(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 746 666 A2

(12) **EUROPEAN PATENT APPLICATION**

(43) Date of publication:
25.06.2014 Bulletin 2014/26

(21) Application number: **13198227.4**

(22) Date of filing: **18.12.2013**

(51) Int Cl.:
F23R 3/34 *(2006.01)* ***F23R 3/28*** *(2006.01)*
F23R 3/14 *(2006.01)*

(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

(30) Priority: **21.12.2012 US 201213723322**

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

(72) Inventors:
- **Chen, Wei**
Greenville, SC 29615 (US)
- **DiCintio, Richard Martin**
Greenville, SC 29615 (US)
- **Karim, Hasan**
Greenville, SC 29615 (US)
- **Slobodyanskiy, Ilya Alexandrovich**
Greenville, SC 29615 (US)

(74) Representative: **Cleary, Fidelma**
GPO Europe
GE International Inc.
The Ark
201 Talgarth Road
Hammersmith
London W6 8BJ (GB)

(54) **System for supplying fuel to a combustor**

(57) A system for supplying fuel to a combustor (20) includes a combustion chamber (48) and a liner (50) that circumferentially surrounds at least a portion of the combustion chamber (48). A plurality of fuel nozzles (46) are radially arranged across the combustor (20) upstream from the combustion chamber (48) to supply a swirling flow of fuel into the combustion chamber (48). A first fuel injector (80) downstream from the plurality of fuel nozzles (46) provides fluid communication for fuel to flow through the liner (50) and into the combustion chamber (48). The first fuel injector (80) is circumferentially clocked with respect to the swirling flow of fuel in the combustion chamber (48).

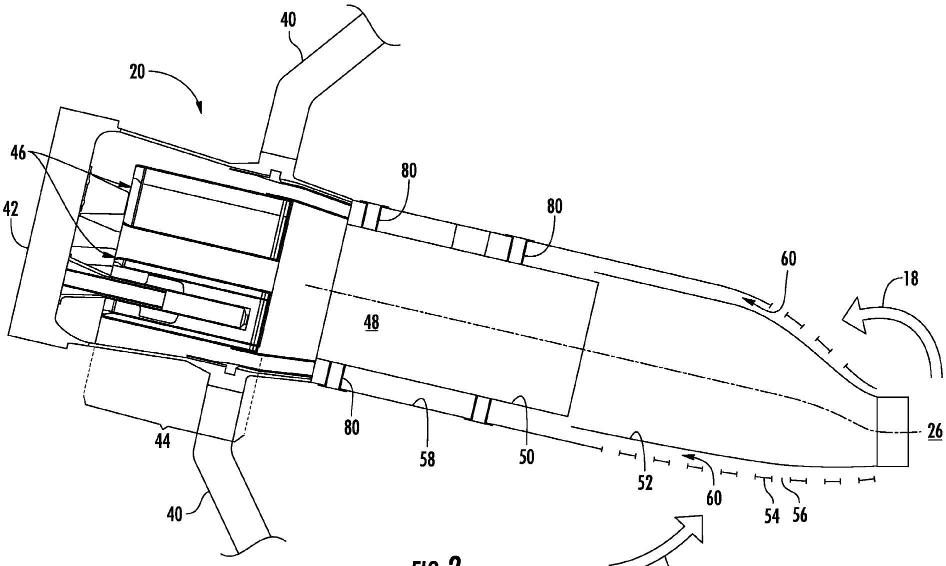

FIG. 2

EP 2 746 666 A2

Description

FIELD OF THE INVENTION

[0001] The present invention generally involves a system for supplying fuel to a combustor. In particular embodiments, the combustor may be incorporated into a gas turbine or other turbo-machine.

BACKGROUND OF THE INVENTION

[0002] Combustors are commonly used in industrial and power generation operations to ignite fuel to produce combustion gases having a high temperature and pressure. For example, turbo-machines such as gas turbines typically include one or more combustors to generate power or thrust. A typical gas turbine includes an inlet section, a compressor section, a combustion section, a turbine section, and an exhaust section. The inlet section cleans and conditions a working fluid (e.g., air) and supplies the working fluid to the compressor section. The compressor section increases the pressure of the working fluid and supplies a compressed working fluid to the combustion section. The combustion section mixes fuel with the compressed working fluid and ignites the mixture to generate combustion gases having a high temperature and pressure. The combustion gases flow to the turbine section where they expand to produce work. For example, expansion of the combustion gases in the turbine section may rotate a shaft connected to a generator to produce electricity.

[0003] The combustion section may include one or more combustors annularly arranged between the compressor section and the turbine section, and the temperature of the combustion gases directly influences the thermodynamic efficiency, design margins, and resulting emissions of the combustor. For example, higher combustion gas temperatures generally improve the thermodynamic efficiency of the combustor. However, higher combustion gas temperatures also promote flame holding conditions in which the combustion flame migrates towards the fuel being supplied by nozzles, possibly causing accelerated damage to the nozzles in a relatively short amount of time. In addition, higher combustion gas temperatures generally increase the disassociation rate of diatomic nitrogen, increasing the production of nitrogen oxides (NO_X) for the same residence time in the combustor. Conversely, a lower combustion gas temperature associated with reduced fuel flow and/or part load operation (turndown) generally reduces the chemical reaction rates of the combustion gases, increasing the production of carbon monoxide and unburned hydrocarbons for the same residence time in the combustor.

[0004] In a particular combustor design, the combustor may include a cap assembly that extends radially across at least a portion of the combustor, and one or more fuel nozzles may be radially arranged across the cap assembly to supply fuel to the combustor. The fuel nozzles may include swirler vanes and/or other flow guides to enhance mixing between the fuel and the compressed working fluid to produce a lean fuel-air mixture for combustion. The swirling fuel-air mixture flows into a combustion chamber where it ignites to generate the combustion gases. The combustor may further include one or more fuel injectors circumferentially arranged around the combustion chamber to supply additional fuel for combustion. The additional fuel supplied by the fuel injectors increases the firing temperature of the combustor without producing a corresponding increase in the residence time of the combustion gases inside the combustion chamber.

[0005] Although effective at enabling higher operating temperatures, the axial and circumferential location of the fuel injectors around the combustion chamber may have a substantial impact on undesirable emissions and/or component wear. For example, fuel injectors that inject fuel directly into the combusting fuel-air mixture flowing from the fuel nozzles may produce undesirable hot streaks inside the combustor that may increase the NO_X emissions and reduce the low cycle fatigue of components. Alternately, fuel injectors that inject fuel too far from the combusting fuel-air mixture flowing from the fuel nozzles may lead to incomplete combustion of the fuel, increasing the production of carbon monoxide and unburned hydrocarbons. As a result, a system for supplying fuel to a combustor that indexes or clocks the fuel injectors to the fuel nozzles and/or the swirling fuel-air mixture flowing from the fuel nozzles may allow for increased combustor temperatures over a wider range of operating conditions without a corresponding increase in undesirable emissions and/or component wear.

BRIEF DESCRIPTION OF THE INVENTION

[0006] Aspects and advantages of the invention are set forth below in the following description, or may be obvious from the description, or may be learned through practice of the invention.

[0007] One aspect of the present invention is a system for supplying fuel to a combustor that includes a combustion chamber and a liner that circumferentially surrounds at least a portion of the combustion chamber. A plurality of fuel nozzles are radially arranged across the combustor upstream from the combustion chamber to supply a swirling flow of fuel into the combustion chamber. A first fuel injector downstream from the plurality of fuel nozzles provides fluid communication for fuel to flow through the liner and into the combustion chamber. The first fuel injector is circumferentially clocked with respect to the swirling flow of fuel in the combustion chamber.

[0008] Another aspect of the present invention is a system for supplying fuel to a combustor that includes a combustion chamber and a liner that circumferentially surrounds at least a portion of the combustion chamber. A plurality of fuel nozzles are radially arranged across the combustor upstream from the combustion chamber to supply a swirling flow of fuel into the combustion chamber. A first set of fuel injectors are circumferentially arranged around the liner downstream from the plurality of fuel nozzles. The first set of fuel injectors provide fluid communication for fuel to flow through the liner and into the combustion chamber and are circumferentially clocked with respect to the swirling flow of fuel in the combustion chamber.

[0009] The present invention may also reside in a gas turbine having a compressor, a combustor downstream from the compressor, and a turbine downstream from the combustor. A plurality of fuel nozzles are radially arranged inside the combustor, and a combustion chamber is downstream from the plurality of fuel nozzles. The plurality of fuel nozzles supply a swirling flow of fuel into the combustion chamber. A first set of fuel injectors are circumferentially arranged around the combustion chamber downstream from the plurality of fuel nozzles. The first set of fuel injectors provide fluid communication for fuel to flow into the combustion chamber and are circumferentially clocked with respect to the swirling flow of fuel in the combustion chamber.

[0010] Those of ordinary skill in the art will better appreciate the features and aspects of such embodiments, and others, upon review of the specification.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] A full and enabling disclosure of the present invention, including the best mode thereof to one skilled in the art, is set forth more particularly in the remainder of the specification, including reference to the accompanying figures, in which:

Fig. 1 is a functional block diagram of an exemplary gas turbine within the scope of the present invention;

Fig. 2 is a simplified side cross-section view of an exemplary combustor according to various embodiments of the present invention;

Fig. 3 is an enlarged partial side cross-section view of the cap assembly and fuel nozzles shown in Fig. 2;

Fig. 4 is an enlarged side cross-section view of an exemplary fuel injector shown in Fig. 2;

Fig. 5 is an upstream partial perspective side cross-section view of the combustor shown in Fig. 2 according to an embodiment of the present invention; and

Fig. 6 is a set of emissions curves at various temperatures.

DETAILED DESCRIPTION OF THE INVENTION

[0012] Reference will now be made in detail to present embodiments of the invention, one or more examples of which are illustrated in the accompanying drawings. The detailed description uses numerical and letter designations to refer to features in the drawings. Like or similar designations in the drawings and description have been used to refer to like or similar parts of the invention. As used herein, the terms "first", "second", and "third" may be used interchangeably to distinguish one component from another and are not intended to signify location or importance of the individual components. The terms "upstream," "downstream," "radially," and "axially" refer to the relative direction with respect to fluid flow in a fluid pathway. For example, "upstream" refers to the direction from which the fluid flows, and "downstream" refers to the direction to which the fluid flows. Similarly, "radially" refers to the relative direction substantially perpendicular to the fluid flow, and "axially" refers to the relative direction substantially parallel to the fluid flow.

[0013] Each example is provided by way of explanation of the invention, not limitation of the invention. In fact, it will be apparent to those skilled in the art that modifications and variations can be made in the present invention without departing from the scope or spirit thereof. For instance, features illustrated or described as part of one embodiment may be used on another embodiment to yield a still further embodiment. Thus, it is intended that the present invention covers such modifications and variations as come within the scope of the appended claims and their equivalents.

[0014] Various embodiments of the present invention include a system for supplying fuel to a combustor. The combustor generally includes a cap assembly that extends radially across at least a portion of the combustor, and a plurality of fuel nozzles radially arranged in the cap assembly supply a swirling flow of fuel into a combustion chamber. One or more fuel injectors may be circumferentially arranged around the combustion chamber to supply fuel into the combustion chamber, and each fuel injector is circumferentially indexed or clocked with respect to the swirling flow of fuel in the combustion chamber. In particular embodiments, the fuel injectors may be axially aligned with one another, while in other particular embodiments, the fuel injectors may be axially staggered inside the combustion chamber. Alternately or in addition, the fuel injectors may intersect the combustion chamber perpendicular to a tangent of the combustion chamber or at a compound angle, depending on the particular embodiment. As a result, various embodiments of the present invention may allow extended combustor operating conditions, extend the life and/or maintenance intervals for various combustor components, maintain adequate design margins of flame holding, and/or reduce undesirable emissions. Although exemplary embodiments of the present invention will be described generally in the context of a combustor incorporated into a gas turbine for purposes of illustration, one of ordinary skill in the art will readily appreciate that embodiments of the present invention may be applied to any combustor incorporated into any turbo-machine and are not limited to a gas turbine combustor unless specifically recited in the claims.

[0015] Referring now to the drawings, wherein identical numerals indicate the same elements throughout the figures, Fig. 1 provides a functional block diagram of an exemplary gas turbine 10 that may incorporate various embodiments of the present invention. As shown, the gas turbine 10 generally includes an inlet section 12 that may include a series of filters, cooling coils, moisture separators, and/or other devices to purify and otherwise condition a working fluid (e.g., air) 14 entering the gas turbine 10. The working fluid 14 flows to a compressor section where a compressor 16 progressively imparts kinetic energy to the working fluid 14 to produce a compressed working fluid 18 at a highly energized state. The compressed working fluid 18 flows to a combustion section where one or more combustors 20 ignite fuel 22 with the compressed working fluid 18 to produce combustion gases 24 having a high temperature and pressure. The combustion gases 24 flow through a turbine section to produce work. For example, a turbine 26 may connect to a shaft 28 so that rotation of the turbine 26 drives the compressor 16 to produce the compressed working fluid 18. Alternately or in addition, the shaft 28 may connect the turbine 26 to a generator 30 for producing electricity. Exhaust gases 32 from the turbine 26 flow through an exhaust section 34 that may connect the turbine 26 to an exhaust stack 36 downstream from the turbine 26. The exhaust section 34 may include, for example, a heat recovery steam generator (not shown) for cleaning and extracting additional heat from the exhaust gases 32 prior to release to the environment.

[0016] The combustors 20 may be any type of combustor known in the art, and the present invention is not limited to any particular combustor design unless specifically recited in the claims. Fig. 2 provides a simplified side cross-section view of an exemplary combustor 20 according to various embodiments of the present invention. As shown in Fig. 2, a casing 40 and an end cover 42 may combine to contain the compressed working fluid 18 flowing to the combustor 20. A cap assembly 44 may extend radially across at least a portion of the combustor 20, and one or more fuel nozzles 46 may be radially arranged across the cap assembly 44 to supply the fuel 22 to a combustion chamber 48 downstream from the cap assembly 44. A liner 50 may circumferentially surround at least a portion of the combustion chamber 48, and a transition duct 52 downstream from the liner 50 may connect the combustion chamber 48 to the inlet of the turbine 26. An impingement sleeve 54 with flow holes 56 may circumferentially surround the transition duct 52, and a flow sleeve 58 may circumferentially surround the liner 50. In this manner, the compressed working fluid 18 may pass through the flow holes 56 in the impingement sleeve 54 to flow through an annular passage 60 outside of the transition duct 52 and liner 50 to provide convective cooling to the transition duct 52 and liner 50. When the compressed working fluid 18 reaches the end cover 42, the compressed working fluid 18 reverses direction to flow through the fuel nozzles 46 and cap assembly 44 into the combustion chamber 48.

[0017] The present invention is not limited to any particular cap assembly 44 or fuel nozzles 46 unless specifically recited in the claims, and Fig. 3 provides an enlarged partial side cross-section view of an exemplary cap assembly 44 and fuel nozzles 46 within the scope of the present invention. As shown in Fig. 3, each fuel nozzle 46 may generally include a center body 62 surrounded by a shroud 64 to define an annular passage 66 between the center body 62 and the shroud 64. The center body 62 generally extends axially from the end cover 42 toward the cap assembly 44 to provide fluid communication for the fuel 22, diluents, and/or other additives to flow from the end cover 42, through the center body 62, and into the combustion chamber 48. The shroud 64 may include a bellmouth opening 68 to enhance the radial distribution of the compressed working fluid 18 flowing through the annular passage 66 between the center body 62 and the shroud 64. In addition, one or more vanes 70 may extend radially between the center body 62 and the shroud 64 to impart a tangential swirl to the compressed working fluid 18 to enhance mixing between the compressed working fluid 18 and the fuel 22 prior to combustion.

[0018] Referring back to Fig. 2, the combustor 20 may further include one or more fuel injectors 80 downstream from the fuel nozzles 46 that that may provide a late lean injection of fuel 22 and compressed working fluid 18 for combustion. The present invention is not limited to any particular fuel injector 80 unless specifically recited in the claims, and Fig. 4 provides an enlarged side cross-section view of an exemplary fuel injector 80 within the scope of the present invention. As shown in Fig. 4, the fuel injector 80 may include a tube 82 or other passage that provides fluid communication through the flow sleeve 58 and the liner 50 into the combustion chamber 48. In the exemplary embodiment shown in Fig. 4, the tube 82 is substantially perpendicular to the flow sleeve 58 and liner 50 to inject the fuel-air mixture transverse to the combustion chamber 48; however, in other embodiments, the tube 82 may be angled axially and/or circumferentially with respect to the flow sleeve 58 and/or liner 50.

[0019] The flow sleeve 58 may include an internal fuel passage 84, and each tube 82 may include one or more fuel ports 86 circumferentially arranged around the tube 82. The internal fuel passage 84 may supply the same or a different fuel 22 to the fuel ports 86 than is supplied to the fuel nozzles 34. The fuel ports 86 may thus provide fluid communication for the fuel 22 to flow into the tubes 82 to allow the fuel 22 and compressed working fluid 18 to mix while flowing through the tubes 82 and into the combustion chamber 48. In this manner, the tubes 82 may supply a lean mixture of fuel 22 and compressed working fluid 18 for additional combustion to raise the temperature, and thus the efficiency, of the combustor 20.

[0020] Fig. 5 provides an upstream partial perspective side cross-section view of the combustor 20 shown in Fig. 2 to illustrate the position of the fuel injectors 80 with respect to the fuel nozzles 46. As shown in Fig. 5, the vanes 70 in the fuel nozzles 46 impart a tangential swirl to the fuel 22 and compressed working fluid 18 flowing through the annular passage 66 between the center body 62 and the shroud 64. As a result, each fuel nozzle 46 supplies a separate swirling flow of fuel 90 that slowly spirals downstream through the combustion chamber 48 as it combusts. In the particular embodiment shown in Fig. 5, a first set of fuel injectors 92 are circumferentially arranged around the liner 50 downstream from the fuel nozzles 46, and a second set of fuel injectors 94 are circumferentially arranged around the liner 50 downstream from the first set of fuel injectors 92. Each fuel injector 80 in each set of fuel injectors 92, 94 has the same axial position as the other fuel injectors 80 in the same set 92, 94. In addition, each fuel injector 80 in the each set of fuel injectors 92, 94 is circumferentially indexed or clocked with respect to the swirling flow of fuel 90 from a different fuel nozzle 46. As used herein, the term "clocked" or "clocking" refers to positioning each fuel injector 80 at a desired circumferential offset 96 with respect to the swirling flow of fuel 90. The circumferential offset 96 between each fuel injector 80 and the swirling flow of fuel 90 avoids or reduces the undesirable hot streaks and incomplete combustion of the fuel 22 associated with previous late lean injections systems and methods. In addition, in the particular embodiment shown in Fig. 5, each fuel injector 80 is angled axially and circumferentially so that each fuel injector 80 intersects the liner 50 at a compound angle to further enhance the benefit of clocking the fuel injectors 80 with respect to the swirling flow of fuel 90.

[0021] The optimum amount of clocking or circumferential offset 96 between each fuel injector 80 and the swirling flow of fuel 90 may be varies according to various factors, such as the number of fuel nozzles 46, the amount of swirl induced by each fuel nozzle 46, the number of fuel injectors 80, the axial and/or circumferential angle of the fuel injectors 80, and the anticipated operating level for the combustor 20. For example, the optimum clocking or circumferential offset 96 may be approximately $\pm$2-15 degrees for a combustor 20 with five or more fuel nozzles 46, approximately $\pm$10-25 degrees for a combustor 20 with four fuel nozzles 46, and approximately $\pm$20-45 degrees for a combustor 20 with three or fewer fuel nozzles 46.

[0022] The particular clocking or circumferential offset 96 for each embodiment may be determined empirically through computational fluid dynamic models and/or through experimentation. For example, Fig. 6 provides a set of emissions curves for a particular circumferential offset 96 for the fuel nozzles 46 and first and second sets of fuel injectors 92, 94. As expected, the carbon monoxide emissions curve 100 indicates that carbon monoxide emissions using only the fuel nozzles 46 increase significantly below lower combustion temperatures associated with reduced fuel flow and/or part load operation (turndown). Supplying additional fuel 22 through the first set of fuel injectors 92 or through both the first and second sets of fuel injectors 92, 94 during turndown operations shifts the carbon monoxide emissions curve 100 to the right. Conversely, the NO_X emissions curve 102 indicates that NO_X emissions using only the fuel nozzles 46 increase significantly above higher combustion temperatures associated with full load operations, and supplying additional fuel 22 through the first set of fuel injectors 92 or through both the first and second sets of fuel injectors 92, 94 during full load operations shifts the NO_X emissions curve 102 to the right. As a result, the NO_X emissions curves 102 indicate that the lean fuel 22 supplied by the first and second set of fuel injectors 92, 94 enable higher combustion temperatures before the NO_X emissions increase significantly. Additional emissions curves 100, 102 as shown in Fig. 6 may be empirically or experimentally created for first and second sets of fuel injectors 92, 94 clocked at different circumferential offsets 96, and the optimum circumferential offset 96 may be selected based on the collection of emissions curves 100, 102 and anticipated operating schedule for the combustor 20.

[0023] The various embodiments described and illustrated with respect to Figs. 1-5 may provide one or more advantages over existing systems. For example, the various combinations of axial positions of fuel injectors 80 clocked to the swirling flow of fuel 90 may allow for higher combustor temperatures before producing a dramatic increase in NO_X emissions. The wider range of combustor temperatures thus enhances the thermodynamic efficiency of the gas turbine 10 without a corresponding increase in undesirable emissions.

[0024] This written description uses examples to disclose the invention, including the best mode, and also to enable any person skilled in the art to practice the invention, including making and using any devices or systems and performing any incorporated methods. The patentable scope of the invention is defined by the claims, and may include other examples that occur to those skilled in the art. Such other examples are intended to be within the scope of the claims if they include structural elements that do not differ from the literal language of the claims, or if they include equivalent structural elements with insubstantial differences from the literal language of the claims.

Claims

1. A system for supplying fuel to a combustor (20), comprising:

    a combustion chamber (48);
    a liner (50) that circumferentially surrounds at least a portion of the combustion chamber (48);
    a plurality of fuel nozzles (46) radially arranged across the combustor (20) upstream from the

combustion chamber (48), wherein the plurality of fuel nozzles (46) supply a swirling flow of fuel (90) into the combustion chamber (48);
at least one first fuel injector (80) downstream from the plurality of fuel nozzles (46), wherein the at least one first fuel injector (80) provides fluid communication for fuel to flow through the liner (50) and into the combustion chamber (48); and
wherein the at least one first fuel injector (80) is circumferentially clocked with respect to the swirling flow of fuel (90) in the combustion chamber (48).

2. The system as in claim 1, wherein each fuel nozzle (46) comprises a plurality of swirler vanes (70) that extend radially between a center body (62) and a shroud (64).

3. The system as in claims 1 or 2, wherein the at least one first fuel injector (80) comprises a first set of fuel injectors (92).

4. The system as in any of claims 1 to 3, wherein the at least one first fuel injector (80) intersects the liner (50) at a compound angle.

5. The system as in claim 1, further comprising at least one second fuel injector downstream from the plurality of fuel nozzles (46), wherein the second fuel injector (94) provides fluid communication for fuel to flow through the liner (50) and into the combustion chamber (48), and wherein the second fuel injector (94) is circumferentially clocked with respect to the swirling flow of fuel (90) in the combustion chamber (48).

6. The system as in claim 5, wherein the at least one second fuel injectors comprises a second set of fuel injectors (94).

7. The system as in claim 5 or 6, wherein the at least one second fuel injector (94) is axially aligned substantially even with the first fuel injector (80).

8. The system as in claim 5 or 6, wherein the at least one second fuel injector (94) is axially aligned in the combustion chamber (48) downstream from the first fuel injector (92).

9. The system as in claim 5 or 6, wherein the at least one second fuel injector (94) intersects the liner (50) at a compound angle.

10. The system as in any preceding claim, further comprising a flow sleeve (58) that circumferentially surrounds at least a portion of the liner (50) and a fuel plenum inside the flow sleeve (58) in fluid communication with the first fuel injector (80).

11. A gas turbine, comprising:

a compressor (16);
a combustor (20) downstream from the compressor (16);
a turbine (26) downstream from the combustor (20); and the system of any of claims 1 to 10.

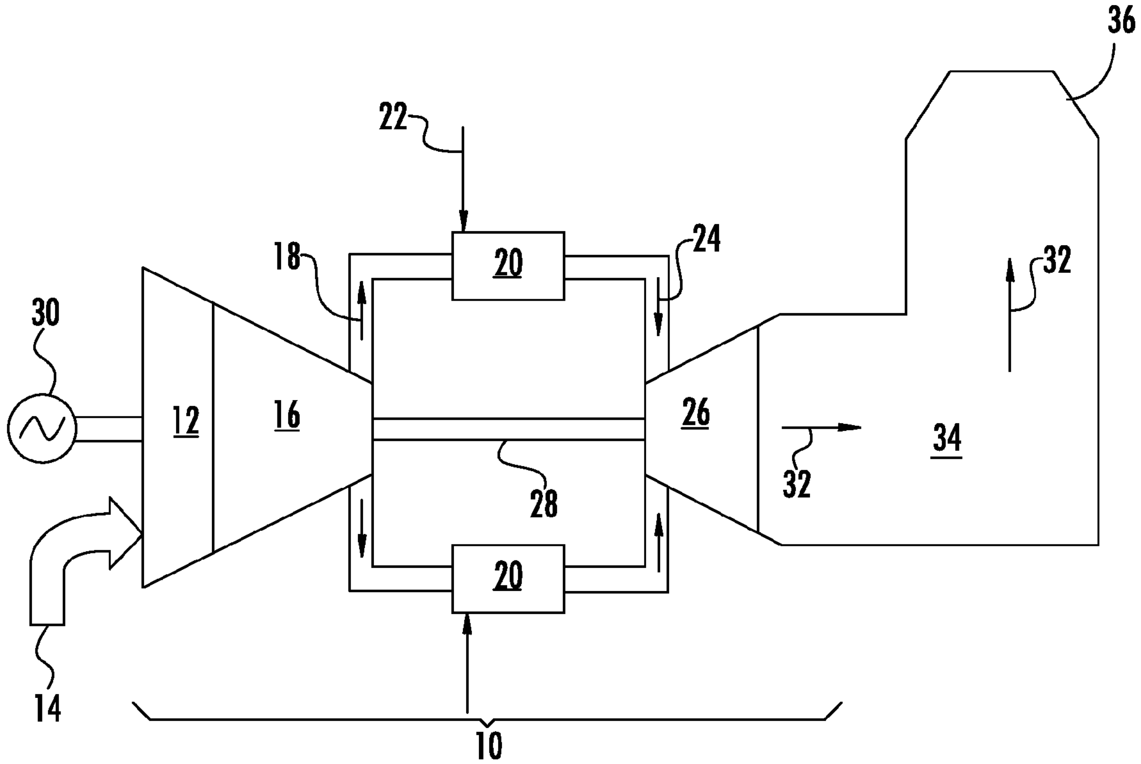

FIG. 1

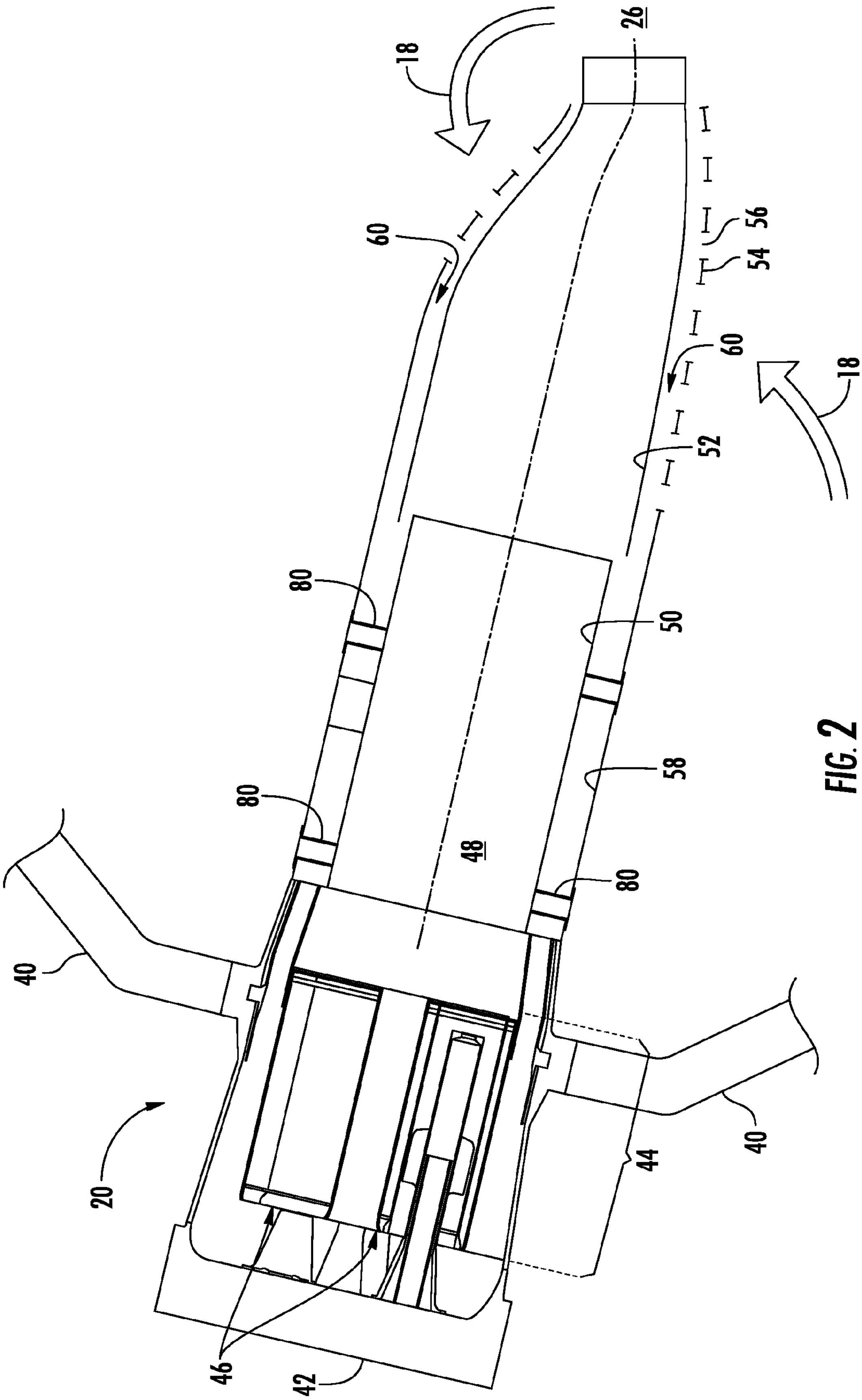

FIG. 2

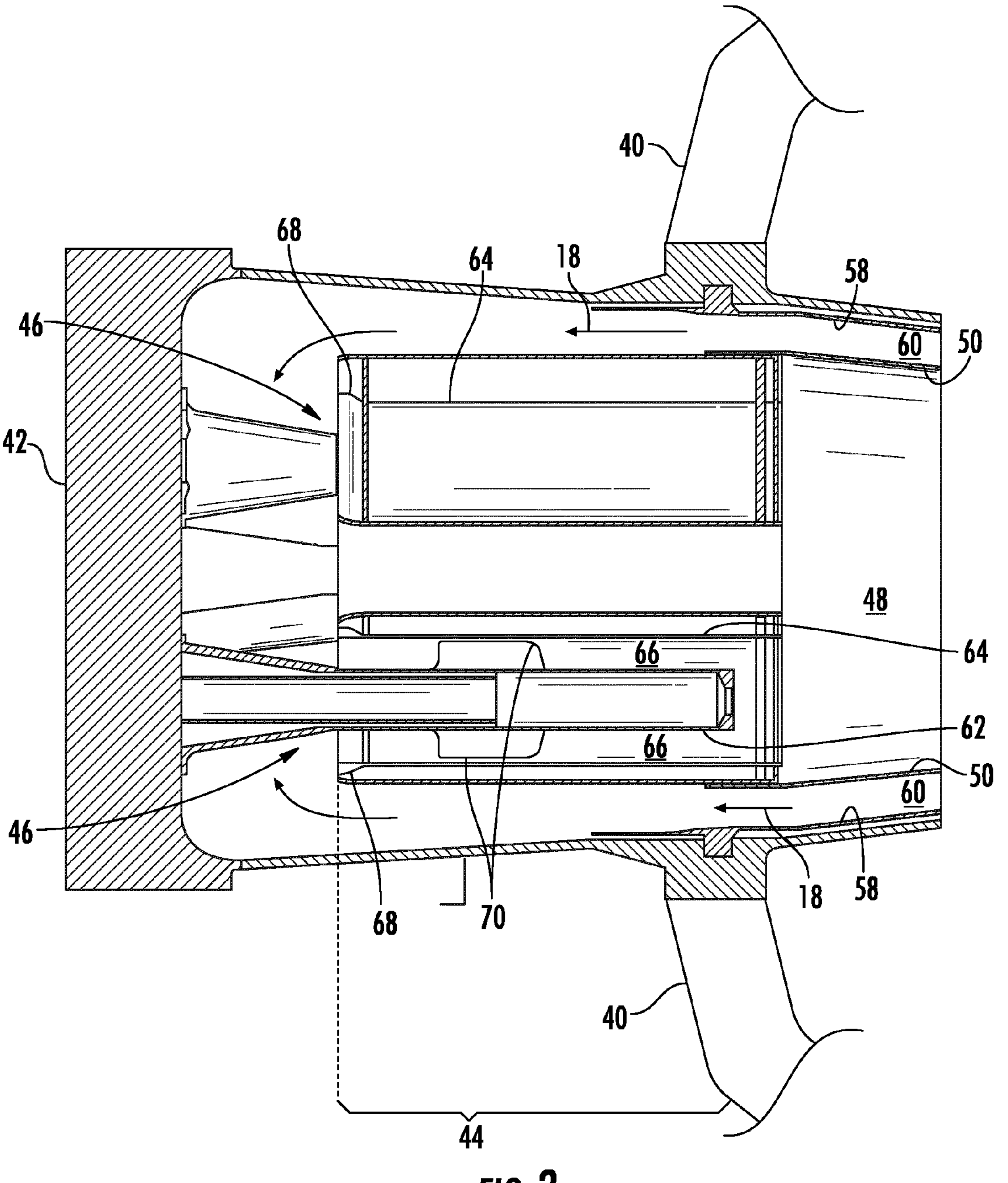

FIG. 3

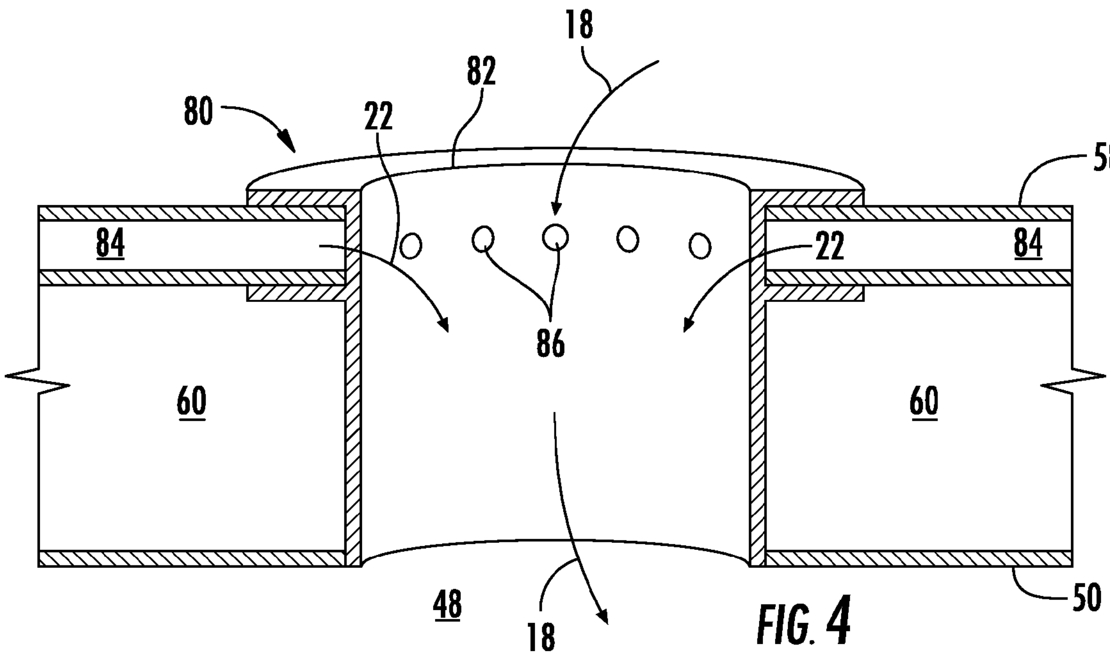

FIG. 4

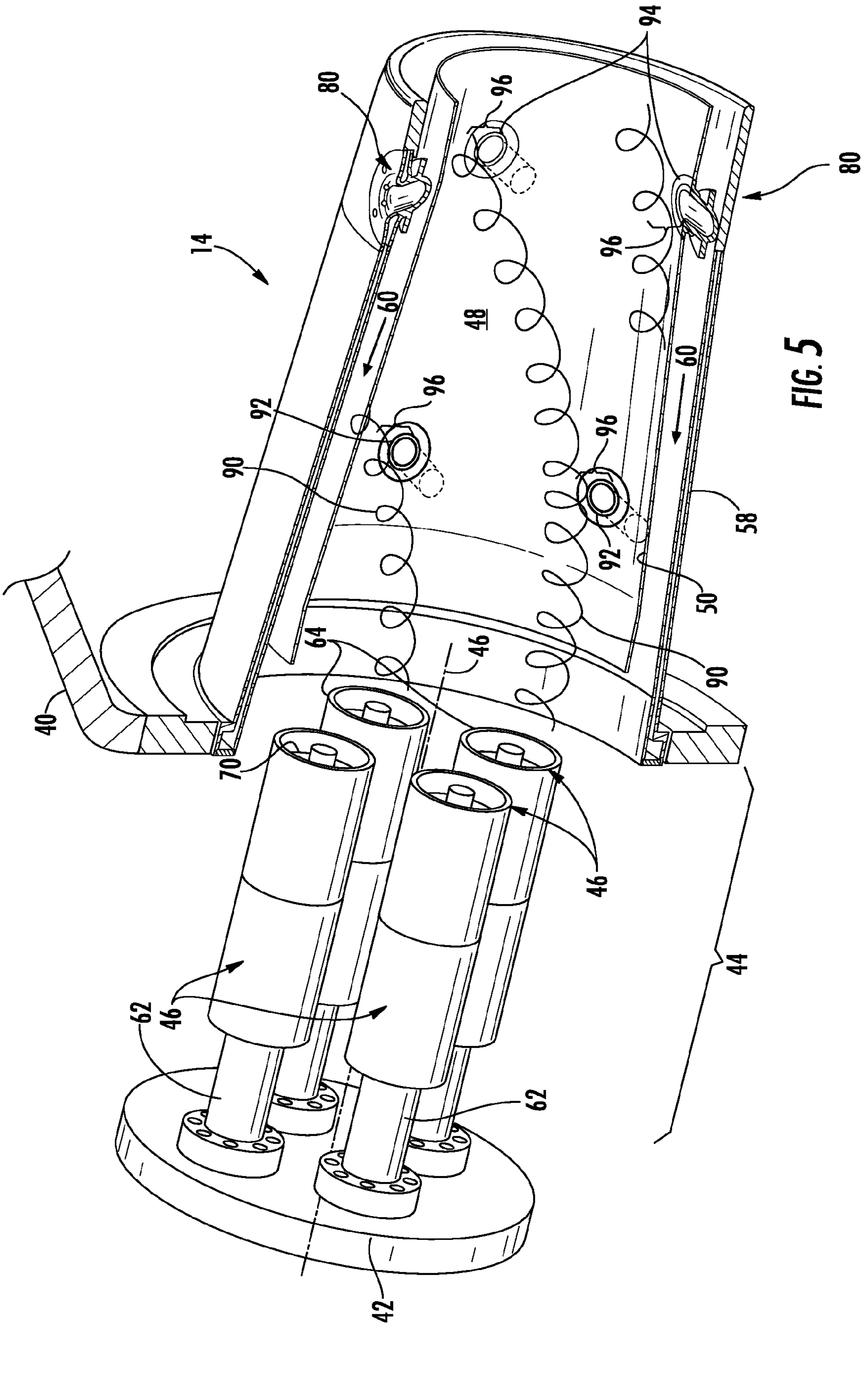
14
80
94
96
80
96
48
60
60
92
96
90
96
92
58
50
90
64
46
40
70
46
44
62
46
62
42

FIG. 5

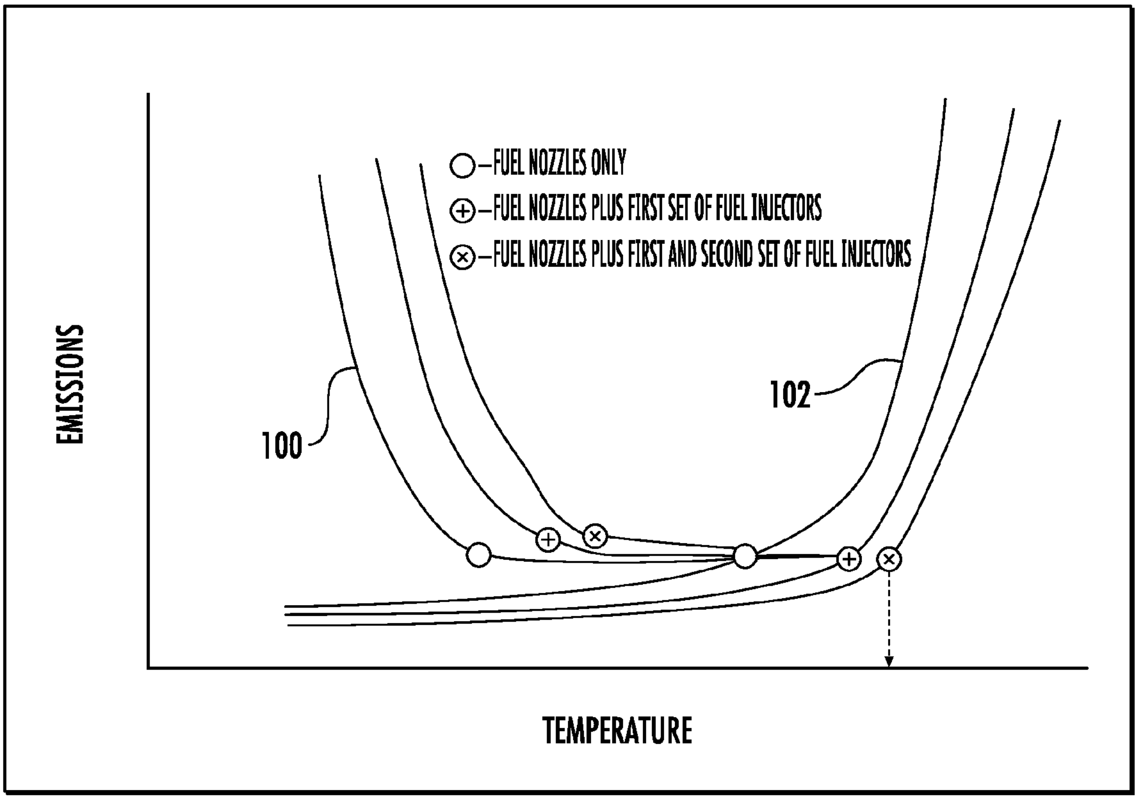
○–FUEL NOZZLES ONLY
⊕–FUEL NOZZLES PLUS FIRST SET OF FUEL INJECTORS
⊗–FUEL NOZZLES PLUS FIRST AND SECOND SET OF FUEL INJECTORS
EMISSIONS
100
102
TEMPERATURE

FIG. 6