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Sherman et al.

[11] **3,851,467**

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[54] **RECIRCULATING COMBUSTION APPARATUS JET PUMP**

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

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[52] **U.S. Cl.**..... **60/39.65,** 60/DIG. 11, 417/196, 417/197, 417/198, 431/116

[51] **Int. Cl.** **F02c 3/00**

[58] **Field of Search** ..... 60/39.52, 269, 271, 231, 60/39.65; 417/196–198, 171, 151; 239/DIG. 7, 265.17; 137/803; 431/116; 244/42 CD

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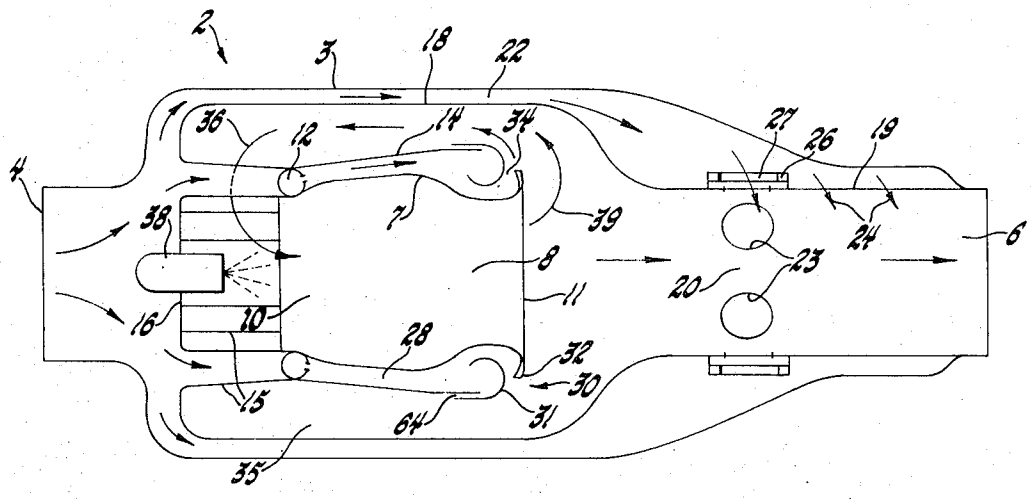
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[57] **ABSTRACT**

A combustion apparatus for a gas turbine engine includes a Coanda effect jet pump by which air introduced for combustion recirculates combustion products into the combustion zone of the apparatus. The jet pump is effective to improve the recirculation ratio while maintaining an acceptably low pressure drop in the combustion apparatus. The combustion air flows through the interior of the body of the Coanda nozzle and over a wall which terminates in a lip converging toward the radial surface of the Coanda nozzle body. A guiding surface at the end of the lip improves flow into the nozzle. Vanes or struts extending across the nozzle preserve alignment of the body and lip.

4 Claims, 4 Drawing Figures



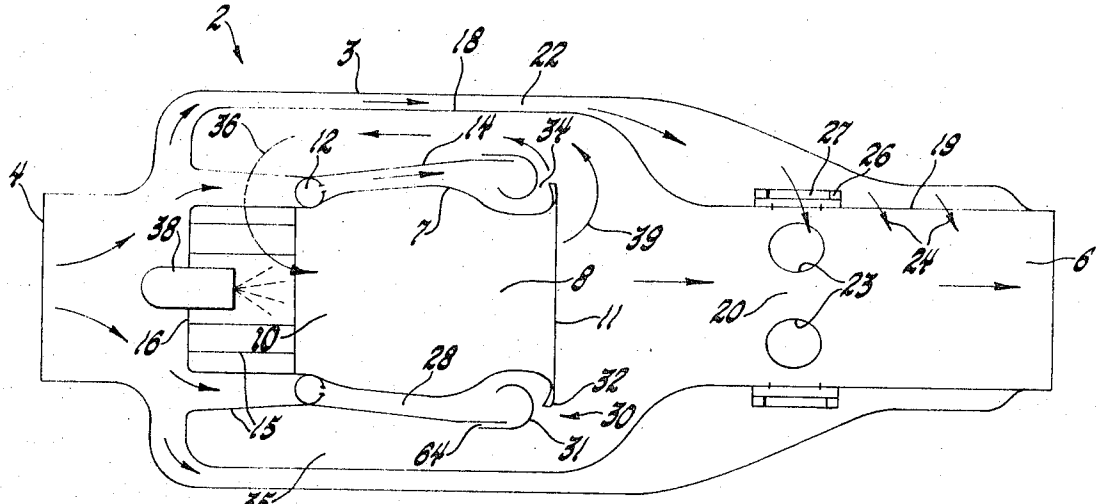


Fig. 1

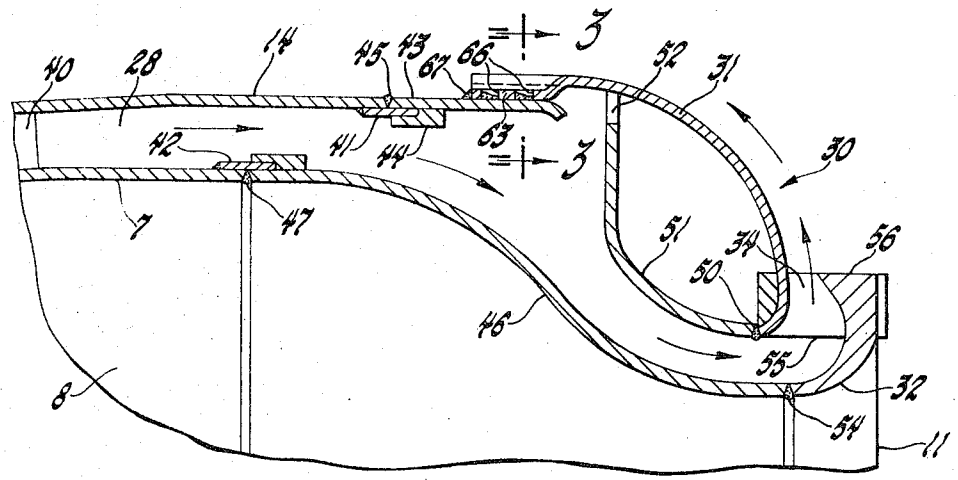


Fig. 2

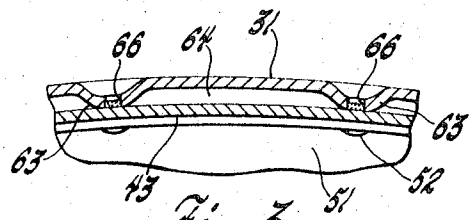


Fig. 3

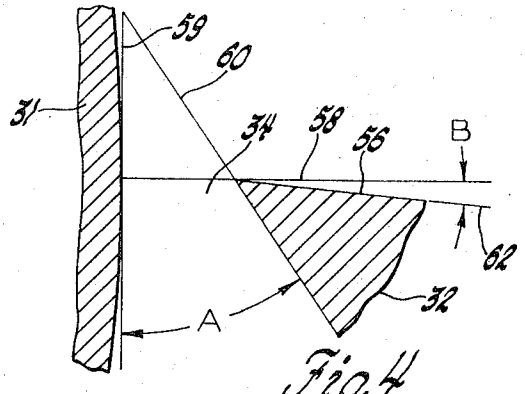


Fig. 4

RECIRCULATING COMBUSTION APPARATUS JET PUMP

Our invention is directed to combustion apparatus, particularly such as operates at substantially superatmospheric pressure; it is more particularly directed to an improved jet pump in such combustion apparatus for causing recirculation of combustion products from the outlet to the inlet of a zone in which combustion takes place.

Reba et al U.S. Pat. No. 3,319,692, May 16, 1967, teaches recirculation of combustion products in an oil burner by a Coanda-type pump to obtain more complete combustion and thus minimize unburned hydrocarbons, carbon monoxide, and smoke.

Recirculation has also been proposed as a means to reduce nitrogen oxides generated in the combustion apparatus by the reaction of nitrogen and oxygen from the atmosphere in a high temperature combustion zone. The amount of nitrogen oxide generated increases with increased temperature and with increasing concentration of oxygen in the combustion zone; also, with time of residence in the hot zone. By recirculating combustion products, the concentration of oxygen in the combustion zone may be lowered and also the temperature may be lowered to some extent. This concept is described in the copending applications of Stettler and Verdouw, Ser. No. 202, 191 filed Nov. 26, 1971 for Combustion System and Ser. No. 220,607 filed Jan. 25, 1972 for Recirculating Combustor, U.S. Pat. No. 3,744,242, both of common ownership with this application.

Our present invention may be regarded primarily as an improvement on the combustion apparatus of Ser. No. 220,607, the improvement residing in a more efficient and effective Coanda effect jet pumping structure for recirculating the combustion products.

To minimize nitrogen oxides a relatively high recirculation ratio is desired, of the order of one to two. The recirculation ratio is the ratio of flow per unit time of recirculated combustion products to flow of primary combustion air entering the combustion apparatus. This is to be distinguished from dilution air which is mixed with the combustion products at the termination of combustion. It is important to effect the recirculation with a minimum of pressure loss in the combustion apparatus, because pressure drops in the combustion apparatus detract from the efficiency of the gas turbine engine. It is also desirable that the recirculation ratio ramain substantially constant over a wide range of flow rates as the output of the combustion chamber is varied to vary engine power output.

The combustion apparatus described in Ser. No. 220,607 includes a jet pump of the Coanda type disposed near the downstream end of the combustion zone of the combustion apparatus to introduce the fresh combustion air and entrain with it combustion products which are recirculated into the upstream end of the combustion apparatus.

The principal object of our present invention is to provide an apparatus of the type described in Ser. No. 220,607 which is more efficient and better meets the requirements of practice. It is a further object to provide a jet pump for such an installation which has better efficiency than those previously known.

The nature of our invention and its advantages will be apparent 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 schematic illustration of a gas turbine combustion apparatus in axial sectional view.

FIG. 2 is an enlarged structural view of the jet pump portion of the combustion apparatus.

FIG. 3 is a fragmentary sectional view taken on the plane indicated by the line 3—3 in FIG. 2.

FIG. 4 is an enlarged diagrammatic illustration of the jet pump nozzle configuration.

FIG. 1 illustrates a combustion apparatus **2**, which preferably is of circular cross section. The apparatus includes an outermost wall **3** which extends from an inlet **4** for combustion air substantially to an outlet **6** for combustion products from the combustion apparatus. An innermost wall **7** defines a combustion zone **8** having an upstream end at **10** and a downstream end at **11.** At its upstream end the wall **7** is connected by a toroidal manifold **12** to an inner wall **14** generally surrounding the innermost wall **7.** Manifold **12** is connected by a number of spaced combustion air tubes **15** (six as shown) to a forward wall **16** disposed near the air inlet **4.**

The forward wall connects tubes **15** to an outer wall **18** lying closely within the outermost wall **3.** Wall **18** is supported from wall **3** by means which need not be described. Wall **18** converges into a discharge portion **19** extending into the outlet **6** and which defines a dilution zone **20.** Some of the air introduced through inlet **4** flows through the annular passage **22** between walls **3** and **18** and through holes **23** into the dilution zone. Additional air may flow through smaller openings as indicated by the arrows at **24.** If desired, means may be provided for varying the quantity of dilution air, indicated schematically as a rotatable ring **26** having openings **27** variably registrable with the holes **23** in the wall **18.**

The primary combustion air flows from the inlet **4** through tubes **15** into manifold **12** and then through a primary air passage **28** between walls **7** and **14** to a Coanda nozzle type jet pump **30.** The pump includes a body **31** defined by the incurved downstream end of wall **14** and a lip **32** defined by the outcurved downstream end of wall **7.** Primary air discharged through the nozzle **34** between the body and lip flows upstream through the recirculation passage **35** defined between walls **14** and **18** and then, as indicated by the arrow **36,** between tubes **15** into the combustion zone **8.** Fuel is introduced through a nozzle **38** supplied from any suitable source and is ignited by suitable means (not illustrated). Combustion products flow through the outlet at the downstream end **11** of the combustion zone. As indicated by arrow **39,** a portion of these combustion products are entrained and pumped by the flow from jet nozzle **34** into the recirculating passage. Preferably, approximately one to two times as much combustion products are recirculated as the flow of primary combustion air through duct **28.** The remainder of the combustion products flow to the dilution zone **20** where additional air is mixed with them, and the resulting mixture is discharged through the outlet **6.**

Except for the difference in the Coanda nozzle structure and the representation of control of dilution air, the structure described above is essentially the same as that described in structural detail in U.S. Pat. No. 3,744,242, and there is no need to enlarge upon details of this structure to understand the present invention.

Referring now to FIGS. 2 and 3, the structure and proportions of the Coanda nozzle and associated structure are more fully described. FIG. 2 illustrates the downstream end of the major portion of walls 7 and 14, which are kept properly spaced by fins 40 fixed to wall 7. These walls terminate in joining strips 41 and 42, respectively, welded to the walls. The main wall 14 has a butt joint with a terminal portion 43 which includes a flange strip 44 which receives the edge of strip 41. The two parts of the wall are tack-welded together as indicated at 45.

The innermost wall 7 has a continuing converging portion 46 which is similarly joined to the innermost wall 7 at the tack weld 47. The wall 14 terminates in a roughly quarter-circular cross section ring 31 which defines the body of the Coanda nozzle. This ring is seam-welded at 50 to an inner ring 51 which defines a gradually converging outlet from the combustion air passage 28 into the Coanda nozzle. The chamber between walls 31 and 51 is ventilated through scallops 52 in the inner ring. The lip 32 of the Coanda nozzle, which also defines the downstream end of the combustion zone, is a ring of the cross section illustrated, the forward surface of which defines one boundary of the jet nozzle 34. Lip 32 is seam-welded at 54 to the portion 46 of the innermost wall.

To connect the body 31 and lip 32 and maintain accurate spacing of these two so that the precise width of the jet nozzle 34 is maintained, there are provided a number of rectangular plates or vanes 55 which are disposed in notches in the outer margin of lip 32 and the inner margin of body 31. These vanes are simply small flat metallic plates which are tack-welded to the body and lip. Preferably, there are 16 of these distributed around the circumference. They extend radially from the axis of the combustor.

It will be noted that the lip 32 has a cylindrical outer surface 56, which we term a guiding surface, extending a suitable distance from the body 31. This guiding surface, in comparison with structures in which the outer edge of the lip is relatively thin, improves the recirculation of combustion products.

It has been found experimentally that a narrow edge to lip 32 (a very small or zero width of surface 56) is not detrimental to the attachment of the impelling flow from gap 34 to the surface of wall 31, but it is inimical to entrainment. Good entrainment begins to be obtained as the ratio of width of guiding surface 56 to the width of the nozzle gap approaches unity, and best results are obtained with a guiding surface somewhat wider than the nozzle gap.

Investigation of the flow employing a surface coated with oil and lampblack to visualize the flow indicated that the guiding surface promotes the formation of vortices adjacent gap 34, thereby increasing the entrainment ratio. Thus the recirculation ratio may be increased, or the pressure loss through the nozzle may be decreased, by the provision of the guiding surface.

The preferred geometry of the jet nozzle as it appears to us from the results of our experiments with the structure may be further explained with reference to FIG. 4. This is an enlarged fragmentary view of the body 31 and lip 32. The line 58 in FIG. 4 is perpendicular to the surface of the body at the plane of the nozzle or outlet 34, and line 59 is tangent to the body at this point. Line 60 represents the direction of convergence of the inner surface of the lip 32, and line 62 represents the direction of the guiding surface 56. The angle indicated as A between lines 59 and 60 represents the angle of convergence of the jet nozzle outlet and the angle indicated as B represents the divergence of the surface 56 from the perpendicular 58 to body 31. Preferably, in the light of results obtained so far, the angle A should be of the order of 35° and angle B of the order of 5°. With angle A equal to 35°, the angle of convergence of the center of the jet nozzle relative to body 31 is 17 ½°. It may also be defined as the angle between a surface equidistant from the boundaries (body 31 and lip 32) of the nozzle and the forward boundary (body 31) at the nozzle outlet.

When our combustion chamber is used in a gas turbine engine, which it is primarily intended for, the airflow will vary quite widely, but there is a maximum airflow determined by the maximum capacity of the engine. It is desired that the ratio of recirculated air to incoming combustion air remain relatively constant at the total airflow changes, and this has been found to be the case with the recirculation structure illustrated. Since airflow is fixed by engine requirements, it is apparent that the pressure drop required to force the incoming combustion air through the nozzle 34 will be a function of its total area, which is fixed by its diameter and the width of the nozzle gap. The nozzle diameter is a function of the allowable dimensions of the combustion chamber, which are determined by various considerations. The gap may be readily varied to suit the requirements. As the gap is widened, the pressure drop of course falls, but it has been found by experiment that the recirculation ratio also drops. The design of such a device therefore should be aimed at the best balance between the desired recirculation ratio and pressure drop.

We have found in practice that narrowing the gap 34 to the point at which the desired recirculation ratio is obtained in a typical combustor leads to undesirably high pressure drops, and our combustion apparatus involves a further feature to give flexibility in overcoming this difficulty. As shown in FIGS. 2 and 3, the forward edge of the body 31 is spaced from the terminal portion 43 of the wall 14 around the circumference of the combustion liner. Inwardly projecting ridges 63 spaced around the forward edge of the body portion 31 engage the terminal portion 43 leaving a substantially annular air outlet 64 between the two. Braze metal deposited in holes 66 in the ridges 63 may fix these together, and an additional seam weld may be provided as shown at 67.

The result of this is that some of the primary combustion air flowing through passage 28 escapes through the outlet 64, flowing forwardly and mixing with the recirculated combustion products and propelling air passing over the outer surface of wall 14. The outlet 64 is not primarily intended as a jet pump, although it should have some effect in pumping the recirculating combustion products. The primary purpose is to reduce the pressure of the primary air and maintain the greatest efficiency of recirculation by the Coanda effect jet pump.

It has been found possible to attain a recirculation ratio of 2.5 with a pressure drop of under 5 percent with an apparatus as illustrated. This is with an apparatus in which the diameter of the combustion zone is approximately 8 ½inches, the diameter of the jet nozzle is approximately 7 ¾ inches, and its width 1/10 inch.

Such a combustion liner is of dimensions suitable for a small gas turbine engine of moderate pressure ratio.

Reference to a "small acute angle" in the appended claims is intended to include an angle of 0°.

It should be apparent to those skilled in the art upon consideration of the foregoing that the apparatus described is very well adapted to function effectively as a combustion apparatus with substantial recirculation.

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, since many modifications may be made by the exercise of skill in the art.

We claim:

1. A combustion apparatus comprising, in combination, an innermost wall defining a combustion zone having upstream and downstream ends, an inner wall defining an annular air passage with the innermost wall, an outer wall defining with the inner wall an annular recirculation passage from the downstream to the upstream end of the combustion zone and defining a discharge passage from the combustion zone, and an outermost wall defining a dilution air passage with the outer wall to conduct air into the discharge passage; the downstream end of the inner wall being curved inwardly to form a forward boundary for a Coanda nozzle, and the downstream end of the innermost wall being curved outwardly to define a rear boundary for the Coanda nozzle, the Coanda nozzle encircling the downstream end of the combustion zone between the said curved ends adapted to discharge into the recirculation passage and entrain combustion products discharged from the combustion zone into the recirculation passage; comprising a structure in which the forward boundary of the nozzle is substantially radial, the rear boundary of the nozzle converges toward the forward boundary to define a converging air entrance to the nozzle such that a surface equidistant from the said boundaries is directed at an acute angle less than 30° to the forward boundary at the nozzle outlet, and the rear boundry terminates in a guiding surface directed at a small acute angle to a perpendicular to the adjacent forward boundary of the nozzle outlet, the guiding surface having a width greater than the width of the nozzle outlet; and a supplementary outlet means from the said air passage into the recirculation passage bypassing the Coanda nozzle.

2. A combustion apparatus comprising, in combination, an innermost wall defining a combustion zone having upstream and downstream ends, an inner wall defining an annular air passage with the innermost wall, an outer wall defining with the inner wall an annular recirculation passage from the downstream to the upstream end of the combustion zone and defining a discharge passage from the combustion zone, and an outermost wall defining a dilution air passage with the outer wall to conduct air into the discharge passage; the downstream end of the inner wall being curved inwardly to form a forward boundary for a Coanda nozzle, and the downstream end of the innermost wall being curved outwardly to define a rear boundary for the Coanda nozzle, the Coanda nozzle encircling the downstream end of the combustion zone between the said curved ends adapted to discharge into the recirculation passage and entrain combustion products discharged from the combustion zone into the recirculation passage; comprising a structure in which the forward boundary of the nozzle is substantially radial, the rear boundary of the nozzle converges toward the forward boundary to define a converging air entrance to the nozzle such that a surface equidistant from the said boundaries is directed at an angle between 15° and 20° to the forward boundary at the nozzle outlet, and the rear boundary terminates in a guiding surface directed at a small acute angle to a perpendicular to the adjacent forward boundary of the nozzle outlet, the guiding surface having a width greater than the width of the nozzle outlet; and a supplementary outlet means from the said air passage into the recirculation passage bypassing the Coanda nozzle.

3. A combustion apparatus comprising, in combination, an innermost wall defining a combustion zone having upstream and downstream ends, an inner wall defining an annular air passage with the innermost wall, an outer wall defining with the inner wall an annular recirculation passage from the downstream to the upstream end of the combustion zone and defining a discharge passage from the combustion zone, and an outermost wall defining a dilution air passage with the outer wall to conduct air into the discharge passage; the downstream end of the inner wall being curved inwardly to form a forward boundary for a Coanda nozzle, and the downstream end of the innermost wall being curved outwardly to define a rear boundary for the Coanda nozzle, the Coanda nozzle encircling the downstream end of the combustion zone between the said curved ends adapted to discharge into the recirculation passage and entrain combustion products discharged from the combustion zone into the recirculation passage; comprising a structure in which the forward boundary of the nozzle is substantially radial, the rear boundary of the nozzle converges toward the forward boundary to define a converging air entrance to the nozzle such that a surface equidistant from the said boundaries is directed at an acute angle less than 30° to the forward boundary at the nozzle outlet, and the rear boundary terminates in a guiding surface directed at an angle less than 10° to a perpendicular to the adjacent forward boundary of the nozzle outlet, the guiding surface having a width greater than the width of the nozzle outlet; and a supplementary outlet means from the said air passage into the recirculation passage bypassing the Coanda nozzle.

4. A combustion apparatus comprising, in combination, an innermost wall defining a combustion zone having upstream and downstream ends, an inner wall defining an annular air passage with the innermost wall, an outer wall defining with the inner wall an annular recirculation passage from the downstream to the upstream end of the combustion zone and defining a discharge passage from the combustion zone, and an outermost wall defining a dilution air passage with the outer wall to conduct air into the discharge passage; the downstream end of the inner wall being curved inwardly to form a forward boundary for a Coanda nozzle, and the downstream end of the innermost wall being curved outwardly to define a rear boundary for the Coanda nozzle, the nozzle encircling the downstream end of the combustion zone between the said curved ends adapted to discharge into the recirculation passage and entrain combustion products discharged from the combustion zone into the recirculation passage; comprising a structure in which the forward

boundary of the nozzle is substantially radial, the rear boundary of the nozzle converges toward the forward boundary to define a converging air entrance to the nozzle such that a surface equidistant from the said boundaries is directed at an angle between 15° and 20° to the forward boundary at the nozzle outlet, and the rear boundary terminates in a guiding surface directed at an angle less than 10° to a perpendicular to the adjacent forward boundary of the nozzle outlet, the guiding surface having a width greater than the width of the nozzle outlet; and a supplementary outlet means from the said air passage into the recirculation passage bypassing the Coanda nozzle.

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