# United States Patent [19]

**Verdouw**

[11] **3,851,466**

[45] **Dec. 3, 1974**


## [54] COMBUSTION APPARATUS


[75] Inventor: **Albert J. Verdouw,** Indianapolis, Ind.

[73] Assignee: **General Motors Corporation,** Detroit, Mich.



[22] Filed: **Apr. 12, 1973**

[21] Appl. No.: **350,383**

[52] **U.S. Cl.**.............. **60/39.36,** 60/39.65, 60/39.66, 60/39.71, 60/39.72 R, 60/39.74 R, 60/DIG. 11

[51] **Int. Cl.**............................. **F02c 3/06,** F02c 7/22

[58] **Field of Search**..... 60/39.71, 39.72 R, 39.74 R, 60/39.65, 39.66, 39.36



[56] **References Cited**

UNITED STATES PATENTS

| | | | |
|---|---|---|---|
| 2,424,765 | 7/1947 | McCollum | 60/39.65 |
| 2,614,384 | 10/1952 | Feilden | 60/39.66 X |
| 2,679,137 | 5/1954 | Probert | 60/39.72 R |
| 2,959,006 | 11/1960 | Ferrie | 60/39.74 R |
| 3,483,699 | 12/1969 | Harvey | 60/39.74 R |
| 3,535,875 | 10/1970 | Sneeden et al. | 60/39.65 X |
| 3,608,309 | 9/1971 | Hill et al. | 60/39.65 |
| 3,618,319 | 11/1971 | Kydd | 60/39.65 X |
| 3,643,431 | 2/1972 | Jamieson | 60/39.71 |



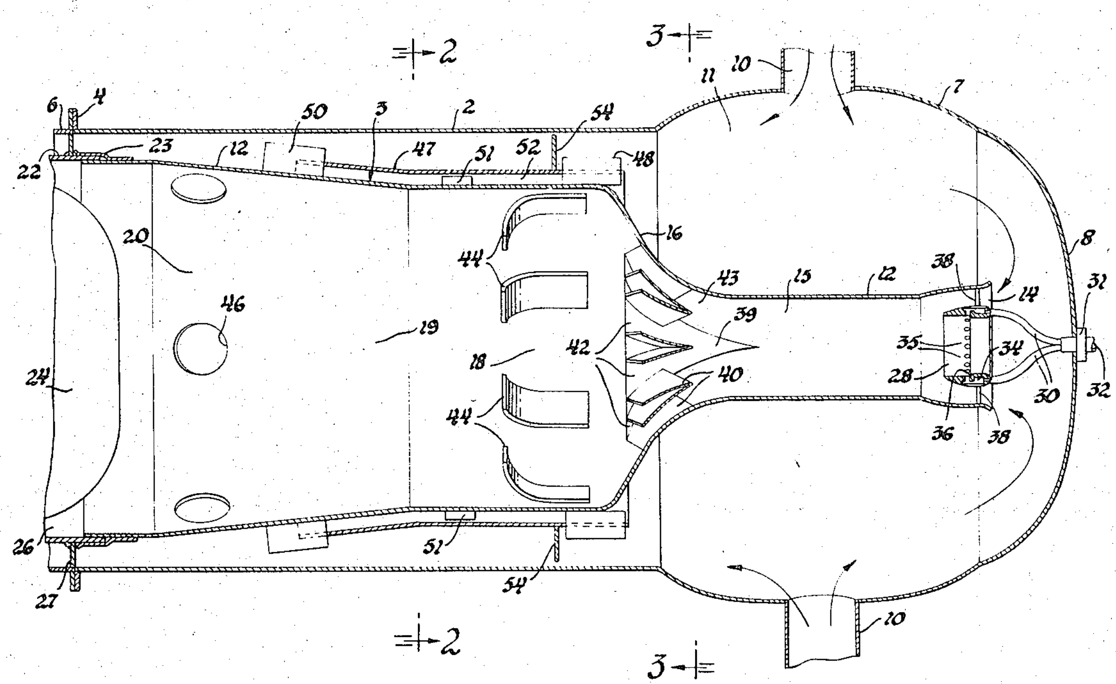
*Primary Examiner*—C. J. Husar
*Assistant Examiner*—Robert E. Garrett
*Attorney, Agent, or Firm*—Paul Fitzpatrick



[57] **ABSTRACT**

A combustion apparatus for a regenerative gas turbine engine includes a combustion liner providing for prevaporization and premixing of fuel, for extended residence time after primary combustion, and for delayed dilution of the combustion products. The liner includes a premix-prevaporiation zone with relatively small cross-sectional area, with fuel injecting means at the upstream end. Air flows without swirl through this zone, and through a flare in the liner where the cross section area increases greatly into the combustion zone. A centerbody in the flare directs flow along the inner surface of the wall and additionally heats the fuel-air mixture. Supports for the centerbody define spaced chutes for the air entering the combustion apparatus, and vanes extending inwardly from the wall downstream of the flare deflect the flow from the chutes toward the center of the combustion zone. Combustion air is admitted only through the premix-prevaporization zone. The combuston zone and part of a residence zone downstream of the combustion zone are cooled by convection only, using dilution air. Entrance holes for dilution air are near the downstream end of the liner.


**5 Claims, 3 Drawing Figures**



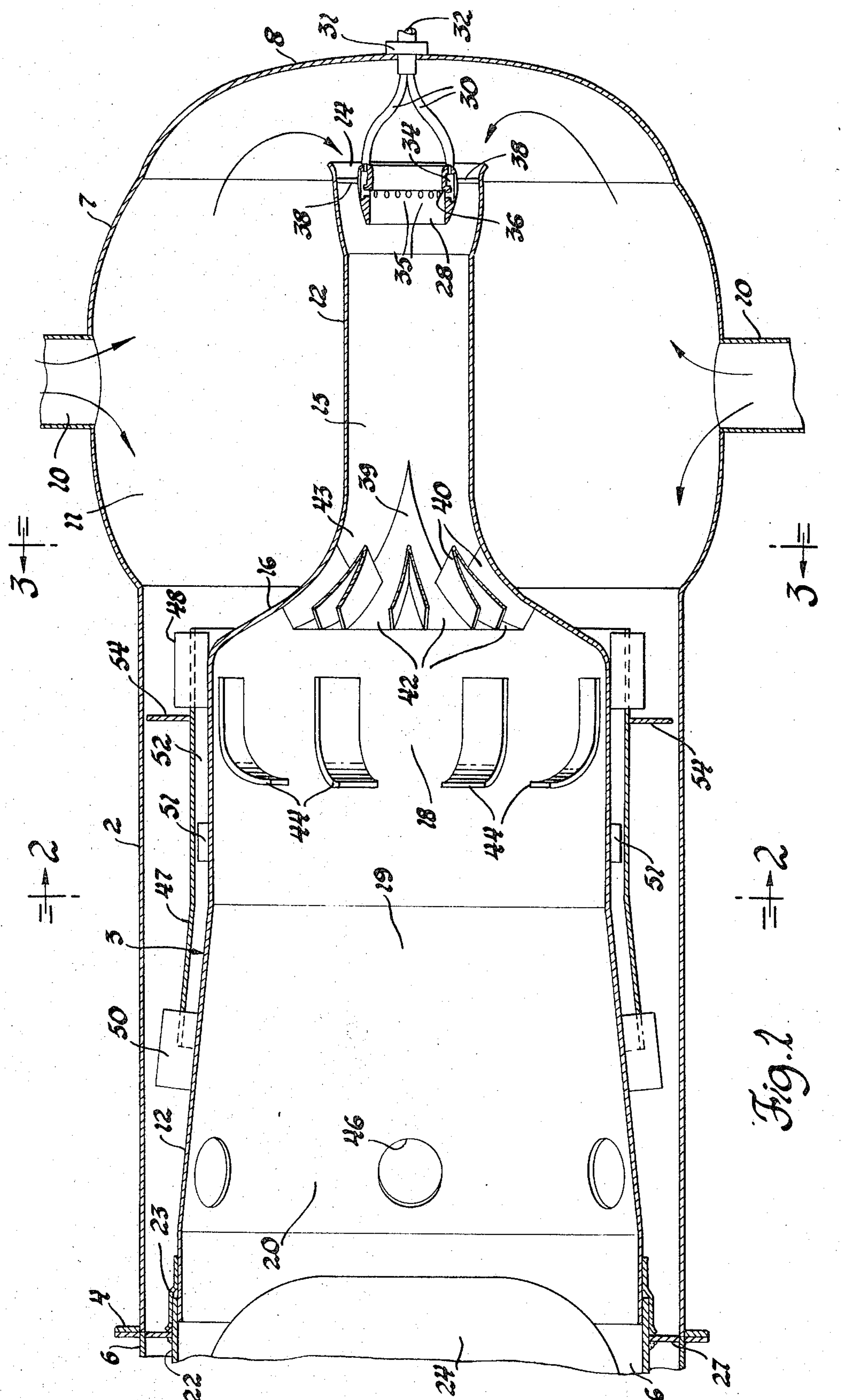

2
3
4
6
7
8
10
11
12
15
16
18
19
20
22
23
24
26
27
28
30
31
32
34
35
36
38
39
40
42
43
44
46
47
48
50
51
52
54
3
3
2
2

Fig. 1

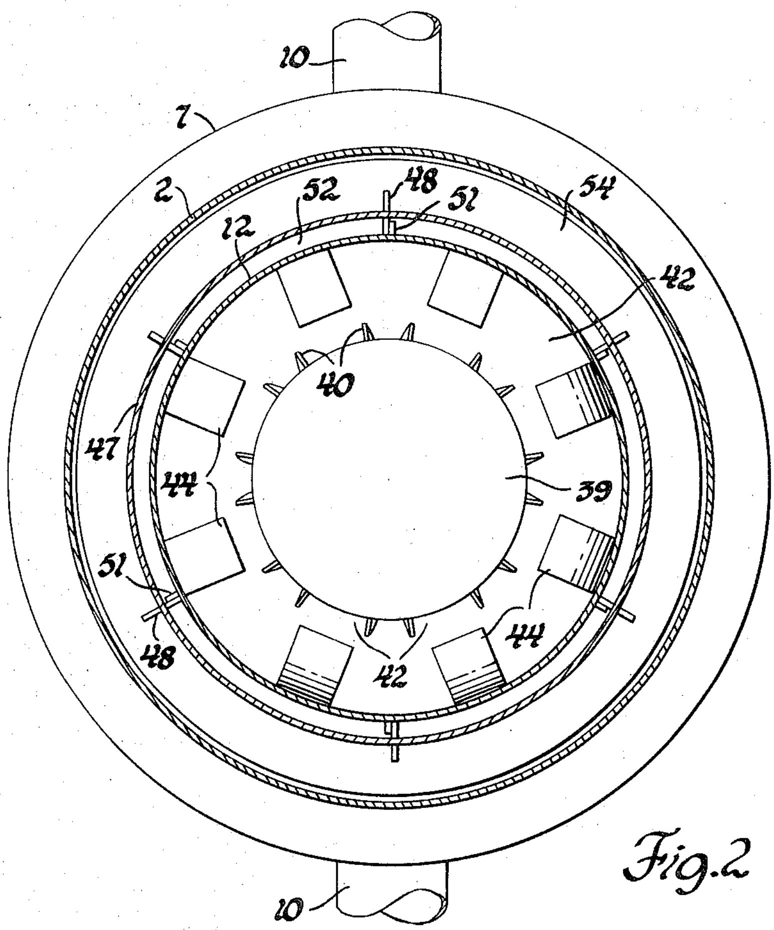

10
7
2
52
48
51
54
12
42
40
47
44
39
51
48
44
42
10

Fig.2

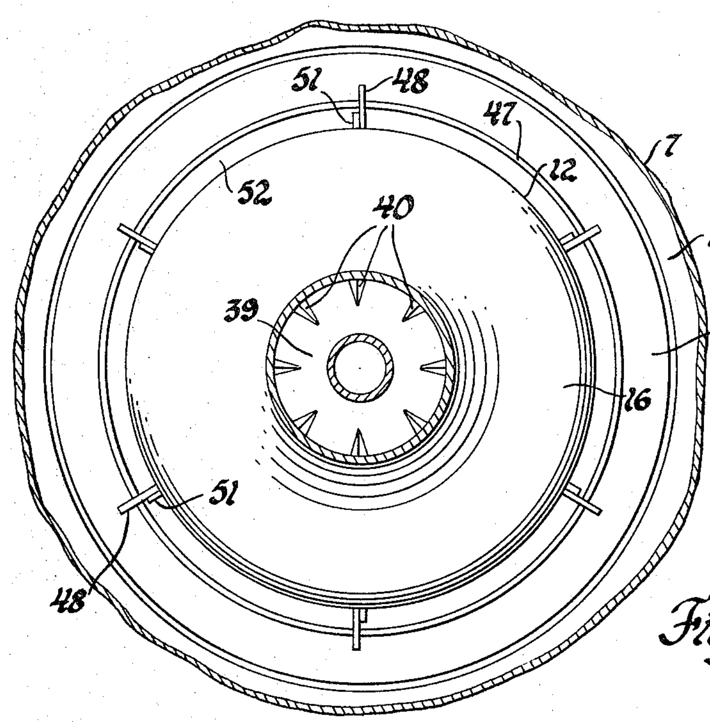

51
48
47
7
12
52
40
11
39
54
16
51
48

Fig.3

## COMBUSTION APPARATUS

My invention is directed to combustion apparatus, particularly to combustion apparatus for use at relatively high air inlet temperatures, and usually at considerable pressure, as contrasted to operation near normal atmospheric conditions. Specifically, the preferred embodiment of my invention is intended as a combustion apparatus for a regenerative gas turbine engine such as might be used for vehicle or aircraft propulsion.

Such engines operate at pressure ratios of the order of four or five to one, which means that the pressure of the air in the combustion apparatus under sea level standard conditions rises to 45 to 60 psig. In a nonregenerative engine, the air is heated to some extent by the compression; in a regenerative engine, it is additionally heated by heat transfer from air exhausted from the engine, so that the air entering the combustion apparatus under full power conditions may be at about 900° F. Prior art combustion chambers for engines of this sort have incorporated combustion liners within which the combustion takes place, and the principal emphasis on design of such liners has been to secure dependable burning of the fuel, minimize pressure drop, minimize the volume of the combustion liner, and provide a durable and trouble-free structure.

Because of the high temperatures and small combustion volume, such combustion apparatuses discharge substances regarded as atmospheric pollutants. Such pollutants are principally particulates (normally unburned carbon), carbon monoxide, unburned hydrocarbons, and nitrogen oxides resulting from the combination of atmospheric nitrogen and oxygen in the hot combustion zone.

Various expedients have been proposed and various combustion liner structures have been designed in an effort to secure more complete combustion, thus a cleaner exhaust; and also to reduce as far as feasible the generation of nitrogen oxides.

The preferred combustion apparatus according to my invention involves the following features to improve emission characteristics:

1. A premix-prevaporization section is provided upstream of the primary combustion section to premix the fuel and primary air and to prevaporize the fuel ahead of the combustion or reaction zone. This is to improve combustor homogeneity and to avoid fuel droplet burning, thereby eliminating carbon entirely.
2. The liner provides for sudden expansion from the premix-prevaporization zone to the combustion zone for flame stabilization.
3. The primary combustion zone is operated somewhat lean to minimize formation of oxides of nitrogen.
4. Dilution of the combustion products is delayed to provide a relatively extended residence of the combustion products for complete consumption of carbon monoxide and hydrocarbons.
5. The combustion zone is cooled by convection cooling rather than film cooling to avoid quenching of the combustion reactions in relatively cold film cooling air as in prior combustion liners.

While a liner according to the invention or including some of the features of it may be employed in other types of installation, the conditions in a regenerative engine are favorable to it because the relatively higher temperature of the air entering the combustion apparatus promotes evaporation of the fuel in the air before its entrance into the combustion zone.

The principal objects of my invention are to provide a combustion apparatus suitable for gas turbine engines and which tends to minimize the generation of atmospheric pollutants; to provide improved apparatus for mixing and evaporation of the fuel in a combustion apparatus before its entrance into the combustion zone; to provide a combustion liner having a relatively great length between the point of initiation of flame and the point of dilution or quenching of the flame; to provide combustion apparatus in which a fuel-air mixture flows over a heated centerbody from a premix-prevaporization zone of low cross-sectional area into a combustion zone of large cross-sectional area; and, in general, to provide combustion apparatus that is better suited to the requirements of practice than those now available.

The nature of my invention and its advantages will be clear to those skilled in the art from the succeeding detailed description of the preferred embodiment of the invention and the accompanying drawings.

FIG. 1 is a longitudinal sectional view of a combustion apparatus embodying the invention.

FIG. 2 is a cross-section view of the same taken on the plane indicated by the line 2—2 in FIG. 1.

FIG. 3 is a cross-section view taken on the plane indicated by the line 3—3 in FIG. 1.

The drawings represent the liner according to my invention as installed in combustion apparatus similar to that of the well known T63 aircraft engine, in which the combustion apparatus is of a single can type and the single liner discharges into an annular turbine inlet. In that engine, compressed air is supplied to the combustion apparatus through air tubes entering the side of a combustion casing. It should be understood, however, that my invention is directed particularly to the structure of the liner and to its cooperation with the combustion outer casing and that various types of combustion casings or air supply means may be used. Also, the liner need not have an annular outlet. Also, the principles of the invention may be embodied in an annular combustion liner in which the liner is constituted by outer and inner walls having an annular combustion space between them.

Referring to FIG. 1, the combustion apparatus includes a casing **2** adapted to receive air under pressure and a liner **3**. The casing **2** is bolted at flanges **4** to an outer case **6** of the turbine of a gas turbine engine. As illustrated, the casing **2** includes a generally cylindrical portion extending in the upstream direction from the flanges **4** and an enlarged upstream portion **7** closed by an end cover **8**. The combustion air is discharged through air tubes **10** into a plenum **11** defined by the upstream portion of the casing. The liner **3**, which is of circular cross-section in the form illustrated, has a side wall **12** defining in succession from the upstream end of the liner a primary or combustion air entrance **14**, a generally cylindrical premix-prevaporization zone **15**, a flare **16**, a combustion zone **18**, a residence zone **19**, and a dilution zone **20**. The downstream end of the liner fits within an outer turbine shroud **22**, and a flange **23** on the exterior of the downstream end of the liner fits over shroud **22**. The liner is thus located at its downstream or discharge end on the turbine outer shroud. An annular baffle **24** mounted on the turbine defines with the shroud **22** an annular entrance **26** into the turbine for the motive fluid generated in the combustion apparatus. A wall indicated schematically at **27** blocks flow of air through the gap between the casing and liner.

The upstream end of liner **3** is supported on a fuel injection ring **28** disposed within the entrance **14** and supported by the fuel tubes **30** or other supporting means from a fitting **31** suitably fixed to the end cover **8.** Fuel is supplied to the combustion apparatus through a fuel tube **32.** The combustion apparatus is designed for use with a liquid hydrocarbon fuel. The fuel injection ring **28** thus supports the upstream end of the liner.

The fuel injection ring, which is of known type, is considered to be the most suitable means for carburetting the air flowing into the inlet. The fuel injection ring **28** is a composite circular ring defining an internal circular manifold **34** for fuel supplied through tubes **30** and having ports **35** extending from the manifold and directed tangentially to the interior surface of ring **28** to discharge fuel in the form of an annulus on the inner surface of the ring. This fuel is discharged behind a step or shoulder **36** on the interior of the ring.

Four or more struts **38** extend from the exterior of ring **28** to the wall of the liner. Air under pressure flows from the plenum **11** over the exterior and through the interior of fuel injection ring **28** and downstream through the premix-prevaporization zone **15.** The fuel is airblast atomized off ring **28** by the air flowing past it. During travel through the premix-prevaporization zone, the heated air evaporates the fuel so as to provide a substantially homogeneous mixture of air and vaporized fuel. It should be noted that the struts **38** are not swirlers, and that the air preferably flows through the zone **15** with no circumferential component of velocity.

There is a transition from the premix-prevaporization zone **15** to the combustion zone **18** through structure defined in part by the flare of the outer wall. There is an enlargement in area of the liner at this point of about 10 to one.

Flow through this transition zone is guided in part by a centerbody **39** of circular cross section, the outer surface of which roughly parallels the inner surface of the liner wall. The centerbody is hollow and is open at its downstream end so that heat from combustion in the combustion zone heats the centerbody, thus contributing a slight amount of heat to the air-fuel mixture flowing over it. The centerbody is supported from the flaring wall portion **16** by eight generally V-shaped sheet metal struts or air guides **40** distributed around the circumference of the centerbody which may be welded to the centerbody and liner wall. These air guides define eight air chutes **42** between the struts. The chute outlets occupy approximately half of the circumference of the annular passage **43** between the centerbody and the liner wall. The centerbody serves to deflect the flow of air and fuel along the inside of the wall **16** and the chutes concentrate this flow into eight jets evenly distributed around the circumference. The centerbody and struts are heated by the combustion just downstream of them and therefore these heated bodies additionally heat the incoming air and fuel somewhat.

The centerbody **39** acts as a flow director, creating a turbulent zone behind it to retain the flame against blowing out downstream of the liner. From the flare **16,** the wall **12** of the liner continues first cylindrical and then slightly diverging to the downstream end of the liner. A thorough mixing of the fuel and air in the combustion zone **18** is promoted by a ring of eight turning vanes **44** welded to the wall, the form of which will be apparent from FIGS. **2** and **3.** These deflect the incoming air-fuel mixture flowing through the chutes **42** toward the axis of the combustion liner and promote formation of a generally toroidal vortex flow and recirculation in the combustion zone to stabilize combustion. The combustion occurs in the region near the flare **16** and vanes **44** and the resulting combustion products, in which the fuel is almost entire burned, flow through the residence zone **19** toward the combustion chamber outlet.

During the flow through the residence zone, time is allowed for completion of the reactions to reduce the remaining traces of unburned fuel to a minimum.

In the combustion apparatus for a regenerative engine, as illustrated, approximately 40 percent of the total air supplied to the combustion apparatus enters through the air entrance **14** and constitutes combustion air. The remaining 60 percent is dilution air which flows radially inward from the casing through a ring of six large dilution air holes **46** disposed near the downstream end of the liner. The space abreast of these holes and extending to the outlet of the liner constitutes the dilution zone **20.**

The proportions of primary air and dilution air may, of course, be varied to suit a particular installation.

The dilution air, before entering the liner through the holes **46,** is used to cool the outer surface of the liner from the flare **16** downstream by convection cooling, avoiding any introduction of air into the liner for film cooling, for instance. Cooling is promoted by an annular shroud **47** surrounding and spaced from the wall **12** of the downstream portion of the liner. The shroud **47** is mounted over the wall **12** with freedom for relative expansion of the parts by a structure including six plates **48** extending radially outwardly from the inner wall adjacent the flare **16** and six similar plates **50** at the downstream end of the shroud **47.** These plates are slidable in slots in the leading and trailing edges of the shroud **47** so the liner may expand radially relative to the cooler shroud. Plates **48** may be welded to the liner before the shroud is put in place and plates **50** then may be inserted in the slots of the shroud and welded to the liner wall. A ring of spacers **51** disposed around the outer surface of the liner wall **12** near the middle of the length of the shroud prevent distortion of this portion of the shroud from partially closing off the annular flow passage **52** between the wall and shroud. A baffle ring or blocking member **54** fixed to the outer surface of shroud **47** extends across the gap between the shroud and the case **2** to minimize or control flow over the outside of the shroud by-passing the cooling air path **52.** This blocking member may be considered to divide the space within the casing into an upstream portion ahead of the blocking member and a downstream portion surrounding the residence and dilution zones.

The operation of the combustion apparatus should be clear from the foregoing, but may be summarized briefly. Hot air under compression ordinarily on the order of four to five atmospheres and heated at about 900° F. in the regenerator (at full power) is introduced into the plenum **11** and hydrocarbon fuel is introduced through pipe **32** into the annular fuel injection ring **28.** The fuel is discharged circumferentially around the interior of the ring **28** and is picked up by air flowing through the center of the ring. The hot air mixes with the fuel, which is evaporated, and the mixture then flows outwardly along the flare wall **16** through the chutes **42** into the combustion zone **18** where it is deflected inwardly by the vanes **44.** The flame is maintained in the zone **18** after ignition by any suitable igniter (not illustrated). The combustion gases flow downstream through the residence zone **19**, further completing oxidation of the fuel and fuel components, and then are quenched and diluted by the large quantity of air entering through dilution holes **46.** The resulting mixture, which is of a temperature suitable for use in the turbine, is discharged through the annular outlet **26** into the turbine. The equivalence ratio in the primary section of the specific liner described is calculated to be 0.73 under full load conditions. This varies with load conditions, and various full load values may be adopted. There are reasons to believe a lower equivalence ratio of the order of 0.5 at full load would provide better emission characteristics.

In connection with combustion, it is recognized that not only the overall equivalence ratio within the burning zone of the combustor, but also local fuel-air ratios at various points within the burning zone are significant. It is well known that as the fuel-air mixture becomes richer from a very low value, the curve of carbon monoxide emissions descends from a high value along a more or less hyperbolic curve to a very low value. Contrariwise, the emissions of nitrogen oxides are very low when the fuel-air ratio is lean, but as the mixture becomes richer the curve of nitrogen oxides begins to rise progressively more steeply. With a rich mixture, the amount of nitrogen oxides produced is relatively high. The best overall emissions characteristic is obtained at an intermediate value of fuel-air ratio. However, if the overall fuel-air ratio should be at the optimum point but there is poor mixing, then there are both leaner and richer fuel-air mixture zones within the combustion area. This causes deterioration in emission performance.

In my combustion apparatus described above, such uneven distribution providing both locally lean and locally rich zones is prevented by turbulent diffusion of the fuel in the air within the premix-prevaporization zone **15** and by flow through the chutes **42.** It is also provided in the combustion zone by the structure impinging the jets from the chutes **42** against the vanes **44** and recirculating the gases within the combustion zone to achieve thorough mixing of the burning and unburned air-fuel mixtures.

For any given engine, it is possible to design the combustion apparatus so as to operate with the fuel-air ratio at the point where emissions are at a minimum.

As pointed out above, the advantages of my combustion apparatus are greatest where the incoming air is relatively hot. This is the case with normal regenerative gas turbine engines. It also may be the case with very high pressure ratio engines in which the work of compression raises the incoming air to relatively high temperatures. Also, in some cases, the combustion apparatus may work with air preheated otherwise than by a regenerator. In any event, the combustion chamber is particularly effective with air in the temperature range of 700° to 900° F. or above.

It will be seen that the apparatus described is well adapted to employ the modes of reduction of undesired contaminants outlined in the introduction to this specification. It will also be seen that it is a relatively simple structure and, while larger than prior art combustion apparatus for such purposes, is not unduly bulky. Specifically, the liner, which is shown to scale in the drawing, is 15 inches long and 6½ inches in diameter at its outlet. It is about 6 inches longer than a typical prior art liner of similar capacity.

The detailed description of the preferred embodiment of the invention for the purpose of explaining its principles is not to be considered as limiting or restricting the invention, as many modifications may be made by the exercise of skill in the art.

I claim:

**1.** A combustion apparatus for a regenerative gas turbine engine or the like comprising, in combination, a casing having an upstream portion and a downstream portion and having an entrance for hot compressed air in the upstream portion; a combustion liner disposed within the casing having an upstream end in the upstream portion of the casing and a downstream end in the downstream portion of the casing; the casing and liner defining between them a space for the compressed air discharging into the liner, and the liner defining an outlet for combustion products at its downstream end; the liner including wall means defining, in flow sequence from its upstream end, a premix-prevaporization zone, a combustion zone, and a dilution zone; the premix-prevaporization zone having an open upstream end defining a primary air inlet adapted to admit air flowing axially of the zone without significant circumferential velocity; means in the air inlet for carburetting the air; the wall means defining a flare from the premix-prevaporization zone into the combustion zone; a centerbody disposed centrally of the flare effective to guide the flow along the inner surface of the wall means at the flare, the centerbody serving to heat additionally the carburetted air; the combustion zone being located immediately downstream of the flare and having substantially greater cross-sectional area than the premix-prevaporization zone, and including means effective to promote circulation and mixing in the combustion zone; shroud means spaced outwardly from the wall means extending downstream from the flare over the combustion zone effective to define a shallow flow path for convection cooling air over the exterior of the wall means; and blocking means between the shroud means and casing disposed between the upstream and downstream portions of the casing effective to direct a major portion of dilution air through the said flow path; the dilution zone of the liner having dilution air entrance holes through the wall means adjacent to the downstream end of the liner to admit dilution air from the downstream portion of the casing; and the liner wall means between the premix-prevaporization and dilution zones being substantially imperforate.

**2.** A combustion apparatus for a regenerative gas turbine engine or the like comprising, in combination, a casing having an upstream portion and a downstream portion and having an entrance for hot compressed air in the upstream portion; a combustion liner disposed within the casing having an upstream end in the upstream portion of the casing and a downstream end in the downstream portion of the casing; the casing and liner defining between them a space for the compressed air discharging into the liner, and the liner defining an outlet for combustion products at its downstream end;

the liner including wall means defining, in flow sequence from its upstream end, a premix-prevaporization zone, a combustion zone, and a dilution zone; the premix-prevaporization zone having an open upstream end defining a primary air inlet adapted to admit air flowing axially of the zone without significant circumferential velocity; means in the air inlet for carburetting the air; the wall means defining a flare from the premix-prevaporization zone into the combustion zone; a centerbody disposed centrally of the flare effective to guide the flow along the inner surface of the wall means at the flare, the centerbody serving to heat additionally the carburetted air; guide means connecting the centerbody to the wall means defining spaced chutes for the air and blocking flow between the chutes; the combustion zone being located immediately downstream of the flare and having substantially greater cross-sectional area than the premix-prevaporization zone, and including means effective to promote circulation and mixing in the combustion zone; shroud means spaced outwardly from the wall means extending downstream from the flare over the combustion zone effective to define a shallow flow path for convection cooling air over the exterior of the wall means; and blocking means between the shroud means and casing disposed between the upstream and downstream portions of the casing effective to direct a major portion of dilution air through the said flow path; the dilution zone of the liner having dilution air entrance holes through the wall means adjacent to the downstream end of the liner to admit dilution air from the downstream portion of the casing; and the liner wall means between the premix-prevaporization and dilution zones being substantially imperforate.

3. A combustion apparatus for a regenerative gas turbine engine or the like comprising, in combination, a casing having an upstream portion and a downstream portion and having an entrance for hot compressed air in the upstream portion; a combustion liner disposed within the casing having an upstream end in the upstream portion of the casing and a downstream end in the downstream portion of the casing; the casing and liner defining between them a space for the compressed air discharging into the liner, and the liner defining an outlet for combustion products at its downstream end; the liner including wall means defining, in flow sequence from its upstream end, a premix-prevaporization zone, a combustion zone, and a dilution zone; the premix-prevaporization zone having an open upstream end defining a primary air inlet adapted to admit air flowing axially of the zone without significant circumferential velocity; means in the air inlet for carburetting the air; the wall means defining a flare from the premix-prevaporization zone into the combustion zone; a centerbody disposed centrally of the flare effective to guide the flow along the inner surface of the wall means at the flare, the centerbody serving to heat additionally the carburetted air; guide means connecting the centerbody to the wall means defining spaced chutes for the air and blocking flow between the chutes; the combustion zone being located immediately downstream of the flare and having substantially greater cross-sectional area than the premix-prevaporization zone, and including stirring vanes extending from the wall means into the path of flow from the chutes effective to promote circulation and mixing in the combustion zone; shroud means spaced outwardly from the wall means extending downstream from the flare over the combustion zone effective to define a shallow flow path for convection cooling air over the exterior of the wall means; and blocking means between the shroud means and casing disposed between the upstream and downstream portions of the casing effective to direct a major portion of dilution air through the said flow path; the dilution zone of the liner having dilution air entrance holes through the wall means adjacent to the downstream end of the liner to admit dilution air from the downstream portion of the casing; and the liner wall means between the premix-prevaporization and dilution zones being substantially imperforate.

4. A combustion apparatus for a regenerative gas turbine engine or the like comprising, in combination, a casing having an upstream portion and a downstream portion and having an entrance for hot compressed air in the upstream portion; a combustion liner disposed within the casing having an upstream end in the upstream portion of the casing and a downstream end in the downstream portion of the casing; the casing and liner defining between them a space for the compressed air discharging into the liner, and the liner defining an outlet for combustion products at its downstream end; the liner including wall means defining, in flow sequence from its upstream end, a premix-prevaporization zone, a combustion zone, a residence zone, and a dilution zone; the premix-prevaporization zone having an open upstream end defining a primary air inlet adapted to admit air flowing axially of the zone without significant circumferential velocity; means in the air inlet for carburetting the air; the wall means defining a flare from the premix-prevaporization zone into the combustion zone; a centerbody disposed centrally of the flare effective to guide the flow along the inner surface of the wall means at the flare, the centerbody serving to heat additionally the carburetted air; the combustion zone being located immediately downstream of the flare and having substantially greater cross-sectional area than the premix-prevaporization zone, and including means effective to promote circulation and mixing in the combustion zone; shroud means spaced outwardly from the wall means extending downstream from the flare over the combustion zone effective to define a shallow flow path for convection cooling air over the exterior of the wall means; and blocking means between the shroud means and casing disposed between the upstream and downstream portions of the casing effective to direct a major portion of dilution air through the said flow path; the dilution zone of the liner having dilution air entrance holes through the wall means adjacent to the downstream end of the liner to admit dilution air from the downstream portion of the casing; and the liner wall means at the combustion and residence zones being substantially imperforate.

5. A combustion apparatus for a regenerative gas turbine engine or the like comprising, in combination, a casing having an upstream portion and a downstream portion and having an entrance for hot compressed air in the upstream portion; a combustion liner disposed within the casing having an upstream end in the upstream portion of the casing and a downstream end in the downstream portion of the casing; the casing and liner defining between them a space for the compressed air discharging into the liner, and the liner defining an outlet for combustion products at its downstream end; the liner including wall means defining, in flow se-

quence from its upstream end, a premix-prevaporization zone, a combustion zone, a residence zone, and a dilution zone; the premix-prevaporization zone having an open upstream end defining a primary air inlet adapted to admit air flowing axially of the zone without significant circumferential velocity; means in the air inlet for carburetting the air; the wall means defining a flare from the premix-prevaporization zone into the combustion zone; a centerbody disposed centrally of the flare effective to guide the flow along the inner surface of the wall means at the flare, the centerbody serving to heat additionally the carburetted air; guide means connecting the centerbody to the wall means defining spaced chutes for the air and blocking flow between the chutes; the combustion zone being located immediately downstream of the flare and having substantially greater cross-sectional area than the premix-prevaporization zone, and including stirring vanes extending from the wall means into the path of flow from the chutes effective to promote circulation and mixing in the combustion zone; shroud means spaced outwardly from the wall means extending downstream from the flare over the combustion zone effective to define a shallow flow path for convection cooling air over the exterior of the wall means; and blocking means between the shroud means and casing disposed between the upstream and downstream portions of the casing effective to direct the major portion of dilution air through the said flow path; the dilution zone of the liner having dilution air entrance holes through the wall means adjacent to the downstream end of the liner to admit dilution air from the downstream portion of the casing; and the liner wall means at the combustion and residence zones being substantially imperforate.

* * * * *