



(11)

**EP 2 620 704 A1**

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:  
**31.07.2013 Bulletin 2013/31**

(51) Int Cl.:  
**F23C 9/00 (2006.01) F23R 3/28 (2006.01)**

(21) Application number: **13152582.6**

(22) Date of filing: **24.01.2013**

(84) Designated Contracting States:  
**AL AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MK MT NL NO PL PT RO RS SE SI SK SM TR**  
Designated Extension States:  
**BA ME**

(72) Inventors:  
• **Abd El-Nabi, Bassam Sabry Mohammad Niskayuna, NY New York 12309 (US)**  
• **Elkady, Ahmed Mostafa Niskayuna, NY New York 12309 (US)**  
• **Leonard, Gary Lee Niskayuna, NY New York 12309 (US)**

(30) Priority: **30.01.2012 US 201213361445**

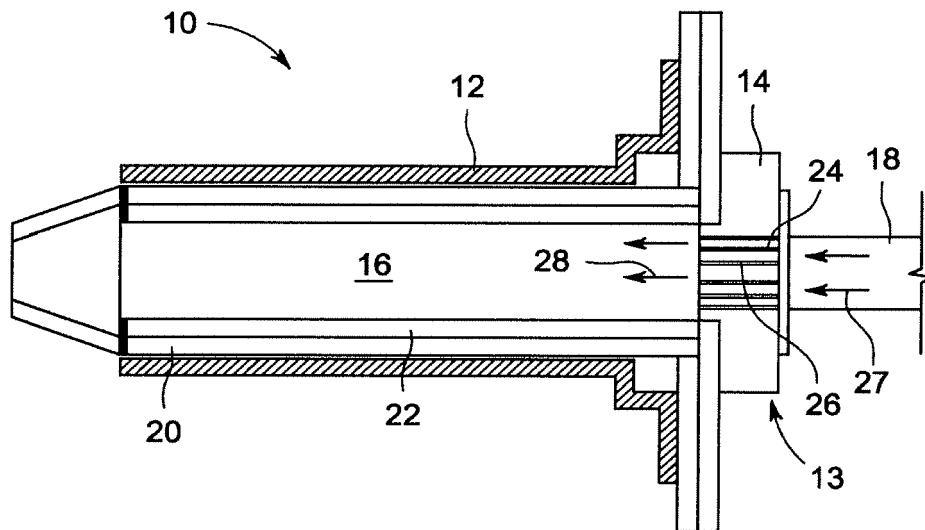
(74) Representative: **Cleary, Fidelma GE International Inc. Global Patent Operation-Europe 15 John Adam Street London WC2N 6LU (GB)**

(71) Applicant: **General Electric Company Schenectady, New York 12345 (US)**

(54) **Jet micro-induced flow reversals combustor**

(57) A jet micro-induced flow reversals combustor (10) is used to reduce NO<sub>x</sub> emissions. The combustor (10) has a nozzle (13) disposed at the head end of the combustion chamber. The nozzle includes a plurality of jets (26) for injecting a fuel and oxidant mixture stream into the combustion chamber. A combustion liner (22) is disposed within the casing (12) on one side of the nozzle (13) and a plenum chamber (18) is disposed on another

side of the nozzle (13) and configured to provide an input of a fuel and oxidant (27). The nozzle (13) and the combustion liner (22) are sized and shaped to input the fuel and oxidant mixture stream (28) into the combustion liner (22) at a high velocity ratio wherein a jet velocity is greater than a combustion mean velocity within the combustion liner (22), to increase turbulence within the combustion liner (22) and reduce combustion emissions.



**FIG. 1**

**EP 2 620 704 A1**

## Description

### BACKGROUND

**[0001]** Embodiments presented herein relate generally to combustors for gas turbines and more particularly concerns a combustor sized and shaped for reduced NO<sub>x</sub> emissions.

**[0002]** Generally described, gas turbine engines include a compressor for compressing air, a combustor for mixing the compressed air with fuel and igniting the mixture, and a turbine blade assembly for producing power. Known turbine engines have developed into highly complex and sophisticated devices.

**[0003]** It is well known that higher temperatures in gas turbines result in a machine operation at high thermal efficiency. At issue with known gas turbine engines is promoting operation at high thermal efficiency without producing undesirable air emissions. The primary air emissions usually produced by gas turbine engines include nitrogen oxides (NO<sub>x</sub>) and carbon monoxide (CO). NO<sub>x</sub> is temperature dependent, and thus at greatest challenge when high firing temperatures are required. Many combustion technologies have proposed to reduce NO<sub>x</sub> and CO to single digits, but have not achieved doing so at high firing temperatures near 3150°F. High firing temperatures mean high thermal efficiency which is translated in terms of reduced amount of overall emissions (less fuel to burn per unit power generated).

**[0004]** Previous combustion technologies that have attempted to reduce NO<sub>x</sub> and CO include stagnation point reverse flow combustors (SPRFC), flameless oxidation combustors (FLOXCOM) and advanced vortex combustors (AVC).

**[0005]** There is a desire, therefore, for a combustor for a gas turbine engine that enables high firing temperatures with increased thermal efficiency and reduced NO<sub>x</sub> and CO emissions. Preferably, the emissions output is reduced while maintaining or improving reliability, efficiency, and performance of the gas turbine engine.

### BRIEF DESCRIPTION

**[0006]** In accordance with one aspect, the invention resides in a combustor including a casing having a longitudinal axis; a nozzle coupled to the casing along the longitudinal axis, a combustion liner formed in the casing on one side of the nozzle; and a plenum chamber formed in the casing on another side of the nozzle and configured to provide an input of a fuel and oxidant. The nozzle includes a plurality of fuel and oxidant jets formed therein. The nozzle and the combustion liner are sized and shaped to input a fuel and oxidant mixture stream into the combustion chamber at a high velocity ratio wherein a jet velocity is greater than a combustion mean velocity within the combustion liner, to increase turbulence within the combustion liner and reduce combustion emissions.

**[0007]** In accordance with another aspect, the inven-

tion resides in a method of reducing combustion emissions in a combustor. The method including providing a casing having a longitudinal axis; coupling a nozzle to the casing along the longitudinal axis, disposing a combustion liner within the casing and on one side of the nozzle; and disposing a plenum chamber on another side of the nozzle and configured to provide an input of a fuel and oxidant. The nozzle including a plurality of fuel and oxidant jets formed therein. The nozzle and the combustion liner are sized and shaped to input a fuel and oxidant mixture stream into the combustion chamber at a high velocity ratio wherein a jet velocity is greater than a combustion mean velocity within the combustion liner, to increase turbulence within the combustion liner and reduce combustion emissions.

**[0008]** Other objects and advantages of the present disclosure will become apparent upon reading the following detailed description and the appended claims with reference to the accompanying drawings. These and other features and improvements of the present application will become apparent to one of ordinary skill in the art upon review of the following detailed description when taken in conjunction with the several drawings and the appended claims.

### DRAWINGS

**[0009]** Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

FIG. 1 is a cross-sectional side view of a jet micro-induced flow reversals combustor according to an embodiment;

FIG. 2 shows a partially cut-away view of the a jet micro-induced flow reversals combustor of FIG. 1 according to an embodiment;

FIG. 3 is a cross-sectional side view of a portion of a jet micro-induced flow reversals combustor according to an embodiment;

FIG. 4 is an image taken through the combustion chamber of a jet micro-induced flow reversals combustor according to an embodiment;

FIG. 5 is a graph comparing the level of NO<sub>x</sub> emissions as a function of flame temperature between experimental jet micro-induced flow reversals combustors according to an embodiments under varying pressure conditions; and

FIG. 6 is a graph comparing the level of NO<sub>x</sub> emissions as a function of flame temperature between an experimental jet micro-induced flow reversals combustor according to an embodiment and the NO<sub>x</sub> emissions from a known combustor.

## DETAILED DESCRIPTION

**[0010]** Referring to the drawings wherein identical reference numerals denote the same elements throughout the various views, FIGS. 1 and 2 show a jet micro-induced flow reversals combustion system 10. The combustion system 10 comprises a casing, or housing, 12 which has a substantially open interior. The casing 12 is shown in the form of a cylindrical tube but is not necessarily limited to this shape. A nozzle 13, configured to include a plurality of fuel and oxidant jets, is disposed at one end of the casing 12, along the longitudinal axis of the casing 12. In an embodiment, nozzle 13 is configured as a perforated plate 14 and is disposed at an end of the casing 12. In an alternate embodiment, the perforated plate 14 may be disposed inside the casing 12 at an intermediate location with the diameter of the perforated plate 14 substantially equal to the inner diameter of the casing 12 so that the plate 14 fits snugly therein. In yet another alternate embodiment, the nozzle 13 may be configured as a plurality of tube-like structures for the input of a fuel and oxidant to the combustion system 10.

**[0011]** In the illustrated embodiment, the nozzle 13, and more particularly the perforated plate 14, divides the combustion system 10 into two distinct sections: a combustion chamber 16 defined within the casing 12 and adjacent to the downstream side of the plate 14 and a plenum chamber 18 adjacent to the upstream side of the plate 14. The combustion chamber 16, which is where fuel is burned, may further include a cooling sleeve 20, formed of a material that is at least moderately resistant to high temperatures, such as Inconel®, an Inconel® alloy, or other material typically used in temperature sensitive applications. The cooling sleeve 20 may provide cooling to the combustion chamber 16 via an inlet air flow from a compressor (described presently) over the outer surface of the cooling sleeve 20 prior to mixing with a fuel in the plenum chamber 18. Thus, the relatively cool compressor air will provide backside cooling to the cooling sleeve 20.

**[0012]** The combustion chamber 16 may further have disposed therein a protective combustion liner 22. In an embodiment, the protective combustion liner 22 may be formed of a ceramic material, or other material typically used in high temperature applications. The flow of combustion products exiting the downstream end of the combustion chamber 16 may be utilized to drive a turbine, or the like.

**[0013]** In the illustrated embodiment, the nozzle 13, and more specifically the perforated plate 14, is generally configured having a plurality of perforations or orifices 24 formed therein. In an embodiment, the perforations 24 are configured as a plurality of fuel and oxidant jets 26. As used herein, the term "jet" refers to an opening from which a stream of fluid is discharged. Thus, by definition, the fuel and oxidant jets 26 discharge a fuel and oxidant mixture stream 28 into the combustion chamber 16, and more particularly into an area defined within the combus-

tion liner 22. In an embodiment, an input fuel and air 27 are premixed prior to injection into the combustion chamber 16, and more specifically premixed outside of the combustion chamber 16 to form the fuel and oxidant mixture stream 28. More specifically, the input fuel and air 27 may be mixed by the nozzle 13, or premixed prior to reaching the nozzle 13. As shown in the Figures, the fuel and oxidant jets 26 are oriented normal to the planar surfaces of the plate 14. Thus, the jets inject the fuel and oxidant mixture stream 28 axially into the combustion chamber 16, and more particularly into the combustion liner 22. The fuel and oxidant jets 26 may alternatively be oriented at an angle to the plate 14 to produce an angular injection of the fuel and oxidant mixture stream 28. The angular injection may create some net swirl in the fuel and oxidant mixture stream 28 which will improve flame stability. Angled injection can also be used to direct the flame front away from the wall of the combustion chamber 16, and more particularly the combustion liner 22, thereby increasing the life of the combustion system 10.

**[0014]** The input fuel and air 27 is delivered to the jets 26 via the plenum chamber 18 with which they are in fluidic communication. The plenum chamber 18 is connected to an external source of fuel (not shown) and a source of air (not shown) which is typically a compressor, which deliver the fuel and oxidant to each one of the plurality of jets 26 via the plenum chamber 18 in one of a mixed, or unmixed state. As previously eluded to, in an embodiment, an air inlet may be configured so that the inlet air flows over the outer surface of the cooling sleeve 20 prior to mixing with the fuel in the plenum chamber 18 or via the nozzle 13. Thus, the relatively cool compressor air may provide backside cooling to the cooling sleeve 20 and the combustion liner 22.

**[0015]** The number of fuel and oxidant jets 26 formed in the perforated plate 14, or the number of tubes carrying the input fuel and oxidant 27 in the nozzle 13, is not restricted to what is shown in FIGS. 1 and 2 but should be sufficient to provide a uniform flow distribution across the combustion chamber 16. Furthermore, in an embodiment incorporating the perforated plate 14, the fuel and oxidant jets 26 should be evenly distributed about the plate 14 to produce a uniform flow distribution.

**[0016]** To achieve reduced combustion emissions, the nozzle 13, and in the illustrated embodiment more particularly the perforated plate 14, and the combustion liner 22 are sized and shaped to input the fuel and oxidant mixture stream 28 into the combustion chamber 16 at a high velocity ratio. More specifically, the fuel and oxidant mixture stream 28 is input into the combustion chamber 16 at a high jet velocity, via jets 26, that is greater than a combustion mean velocity within the combustion chamber 16, to increase turbulence within the combustion chamber 16 and reduce combustion emissions. Simply stated, the jet speed is greater than the mean flow speed within the combustion chamber 16. The increase in turbulence in the combustion chamber 16, and more par-

ticularly the combustion liner 22, provides reduction in a length of a combustion flame, reduced combustion emissions, and provides mixing of a portion of combustion products in a flame front.

**[0017]** The high velocity ratio between the jet velocity and the combustion mean velocity provides the development of flow reversals and a stirring action within the combustion chamber 16 that will result in the reduction of combustion emissions. Referring more specifically, to FIG. 3, illustrated in a simplified cross-section is the combustion chamber 16 and a plurality of vortical structures 25 formed during combustion and showing a flame length of "x". Illustrated in FIG. 4 is an image of the vortical structures 25 taken during combustion. The difference in velocity will yield an internal stirring action that mixes the combustion products with the input fuel and oxidant mixture stream 28. The stirring action is mainly due to the large numbers of vortical structures 25 that develop around the jet 26 edges, and more particularly around a perimeter of each of the perforations or orifices 24 formed in the plate 14 or around each of the tube-like structures that form nozzle 13. As can be seen in FIGS. 3 and 4, the density of the vortical structures 25 increase with the increase in velocity ratio. The internal recirculation damps the NO<sub>x</sub> generation and burns CO. The end result is a single digit NO<sub>x</sub> and CO over a wide range of flame temperatures.

**[0018]** In general, three factors influence NO<sub>x</sub> generation: temperature, oxygen and residence time. The combustion system 10 permits reduction of the NO<sub>x</sub> concentrations based on reduction of the free oxygen radicals due to internal mixing and increased velocity. This is achieved through the increase of the reacting mixture velocity while reducing the combustion products velocity. The effective residence time of the combustion products is much less than the effective flame residence time. As a result, NO<sub>x</sub> production in a low oxygen environment will be suppressed. Given enough residence time, CO concentration will be kept low as influenced by the high firing temperature as well as the expected high degree of homogeneity. The high degree of homogeneity and internal mixing ensures CO burn out at low flame temperatures. This is primarily due to forcing the fresh premixed fuel and oxidant mixture stream 28 to react in the presence of hot gases.

**[0019]** The concept of the present disclosure was tested on various laboratory-scale jet micro-induced flow reversals combustors. The testing was performed under substantially high pressure conditions. Illustrated in FIG. 5 is a comparison between the NO<sub>x</sub> emissions resulting from a jet micro-induced flow reversals combustor as disclosed herein operating under different high pressure conditions. Illustrated comparatively are the NO<sub>x</sub> emissions in parts per million against the flame temperature. The plotted points show combustion emissions data from three variations of the laboratory-scale device of the present disclosure represented by the plotted points and Curves A, B and C. Curve A is representative of a jet

micro-induced flow reversals combustor according to an embodiment disclosed herein operating at approximately 300 psi. Curve B is representative of a jet micro-induced flow reversals combustor according to an embodiment disclosed herein operating at approximately 245 psi. Curve C is representative of a jet micro-induced flow reversals combustor according to an embodiment disclosed herein operating at approximately 180 psi. The results show that by decreasing the operating pressure and sizing and shaping the combustion chamber 16, and more particularly the nozzle 13 relative to the combustion liner 22, to input the fuel and oxidant mixture stream 28 into the combustion chamber 16 at a high velocity ratio (jet velocity greater than a combustion mean velocity within the combustion chamber 16), the NO<sub>x</sub> emissions are decreased at increasing flame temperatures. It should be kept in mind that these results are based on laboratory-scale experiments.

**[0020]** In addition, illustrated in FIG. 6 is a comparison between the NO<sub>x</sub> emissions of a laboratory-scale jet micro-induced flow reversals combustors disclosed herein and the NO<sub>x</sub> emissions from a combustion device running under low velocity ratio. Data is represented by the plotted points that form Curve D representative of data collected from a known conventional combustor (running under low velocity ratio). Data is represented by the plotted points that form Curve E representative of data collected from a laboratory-scale jet micro-induced flow reversals combustor as disclosed herein. The curves illustrate the increase in NO<sub>x</sub> emissions at increasing flame temperatures of the combustors. It should be noted that as evidenced by Curve E, the NO<sub>x</sub> reduction benefits from the jet micro-induced flow reversals combustor as disclosed herein are shown. Results show that the jet micro-induced flow reversals combustor sized and shaped as disclosed herein may achieve an approximate 75% reduction in combustion emissions over that of the low velocity ratio.

**[0021]** The foregoing has described a jet micro-induced flow reversals combustor which provides low combustion emissions at elevated temperatures. More particularly, disclosed is a jet micro-induced flow reversals combustor that provides reduced NO<sub>x</sub> emissions from those currently known in the art, thereby increasing gas turbine thermal efficiency to higher levels than current combustors, increasing turndown with minimal CO penalty and enabling the use of liquid fuel while maintaining emission compliance. While the disclosure has been illustrated and described in typical embodiments, it is not intended to be limited to the details shown, since various modifications and substitutions can be made without departing in any way from the spirit of the present disclosure. As such, further modifications and equivalents of the disclosure herein disclosed may occur to persons skilled in the art using no more than routine experimentation, and all such modifications and equivalents are believed to be within the spirit and scope of the disclosure as defined by the subsequent claims.

**Claims**

1. A combustor (10) comprising:
- a casing (12) having a longitudinal axis; 5
  - a nozzle (13) coupled to the casing (12) along the longitudinal axis, the nozzle (13) having a plurality of fuel and oxidant jets (26) formed therein;
  - a combustion liner (22) formed in the casing (12) on one side of the nozzle (13); and 10
  - a plenum chamber (18) formed in the casing (12) on another side of the nozzle (13) and configured to provide an input of a fuel and oxidant (27), 15
- wherein the nozzle (13) and the combustion liner (22) are sized and shaped to input a fuel and oxidant mixture stream (28) into the combustion liner (22) at a high velocity ratio wherein a jet velocity is greater than a combustion mean velocity within the combustion liner (22), to increase turbulence within the combustion liner (22) and reduce combustion emissions. 20
2. A combustor (10) as claimed in Claim 1, wherein the nozzle (13) is a perforated plate (14). 25
3. A combustor (10) as claimed in Claim 1 or 2, wherein the increase in turbulence in the combustion liner (22) reduces a length of a combustion flame. 30
4. A combustor (10) as claimed in Claim 1, 2 or 3, wherein the increase in turbulence in the combustion liner (22) reduces combustion emissions. 35
5. A combustor (10) as claimed in any of Claims 1 to 4, wherein, the increase in turbulence in the combustion liner (22) mixes a portion of combustion products in a flame front. 40
6. A combustor (10) as claimed in any preceding Claim, further comprising a cooling sleeve (20) disposed between the casing (12) and the combustion liner (22). 45
7. A combustor as claimed in any preceding Claim, wherein the nozzle is a perforated plate.
8. A combustor as claimed in any preceding Claim, wherein the increase in turbulence within the combustion liner reduces NO<sub>x</sub> emissions. 50
9. A combustor as claimed in any preceding Claim, wherein the fuel and oxidant are premixed in the plenum chamber. 55
10. A method of reducing combustion emissions in a combustor (10) comprising:
- providing a casing (12) having a longitudinal axis;
  - coupling a nozzle (13) to the casing (12) along the longitudinal axis, the nozzle (13) having a plurality of fuel and oxidant jets (26) formed therein;
  - disposing a combustion liner (22) within the casing (12) and on one side of the nozzle (13); and
  - disposing a plenum chamber (18) on another side of the nozzle (13) and configured to provide an input of a fuel and oxidant (27), wherein the nozzle (13) and the combustion liner (22) are sized and shaped to input a fuel and oxidant mixture stream (28) into the combustion liner (22) at a high velocity ratio wherein a jet velocity is greater than a combustion mean velocity within the combustion liner (22), to increase turbulence within the combustion liner (22) and reduce combustion emissions.
11. A method of reducing combustion emissions in a combustor (10) as claimed in Claim 10, wherein the increase in turbulence in the combustion liner (22) reduces a length of a combustion flame and combustion emissions.
12. A method of reducing combustion emissions in a combustor (10) as claimed in Claim 10 or 11, wherein the increase in turbulence in the combustion liner (22) mixes a portion of combustion products in a flame front.
13. A method of reducing combustion emissions in a combustor (10) as claimed in any of Claims 10 to 12, further comprising disposing a cooling sleeve (20) between the casing (12) and the combustion liner (22).
14. A method of reducing combustion emissions in a combustor as claimed in any of Claim 10 to 13, wherein the increase in turbulence within the combustion liner (22) reduces NO<sub>x</sub> emissions.
15. A method of reducing combustion emissions in a combustor as claimed in any of Claims 10 to 14, wherein the combustor (10) comprises a jet micro-induced flow reversals can combustor.

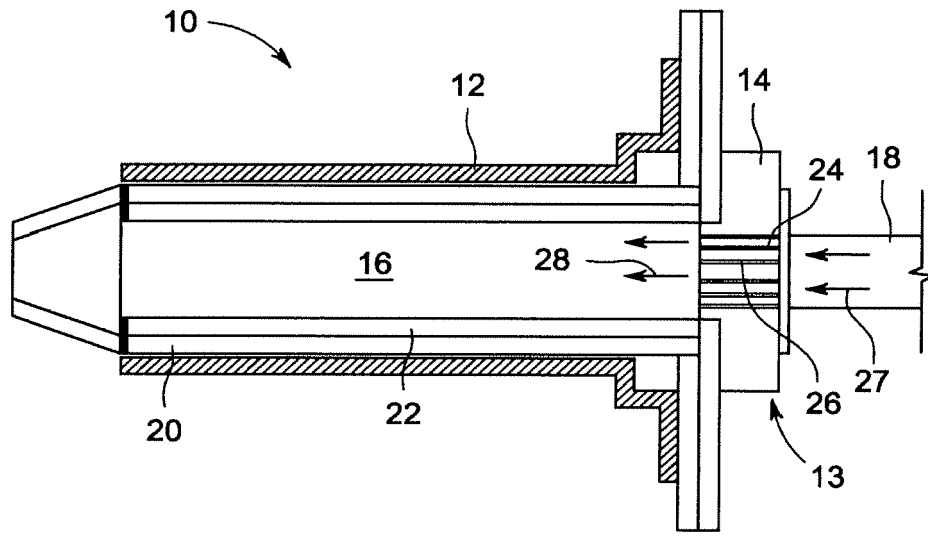


FIG. 1

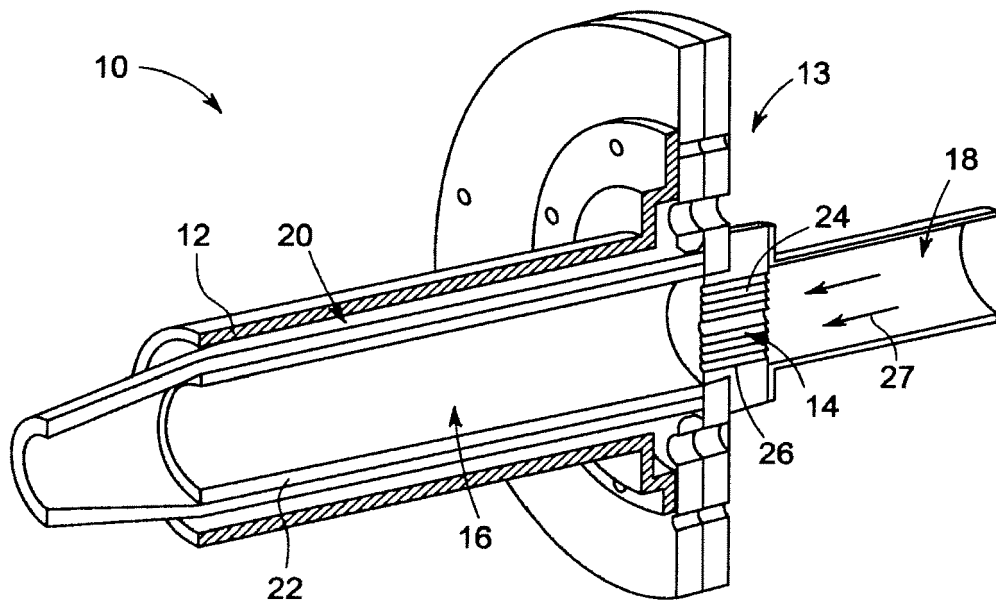


FIG. 2

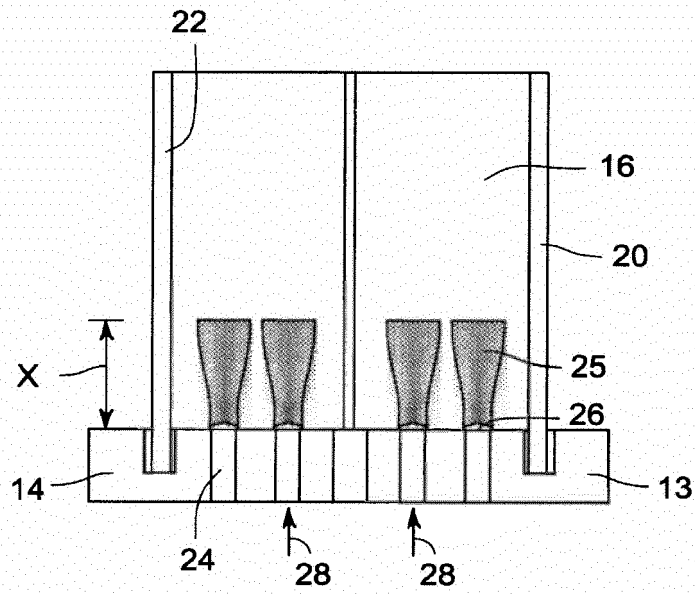


FIG. 3

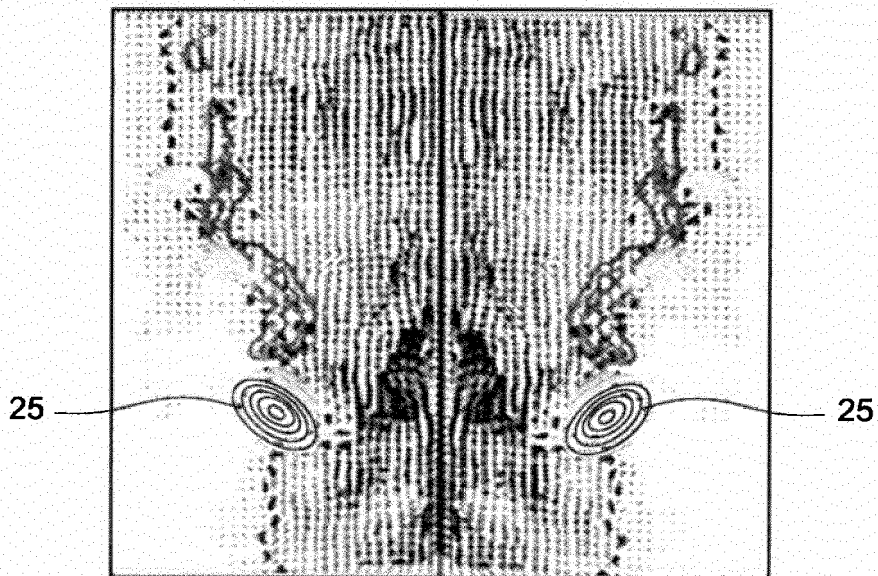


FIG. 4

- 300 Psi\_15ms CERAMIC COMBUSTOR
- 245 Psi\_15ms CERAMIC COMBUSTOR
- ▲ 180 Psi\_15ms CERAMIC COMBUSTOR

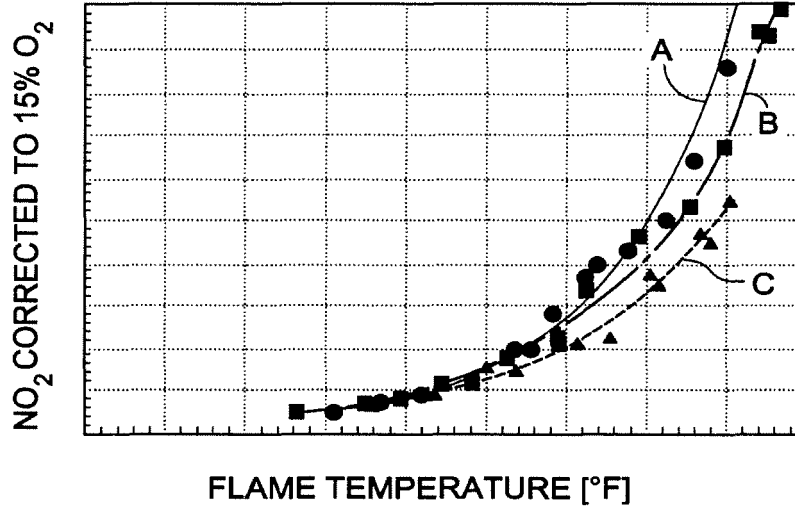


FIG. 5

- ⊠ 180 Psia,670F, 20ms, CONVENTIONAL COMBUSTION
- 180 Psi,725F, 20ms, LET INDUCED MICRO-FLOW REVERSALS COMBUSTOR

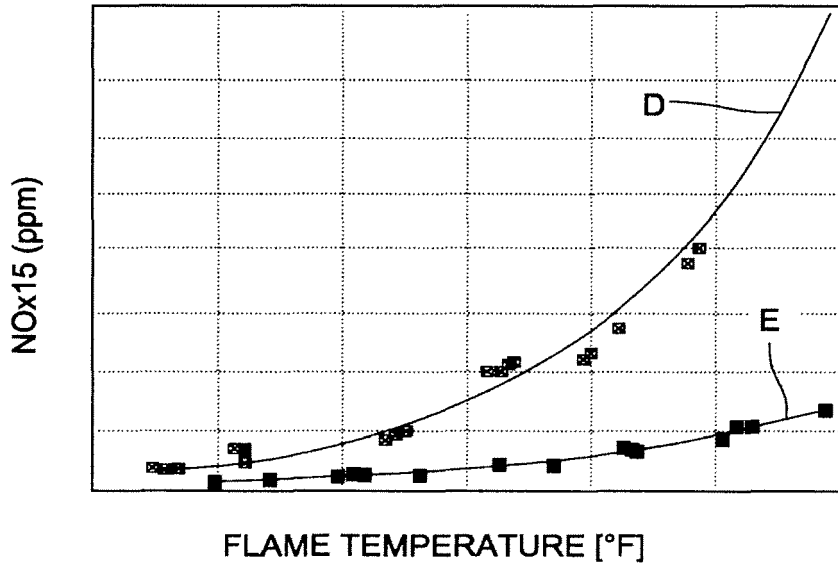


FIG. 6



EUROPEAN SEARCH REPORT

Application Number  
EP 13 15 2582

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2005/282097 A1 (CARREA ELISABETTA [CH] ET AL) 22 December 2005 (2005-12-22) * page 1, paragraphs 3,8 * * page 2, paragraph 12 - paragraph 17 * * page 4, paragraph 42 * * page 5, paragraph 58 - paragraph 59 * * claims 1,6,8; figures 4,6 * -----	1-15	INV. F23C9/00 F23R3/28
X	JP 2009 014324 A (HITACHI LTD) 22 January 2009 (2009-01-22) * abstract; figure 2 * -----	1,2,9,10	
			TECHNICAL FIELDS SEARCHED (IPC)
			F23C F23R
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 21 March 2013	Examiner Gavriliu, Costin
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons ..... & : member of the same patent family, corresponding document	

1  
EPO FORM 1503 03/82 (P04/C01)

**ANNEX TO THE EUROPEAN SEARCH REPORT  
ON EUROPEAN PATENT APPLICATION NO.**

EP 13 15 2582

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on  
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

21-03-2013

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2005282097 A1	22-12-2005	AU 2003300249 A1	30-06-2004
		DE 10257704 A1	15-07-2004
		EP 1570211 A1	07-09-2005
		US 2005282097 A1	22-12-2005
		WO 2004053395 A1	24-06-2004
-----			
JP 2009014324 A	22-01-2009	JP 4854613 B2	18-01-2012
		JP 2009014324 A	22-01-2009
-----			

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82