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[54] METHOD FOR ADMIXING COMBUSTION AIR IN A BURNER

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Related U.S. Application Data

[63] Continuation-in-part of Ser. No. 264,635, June 20, 1972, abandoned.

[52] **U.S. Cl.** **431/9,** 431/183, 431/353, 239/406
[51] **Int. Cl.** **F23m 3/00**
[58] **Field of Search** 431/183, 184, 353, 9; 239/405, 406, 402.5

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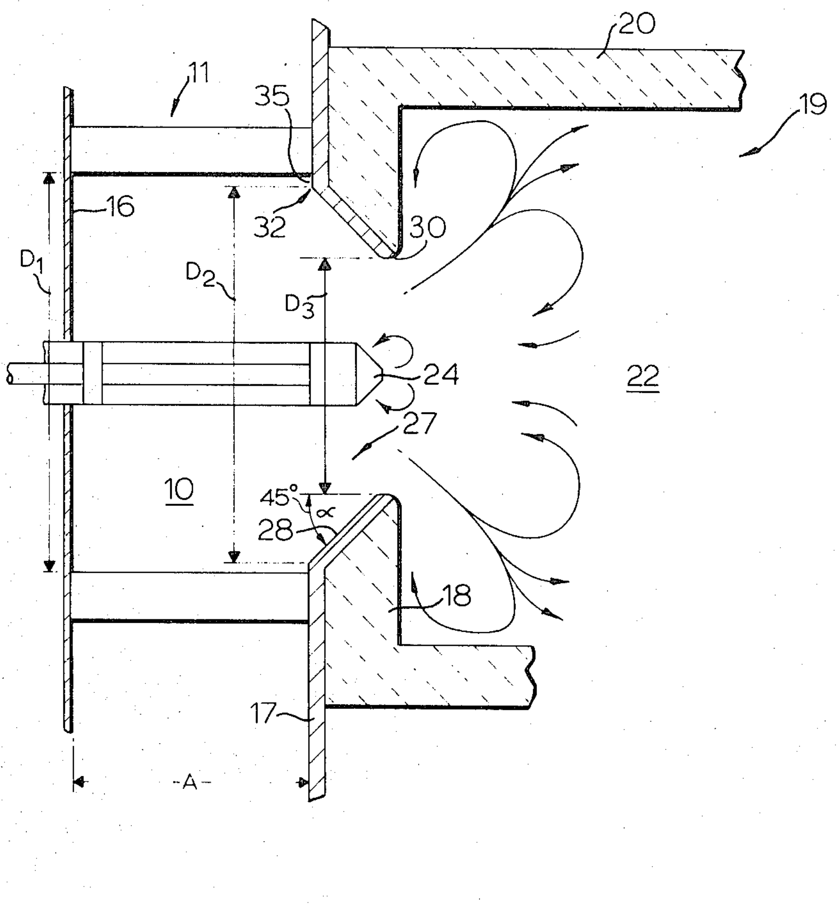
[57] **ABSTRACT**

This invention provides a method for admixing combustion air supplied at low pressure with fluid fuel for combustion, preferably in stoichiometric proportions, by passing the air spirally inwardly between multiple overlapping vanes into a vortex chamber, thence through a coaxially aligned frustoconical nozzle into a coaxially aligned cylindrical combustion chamber with the fuel being injected into the air passing through the nozzle, the flow of the air being constrained by its passage between the vanes, through the vortex chamber, through the nozzle and into the combustion chamber to generate therein a tangential velocity (swirl) which is sufficiently strong to establish a critical recirculating centre core of combustion gases in the combustion chamber and ensure complete combustion of the fuel.

8 Claims, 3 Drawing Figures



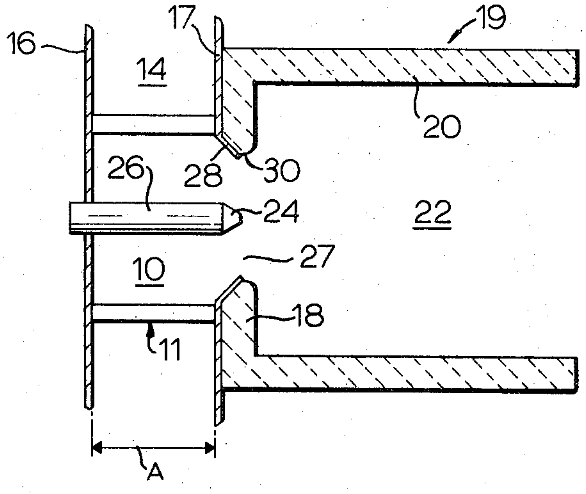


FIG.1

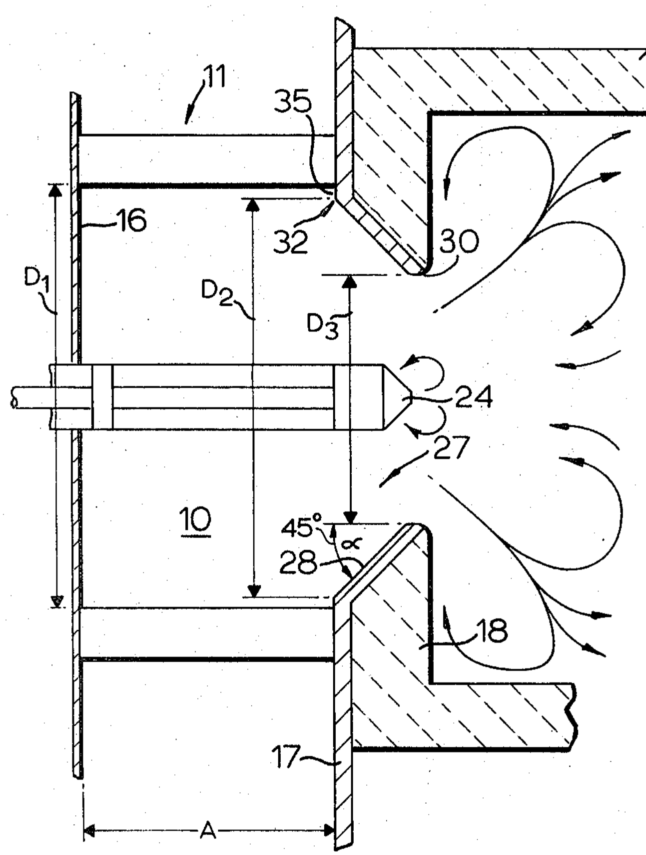


FIG. 2

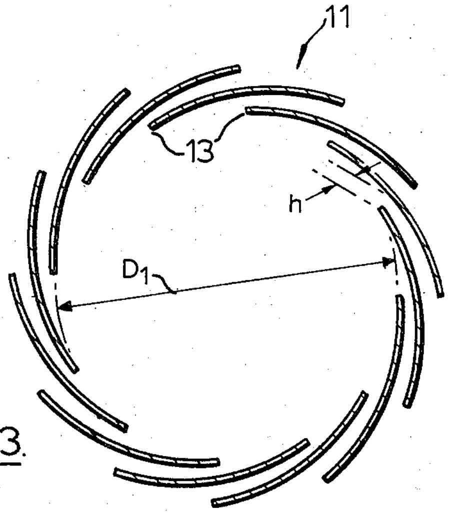


FIG. 3.

METHOD FOR ADMIXING COMBUSTION AIR IN A BURNER

This application is a continuation-in-part of our application Ser. No. 264,635 filed June 20, 1972 and now abandoned.

This invention relates generally to admixing of air and fuel particularly in oil burners in which combustion air is introduced into the combustion chamber in a swirling or vortex motion in the centre of which is coaxially located the atomizer for the liquid fuel.

An object of this invention is to provide a method for admixing air and fuel in a burner including a combustion chamber configuration in which the design of the vortex chamber is such that the burner requires a relatively low air pressure differential, while providing the advantages of a high turndown ratio and a low excess air requirement.

A preferred embodiment of apparatus for carrying out the method of this invention is shown on the accompanying drawings, in which like numerals denote like parts throughout the several views, and in which:

FIG. 1 is an axial sectional view through an oil burner and combustion chamber;

FIG. 2 is an enlarged axial sectional view of a portion of the combination shown in FIG. 1; and

FIG. 3 is a cross-sectional view of the inlet blades utilized in the preferred embodiment.

FIG. 1 shows a vortex chamber **10** which is defined by a plurality of arcuate inlet vanes **11** the configuration of which is clearly seen in FIG. 3. In the embodiment shown, there are 12 identical blades equally spaced at 30° intervals around the exterior of the vortex chamber **10**. In essence, there is no specific cylindrical surface defining the outer periphery of the vortex chamber **10**. Rather, the vortex chamber **10** can be considered to be defined by the inner edges **13** of the vanes **11** (see FIG. 2). A windbox **14** is defined between an outer wall **16** and an inner wall **17**. A combustor **19** includes a circumferential wall **20**, and an end wall **18**. The walls **18** and **20** define a combustion chamber **22**. As in conventional vortex burners, a suitable fan is utilized to provide air pressure within the windbox **14**, and this pressure causes air to move inwardly between the vanes **11** and into the vortex chamber **10**, where the air spirals inwardly. A fuel injector **24** is supported on the end of a tube **26** which contains fuel lines, for example in accordance with U.S. Pat. No. 3,510,061, issued May 5, 1970 to C. F. Peczeli, et al., and entitled "Two-Stage Sonic Atomizing Device."

The right-hand or discharge end of the vortex chamber **10**, as seen in FIG. **2**, comprises a nozzle **27** which is defined in part by a substantially 45° conical frustum **28**. The upstream extremity **32** of the conical frustum **28** is in the same plane as the right-hand edges of the vanes **11**, and thus also the inner wall **17**, but defines a circle of slightly less diameter than the hypothetical circle which touches the inner edges **13** of all of the vanes **11**. In FIG. **2**, the diameter of the upstream end of the conical frustum **28** is marked as D_2, whereas the hypothetical circle touching the inner edges of the vanes **11** is indicated as having diameter D_1. The difference between D_1 and D_2 represents an annular wall **35** which of course extends further to become the inner wall **17** of the windbox **14**. The minimum diameter of the conical frustum **28**, i.e., the diameter of the downstream or rightward end of the conical frustum **28**, is marked as D_3 on the accompanying Figures.

Essentially, this invention resides in the disclosure of a method of admixing air and fuel in a burner utilizing the vortex principle and having particular optimum values for the different dimensions marked on the drawings. The invention thus consists of a method for admixing combustion air and fluid fuel in substantially stoichiometric proportions for combustion, said method comprising the steps:

passing said air tangentially through a plurality of overlapping vanes spaced around a hypothetical cylindrical surface coaxial with a fuel injector and extending between first and second parallel walls perpendicular to the axis of said surface thereby to give the air an initial rotation, the diameter of said surface in inches being designated as a dimension D_1, the parallel walls being separated by a distance A in inches which is substantially equal to 0.64 D_1, the total minimum inlet area I between said vanes in square inches being substantially equal to $0.43\ D_1^2 - 7.63$,

passing said rotating air spirally inwardly from said surface to an outer circular limit which is the largest circumference of a substantially 45° frusto-conical nozzle in said first wall coaxial with said surface, said nozzle having a largest circular diameter D_2 in inches substantially equal to 0.95 D_1, the smallest circular diameter D_3 of the frusto-conical nozzle being substantially equal to $(0.34\ D_1^2 - 6)^{1/2}$,

passing the spiralling air (a) radially inwardly adjacent said nozzle and (b) axially out through said nozzle into a substantially cylindrical combustion chamber coaxial with said nozzle and having a forward wall adjacent said nozzle and normal to the combustion chamber axis,

and injecting said fluid fuel through the said injector centered within said nozzle at a rate for stoichiometric combustion with the passing air, thereby to mix said air and said fuel in said combustion chamber.

In order to explain why the dimensional criteria are of such critical importance, a brief digression into theory is necessary.

One of the primary requirements for good combustion of a liquid fuel in a combustion chamber of the type illustrated in the accompanying drawings is that some of the heat from the downstream end of the combustion zone be transferred back to the upstream end. This process is an essential aid to evaporation, and since all liquid fuel must be vaporized before it can be burned this transfer of heat becomes of critical importance. Although gaseous fuel does not require vaporization before its combustion, the present invention is fully applicable also for complete combustion of such fuels at optimum efficiency.

There are essentially three processes which can take place in a combustion chamber and which provide a heat transfer from the downstream end of a combustion zone to the upstream end. One of these processes is the establishment of a recirculating centre core, as illustrated by the centre arrows in FIG. **2**. When the air-fuel mixture is ejected from the vortex chamber **10** into the combustion chamber **22** with a relatively high tangential velocity, (i.e., a relatively high swirl), then the centrifugal force in the swirling mixture creates a low pressure core in the centre. At the downstream end of the swirling mass the centrifugal force is appreciably less, hence some of the hot gases are drawn into the centre core and are carried in a continuous stream toward the upstream end of the combustion zone.

In addition to the recirculating centre core, the recirculating eddy pattern is relied upon for heat transfer. The eddy currents take place in the upstream corner area of the combustion chamber **22**, and in FIG. **2** the back-curving arrows in the corner area show the direction of eddy flow. Essentially, a swirl mixture discharging conically into the combustion chamber creates a low pressure area in the corner zone, and this low pressure draws in hot gases from its downstream side, creating the eddy currents.

Although the latter mechanism can be established without swirl, it is more effective with a swirl.

Another mechanism by which heat from the combustion area is used to help vaporize the liquid fuel has to do with radiation. If the hot gases heat up the refractory walls of the combustion chamber, part of the heat will be radiated back to and absorbed by the atomized fuel particles in the central zone.

While the principles described above are simple and generally known, the details of the various processes are very complex. Because of this complexity, it has hitherto been difficult to produce a high performance burner capable of optimizing the different characteristics that must be taken into consideration.

Through a process of repeated testing while altering incrementally first one dimensional parameter and then another, we have arrived at a dimensional formulation for a fluid fuel burner combination, which formulation is capable of admixing combustion air and fuel to provide a high output rating with extremely low excess air requirement, and simultaneously a low static pressure differential requirement across the vanes.

Certain remarks in regard to the swirl itself are called for. A swirl strong enough to create an efficient recirculation in the combustion zone has a very pronounced tendency to create similar recirculating patterns at the discharge plane (the small diameter of the conical frustum **28**), and possibly within the vortex chamber **10.** Although a recirculation pattern inside the vortex chamber is merely a waste of energy, any recirculation across the discharge plane will carry unburnt and partially burned liquid fuel particles back into the vortex chamber. In the relatively cool interior of the vortex chamber these particles will tend to form an everincreasing burden of deposits.

Since the build-up of deposits cannot be tolerated, many burners avoid deposits by the use of a weak swirl only, which assists mixing but does not generate an effective recirculation pattern. Other burners employ a complex baffle arrangement to prevent back flow.

Using the dimensional formulations disclosed, the burner combination described herein is capable of generating a swirl sufficiently strong to assure virtually complete combustion of all common fluid, (i.e., liquid and gaseous) fuels, while using a single air supply only. At the same time, back flow and the back flow deposits are eliminated. Also, a relatively low static pressure is required.

We now wish to discuss in greater detail the generation of the swirl pattern within the vortex chamber and the nozzle **27.** To begin with, air is delivered into the windbox at a pressure which may be, for example, in the range of about 6 inches water column (0.0152 kg/cm^2). Under normal conditions, the energy of the air in the windbox would be primarily in the form of pressure, and only fractionally in the form of velocity. The vanes **11** guide the air into the vortex chamber **10,** and as the air passes between the vanes it is accelerated in the tangential direction. At the same time, the radial velocity remains at a low value. Both the radial and the tangential velocity components increase as the air is forced inwardly from D_1 to D_2 between the parallel walls due to the pressure gradient. From D_2 to D_3 the axial dimension of the vortex chamber increases gradually due to the conical shape of the nozzle **27.** As the air is forced inwardly from D_2 to D_3, its tangential velocity component continues to increase, but more importantly its velocity component in planes intersecting the axis changes smoothly from being purely radial to being partly axial-partly radial. In other words, as the air moves inwardly from D_2, it gradually begins to move toward the combustion chamber due to the fact that the vortex chamber increases in axial dimension from D_2 to D_3.

The flow pattern generated from D_1 to D_2 has a strong tendency to create back flow, because from D_1 to D_2 no velocity component parallel to the axis of the vortex chamber is created. Thus, most of the available energy goes into the creation of straight swirl which produces a high centrifugal force in turn producing a low pressure at the central core and inducing a back flow recirculation pattern along the centre core. For this reason, the step from D_1 to D_2 is kept as small as manufacturing considerations will allow.

Since the swirl component added between D_1 and D_2 is minimized, it follows that the total swirl at D_3 (the entrance to the combustion chamber) is essentially a product of that imparted by the vanes themselves, plus the increase from D_2 to D_3. Practical experience indicates that the tendency for centre core back flow is reduced if the swirl imparted by the vanes is small and the increase from D_2 to D_3 is relatively large.

Practical consideration, however, limits the extent of the increase from D_2 to D_3. It must firstly be appreciated that the value for D_3 is set by the requirement of the axial velocity component of the mixture as it enters the combustion chamber. Thus, the tangential velocity gained between D_2 and D_3 can be increased only by enlarging D_2 and thus increasing the diameter of the vortex chamber. However, as the vortex chamber becomes larger, its cost increases, and its external dimensions can reach a practical limit particularly where several burners are spaced closely together in multiple installations.

The dimensional relationships set out below represent a practical compromise for the above problem of optimization. Actual experience indicates that there are no undesirable deposits and no centre core back flow with the dimensional formulations set out below, and further that the diameter of the vortex chamber remains smaller than that of the combustion chamber, and hence the spacing of the burners in a multiple installation is not affected.

Because burners are of many different sizes due to the many different heat outputs required, it has been found convenient to correlate the various dimensions against the "rating." The "rating" is defined as the gross heat input with essentially stoichiometric mixtures and with air supplied arbitrarily under pressure of 6 inches water column (0.0152 kg/cm^2) and 80°F (27°C) temperature.

It will be understood that the burner is perfectly capable of loads higher or lower than the "rating" defined above, provided that the other conditions are appropriately changed, e.g., the air supply pressures varied both above and below 6 inches water column.

The burner to which this application is directed is primarily intended for industrial applications, and thus the design formulae given below relate to burners with rated loads of 4×10^6 Btu/hr (1×10^6 kilogram calorie/hr.) and up.

Firstly, the angle of the nozzle **27** defines the direction of the flow in axial planes within the combustion chamber immediately adjacent the nozzle. It has been found that a change of 5° or more from the preferred angle of 45° in either direction will markedly increase the tendency for back flow along the centre core.

The following parameters are used in defining the principal dimensions of the oil burner:

Parameter	Definition	Units (f.p.s.)	Units (c.g.s.)
R	= Rating	10^6 Btu/hr.	10^6 kilogram cal/hr.
D_1	= Hypothetical inside diameter of vanes	inches	millimeters
D_2	= Large diameter of conical frustum	inches	millimeters
D_3	= Small diameter of conical frustum	inches	millimeters
α	= Angle of conical frustum	degrees	degrees
A	= Axial separation between walls 16 and 17 (see FIG. 2)	inches	millimeters
n	= Number of vanes		
h	= Minimum separation between two adjacent vanes (see FIG. 3)	inches	millimeters
I	= Inlet area = n × h × A	inches^2	cm^2

In the design of a burner in accordance with this invention, the small diameter D_3 of the nozzle **27** defines the axial velocity of the combustion air as it enters the combustion chamber. This velocity is not uniform; it is highest at the periphery, while in the centre quarter of the area the outflow is negligible. It follows that any reduction of D_3 will have a strong effect on the required air pressure. If the tangential velocity is correspondingly increased, then the increased energy in the air will improve combustion. In other words, a burner design with the formula given in this disclosure can be run at higher loads if the air pressure is appropriately increased. However, with an unchanged tangential velocity, any reduction of D_3 causes the diameter of the burning mass downstream to become smaller, which prohibits the formation of the recirculating centre core. Conversely, a larger D_3 with an appropriately reduced tangential velocity will require less air pressure and the lower velocities will contribute less towards good combustion, by reason of the lower mixing efficiency and weaker recirculating patterns. Without a corresponding reduction of the tangential velocity, a larger D_3 will result in the generation of centre core back flow.

In view of the foregoing considerations, the dimensional relationships defining a burner in which the method claimed in this application can be carried out are as follows, in both the f.p.s. and c.g.s. systems:

f.p.s. System	c.g.s. System
$I = 7.63\ R$	$I = 196R$
$D_2 = 4.03\ (R + 1)^{1/2}$	$D_2 = 204\ (R + 0.25)^{1/2}$
$D_1 = 1.05\ D_2 = 4.23\ (R + 1)^{1/2}$	$D_1 = 1.05\ D_2$
$D_3 = 2.45\ R^{1/2}$	$D_3 = 124\ R^{1/2}$
$A = 2.69\ (R + 1)^{1/2}$	$A = 136\ (R + 0.25)^{1/2}$
$\alpha = 45°$	$\alpha = 45°$

It has been found that a deviation of even plus or minus 10 percent from these values seriously affects the performance of the burner.

From the foregoing relationships which correlate burner rating and the corresponding critical combustion air passage parameters of a burner, simple algebraic substitution permits expression of these latter parameters in terms of one another; hence corresponding values for A, I, D_2, and D_3 can be expressed in terms of D_1 by substitution of the value of D_1 in the formulae for the corresponding value of R for any burner. Thus for a burner to achieve the method of this invention, the foregoing parameters are related by formulae, for example in the f.p.s. system:

$$A = 0.64\ D_1 \quad ; \qquad I = 0.43\ D_1^2 - 7.63 \quad ;$$
$$D_2 = 0.95\ D_1 \quad ; \qquad D_3 = (0.34\ D_1^2 - 6) \quad .$$

From the foregoing relationships, it also follows that at D_1 the ratio of the tangential and radial velocity components is 4.69 $(R + 1/R)$ in the f.p.s. system and 4.69 $(R + 0.25/R)$ in the c.g.s. system.

Also, but only under rated conditions:

Tangential velocity at D_1 is 3,140 feet per minute (f.p.s.) or 16m/sec (c.g.s.), equivalent to 0.62 inches of water column (f.p.s.) or 0.0016 kg/cm^2 (c.g.s.). Radial velocity in the same location = 660 feet per minute (f.p.s.) or 3.35 meters per second (c.g.s.) and thus velocity pressure is negligible.

Nominal axial velocity at D_3 is 5,080 feet per minute (1.63 inches water column) or 25.8 meters per second (0.00413 kg/cm^2). In practice, most of the air is discharged through the nozzle in the plane of its least dimension with an axial velocity of approximately 6,750 feet per minute (2.88 inches water column) or 34.3 meters per second (0.0073 kg/cm^2).

NUMERICAL EXAMPLE

The effect of changing the principal dimensions to values outside of the relationships given above is illustrated in the following comparison of the performance of two burners, one constructed with a preferred configuration, (i.e., falling within the relationships defined), and one constructed with an inferior configuration, (i.e., not falling within the relationships defined). Dimensions not given below, including combustion chamber dimensions are identical in the two burners.

f.p.s. System	R	I	D_1	D_2	D_3	Air Pressure
Inferior	48	328	28.5	27	19	6 inches water column
Preferred	60	458	33	31.5	19	6 inches water column
Preferred, run at same load as Inferior	48	458	33	31.5	19	3.8 inches water column

c.g.s. System	R	I	D_1	D_2	D_3	Air Pressure
Inferior	12	2120	725	686	483	0.0152 kg/cm^2
Preferred	15	2955	840	800	483	0.0152 kg/cm^2
Preferred, run at same load as Inferior	12	2955	840	800	483	0.0096 kg/cm^2

The burner with the inferior configuration (the one not falling within the relationships) gained more swirl between the vanes and less between D_2 and D_3. As a consequence, its rated load was only 80 percent of the burner whose dimensions fall within the relationships. Further, the preferred burner performed well even at the highest load (96 × 10^6 Btu/hr or 24 × 10^6 kilogram-calorie/hr) permitted by the supporting equipment (windbox air pressure of 15 inches water column), while the inferior configuration showed a noticeable deterioration at loads above the rated load. It will be noted in the table that the burner with the preferred configuration requires less windbox air pressure than does the burner with the inferior construction at the same load.

It is believed that the performance of the vanes, within reason, does not depend upon the number of the vanes. It can be said, however, that if the number is less than eight, then the individual layers of the air entering will be too thick (h will be too large), which leads to unnecessary turbulence. Furthermore, a minimum ratio of vane overlap to radial vane spacing at the inner edges is required to prevent "short-circuiting" of the air. This ratio is around 3:1.

The outside diameter of the set of vanes can be reduced by increasing the number of vanes, without decreasing D_1, but manufacturing economy will set a limit here.

Preferably, the vanes are gently curved as shown in FIG. 3, and ideally the direction of the air as it enters the vortex chamber should correspond to the tangential/radial ratio defined above.

What we claim is:

1. A method for admixing combustion air and oil in substantially stoichiometric proportions for combustion at a predetermined rate related to a specific rating R in 10^6 Btu/hr., said specific rating R corresponding to combustion air being supplied at a pressure of about 6 inches water column and at about 80°F, said method comprising the steps:

passing said air tangentially through a plurality of overlapping vanes spaced around a hypothetical cylindrical surface coaxial with an oil atomizer and extending between first and second parallel walls perpendicular to the axis of said surface thereby to give the air an initial rotation, the diameter of said surface in inches being substantially equal to 4.23 $(R + 1)^{1/2}$, the parallel walls being separated by a distance A in inches which is substantially equal to 2.69 $(R + 1)^{1/2}$, the total minimum inlet area I between said vanes in square inches being substantially equal to 7.63 R,

passing said rotating air spirally inwardly from said surface to the outer circular limit of a substantially 45° frusto-conical nozzle in said first wall coaxial with said surface, said outer circular limit in inches being substantially equal to 4.03 $(R + 1)^{1/2}$, the inner circular limit of the frusto-conical nozzle being substantially equal to 2.45 $R^{1/2}$,

passing the spiralling air (a) radially inwardly adjacent said nozzle and (b) axially out through said nozzle into a substantially cylindrical combustion chamber coaxial with said nozzle and having a forward wall adjacent said nozzle and normal to the combustion chamber axis,

and atomizing the oil at the said predetermined rate in the said atomizer centered within said nozzle, thereby to mix said air and said atomized oil in said combustion chamber.

2. A method of burning oil at a predetermined rate which comprises performing the steps set out in claim **1**, and igniting the mixture of atomized oil and swirling air in said combustion chamber.

3. A method for admixing combustion air and fluid fuel in substantially stoichiometric proportions to permit stable combustion over a range of combustion air supply conditions including pressures above and below about 6 inches water column, there being a specific rating R in 10^6 Btu/hr. at a combustion air supply pressure of 6 inches water column and a combustion air supply temperature of 80°F which is related to a predetermined rating at the said supply conditions, said method comprising the steps:

passing said combustion air, at a pressure and temperature in said range, tangentially through a plurality of overlapping vanes spaced around a hypothetical cylindrical surface coaxial with a fuel injector and extending between first and second parallel walls perpendicular to the axis of said surface thereby to give the air an initial rotation, the diameter of said surface in inches being substantially equal to 4.23 $(R + 1)^{1/2}$, the parallel walls being separated by a distance A in inches which is substantially equal to 2.69 $(R + 1)^{1/2}$, the total minimum inlet area I between said vanes in square inches being substantially equal to 7.63 R,

passing said rotating air spirally inwardly from said surface to the outer circular limit of a substantially 45° frusto-conical nozzle in said first wall coaxial with said surface, said outer circular limit in inches being substantially equal to 4.03 $(R + 1)^{1/2}$, the inner circular limit of the frusto-conical nozzle being substantially equal to 2.45 $R^{1/2}$,

passing the spiralling air (a) radially inwardly adjacent said nozzle and (b) axially out through said nozzle into a substantially cylindrical combustion chamber coaxial with said nozzle and having a forward wall adjacent said nozzle and normal to the combustion chamber axis,

and injecting the fluid fuel into the air at a rate which provides said substantially stoichiometric proportions, based on the quantity of combustion air entering the combustion chamber, said injection taking place centrally in said nozzle.

4. A method for admixing combustion air and fluid fuel in substantially stoichiometric proportions to permit stable combustion said method comprising the steps:

passing said combustion air, at a maximum pressure of about 6 inches water column and at about 80°F, tangentially through a plurality of overlapping vanes spaced around a hypothetical cylindrical surface coaxial with a fuel injector and extending between first and second parallel walls perpendicular to the axis of said surface thereby to give the air an initial rotation, the diameter of said surface in inches being designated as a dimension D_1, the parallel walls being separated by a distance A in inches which is substantially equal to 0.64 D_1, the total minimum inlet area I between said vanes in square inches being substantially equal to 0.43 $D_1^2 - 7.63$,

passing said rotating air spirally inwardly from said surface to an outer circular limit which is the largest circumference of a substantially 45° frusto-conical nozzle in said first wall coaxial with said surface, said nozzle having a largest circular diameter D_2 in inches substantially equal to 0.95 D_1, the smallest circular diameter D_3 of the frusto-conical nozzle being substantially equal to $(0.34\ D_1^2 - 6)^{1/2}$,

passing the spiralling air (*a*) radially inwardly adjacent said nozzle and (*b*) axially out through said nozzle into a substantially cylindrical combustion chamber coaxial with said nozzle and having a forward wall adjacent said nozzle and normal to the combustion chamber axis,

and injecting said fluid fuel through the said injector centered within said nozzle at a rate for stoichiometric combustion with the combustion air, based on the rate at which the air enters the combustion chamber.

5. A method as claimed in claim **3** in which there is a plurality of at least eight vanes and the ratio of the overlapping to the minimum distance between adjacent vanes is at least about 3:1.

6. A method as claimed in claim **5** in which the fluid fuel is oil and the fuel injector is an oil atomizer.

7. A method of burning oil, which comprises the steps of:

providing combustion air at a maximum supply pressure of about 6 inches water column and 80°F,

admixing said combustion air with oil in accordance with the method claimed in claim **6**,

and combusting the mixture of atomized oil and swirling air in said combustion chamber.

8. A method of burning oil as claimed in claim **7**, in which the oil is supplied at a rate equivalent to an arbitrary rating R in 10^6 Btu/hr. which satisfies the formula: $D_1 = 4.23\ (R + 1)^{1/2}$.

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