

[54] **BURNING METHOD FOR GAS TURBINE COMBUSTOR AND A CONSTRUCTION THEREOF**

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[22] Filed: **Oct. 26, 1973**

[21] Appl. No.: **410,105**

[30] **Foreign Application Priority Data**

Oct. 30, 1972 Japan..... 47-107993
Oct. 30, 1972 Japan..... 47-107997

[52] U.S. Cl. 60/39.65; 60/39.74 R

[51] Int. Cl.² F02C 7/22

[58] Field of Search 60/34.65, 39.74 R

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[57]

ABSTRACT

A gas turbine combustor comprising a conical liner cone formed at a liner head of an annular liner wall, a fuel nozzle for spraying fuel in a conical form provided in the central part of the liner cone, inwardly directed flow jet ports for discharging air arranged annularly in the part of the liner cone in the vicinity of said fuel nozzle, and air jet ports for forming annularly an outwardly directed flow or a turning flow provided outside said inwardly directed flow jet ports, and characterized in that fuel is sprayed by said fuel nozzle to form a central flame, and at the same time, an annular small flame is formed in the vicinity of the fuel nozzle.

8 Claims, 19 Drawing Figures

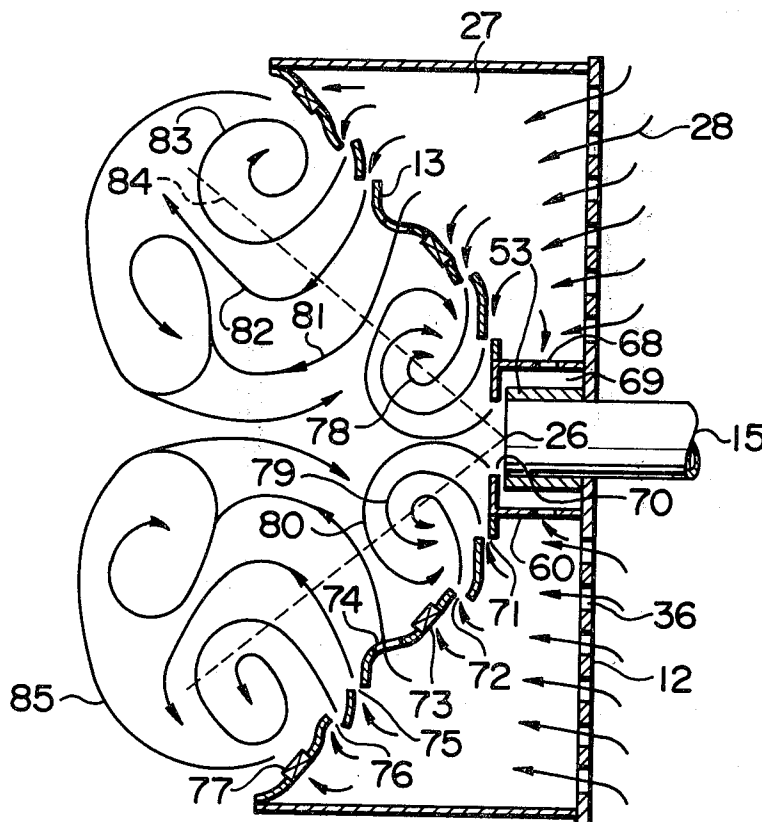


FIG. 1
PRIOR ART

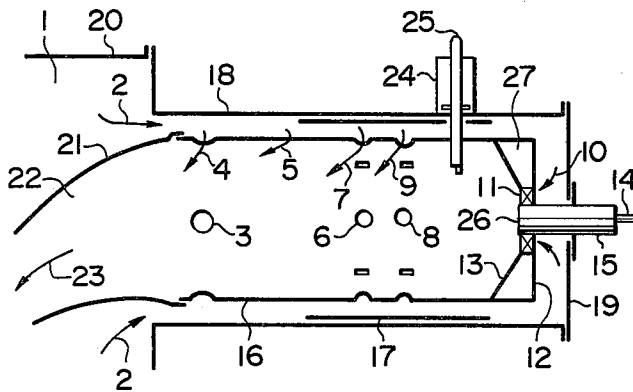


FIG. 3
PRIOR ART

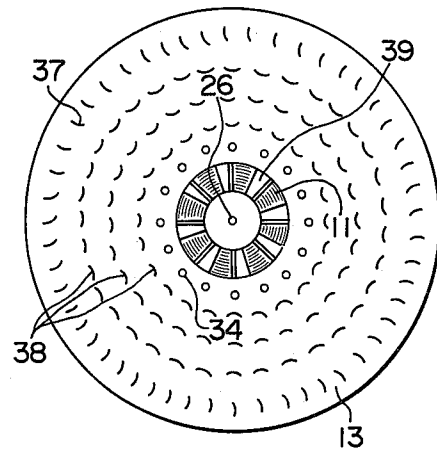


FIG. 2
PRIOR ART

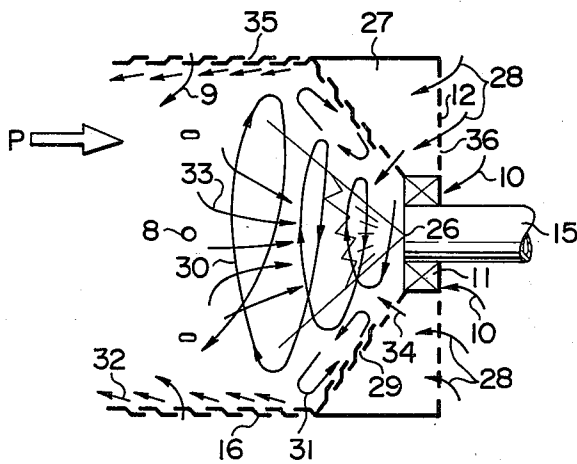


FIG. 4
PRIOR ART

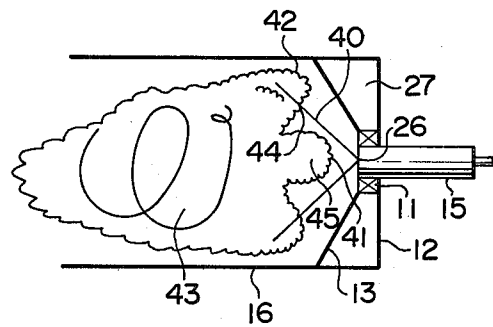


FIG. 5

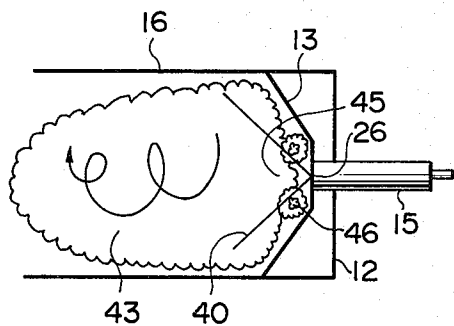


FIG. 7

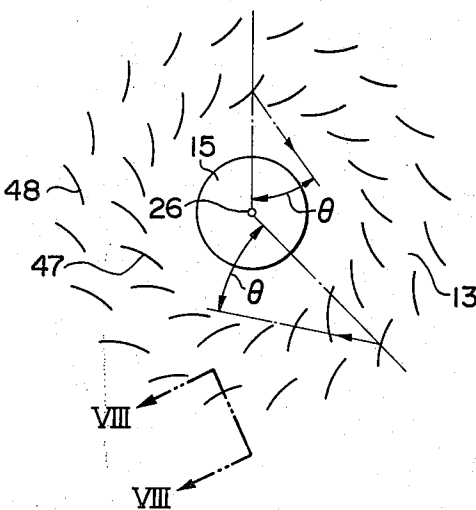


FIG. 6

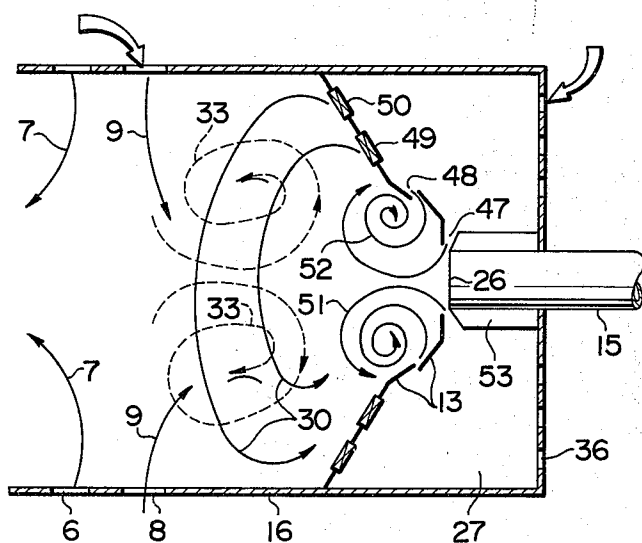


FIG. 8

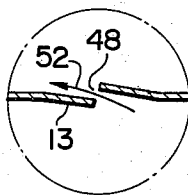


FIG. 9

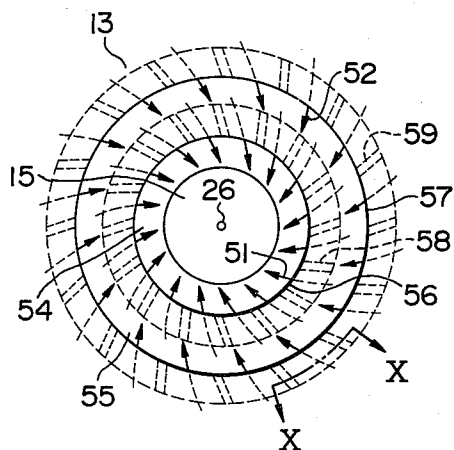


FIG. 11

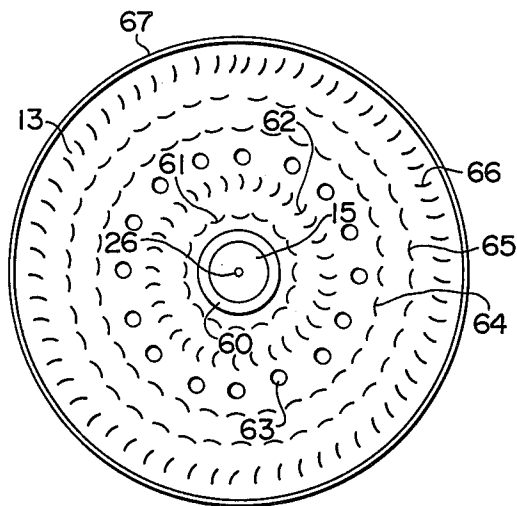


FIG. 10

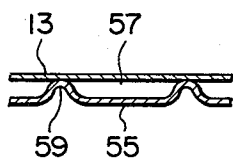
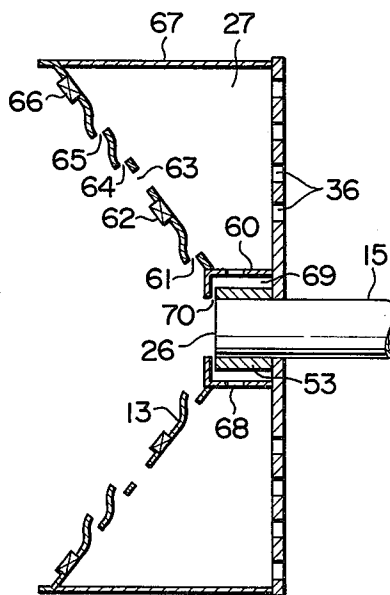


FIG. 12



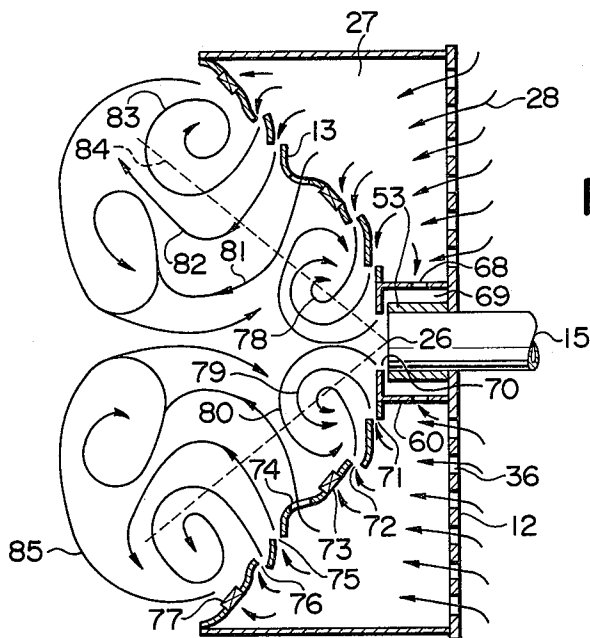


FIG. 13

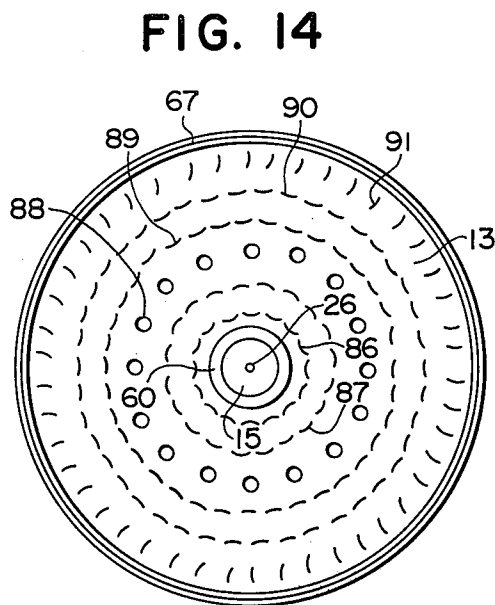


FIG. 14

FIG. 15

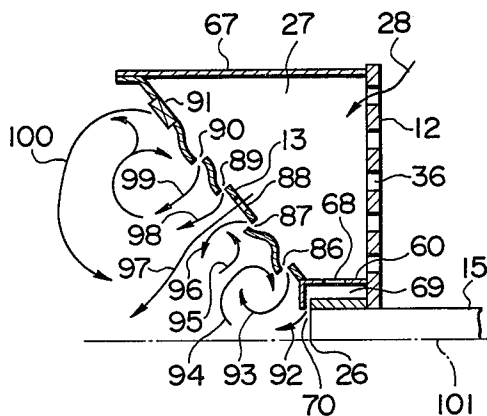


FIG. 16

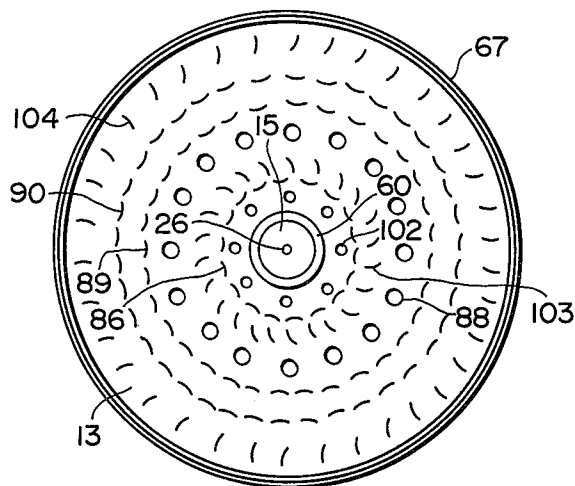


FIG. 17

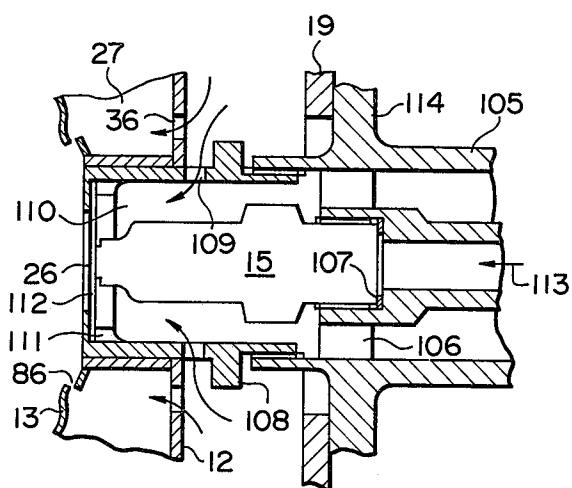


FIG. 18

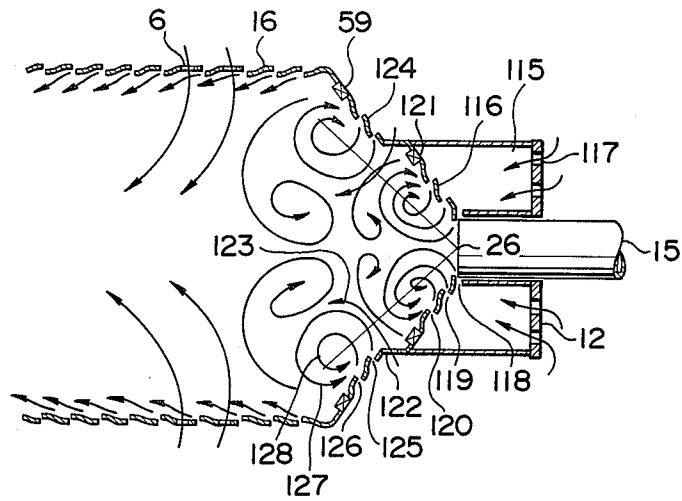
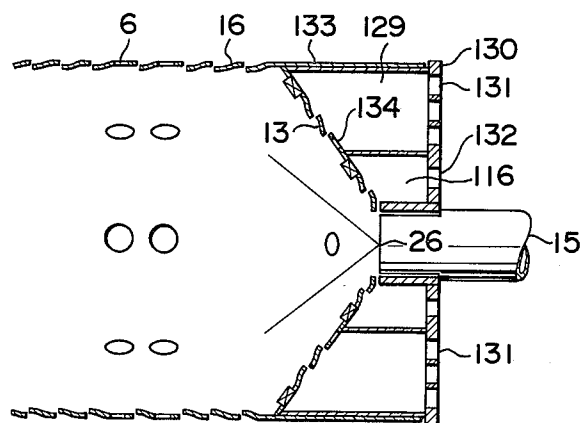


FIG. 19



BURNING METHOD FOR GAS TURBINE COMBUSTOR AND A CONSTRUCTION THEREOF

BACKGROUND OF THE INVENTION

The present invention relates to an improvement of a gas turbine combustor having a means for forming a small flame in the vicinity of a fuel nozzle jet port.

Smoke contained in the exhaust gas of a gas turbine is due to the carbon in fuel separated from the fuel during an excessive burning which takes place locally in some part of a burning zone. In order to prevent the generation of this smoke, the prior art has provided various methods for introducing air into a combustor liner which are aimed to eliminate excessive burning spots formed locally in the burning zone. In particular, a widely used method is to supply an excessive amount of air to the primary burning zone and produce turbulence in the air flows using a primary turning blade (called "turbulator") arranged for such a purpose. However, the supply of an excessive amount of air to the primary burning zone has often caused unstable flames, incomplete combustion, difficulty in firing, and so forth. For the purpose of stabilizing the flame in gas turbine combustor, there has been generally employed a method to supply a portion of burning air, which is in the form of a turning flow, to the combustor liner for forming a turning flame, which results in a decreased pressure in the vicinity of the center axis of turning and generation of a circulating flow. In this method, since the flame surface is formed in a space remote from the fuel nozzle jet port and is under direct influence of the flowing movement of primary air, there has remained a disadvantage that the range of air-fuel ratio for achieving an excellent burning is narrowed. In gas turbines, it is necessary to perform a good burning throughout a wide range of operation from firing to rated load state. The amount of fuel flow changes from 8% at the time of starting to about 120% at the time of overload. According to said prior art burning method using a turning flame, it is difficult to maintain a good burning throughout a wide range of fuel amount variation of from 8 to 120%. If the burning zone having a small amount of fuel flow is taken as a standard for optimum burning state, black smoke will be produced when rated load or overload operation is carried out. On the other hand, if the burning zone having a large amount of fuel flow is taken as a standard for optimum burning state, there will occur, when starting the turbine, undesirable phenomena such as generation of white smoke and difficulty in firing. Increasing the amount of primary air to decrease the amount of smoke contained in exhaust gas means that the burning zone having a large amount of fuel flow is selected as a standard for optimum burning state, naturally incurring said problems. A brief explanation will be given here on the cause of such phenomena as difficulty in firing at the time of starting, generation of white smoke, and unstable flames. The difficulty in firing is principally due to a large air-fuel ratio in the primary burning zone (decreased fuel density). According to the experimental results obtained so far, the optimum firing condition is a state in which fuel is excessive in amount compared with air in view of a theoretical mixing ratio. Firing performance is degraded when the air-fuel ratio in the primary burning zone is made larger. At the same time, owing to the unstable condition of flame, the once fired flame is often extinguished by a blow of air. In general,

this blowing out phenomenon is included in the category of difficulty in firing. White smoke at the time of starting is generated by the cooling of the sprayed fuel particles due to an excessive amount of the primary air. Generation of white smoke takes place more often in winter when atmospheric temperature is low and the cooling effect is great. From the results of component analysis of the white smoke, it is known that a principal component of the smoke is hydrocarbon (fuel oil) and the smoke also contains some amount of CO. This white smoke shows that, owing to the cooling action of the primary air, fuel particles are discharged to the atmosphere without undergoing complete evaporation, resulting in a very low combustion efficiency. After the gas turbine reached a state of rated operation, the air temperature is, by virtue of insulation and compression, kept at about 250°–300°C which is substantially the same as the average boiling point of fuel oil, and the cooling of fuel particles by primary air is ceased to terminate the generation of white smoke.

In the flame stabilizing method using a circulating flow described previously, the turning of a burning air flow is weak and likely to become unstable because the amount of air flow is small, especially at the time of firing when the turbine revolves at a low speed. When operating a gas turbine, stabilization of flame poses nearly no problem during rated load operation, but has a very important meaning when the turbine is started. An unstable flame is particularly likely to take place in the combustors having a smoke consuming apparatus. According to the prior art, smoke is generated during rated load operation and complete elimination of the smoke cannot be attained because, as described previously, it is impossible to supply an excessive amount of primary air to the primary burning zone. Nitrogen oxides, which are considered to be one of the harmful substances contained in the exhaust gas of a gas turbine, are produced by the reaction of nitrogen and oxygen at a high temperature. Studies to date shows that the nitrogen oxides increase in amount in a manner of exponential function at temperatures exceeding 1,500°C. In the prior art, during rated load operation, about 150–200 ppm of nitrogen oxides are contained in the exhaust gas of a gas turbine, due to the fact that, as described previously, an excessive amount of air cannot be supplied to the primary burning zone for lowering the flame temperature. Decrease in amount of the nitrogen oxides can be achieved by limiting the flame temperature within a range of less than 1,500°C.

One of the methods according to the prior art for decreasing nitrogen oxides contained in the exhaust gas of a gas turbine, is to mix in the burning air a steam having a relatively large value of specific heat. Temperature of the exhaust gas of a gas turbine is about 400°–450°C. This is fairly high in comparison with temperature of the exhaust gas of a boiler. For this reason, for instance, a waste heat boiler can be connected to the gas turbine to obtain steam, thereby improving the gas turbine output and the thermal efficiency. But with the provision of such an attachment, the gas turbine loses some of its valuable properties such as rapid starting and needlessness of water. Other problems entailing this method are generation of black smoke due to the lowering of burning performance resulting from the mixing of steam, generation of other harmful substances owing to incomplete combustion, high temperature corrosion of passage walls and turbine blades

caused by high temperature gases such as hydrogen generated through decomposition of steam, and the like.

Another method according to the prior art for decreasing nitrogen oxides employs water discharging. A notable improvement of thermal efficiency cannot be expected from this method as this method has disadvantages such as increased loss of exhaust heat due to latent heat of water, in addition to the problems described above.

Still another method according to the prior art for decreasing nitrogen oxides is to recirculate exhaust gas. However, this method also has undesirable features such as compression of exhaust gas, increased amount of work, and so forth, and results in the decrease of gas turbine output and the lowering of thermal efficiency.

As described in the foregoing, the prior art relating to gas turbine combustor involves a large number of problems to be solved.

SUMMARY OF THE INVENTION

An object of the present invention is to provide a combustor in which a main flame is stabilized by the use of a small flame and an excellent burning property is obtainable throughout a wide range of operation.

Another object of the present invention is to provide a combustor in which a sure firing operation is possible when starting a gas turbine.

Still another object of the present invention is to prevent the discharge to atmospheric air of such substances as hydrocarbon and carbon monoxide produced by incomplete combustion at the time of starting of a gas turbine.

Further object of the present invention is to decrease the density of smoke contained in exhaust gas during rated load operation of a gas turbine.

Further object of the present invention is to decrease the concentration of nitrogen oxides contained in exhaust gas during rated load operation of a gas turbine.

In accordance with the present invention, a central flame, i.e., main flame, is formed by spraying fuel from a fuel nozzle, an annular small flame is formed in the vicinity of the fuel nozzle, and with the use of this annular small flame evaporation of the sprayed fuel is accelerated and primary air is preheated.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is an explanatory longitudinal sectional view of a typical conventional boiler type combustor;

FIG. 2 is an explanatory longitudinal section view showing a detailed construction of the combustor of FIG. 1 in the vicinity of a liner head thereof and the direction of air flow movements within the liner;

FIG. 3 is a view taken in the direction of P of FIG. 2 illustrating a liner cone in plan;

FIG. 4 is an explanatory view showing the shape of a flame formed in the liner of the combustor illustrated in FIG. 1;

FIG. 5 is an explanatory view showing the shape of a flame including an annular small flame in accordance with the present invention;

FIG. 6 is an explanatory longitudinal sectional view illustrating in more detail the formation of the annular small flame in accordance with the present invention;

FIG. 7 is an explanatory view showing a louver perforation construction in the vicinity of a fuel nozzle of the liner cone in accordance with the present invention;

FIG. 8 is a sectional view taken along the line C—C of a louver perforation illustrated in FIG. 7;

FIG. 9 is a plan view showing inwardly directed flow jet ports constituted by a plurality of liner cones;

FIG. 10 is a sectional view taken along the line D—D of FIG. 9;

FIG. 11 is a left side view of FIG. 12 illustrating an embodiment for forming the annular small flame in accordance with the present invention;

FIG. 12 is a longitudinal sectional view of FIG. 11;

FIG. 13 is a longitudinal sectional view showing another embodiment for forming the annular small flame in accordance with the present invention;

FIG. 14 is a left side view of FIG. 15 illustrating still another embodiment for forming the annular small flame in accordance with the present invention;

FIG. 15 is a sectional view of FIG. 14 with a symmetrical lower part omitted;

FIG. 16 is a side view showing a further embodiment for forming the annular small flame in accordance with the present invention;

FIG. 17 is a longitudinal sectional view illustrating a construction in the vicinity of a fuel nozzle cap for facilitating the formation of the annular small flame in accordance with the present invention;

FIG. 18 is a longitudinal sectional view showing another embodiment of the combustor in accordance with the present invention; and

FIG. 19 is a longitudinal sectional view illustrating still another embodiment, different from that of FIG. 18, of the combustor in accordance with the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Prior to the description of the present invention, an explanation will be made on the construction of a typical conventional combustor.

FIG. 1 shows a longitudinal section of a boiler type combustor for gas turbine and FIG. 2 illustrates a detailed construction in the vicinity of the liner head shown in FIG. 1. Numeral 1 indicates an air chamber which will be used as a common air chamber when a plurality of boiler type combustors are employed. Numerals 2, 3, and 4 respectively designate completely burning air flows, diluting air holes, and diluting air flows passing through the diluting air holes. Numeral 5 is a cooling air to flow along the inner surface of a liner wall 16 performing a film cooling so that the liner wall 16 is insulated from flame for its own protection. Numerals 6 and 8 are secondary air holes provided in the liner wall 16, and numerals 7 and 9 indicate secondary air flows supplied to the liner through the secondary air holes 6 and 8. Numeral 10 is a turbulater air flow to form a part of primary air and numeral 11 is a turbulater for generating the turbulater air flow 10. Numeral 12 designates a liner head plate for regulating the amount of primary air flow and for increasing the strength of the liner. Numeral 13 is a liner cone portion having openings for supplying the primary air to the liner. Numeral 14 is a supplying portion of fuel coming from a fuel pump (not shown). Numeral 15 indicates a fuel nozzle to supply a fuel spray to the liner, and numeral 17 is a radiation shield plate for preventing conduction of radiation heat from the flame in the liner or from the liner wall 16. Numeral 18 is an outer cylinder of the combustor provided with such means as an at-

taching seat for ignition plug. Numeral 19 designates a combustor head plate having an attaching seat of the fuel nozzle 15 and constituting an end of the combustor. Numeral 20 is an air chamber wall for forming the air chamber 1. Numeral 21 is a transition piece to connect the liner wall 16 with a stationary blade of the turbine (not shown). Numeral 22 indicates a gas diluting portion for evenly mixing the diluting air flows 4 and a burning gas. Numeral 23 is a gas flow generated in the combustor and numeral 24 is a guide for moving an ignition plug. Numeral 25 is an ignition plug to carry out firing with the use of a spark obtained by the application of a high voltage. Numeral 26 designates a fuel nozzle jet port for supplying fuel coming from the fuel nozzle 15 in the form of a spray. Numeral 27 indicates a primary air chamber for storing and decompressing the primary air 28 introduced through holes 36 regulating the amount of primary air. The primary air chamber 27 serves the double purposes of reinforcing the construction of the liner head and of adjusting to an optimum value the speed jet port of the primary air supplied to the liner through the openings of the liner cone portion 13. Numeral 28 is the primary air introduced into the primary air chamber 27 through the primary air regulating holes 36 arranged in the liner head plate 12. Numeral 29 is cone louver perforations provided in the liner cone portion 13, which are designed to cool the liner cone portion 13 and to regulate air movements within the primary burning zone in the liner. Numeral 30 designates a turning air flow generated by certain numbers of the cone louver perforations 29, which further generates turning flows coming from the turbulator 11 and the liner cone portion 13. Numeral 31 is flows circulating on the cone generated by certain numbers of the cone louver perforations 29, and said air flows 31 further generates an inwardly directed flow from the liner cone portion 13. Numeral 32 is liner wall air flows to perform, in cooperation with liner louver perforations 35 in the liner wall 16, the cooling of the liner wall 16 along a wall inside the liner. Numeral 33 indicates a main circulating flow generated by the turning air flow 30 and moving toward the fuel nozzle jet port 26. Numeral 34 is cone portion air holes arranged in the liner cone portion 13 for discharging the primary air.

FIG. 3 is a view taken in the direction of P of FIG. 2 and shows the construction and shape of the turbulator 11 including a turbulator jet port 39, the cone portion air holes 34, cone turning flow louver perforations 37, and cone inwardly directed flow louver perforations 38.

In the conventional combustor described above, the turning air flow 30 is generated in the liner using such means as the turbulator 11 and the cone turning flow louver perforations 37, and the stabilization of flame is carried out by the main circulating flow 33 generated by said turning air flow 30 and moving toward the fuel nozzle jet port 26. A principal purpose of this type of combustor resides in that, simultaneously with the air flow actions mentioned above, the flows circulating on the cone 13 are generated by means of the cone inwardly directed flow louver perforations 38 to enlarge the flame for reinforcing the flame stabilizing action of the main circulating flow 33. Thus, the flame stabilizing action of the main circulating flow 33 is determined by the force of the turning air flow 30. Hence, the stabilization of flame cannot be performed satisfactorily

when only very slight amount of burning air flow exists within the turbine, as is the case at the time of starting.

As described above, when the firing is carried out, the gas turbine combustor is in a state in which the stabilization of flame is inadequate, and it often happens that a flame formed using the ignition plug 25 is blown out by the succeeding air flows. Particularly, in order to eliminate smoke, it is necessary to enlarge the turbulator air flow 10 by increasing the size of the turbulator jet port 39 for increasing air-fuel ratio in the primary burning zone to avoid the generation of a local excessive fuel spot. However, in this case, said difficulty in firing is very likely to take place.

Thus, according to the prior art in which the turning air flow 30 is utilized for stabilizing the flame, it has been impossible to carry out an efficient burning throughout a wide range of operation from starting to rated load state. The observations and experiments show that the combustor liner of the prior art generates a turning flame such shown in FIG. 4. As long as the gas turbine is kept in this burning condition, if atmospheric temperature, number of revolution of the gas turbine, and burning air pressure are all low, evaporation is delayed owing to the cooling of fuel spray particles by the low temperature air. As a result, the flame moves backward (to the left in Fig. 4). In case the burning air temperature is lower, the flame will be blown out since its maintenance is made impossible. In gas turbines, as atmospheric temperature is decreased, the mass of air and the atmospheric temperature is decreased, the mass of air and the amount of air flow are increased in inverse proportion to the absolute temperature of atmospheric air. Therefore, with the decrease of evaporation speed of fuel due to the decrease of atmospheric temperature, air-fuel ratio is increased, thus degrading the burning condition in a multiplying manner. In this condition of flame, fuel particles sprayed from the fuel nozzle jet port 26 are preheated from the central part of their mass receiving the radiation heat of a central flame 45. The fuel spray is, at the same time, cooled from outer boundary surface thereof by the turbulator air flow 10 and the primary air supplied through the turbulator 11 and the openings of the liner cone portion. Consequently, evaporation of the fuel particles is retarded, resulting in insufficient increase in flame temperature and incomplete combustion. Thus, in the exhaust gas are included large amounts of hydrocarbon, carbon monoxide, and other substances. Fuel particles sprayed from the fuel nozzle jet port 26 receive the cooling action of primary air which is much stronger in effect than the preheating action of radiation heat from the central flame 45, which they also receive, until they reach an entering point to circulating flame 44. Under such a burning condition, a large quantity of white smoke is generated at the starting of gas turbine. This is undesirable not only from a standpoint of air pollution but also from a standpoint of increased consumption of fuel.

In this burning method according to the prior art, owing to the fact that a great amount of primary air cannot be supplied to the gas turbine, temperature of a secondary flame 43 is increased disadvantageously during rated load operation of the turbine, and a large amount of nitrogen oxides is undesirably produced. The flame stabilizing method utilizing a turning flame has a number of drawbacks as described in the foregoing.

The present invention provides a new method for stabilizing flame with a view to obviating such drawbacks and disadvantages of the prior art. The present invention will be explained hereinafter in detail. Throughout the drawings, like numerals or symbols indicate like parts.

To begin with, the flame in accordance with the present invention has a section shown in FIG. 5. In comparison with FIG. 4, it is seen that a small flame 46 is formed in the extreme vicinity of a fuel nozzle jet port 26. The small flame 46 is located just outside the outer boundary surface of a fuel spray 40. This annular small flame 46 provides an effect to accelerate the evaporation of fuel particles discharged from the fuel nozzle jet port 26 so that incomplete combustion due to delayed evaporation of fuel can be prevented in contrast to the prior art combustor of FIG. 4 which is unable to avoid such an incomplete combustion. Thanks to the formation of the annular small flame 46, the preheating of primary air as well as the improved evaporation of fuel spray particles can be achieved to increase burning speed, thereby completely eliminating the disadvantages of the prior art described above. If the annular small flame 46 is extremely stable, an excessive amount of primary air does not result in the blowing out of flame and a stabilized burning can be attained so that it is made possible to prevent the generation of white smoke in exhaust gas during rated load operation of a gas turbine and to perform efficiently and in a stable manner a low temperature burning at a temperature of less than 1,500°C, averting the production of nitrogen oxides.

As described above, the present invention aims to accomplish the stabilization of main flame by the use of the annular small flame 46 and differs totally from the conventional flame stabilizing method utilizing the main circulating flow 33 and can attain a stable burning throughout an extremely wide range of operation.

Hereinafter explanations will be made on the method for forming the annular small flame in accordance with the present invention.

Fuel particles sprayed from the fuel nozzle jet port 26 are not uniform and can be expressed by the following formula:

$$f(x)=ax^p \exp(-bx^q)$$

In the above formula, a and b are constants inherent in the fuel nozzle, and p and q are the values determined by spraying method and spraying condition.

Fuel particles needed to form the annular small flame 46 of the present invention are extremely fine particles having a diameter of less than 20 μ , the distribution of which is expressed in the above formula. These fuel particles can be readily transferred by means of air flow. Therefore, if an air flow is provided so that the annular small flame 46 is formed, the original purpose can be achieved.

A detailed explanation will be given here, with reference to FIGS. 6 through 10, on the formation of the annular small flame 46 in accordance with the principles of the present invention.

First of all, first inwardly directed flow jet ports 47 and second inwardly directed flow jet ports 48 are arranged about the jet port 26 of a fuel nozzle 15 mounted at a liner center axis. Although said jet ports 47 and 48 preferably have the shape of a continuous annular slit, the same effect can be obtained even if

they are formed as discontinuous louver perforations as shown in FIG. 3.

In FIG. 6 are shown two rows of the first jet ports 47 and the second jet ports 48. However, when the spray capacity of fuel nozzle is small, only one row of the jet ports can perform the job satisfactorily. If the spray capacity is very large and a liner 16 has a large diameter, it is necessary to provide more than three rows of the inwardly directed flow jet ports. The reason for this is that, with the increased spray capacity of fuel nozzle, the annular small flame 46 must be increased in size proportionally to effectively carry out the evaporation of fuel spray and the preheating of primary air. A first annular jet flow and a second annular jet flow flowing in through the first inwardly directed flow jet ports 47 and the second inwardly directed flow jet ports 48 shown in FIG. 6, are preferably inwardly directed flows which do not make a turning movement and move toward the fuel nozzle jet port 26. However, said first and second annular jet flows may make a slight turning movement. The experimental results shows that the object of the present invention can be attained if the first and second annular jet flows flow in maintaining a crossing angle θ within a range of 0° to 45° with the radial line starting from the fuel nozzle jet port 26 (assuming that the jet port 26 is arranged on the liner center axis) as shown in FIG. 7. The first annular jet flow 51 and the second annular jet flow 52 passing through the first inwardly directed flow jet ports 47 and the second inwardly directed flow jet ports 48 are formed into annular turning flows shown in FIG. 6 due to the influence of inwardly directed flows. If said crossing angle θ exceeds 45°, velocity vector of the turning flows becomes larger than that of the inwardly directed flows so that the first annular jet flow 51 and the second annular jet flow 52 taking directions shown in FIG. 6 vanish. Thus, the object of the present invention cannot be achieved.

In order to reinforce the annular jet flows 51 and 52 shown in FIG. 6, there are provided in a liner cone portion 13 first turning flow jet ports 49 and second turning flow jet ports 50. By means of the first turning flow jet ports 49 and the second turning flow jet ports 50, turning air flows 30 are generated, and due to the turning effect of said turning air flows 30, main circulating flows 33 are put in movements shown by the broken lines. Turning direction of the main circulating flows 33 is opposite to that of the first and second annular jet flows 51 and 52. At the points of contact, the main circulating flows 33 and the first and second annular jet flows 51 and 52 form flows moving toward the liner cone portion 13. As the first annular jet flow 51 and the second annular jet flow 52 are reinforced by the main circulating flows, fine fuel particles sprayed by the fuel nozzle jet port 26 are carried by the strong annular jet flows 51 to 52 to form an annular small flame. Though the annular jet flows 51 and 52 have as their principal purpose the formation of said annular small flame, they can also prevent carbon accumulation on the liner cone portion 13 and the jet port surface of the fuel nozzle 15. The annular jet flows 51 and 52 further have a cooling effect as they form film-like air flows.

On the other hand, secondary air flows 9 flowing in through secondary air holes 8 reach the central part of the liner with the aid of the main circulating flows 33 so that the mixing of fuel and burning air can be improved. In contrast to the flame stabilizing method for

gas turbine combustor according to the prior art which utilizes the main circulating flows, the present invention has a distinct feature that the same effect is achieved by the annular small flame 46 formed in the vicinity of the fuel nozzle jet port 26.

FIG. 7 shows the construction in the vicinity of the fuel nozzle as far as the second inwardly directed flow jet ports 48. The construction outside the jet ports 48 is not shown. The first inwardly directed flow jet ports 47 and the second inwardly directed flow jet ports 48 shown in FIG. 7 are louver perforations having a section shown in FIG. 8. As the object of the present invention to form inwardly directed flows such as the first annular jet flow 51 and the second annular jet flow 52 shown in FIG. 6, any suitable construction other than the louver perforations, for example, the construction of FIG. 9, may be employed.

FIG. 9 shows a construction comprising a first small cone portion 54 and a second small cone portion 55 combined with a liner cone portion 13, which constitute inwardly directed flow jet ports 56 and inwardly directed flow jet ports 57. On the outer peripheral surfaces of the first cone portion 54 and the second cone portion 55 are respectively provided first small cone projections 58 and second small cone projections 59 to form the inwardly directed flow jet ports 56 and 57. The inwardly directed flow jet ports 56 and 57 may also be formed by arranging projections on the inner peripheral surfaces of the second small cone portion 55 and the liner cone portion 13.

FIG. 10 is a sectional view taken along the line D—D of FIG. 9. The second small cone projections 59 are provided on the outer periphery of the second small cone portion 55 to be in contact with the liner cone portion 13 for forming the inwardly directed flow jet ports 57. By investigating FIG. 10, the construction of FIG. 9 can be understood more readily. Although two rows of the inwardly directed flow jet ports 56 and 57 are shown in FIG. 9, only one row of the jet ports is enough when the spray capacity of fuel nozzle is small. But if the fuel nozzle has a large spray capacity, it is naturally needed to provide three or more rows of the jet ports.

As the fundamental operational principles of the present invention have been described in the foregoing, the present invention will be explained hereinafter with reference to the embodiments thereof.

FIGS. 11 and 12 show an embodiment of the present invention. A liner cone portion 13 has louver perforations constituting inwardly directed flow jet ports and turning flow jet ports, and primary air supply holes 63 are arranged as shown in the figure, thereby to form double annular flames throughout the cone portion.

FIG. 12 is a sectional view of FIG. 11. Air passing through primary air regulating holes 36 is supplied to each jet port by way of a primary air chamber 27. Air coming in through inner periphery air supply holes 68 passes through an air reservoir 69 constituted by a fuel nozzle collar 53 and an inside ring 60 and through an inner periphery jet port 70 to be discharged in the form of a film toward a liner center axis. Air is also discharged into the liner toward the liner center axis through first inwardly directed flow jet ports 61 comprising louver perforations in the liner cone portion 13. On the outer periphery of the series of the first inwardly directed flow jet ports 61 are arranged, as shown in the figure, first turning flow jet ports 62 comprising louver

perforations to give a turning movement to the air flows within the liner.

Thanks to the operational principles of the present invention described previously, a primary annular small flame can be formed about a fuel nozzle jet port 26 in the central part of the liner cone portion 13 by means of the inner periphery jet port 70, first inwardly directed flow jet ports 61, and first turning flow jet ports 62. The primary air supply holes 63 are provided on the outer periphery of the series of the first turning flow jet ports 62 for accelerating the mixing of air and fuel in the primary burning zone to prevent the generation of smoke caused by burning. On the outer periphery of the series of the primary air supply holes 63 are arranged second inwardly directed flow jet ports 64 and third inwardly directed flow jet ports 65 all in the form of louver perforations to again form air flows directed toward the liner center axis. These air flows can form a secondary annular flame by joining in the air flows coming in through second turning flow jet ports 66 comprising louver perforations located on the outermost periphery of the liner cone portion 13. It is known from the experimental results that only the annular small flame is formed with the secondary annular flame lacking if a small amount of fuel is sprayed as is when the gas turbine is started. However, if the amount of fuel spray is large, as is in rated load operation, the secondary annular flame is formed in addition to the primary annular small flame to a stable burning condition. Since the annular flames are formed in response to the variation in the amount of fuel spray as described above, a very efficient burning can be obtained throughout a wide range of variation in fuel spray amount. Air flows discharged from the first turning flow jet ports 62 not only form the primary annular small flame but also preheat the primary air passing through the primary air supply holes 63. For this reason, a stable, high-efficiency burning operation can be performed even when the burning air temperature is very low, such as the time of starting of a gas turbine during cold winter.

FIG. 13 shows another embodiment in accordance with the present invention. Unique features of this embodiment will be evident if compared with FIG. 12. The part of a liner cone portion 13 inwardly of primary air flow supply holes 74 is constructed in a cup-like shape to increase the stability of annular small flame. By providing the primary air flow supply holes 74 in a direction toward the central part of a liner, primary air jet flows 81 can be supplied to a part in the vicinity of the central part the liner so that the local excessive fuel spots are avoided to prevent the generation of smoke. In FIG. 13, a cup-shaped structure in the central part of the liner cone portion 13 has a relatively small depth. It is known from the experiments that the most stable annular small flame is obtained when said cup-shaped structure has a depth substantially equal to the largest radius thereof. However, if fuel spray cone discharged from a fuel nozzle 15 has a very large vertical angle, there is a possibility that the fuel spray collides with the liner cone portion 13 to burn it. In designing this cup-shaped structure, the depth thereof should be determined taking this fact into consideration. In comparison with the construction of FIG. 12, a second inwardly directed flow jet port group 72 is added to the construction shown in FIG. 13. As described previously, the number of rows of such jet ports should be deter-

mined at an optimum value depending upon the capacity and spraying property of respective fuel nozzle. It should not be understood as an invariable factor usable for all liner designs. When fuel nozzle has an extremely good spraying property, fine fuel particles carried by annular jet flows 78 through 80 are increased in amount, resulting in an annular small flame which is too large in proportion to a main flame. In this case, it is necessary to increase opening area, number of row, and other factors of the inwardly directed flow jet ports. Increase in the spray capacity of fuel nozzle also brings about increased fuel particles. In this case, too, opening area and number of row of the inwardly directed flow jet ports must be increased.

The method for forming an annular small flame so far described utilizes the combinations of inwardly directed flows and turning flows. However, the object of the present invention can also be achieved by using the combinations of inwardly directed flows and outwardly directed flows.

FIG. 14 is a plan view of an embodiment of the present invention employing the above described method. FIG. 15 is a sectional view of said embodiment showing the movement of air flow passing through each jet port. An inside ring 60 is arranged on the outer periphery of a fuel nozzle 15 for forming an annular jet flow 92. On the outer periphery of said inside ring 60 is provided a first inwardly directed flow jet port group 86 to generate an annular jet flow 93. On the outer periphery of said first inwardly directed flow jet port group 86 is arranged a first outwardly directed flow jet port group 87 to generate an outwardly directed jet flow 96. On the outer periphery of said first outwardly directed flow jet port group 87 are provided primary air supply holes to generate a primary air jet flow 97. On the outer periphery of the series of said primary air supply holes is arranged a second inwardly directed flow jet port group 89 to generate second annular jet flow 98. On the outer periphery of said second inwardly directed flow jet port group 89 is provided a third inwardly directed flow jet port group 90 to generate a second annular jet flow 99. And on the outer periphery of said third inwardly directed flow jet port group 90 is arranged a first turning flow jet port group 91 to generate a main turning and circulating flow 100. In this embodiment, an annular small flame formed in front of the fuel nozzle 15 is not made into a turning flow about a liner center axis 101. However, in actual practice, said annular small flame begins to make a slow turning movement about the liner center axis 101 under the influence of the first turning flow jet port group 91. Needless to say, it is within the scope of the present invention to give a turning function to both of, or any one of, the first inwardly directed flow jet port group 86 and the first outwardly directed flow jet port group 87.

As is apparent from FIG. 15, by combining the inwardly directed flows and the outwardly directed flow, annular circulating flows 94 and 95 are obtained. The annular circulating flows 94 and 95 are further combined with the annular jet flow 92 and the annular jet flow 93 to form an extremely stable annular small flame.

On the other hand, the second inwardly directed flow jet port group 89 and the third inwardly directed flow jet port group 90 are not only capable of generating the second annular jet flows 98 and 99 shown in FIG. 15 but also has a function to send the primary air jet flow

97 coming in through the primary air supply holes 88 to the area in close vicinity to the liner center axis 101 for preventing the generation of smoke. Therefore, there is a necessity to make the second annular jet flows 98 and 99 stronger than the main turning and circulating flow 100 passing through the first turning flow jet port group 91. Considering the prevention of smoke generation, two rows of jet port, i.e., the second inwardly directed flow jet port group 89 and the third inwardly directed flow jet port group 90, are arranged in the construction shown in FIG. 14. If the first outwardly directed flow jet port group 87 is omitted in the construction of FIG. 15, force of the annular circulating flows 94 and 95 will be decreased, although the annular small flame is formed. In this case, stable range of the annular small flame will be decreased to a large degree. This construction without the first outwardly directed flow jet port group 87 is not suitable for use in gas turbines where a burning state stable throughout a wide range of operation is required, but may be used in other combustion equipment where only a narrow range of operational variation is needed.

Explanations have been given in the foregoing on the basic embodiments in accordance with the present invention. Further, applied examples of the present invention will be described hereinafter.

FIG. 16 shows an applied example in accordance with the present invention. This applied example has an object to prevent the generation of smoke caused by the annular small flame by providing annular flow air holes 102 so that air is supplied to the annular small flame of the present invention. The annular small flame will become unstable if total area of the annular flow air holes 102 is unproportionally larger than that of a first inwardly directed flow jet port group 86. From the experiments it is known that the annular small flame is extinguished if total area of the annular flow air holes 102 exceeds about 1.8 times that of the first inwardly directed flow jet port group 86. Particularly it has been clearly observed that the annular small flame tends to vanish if the pitch between the annular flow air holes 102 is made smaller.

In determining size, number, and other factors of the annular flow air holes 102, it is necessary to take into consideration the experimental results described above. A second feature of this applied example lies in the fact that an outwardly directed turning flow jet port group 103 is provided on the outer periphery of the first inwardly directed flow jet port group 86. The method for forming the annular small flame using the combination of the first inwardly directed flow jet port group 86 and the outwardly directed turning flow jet port group 103 is a method utilizing both the embodiments shown in FIGS. 11 and 14. The first inwardly directed flow jet port group 86 must have a crossing angle θ shown in FIG. 7 of less than 45° to generate a strong inwardly directed flow and a weak turning flow. However, as is apparent from FIGS. 11, 14, and 16, there is no restriction in determining the crossing angle of the outwardly directed turning flow jet port group 103.

FIG. 17 shows an applied example in accordance with the present invention in which an annular inner periphery flow jet port 112 is arranged on a fuel nozzle cap. Most gas turbines have a construction wherein both liquid fuel and gas fuel can be used. In such a construction, the fuel nozzle cap 108 is attached to a fuel

nozzle 15. Thus, in the fuel nozzle cap 108 are provided inner periphery air supply holes 109 to supply air to an air chamber 110. Air is discharged in an inward direction from annular inner periphery flow jet ports 112 through air supply holes 111. Air discharged from the annular inner periphery flow jet ports 112 must have, as is the case with the first inwardly directed flow jet port group 86, the weakest possible turning flow. Said air from the jet ports 112 preferably has no turning flow. In gas turbines designed to be compact and light weight such as jet engines, it is common to employ an annular combustor having an annular space construction different from the construction of the boiler type combustor described in the foregoing. There are also used a so-called cannular combustor having a common combustor outer cylinder 18. In these combustors, it is also possible to form the annular small flame of the present invention about the fuel nozzle jet port in the same manner as in the boiler type combustor described above. In the figure, numerals 105, 106 107, 113, and 114 indicate respectively a nozzle body, a nozzle holder, a packing, direction of fuel supply, and an attaching flange portion.

FIG. 18 shows one of the applied examples of the combustor liner in accordance with the present invention. Difference between this combustor liner and the typical conventional combustor liner shown in FIG. 2 is that the primary air chamber 27 is reduced in volume to form a primary air chamber 115 covering only the area in the vicinity of the fuel nozzle 15. In the conventional combustor liner construction, the primary air regulating holes 36 limits the amount of air supplied to the primary air chamber 27 so that the primary air supplied to the liner through the cone louver perforations 29 and the cone portion air holes 34 has a decreased flowing speed. Thus, said primary air moves over a decreased flowing distance without reaching the central part of liner due to its low flowing speed. It is known from the smoke density distribution experiments that the largest smoke density is shown in the central part of liner. This fact evidences the shortage of air supply to the central part of liner. According to the conventional construction, said flowing distance can be increased by employing larger primary air regulating holes 36. But increase in size of said primary air regulating holes 36 has a certain limit because flame becomes unstable if extremely large holes 36 are used. In actual practice, total area of the primary air regulating holes 36 has been determined to be equal to or less than total area of all the openings of the liner cone portion 13. In order to supply the primary air to the area in the vicinity of the central part of liner, the prior art employs the turbulator 11 as shown in FIG. 2 for generating the turbulator air flow 10. If the air not turning is directed toward the liner center, air supply to the area in the vicinity of the central part of liner can be achieved effectively. However, in this case, the blowing out takes place very often owing to unstable condition of flame. In solving this problem, the prior art gives to the turbulator 11 a turning function within a range of 20° to 30° to attain the stabilization of flame.

In the present invention, as shown in FIG. 18, the primary air chamber 115 is provided about the fuel nozzle to form an extremely stable annular flame on the first cone portion 116. The optimum amount of air flow is obtained by primary air adjusting holes 117 so that air is discharged at an optimum speed from first primary

air jet ports 118, second primary air jet ports 119, third primary air jet ports 120, and first turning flow jet ports 121. Very stable flames can be obtained since this stable annular flame performs simultaneously the evaporation of sprayed fuel particles and the preheating of primary air. Thanks to this arrangement, the stabilization of flame is not threatened when a primary air hole jet flow 123 coming in through primary air holes 122 is directed toward the liner center. Thus, air-fuel ratio in the zone after a second cone portion 124 can be increased to achieve a low temperature burning with an excess amount of air so that the production of smoke and nitrogen oxides can be prevented during normal operation of gas turbine. With the provision of the second cone portion 124 and the primary air holes 122 enabled by the elimination of a part of the primary air chamber 27 according to the prior art (FIG. 2), flowing speed of the air flowing into the liner is increased and the fuel particles and the primary air are mixed uniformly. Thus, the air shortage in the central part of liner experienced in the conventional liners can be solved and the burning is carried out efficiently throughout a wide range of load variation. Fourth primary air jet ports 125 and fifth primary air jet ports 126 are provided directed inwardly so that the primary air hole jet flow 123 can reach the area in the vicinity of the liner center and a secondary annular flame can be formed on the second cone portion 124 with the use of a fourth primary air jet flow 127, a fifth primary air jet flow 128, and a second turning jet flow.

FIG. 19 shows another embodiment different from that of FIG. 18. As is readily seen when compared with the embodiment shown in FIG. 18, the embodiment of FIG. 19 has a double chamber construction comprising a primary air chamber 50 and an air chamber 129 arranged outside said primary air chamber 50. The amount of the air flowing in each of said chambers 50 and 129 is regulated by outer air regulating holes 131 and inner air regulating holes 132 provided in an air regulating head plate 130 so as to achieve more proper introduction and distribution of air in the primary burning zone. The first reason of employing the double chamber construction is to maintain the burning in the primary burning zone in the best condition. The second reason of employing the double chamber construction is that a liner cone portion 13 can be readily replaced with new one thanks to this separate and independent construction when it is burned or damaged for one reason or another. In this burning method, since the primary air larger in amount than the primary air according to the prior art is introduced through the liner cone portion 13 for performing a low temperature burning to prevent the production of nitrogen oxides, a flame formed inside a liner wall 16 has a smaller quantity of radiation heat conducted to the liner wall 16 so that the durability of the liner wall 16 is improved greatly. On the other hand, the liner cone portion 13 has a durability inferior to that of the liner wall 16 due to the fact that a relatively high temperature zone is established on the liner cone portion 13 for forming a stable annular small flame. Thus, the liner cone portion 13 can be easily repaired or replaced with a new one at a low cost thanks to this advantageous separate and independent construction. The third reason of employing the double chamber construction is to attain a sure support of the combustor liner. Especially in the reverse flow type combustor shown in FIG. 1, spacers are arranged be-

tween the combustor outer cylinder 18 and the liner head outer cylinder 133 for supporting the liner. For this reason, a certain amount of mechanical strength is required for the liner head. In this case, the double chamber construction shown in FIG. 19 can be used to full advantage. In case of the double chamber construction, total area of the inner air regulating holes 132 for supplying air to a primary air chamber 116 should be equal to or a little smaller than total area of all the openings of the part of liner cone portion 13 facing the primary air chamber 116 to obtain a large fluidity resistance at the inner air regulating holes 132. Total area of the outer air regulating holes 131 for supplying air to the air chamber 129 should be equal to or larger than total area of all the openings of the part of liner cone portion 13 facing the air chamber 129. The experiments have shown that an excellent burning performance is available by following the above procedures. The reason is that a stable annular small flame is formed by making small the amount and speed of the air coming in through the openings of the part of liner cone portion 13 facing the primary air chamber 116. In particular, the optimum amount of air should be determined by the spray property of fuel nozzle. For instance, a larger amount of air is required for a fuel nozzle spraying a great quantity of fine fuel particles of less than 20 μ size. On the other hand, by making large the amount and speed of the air coming in through the openings of the part of liner cone portion 13 facing the air chamber 116, the mixing of primary air and sprayed fuel particles is improved, a low temperature burning can be carried out thanks to the increased air fuel ratio in the primary burning zone, and the flowing distance of primary air hole jet flow flowing in through primary air holes 134 can be increased. Thus, the object of the present invention can be achieved satisfactorily by making large the fluidity resistance of the inner air regulating holes 132 and by making small the fluidity resistance of the outer air regulating holes 131.

Although the present invention has been described in detail with reference to the boiler type combustor, it is also applicable to other types of gas turbine combustor, i.e., cannular type combustor and annular type combustor.

The burning method in accordance with the present invention can be applied to, in addition to gas turbines, other burning equipment such as boiler and small heating apparatus since it has a distinct feature that the production of unburned hydrocarbon, carbon monoxide, soot, and nitrogen oxides, which cause air pollution, is limited to the lowest level.

With the formation of the annular small flame in accordance with the present invention, it is possible to decrease the amount of harmful substances such as unburned hydrocarbon (observed mostly as a white smoke) and carbon monoxide heretofore produced by incomplete combustion at the time of starting in cold winter. Further, by inserting an ignition plug in the annular small flame, a very sure firing can be performed. In this instance, a quite reliable firing is possible because extremely fine fuel particles gather in the annular small flame and the firing is carried out in a manner as if a gas fuel were ignited.

On the other hand, in normal load operation, the evaporation of fuel particles is accelerated so that complete combustion is accomplished to prevent the generation of smoke.

The burning method in accordance with the present invention, in contrast to the conventional hydrodynamic flame stabilizing method, utilizes the extremely stable annular small flame and is capable of increasing to a large degree the excessive amount of air in the primary and secondary burning zones located adjacent to the annular small flame to obtain a reduced main flame temperature for effectively decreasing nitrogen oxides produced by the burning operation. Thus, the present invention can provide a gas turbine power plant with a very low level of environmental pollution since the harmful substances described above, which are the source of air pollution, are produced only in the slightest possible amount if the burning method in accordance with the present invention is applied to a gas turbine.

We claim:

1. A gas turbine combustor comprising a cylindrical liner wall;

a conical liner cap located at one end of said cylindrical liner wall, whereby said cylindrical liner wall and said liner cap form a combustion chamber for the gas turbine;

a fuel nozzle provided at said liner cap for spraying fuel in a conical manner into the combustion chamber;

first air supply ports annularly arranged on said liner cap in the vicinity of said fuel nozzle in such manner that air flows along said liner cap toward said fuel nozzle;

second air supply ports annularly arranged on said liner cap downstream of said first air supply ports with respect to the stream of fuel sprayed from said fuel nozzle in such manner that a turning air flow about the axis of the combustion chamber results and together with the air flow from said first air supply ports forms a first annular vortex stream along said liner cap in the vicinity of the fuel nozzle; and

third air supply ports annularly arranged on said liner cap downstream of said second air supply ports in such manner that air flows toward the downstream side of the first annular vortex stream.

2. A gas turbine combustor as set forth in claim 1, wherein said first air supply ports have a plurality of louvers opening toward the center of said liner cap for causing the air to flow along said liner cap toward said fuel nozzle;

said second air supply ports have a plurality of louvers which open tangentially about a concentric circle of said liner cap; and

said third air supply ports have a plurality of holes for directing the flow of air toward the downstream side of the first annular vortex stream in an amount greater than the flow of air from said first and second air supply ports.

3. A gas turbine combustor as set forth in claim 2, wherein said plurality of louvers comprising said first air supply ports are arranged along a plurality of concentric circles on said liner cap; and said second air supply ports are arranged downstream of said first air supply ports along a plurality of concentric circles on said liner cap.

4. A gas turbine combustor as set forth in claim 1, further comprising fourth air supply ports annularly arranged on the downstream side of said third air supply ports for spraying air along said liner cap toward said

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fuel nozzle; and fifth air supply ports annularly arranged downstream of said fourth air supply ports for spraying air in a turning flow about the axis of the combustion chamber so that the air flow from the fourth and fifth air supply ports forms a second annular vortex stream along said liner cap on the downstream side of said third air supply ports.

5. A gas turbine combustor as set forth in claim 1, wherein a radial line emanating from the fuel nozzle disposed along the axis of the combustion chamber and said first air supply ports have a crossing angle in a range of 0° to 45° as viewed in the axial direction of the combustion chamber.

6. A gas turbine combustor as set forth in claim 1, wherein said liner cap includes a cup-shaped cone in the vicinity of said fuel nozzle, and the axis of said third air supply ports are provided substantially at right angles to the axis of the combustion chamber.

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7. A gas turbine combustor as set forth in claim 1, including an air chamber for regulating the speed and flow of air arranged on the surface of said liner cap opposite to the interior burning surface of said liner cap, said liner cap being cup-shaped in the vicinity of said fuel nozzle.

8. A gas turbine combustor as set forth in claim 1, including an air chamber for regulating the speed and flow of air discharged from said third air supply ports, fourth air supply ports annularly arranged on the downstream side of said third air supply ports, and fifth air supply ports annularly arranged downstream of said fourth air supply ports for spraying air in a turning flow about the axis of said combustion chamber, wherein said fourth and fifth air supply ports are arranged on a surface of said liner cap opposite to the interior burning surface of said liner cap.

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