Jan. 18, 1966 F. C. MOCK 3,229,464

COMBUSTOR COMPRISING A FLAME TUBE AND INSULATING MEANS

Filed Jan. 15, 1962 4 Sheets-Sheet 1

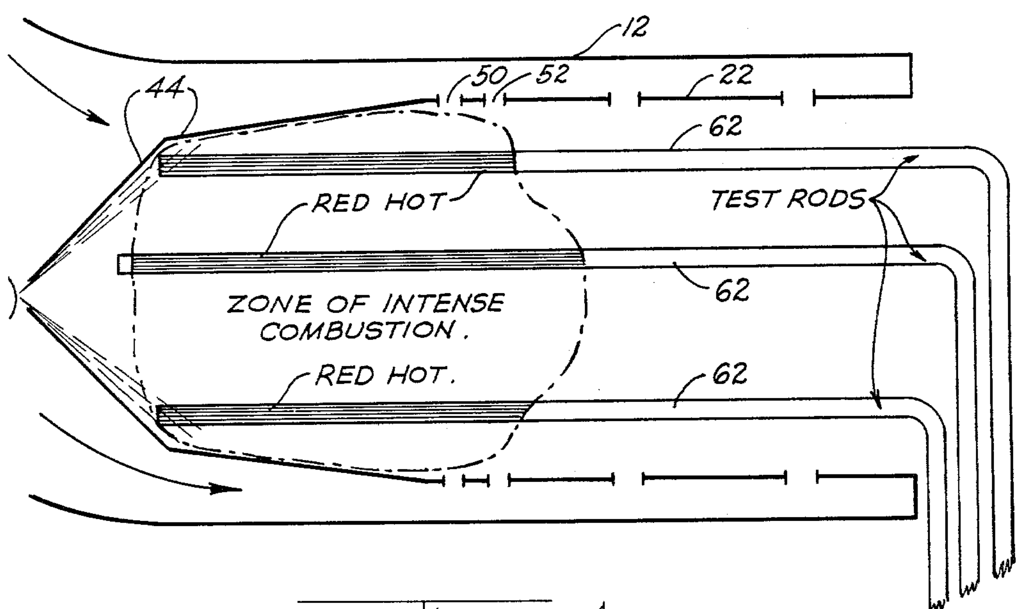

FIG. 1

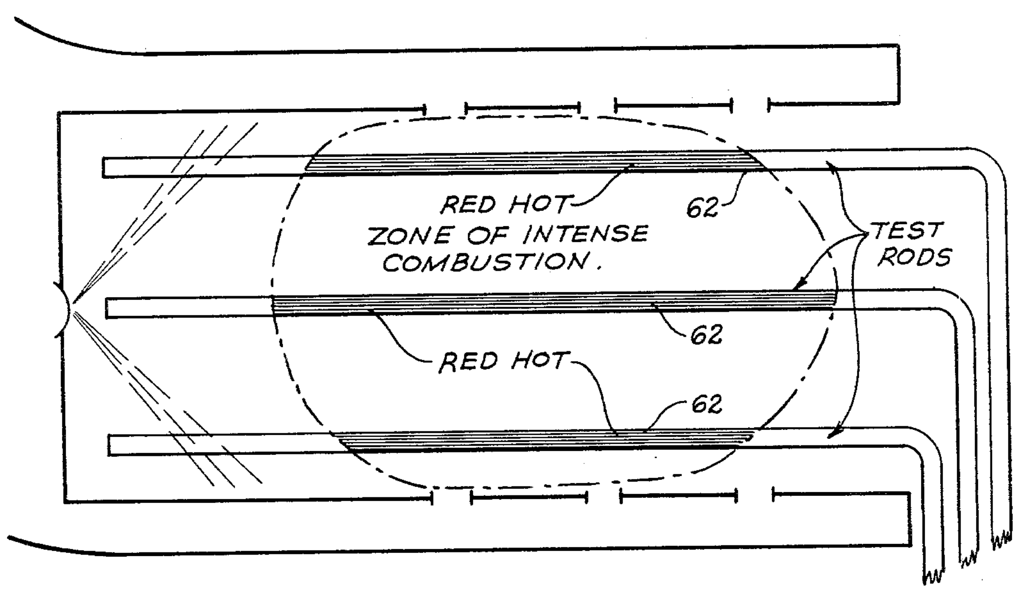

FIG. 2

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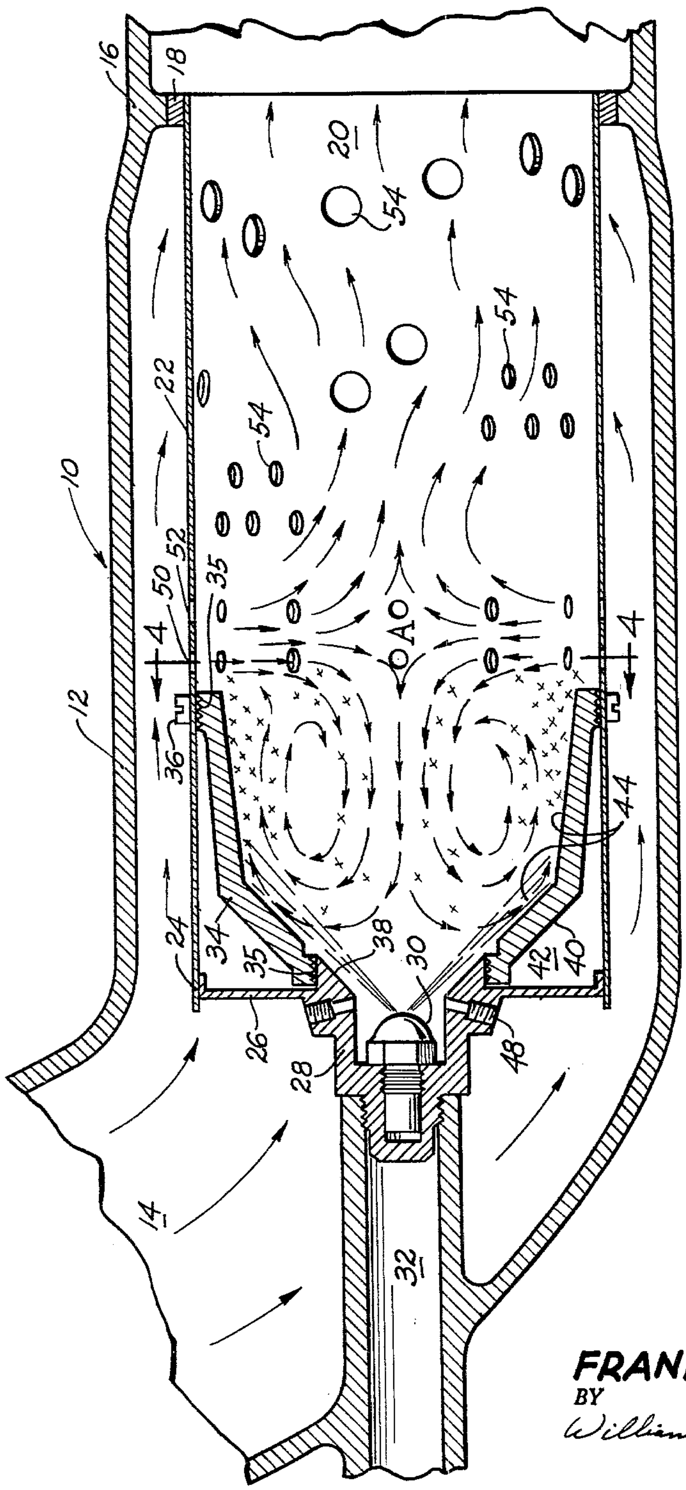

FIG. 3

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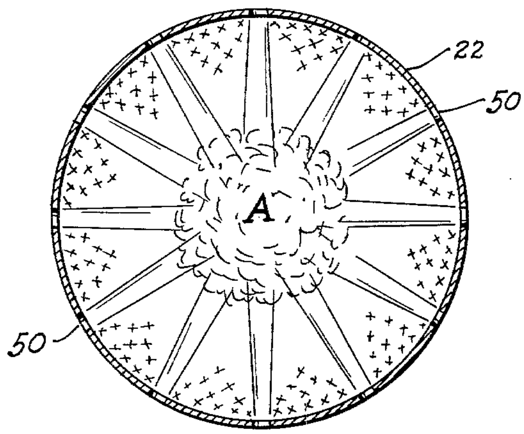

FIG. 4

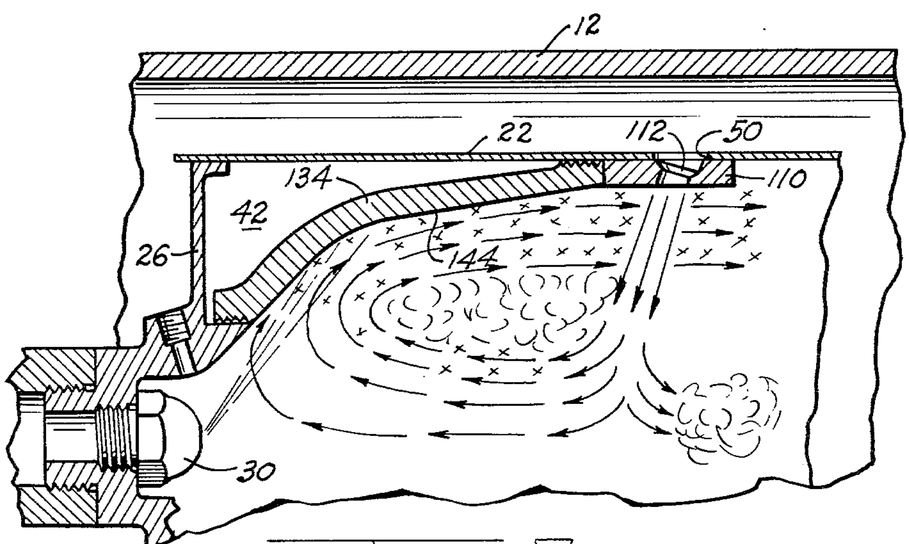

FIG. 7

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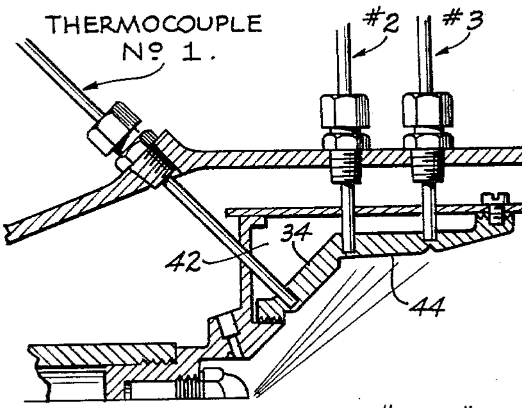

FIG_5

Wa-1260 LBS. PER HOUR.

Wf LBS. PER HOUR	TEMPERATURE THERMOCOUPLE. 1	2	3
11.2 FINE MIST.	870	828	676
15 DRY.	785	722	575
20 DRY.	686	584	448

Wa-1880 LBS. PER HOUR.

Wf LBS. PER HOUR.	TEMPERATURE THERMOCOUPLE. 1	2	3
15 DRY.	805	730	575
20 DRY.	675	595	480
26 DRY.	540	430	380

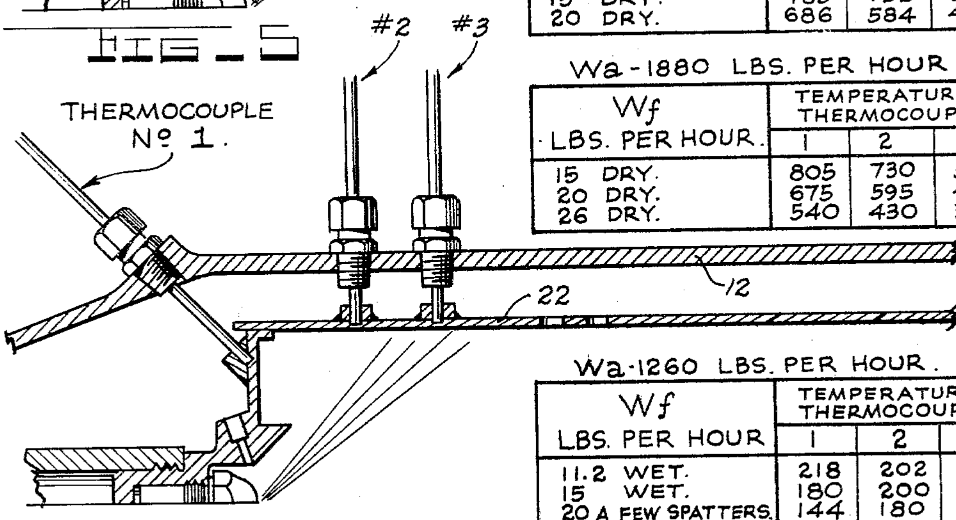

FIG_6

Wa-1260 LBS. PER HOUR.

Wf LBS. PER HOUR	TEMPERATURE THERMOCOUPLE. 1	2	3
11.2 WET.	218	202	276
15 WET.	180	200	246
20 A FEW SPATTERS.	144	180	198

Wa-1880 LBS. PER HOUR.

Wf LBS. PER HOUR	TEMPERATURE THERMOCOUPLE. 1	2	3
15 FINE SPRAY.	150	174	223
20 FINE MIST	140	172	206
26 DRY.	124	155	175

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COMBUSTOR COMPRISING A FLAME TUBE AND INSULATING MEANS

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3 Claims. (Cl. 60—39.71)

The present invention relates to an improved combustor and more particularly to a combustor adapted for use with a gas turbine engine.

The combustor of the present invention may be utilized most effectively in gas turbine engines having requirements of wide load variations and high efficiency requirements such as are currently being developed for automotive usage and also as disclosed in my copending application Serial No. 780,531 filed December 15, 1958, now U.S. Patent 3,025,668 issued March 20, 1962, and commonly assigned with the present application.

It has been found that prior art combustors are inadequate for this application as evidenced by premature flame blow-outs and a significant amount of unburned liquid fuel particles detected in the exhausting gas combustion products as induced by the puddling of fuel along the internal sidewalls of the combustor. These limitations become particularly pronounced the greater the deviation from optimum design condition of prior art combustors such as encountered when throttling back to low or part low conditions.

Although the present invention was conceived to overcome combustor limitations when applied to wide range engines, the acquired advantages of greater flame stability, and full range improved efficiency are beneficial to most all combustor applications.

It is an object of the present invention therefore to provide an improved combustor having greater efficiency and capable of operation over a wider range than combustors known heretofore in the art.

It is another object of the present invention to provide a combustor having a generally conical or modified conical end wall configuration for improving combustion efficiency and flame stability in the low power ranges.

It is still a further object of the present invention to provide a combustor having features for maintaining the temperature of the end dome higher than the vaporization temperature of the fuel being used under substantially all conditions of combustor operation.

The foregoing and other objects and advantages will become apparent in view of the following description taken in conjunction with the drawings wherein:

FIGURE 1 is a schematic view of a combustor having an end wall configuration of conical or modified conical cross sectional shape;

FIGURE 2 is another schematic view of a combustor having a generally rectangular end wall cross sectional shape;

FIGURE 3 is a section view taken longitudinally through a preferred embodiment of a combustor in accordance with the present invention;

FIGURE 4 is a section view taken along section 4—4 of FIGURE 3;

FIGURE 5 is a partial section view of a combustor of FIGURE 1 with temperature probes and temperature tables showing exemplary temperature distributions of my combustor;

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FIGURE 6 is a partial section view and temperature table of one form of prior art combustor for comparison with FIGURE 5; and

FIGURE 7 is a partial section view of a modified form of a combustor in accordance with the present invention.

Based on the observed fact that combustion is very slow between a relatively cool fuel spray and air charge, this invention provides means for transferring heat to the newly entering air and fuel charges from the charges already burning. This makes the burning process a continuing "chain-reaction" to which stability at low air and fuel quantities is contributed by having the fuel spray closely surrounded by, and partially impinging on, a conical or modified conical shaped end wall whose temperature is maintained above the boiling point of the fuel being used. Actually, keeping such a wall hot is very difficult to achieve particularly under all spraying conditions. At high fuel deliveries the cooling effect of the spray is very great: also the variation of the air/fuel ratio affects not only the area of fuel impact, but also the balance of heat input and heat out-take at the wall surface.

This objective may also be expressed in another way. With present combustor practice, at the lower powers and the lower temperature ranges, much of the fuel spray is found to impinge and puddle upon the combustor wall in significant quantities and forms fuel droplets which pass through the combustion zone without burning. This condition may be detected either by visually observing fuel droplets escaping in the combustion exhaust products, or by holding a cold steel bar across the flame discharge and observing the many condensed drops of fuel which quickly form on the bar. If, however, the wall upon which the fuel spray impinges can be held at a temperature well above the boiling point of the fuel, the fuel comes off of the impingement wall as a vapor or steam, no puddling occurs on the combustor wall, and no fuel droplets can be observed in the exhausting combustion products. A main part of this invention is the means for securing adequate flow of gases to this hot wall to hold up its temperature at low powers under the relatively high heat subtraction of the fuel spray.

Description of my invention proceeds with reference to FIGURES 1, 3, 4 and 5 with particular reference to FIGURE 3 which is a detail view of a complete combustor arrangement in accordance with the present invention. Numeral 10 designates my combustor generally and includes an outer shell or casing 12 which at its upstream end 14 is adapted for connection with the compressor or source of pressurized air. The downstream end 16 of shell 12 is provided with an inwardly projecting flange which clampingly engages the downstream end 20 of an inner casing or flame tube 22 to prevent the passage of air. Flame tube 22 is of generally hollow cylindrical construction and is closed at its upstream or closed breech end 24 by end wall 26 and is opened at its downstream end 20 for the discharge of the products of combustion in excess air. End wall member 26 includes a centrally located hub like portion 28 to provide a mounting for fuel nozzle 30 to thereby discharge a conically shaped pattern of fuel axially of the flame tube 22 toward the open end 20 thereof. Nozzle 30 is supplied with fuel through a passage 32 from a source, not shown. A fuel vaporizing end dome member 34 is secured adjacent the closed or breech end of flame tube 22 by screws 36 extending through the flame tube sidewalls, and surrounds nozzle 30 where it overlaps and is supported by the circular lip 38 formed as part of end wall 26. Insulation grooves 35 are formed in vaporizing dome member 34 in the area of contact with flame tube 22 and lip 38 to inhibit the transfer of heat from dome member 34. End dome 34 is positioned within the flame tube to receive impingement of the fuel spray from nozzle 30 over the inner surface or vaporizing wall 44 thereof. The outer surface 40 of end dome 34 is in spaced relation to flame tube 22 and end wall 26 to define a dead or insulating air chamber 42 externally of the end dome. The inner surface 44 of end dome 34 is constructed to define a progressively increasing cross sectional area proceeding from nozzle 30 toward the downstream end of flame tube 22. To facilitate description, the contour of vaporizing wall 44 is herein referred to as being of conicacl or modified conical shape.

A plurality of small radial passages 48 are provided in the hub-like portion 28 of end wall 26 to permit a small quantity of air from casing 10 to be directed towards the tip of nozzle 30 to prevent burning at the nozzle and the consequent formation of carbon deposits thereon which might plug the nozzle. Passages 48 are preferably theraded to permit the insertion of small pleated members, not shown, so that the air quantity may be limited to the degree necessary to prevent carbon formation while not contributing a significant percentage of the total air supplied internally of flame tube 22. It is preferable for best operation of my combustor that the air passed by passages 48 be limited to the small percentage of total air so as not to provide an appreciable cooling effect on end dome 34 or otherwise disturb the basic air flow pattern within the combustor.

Preliminary or primary stage combustion air of a stoichiometric amount is supplied through a plurality of circumferentially spaced ports or holes 50 formed in the sidewalls of flame tube 22 in a plane proximate the downstream end of vaporizing member 34. The secondary or dilution air is provided to a plurality of circumferentially spaced ports 52 also formed in the sidewalls of flame tube 22 in a plane closely proximate primary air holes 50 and on the downstream side thereof. Further dilution or tertiary air is supplied by ports 54 grouped in a staggered pattern in the downstream end of flame tube 22 to provide thorough mixing of the combustion products.

The air flow pattern produced by air supply holes 50 through 54 is as described below. Air is injected radially inwardly through primary and secondary holes 50 and 52 causing a high pressure region A at the axial center line of flame tube 22 and in between the planes of holes 50 and 52. High pressure in the region A causes primary air from holes 50 to deflect and change direction and flow axially of the flame tube upstream toward fuel nozzle 30 as indicated by the arrows in FIGURE 3. Secondary air from ports 52 also deflects and flows axially of the flame tube mainly in a downstream direction. As primary air approaches the closed end provided by the inner surface 44 of vaporizing member 34, it reverses direction, flowing radially outwardly and thence in a downstream direction in an outer sheath along the hot inner surface 44, at the same time encountering and burning the heated fuel drops. As the primary air and flame leave the downstream end of vaporizing dome 34, a first portion continues flowing in a downstream direction by passing between adjacent holes 50 and 52 where it mixes with dilution air in the downstream portion of flame tube 22. A second portion of the flammable mixture leaving

dome 34 is entrained in the air injected through holes 50 and recirculates in a toroidal flow path to form a ball of flame within dome 34. The staggered location of third stage holes 54 produces a somewhat turbulent intermixing of air in a break up of the sheath from dome 34.

When the fuel is sprayed from nozzle 30, the conical fuel spray pattern impinges on the modified conical surface 44 whereupon vaporization occurs and intermixing of the vaporized fuel with air. The area of impingement of fuel on surface 44 is determined by the axial location of nozzle 30 with respect to surface 44; by the fuel cone angle being ejected from nozzle 30; the fuel pressure in conduit 32; and the velocity and pressure of air circulating in the toroidal flow path which is determined by the design of primary air holes 50 and the pressure of air in casing 12. The area of impingement will vary for varying air and fuel quantities since in general increased air flow will blow fuel near the back surface of dome 34 whereas increased fuel delivery pressures will project the area of impingement forwardly in the direction of air ports 50. Vaporizing member 34 therefore is designed to be of sufficient length to encompass the full range of variation in the area of impingement for a given combustor design. Further, it is best that the fuel spray be somewhat diffused by nozzle 30 to avoid "spot" impingement and the development of a cold spot on surface 44.

During the combustion process heat is supplied to wall 44 by positively recirculating a portion of the air containing burning fuel in intermixing with the incoming air from ports 50. This burning mixture follows the toroidal flow path and passes adjacent to surface 44 of the dome 34 transferring heat thereto. The supply of heat to wall 44 is established by the proportion of air and fuel recirculated to that flowing past ports 50 and 52 to the downstream portion of flame tube 22. This proportion is established by the selected profile and spacing between adjacent ports 50.

In order to provide nearly instantaneous vaporization of the fuel impinging on surface 44, the heat supplied thereto by flame recirculation should be equal to or exceed that extracted by fuel vaporization and other losses sufficiently to maintain the temperature at wall 44 above the boiling point of the fuel, which may run between 140° F. minimum and 660° F. maximum including the full range between the volatile portions JP–4 aviation fuel to the heavy portions of diesel fuel. Insulating chamber 42 is provided externally of the dome 34 to prevent excessive heat loss to the relatively cool moving air within casing 12 and thereby increase the efficiency of the air to fuel heat transfer cycle.

An important feature of my combustor is the generally conical or modified conical configuration of the surface 44 of dome 34 to permit the unimpeded expansion of combustion products in and from the area where initial combustion occurs. A marked decrease in temperature of wall 44 is found to occur with non-sloping configurations resulting in a decrease in vaporization efficiency. This effect is attributed to reduction in toroidal circulation which supplies the heat input to surface 44. This has been confirmed, referring now to FIGURES 1 and 2, by inserting test rods 62 at various locations while the combustor is firing until the rods become thoroughly heated. When withdrawn, it is observed that the test rods have been heated to a red-hot condition in a clearly defined area which may be called the "zone of intense combustion" within the combustor. With respect to the combustor of FIGURE 1 having a modified conical sloping end wall 44, the rod test has indicated that intense combustion has moved forwardly towards the breech end of the combustor as compared with similar tests for the combustor configuration, shown in FIGURE 2 having non-conical end walls. This fact is further confirmed by optical observation with intense white light which further shows the puddling of fuel along the inner surface of the breech of the combustor of FIGURE 2. The hot rod test of FIGURE 1 shows that the zone of active combustion extends back into the breech end of the combustor, which makes it possible to maintain stable combustion down to very low fuel flows, irrespective of the air flow rate. Also, at both medium and higher power outputs, the "ball of flame" is more compact and concentrated near the breech than with conventional combustor designs. The combustor liner has fewer intense hot spots in the downstream portion of flame tube **22** due to the more thorough initial mixing of the fuel and air quantities.

FIGURES 5 and 6 show respectively an embodiment of a combustor in accordance with the teachings of the present invention and the prior art combustion and the results of comparative temperature tests run on each. Thermocouples were located at three stations designated in the drawings as stations Nos. 1, 2, 3 for recording the temperature at the respective locations of the inner surface of the breech end of the combustor. As indicated and recorded in the tables accompanying each figure, various quantities in lbs./hr. of air flow (W_a) and fuel flow (W_f) were supplied to the combustor and the temperature readings at each station recorded. In addition, at each air and fuel condition a visual check and cold bar test were conducted to determine the degree, if any, of unburnt fuel particles escaping from the combustion chamber. The results of this droplet test are recorded to the adjacent fuel flow quantities by word description. It will be observed that the temperatures recorded in the FIGURE 5 device are appreciably higher than those for the FIGURE 6 arrangement insuring complete vaporization of fuel at substantially all air and fuel ratios. This temperature increase can be attributed to the following characteristics of my combustor:

(1) The establishment of toroidal circulation into the breech end of the combustor which recirculates burning combustion products to supply a heat input to the hot wall **44**.

(2) Closely surrounding the fuel spray with the hot wall so that fuel impingement for all fuel quantities strikes the hot wall member.

(3) The conical or modified conical sloping configuration of the hot wall **44** which permits air and combustion products within the toroidal circulation path to continually expand as it proceeds along its flow path.

(4) A relatively heavy mass of vaporizing dome **34** which permits the storage of heat sufficient to prevent the area of fuel impingement from becoming a cold spot and thus fall below fuel vaporization temperature.

(5) The provision of insulating chamber **42** which reduces substantially the heat loss to the relatively cool air stream within casing **12**. Each of these characteristics contributes to a portion of the temperature increase tabulated in FIGURE 5.

For fuels having a high average vaporization temperature and combustor applications intended to be operative over a wide fuel/air ratio range all of these characteristics should be used to insure complete vaporization and efficient burning.

In combustor applications utilizing lower temperature vaporizing fuel or operative in an engine requiring less variation in fuel/air ratio quantities, it is contemplated that less than all of these features may be employed and the object of complete vaporization will nevertheless be achieved in these less demanding designs.

In the embodiment shown in FIGURE 7, parts identical to those contained in FIGURE 3 bear identical numerals. A vaporizing dome **134** includes an inner surface **144** forming an end wall in the combustor of generally parabolic shape which for the purpose of this disclosure is considered within the range described by the terminology "modified conical shape" to more fully define the complete range of operative shapes. Immediately adjacent the downstream end of dome **134** there is disclosed a primary air flow guide ring **110** having a plurality of passages **112** mating with ports **50**. Passages **112** are inclined at an angle with respect to the plane through holes **50** to inject primary air rearwardly into the dome **134**. It has been found with the passages **112** injecting air at an angle of substantially 5° from the vertical, optimum toroidal circulation and fuel/air mixing occur. This arrangement does not require secondary air injection as by ports **52** of FIGURE 3 to create the high pressure region A, however, dilution or secondary air would be supplied by holes (not shown) similar to tertiary holes **54** shown in FIGURE 3 disposed downstream of the primary air flow guide ring **110**. Angles of inclination substantially greater than 5°, approximately 15°, may cause too great a reverse air flow throwing fuel spray in large concentrations against the back wall and reduce vaporization efficiency.

While I have shown specific embodiments of my invention, it will be obvious to those skilled in the art that various additional modifications may be made without departing from my invention, and I intend the appended claims to cover all such modifications as fall within the spirit and scope of the invention.

I claim:

1. A combustor comprising a flame tube, a closed breech providing a closed end wall at the upstream end of said flame tube, said flame tube having a downstream outlet opposite said breech, a fuel nozzle approximately centering said breech producing a substantially conical fuel spray pattern, a heating dome of generally frusto-conical shape abutting at one end with said breech concentric to said fuel nozzle and contacting with the other end the interior of said flame tube a spaced distance downstream from said breech to provide an insulating dead air space adjacent the external surface of said heating dome, said heating dome operative to receive fuel impingement from said nozzle on the internal surface thereof, at least one ring of primary air holes formed in the side of said flame tube proximate the downstream end of said heating dome, said primary air holes adapted to cause a low velocity flow of air up the axis of said flame tube toward said spray initiating toroidal air flow circulation confined in its outer extremity by the generally conical contour of said heating dome, said ring primary air holes having a predetermined spaced distance between adjacent holes to permit the outflow of a burning air and fuel mixture from said heating dome to the downstream portion of said flame tube, and secondary air holes formed in the sides of said flame tube downstream of said primary holes.

2. A combustor comprising a flame tube with a closed and an open end, a fuel nozzle arranged substantially centrally of the closed end of said flame tube adapted to inject fuel in a substantially conical spray pattern, an insulated vaporizing end dome insulated from air externally of said flame tube disposed within the closed end of said flame tube for receiving and vaporizing fuel injected by said fuel nozzle, said end dome having an inner surface contour of generally increasing area in the direction from said closed to said open end of said flame tube, primary air supply means downstream of said vaporizing dome inducing toroidal air circulation within said vaporizing dome, and secondary air supply means downstream of said primary air supply means.

3. A combustor comprising a flame tube, a closed breech providing a closed end wall at the upstream end of said flame tube, said flame tube having a downstream outlet opposite said breech, a fuel nozzle approximately centering said breech, producing a substantially conical fuel spray pattern, a heating dome arranged near the breech end of said flame tube adapted to receive the fuel impingement from said nozzle, primary air supply means comprising a single ring having a plurality of circumferentially-spaced air nozzles formed therein and extending through the side walls of said flame tube, each of said plurality of spaced air nozzles rearwardly inclined from a cross section normal to the walls of the flame tube to

direct air flow along the axial center of said flame tube which provides a toroidal primary air flow pattern within said heating dome, said air supply means further operative to permit a portion of burning air and fuel mixture to flow from said heating dome between the spaced air nozzles to the downstream portion of said flame tube, said heating dome having an inner surface contour providing a generally-increasing area for gas flow in the direction of said downstream outlet, and secondary air holes formed in the sides of said flame tube downstream of said primary air supply means.

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