees (3°) between the surface of said first section and the surface of a theoretical cylinder placed concentrically with said first section and of a diameter equal to the diameter of the inlet of said first section.

6. The burner apparatus of claim 4 wherein said angle of divergence is between about one-half degree (½°) and about three degrees (3°).

7. The burner apparatus of claim 4 wherein said angle of divergence is between about one degree (1°) and about two degrees (2°).

8. The burner apparatus of claim 4 wherein said fuel conduit is disposed within and substantially concentrically to said secondary conduit, and said secondary conduit is positioned within and substantially concentrically to said combustion air conduit.

9. The burner apparatus of claim 8 further including nozzle means attached to the outlet of said fuel conduit, said nozzle tending to restrict the size of the outlet from said secondary conduit, said fuel conduit being adjustable along its longitudinal axis is relation to said secondary conduit, so that adjustment varies the size of the outlet from said secondary conduit.

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