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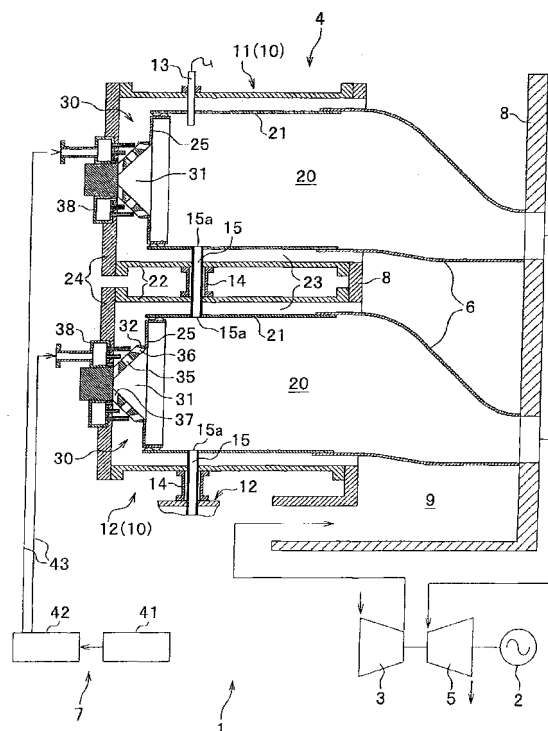
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(54) **Gas turbine combustor**

(57) In a gas turbine combustor, mixing of a fuel and air is accelerated in a mixing chamber of a burner as well as in air introduction passages provided in a wall of the mixing chamber, whereby NO<sub>x</sub> emissions from premixed combustion are reduced while at the same time, ignition characteristics and flame propagation characteristics improve.

The gas turbine combustor includes a plurality of combustors 10, a spark plug 13, and a cross-fire tube 15 that propagates a flame between the combustors 10. Each combustor 10 includes the burner 30 equipped with a fuel nozzle and the mixing chamber wall 32 forming the mixing chamber 31. A plurality of air introduction holes 35, 36 for introducing combustion air, along with the fuel from the fuel nozzle, into the mixing chamber 31, are provided in the mixing chamber wall 32. The combustion air and fuel jetted from the air introduction hole 35 into the mixing chamber 31 are mixed in the form of a mixture "m1", "m2" and directed towards the spark plug 13 and the cross-fire tube 15.

**FIG. 1**



## Description

### BACKGROUND OF THE INVENTION

#### 1. Field of the Invention

**[0001]** The present invention relates to a gas turbine combustor including a plurality of combustors for supplying to a turbine, combustion gases resulting from combustion of a fuel-air mixture, a spark plug for igniting the mixture, and cross-fire tubes for propagating flames between the combustors.

#### 2. Description of the Related Art

**[0002]** Among the gas turbine combustors equipped in commonly used conventional gas turbines is traditionally known a type including a plurality of can-type combustors. These combustors are constructed so that each creates high-temperature high-pressure combustion gases by causing reactions between fuel and air in order to rotationally drive the turbine. Such a type of combustor is disclosed in Japanese Patent No. 3940705, for example.

**[0003]** The combustors in the can-type gas turbine combustor are arranged circularly in a circumferential direction of the turbine rotor, and the combustors adjacent to one another in the circumferential direction are each interconnected by a connecting pipe, with a cross-fire tube being disposed inside the pipe. The cross-fire tube is of a tubular shape, and is constructed so that upon a differential pressure occurring between the pipe-connected combustors, combustion gases pass through the cross-fire tube.

**[0004]** During a start of operation, the gas turbine is driven by an external drive, then reaches a rotational speed at which ignition is to be started, and introduces fuel and air into all combustors. The combustor initiates combustion by developing a spark from the spark plug (s) set in one or two of the combustors. The combustion in each ignited combustor generates hot combustion gases, raising an internal pressure of the particular combustor. When adjacent combustors are not in an ignited condition, the differential pressure with respect to the ignited combustor causes hot combustion gases to flow into the unignited combustors through the cross-fire tubes. In this way, ignition initially starts from one or two combustors only and then sequentially propagates to other combustors adjacent thereto, whereby all combustors are ignited in order.

### SUMMARY OF THE INVENTION

**[0005]** The plurality of combustors constituting a gas turbine combustor are each equipped with a burner. The burner is inclusive of a mixing chamber wall forming a mixing chamber, and of a fuel nozzle, and the mixing chamber wall includes a plurality of air introduction pas-

sages that introduce air for combustion into the mixing chamber along with a fuel supplied from the fuel nozzle. Thus, mixing of the fuel and air in the air introduction passages and in the mixing chamber is accelerated and NOx reduction by premixed combustion becomes possible.

**[0006]** The gas turbine exhibits better starting ignition characteristics and flame propagation characteristics as the mixture has a higher fuel concentration, that is, a higher fuel-air ratio. During premixed combustion, however, the starting ignition characteristics and flame propagation characteristics of the gas turbine often decrease since the mixture in the mixing chamber tends to be homogenized in fuel concentration.

**[0007]** An object of the present invention is to improve starting ignition characteristics and flame propagation characteristics in a gas turbine combustor while at the same time reducing NOx during premixed combustion by accelerating fuel-air mixing in a mixing chamber of a burner and in air introduction passages provided in a wall of the mixing chamber.

**[0008]** According to a first aspect of the present invention, the gas turbine combustor includes a plurality of combustors each for supplying to a gas turbine a combustion gas resulting from combustion of a mixture of a fuel and combustion air introduced from a compressor; a spark plug for igniting the mixture; and/or a cross-fire tube for propagating between the combustors a flame formed by the combustion of the mixture; wherein: the combustors each include a burner, the burner including a mixing chamber wall for forming a mixing chamber which opens towards a downstream side in an axial direction of the combustor, a fuel nozzle for supplying a fuel, and/or a plurality of air introduction passages installed in the mixing chamber wall each for introducing combustion air, along with the fuel from the fuel nozzle, into the mixing chamber, flows of the combustion air and fuel jetted from the air introduction passages into the mixing chamber are directed towards at least one of the spark plug and the cross-fire tube.

**[0009]** According to the first aspect, in the gas turbine combustor including the plurality of combustors, the spark plug, and the cross-fire tubes, the combustion air is jetted from the air introduction passages that introduce the combustion air into the mixing chamber of the burner of each combustor, into the mixing chamber in the form of a mixture with the fuel supplied from the fuel nozzle. The jetted mixture flows towards at least one of the spark plug and the corresponding cross-fire tube. As a result, at a location of and in vicinity of at least one of the spark plug and the cross-fire tube, a mixture with a high fuel concentration exists, which facilitates ignition, improves at least one of ignition characteristics and flame propagation characteristics, and thus improves startability of the gas turbine.

**[0010]** According to a second aspect of the present invention, in the gas turbine combustor, the mixing chamber wall is such that the air introduction passages are

arranged so as to form a first row and a second row adjacently to each other, in the axial direction or in the radial direction; the air introduction passage for jetting the combustion air which flows towards the spark plug belongs to the first row; and the air introduction passage for jetting the combustion air which flows towards the cross-fire tube belongs to the second row.

**[0011]** According to the second aspect, since the air introduction passages for jetting the mixture to be oriented towards the spark plug and the cross-fire tube are divided into the first and second rows, the air introduction passages improve in flexibility of layout and shapes in the mixing chamber wall. This improvement enables suitable air introduction passages to be designed more easily for better ignition characteristics and enhanced flame propagation characteristics.

**[0012]** According to a third aspect of the present invention, the gas turbine combustor includes a central burner as the burner; and a plurality of outer peripheral burners each disposed at an outer peripheral side relative to the central burner; wherein: the central burner includes a central mixing chamber wall that is the mixing chamber wall forming a central mixing chamber which is the mixing chamber, and a central fuel nozzle as the fuel nozzle; the outer peripheral burners each include an outer peripheral mixing chamber wall forming an outer peripheral mixing chamber which opens towards a downstream side in the axial direction, and an outer peripheral fuel nozzle for supplying a fuel to the outer peripheral mixing chamber; in the central mixing chamber wall, the combustion air introduction passages are provided so as to form a first row and a second row adjacently to each other, in the axial direction; the air introduction passage for jetting the combustion air which flows towards at least one of the spark plug and the cross-fire tube belongs to the first row; and the combustion air jetted from the air introduction passage belonging to the second row flows towards an exit of the outer peripheral mixing chamber.

**[0013]** According to the third aspect, the combustion air jetted from air introduction holes along with the fuel will flow towards an exit of each outer peripheral burner, and hot combustion gases resulting from combustion of a mixture jetted from the air introduction passages belonging to the second row will be supplied to the exit of the outer peripheral burner. Thus, the mixture supplied from the outer peripheral burner will be easy to burn, and for example, even if the mixture in the outer peripheral burner is low in fuel concentration, the combustion can be started easily. This will improve combustion capabilities of the combustor including the outer peripheral burner, and enable an operational load range of the gas turbine to be extended.

**[0014]** Additionally, since the air introduction passages are divided into the first and second rows, flexibility of layout and shapes of the air introduction passages in the mixing chamber wall improves, which in turn enables suitable air introduction passages to be designed more easily for an easier start of the combustion of the mixture sup-

plied from the outer peripheral burner, as well as for better ignition characteristics and enhanced flame propagation characteristics.

**[0015]** According to a fourth aspect of the present invention, the gas turbine is such that the number of the air introduction passages constituting the second row in the central burner is an integral multiple of the number of the outer peripheral burners.

**[0016]** According to the fourth aspect, since the number of air introduction passages is an integral multiple of that of outer peripheral burners, the air introduction passages for jetting the mixture to flow towards the outer peripheral burners can be allocated in equal numbers to each thereof. Additionally, since the layout and shapes of the air introduction passages to be allocated can be made equal easily, burner structural simplification and improvement of combustion stability are realized.

**[0017]** According to a fifth aspect of the present invention, the gas turbine combustor is such that in the first row and the second row, six of the air introduction passages configure an upstream row in the axial direction, and twelve of the air introduction passages configure a downstream row; and

the number of the outer peripheral burners is four or six.

**[0018]** According to the fifth aspect, since the row located downstream has more air introduction passages than the row located upstream, the mixture that flows towards the downstream side is oriented in the downstream direction more reliably. In addition, since the number of air introduction passages in the row located downstream is an integral multiple of the number of outer peripheral burners, the fifth aspect works as effectively as the fourth aspect of the present invention.

**[0019]** According to the present invention, since the mixing of a fuel and air in the mixing chamber as well as air introduction passages of a gas turbine combustor is accelerated, NOx reduction by premixed combustion is accomplished, with ignition characteristics and flame propagation characteristics also being improved.

## BRIEF DESCRIPTION OF THE DRAWINGS

### **[0020]**

Fig. 1 is a sectional view that schematically shows essential elements of a gas turbine plant which uses a gas turbine equipped with a gas turbine combustor according to a first embodiment of the present invention;

Fig. 2 is a schematic diagram that illustrates combustors and cross-fire tubes, both equipped in the gas turbine combustor of Fig. 1;

Fig. 3 is an enlarged view of the essential elements shown in Fig. 1, with burner air introduction holes being shown in simplified form;

Fig. 4 is a sectional view taken along line IV-IV in Fig. 3;

Fig. 5 is a sectional view taken along line V-V in Fig. 3;

Fig. 6 shows a modification of the first embodiment, the figure corresponding to the essential elements shown in Fig. 3;

Fig. 7 shows a second embodiment of the present invention, the figure corresponding to Fig. 3;

Fig. 8 shows the element of the second embodiment that corresponds to Fig. 4;

Fig. 9 is a graph representing a relationship between a gas turbine load and in-burner fuel flow rates in the second embodiment;

Fig. 10 shows a third embodiment of the present invention, the figure corresponding to Fig. 3;

Fig. 11 shows elements of the third embodiment that correspond to Fig. 4;

Fig. 12 is a graph relating to the third embodiment, the graph representing a relationship equivalent to that of Fig. 4;

Fig. 13 shows a fourth embodiment of the present invention, the figure corresponding to Fig. 3; and

Fig. 14 shows elements of the fourth embodiment that correspond to Fig. 4.

#### DESCRIPTION OF THE PREFERRED EMBODIMENTS

**[0021]** Hereunder, gas turbine combustors according to embodiments of the present invention will be described with reference to Figs. 1 to 14.

(First Embodiment)

**[0022]** A gas turbine combustor 4 according to a first embodiment of the invention is described below referring to Figs. 1 to 5.

**[0023]** Referring to Fig. 1, a gas turbine plant equipped with a gas turbine 1 is a power-generating gas turbine plant including an electric power generator 2 driven by the gas turbine 1.

**[0024]** The gas turbine 1 includes: a compressor 3 that compresses air; a gas turbine combustor 4 that creates combustion gases by burning a fuel by means of combustion air which is part of the compressed air obtained in the compressor 3; a turbine 5 that rotates upon being driven by the high-temperature high-pressure combustion gases created by the gas turbine combustor 4; transition pieces 6 that guide the combustion gases from the gas turbine combustor 4 to the turbine 5; a fuel supply system 7 that supplies the fuel, a gaseous fuel such as liquefied natural gas, to the gas turbine combustor 4; and a casing 8 serving to support the gas turbine combustor 4 as well as to form a cylinder 9 through which the compressed air is to flow after being discharged from the compressor 3.

**[0025]** The compressor 3 and the power generator 2 are coupled to the turbine 5 and rotationally driven by the turbine 5. The transition pieces 6 are accommodated in the cylinder 9.

**[0026]** Referring additionally to Fig. 2, the gas turbine combustor 4 includes: a plurality of (in the present em-

bodiment, ten) can-type combustors 10 equally spaced in a circumferential direction of the turbine 5 and compressor 3 with a rotational axis C1 thereof as a center; a spark plug 13 that ignites the mixture generated when the fuel and the combustion air are mixed; connecting pipes 14 that each interconnect two adjacent combustors 10; and cross-fire tubes 15 accommodated in the connecting pipes 14, the cross-fire tubes each propagating a flame created between the two adjacent combustors by the combustion of the mixture.

**[0027]** One portion of the combustors 10 constituting the gas turbine combustor 4 includes one or a plurality of (in the present embodiment, two) first combustors 11, as specific combustors, each having a spark plug 13, and the remaining combustors 10 are second combustors 12 without a spark plug 13. The first combustors 11 and the second combustors 12 have basically the same structure, except for a structure relevant to the spark plug 13 in the first combustor 11. In the following description, when no distinction is drawn between the first combustors 11 and the second combustors 12, both are referred to simply as the combustors 10.

**[0028]** Referring to Figs. 1 and 3, each combustor 10 that supplies to the gas turbine 1 the combustion gases that have been generated by the combustion of the fuel - combustion air mixture includes: a cylindrical inner liner 21 forming a combustion chamber 20; a cylindrical outer liner 22 disposed around the inner liner 21, the outer liner 22 forming an ring-shaped air passage 23 in a space between the inner and outer liners in order to allow the combustion air from the compressor 3 to flow through the air passage; an end cover 24 forming an upstream end wall; a burner 30 disposed on the combustor axis C2, the burner 30 supplying the combustion air and the fuel to the combustion chamber 30; and a flame holder 25 disposed at an exit of the burner 30, the flame holder serving as a flame stabilizer to assist in stabilizing the combustion flame.

**[0029]** The air that has been compressed by the compressor 3 flows therefrom into the cylinder 9, and part of the compressed air is supplied to the combustor 10 as the combustion air.

**[0030]** The combustor axis C2 (also, see Fig. 2) is a central axis of the inner liner 21 or the combustion chamber 20, the wording "axial direction" used herein is a direction parallel to the combustor axis C2, and unless otherwise indicated, radial and circumferential directions are those with the combustor axis C2 taken as a center.

**[0031]** In addition, the wording "upstream" and "downstream" relates to a flow of combustion air in the burner 30 or a flow of combustion gases in the combustion chamber 20, in the axial direction.

**[0032]** The burner 30 disposed so as to have its center positioned substantially on the combustor axis C2 includes a mixing chamber wall 32 forming a mixing chamber 31 which opens towards the combustion chamber 20, in the axial direction, and a fuel nozzle 38 that supplies the fuel. The mixing chamber wall 32 is disposed up-

stream relative to the combustion chamber 20, in the axial direction, the mixing chamber wall 32 being of a hollow conical shape spread radially towards the combustion chamber 20, in the axial direction with the combustor axis C2 taken as the axis. The mixing chamber wall 32, by having a conical mixing-chamber wall surface 33, forms internally to the wall 32 the mixing chamber 31 spread at an apex angle  $\alpha$  towards the downstream side. The mixing-chamber wall surface 33, therefore, is of a conical shape with the apex angle  $\alpha$ .

**[0033]** In the mixing chamber wall 32 are provided a plurality of air introduction holes, 35, 36, and 37, each forming an independent air introduction passage to introduce the combustion air into the mixing chamber 31. Each air introduction hole 35, 36, 37 that is a rectilinear round hole forms a different angle  $\beta_1$ ,  $\beta_2$ , or  $\beta_3$ , with respect to the mixing-chamber wall surface 33. The angles  $\beta_1$ ,  $\beta_2$ , and  $\beta_3$  each are an angle formed between each central axis of the air introduction holes 35, 36, 37 and a generating line (an intersection of the conical mixing-chamber wall surface 33 and a plane including the combustor axis C2) of the mixing-chamber wall surface 33.

**[0034]** The fuel supply system 7 includes a fuel supply device 41, a fuel distributor 42, and a fuel supply line 43. The fuel supply line 43 for guiding the fuel received from the fuel supply device 41, via the fuel distributor 42 that distributes the fuel to each combustor, is connected to the fuel nozzle 38. The fuel supply system 7 is constructed so that the fuel from the fuel supply line 43 is supplied to the fuel nozzle 38 including a fuel manifold 38a, and so that the fuel, after being jetted from the fuel nozzle 38, is fed into all of the air introduction holes 35, 36, 37. Each air introduction hole 35, 36, 37, therefore, introduces the combustion air, along with the fuel supplied from the fuel nozzle 38, into the mixing chamber 31 while generating the mixture of the air and the fuel.

**[0035]** In each of two combustors 11, the spark plug 13 is mounted to the outer liner 22 so that the plug has its igniter 13a positioned inside the combustion chamber 20.

**[0036]** Combustors 10 adjacent to each other in a circumferential direction are interconnected by the connecting pipe 14 that interconnects the respective outer liners 22. The combustion chambers 20 or inner liners 21 of the adjacent combustors 10 communicate with each other via a cross-fire tube 15. Opposite open ends of the cross-fire tube 15 configure an entrance/exit 15a open to the combustion chamber 20. This means that the entrance/exit 15a can serve as a flame entrance to an adjacent combustor 10 or as a flame exit from the adjacent combustor 10.

**[0037]** When the mixture ignited by the spark plug 13 in the combustor 11 burns and combustion gases are generated, an internal pressure of the combustion chamber 20 present internally to the inner liner 21 increases and a differential pressure occurs between the combustion chamber 20 of the combustor 11 and that of an ad-

jacent combustor 12 communicating via the cross-fire tube 15. This differential pressure moves the combustion gases 27 into the adjacent combustor 12, thereby igniting the mixture generated by the adjacent combustor 12. Similar ignition takes place in other adjacent combustors 12 sequentially, whereby all combustors 10 are ignited.

**[0038]** Referring to Figs. 3 and 4, the air introduction holes 35-37 formed in the mixing chamber wall 32 are arranged side by side in a plurality of rows, in the first embodiment, three rows (first row R1 to third row R3), in the axial direction. The rows R1-R3 are each configured by at least one, in the present embodiment, a plurality of air introduction holes 35-37 arranged in ring form with a circumferential spacing, circumferentially at their forming positions in the axial direction.

**[0039]** Part of the structure shown in Fig. 3 is omitted from Fig. 4 to avoid complexity of the drawing.

**[0040]** As shown partially in Figs. 4 and 5, the air introduction holes 35-37 belonging to each row R1-R3 are arranged in the mixing chamber wall 32 concentrically with the combustor axis C2 as their center. In addition, in order that a swirling flow is generated in the mixing chamber 31 by the combustion air jetted from the air introduction holes 35-37, the air introduction hole 37 is formed in circumferentially offset form and the air introduction holes 35, 36 are formed in axially and circumferentially offset form.

**[0041]** In terms of axial positions of the first row R1 and the second row R2, the first row R1 is an upstream row positioned at the upstream side, and the second row R2 is a downstream row positioned at the downstream side. In addition, the second row R2 is positioned more outward in the radial direction than the first row R1, and is disposed on a circumference of a larger diameter than a circumference having the first row R1 thereupon.

**[0042]** Referring to Fig. 4, of the air introduction holes 35-37 in each combustor 10, at least one, in the present embodiment, a plurality of specific air introduction holes 35a and 35b as specific air introduction passages, are formed in axially and circumferentially offset form. Thus, the combustion air jetted from the specific air introduction holes 35a, 35b into the mixing chamber 31 will, together with the fuel flowing with the combustion air through the specific air introduction holes 35a, 35b, be directed towards the igniter 13a of the spark plug 13 and the entrance/exit 15a of the cross-fire tube 15. The igniter 13a and the entrance/exit 15a are both disposed in the inner liner 21.

**[0043]** More specifically, in the combustor 11, a mixture "m1" of the fuel and the combustion air jetted from a first specific air introduction hole 35a will flow towards the igniter 13a, and mixtures "m2" of the fuel and the combustion air jetted from two second specific air introduction holes 35b will flow towards the entrance/exit ports 15a of two cross-fire tubes 15.

**[0044]** In the combustor 12 (see Fig. 1), a mixture of the fuel and the combustion air jetted from a second specific air introduction hole 35b will flow towards the en-

trance/exit ports 15a of two cross-fire tubes 15.

**[0045]** Referring to Fig. 5, since the air introduction hole 37 is formed at a position offset through an offset distance "s" from the combustor axis C2 which is also a central axis of the burner 30, the mixture that has flown in from the air introduction hole 37 generates a swirling flow inside the mixing chamber 31. As with the air introduction hole 37, the air introduction holes 35, 36 are also formed at positions offset through the offset distance "s" from the burner central axis, so each can generate a swirling flow inside the mixing chamber 31. These swirling flows, in turn, generate a stable circulating flow at a downstream region of the burner 30, thus providing combustion stability.

**[0046]** In the present embodiment, the air introduction holes 35 are formed such that the mixtures "m1" and "m2" jetted from the specific air introduction holes 35a and 35b, respectively, of the air introduction holes 35 belonging to the first row R1 will flow towards the spark plug 13 and the cross-fire tubes 15, respectively. The formation of the air introduction holes 35 is based on the directions in which the mixtures are to flow. The flow directions of the mixtures are determined by the apex angle  $\alpha$  of the mixing chamber wall 32 forming the mixing chamber 31, a forming angle  $\beta_2$  of each air introduction hole, and the offset distance "s" from the burner central axis or from the combustor axis C2.

**[0047]** In addition, in the present embodiment, a ratio of the offset distance "s" from the burner axis with respect to an inside diameter "d" (see Fig. 5) of the mixing chamber 31 forming the air introduction holes 35-37, that is, "s/d" can be set optionally. Thus, the fuel - combustion air mixtures "m1" and "m2" (see Fig. 4) jetted from the air introduction holes 35 will deflect towards the locations of the spark plug 13 and the cross-fire tubes 15. Furthermore, the circulating flow necessary to obtain combustion stability can be generated at a downstream region of the burner 30 by controlling the ratio "s/d" of the air introduction holes 35-37. Therefore, the gas turbine combustor 4 is supplied that is satisfactory in ignition characteristics and in flame propagation characteristics and achieves stable combustion.

**[0048]** Referring to Figs. 3, 4, during a start of the gas turbine 1 in the thus-constructed gas turbine combustor 4, when the gas turbine combustor 4 is ignited, the fuel from the fuel supply device 41 (also, see Fig. 1) is supplied to the fuel nozzle 38. The fuel is jetted from the fuel nozzle 38, towards the air introduction holes 35-37, and mixed with the combustion air in the air introduction holes 35-37 and in the mixing chamber 31, thereby generating mixtures. The mixtures that have thus been jetted from the air introduction holes 35-37 are ignited by the spark plug 13, to initiate premixed combustion.

**[0049]** The specific air introduction holes 35a, 35b of the air introduction holes 35 constituting the first row R1 of the first to third rows (R1 to R3), that is, the second row from the upstream side (in Fig. 3, the second row from left) are formed so that the mixtures "m1", "m2" are

jetted from the specific air introduction holes 35a, 35b, towards the igniter 13a of the spark plug 13 and the entrance/exit ports 15a of the cross-fire tubes 15.

**[0050]** In the combustor 11, therefore, a mixture higher in fuel concentration, that is, higher in fuel-air ratio, is present at and near the igniter 13a of the spark plug 13, so ignition becomes easier and ignition characteristics improve.

**[0051]** In addition, since the ignition of the combustor 11 raises the internal pressure of the combustion chamber 20, the combustion gases 27 become jetted towards unignited adjacent combustors 11 via corresponding cross-fire tubes 15. In the present embodiment, since the mixture "m2" is jetted from the specific air introduction holes 35a, 35b, towards the entrance/exit ports 15a of the cross-fire tubes 15, a mixture of a higher fuel concentration is present at and near the entrance/exit 15a in the combustor 11 (in this case, the entrance/exit 15a functions as the exit), so a combustion gas higher in temperature can be generated. Accordingly, the hot combustion gas (a flame) is jetted towards the combustion chamber 20 of an adjacent combustor 12 through a cross-fire tube 15.

**[0052]** Meanwhile, in the adjacent combustor 12 to which the flame from the combustor 11 propagates, the mixture of a higher fuel concentration from a specific air introduction hole 35b is being jetted towards the entrance/exit 15a of the cross-fire tube 15 (in this case, the entrance/exit 15a functions as the entrance). Accordingly the combustion gas flowing in from the combustor 11 through the cross-fire tube 15 facilitates flame propagation, makes combustion easier to start, and hence improves flame propagation characteristics.

**[0053]** In the first embodiment, the mixing chamber wall 32 is formed at the apex angle  $\alpha$  and forms the conical mixing chamber 31, and in the mixing chamber 31, the fuel jetted from the fuel nozzle 38 is mixed with the combustion air and fuel jetted from the air introduction holes 35-37. An effect of NOx emissions being further reduced by premixed combustion with an even more homogeneous mixture is anticipated as a result. The improvement of combustion stability by an increase in swirling strength is also anticipated since the swirling flows of mixtures in the mixing chamber 31 are restrained by the mixing chamber wall 32.

**[0054]** Additionally, the hollow conical shape of the mixing chamber wall 32 dimensionally increases a forming region of the air introduction holes 35-37 in the mixing chamber wall 32, compared with a case in which the mixing chamber wall 32 is a ring-shaped flat plate, for example. Such an increase creates an advantage of increased flexibility in determination of air introduction hole specifications such as the number of air introduction holes 35-37 and diameters thereof. The air introduction holes 35-37 also become easier to form.

**[0055]** If an inside diameter of the inner liner 21 is expressed as D, and an axial distance from an upstream end of the inner liner 21 to the igniter 13a or the entrance/

exit 15a is expressed as  $L$ , an axial design position of the spark plug 13 or cross-fire tube 15 in the inner liner 21 is usually determined for a ratio of  $L/D$  to lie in a range of  $0.3 < L/D < 0.7$ . For this reason, the specific air introduction holes 35a, 35b are desirably formed so that the mixtures jetted therefrom will be directed towards a position at the inner liner 21 where  $0.3 < L/D < 0.7$  is satisfied.

**[0056]** In addition, since ignition characteristics of the spark plug 13 can be improved by adjusting its radial insertion position in the inner liner 21, if the axial positions of the spark plug 13 and the cross-fire tube 15 significantly differ, the specific air introduction hole 35b is desirably formed so that the mixture "m2" is jetted towards the position at which the entrance/exit 15a of the cross-fire tube 15 is formed.

**[0057]** In a modification of the first embodiment, if the air introduction holes 35-37 are formed in a plurality of rows next to one another in an axial direction, an air introduction hole 35 belonging to a first row R1 which is one of the axial rows may be formed in offset form so that a mixture "m1" from that air introduction hole 35 is directed towards the igniter 13a of the spark plug 13, and an air introduction hole 36 belonging to a second row R2 different from the first row R1 may be formed in offset form so that a mixture "m2" from that air introduction hole 36 is directed towards the entrance/exit 15a of the cross-fire tube 15. Additionally if a third row R3 as the remaining row is present (the number of third rows can be more than one), an air introduction hole 37 may be formed in the third row R3 so that a mixture from this air introduction hole 37 contributes to stable combustion by generating a swirling flow inside the mixing chamber 31.

**[0058]** This, as in the first embodiment, will improve ignition characteristics and flame propagation characteristics, and hence, the startability of the gas turbine 1, thus enabling a burner 30 satisfactory in combustion stability to be supplied.

**[0059]** In addition, since the specific air introduction holes 35a and 35b that jet the mixtures "m1" and "m2" to be directed towards the igniter 13a and the entrance/exit 15a are divided into the first row R1 and the second row R2, respectively, the air introduction passages 35, 36 improve in flexibility of layout and shapes in the mixing chamber wall 32. This improvement enables suitable air introduction holes 35, 36 to be designed more easily for better ignition characteristics and enhanced flame propagation characteristics.

**[0060]** Furthermore, the gas turbine combustor 4 according to the first embodiment may use, in addition to a gaseous fuel as a first fuel, a liquid fuel (e.g., a class-A fuel oil or a light oil) as a second fuel for the gas turbine 1. In connection with this, another modification of the first embodiment is described below referring primarily to Fig. 6 with reference also being made to Figs. 3 and 4.

**[0061]** A combustor 10 includes a liquid-fuel nozzle 39 disposed as a second fuel nozzle at an upstream side of a mixing chamber 31 in a burner 30 having a fuel nozzle 38 used as a first fuel nozzle to supply a gaseous fuel as

the first fuel, the liquid-fuel nozzle 39 being provided to blast a liquid fuel as the second fuel. The liquid fuel from a fuel supply device 44 which a fuel supply system 7 includes is supplied to the liquid-fuel nozzle 39.

**[0062]** The liquid-fuel nozzle 39 is intended to atomize and spray the liquid fuel so that it mixes with hot combustion air 5 in the mixing chamber 3 and evaporates to burn easily. The liquid-fuel nozzle 39 plays a crucial role particularly in atomizing the fuel into smaller droplets. In general, liquid fuel is atomizable using either an air-atomize fuel nozzle that forms fine particles by utilizing its force of shearing air, or a pressure-atomize fuel nozzle that forms fine particles by utilizing its fueling pressure. The present invention works effectively with either scheme/method or with a liquid-fuel nozzle of an atomizing type other than those described above.

**[0063]** In the present embodiment, the liquid-fuel nozzle 39 is positioned on the combustor axis C2 of the burner 30 and at the upstream side of the mixing chamber 31, so that the droplets conically sprayed from the liquid-fuel nozzle 39 will mix in the mixing chamber 31 with the combustion air jetted from the air introduction holes 35-37 in the burner 30.

**[0064]** As in the first embodiment, the air introduction holes 35 are formed in axially and circumferentially offset form so that the combustion air therefrom are jetted towards the igniter 13a of the spark plug 13 and the entrance/exit 15a of the cross-fire tube 15, the igniter 13a and the entrance/exit 15a both being disposed in the inner liner 21. Therefore, a mixture from the air introduction holes 35 and a mixture from the liquid-fuel nozzle 39, the latter mixture containing the atomized liquid fuel, are supplied to the locations of the igniter 13a and the entrance/exit 15a. Of the two mixtures, the higher in fuel concentration improves ignition characteristics and flame propagation characteristics.

**[0065]** The liquid-fuel nozzle 39 in the burner 30 is set so that a spraying angle of the nozzle (i.e., a spread angle of the liquid fuel sprayed) will be smaller than the apex angle  $\alpha$  of the mixing chamber 31. If the spraying angle of the liquid-fuel nozzle 39 is greater than the apex angle  $\alpha$ , the droplets sprayed from the nozzle 39 are liable to collide against the mixing chamber wall 32 and become carbonized thereupon (this event is called coking). Coking could deteriorate various performance characteristics of the burner 30. Setting the liquid-fuel nozzle 39 to have a spraying angle smaller than the apex angle  $\alpha$  helps prevent coking from occurring.

## (Second Embodiment)

**[0066]** A second embodiment of the present invention is described below referring to Figs. 7 to 9. The second embodiment includes a plurality of main burners 50, 60 disposed at an outer peripheral side of the burner 30, with all other constituent elements of the embodiment being basically the same as in the first embodiment.

**[0067]** In the second embodiment and in third and

fourth embodiments described later herein, description substantially of the same elements as those of the first embodiment is omitted or simplified, with attention being focused primarily upon differences. In addition, the same members as used in the first embodiment, or corresponding members in each of the second to fourth embodiments are each assigned the same reference number or symbol as appropriate. The second to fourth embodiments yield substantially the same operation and effect as those of the first embodiment.

**[0068]** Furthermore, the mixing chamber walls, mixing chambers 31, and fuel nozzles in the second to fourth embodiments are central mixing chamber walls, central mixing chambers, and central fuel nozzles, respectively, and each mixing chamber wall, mixing chamber, and fuel nozzle are an outer peripheral mixing chamber wall, an outer peripheral mixing chamber, and an outer peripheral fuel nozzle, respectively. The burner and a pilot burner are central burners, and the main burners are outer peripheral burners.

**[0069]** Moreover, in figures relating to the second to fourth embodiments, only mixtures "m3" and "m4" (described later herein) that will be directed towards, for example, part of the main burners, are shown to avoid complexity of the drawing.

**[0070]** Referring to Figs. 7 and 8, the burners 30, 50, 60 in combustors 10 equipped in a gas turbine combustor 4 according to the second embodiment include the burner 30 as the pilot burner, and the main burners 50, 60.

**[0071]** At least one, in the present embodiment, six, main burners 50, 60 arranged at the outer peripheral side (i.e., radially outwardly) of the burner 30 are configured by the same number of (six) main burners, that is, three first main burners 50 and three second main burners 60.

**[0072]** Each main burner 50, 60 includes a mixing chamber wall 52, 62 that serves as an outer peripheral mixing chamber wall forming a mixing chamber 51, 61 formed as an outer peripheral mixing chamber which opens towards a downstream side in an axial direction. The main burner 50, 60 also includes a fuel nozzle 59, 69 serving as an outer peripheral fuel nozzle to supply a fuel. The mixing chamber wall 52, 62 disposed at a downstream side of a combustion chamber 20 in the axial direction of the burner includes an upstream wall 52a, 62a having a conically shaped mixing-chamber wall surface 53, 63 spread towards the combustion chamber 20, in the axial direction with a combustor axis C2 as a center. The mixing chamber wall 52, 62 also includes a cylindrical downstream wall 52b, 62b connecting to the upstream wall 52a, 62a, the downstream wall 52b, 62b also extending in a downstream direction. The mixing chamber wall 52, 62 forms a mixing chamber 51, 61 inside the wall. The mixing chamber wall 52, 62 further includes a cylindrical outer surface.

**[0073]** While the main burner 50, 60 is basically of the same construction as that of the burner 30, the mixing chamber 51, 61 has an axial length greater than that of the mixing chamber 31 in the burner 30, to accelerate

mixing of combustion air and fuel in the mixing chamber 51, 61.

**[0074]** A plurality of air introduction holes 55 to 57 and 65 to 67, for introducing the combustion air independently or along with the fuel into the mixing chamber 51, 61, are formed in the upstream wall 52a, 62a. The air introduction holes 55-57 and 65-67 are arranged in three axial rows, with a second row R2 being closer to an exit of the burner 30 and an exit of the main burner 50, 60, than a first row R1, in the axial direction.

**[0075]** The fuel nozzle 59, 69 includes a fuel manifold 59a, 69a formed at an upstream section of the main burner 50, 60, and fuel nozzle ports 59b, 69b that make the fuel manifold 59a, 69a and the air introduction holes 55-57 and 65-67 communicate with each other.

**[0076]** A fuel supplied to the fuel manifold 59a, 69a from a fuel supply device 45, 46 provided in a fuel supply system 7 is supplied by being jetted from the fuel nozzle ports 59b, 69b into the air introduction holes 55-57 and 65-67.

**[0077]** The fuel, after being supplied to the air introduction holes 55-57 and 65-67, mixes with combustion air in the air introduction holes 55-57 and 65-67 and in the mixing chamber 51, 61, and forms a premixed flame in the combustion chamber 20 located downstream with respect to the main burner 50, 60, followed by premixed combustion.

**[0078]** Whereas the main burner 50 thus has substantially the same construction as that of the main burner 60, fuel is supplied from a fuel supply device 45 different from the fuel supply device 46 of the main burner 60. More specifically, therefore, fuel is supplied from independent supply devices to the seven burners; from a fuel supply device 41 to the burner 30, from the fuel supply device 45 to the three main burners 50, and from the fuel supply device 46 to the other three main burners 60.

**[0079]** Next, a method of operating the gas turbine 1 (see Fig. 1) equipped with the gas turbine combustor 4 according to the second embodiment is described below with reference being made to Fig. 9.

**[0080]** While a load as an operational state indicator for the gas turbine 1 lies in a load state range from load "a" (non-loaded) to a level less than load "b", fuel is supplied to the burner 30 and the gas turbine 1 is operated using the burner 30 alone. Under a load state from load "b" to a level less than load "c", a flow rate of fuel in the burner 30 is reduced under load "b", whereas fuel is supplied to each main burner 50 and the gas turbine 1 is operated using both of the burner 30 and the main burner 50. Under a load state from load "c" to rated load "d", the flow rates of fuel in the burner 30 and in the main burner 50 are reduced under load "c", whereas fuel is supplied to each main burner 60 and the gas turbine 1 is operated using all of the burner 30 and the main burners 50, 60.

**[0081]** Under rated load "d" that is a rated operating load, low-NOx combustion can be conducted by ensuring combustion stability and then adjusting a ratio between the fuel flow rate in the burner 30 and those of the main

burners 50, 60.

**[0082]** In this way, low-NO<sub>x</sub> operation and combustion stability can be simultaneously achieved in the second embodiment by disposing the burner 30 centrally on the combustor axis C2 of the combustor 10, arranging the six main burners 50, 60 at the outer peripheral side of the burner 30, and during rated operation, adjusting the ratio between the fuel flow rate in the burner 30 for diffuse combustion and the fuel flow rates in the main burners 50, 60 for premixed combustion.

**[0083]** As shown in Figs. 7 and 8, in the combustor with the main burners 50, 60 arranged at the outer peripheral side of the burner 30 and with the spark plug 13 and the cross-fire tubes 15 further arranged at an outer peripheral side of each main burner, the ignition characteristics and flame propagation characteristics of the burner 30 are likely to be reduced by the combustion air jetted from the main burners 50, 60 during the ignition of the combustor.

**[0084]** Additionally, in the combustor 10 of the present second embodiment, as shown in Fig. 9, from the independent operational state of the burner 30 which is a pilot burner, fuel is supplied to the main burners 50 under load state "b" and premixed combustion is started using the main burners 50, and further under load "c", fuel is supplied to the main burners 60 and operation with all burners is started. Accordingly, when premixed combustion with the main burners 50, 60 is started and/or stopped, combustion may become unstable depending on the particular load state. A range in which the gas turbine 1 is put into stable operation, therefore, is desirably such that the turbine be operated at a load higher than load "c" under which fuel is supplied to all burners 30, 50, 60. On the other hand, if load "c", the operational load state under which fueling to all burners 30, 50, 60 is started, is set to be slightly lower, operational flexibility increases since the load range in which the gas turbine 1 can be stably operated is extended.

**[0085]** In the second embodiment, therefore, the air introduction holes 36 belonging to the second row R2 are formed so that the mixtures "m3" and "m4" from the air introduction holes 36 are jetted towards the exits of the main burners 50, 60, and thus, high-temperature combustion gases are supplied to the exits of the main burners 50, 60. This allows premixed combustion in the main burners 50, 60 to be started, even under the conditions that the mixtures supplied from the main burners 50, 60 are low in fuel concentration, that is, under a low-load operational state of the gas turbine 1. The above in turn allows a lower load to be set as load "c" that is the starting load of the combustion in all burners 30, 50, 60. Thus, the operating load range of the gas turbine 1 can be extended.

**[0086]** As shown in Fig. 8, as in the first embodiment, the mixture "m1" from a specific air introduction hole 35a in the combustor 11 is jetted towards the igniter 13a of the spark plug 13, and the mixture "m2" from a specific air introduction hole 35b is jetted towards the entrance/

exit 15a of the cross-fire tube 15. Therefore, the mixture "m1" or "m2", whichever is the higher in fuel concentration, can be supplied to the locations of the spark plug 13 and the cross-fire tube 15, and this improves the starting ignition characteristics and flame propagation characteristics of the gas turbine 1.

**[0087]** Additionally, since the spark plug 13 and the cross-fire tube 15 are arranged substantially midway in the main burner 50, 60, in the circumferential direction, the mixtures "m1", "m2" are made less susceptible to any impacts of the combustion air or air jetted from the main burner 50, 60. This advantage also helps improve ignition characteristics and flame propagation characteristics.

**[0088]** Furthermore, as indicated by the fact that six air introduction holes 35 and twelve air introduction holes 36 are formed in the burner 30 and six main burners 50, 60 are arranged at the outer peripheral side of the burner 30, if the number of air introduction holes 36 in the burner 30 is increased to an integral multiple of the number of main burners 50, 60 and appropriate circumferential positions of the air introduction holes 35 in the first row R1 are set, the mixture that the burner 30 generates can be used efficiently to improve the starting ignition characteristics and flame propagation characteristics of the gas turbine 1. In addition, if appropriate circumferential positions of the air introduction holes 36 in the second row R2 are set, heat energy of the combustion gases from the burner 30 can be efficiently transferred to the main burners 50, 60 that conduct premixed combustion. Operation of the gas turbine 1 with all burners can therefore be started, even under low load, and this advantage also aids in stable turbine operation and in extending the load range.

**[0089]** Furthermore, since the specific air introduction holes 35a and 35b that jet the mixtures "m1" and "m2" to be directed towards the igniter 13a and the entrance/exit 15a, and the specific air introduction holes 36 that jet the mixtures "m3" and "m4" to be directed towards the exits of the main burners 50, 60 are divided into the first row R1 and the second row R2, respectively, the air introduction holes 35, 36 improve in flexibility of layout and shapes in the mixing chamber wall 32. This improvement enables suitable air introduction holes 35, 36 to be designed more easily for better ignition characteristics and enhanced flame propagation characteristics.

**[0090]** Furthermore, since the number of air introduction holes 36 is an integral multiple of that of main burners 50, 60, the air introduction holes 36 for jetting the mixtures to be directed towards the main burners 50, 60 can be allocated in equal numbers to each thereof. Additionally, since the layout and shapes of the air introduction holes 36 to be allocated can be made equal easily, burner structural simplification and improvement of combustion stability are realized. Moreover, since the second row R2 positioned more downstream relative to the first row R1 has more air introduction holes than the first row R1, the mixtures that flow in the downstream direction can be directed more reliably towards the main burners 50, 60.

(Third Embodiment)

**[0091]** A third embodiment of the present invention is described below referring to Figs. 10 to 12.

**[0092]** Referring to Figs. 10, 11, burners 70, 80 in combustors 10 equipped in a gas turbine combustor 4 according to the third embodiment include a pilot burner 70 equivalent to the burner 30 in the second embodiment, and a main burner 80.

**[0093]** The pilot burner 70 includes a mixing chamber wall 72 that forms a conical mixing chamber 71 opening towards a downstream side in an axial direction. The pilot burner 70 also includes a fuel nozzle 79 serving as a central nozzle to supply a fuel. The mixing chamber wall 72 has a mixing chamber wall surface 73 formed into a conical shape, thereby forming the conical mixing chamber 71.

**[0094]** In the mixing chamber wall surface 72, a plurality of air introduction holes 75, 76 that form a plurality of air introduction passages for introducing combustion air independently or along with fuel into the mixing chamber 71, are arranged in two axial rows, namely, a first row R1 and a second row R2. The fuel nozzle 79 that supplies fuel by jetting it into each air introduction hole 75, 76, is disposed at an upstream side of the mixing chamber wall 72.

**[0095]** The first row R1 is configured by at least one, in the present embodiment, six air introduction holes 75 formed spacedly in a circumferential direction, and the second row R2 is configured by at least one, in the present embodiment, twelve air introduction holes 76 formed spacedly in the circumferential direction.

**[0096]** In addition, each air introduction hole 75, 76 includes a linear portion 75c, 76c and offset portions 75d, 76d connecting to, and at a downstream side of, the linear portion 75c, 76c. The offset portions 75d, 76d, exits to the air introduction hole 75, 76, is formed in axially and circumferentially offset form so that the combustion air or mixture jetted from the air introduction hole 75, 76 will create a swirling flow inside the mixing chamber 71. The linear portion 75c, 76c that includes an entrance to the air introduction hole 75, 76, extends substantially in parallel from the offset portions 75d, 76d, in an axial direction towards an upstream side, and is formed to have at least twice an axial length of the offset portions 75d, 76d.

**[0097]** In addition, fuel from a fuel supply device 41 is supplied to the fuel nozzle 79 having a fuel manifold 79a, and the fuel from the fuel nozzle 79 is jetted to be fed into each air introduction hole 75.

**[0098]** The main burner 80, disposed at an outer peripheral side relative to the pilot burner 70, includes a cylindrical mixing chamber wall 82 that forms a mixing chamber 81 opening towards a downstream side in an axial direction. The main burner 80 also includes a fuel nozzle 89 that supplies fuel. The mixing chamber wall 82 as an outer peripheral mixing chamber wall, includes an outer peripheral chamber wall 82a and an inner peripheral chamber wall 82b.

**[0099]** The mixing chamber 81 with an axial length greater than that of the mixing chamber 71 extends axially and is formed circularly, with the fuel nozzle 89 being disposed at an upstream side of the mixing chamber 81 and an annularly shaped bluff body 84 being disposed at an exit of the mixing chamber 81.

**[0100]** Fuel from a fuel supply device 47 equipped in a fuel supply system 7 is supplied to a fuel manifold 88. The fuel jetted from the fuel nozzle 89 mixes with combustion air in the mixing chamber 81, whereby a mixture of the fuel and the combustion air is generated. The mixture flows downstream towards the combustion chamber 20, where premixed combustion takes place stably by an action of a circulating flow formed at a downstream side of the bluff body 84. A pilot burner cone 78 is disposed between the pilot burner 70 and the main burner 80, in a radial direction.

**[0101]** Referring to Fig. 11, the mixing chamber 81 of the main burner 80 is divided into four mixing chambers, 81a to 81d, by four separating walls 87 as separators disposed inside the mixing chamber 71. In order to suit this mixing chamber arrangement, the fuel supply device 47 is also divided into four independent fuel supply devices, 47a-47d, as many as there actually the mixing chambers 81a-81d. In addition, the fuel nozzle 89 is likewise divided into four independent fuel nozzles, 89a to 89d, in order that fuel is supplied from each of the fuel supply devices, 47a-47d independently.

**[0102]** For these reasons, the main burner 80 is configured by four independent main burners, 80a to 80d. The main burners 80a-80d each include the corresponding fuel nozzle 89a-89d plus a mixing chamber wall configured by a segment and separating wall 87 of one of the mixing chamber walls 82 forming the mixing chambers 81a-81d. The fuels supplied to the four fuel nozzles, 89a-89d, can be separately controlled in flow rate.

**[0103]** In this way, since the mixing chamber 81 is axially longer than the mixing chamber 71 of the pilot burner 70, the combustor 10 in the third embodiment includes the main burner 80 that is the very-low-NO<sub>x</sub> type of burner that accelerates fuel - combustion air mixing. In addition, since axial length of the air introduction hole 75, 76 includes the linear portion 75c, 76c, the combustor 10 in the third embodiment further includes the pilot burner 70 longer than the air introduction holes 35, 36 of the first or second embodiment that only include nearly a portion equivalent to the offset portions 75d, 76d.

**[0104]** In the pilot burner 70, whose mixing chamber wall surface 73 is of a conical shape and whose upstream end wall surface 74 is of a planar shape, the air introduction hole 75, 76 can have its linear portion 75c, 76c into a shape extending in parallel in an axial direction, fuel - combustion air mixing in the air introduction hole 75, 76 is fully accelerated, and NO<sub>x</sub> emissions from a flame formed by the pilot burner 70 are therefore reduced.

**[0105]** In the third embodiment, the air introduction hole 75 at an inner peripheral side (or an upstream side) of the pilot burner 70 is formed by six circumferential

holes, and the air introduction hole 76 at an outer peripheral side (or a downstream side) is formed by twelve circumferential holes. Accordingly, the air introduction hole 76 located radially outward relative to the air introduction hole 75 is longer than the air introduction hole 75, so a fuel - combustion air mixing distance in the air introduction hole 76 is longer and mixing is correspondingly accelerated for further reduced NOx.

**[0106]** Additionally, the offset portions 75d, 76d of the air introduction hole 75, 76 are axially and circumferentially offset, and advantageous effects obtained in connection with this offsetting are substantially the same as in the first and second embodiments.

**[0107]** More specifically, according to the third embodiment, fuel sprayed from a fuel nozzle 79 is mixed with combustion air in the air introduction hole 75, 76 and jetted into the mixing chamber 71. The axially and circumferentially offset shape of the air introduction hole 75, 76 then creates a swirling flow in the mixing chamber 71. An angle at which the mixture is jetted from the air introduction hole 75, 76 can be controlled by adjusting the offset angle thereof.

**[0108]** After the creation of the swirling flow, as shown in Fig. 11, a mixture "m1" jetted from a specific air introduction hole 75a of the air introduction hole 75 is directed towards an igniter 13a of a spark plug 13. A mixture "m2" jetted from a specific air introduction hole 75b of the air introduction hole 75 is directed towards an entrance/exit 15a of a cross-fire tube 15. A mixture of a higher fuel concentration is therefore formed at and near the igniter 13a of the spark plug 13 and the entrance/exit 15a of the cross-fire tube 15, and the formation of the mixtures improves starting ignition characteristics and flame propagation characteristics of the gas turbine 1 (see Fig. 1).

**[0109]** In addition, a mixture "m3" jetted from the air introduction hole 76 flows towards a downstream region of bluff bodies 84 (see Fig. 10) of each main burner 80a-80d constituting the main burner 80. During a start of premixed combustion with the main burner 80, therefore, hot combustion gases are supplied to the downstream region of each bluff body 84. This enables premixed combustion to be started under the conditions of a low fuel concentration, and hence improves the combustion characteristics (hereinafter, referred to as switching characteristics) developed during the start of premixed combustion with the main burner 80.

**[0110]** Next, a method of operating the gas turbine combustor 4 according to the third embodiment is described below referring primarily to Fig. 12, with reference also being made to Figs. 10 and 11.

**[0111]** After an operational start of the gas turbine 1 (see Fig. 1), the gas turbine 1 reaches load level "e" shown in Fig. 12, a graph that represents changes in no-load rated turbine speed. The load of the gas turbine 1 increases upon fuel being supplied to the pilot burner 70 only.

**[0112]** Upon the gas turbine 1 arriving at load level "f", the flow rate of the fuel in the pilot burner 70 is reduced,

then fuel is supplied to the main burner 80a, and in the bluff body 84, a premixed flame is formed at a downstream side of a region corresponding to the mixing chamber 81a. At this time, the fuel flow rates in the pilot burner 70 and the main burner 80a are substantially equal and the mixture jetted from the mixing chamber 71 can obtain high-calorie heat energy of the hot combustion gases from the pilot burner 70, at the downstream side of the bluff body 84. The result is that the premixed flame formed at the downstream side of the mixing chamber 81a exhibits appropriate switching characteristics.

**[0113]** After the load of the gas turbine 1 has increased to load level "g", fuel is also supplied to the main burner 80b. At load level "h", fuel is supplied to the main burner 80c as well and the main burners 80b and 80c then start premixed combustion. However, a consequential decrease in the rate of the fuel flow in the pilot burner 70 to that required for remixed combustion causes a switching tolerance to tend to decrease (or narrow). The switching tolerance here is an indicator of breadth of a fuel-air ratio tolerance needed to ensure combustion stability during switching. As the switching tolerance increases, switching with the required combustion stability ensured in a wider fuel-air ratio range is achievable and switching characteristics improve.

**[0114]** Load level "i" indicates a load state under which the pilot burner 70 and the entire main burner 80 (therefore, the main burners 80a-80d) start the combustion. In this operational state, since the fuel flow rate in the pilot burner 70 decreases relative to that of the main burner 80, the energy level of the heat supplied from the pilot burner 70 decreases and the switching tolerance in switching characteristics decreases.

**[0115]** In the present third embodiment, however, since a mixture "m5" from the air introduction hole 75 in the first row R1 is jetted towards the downstream side of each mixing chamber 81a-81d and since the mixture "m3" from the air introduction hole 76 in the second row R2 is jetted towards the downstream side of each mixing chamber 81a-81d, hot combustion gases can be concentrated at the downstream side of the bluff body 84, at positions corresponding to each mixing chamber 81a-81d. The switching characteristics at load level "i" can be improved as a result.

**[0116]** In addition, in the present third embodiment with the main burner 80 having its mixing chamber 81 divided into the four mixing chambers (81a-81d), the air introduction hole 76 in the pilot burner 70 is configured by 12 holes, this number being an integral multiple of the number of mixing chambers 81a-81d. Consequently, the heat energy of the combustion gases from the pilot burner 70 can be equally supplied to the downstream side of the mixing chambers 81a-81d.

**[0117]** Furthermore, since six air introduction holes 75 are formed in the first row R1 at the inner peripheral side of the pilot burner 70, a mixture of a higher fuel concentration is formed at and near the igniter 13a of the spark plug 13 and the entrance/exit 15a of the cross-fire tube

15. At the same time, at the load level "i" where the switching tolerance is minimized, the mixtures "m5", "m3" from the air introduction holes 75, 76 are jetted towards the exit and vicinity of the mixing chamber 81d. Thus, the supply rate of the mixture from each air introduction hole 75 at the inner peripheral side becomes twice that obtained at the mixing chamber 81b, 81c. This allows effective use of the heat energy of the combustion gases, and hence the improvement of the switching characteristics.

**[0118]** As shown in Fig. 12, at load level "i", increasing the fuel flow rate in the pilot burner 70 controls the switching characteristics to improve, but if the heat energy from the pilot burner 70 is too great, this elevates temperature of the premixed flame and increases thermal NOx emissions. In order to avoid these events, after switching at load level "i" to all-burner combustion, the fuel flow rate in the pilot burner 70 is reduced and that of the main burner 80 is increased, whereby NOx emissions are reduced.

**[0119]** In this fashion, the third embodiment allows the axial length of the air introduction hole 75 to be extended. In addition, if the pilot burner 70 designed so that the jetting directions of the combustion air and mixture jetted from the air introduction hole 75 are adjustable at the exits of the air introduction holes 75, 76 is combined with the main burner 80 having the axially extended mixing chamber 81, then the gas turbine combustor 4 can be supplied that is satisfactory in ignition characteristics and in flame propagation characteristics and is able to burn at a very low NOx level under the rated load as well as to reduce the switching load of the gas turbine 1.

(Fourth embodiment)

**[0120]** A fourth embodiment of the present invention is hereinafter described with reference to Figs. 13 and 14.

**[0121]** Burners 90, 100 in combustors 10 equipped in a gas turbine combustor 4 according to the fourth embodiment include a pilot burner 90 equivalent to the burner 30 in the second embodiment, and a main burner 100.

**[0122]** The pilot burner 90 includes a mixing chamber wall 92 forming a mixing chamber 91 which opens towards a combustion chamber 20 in the axial direction, and fuel nozzles 98, 99 that supply fuel. A mixing chamber wall surface 93 of the mixing chamber wall 92 is formed in a conical surface shape to provide the mixing chamber 91 formed in a conical shape. The mixing chamber wall 92 is formed with a plurality of air introduction holes 95, 96 arranged in two rows, i.e., in first and second rows R1, R2. The air introduction holes 95, 96 are adapted to eject a mixture of combustion air and fuel. The fuel nozzle 98 is disposed at the upstream side of the air introduction holes 95, 96 in the axial direction at a position facing the air introduction holes 95, 96. The fuel nozzle 98 jets and supplies fuel into the air introduction holes 95, 96. The air introduction holes 95, 96 are each formed in axially and circumferentially offset form so that the

combustion air or the mixture jetted from the air introduction holes 95, 96 may produce a swirl flow in the mixing chamber 91.

**[0123]** The fuel nozzles 98, 99 are composed of a gas fuel nozzle 98 as a first fuel nozzle adapted to supply gas fuel as a first fuel and a liquid fuel nozzle 99 as a second fuel nozzle adapted to supply liquid fuel as a second fuel.

**[0124]** Fuel which is gas fuel from a fuel supply device 41 included in a fuel supply system 7 is jetted and supplied from the fuel nozzle 98 having a fuel manifold portion 98a into the air introduction holes 95, 96.

**[0125]** Fuel which is liquid fuel from a fuel supply device 46 included in the fuel supply system 7 is jetted into the mixing chamber 91 from the liquid fuel nozzle 99 installed on the upstream side of the combustion chamber 20 on a combustor axis C2. As described above, fuels are individually supplied to the fuel nozzles 98, 99. Therefore, the pilot burner 90 allows for single combustion of gas fuel, single combustion of liquid fuel, and mixed combustion of gas fuel and liquid fuel.

**[0126]** The six main burners 100 are arranged at circumferential intervals on the outer circumferential side of the pilot burner 90. The main burners 100 are each such that a plurality of air introduction holes 105-107 arranged in a concentric pattern are axially arranged in three rows with the burner central axis of the main burner 100 as a center. Fuel nozzles 109 are disposed for the air introduction holes 105-107. The fuel nozzles 109 substantially axially jet and supply fuel to the air introduction holes 105-107 in parallel

**[0127]** Fuel as gas fuel from the fuel supply devices 48 included in the fuel supply system 7 (see Fig. 1) is supplied to fuel nozzles 109 having respective fuel manifold portions 109a. In addition, the fuel from the fuel nozzles 109 are jetted and supplied into the air introduction holes 105-107.

**[0128]** Combustion air, along with the fuel jetted from the fuel nozzles 109, is jetted into the combustion chamber 20 through the air introduction holes 105-107. When the mixture of combustion gas and fuel is jetted from the respective narrow spaces of the air introduction holes 105-107 to the wide space of the combustion chamber 20, the mixture flow produces large turbulent. Thus, mixing of combustion gas with fuel is accelerated in the combustion chamber 20.

**[0129]** In the fourth embodiment, a large number of the air introduction holes 105, 106, 107 are formed in the respective main burners 100. In addition, the fuel nozzles 109 are arranged in association with the corresponding air introduction holes 105-107. Fuel is previously dispersed in accordance with the number of the air introduction holes 105-107. Thus, a boundary area between combustion air and fuel is increased. This accelerates the mixing of combustion air with fuel even if the axial distance in mixing of air and fuel is short, which allows for ultralow NOx combustion.

**[0130]** In general, if the axial length of the mixing chamber 91 is large, there is a risk that flame goes back in the

mixing chamber 91. However, the main burner 100 in the fourth embodiment mixes fuel with combustion air in the combustion chamber 20; therefore, it is possible to avoid the risk that flame goes back in the main burner 100.

**[0131]** In the fourth embodiment, since the mixing of fuel with combustion air is accelerated as described above, the fuel concentration of the mixture jetted to the downstream of the main burner 100 is uniform, which is effective for low NO<sub>x</sub> combustion.

**[0132]** However, the mixture jetted from the main burner 100 is uniform in fuel concentration, i.e., does not have a portion with increased concentration. Therefore, it is conceivable that the mixture becomes hard to be ignited and ignition characteristics decrease when premixed combustion is started upon receipt of thermal energy from the flame produced by the pilot burner 90. Because of this, as long as the gas turbine 1 (see Fig. 1) does not have a high load, combustion in all burners 90, 100 becomes impossible. Consequently, there is a possibility that load range in which to operate the gas turbine 1 becomes narrow.

**[0133]** To eliminate such a possibility, as shown in Fig. 14, the first row R1 is configured by at least one, in the fourth embodiment, six air introduction holes 95 formed spacedly in a circumferential direction, and the second row R2 is configured by at least one, in the fourth embodiment, twelve air introduction holes 96 formed spacedly in the circumferential direction, similar to the second embodiment. Thus, the number of the air introduction holes 96 is the integral multiple of the number of the main burners 100.

**[0134]** A mixture "m1" from a specific air introduction hole 95a of the air introduction holes 95 is jetted towards an igniter 13a of a spark plug 13. A mixture "m2" from specific air introduction holes 95b of the air introduction holes 95 is emitted towards the entrance/exit 15a of cross-fire tubes 15. A mixture "m3" from the air introduction holes 96 is emitted towards corresponding respective exits of the main burners 100. In this way, the thermal energy of the flame (i.e., also combustion gas) produced by the pilot burner 90 can efficiently be used for ignition, flame propagation and further the ignition of premixed flame. Therefore, the ignition characteristics, flame propagation characteristics and switching characteristics are improved. As a result, the gas turbine combustor 4 can be provided that is satisfactory in ignition characteristics and in flame propagation characteristic. Also the gas turbine combustor 4 can lower the switching load of the gas turbine 1, and allows for ultralow NO<sub>x</sub> combustion under the rated load condition.

**[0135]** Since the main burner 100 used in the fourth embodiment does not permit flame to go back therein, it can be applied as a low NO<sub>x</sub> combustor for hydrogen-containing fuel having fast fuel speed. Hydrogen-containing fuel may be used as fuel for a gas turbine. In such a case, since hydrogen has a wide combustible range, in some cases liquid fuel (e.g. light oil) is used for ignition and flame propagation and then hydrogen-containing fu-

el is used for combustion, thereby avoiding explosion due to ignition failure during ignition.

**[0136]** On the other hand, in the fourth embodiment, the pilot burner 90 is provided with both the fuel nozzle 98 for gas fuel and the fuel nozzle 99 for liquid fuel. Therefore, the pilot burner 90 allows for single combustion of gas fuel, single combustion of liquid fuel, and mixed combustion of gas fuel and liquid fuel. In addition, it also is satisfactory in ignition characteristics and flame propagation characteristics during the use of liquid fuel. Thus, the gas turbine combustor 4 according to the fourth embodiment is effective for a gas turbine combustor using hydrogen-containing fuel.

**[0137]** A description is given of configurations of modified examples of the embodiments described above.

**[0138]** The mixing chamber in the burner 11 according to the first embodiment and the mixing chambers in the pilot burners according to the second-fourth embodiments are formed in a conical shape spread towards the downstream of the combustor. However, the downstream side shape of the pilot burner may be formed in a flat plate shape or in a convex shape whose central portion projects towards the downstream side. In other words, the downstream side shape of the pilot burner is formed so that the combustion air from the air introduction hole and the mixture of the fuel and combustion air are each jetted towards a corresponding one of the igniter of the spark plug, the entrance/exit of the cross-fire tube, and the outlet port of the main burner for premixed combustion. In short, it is needed only to adjust the ejecting direction of the air introduction hole of the pilot burner so that the thermal energy of the flame of the pilot burner may be used effectively.

**[0139]** The air introduction passage may be formed of a tubular member.

**[0140]** Fuel may not be supplied to an air introduction hole other than the specific air introduction holes. In such a case, such an air introduction hole is adapted to eject only combustion air into the mixing chamber.

**[0141]** The combustion air- and fuel-containing mixture jetted from the specific air introduction hole may be deflected, by deflection means (e.g. a deflection plate or deflection air flow), towards the igniter 13a or the entrance/exit 15a and its vicinity before it will reach the igniter 13a or the entrance/exit 15a and its vicinity.

**[0142]** The first row R1 may be located at a downstream side and the second row R2 may be located at an upstream side.

**[0143]** The plurality of air introduction passages may be formed in a plurality of rows in the radial direction. In such a case, the same operation and effect as in the case where the rows are formed in the axial direction can be provided. If the plurality of air introduction passages are formed in a plurality of, i.e., three or more, rows in the axial direction or in the radial direction, first and second rows are applied to any two rows of the plurality of rows.

**[0144]** The present invention can be applied, in addition to a gas turbine combustor for a power generation

gas turbine, to a gas turbine constituting part of a cogeneration system capable of supply of both heat and electric power, a gas turbine for driving a machine such as a pump, a compressor or the like, or other various gas turbines.

**[0145]** Features, components and specific details of the structures of the above-described embodiments may be exchanged or combined to form further embodiments optimized for the respective application. As far as those modifications are apparent for an expert skilled in the art they shall be disclosed implicitly by the above description without specifying explicitly every possible combination.

## Claims

### 1. A gas turbine combustor, comprising:

a plurality of combustors (4) each for supplying to a gas turbine (1) a combustion gas resulting from combustion of a mixture of a fuel and combustion air introduced from a compressor (3), and each including a burner (30);  
a spark plug (13) for igniting the mixture; and  
a cross-fire tube (15) for propagating between the combustors (4) a flame formed by the combustion of the mixture; wherein:  
the burner (30) includes  
a mixing chamber wall (32) for forming a mixing chamber (31) which opens towards a downstream side in an axial direction of the combustor (4),  
a fuel nozzle (38) for supplying a fuel, and  
a plurality of air introduction passages installed in the mixing chamber wall (32) each for introducing combustion air, along with the fuel from the fuel nozzle (38), into the mixing chamber (31); and  
flows of the combustion air and fuel jetted from the air introduction passages into the mixing chamber (31) are directed towards at least one of the spark plug (13) and the cross-fire tube (15).

### 2. The gas turbine combustor according to claim 1, wherein:

in the mixing chamber wall (32), the air introduction passages are arranged so as to form a first row and a second row adjacently to each other, in the axial direction or in the radial direction;  
the air introduction passage for jetting the combustion air which flows towards the spark plug (13) belongs to the first row; and  
the air introduction passage for jetting the combustion air which flows towards the cross-fire tube (15) belongs to the second row.

### 3. The gas turbine combustor according to claim 1, further comprising:

a central burner as the burner; and  
a plurality of outer peripheral burners each disposed at an outer peripheral side relative to the central burner; wherein:  
the central burner includes a central mixing chamber wall that is the mixing chamber wall forming a central mixing chamber which is the mixing chamber, and a central fuel nozzle as the fuel nozzle;  
the outer peripheral burners each include an outer peripheral mixing chamber wall forming an outer peripheral mixing chamber which opens towards a downstream side in the axial direction, and an outer peripheral fuel nozzle for supplying a fuel to the outer peripheral mixing chamber;  
in the central mixing chamber wall, the combustion air introduction passages are provided so as to form a first row and a second row adjacently to each other, in the axial direction;  
the air introduction passage for jetting the combustion air which flows towards at least one of the spark plug and the cross-fire tube belongs to the first row; and  
the combustion air jetted from the air introduction passage belonging to the second row flows towards an exit of the outer peripheral mixing chamber.

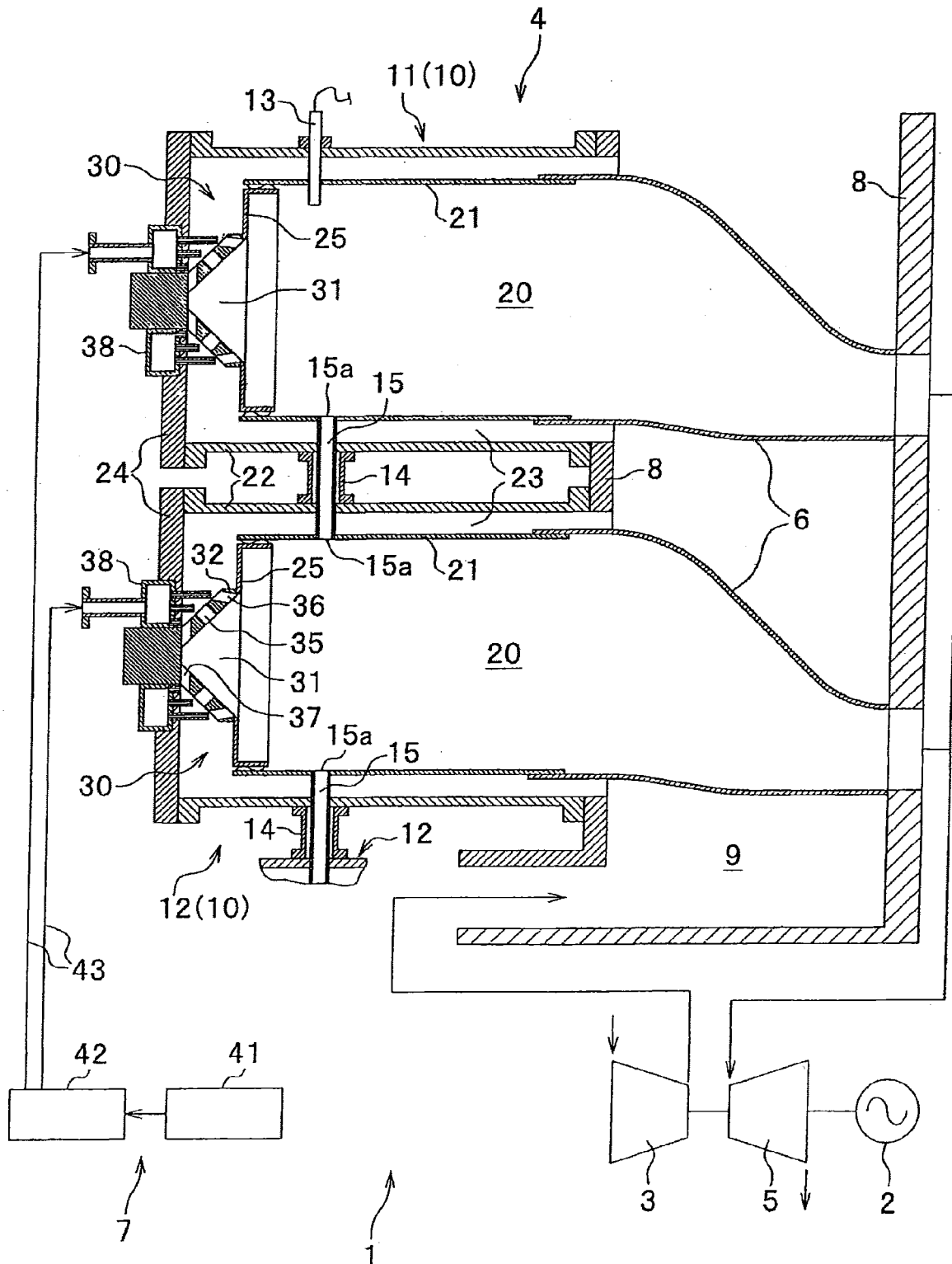
### 4. The gas turbine combustor according to claim 3, wherein:

the number of the air introduction passages configuring the second row in the central burner is an integral multiple of the number of the outer peripheral burners.

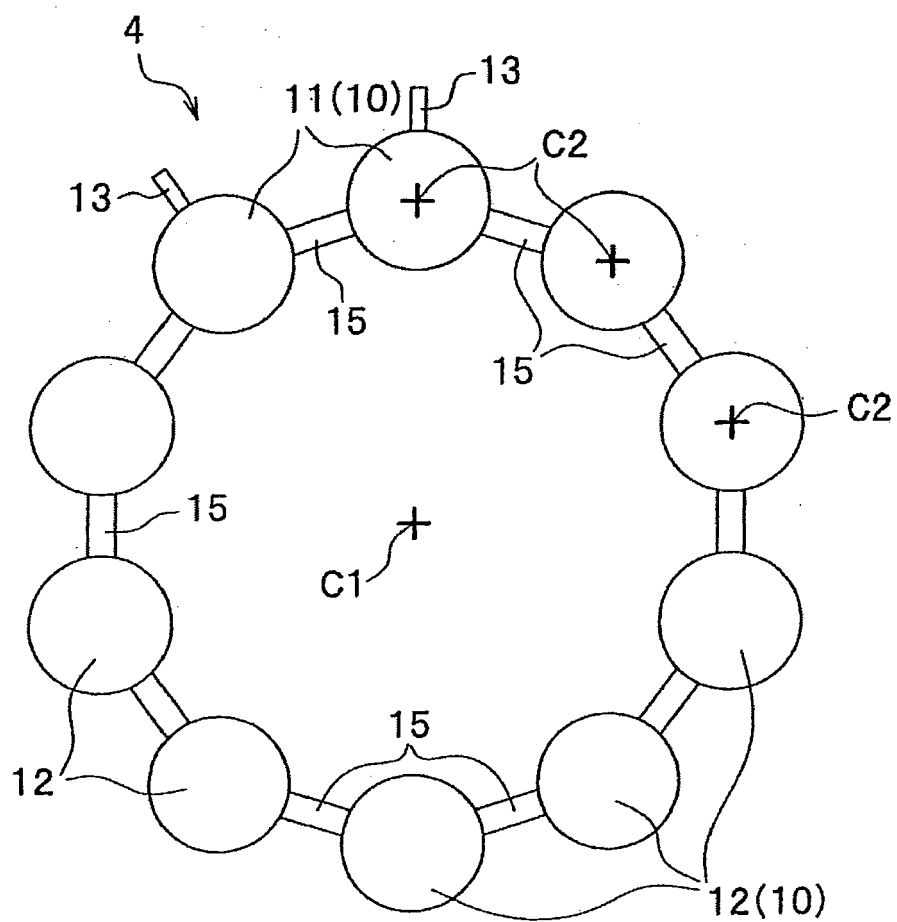
### 5. The gas turbine combustor according to either claim 3 or 4, wherein:

the number of the air introduction passages configuring an upstream row of the first row and the second row in the axial direction is six, the number of the air introduction passages configuring a downstream row of the first row and the second row is twelve, and the number of the outer peripheral burners is four or six.

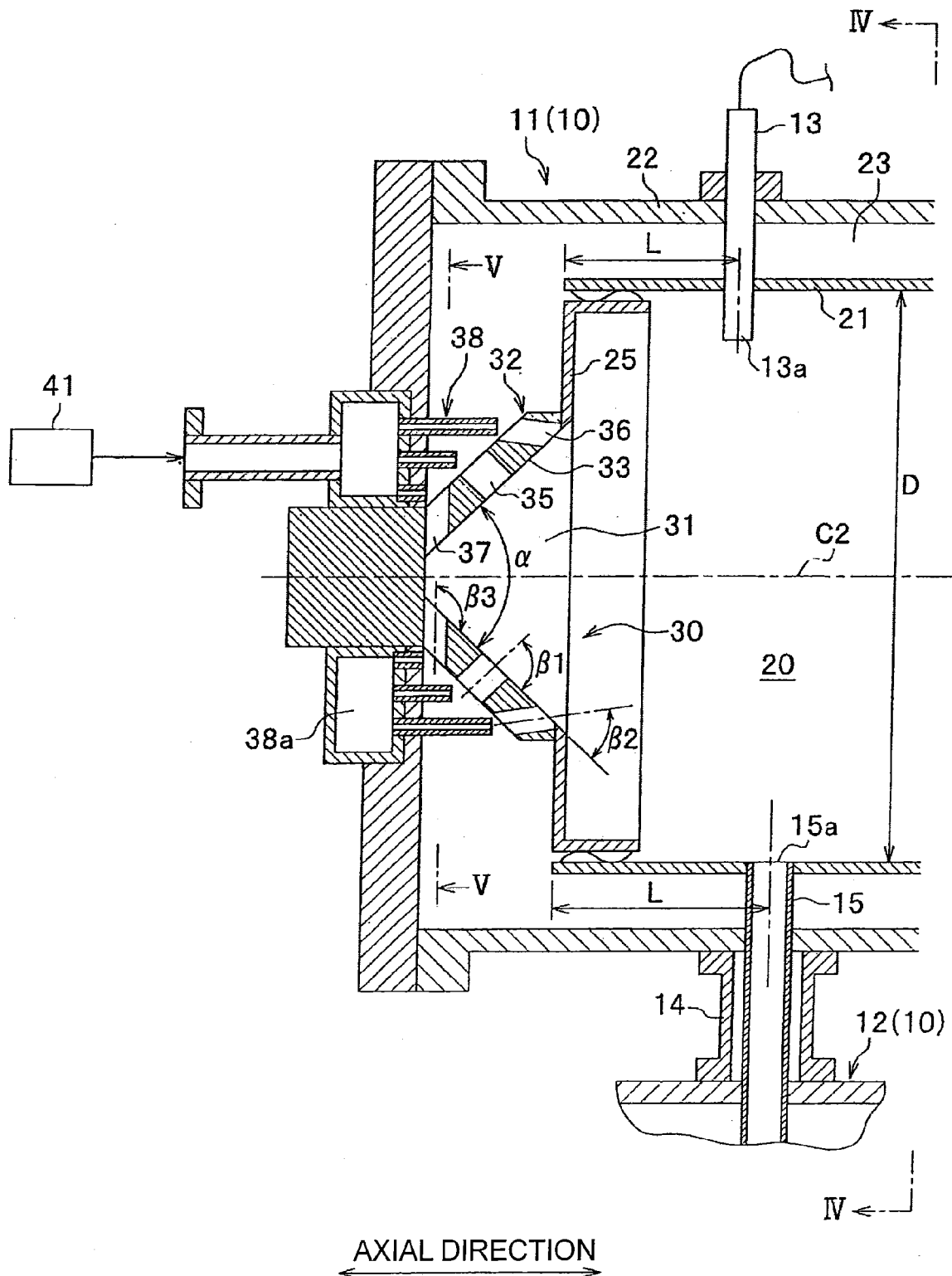
**FIG. 1**



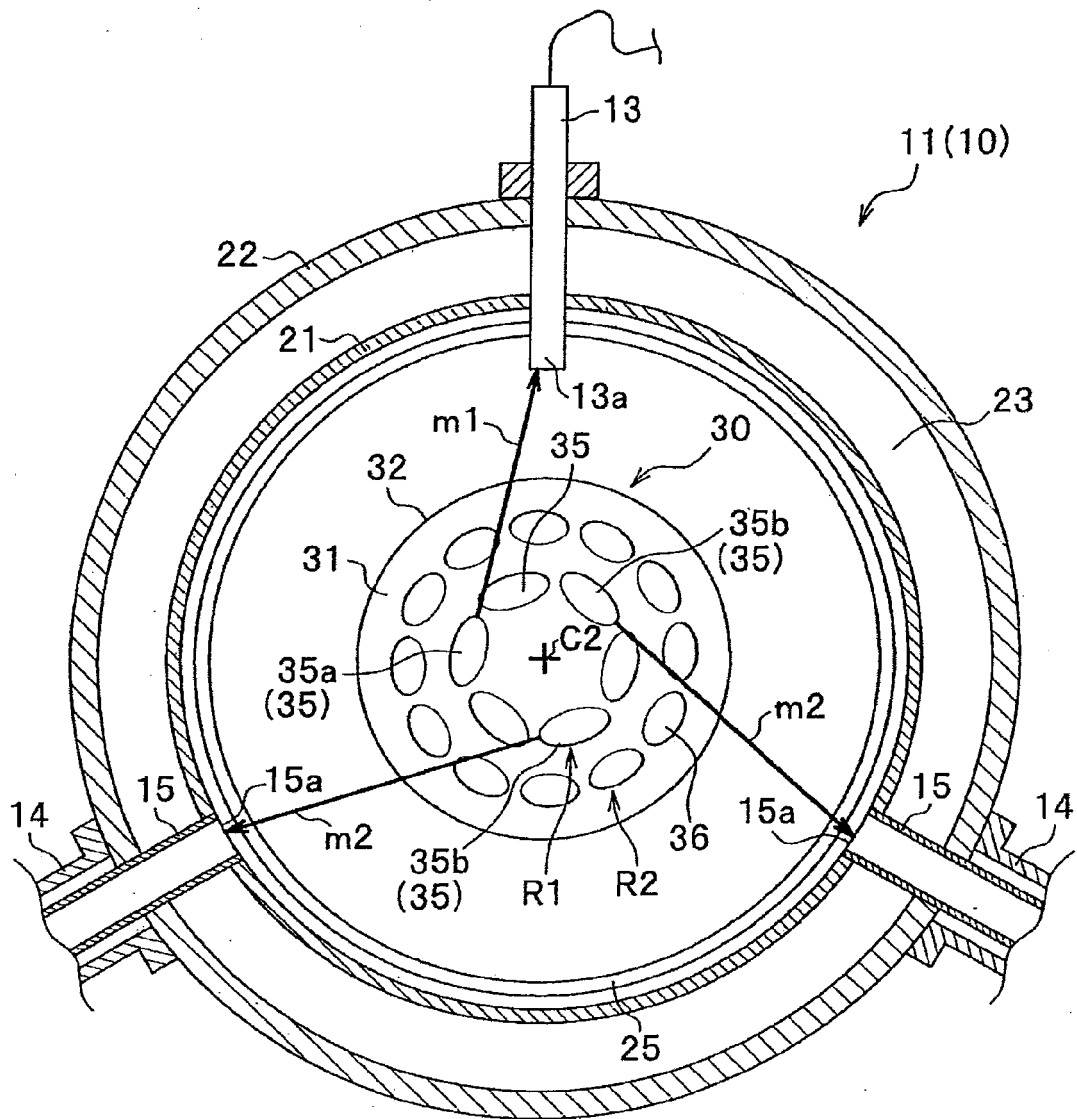
**FIG. 2**



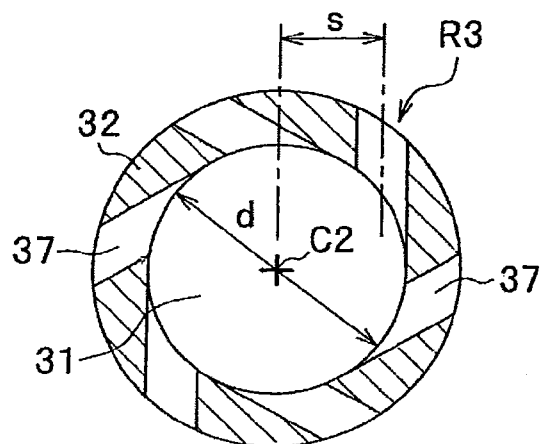
**FIG. 3**



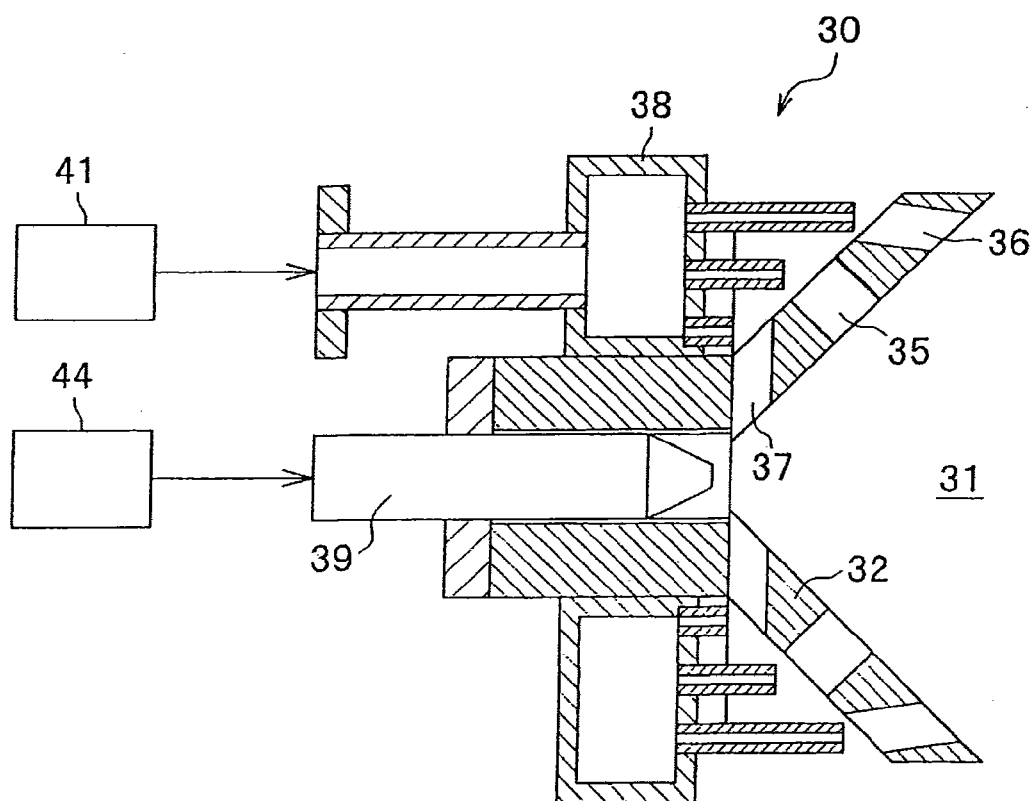
**FIG. 4**



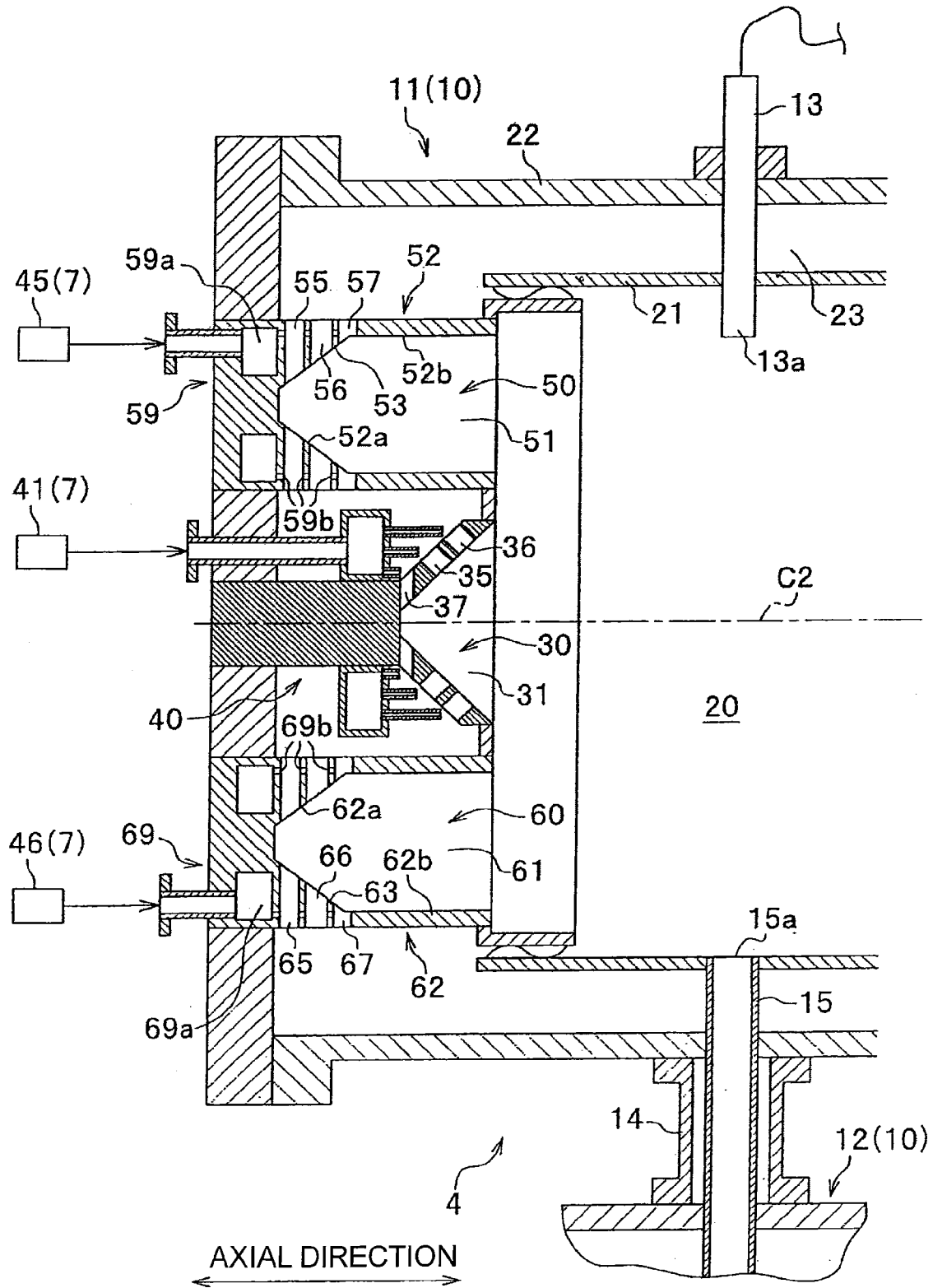
**FIG. 5**



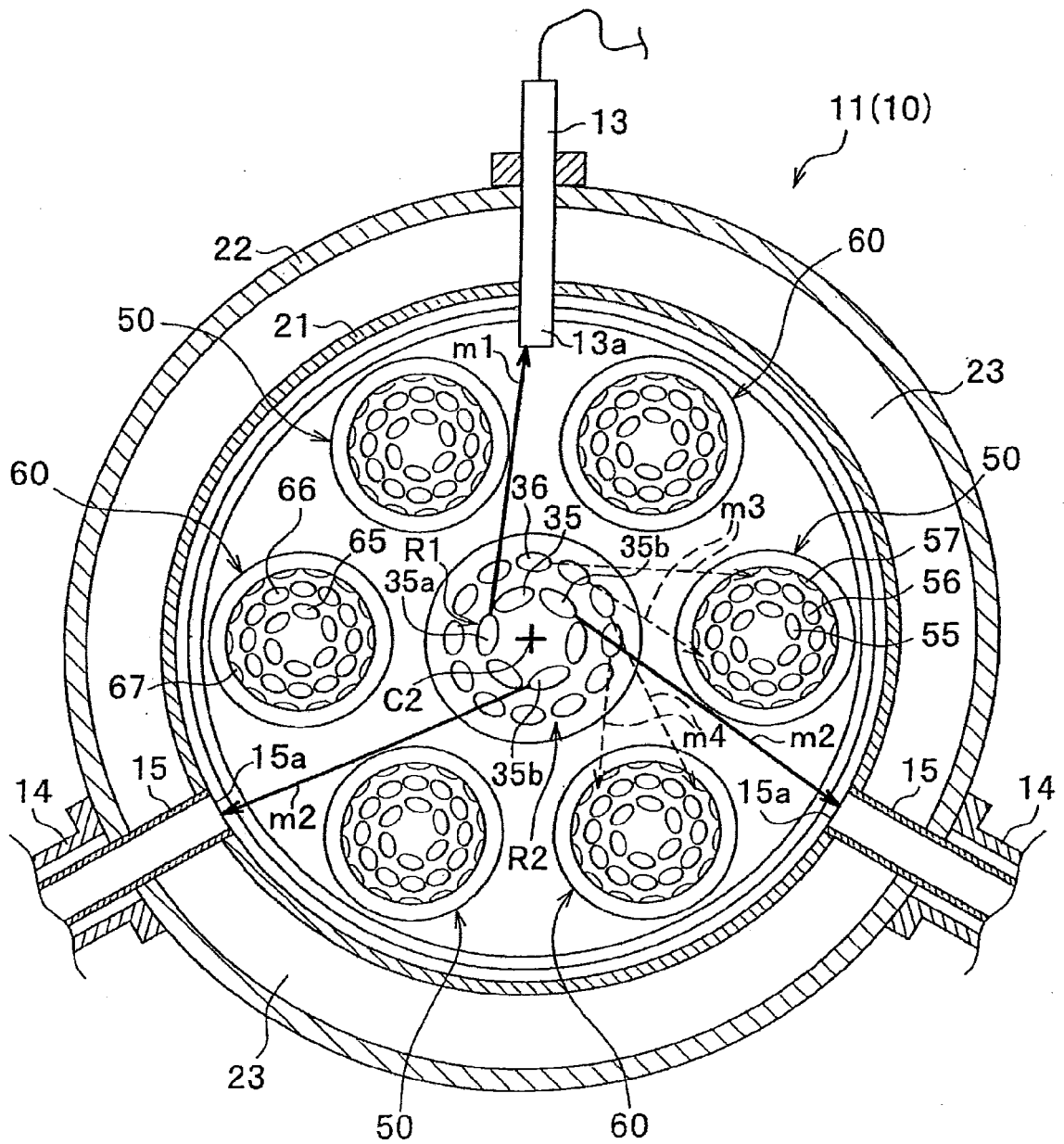
**FIG. 6**



**FIG. 7**



**FIG. 8**



**FIG. 9**

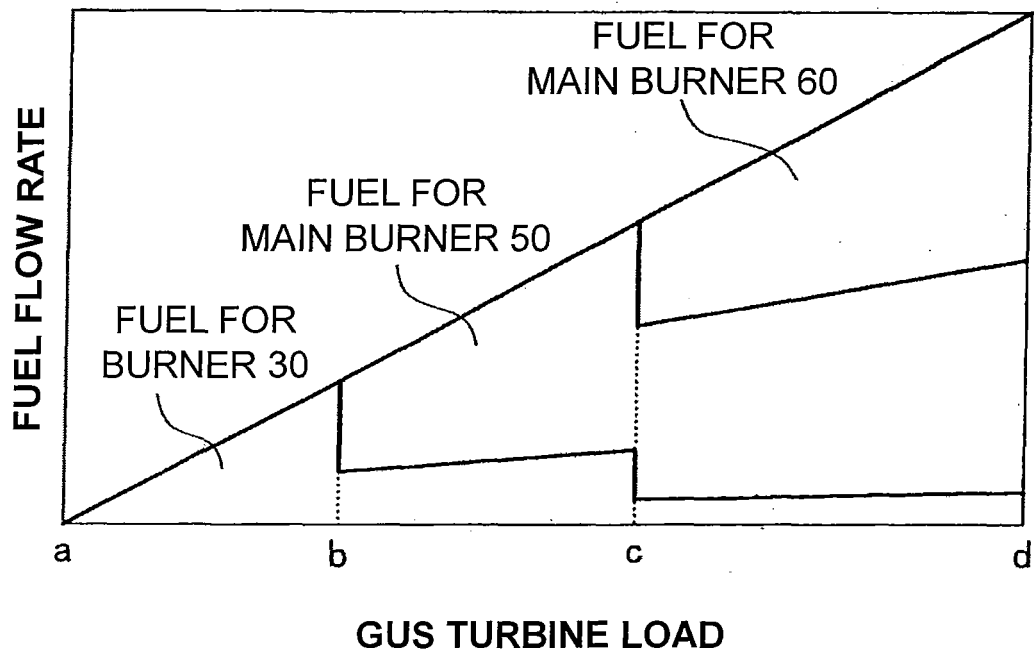
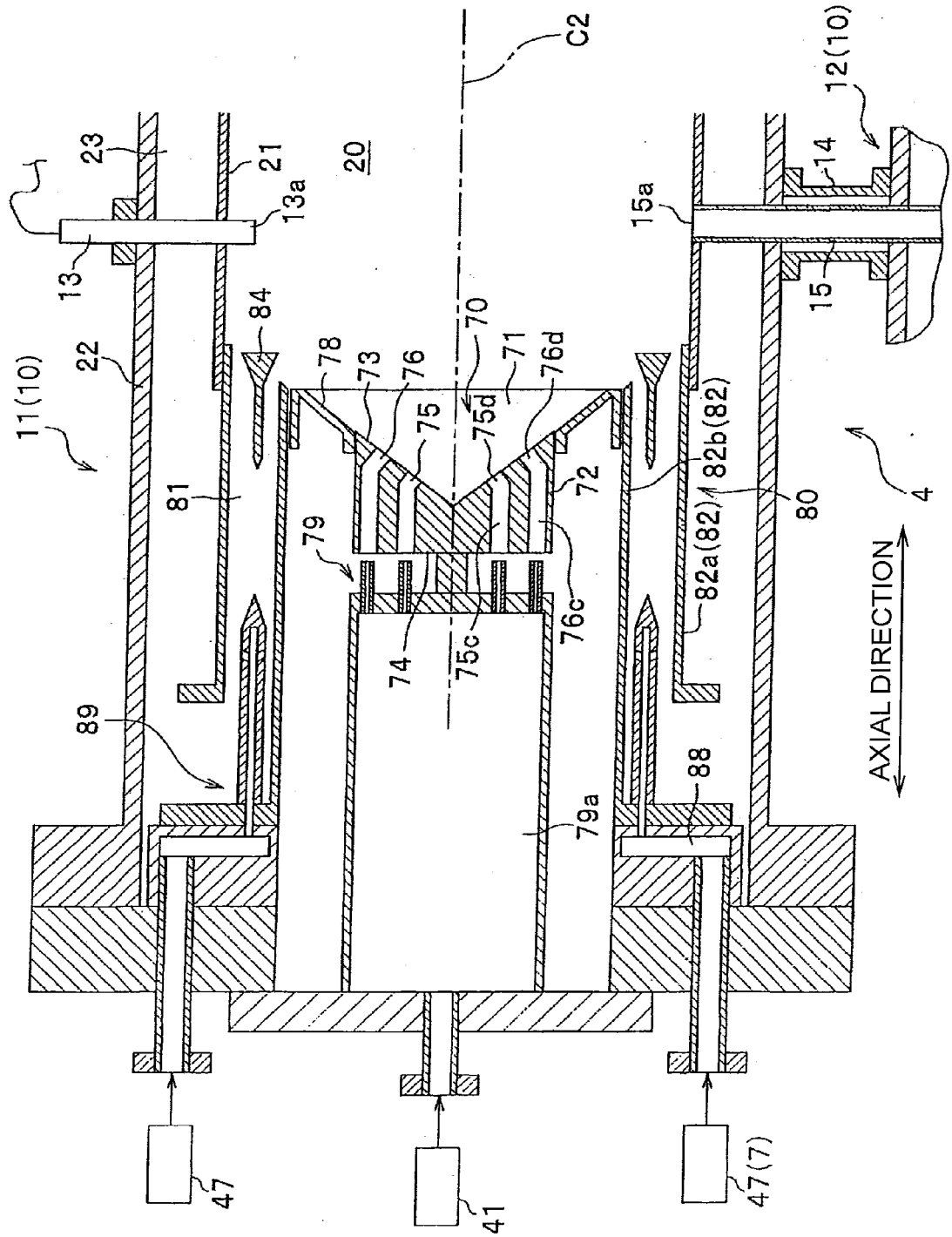
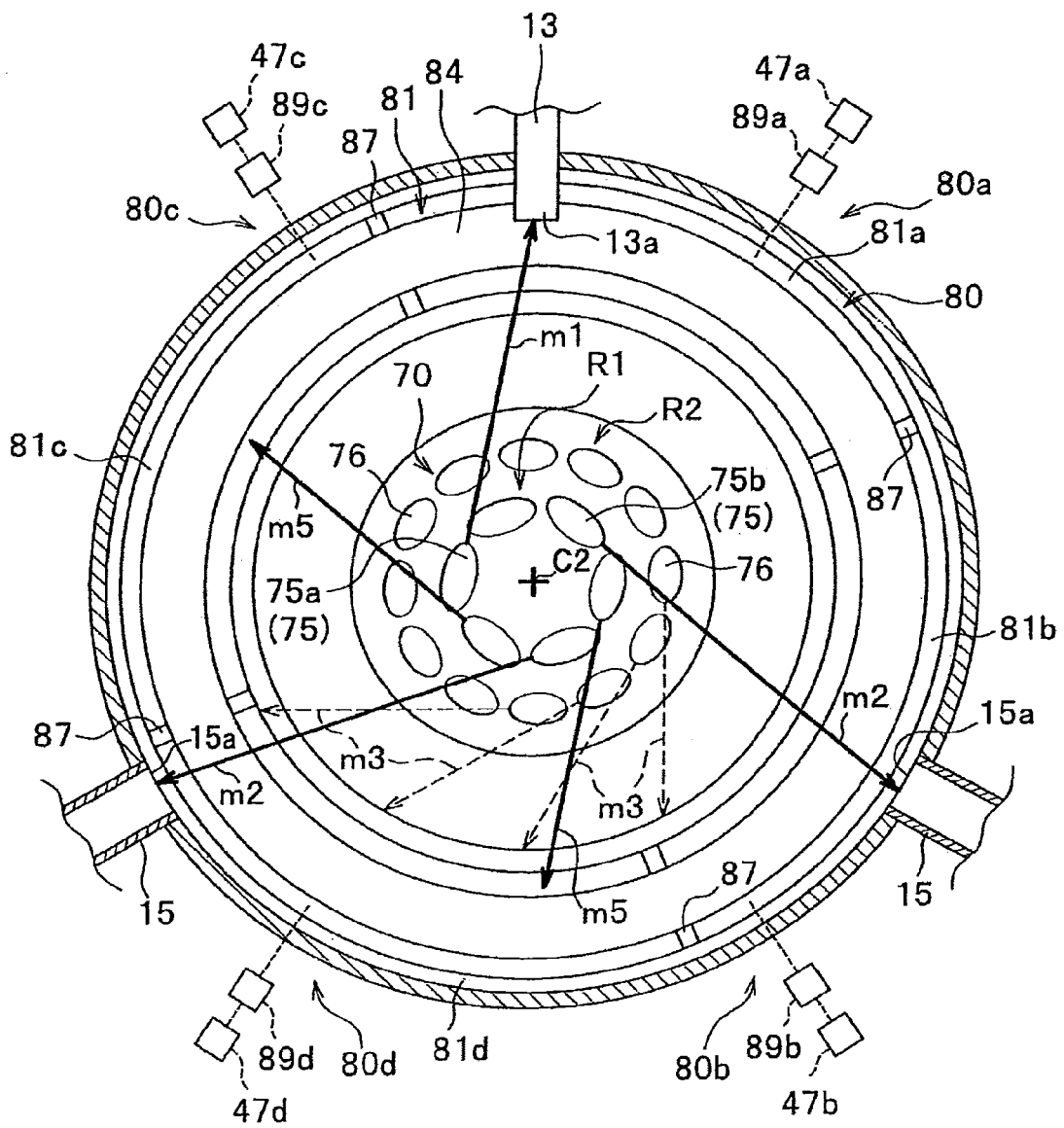


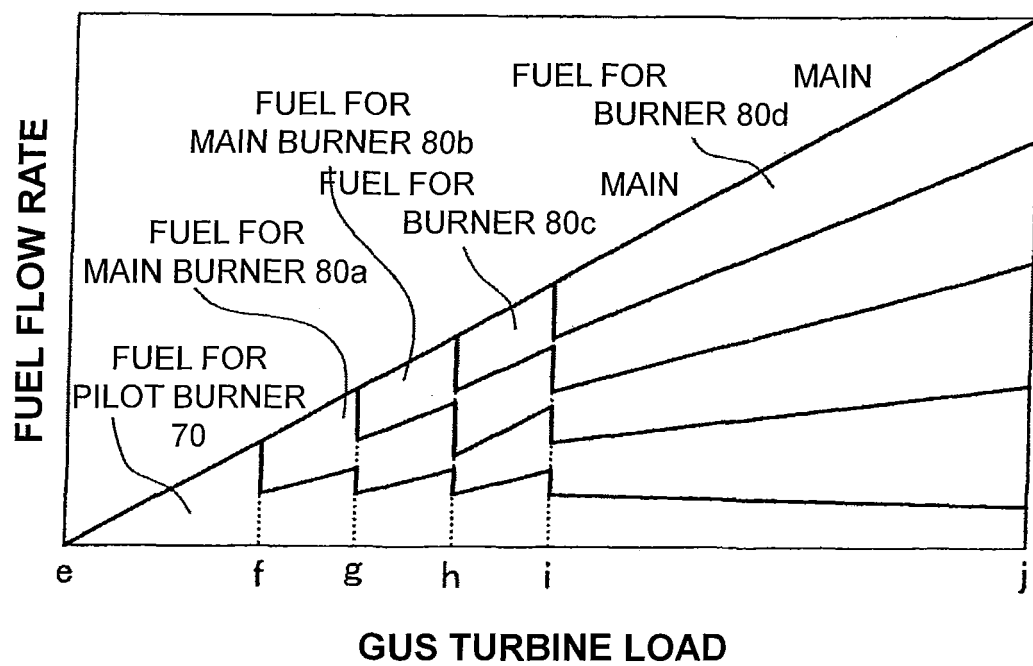
FIG. 10



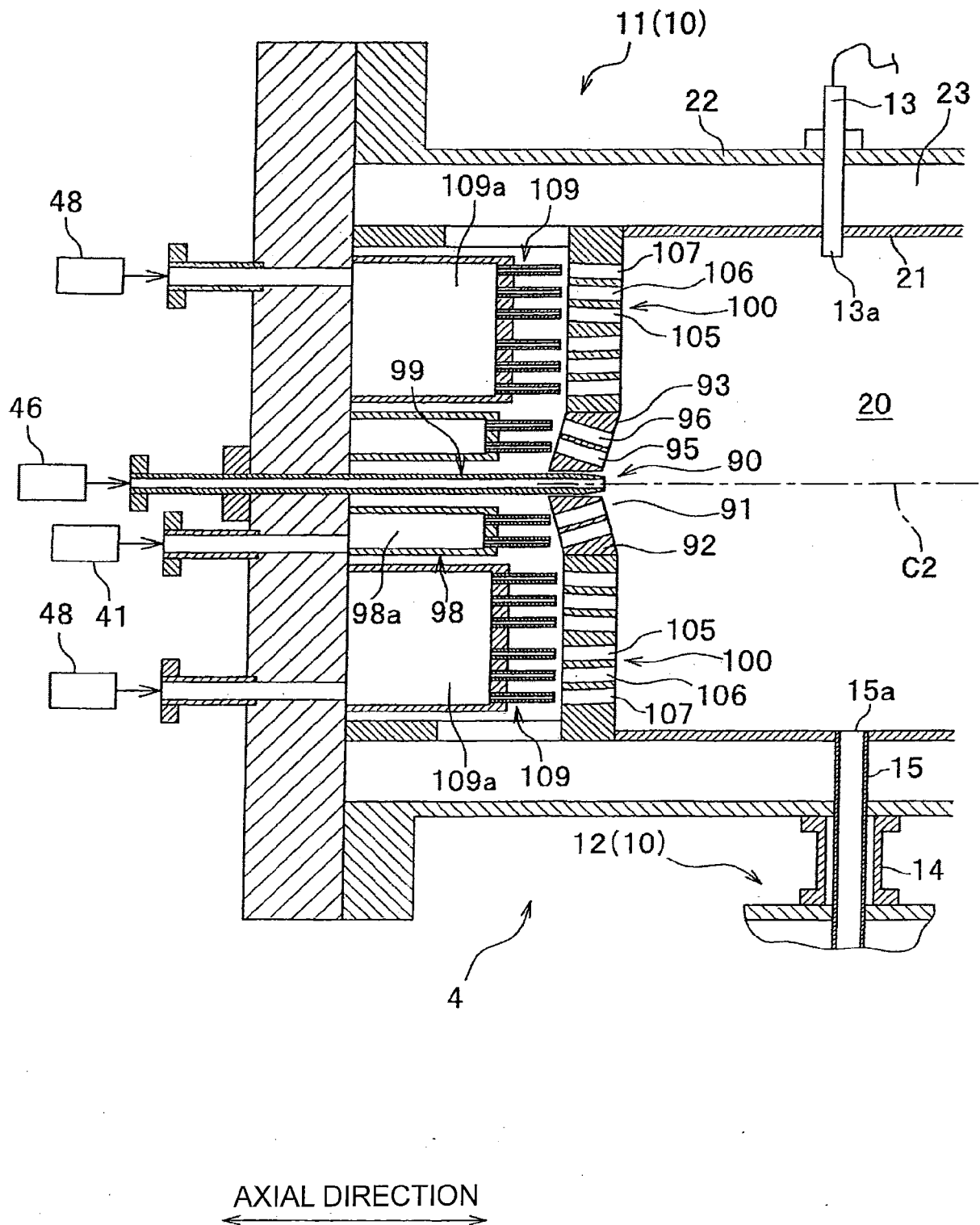
**FIG. 11**



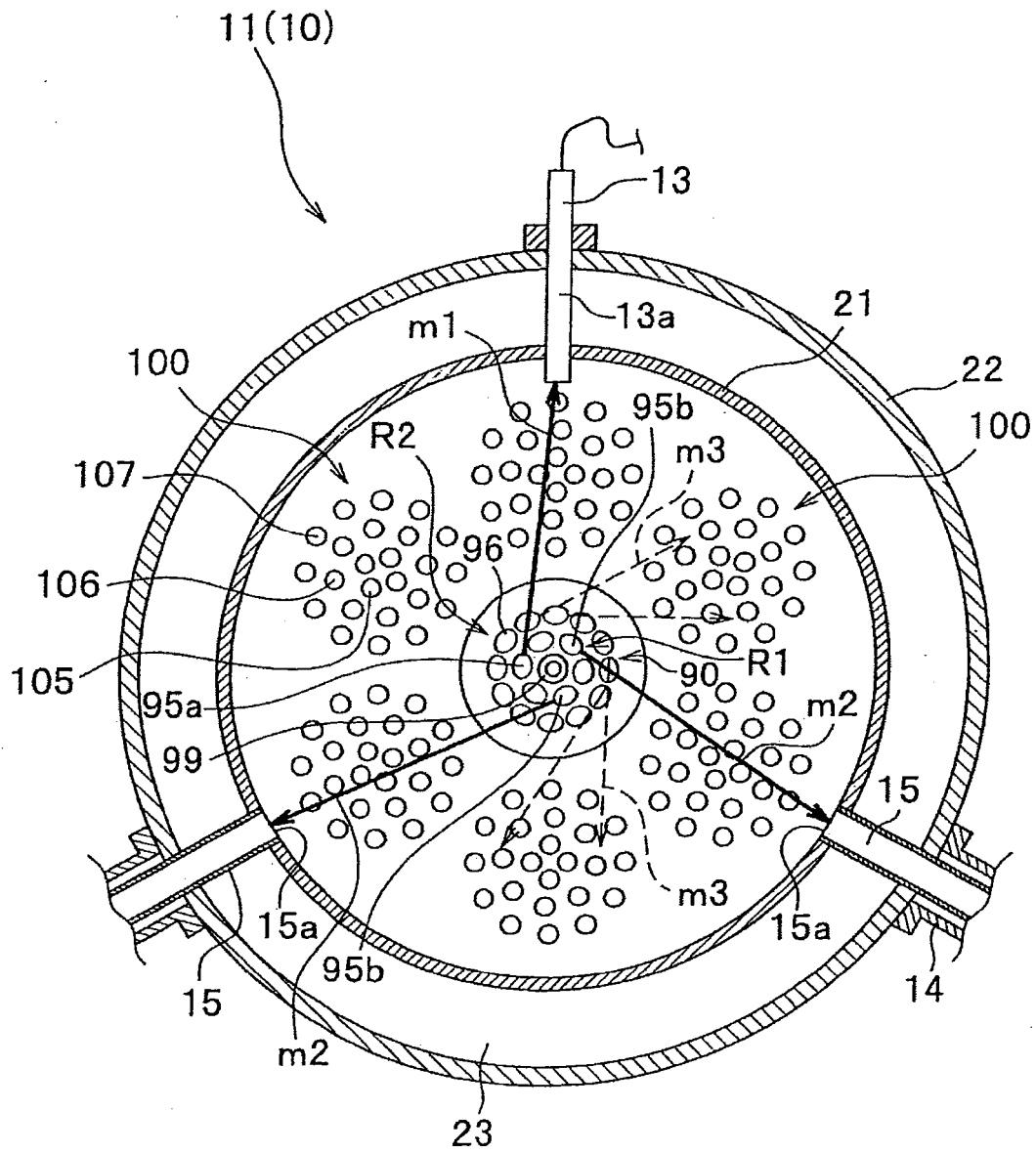
**FIG. 12**



**FIG. 13**



**FIG. 14**



**REFERENCES CITED IN THE DESCRIPTION**

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**Patent documents cited in the description**

- JP 3940705 B [0002]