

[54] COMBUSTOR

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[22] Filed: July 9, 1971

[21] Appl. No.: 161,179

[52] U.S. Cl. 60/39.65, 60/39.66
[51] Int. Cl. F02c 3/00, F02c 7/12
[58] Field of Search. 60/39.65, 39.66

[56] References Cited

UNITED STATES PATENTS

2,654,996	10/1953	Boninsegni	60/39.65
2,617,255	11/1952	Niehus	60/39.65
2,603,064	7/1952	Williams	60/39.65
3,433,015	3/1969	Sneeden	60/39.65
2,611,241	9/1952	Schulz	60/39.66
2,560,207	7/1951	Berggren et al.	60/39.65
2,577,918	11/1951	Rowe	60/39.65
3,352,106	11/1967	Pianko	60/39.65
2,579,614	12/1951	Ray	60/39.65

FOREIGN PATENTS OR APPLICATIONS

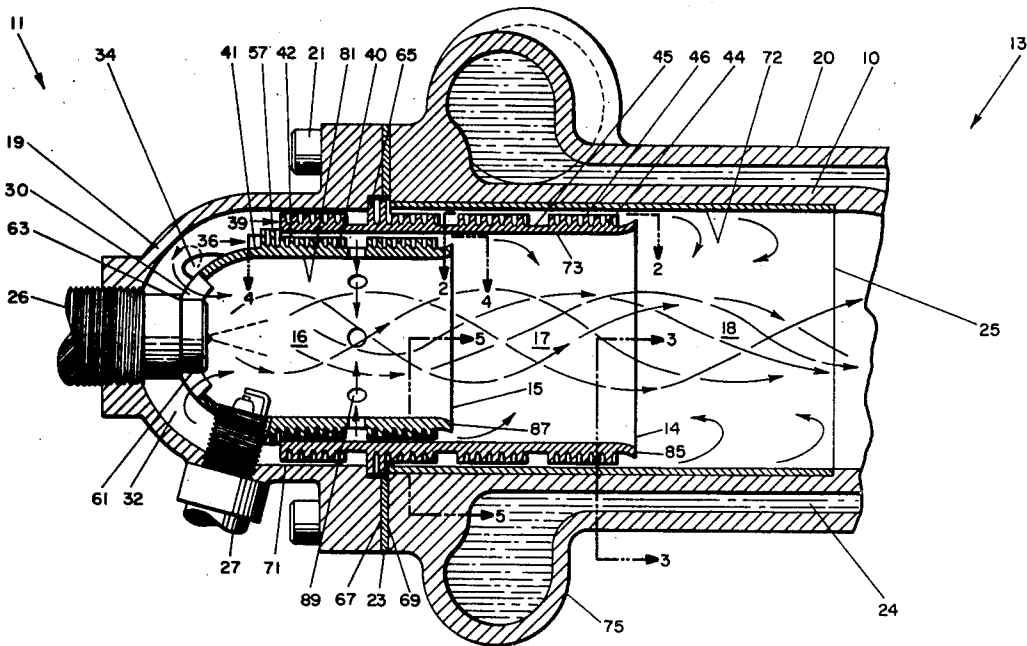
762,596 1956 Great Britain.....60/39.65

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[57] ABSTRACT

A combustor is provided having a housing with a liquid coolant jacket and having a combustion chamber which is divided into separate combustion zones. Each zone is regeneratively cooled by members disposed within the combustor which are arranged to swirl the process air and to contain and cool the flame. The heat removed from the flame is returned to the process air before it is supplied for staged combustion. The combustor is capable of operating at high temperatures, high equivalence ratios and high efficiencies.

14 Claims, 6 Drawing Figures



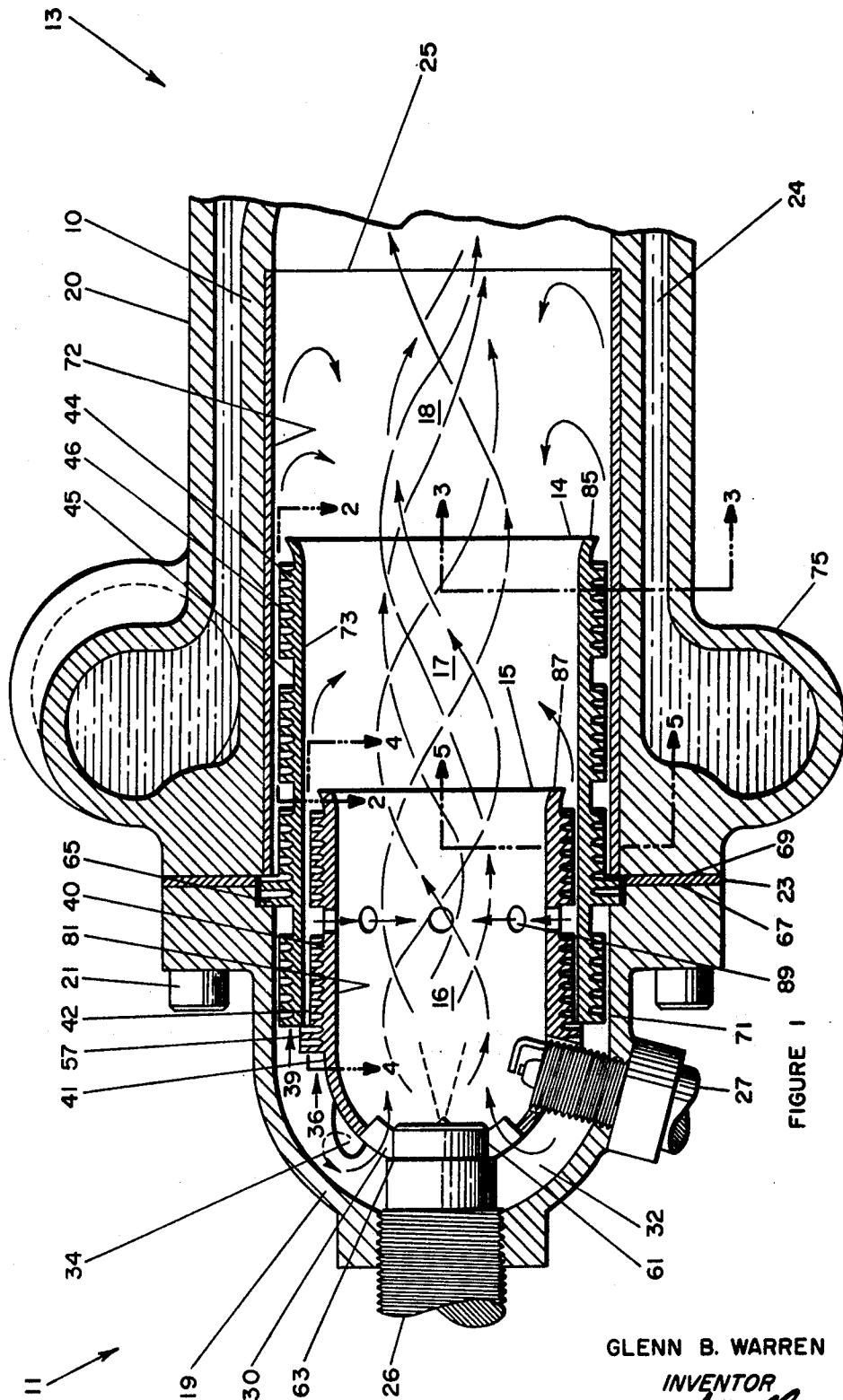


FIGURE 1

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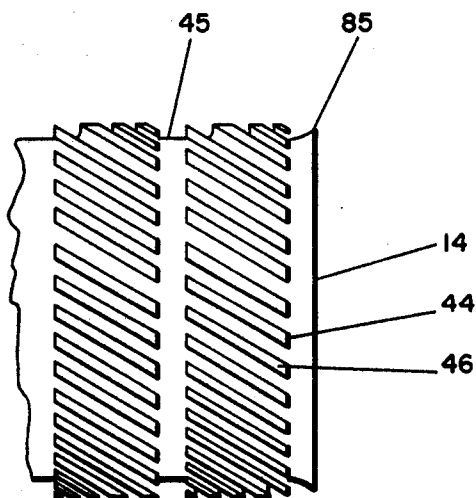


FIGURE 2

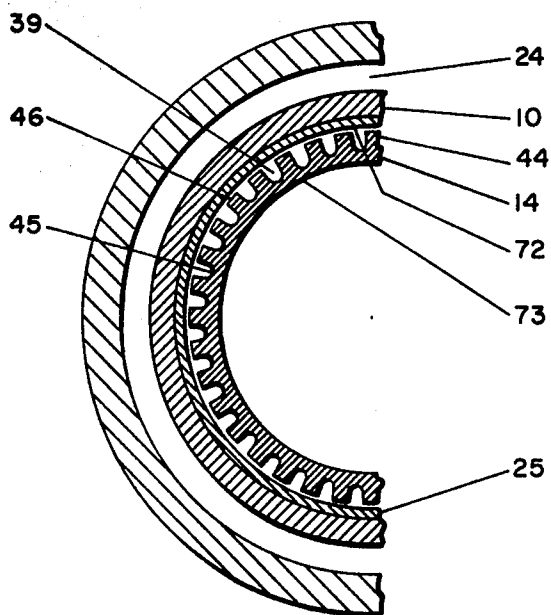


FIGURE 3

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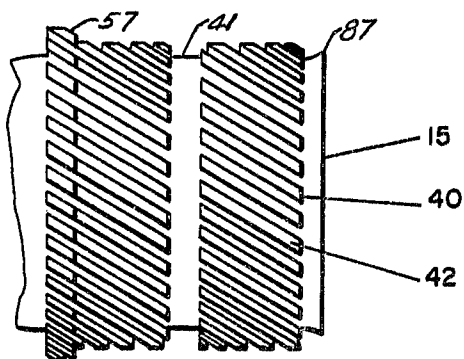


FIGURE 4

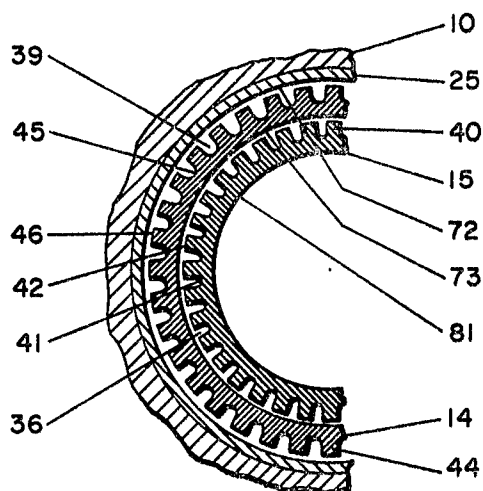


FIGURE 5

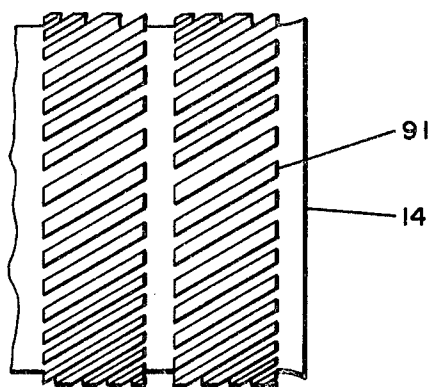


FIGURE 6

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1

COMBUSTOR

This invention relates generally to combustors and more particularly to combustors which are capable of operating at high temperatures and high efficiencies over wide ranges of operating conditions. The present invention is particularly suited for combustor construction for power plants as well as for cooled reciprocating piston engines and gas turbines.

In order to attain high efficiencies over wide ranges of operating conditions, wherein large amounts of energy are released per unit volume, the problems of excessive flame temperatures and of excessive heat loss must be avoided. Excessive flame temperatures may result in local temperature levels which may be so high as to cause structural damage to the combustor and cause the production of large quantities of oxides of nitrogen. In instances where cooling means had been provided in the prior art combustors, incomplete combustion and lowered operating efficiencies had been incurred. This invention overcomes these problems to a great extent by dividing the combustion chamber into a plurality of effectively separate combustion zones; preferably the combustion chamber provides for primary, secondary and tertiary zones. Air to the primary zone is controlled to provide a fuel-rich flame and the air to the secondary and tertiary zones is controlled to complete the combustion process in staged combustion. The combustor further includes means whereby the flame in the respective zones is regeneratively cooled and contained along the longitudinal center portion of the combustion chamber. That is, the heat removed from the flame is returned to the secondary and tertiary zones with the air supplied thereto thereby providing high overall efficiency.

Accordingly, it is an object of this invention to provide a new and improved combustor capable of operation at high temperatures and over wide ranges of load conditions and high efficiency.

It is another object of this invention to provide new and improved combustor having regenerative flame cooling means whereby a higher space heat release rate of combustion is obtained while maintaining a flame temperature level which is relatively low.

Briefly stated, in accordance with one aspect of this invention a new and improved combustor comprises a hollow housing means with first and second hollow members disposed therein in radially spaced-apart axially overlapping relationship to define with the housing means a combustion chamber having an inlet and an outlet, and primary, secondary and tertiary combustion zones therebetween. The combustor is provided with means to supply a controlled flow of fuel as well as means to supply a controlled forced flow of air to the primary combustion zone. This air is given a first direction of helical motion. As a result of this motion centrifugal force urges the colder relatively denser unreacted air towards the inside surfaces of the hollow members and the hot relatively light gases of the combustion reaction towards the center of the chamber. Additionally, the first and second hollow members provide regenerative flame cooling. The combustor is also provided with means to supply a controlled forced flow of air having the first direction of helical motion to each of the secondary and tertiary combustion zones. The latter means include first and second annular air passage means each having extended surface means extending

2

therein. These surface means are operative to cool each of the first and second hollow members and impart the first direction helical motion to the air flowing in each of the first and second air passage means. The air passage means supply the heated air to the respective secondary and tertiary combustion zones.

For applications, such as for gas turbines, where it is desired not to confine the hot combustion products to a hot central core at the exit, the extended surface means are arranged to impart to the air provided to the tertiary combustion zone a helical motion in the direction opposite to the first direction. The consequent turbulent mixing of the relatively colder unreacted air and hot combustion products provides hot gases at the outlet which have a uniform temperature across the combustion chamber.

The novel features believed characteristic of this invention are set forth with particularity in the appended claims. The invention itself, however, both as to its organization and method of operation together with further objects and advantages thereof may best be understood by reference to the following description taken in conjunction with the accompanying drawings, and in which:

FIG. 1 is a diagrammatic partial section view of one embodiment of the combustor of this invention;

FIG. 2 is an outside view of a portion of the outer hollow member in the direction 2—2;

FIG. 3 is a section view of a portion of the combustor in the direction 3—3;

FIG. 4 is an outside view of a portion of the inner hollow member in the direction 4—4;

FIG. 5 is a section view of a portion of the combustor in the direction 5—5; and

FIG. 6 is an outside view of a portion of an alternative outer hollow member in the direction 2—2.

Referring now to the drawings there is shown in FIG. 1 a combustor in accordance with one embodiment of this invention. The combustor includes a housing means 10 having an inlet end 11 and an outlet end 13. The combustor also includes first and second hollow members 14 and 15 disposed within the housing means 10 in radially spaced-apart axially overlapping relationship to define therewith a combustion chamber having a primary combustion zone 16, a secondary combustion zone 17 and a tertiary combustion zone 18.

Conveniently, housing means 10 may be provided by a head portion 19 suitably connected in sealing relationship with a body portion 20. For example, head portion 19 may be connected by bolts 21 and seal 23 to the body portion 20 to provide the complete housing means 10. Preferably, especially for high temperature operation, the body portion 20 may be provided with a liquid cooling jacket 24 and an inner liner means 25. Also, to avoid the problems associated with providing a high temperature-high pressure seal, the connection between the head portion 19 and the body portion 20 may be made at a point remote from the high temperature region of the combustor.

The combustor is provided with a suitable means, shown as nozzle means 26, to supply a controlled flow of fuel to the primary combustion zone 16 and a suitable ignition means, shown as a spark plug 27.

The combustor of this invention is capable of attaining high combustion efficiency over a wide range of operating conditions. It is particularly suited to high output operation in which the exit gases may become very hot.

While damaging temperatures may be obviated by providing a liquid cooling jacket for the combustor, the resulting loss of heat to the cooling liquid could greatly lower the combustor efficiency. It is an important feature of this invention, therefore, to provide means for providing both flame containing and cooling functions with little or no heat loss. This is accomplished in accordance with this invention by causing the combustion products to be swirled in a helical motion in all of the combustion zones while at the same time providing regenerative flame cooling. That is, the heat transferred to the cooling air used to cool the combustion zones is returned to the combustion process at a point distant from the one at which it was removed with little or no heat loss. Accordingly, the peak combustion temperature is reduced with little or no heat loss.

Moreover, since the quantity of oxides of nitrogen generated is generally determined by peak temperature levels of regions through which the combustion gases pass, the regenerative cooling provided in a combustor of this invention will thus provide low oxide of nitrogen levels in the combustion products as described in more specific detail hereinafter.

A combustor of this type is inherently capable (so long as excess air over stoichiometric is provided) of giving combustion products which are low in CO and unburned hydrocarbons.

Unless special precautions are taken, however, the nitrogen oxide (NOx) components of the exhaust, although inherently lower than in an explosion cycle engine because of lower peak combustion temperatures, may still be higher than permitted by the new Federal Air Pollution Standards for automotive engines.

Accordingly, the combustor of this invention is made to operate with the so-called "staged combustion technique." This technique has been used in a few large steam turbine power plant boiler furnaces by some boiler manufactureres, but so far as I am aware it has never before been incorporated into a combustor capable of operating at high temperatures and pressures and over a large output range.

The principle of operation of such staged combustion so far as generation of low NOx is concerned depends upon the basic physics of such combustion in that the extent of NOx formation is first a power function of the temperature (probably fifth power) and second of the amount of excess oxygen available. This means that such NOx is a maximum at about 10% - 15% excess air over that required for stoichiometric. The amount of NOx is also a function of the dynamics or speed of formation which is also a drastic function of the temperatures at which the excess oxygen is made available. Considering these laws it follows that if with an ultimate equivalence ratio at the exit of say 0.7 (lean) the primary zone is kept at an equivalence ratio of 1.2 (rich), the flame in such primary zone would be lower in temperature than stoichiometric and little or no excess oxygen would be present. If then this flame is further cooled either by a liquid cooling jacket, or by regenerative air cooled walls before the remainder of the combustion air is added, then, when it is added the lower resulting temperature will reduce both the extent of NOx formation by temperature alone, and will also so slow the oxidation process down in time as to reduce the total NOx formed before the gases are further chilled by the prime mover into which they are fed.

To this end, the combustor is provided with means to supply a forced flow of air to the primary combustion zone 16. The air so supplied has a helical motion imparted to it in a given direction so as to cause swirling of the air and fuel within primary combustion zone 16 so that when ignited by spark plug 27 the hot lighter combustion gases will be confined to the longitudinal center of the combustion zone and the cooler heavier portions of the combustion gases will be urged into contact with the outer walls of the member 16 defining the primary combustion zone. This swirling action provides a significant cooling effect to the walls of the combustion zone.

In the arrangement illustrated a suitable nozzle means 30, which may be a plurality of inclined blades, is disposed in the end wall of member 15 so as to communicate on one side with an air plenum 32 and on the other side with the primary combustion zone 16. Air plenum 32 is adapted to be connected with a suitable source of air under pressure (not shown). Advantageously, the air supplied to plenum 32 may enter tangentially through supply ports 34, only one of which is shown, to provide initial helical motion to the air in the plenum. Nozzle means 30 not only meters or controls the amount of air supplied to the primary combustion zone 16 but also imparts the desired helical motion to it so that the hot lighter combustion gases will be confined to the longitudinal center of the zone and the cooler heavier gases will be urged into contact with the walls thereof to provide a cooling effect therefor.

To provide for the desired operation of the combustor, a controlled forced flow of air is also supplied to the secondary and tertiary combustion zones. Also, the combustion zones must be suitably cooled in a manner which will prevent damage from excessive temperature and allow for a desired "staged combustion" effect all with little or no loss of heat.

As indicated in connection with the supply of air to the primary combustion zone 16, partial cooling may be effected by providing the swirling action to confine the lighter hot combustion gases to the longitudinal center of the combustion zone. For the higher output condition additional cooling must be provided.

In accordance with this invention means are provided to supply a controlled flow of air to the secondary and tertiary combustion zones which air has imparted to it the desired helical motion to produce the swirling effect. Also, the air is utilized to cool the combustion zones and the heated air is then utilized in the secondary and tertiary combustion zones. That is, the air supplied to the secondary and tertiary combustion zones is first utilized to cool the primary and secondary combustion zones and the flame contained therein before entering the appropriate secondary and tertiary combustion zones. Since the heat transferred to the air in providing the cooling of such combustion zone is then utilized in the combustion process such cooling is effected with little or no loss of heat.

In accordance with this invention the air for the secondary combustion zone 17 is supplied from the plenum 32 through an annular air passage means 36 provided between the first member 14 and the second member 15. As shown, one end of annular air passage means communicates with the air plenum 32 and the other end communicates with secondary combustion zone 17.

Similarly, the air for the tertiary combustion zone 18 is supplied from plenum 32 through annular air passage means 39, one end of which communicates with plenum 32 and the other end of which communicates with the tertiary combustion zone 18.

To provide for the desired regenerative air cooling of the primary and secondary combustion zones extended surface means are provided on each of the hollow members 14 and 15 over which the air being supplied to the secondary and tertiary combustion zones passes; the extended surface means being arranged and adapted to impart the desired helical motion to the air as well.

In the arrangement shown member 15 is provided with extended surface means, shown as a plurality of fins 40 integral with the outer surface 41 of member 14 and extending into the annular air passage means 36. Fins 40 terminate in the end surfaces 42. Also, fins 40 are arranged as shown more clearly in FIG. 4 to impart the desired helical motion to the air supplied through air passage means 36 and passing over such fins to provide the desired regenerative cooling of the primary combustion zone 16 and the flame contained therein.

Similarly, the member 14 is provided with extended surface means, shown as a plurality of fins 44 integral with the outer surface 45 of member 14 and extending into the annular air passage means 39. Fins 44 terminate in end surfaces 46. The arrangement of the fins 44, shown in more detail in FIG. 2 is such that the desired helical motion is imparted to the air flowing in passage 39.

Member 15 may be fitted size-on-size within member 14 and held in axial alignment by means of a radially raised portion 57 of fins 40. Added support for member 15 may be provided by fitting blades 30 size-on-size on surface 61 of fuel nozzle 26 in axial disposition against a suitable step 63. Member 14 may be similarly fitted size-on-size within housing 10 and held by means of a radial raised portion 65 of fins 44 extending between the surfaces 67 and 69 of head portion 19 and body portion 20 respectively. Some axial crushing of portions 65 may take place as bolts 21 are tightened to cause surfaces 67 and 69 to be brought into sealing relationship on seal 23.

Similarly, if provided, liner means 25 is fitted size-on-size within housing 10 with member 14 fitted size-on-size within it. Liner means 25 may extend within housing 10 for any suitable axial distance. Conveniently liner means 25 may extend from near surface 69 of housing 10 to a point axially distance from member 14 and into tertiary combustion zone 18.

In operation at any given air flow the combustor output and exit temperature depends upon the quantity of fuel injected relative to the air flow. At low output it has been observed that the flame is therefore relatively small and is confined to the inlet end of the combustion chamber within member 15. Under these operating conditions the primary air is adequate to provide complete combustion and the secondary and tertiary air provide cooling. The temperatures of housing 10, liner means 25 and members 14 and 15 are correspondingly low. When the combustor operates at high output, the flame region may extend axially throughout the entire combustion chamber. Under these operating conditions the primary air is insufficient for the combustion process and the secondary and tertiary air are provided both for cooling and to complete combustion. The tem-

peratures of housing 10, liner means 25 and members 14 and 15 are correspondingly higher. The temperature ranges between low and high output operation of liner means 25 and members 14 and 15, particularly where exposed to the flame and hot combustion products, are much greater than that of housing 10. The more rigid housing, however, constrains their radial thermal expansion and causes them to undergo circumferential crushing and radial shortening during the periods of early operation. Consequently when operating temperatures are reduced as at lower loads, liner means 25 and members 14 and 15 will remain in size-on-size relationship with opposing surfaces at their ends closer to inlet end 11 only, but will be spaced apart from opposing surfaces in portions which had been exposed to the flame and hot combustion products due to contraction of the circumferentially crushed members.

Utilization of the thermal fitting just described of members 14 and 15 and liner means 25 within each other and within housing 10 is a very inexpensive and simple way of providing the desired operating relationship of the components. When members and liner means are spaced apart during combustor operation at low output, excessive cooling of the fuel-air mixture by members 14 and 15 and liner means 25 is avoided at a time when heat losses to the housing 10 and water jacket 24 cannot be afforded. The tight thermal fitting provides for increased cooling of members 14 and 15 and liner means 25 when the combustor is operating at high output and increased flame and metal cooling of the liners is desired. At the corresponding elevated temperatures the members and liner means grow radially outwards to cause the fin surfaces 46 to enter into butting relationship with the confronting inside surfaces 71 and 72 of the housing 10 and the liner means 25, respectively, and the fin surfaces 42 with the confronting inside surface 73 of member 14. Similarly liner means 25 enters again into a size-on-size fit with housing 10.

To prevent undue thermal stress in housing 10 at high combustor output the liquid cooling jacket 24 is provided with a suitable relatively more flexible portion 75 which is capable of accommodating the entire range of differential thermal distortions which may be encountered.

In operation, fuel and air are fed into the primary combustion zone 16. Ignition may be provided by spark plug 27 or by any other suitable means. The air supplied to plenum 32 may enter tangentially (one supply port 34 is shown) to provide initial helical motion and is divided into primary, secondary and tertiary portions: the primary air is that required to sustain combustion under all operating conditions, while the secondary and tertiary air is that required to complete the combustion process in staged combustion, for modulation of the burning rate and for cooling purposes.

As already stated, blades 30 are adapted to meter the air into the primary combustion zone 16 to provide a fuel rich-fuel air mixture. They are adapted also to provide helical motion to the primary air thus forming a primary vortex which cooperates in containing the combustion reaction away from the inside surface 81 of member 15 by forming a helical vortex of hot gases within the longitudinal center of the combustion chamber. In this regard, centrifugal force will urge the colder relatively denser unreacted air towards the inside surface 81 and the hot relatively light gases of the combus-

tion reaction will be displaced towards the center of the chamber. The effect is the same as enclosing the combustion process in a "pipe" disposed along the axis of the combustion chamber, the "pipe" being formed by the swirling relatively colder air. The heat acquired by member 15 in effecting the desired flame cooling is returned to the secondary air coursing over fins 40 thus preheating it. Member 15, consequently, is capable of providing the desired thermal environment for the primary combustion process while, at the same time, contributing towards an overall combustor heat economy by regenerative air heating.

The secondary air flows through the inner air passage means 36 and enters the secondary combustion zone 17 at a point axially distant from the inlet end portion 11 of the combustor. Fins 40, which the secondary air traverses, are arranged and adapted to impart a helical motion to the air forming a secondary vortex in the same direction as the primary vortex. The secondary air not only aids in staged combustion but also assists in containing the hot combustion products away from the inside surface 73 of member 14 in the manner described with respect to the primary vortex. The heat acquired by member 14 in effecting desired flame cooling is returned to the tertiary air coursing over fins 44 thus preheating it. Member 14 consequently is capable of providing the desired lower temperature environment for the secondary combustion process while, at the same time, contributing further towards an overall combustor heat economy by regenerative air heating.

The tertiary air flows through the outer air passage means 39 and enters the tertiary combustion zone 18 at a point axially distant from member 15. Fins 44, which the tertiary air traverses, are arranged and adapted to impart a helical motion to the air forming a tertiary vortex in the same direction as the primary and secondary vortices. Again the tertiary air aids in staged combustion but also assists in containing the hot combustion products away from the inside surface 72 of liner means 25 in the manner already described.

Control over the secondary and tertiary air may be effected by providing the members 14 and 15 with flared ends 85 and 87, respectively. Additionally, outward growth of members 14 and 15, when the combustor is operated at higher output, causes a reduction in the cross-sectional areas of the outer air passage means 39 and the inner air passage means 36. As a consequence the quantity of secondary and tertiary air supplied to the combustion chamber is automatically reduced and that of the primary air is increased which is a desirable condition.

Stabilization of the flame is done in any convenient manner such as by providing holes 89 in member 15 communicating on one side with the inner air passage means 36 and on the other side with the primary combustion zone 16. The inflow of stabilizing air provides a region of slightly elevated pressure which prevents flame blow-out at low output operation.

As already described, combustion air control is an important feature in the combustor according to this invention. Variations in the rate of air flow provide variations in the combustion process and pattern and in the temperature levels of component members. An important feature is that the amount of air required for combustion is introduced into the combustion chamber as primary, secondary and tertiary air. Good combustor performance may be achieved, for example, when pro-

viding a distribution of 20% primary air, 10% flame stabilizing air, 30% secondary air and 40% tertiary air.

The combustor of this invention is capable of attaining high combustion efficiencies over wide ranges of operating conditions. The provision of liquid cooling of the housing and of regenerative cooling of the flame and swirling of the combustion air permits the combustor to be operated at high equivalence ratios and at high temperatures with the hot combustion products confined to a central core. Since, in addition, the production of oxides of nitrogen in the combustion products is low, the combustor of this invention is particularly useful as an external combustor of a suitably cooled reciprocating piston engine similar to the one disclosed in U.S. Pat. No. 3,577,729, issued in the name of Glenn B. Warren.

In the embodiment of the invention described in connection with FIGS. 1 through 5 the primary, secondary and tertiary air were all given a helical motion in the same direction. In such an arrangement the hot gases are confined to the longitudinal center of the combustion chamber due to the swirling action and such narrow hot centrally confined gases extend to the exit end. This is a very desirable and advantageous arrangement for many applications especially for an application with an engine of the type disclosed in the foregoing U.S. Pat. No. 3,577,729.

For certain other applications such as in a gas turbine for example this could be undesirable and it would be preferable to have the combustion spread out at the exit end. That is, a more uniform temperature profile should be provided across the exit end of the combustion chamber to prevent excessive local heating of the turbine buckets.

This more uniform temperature distribution of the combustion gases can be very readily provided in accordance with another embodiment of the invention. In this embodiment the combustor would be constructed in substantially the same manner as that described except that the direction of the helical motion imparted to the tertiary air would be made opposite the direction of the helical motion imparted to the primary and secondary air.

This can be very readily effected by merely arranging the fins on the surface of member 14 in the opposite arrangement to the fins on the surface of member 15.

This can be seen more clearly by a comparison of FIGS. 2, 4 and 6. In FIGS. 2 and 4 the fins 40 of the member 14 are arranged in the same direction as the fins 44 on the surface of member 15 so that the secondary and tertiary air will rotate in the same direction.

On the other hand, in FIG. 6 the fins 91 on the surface of member 14 are shown arranged in a direction opposite the fins 44 on member 15 so that the motion imparted to the secondary air by fins 44 will be in a direction opposite that imparted to the tertiary air by the fins 91. Thus while the tertiary air aids in staged combustion it brings the rotary movement of combustion products within the combustion chamber to zero and provides increased turbulent mixing of the relatively colder unreacted air and hot combustion products and tends to bring about a more uniform temperature profile in the outlet combustion gases by breaking up the hot center.

Although there has been described what are considered at present to be preferred embodiments of the invention, many modifications and changes may occur to

those skilled in the art. Therefore, it is intended that the appended claims cover all such modifications and changes as fall within the true spirit and scope of the invention.

What we claim as new and desire to secure by United States Letters Patent is:

1. A combustor comprising:
 - a. a hollow housing means;
 - b. first and second hollow members disposed within said housing means with a substantial portion of their axial lengths in radially spaced-apart axially overlapping relationship to define with said housing an inlet and an outlet and axially-spaced primary, secondary and tertiary combustion zones therebetween;
 - c. means including a plenum adapted for connection with a supply of air under pressure;
 - d. means to supply a controlled flow of fuel to said primary combustion zone;
 - e. means communicating with said plenum and said primary combustion zone for supplying a controlled forced flow of air to said primary combustion zone having a given direction helical motion operative to effect a fuel rich burning mixture wherein the hot combustion gases are confined to a narrow zone along the longitudinal center thereof;
 - f. means to ignite the combustible materials in said primary combustion zone;
 - g. first annular air passage means defined by the radially spaced confronting surfaces of said first and second hollow members and communicating at one end with said plenum and at the other end with said secondary combustion zone;
 - h. second annular air passage means defined by the radially spaced confronting surfaces of said housing means and said first hollow member and communicating at one end with said plenum and at the other end with said tertiary combustion zone, said first and second annular air passage means each including means operative respectively to control the flow of air to each of said secondary and tertiary combustion zones to complete the combustion process in staged combustion;
 - i. first fin means comprising a plurality of circumferentially spaced-apart fins helically disposed on the outer surface of said first hollow member and extending into said first air passage means so that the air flowing therein has said given direction helical motion imparted to it and cools said first hollow member and the flame in said primary combustion zone before introduction as combustion air to said secondary combustion zone and wherein the helical motion is operative to confine the hot combustion gases of said secondary combustion zone to the longitudinal center thereof; and
 - j. second fin means comprising a plurality of circumferentially spaced-apart fins helically disposed on the outer surface of said second hollow member and extending into said second air passage means so that the air flowing therein has helical motion imparted to it and cools said second hollow member and the flame in said secondary combustion zone before introduction as combustion air to said tertiary combustion zone.

2. The combustor recited in claim 1 wherein at least a portion of said hollow housing means includes a liquid cooling jacket means.

3. The combustor recited in claim 2 including liner means disposed adjacent the inner surface of said hollow housing member and extending along the major part of the portion thereof which includes said liquid cooling jacket means for reducing the loss of heat from the combustion chamber to the liquid of said liquid cooling jacket means during low temperature operating conditions.

4. The combustor recited in claim 3 including means to prevent intimate uniform surface contact between said liner means and the portion of said housing which includes said liquid cooling jacket means to reduce the loss of heat from the combustion chamber.

5. The combustor recited in claim 3 wherein said plurality of circumferentially spaced-apart fins of each of said first and second fin means are arranged in a plurality of axially spaced-apart rows.

6. The combustor recited in claim 1 wherein the helical motion imparted to the air supplied to said primary, secondary and tertiary combustion zones have a common direction of rotation.

7. The combustor recited in claim 1 wherein the helical motion imparted to the air supplied to said tertiary combustion zone has a direction opposite that of said given direction.

8. The combustor recited in claim 1 wherein said first and second hollow members and fin means associated therewith are dimensioned so that at other than high temperature operation there will be some space between the outer surface of said fin means and the surface of the adjacent member over the major part of the axial length of said members.

9. The combustor recited in claim 8 wherein said plurality of circumferentially spaced-apart fins of each of said first and second fin means are arranged in a plurality of axially spaced-apart rows.

10. The combustor recited in claim 1 wherein part of the fins of said fin means are dimensioned radially larger than the remainder of said fins, said radially larger fins being arranged to rigidly mount and support the respective hollow members within said housing means.

11. The combustor recited in claim 10 wherein said plurality of circumferentially spaced-apart fins of each of said first and second fin means are arranged in a plurality of axially spaced-apart rows.

12. The combustor recited in claim 1 wherein the outlet end of each of said first and second hollow members includes an outwardly flared region operative to cause the size of the outlet of the respective annular air passage means to decrease with increase in temperature and to increase with decrease in temperature to provide an automatic control of the air supplied to the primary, secondary and tertiary combustion zones as a function of the operating temperature of said combustion chamber.

13. The combustor recited in claim 12 wherein said plurality of circumferentially spaced-apart fins of each of said first and second fin means are arranged in a plurality of axially spaced-apart rows.

14. The combustor recited in claim 1 wherein said plurality of circumferentially spaced-apart fins of each of said first and second fin means are arranged in a plurality of axially spaced-apart rows.

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