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Wade

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[54] COMBUSTION APPARATUS

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[51] **Int. Cl.** **F02c 3/00,** F02c 7/08

[58] **Field of Search** 60/39.65, 39.52; 431/116, 352

[56] **References Cited**

UNITED STATES PATENTS

3,024,608	3/1962	Carlotti	60/39.65
3,498,055	3/1970	Faitani	60/39.65

FOREIGN PATENTS OR APPLICATIONS

460,206	11/1950	Italy	60/39.52
550,737	12/1959	Belgium	431/116
1,130,958	6/1962	Germany	431/116

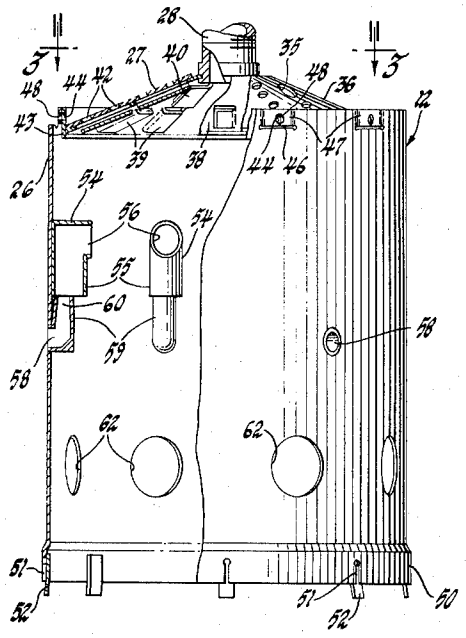
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[57] **ABSTRACT**

A gas turbine combustion apparatus includes a cylindrical combustion liner with a dome through which primary combustion air is admitted in part. Film cooling air is admitted between the dome and the side wall to flow along the side wall and additional primary combustion air is admitted through mixing devices which mix the air with some combustion products, the resulting mixing being cooled in part by the combustion liner film cooling air. The result is to dilute oxygen at the flame and lower combustion temperatures, and therefore minimize formation of oxides of nitrogen.

5 Claims, 3 Drawing Figures



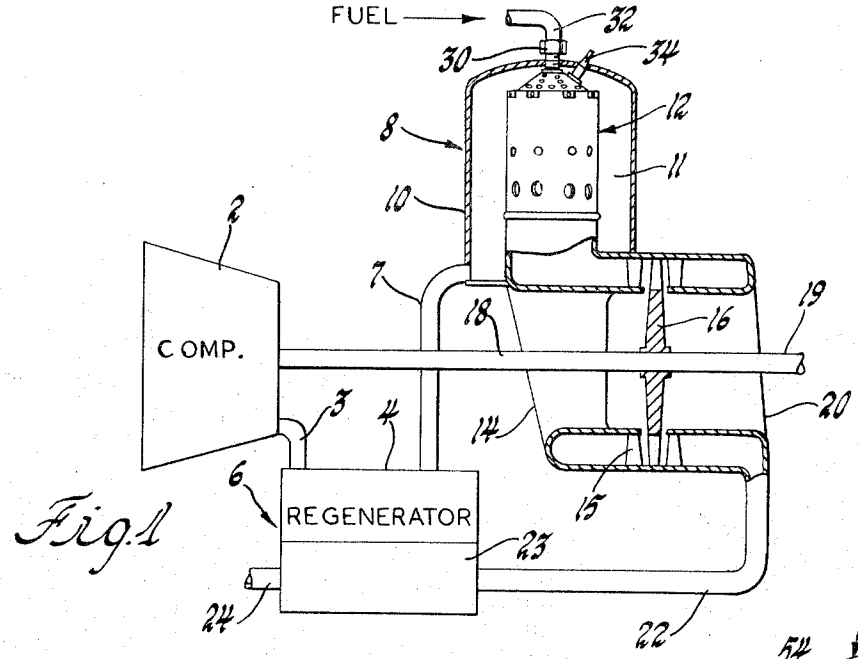


Fig. 1

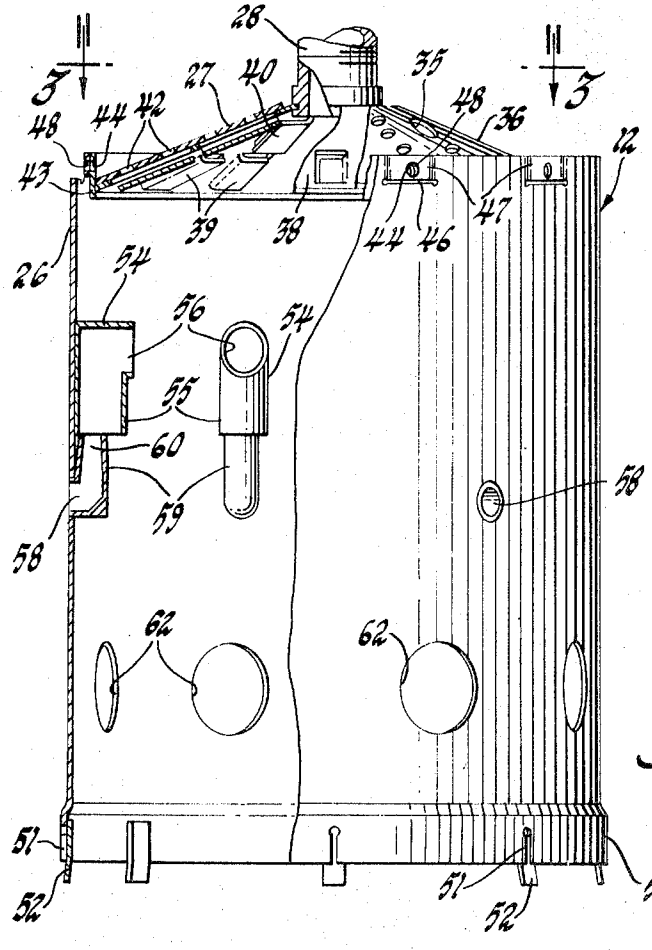


Fig. 2

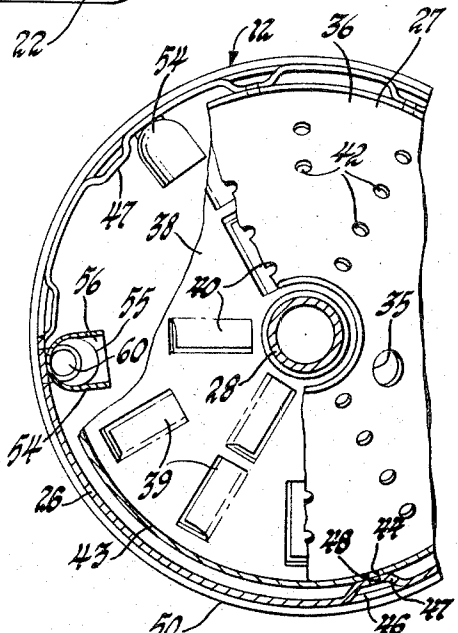


Fig. 3

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COMBUSTION APPARATUS

My invention relates to combustion apparatus, particularly to combustion devices having high heat release rates such as are used in gas turbine engines. Typical combustion devices for gas turbines include a casing to which air is supplied under substantial pressure from the compressor of the engine and a liner or liners within the casing within which fuel is mixed with air, the fuel is burned, and the resulting combustion products are further diluted with air to provide the motive fluid for the turbine.

By the nature of the gas turbine combustion process, properly designed gas turbine combustors ordinarily have a very low output of unburned hydrocarbons and of carbon monoxide. However, since the combustion takes place at rather high temperatures, there is a considerable tendency for oxygen and nitrogen molecules to become dissociated and to recombine to form an oxide of nitrogen. These oxides of nitrogen are regarded as atmospheric pollutants.

By and large, the NO_x problem is intensified if the gas turbine engine includes a regenerator which heats the combustion air by heat exchange with the turbine exhaust, resulting in higher temperatures in the combustion zone of the combustion apparatus.

More specifically, my invention is based upon the fact that nitric oxide is formed in a combustion process by the fixation of nitrogen and excess oxygen at elevated reaction temperatures. The combustion zone in a gas turbine is typically somewhat rich in oxygen over the stoichiometric amount. It can be shown by chemical equilibrium considerations that the concentration of nitric oxide can be reduced by decreasing the available excess oxygen concentrations or by reducing the reaction temperature.

The addition of a cooled inert diluent to replace the excess oxygen in a combustion process should, therefore, result in reductions of nitric oxide concentrations. According to my invention, the combustion liner of a gas turbine combustor includes structure which serves to circulate inert combustion products from the downstream end of the primary or combustion zone through an air-cooled recirculation tube. Recirculation is accomplished by the use of the pressure drop created by a venturi or injector effect of an entering primary or combustion air flow. A mixture of primary combustion air and cooled inert combustion products is injected into the primary or combustion zone. In this way, both the concentration of oxygen and the reaction temperature in the combustion zone can be reduced, thereby reducing the formation of nitrogen oxides.

The principal objects of my invention are to provide a practical and efficient gas turbine combustion apparatus which has a low output of nitrogen oxides, to improve the emission characteristics of gas turbine engines and other continuous combustion devices, and to provide a simple and practical structure for recirculating cooled combustion products to the combustion zone in a combustion apparatus.

The nature of my invention and its advantages will be more clearly apparent from the succeeding detailed description of the preferred embodiment of my invention and the accompanying drawings thereof. Referring to the drawings:

FIG. 1 is a schematic diagram of a gas turbine engine.

FIG. 2 is a longitudinal view of a combustion liner with parts cut away and in section.

FIG. 3 is a partial end view of the combustion liner with parts cut away and in section, as indicated by the line 3 —3 in FIG. 2.

The gas turbine engine shown schematically in FIG. 1 may be considered to be conventional, except for the combustion liner structure to be described more particularly.

The engine comprises a compressor 2 which discharges through a conduit 3 and a high pressure air pass 4 of a regenerator 6 in which the compressed air is heated. The heated air flows through a conduit 7 into combustion apparatus 8 which includes a casing 10 defining within it a space 11 from which the compressed air flows into a combustion liner 12. The combustion liner is mounted upon a transition duct or scroll 14 from which the combustion products generated in the liner 12 flow through an annular turbine nozzle 15 which directs the gas onto blades on the circumference of a turbine wheel 16. The wheel 16 is connected by a shaft 18 to drive the compressor 2. It also may drive a power output shaft 19. The exhaust of the turbine flows through a turbine exhaust casing 20, a duct 22, the hot gas pass 23 of the regenerator 6, and exhaust line 24 to atmosphere. The regenerator may be either a fixed structure, commonly called a recuperator, or a rotary regenerator, the details being immaterial. My invention is applicable to engines from which the regenerator is omitted; but, because of the hotter combustion air in the regenerative engine, the combustion system of my invention is more advantageous in such an engine.

The gas turbine engine may be of various types. For example, it may be of the well-known free turbine type in which the output shaft 19 is driven by another turbine in the motive fluid path rather than by the turbine 16. In general, structurally speaking, the engine might be of structure similar to either of those shown in U.S. Pat. Nos. 3,116,605 of Amann et al., Jan. 7, 1964 and 3,267,674 of Collman et al., issued Aug. 23, 1966. It may be noted that these patents illustrate prior art combustion liners and the structure of transition duct 14 as well as structures of compressors, turbines, regenerators, and other elements which make up the complete power plant.

The combustion liner 12 (see also FIGS. 2 and 3) comprises a side wall or body portion 26, which is cylindrical in the illustrated embodiment, and a dome 27 which is a shallow conical structure. A ferrule 28 at the center of the dome which projects through the casing 10 is threaded for a nut 30. The fuel is injected into the combustion chamber by a fuel nozzle (not illustrated) mounted in ferrule 28, to which fuel is supplied through a line 32. The nozzle is thus mounted at the center of the dome projecting slightly into the combustion liner and delivers the fuel in a conical spray pattern, as is well known. See, for example, U.S. Pat. No. 3,064,424 of Tomlinson, Nov. 20, 1962. An igniter 34 which serves to initiate combustion projects through a hole 35 in the dome.

The dome 27 comprises an outer sheet 36 and an inner sheet 38, these being spot-welded together. The inner sheet is slit and offset in a press to define an outer row of twelve air swirl blades 39 which swirl air entering through the dome in one direction around the liner axis, and to define an inner row of six swirl blades 40 which swirl the air in the opposite direction. Air is admitted through the outer sheet 36 to the upper surface of the swirl blades through perforations 42 in the outer sheet. The swirling air thus entering the combustion liner serves to scour the dome and to provide a portion of the combustion air.

The outer margin of the dome is defined by a flat ring 43 which is welded to the edge of the sheets 36 and 38. Ten small holes 44 distributed equally around the ring 43 provide for attaching the dome to the liner body 26. The liner body is slit at ten equally spaced places around its upper margin as indicated at 46 and the metal is deformed inwardly to provide an offset bracket 47 above each slit. Holes 48 through the brackets 47 align with the holes 44 in the dome margin, and the two are retained in proper relation by sheet metal screws or the like. In the particular example, the diameter of the dome overall is 7.05 inches and the interior diameter of the body is 7.50 inches, so that there is a gap almost a quarter inch wide between the edge of the dome and the wall of the body 26. A strong flow of air enters at this point and flows along the inner surface of the wall 26 to provide film cooling of the wall by convection and also to isolate the wall from the extremely hot combustion products which are substantially confined within the film cooling air, although some mixing will occur.

The downstream or outlet end of the combustion liner wall 26 is flared slightly as indicated at 50, is slitted at indicated at 51, and has a ring of tabs 52 each of which is welded to the wall along one edge only of the slit 51. These tabs are provided to align the combustion liner with the transition duct 14.

Primary or combustion air enters the liner through fixed recirculation tubes **54** which are of circular cross section, each including an entrance portion **55** and an outlet **56**. As will be apparent from the figures, the inlet faces away from the dome of the liner and the outlet **56** is directed radially inward toward the axis of the liner. The tubes **54** are spot-welded to wall **26**. The outlets **56** substitute for the normal combustion air inlets in the prior art liner of which mine is an improvement; which inlets were located at the same station along the length of the liner as the recirculation tube outlets **56**.

In my improved combustion liner the primary air entrances **58** are disposed farther downstream in the combustion apparatus. Each primary air entrance is a right angle bend tube **59** of circular cross section spot-welded into the wall **26**. Each primary air tube **59** has a converging outlet defining an air nozzle **60** disposed at the entrance to the recirculation tube **54**. Because of the pressure difference between the outside and the inside of the combustion liner, compressed air enters through each of the ring of entrances **58** and is accelerated through the nozzle **60** into the recirculation tube **54**. The entering air entrains with it combustion products circulating within the liner and drives the combustion products with the entering clean air through the recirculation tube **54** and into the combustion zone of the combustion liner through the outlets **56**. The film cooling air flows past recirculation tubes **54** in the wrong direction to enter them.

While there is no exact demarcation of the end of the combustion zone of the liner, it may be considered to be approximately at the lower or downstream end of the recirculation tubes **54**. The boundary or terminus of the combustion zone will vary somewhat with the energy level or rate of fuel flow in the combustion chamber. The entrance to tube **60** should be disposed so as to receive combustion products with the lowest oxygen level; that is, after full combustion but before dilution.

The mixture of compressed air and combustion products flowing through the recirculation tube **54** is cooled to some extent by conduction to the wall **26** which has compressed air on its outer surface, and to a greater extent by convection to the quite substantial stream of film cooling air flowing along the inner surface of wall **26** and past the outer surface of the recirculation tubes.

The recirculation tubes thus provide combustion air much as the prior combustion air entrances, except that the air is mixed with combustion products and the resulting mixture is considerably cooled. Therefore, the combustion air is diluted with the combustion products, reducing the concentration of oxygen in the primary combustion zone and reducing the maximum temperature attained.

The portion of the combustion chamber downstream of the combustion zone is commonly called the dilution zone. In this, the combustion products are mixed with a relatively large amount of air provided by the compressor (and heated by the regenerator if regenerator present). Dilution air brings the overall temperature of the combustion products down to a level which is acceptable to the turbine. In the liner of FIG. **2**, the dilution air is admitted through a ring of eight large holes **62**.

It will be apparent that my improvement is achieved without any involved or complicated combustion liner structure and that the modifications to the previous combustion liner, which essentially involves relocating the ports **58** and installing the recirculation tubes **54** and tubes **59**, are readily accomplished.

While the proportions of the air which are admitted in various parts of the liner may vary depending upon design choices, the turbine operating temperature, the presence or absence of a regenerator, and other factors, it may be desirable to discuss this to some extent. In the particular combustion liner illustrated, approximately 9 or 10 percent of the total air discharged by the compressor flows through the swirlers in the dome **27**. About 5 percent of the compressor discharge is admitted through the primary area inlets **58**. Approximately 28 percent of the total air enters through the gap between the margin of the dome and the side wall **26**, this being primarily film cooling air, although it is considered that about one-eighth of this, or about 3 one-half percent of the total compressor discharge, becomes part of the combustion air. Thus, in this case, about 18 or 19 percent of the total compressor discharge is combustion air. About 58 percent of the total air is admitted through the dilution openings **62**.

The amount of recirculated combustion products injected by the action of nozzles **60** may be varied by varying the convergence of the nozzles and other dimensions of the parts according to principles well known to those skilled in aerodynamics. In the particular case illustrated, the ratio of recirculated air to the air entering from outside the liner in the outlets **56** is approximately six tenths. This may be varied as is deemed desirable in individual cases.

It will be seen from the foregoing that I have devised a simple and effective means for reducing combustion temperatures and oxygen concentrations in the combustion zone of a high energy release combustion apparatus such as that ordinarily used in gas turbines. This is effective in reducing nitrogen oxide formation.

The invention is applicable to annular combustion chambers and other configurations as well as that illustrated.

The detailed description of the preferred embodiment of the invention for the purpose of explaining the principles thereof 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 without departing from the spirit of the invention.

I claim:

1. A combustion apparatus for burning fuel in air at substantially superatmospheric pressure and at high heat release rates and adapted to minimize formation of nitrogen oxides, the apparatus comprising, in combination, a casing adapted to receive air under pressure and a combustion liner within the casing adapted to receive air from within the casing, the liner providing a combustion zone for burning fuel in the air and a dilution zone for diluting the combustion products with further air from within the casing, the liner defining an outlet for the combustion products, the combustion liner having a partially closed upstream end and a side wall, the combustion zone lying between the said end and the dilution zone, and the dilution zone lying between the combustion zone and the outlet; the liner including means for directing a flow of film cooling air over the inside of the side wall, means for introducing combustion air through the side wall, means for mixing combustion products from the combustion zone with the said combustion air, means for cooling the mixture of combustion air and combustion products by heat exchange with the said film cooling air, and means for directing the said mixture into the combustion zone for intermixture with fuel, air, and combustion products within the combustion zone.

2. A combustion apparatus for burning fuel in air at substantially superatmospheric pressure and at high heat release rates and adapted to minimize formation of nitrogen oxides, the apparatus comprising, in combination, a casing adapted to receive air under pressure and a combustion liner within the casing adapted to receive air from within the casing, the liner providing a combustion zone for burning fuel in the air and a dilution zone for diluting the combustion products with further air from within the casing, the liner defining an outlet for the combustion products, the combustion liner having a partially closed upstream end and a side wall, the combustion zone lying between the said end and the dilution zone, and the dilution zone lying between the combustion zone and the outlet; the liner including means for directing a flow of film cooling air over the inside of the side wall, nozzle means for introducing combustion air through the side wall, injector means energized by the said combustion air for mixing combustion products from the combustion zone with the said combustion air and directing the said mixture into the combustion zone for intermixture with fuel, air, and combustion products within the combustion zone and means for cooling the mixture of combustion air and combustion products by heat exchange with the said film cooling air.

3. A combustion apparatus for burning fuel in air at substantially superatmospheric pressure and at high heat release rates and adapted to minimize formation of nitrogen oxides, the apparatus comprising, in combination, a casing adapted to receive air under pressure and a combustion liner within the casing adapted to receive air from within the casing, the liner providing a combustion zone for burning fuel in the air and a dilution zone for diluting the combustion products with further air from within the casing, the liner defining an outlet for the combustion products, the combustion liner having a partially closed upstream end and a side wall, the combustion zone lying between the said end and the dilution zone, and the dilution zone lying between the combustion zone and the outlet; the liner including means for directing a flow of film cooling air over the inside of the side wall from adjacent the closed end, means for introducing combustion air through the side wall adjacent the demarcation between combustion and dilution zones, means for mixing combustion products from the combustion zone with the said combustion air, means for cooling the mixture of combustion air and combustion products by heat exchange with the said film cooling air, and means for directing the said mixture into the combustion zone for intermixture with fuel, air, and combustion products within the combustion zone.

4. A combustion apparatus for a gas turbine engine comprising, in combination, a casing adapted to contain air under pressure; a combustion liner mounted in the casing comprising a side wall and a dome defining an end wall of the liner; the liner defining a primary combustion zone adjacent the dome and a dilution zone remote from the dome and providing an outlet from the dilution zone for combustion products; the liner including means for introducing primary combustion air mixed with combustion products into the combustion zone, the last-recited means including recirculation means distributed around the side wall defining an entrance for combustion products opening away from the dome and defining an outlet directed away from the wall into the combustion zone and also including air nozzle means having an entrance for compressed air from the casing and an outlet into the recirculation means so as to entrain and mix combustion products with the air from the nozzle means and direct the resulting mixture into the combustion zone.

5. A combustion apparatus for a gas turbine engine comprising, in combination, a casing adapted to contain air under pressure; a combustion liner mounted in the casing comprising a side wall and a dome defining an end wall of the liner; the liner defining a primary combustion zone adjacent the dome and a dilution zone remote from the dome and providing an outlet from the dilution zone for combustion products, the liner including means for introducing primary combustion air mixed with combustion products into the combustion zone, the last-recited means including a plural number of recirculation tubes distributed around the side wall each having an entrance for combustion products opening away from the dome adjacent the downstream end of the combustion zone and defining an outlet directed away from the wall into the combustion zone and also including an air nozzle for each recirculation tube, the air nozzles having an entrance for compressed air from the casing and an outlet into the recirculation tube so as to entrain and mix combustion products with the air from the nozzles and direct the resulting mixture into the combustion zone.

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