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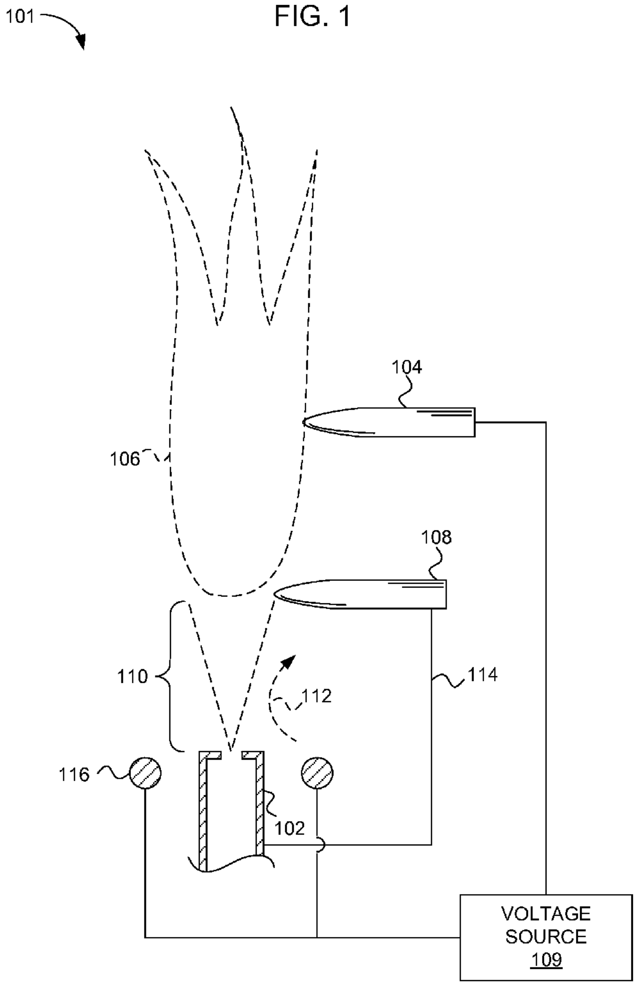
(54) Title: LOW NOx LIFTED FLAME BURNER

FIG. 1



(57) Abstract: Nitrogen oxides (NOx) generated by a fuel burner is reduced by anchoring the flame to a conductive anchor disposed a lift distance from a fuel nozzle, using a voltage applied to the flame.

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LOW NOx LIFTED FLAME BURNER

CROSS-REFERENCE TO RELATED APPLICATIONS

The present application claims priority benefit from U.S. Provisional Patent Application No. 61/653,722, entitled “LOW NO_X LIFTED FLAME BURNER”, filed May 31, 2012, and U.S. Provisional Patent Application No. 61/669,634, entitled “LOW NO_X BURNER AND METHOD OF OPERATING A LOW NO_X BURNER”, filed July 9, 2012, which, to the extent not inconsistent with the disclosure herein, are incorporated by reference.

SUMMARY

According to an embodiment, a lifted flame burner includes a fuel nozzle configured to provide fuel, an electrode configured to carry a voltage and, when the lifted flame burner is operating, to apply the voltage or corresponding charges to a flame supported by the fuel. The electrode may be of any conductive medium including but not limited to solid, liquid, vapor, plasma, gas suspension, or liquid slurry. An electrically conductive flame anchor is positioned adjacent to a fuel jet emitted by the fuel nozzle and not in contact with the electrode. The voltage or charge applied to the flame acts to anchor the flame to the conductive flame anchor. A lift distance between the fuel nozzle and the conductive flame anchor operates as a mixing zone to entrain air or flue gas into, to enhance air mixing with, or to vitiate the fuel jet, which may in turn reduce flame temperature and/or provide reactant stoichiometry to reduce the production of oxides of nitrogen (NOx) by the burner.

According to another embodiment, a method for operating a low NOx burner includes emitting fuel from a fuel nozzle, supporting a flame with the emitted fuel, applying a voltage or majority charge to the flame with an electrode, and anchoring the flame with an electrically conductive flame anchor disposed between the fuel nozzle and the electrode. A lift distance between the fuel nozzle and the electrically conductive flame anchor provides a zone for mixing air or flue gas with the emitted fuel. The mixing of air or flue gas with the emitted fuel may reduce flame temperature and/or provide reactant stoichiometry to reduce the output of NOx by the burner.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a diagram of a lifted flame burner, according to an embodiment.

FIG. 2 is a detail of a lifted flame burner in which the flame anchor includes a ring disposed axially and circumferentially to the fuel nozzle, according to an embodiment.

FIG. 3 is a detail of a lifted flame burner in which the flame anchor includes one or more projections extending from the fuel nozzle, according to an embodiment.

FIG. 4 is a diagram of a lifted flame burner including a flame anchor positioning mechanism configured to actuate a position of the flame anchor between two or more distances from the fuel nozzle, according to an embodiment.

FIG. 5 is a flow chart showing a method for operating a low oxides of nitrogen (NOx) burner, according to an embodiment.

FIG. 6 is a diagram showing an illustrative mechanism for flame anchoring phenomena described in conjunction with **FIGS. 1-5**, according to an embodiment.

DETAILED DESCRIPTION

In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, similar symbols typically identify similar components, unless context dictates otherwise. The illustrative embodiments described in the detailed description, drawings, and claims are not meant to be limiting. Other embodiments may be utilized, and other changes may be made, without departing from the spirit or scope of the subject matter presented here.

FIG. 1 is a diagram of a lifted flame burner 101, according to an embodiment. The lifted flame burner 101 includes a fuel nozzle 102 configured to provide fuel, an electrode 104 configured to carry a voltage and positioned away from the fuel nozzle 102, and a conductive flame anchor 108 positioned between the fuel nozzle 102 and the electrode 104. The conductive flame anchor 108 is typically supported to be away from contact with the electrode 104. When the lifted flame burner 101 is operating, the electrode 104 is in at least intermittent contact with a flame 106 supported by the fuel nozzle 102. In other embodiments, the electrode 104 may be in proximity to the flame 106, but not in direct contact with the flame 106.

The electrode 104 and the flame anchor 108 may be similar or even identical in structure, as shown in **FIG. 1**, or they can have significant differences in shape or structure. In general, a principle distinction between the electrode 104 and the flame anchor 108 is that the electrode 104 applies charges to the combustion fluid (e.g. applies a voltage to the flame 106), and the flame anchor 108 conducts current from the flame 106 to a holding voltage node (e.g., to ground). The electrode 104 can be placed in contact with the flame 106 to apply the voltage. Alternatively, the electrode 104 can be positioned upstream from the flame 106 to output charges for entrainment in the fuel jet 110, combustion air, or flue gas 112 that is, in turn, entrained into the flame 106.

A voltage source 109 is configured to apply the voltage to the electrode 104.

The fuel nozzle 102 may be configured to provide a gaseous liquid or powdered solid fuel. It is contemplated that the approaches disclosed herein can work with many fuels that can be delivered through a nozzle. For example, additional fuels may include various hydrocarbon gases such as methane (natural gas), ethane, propane, and acetylene; liquid hydrocarbon fuels such as various grades of oil, kerosene, and gasoline; and/or solid hydrocarbon fuels such as powdered coal. It is possible that a partially-reacted fuel carrying ions able to carry positive charges, such as, e.g., carbocations will work better than a fuel not able to form an ion.

The fuel nozzle 102 is configured to cause the fuel jet 110 to flow past the flame anchor 108. The velocity of the fuel jet 110 may be greater than a flame propagation velocity in at least some cases. The voltage carried by the electrode 104 causes the flame 106 to anchor to the conductive flame anchor 108, even at a high fuel jet 110 velocity. In some embodiments, the flame anchor 108 is in direct continuity with ground. According to other embodiments, the flame anchor 108 is in continuity with ground through a high impedance device such as a resistor, is isolated from ground, or is configured to carry a voltage that is inverted relative to the voltage carried by the electrode 104. The high impedance may be between 0.1 and 100 mega-ohms (MΩ), or (more particularly, for some embodiments) a simple resistor having a value between about 1 and about 50 MΩ. In an embodiment, the resistor is between 6 and 8 MΩ.

Optionally, a reflection electrode 116 is disposed circumferential to the fuel nozzle 102 and configured to carry a voltage having the same polarity as the voltage carried by the electrode 104. The reflection electrode 116 is configured to reduce or prevent flashback between the flame anchor 108 and the fuel nozzle 102.

At least a portion of the flame anchor 108 is spaced away from the fuel nozzle 102. The fuel nozzle 102 is configured to cause fuel to flow past the flame anchor 108. The fuel flow 110 between the fuel nozzle 102 and the spaced away portion of the flame anchor 108 entrains air or flue gas 112 to provide premixing or dilution of the fuel with the air or flue gas 112. Flue gas 112 is typically about 3% oxygen. If the entrained gas 112 is flue gas 112, the main effect of entraining flue gas 112 is dilution of the fuel or fuel/air mixture, and is typically done to reduce flame temperature. Air is typically about 21% oxygen. If the entrained gas 112 is air, the main effect of entraining air is premixing the oxygen in the air with the fuel to provide better homogeneity of the flame 106. Moreover, it may be desirable to burn the flame 106 with oxidizer and fuel at least partially premixed to near a stoichiometric ratio and/or near a flammability limit in the presence of an electric field produced at least partially by the electrode 104.

An effect of the premixing of the fuel of lifted flame burner 101 with the entrained air or flue gas 112 is a reduced temperature of the flame 106. A reduced temperature of the flame 106 may cause a reduction in the production of oxides of nitrogen (NOx).

According to an embodiment, the fuel nozzle 102 is a premix nozzle configured to at least partially premix fuel with combustion air prior to emitting the fuel jet 110.

In the lifted flame burner 101, the electrode 104 is typically configured to impart electrical charges or a voltage onto the flame 106. The voltage source 109 drives the electrode 104. The voltage source 109 may drive the electrode 104 to impart a time-varying voltage such as an AC voltage onto the flame 106. The time-varying voltage may include a peak-to-peak voltage variation of about ±2000 volts to ±100,000 volts. Other voltages outside this range may also be appropriate for particular applications.

The inventors have found that the best voltage range tends to be proportional to the velocity of a fuel jet 110, or alternatively, fuel pressure (ceteris paribus): the lower the fuel velocity or pressure, the lower the required voltage. Thus, even high heat release applications may be anchored with a voltage at the low end of the indicated range if the orifice size is sufficiently large or the distance from the fuel nozzle 102 to the conductive flame anchor 108 is sufficiently large. Fuel jet 110 velocity is proportional to 1/d and 1/x, where d is the fuel nozzle 102 diameter and x is the distance from the fuel nozzle 102. Reducing fuel velocities (pressures) is limited by flame quality; low velocity jets have low momentum and are poor at entraining surrounding air or fluid. Increasing distance from the fuel nozzle 102 is limited by the flammability limits; eventually, one gets so far away from the fuel nozzle 102 that too much flue gas 112 or air is entrained and the mixture is no longer flammable. Embodiments described herein have been found to allow quite large distances between the fuel nozzle 102 and the flame anchor 108 and still have a stable flame 106, especially when voltage is applied which may accelerate the flame speed and chemical kinetics.

The time-varying voltage may include a waveform having a frequency between about 1 and about 2000 Hertz, or (more particularly, for some embodiments) a waveform having a frequency between about 100 and about 1000 Hertz. The waveform of the time-varying voltage may include a sinusoidal, square, triangle, truncated triangle, or sawtooth waveform, or an arbitrary waveform including combinations of the mentioned waveforms. Asymmetric waveforms may be most appropriate for some embodiments.

The flame anchor 108 is electrically isolated from ground and from voltages not carried by the flame 106. The fuel nozzle 102 is conductive and electrically isolated from ground and from voltages not carried by the flame 106. The flame anchor 108 and the fuel nozzle 102 can be in electrical continuity with one another; for example, via an electrical connection 114.

FIG. 2 illustrates an embodiment 201 of a lifted flame burner in which the flame anchor 108 includes a ring disposed axially and circumferentially to the fuel nozzle 102. The ring is disposed near an outer periphery of a fuel jet 110 emitted from the fuel nozzle 102 during operation of the lifted flame burner 201.

FIG. 3 illustrates an embodiment 301 of a lifted flame burner in which the flame anchor 108 includes one or more projections extending from the fuel nozzle 102. The fuel jet region 110 for entrainment of air or flue gas 112 corresponds to the height of the projection(s) 108.

In another embodiment, the flame anchor 108 may be centrally located. For example, in experiments conducted by the inventors, a centrally located projection surrounded by a fuel nozzle 102 array, including a plurality of orifices, was found to work substantially as described.

FIGS. 1-3 illustrate some alternative flame anchor 108 embodiments. Other arrangements fall within the scope of the description and claims herein. For example, flame anchors 108 need not necessarily be axially symmetric with respect to flame axis. One embodiment of this is illustrated in **FIG. 1**. Referring to **FIG. 3**, the one or more projections 108 may be slanted toward or away from a central axis of a fuel jet 110 or flame 106. Such embodiments may allow automatic migration of a flame attachment point with changes in operating conditions, optionally, with or without concurrent changes in operating parameters via a logic circuit such as a flame anchor controller 404 (described below) or a logic circuit operatively coupled to or embedded in a voltage source 109.

According to an embodiment, a plurality of flame anchors 108 is provided; each positioned at a different distance from the fuel nozzle 102. A flame anchor controller 404 is configured to selectively isolate from or couple the individual flame anchors 108 to, e.g., ground or a voltage source 109. The flame anchor controller 404 can thus select which of the flame anchors 108 will act at any given moment to anchor the flame 106, and therefore the distance from the fuel nozzle 102 at which the flame 106 is anchored.

FIG. 4 illustrates a lifted flame burner 401 including a flame anchor positioning mechanism 402 configured to control a distance of the flame anchor 108 from the fuel nozzle 102, according to an embodiment. A flame anchor controller 404 is configured to drive the flame anchor positioning mechanism 402 to position the flame anchor 108 within a range of distances. The flame anchor controller 404 may select a position responsive to a condition of the flame 106, a fuel flow rate, a voltage carried by the flame anchor or electrode, etc., as detected by a sensor 406 that is operatively coupled to the flame anchor controller 404. Conditions of the flame 106 that are sensed by the sensor 406 may include, for example, temperature, luminosity, and/or size.

The flame anchor controller 404 may be configured to drive the flame anchor positioning mechanism 402 to reduce a distance between the fuel nozzle 102 and the flame anchor 108 if the temperature, luminosity, or size of the flame 106 diminishes in a way that is indicative of too much dilution of the fuel. Conversely, the flame anchor controller 404 may be configured to drive the flame anchor positioning mechanism 402 to increase a distance between the fuel nozzle 102 and the flame anchor 108 if the temperature, luminosity, or size of the flame 106 increases in a way that is indicative that more fuel dilution is desirable. Alternatively, the flame anchor controller 404 may be configured to drive the flame anchor positioning mechanism 402 to increase the distance between the fuel nozzle 102 and the flame anchor 108 responsive to sensing or opening a valve corresponding to increased fuel flow, or may drive the flame anchor positioning mechanism 402 to decrease the distance between the fuel nozzle 102 and the flame anchor 108 responsive to decreased fuel flow.

The inventors found that flames are typically more luminous the closer they are attached to the fuel nozzle 102. In other words, closer spacing between the fuel nozzle 102 and the flame anchor 108 were found to exhibit larger visible radiation output from the flame 106. Accordingly, luminosity can act as a gauge of attachment position, and a feedback circuit based on flame luminosity may have advantageous attributes.

The flame anchor controller 404 may be configured to drive the flame anchor positioning mechanism 402 to maintain the flame anchor 108 in a stable flame-anchoring position consistent with the voltage applied to the electrode 104. For example, in embodiments where the fuel flows past the flame anchor 108 at a velocity higher than a flame propagation velocity, loss of electrode voltage may nominally result in flame blow-off. According to an embodiment, the flame anchor positioning mechanism 402 includes a fail-safe feature that includes a spring configured to move the flame anchor 108 to a position corresponding to a lower fuel jet 110 velocity if a solenoid fails to hold the flame anchor 108 at an electrode voltage-on position. A loss of electrode voltage deenergizes the solenoid, which engages the fail-safe feature to reposition the flame anchor 108. Additionally or alternatively, the flame anchor controller 404 may be configured to actuate the flame anchor positioning mechanism 402 responsive to a loss in electrode voltage.

According to an embodiment, the flame anchor controller 404 includes a human interface configured to receive manual input for positioning the flame anchor 108.

FIG. 5 is a flow chart 501 of a method for operating a low oxides of nitrogen (NOx) burner, according to an embodiment. In step 502, fuel is emitted from a fuel nozzle. Step 502 may include emitting the fuel past the flame anchor at a velocity higher than a flame propagation velocity, for example. The emitted fuel may be a gaseous, liquid, or powdered solid flue, for example.

Step 504 includes supporting a flame with the emitted fuel. It is contemplated that the approaches disclosed herein can work with substantially any fuel that can be delivered through a nozzle. For example, acceptable fuels include various hydrocarbon gases such as methane (natural gas), ethane, and acetylene; liquid hydrocarbon fuels such as various grades of oil, kerosene, and gasoline; and/or solid hydrocarbon fuels such as powdered coal; and any combination of the above blended to some extent with hydrogen.

Proceeding to step 506, a voltage or majority charge is applied to the flame with an electrode. For example, a voltage source can be operated to deliver the voltage to the electrode.

Applying a voltage or majority charge to the flame with an electrode may include applying a time-varying voltage to the electrode. The time-varying voltage may include an AC voltage, for example. The AC voltage may have an amplitude of about ±2000 volts to ±100,000 volts. In some experiments, it was found that ±2000 volts to ±8,000 volts was sufficient to provide lifted flame anchoring. Applying a time-varying voltage to the electrode may include applying a waveform having a frequency between about 1 and about 2000 Hertz, or may (more particularly) include applying a waveform having a frequency between about 200 and about 800 Hertz. Applying a time-varying voltage to the electrode and with the electrode may include applying a sinusoidal, square, triangle, truncated triangle, asymmetric waveform, or sawtooth waveform to the electrode, for example.

Proceeding to step 508, a selected voltage condition is applied to an electrically conductive flame anchor. Step 508 may include providing electrical isolation from the ground and from voltages other than a voltage received from the flame. Alternatively, step 508 may include providing electrical continuity between the electrically conductive flame anchor and an electrically conductive fuel nozzle. The flame anchor and the fuel nozzle may be held in electrical isolation from ground and from voltages other than a voltage received from the flame. Alternatively, step 508 may include holding the flame anchor in electrical continuity with ground, or carrying a voltage on the flame anchor that is different from a voltage carried by the electrode. The flame anchor used in method 501 may or may not be in contact with the electrode.

Proceeding to step 510, the flame is anchored to the electrically conductive flame anchor disposed between the fuel nozzle and the electrode. The flame anchor may include a ring disposed axial and circumferential to the fuel nozzle, for example. The ring is disposed near an outer periphery of a fuel jet emitted from the fuel nozzle. The flame anchor may additionally or alternatively include one or more projections extending from the fuel nozzle.

Step 510 may include anchoring the flame to the flame anchor responsive to at least intermittent current flow between the flame and the flame anchor.

FIG. 6 is a diagram 601 illustrating a theory explaining the behavior of the methods and systems described in conjunction with **FIGS. 1-5**, according to an illustrative embodiment. In the diagram 601, voltage V is plotted as a function of time, t. A first voltage waveform 602, shown as a solid line approximating a sine wave, corresponds to a time-varying voltage applied to the electrode 104 (as shown in **FIG. 1**) described above. When the flame anchor 108 is allowed to float electrically, its voltage is described by a phase-shifted waveform 604, shown as a dashed line. As the first voltage waveform 602 applied to the first electrode increases, the phase-shifted waveform 604 of the conductor follows.

During a first half cycle 606 of the system, the first voltage waveform 602 applied by the electrode to the flame is lower than the phase-shifted waveform 604 responsively held by the flame anchor. During the half cycle 606, electrons are attracted out of the flame toward the flame anchor. Similarly, positively charged species are attracted from proximity to the flame anchor toward the flame. Thus, an increasingly negative charge is accumulated on the flame anchor. Current flow of electrons toward the flame anchor during the half cycle 606 produces the anchoring phenomena described herein.

During a second half cycle 608 of the system, the first voltage waveform 602 applied by the electrode to the flame is higher than the phase-shifted waveform 604 responsively held by the flame anchor 108 (as shown in **FIG. 1**). During the half cycle 608, electrons are attracted from proximity to the flame anchor 108 and into the flame 106 and positive species are attracted from the flame 106 and into proximity with the flame anchor 108. Current flow of positive ions toward the flame anchor or of electrons away from the flame anchor during the half cycle 608 produces the anchoring phenomena described herein.

The movement of charged species to and from the flame anchor 108 is believed to act to initiate the combustion reaction. For example, the charged species may tend to combine with fuel or oxygen to form reactive species that participate in the combustion reaction. Alternatively, the charge species may tend to attract oppositely charged species from fuel or oxygen, with the remaining fuel or oxygen fragment being a reactive species that participates in the combustion reaction.

Other theories may also explain the effects described herein. For example, it is possible that recombination of charges may locally release energy that causes a local portion of the fuel/oxidizer mix to reach an activation energy. Alternatively, a larger effective diameter of an AC-coupled charged species may tend to increase collisions between reactants, and thereby aid initiation of the reaction.

Returning again to **FIG. 5**, proceeding from step 510, at step 512 air or flue gas is entrained into the emitted fuel. The air or flue gas is entrained between the fuel nozzle and at least a portion of the flame anchor, for example. This provides premixing of the fuel with the air or flue gas. Premixing of the fuel with the air or flue gas typically cause a reduced flame temperature, as compared to a flame supported by a fuel jet in which there is no premixing. The reduced flame temperature also causes a reduction in production of oxides of nitrogen (NOx), comparatively. Moreover, increased mixing within the flame (corresponding to responses to inserted voltage or charges) may further cause a decrease in production of NOx.

According to an embodiment, method 501 additionally includes the steps 514 and 516. In step 514, a condition corresponding to the flame is detected, such as, *e.g.*, a flame condition, a fuel flow rate, or a voltage carried by the electrode. At step 516, a flame anchor positioning mechanism is controlled to position the flame anchor responsive to the condition detected in step 514. Step 516 may include actuating a position of the flame anchor between two or more distances from the fuel nozzle. A flame anchor controller is configured to drive the flame anchor positioning mechanism to position the flame anchor .

Detecting the condition in step 514 is accomplished by operating a sensor to sense the flame condition, the fuel flow rate, the voltage carried by the electrode, etc. Flame conditions that may be sensed by the sensor include, e.g., flame temperature, luminosity, and size.

In carrying out step 516 of method 501, the flame anchor controller may for example drive the flame anchor positioning mechanism to reduce a distance between the fuel nozzle and the flame anchor if the temperature, luminosity, or size of the flame diminishes in a way that is indicative of too much dilution of the fuel. Conversely, the flame anchor controller may drive the flame anchor positioning mechanism to increase a distance between the fuel nozzle and the flame anchor if the temperature, luminosity, or size of the flame increases in a way that is indicative that more fuel dilution is desirable. Alternatively, the flame anchor controller may drive the flame anchor positioning mechanism to increase a distance between the fuel nozzle and flame anchor responsive to sensing increased fuel flow or opening a valve corresponding to increased fuel jet, or the flame anchor controller may drive the flame anchor positioning mechanism to decrease a distance between the fuel nozzle and flame anchor responsive to decreased fuel jet.

Step 516 may also include moving the flame anchor to a stable flame-anchoring position if the voltage applied to the electrode diminishes. For example, in embodiments where the fuel flows past the flame anchor at a velocity higher than a flame propagation velocity, loss of electrode voltage may nominally result in flame blow-off. The flame anchor positioning mechanism may include a fail-safe feature where a spring moves the flame anchor to a position corresponding to a lower flow velocity if a solenoid fails to hold the flame anchor at an electrode voltage-on position. Additionally or alternatively, the flame anchor controller may actuate the flame anchor positioning mechanism responsive to a loss in electrode voltage.

Method 501 may also include a step of applying a voltage having the same sign as the voltage carried by the electrode to a reflection electrode that is disposed circumferential to the fuel nozzle. Applying the voltage to the reflection electrode may cause a reduction or prevention of flashback between the flame anchor and the fuel nozzle.

While various aspects and embodiments have been disclosed herein, other aspects and embodiments are contemplated. The various aspects and embodiments disclosed herein are for purposes of illustration and are not intended to be limiting, with the true scope and spirit being indicated by the following claims.

CLAIMS

What is claimed is:

1. A lifted flame burner, comprising:

a fuel nozzle configured to emit fuel;

an electrode positioned a first distance from the fuel nozzle and configured to apply a voltage to a flame supported by the fuel nozzle; and

a conductive flame anchor positioned a second distance from the fuel nozzle, the flame anchor being electrically isolated from the electrode.

2. The lifted flame burner of claim 1, wherein the fuel nozzle is configured to emit fuel to flow past the flame anchor at a velocity greater than a flame propagation velocity; and

comprising a voltage source operatively coupled to the electrode and configured to apply a voltage to the flame, via the electrode, sufficient to cause the flame to anchor to the conductive flame anchor.

3. The lifted flame burner of claim 1, wherein at least a portion of the flame anchor is spaced away from the fuel nozzle;

wherein the fuel nozzle is configured to emit fuel to flow past the flame anchor; and

wherein the second distance is sufficient to permit entrainment of air and/or flue gas by the fuel before the fuel passes the flame anchor .

4. The lifted flame burner of claim 3, wherein the premixing causes a reduced flame temperature.

5. The lifted flame burner of claim 4, wherein the reduced flame temperature causes a reduction in production of oxides of nitrogen (NOx).

6. The lifted flame burner of claim 1, further comprising:

a voltage source configured to deliver the voltage to the electrode.

7. The lifted flame burner of claim 6, wherein the voltage source is configured to deliver a time-varying voltage.

8. The lifted flame burner of claim 7, wherein the voltage source is configured to deliver an AC voltage.

9. The lifted flame burner of claim 7, wherein the time-varying voltage includes a peak-to-peak voltage variation within a range of about 2000 volts to 100 kilovolts.

10. The lifted flame burner of claim 7, wherein the time-varying voltage includes a waveform having a frequency of between about 1 and about 2000 Hertz.

11. The lifted flame burner of claim 10, wherein the time-varying voltage includes a waveform having a frequency of between about 200 and about 800 Hertz.

12. The lifted flame burner of claim 7, wherein the time varying voltage includes a sinusoidal, square, triangle, truncated triangle, sawtooth, or asymmetric waveform.

13. The lifted flame burner of claim 1, wherein the flame anchor is electrically isolated from ground and from voltages not carried by the flame.

14. The lifted flame burner of claim 1, wherein the fuel nozzle is conductive and electrically isolated from ground and from voltages not carried by the flame.

15. The lifted flame burner of claim 1, wherein the flame anchor and the fuel nozzle are in electrical continuity with one another.

16. The lifted flame burner of claim 1, wherein the flame anchor includes a ring disposed axially and circumferentially to the fuel nozzle.

17. The lifted flame burner of claim 16, wherein the ring is disposed near an outer periphery of a fuel jet emitted from the fuel nozzle during operation of the lifted flame burner.

18. The lifted flame burner of claim 1, wherein the flame anchor includes one or more projections extending the second distance from the fuel nozzle.

19. The lifted flame burner of claim 1, wherein

the fuel nozzle comprises a plurality of fuel orifices; and

wherein the flame anchor comprises an electrically conductive projection disposed within an area subtended by the plurality of fuel orifices.

20. The lifted flame burner of claim 1, wherein the flame anchor comprises a plurality of conductive elements.

21. The lifted flame burner of claim 20, wherein the plurality of conductive elements comprising the flame anchor are arranged proximate a single fuel nozzle.

22. The lifted flame burner of claim 20, wherein the plurality of conductive elements comprising the flame anchor are distributed amongst a plurality of fuel nozzles.

23. The lifted flame burner of claim 1, wherein the flame anchor includes an elongated body slanted with respect to a fuel nozzle axis.

24. The lifted flame burner of claim 1, wherein the flame anchor includes a plurality of flame anchors disposed at respective distances from the fuel nozzle.

25. The lifted flame burner of claim 24, further comprising:

a flame anchor controller configured to switch electrical continuity amongst the plurality of flame anchors.

26. The lifted flame burner of claim 1, wherein the second distance is a range of distances from the fuel nozzle, the burner further comprising:

a flame anchor positioning mechanism configured to control a position of the flame anchor within the range of distances from the fuel nozzle.

27. The lifted flame burner of claim 26, further comprising:

a flame anchor controller configured to drive the flame anchor positioning mechanism to position the flame anchor responsive to a condition of the burner.

28. The lifted flame burner of claim 27, wherein the condition is one of a flame condition, a fuel flow rate, or a voltage carried by the electrode.

29. The lifted flame burner of claim 27, wherein the condition is a temperature of the flame.

30. The lifted flame burner of claim 27, further comprising:

a sensor operatively coupled to the flame anchor controller and configured to sense one of the flame condition, the fuel flow rate, or the voltage carried by the electrode.

31. The lifted flame burner of claim 27, wherein the flame anchor positioning mechanism is configured to move the flame anchor to a stable flame anchoring position if the voltage applied to the electrode diminishes.

32. The lifted flame burner of claim 1, wherein the flame anchor is in electrical continuity with ground.

33. The lifted flame burner of claim 1, wherein the flame anchor is configured to carry a voltage inverted from the voltage carried by the electrode.

34. The lifted flame burner of claim 1, wherein the fuel nozzle includes a nozzle configured to premix fuel and air prior to emitting mixed fuel and air.

35. A method for operating a low oxides of nitrogen (NOx) burner, comprising:

projecting fuel from a fuel nozzle;

supporting a flame with the projected fuel;

applying a voltage or majority charge to the flame; and

anchoring the flame with an electrically conductive flame anchor disposed between the fuel nozzle and the electrode.

36. The method for operating a low NOx burner of claim 35, wherein the voltage or majority charge carried by the flame electrically communicates with the electrically conductive flame anchor to cause the anchoring of the flame.

37. The method for operating a low NOx burner of claim 35, wherein anchoring the flame comprises:

providing a selected voltage condition to the flame anchor.

38. The method for operating a low NOx burner of claim 37, wherein providing the selected voltage condition comprises:

electrically isolating the flame anchor from ground and from voltages other than a voltage received from the flame.

39. The method for operating a low NOx burner of claim 37, wherein providing the selected voltage condition includes providing electrical continuity with a conductive fuel nozzle; and

wherein the flame anchor and the fuel nozzle are held in electrical isolation from ground and from voltages other than a voltage received from the flame.

40. The method for operating a low NOx burner of claim 37, wherein providing the selected voltage condition includes holding the flame anchor in electrical continuity with ground.

41. The method for operating a low NOx burner of claim 37, wherein providing the selected voltage condition includes electrically coupling the flame anchor to ground through a high impedance circuit.

42. The method for operating a low NOx burner of claim 37, wherein providing the selected voltage condition includes providing to the flame anchor a voltage inverted from a voltage carried by the electrode.

43. The method for operating a low NOx burner of claim 35, wherein the flame anchor is not in contact with the electrode.

44. The method for operating a low NOx burner of claim 35, wherein projecting the fuel includes projecting the fuel past the flame anchor at a velocity higher than a non-electrically-enhanced flame propagation velocity.

45. The method for operating a low NOx burner of claim 35, wherein anchoring the flame comprises generating at least intermittent current flow between the flame and the flame anchor.

46. The method for operating a low NOx burner of claim 35, further comprising:

entraining air or flue gas with the fuel between the fuel nozzle and at least a portion of the flame anchor to provide premixing of the fuel with the air or flue gas including oxygen.

47. The method for operating a low NOx burner of claim 46, wherein providing premixing causes a reduced flame temperature.

48. The method for operating a low NOx burner of claim 47, wherein the reduced flame temperature causes a reduction in production of oxides of nitrogen (NOx).

49. The method for operating a low NOx burner of claim 46, further comprising:

applying a voltage to a reflection electrode to reduce the incidence of or substantially prevent flashback in premixed fuel and oxygen.

50. The method for operating a low NOx burner of claim 35, further comprising:

premixing the fuel with an oxidizer; and

reducing flashback in premixed fuel and oxidizer by applying a voltage to a reflection electrode.

51. The method for operating a low NOx burner of claim 35, wherein applying a voltage or majority charge to the flame with an electrode includes applying a time-varying voltage to the electrode.

52. The method for operating a low NOx burner of claim 51, wherein applying a time-varying voltage to the electrode includes applying an AC voltage to the electrode.

53. The method for operating a low NOx burner of claim 51, wherein applying a time-varying voltage to the electrode includes applying a peak-to-peak voltage of between about 2000 volts and 100 kilovolts.

54. The method for operating a low NOx burner of claim 51, wherein applying a time-varying voltage to the electrode includes applying a waveform having a frequency of between about 1 and about 2000 Hertz.

55. The method for operating a low NOx burner of claim 54, wherein applying a time-varying voltage to the electrode includes applying a waveform having a frequency of between about 200 and about 800 Hertz.

56. The method for operating a low NOx burner of claim 51, wherein applying a time-varying voltage to the electrode includes applying a sinusoidal, square, triangle, truncated triangle, sawtooth or asymmetric waveform to the electrode.

57. The method for operating a low NOx burner of claim 51, wherein the time varying voltage is selected to increase flame homogeneity.

58. The method for operating a low NOx burner of claim 35, wherein the flame anchor includes a ring disposed axial and circumferential to the fuel nozzle.

59. The method for operating a low NOx burner of claim 58, wherein the ring is disposed near an outer periphery of a fuel jet emitted from the fuel nozzle.

60. The method for operating a low NOx burner of claim 35, wherein the flame anchor includes one or more projections extending from the fuel nozzle.

61. The method for operating a low NOx burner of claim 35, further comprising:

operating an electrode controller to apply the voltage to the electrode.

62. The method for operating a low NOx burner of claim 35, further comprising:

supporting the flame anchor with a flame anchor positioning mechanism; and

changing a distance of the flame anchor from the fuel nozzle by operating the flame anchor positioning mechanism.

63. The method for operating a low NOx burner of claim 35, further comprising:

anchoring the flame to a selected one of a plurality of flame anchors disposed at respective distances from the fuel nozzle by establishing a voltage condition of the selected flame anchor.

64. The method for operating a low NOx burner of claim 35, further comprising:

positioning the flame anchor responsive to a flame condition, a fuel jet rate, or a voltage carried by the electrode by operating a flame anchor controller to drive the flame anchor positioning mechanism.

65. The method for operating a low NOx burner of claim 35, further comprising:

moving the flame anchor to a stable flame anchoring position if the voltage applied to the electrode diminishes.

FIG. 1

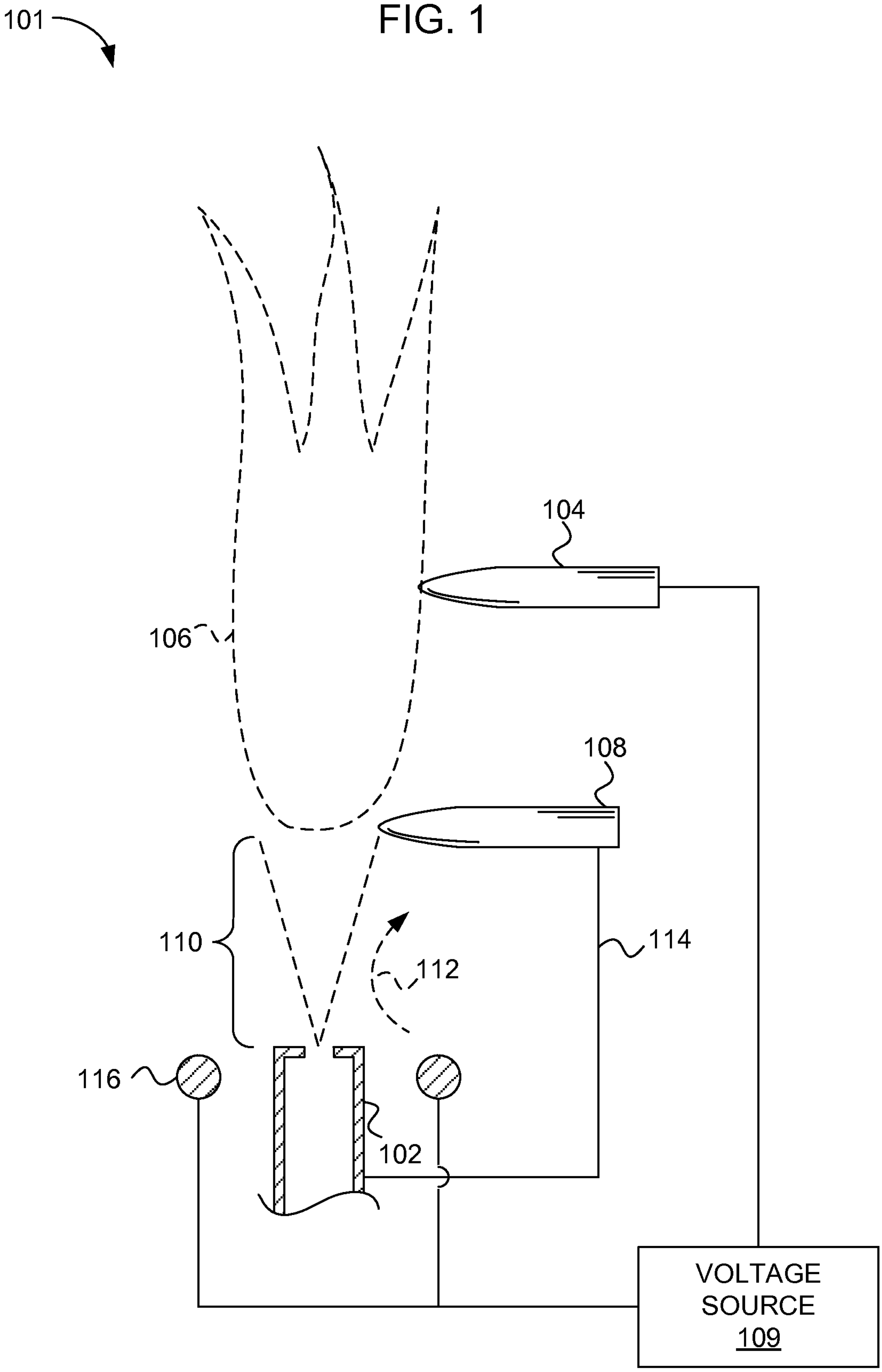


FIG. 2

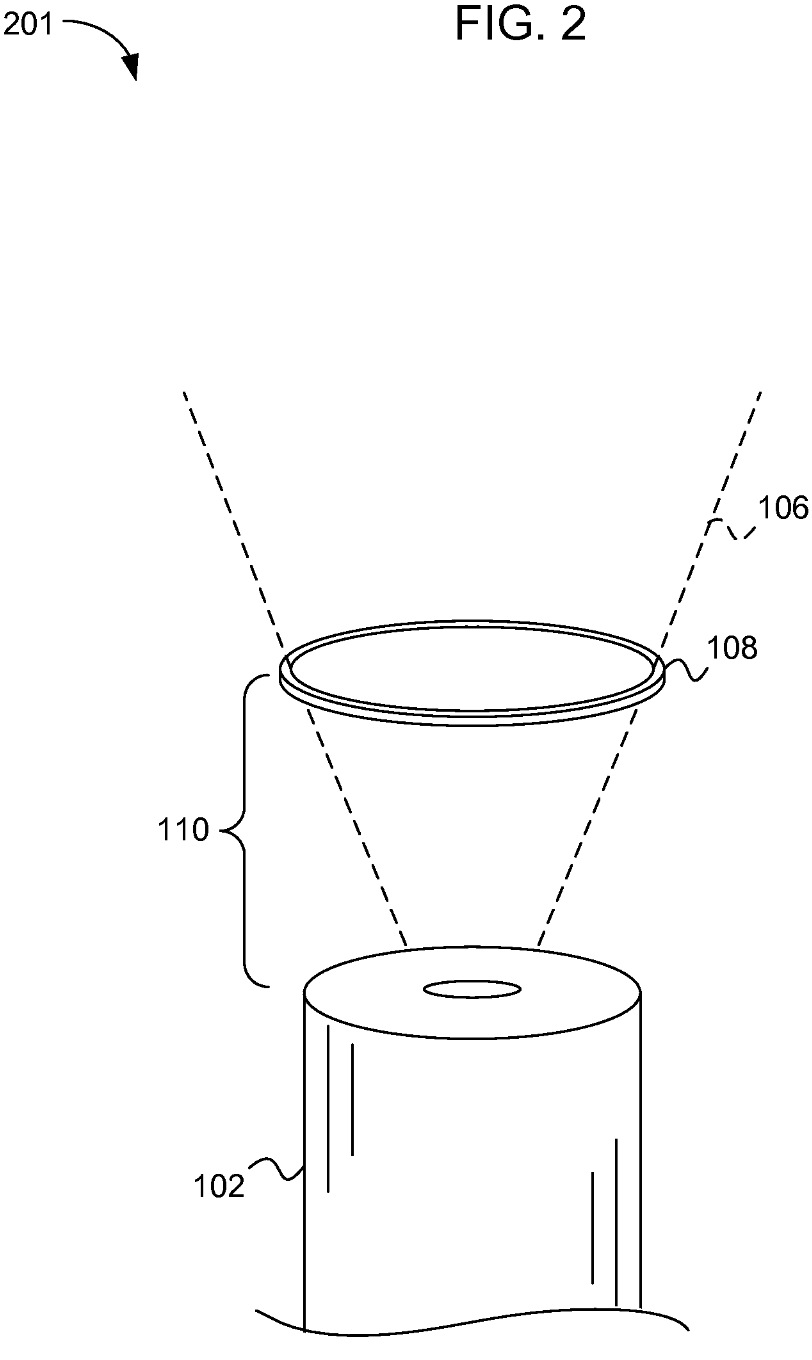


FIG. 3

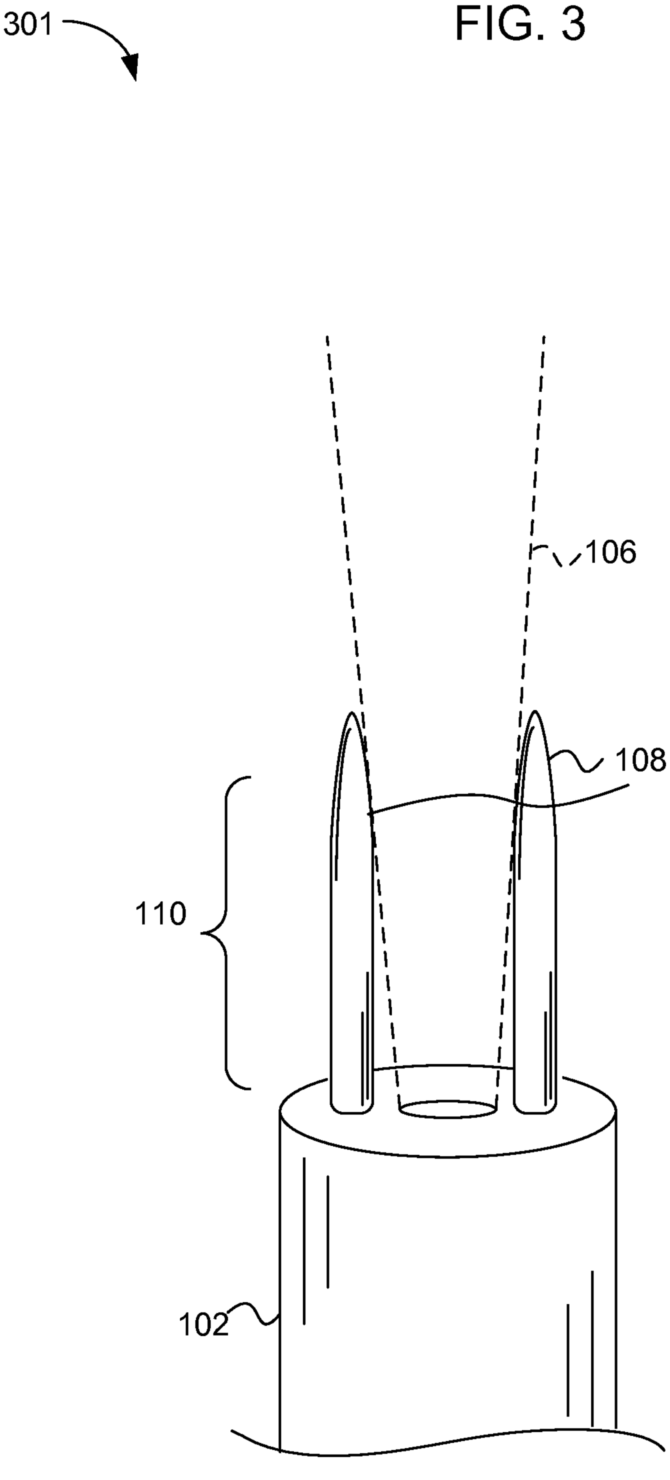


FIG. 4

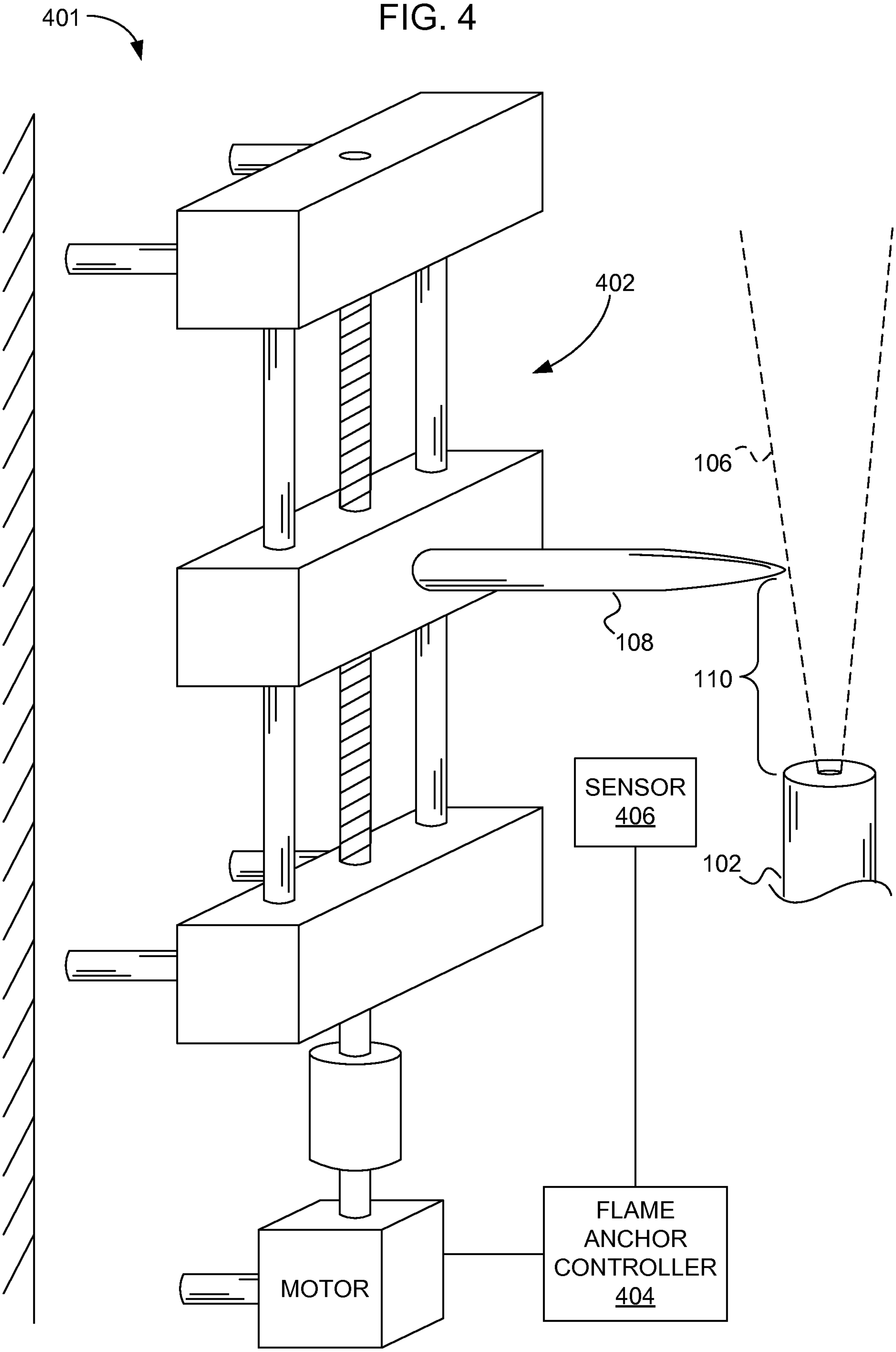

401
402
106
108
110
SENSOR
406
102
FLAME
ANCHOR
CONTROLLER
404
MOTOR

FIG. 5

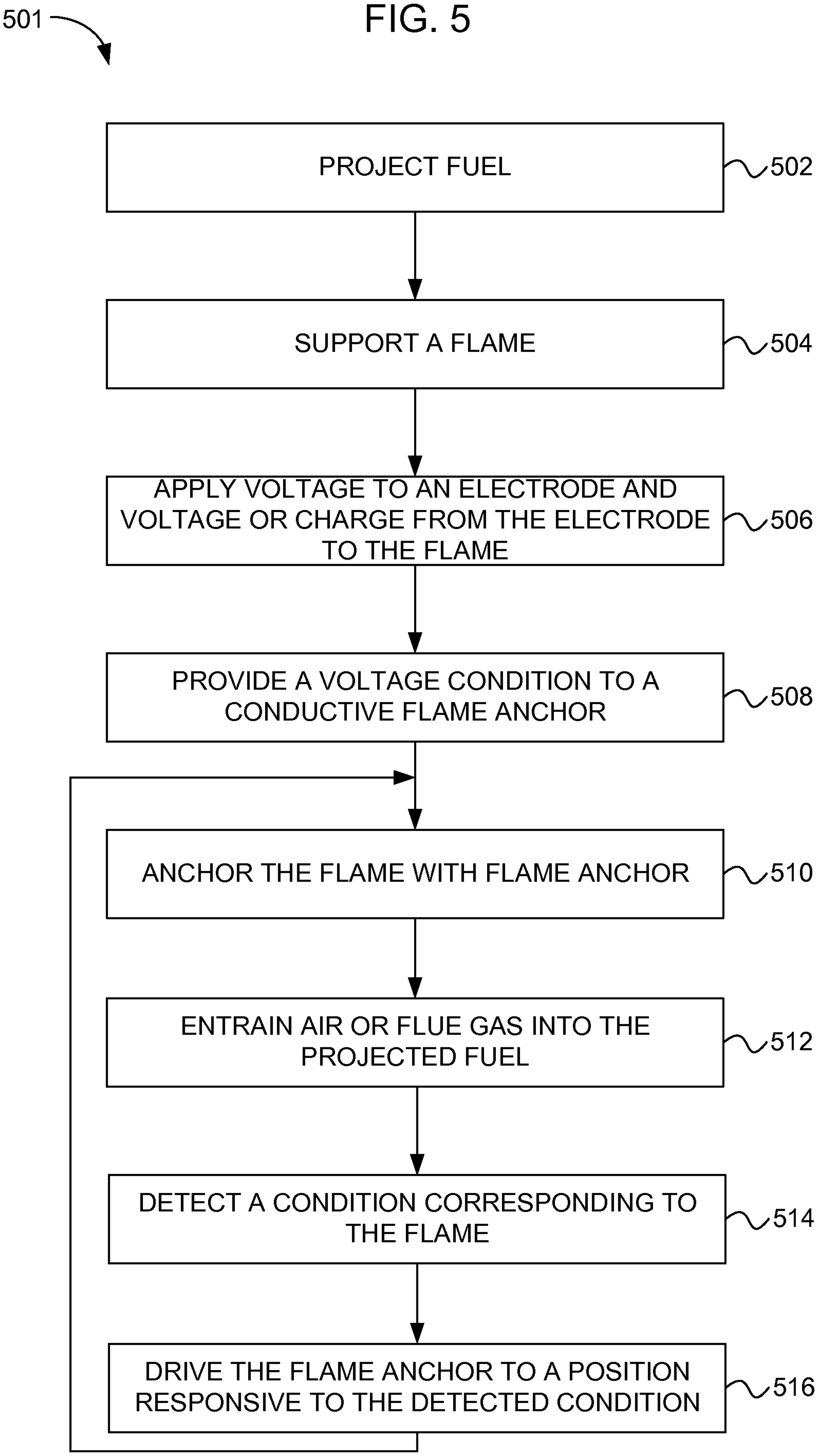
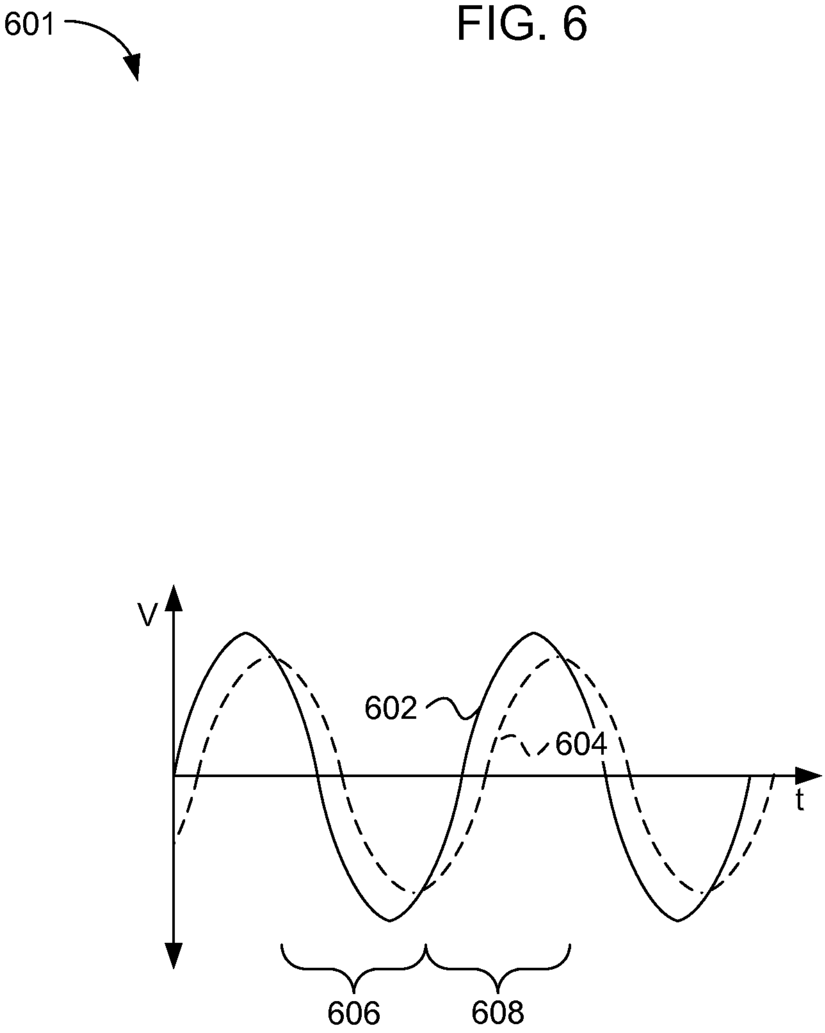

501
PROJECT FUEL
502
SUPPORT A FLAME
504
APPLY VOLTAGE TO AN ELECTRODE AND VOLTAGE OR CHARGE FROM THE ELECTRODE TO THE FLAME
506
PROVIDE A VOLTAGE CONDITION TO A CONDUCTIVE FLAME ANCHOR
508
ANCHOR THE FLAME WITH FLAME ANCHOR
510
ENTRAIN AIR OR FLUE GAS INTO THE PROJECTED FUEL
512
DETECT A CONDITION CORRESPONDING TO THE FLAME
514
DRIVE THE FLAME ANCHOR TO A POSITION RESPONSIVE TO THE DETECTED CONDITION
516

FIG. 6



INTERNATIONAL SEARCH REPORT

International application No.
PCT/US2013/043635

A. CLASSIFICATION OF SUBJECT MATTER

F23N 5/12(2006.01)i, F23D 14/46(2006.01)i, F23D 99/00(2010.01)i

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
F23N 5/12; F23L 15/00; F23C 5/00; F23C 11/04; F23Q 3/00; F24C 3/02; F23D 14/46; F23N 5/24; F23D 99/00

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched
Korean utility models and applications for utility models
Japanese utility models and applications for utility models

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)
eKOMPASS(KIPO internal) & keywords: flame, torch, plasma, flare, fuel, nozzle, electrode, voltage, electric, ground

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y A	US 2005-0208442 A1 (HEILIGERS et al.) 22 September 2005 See abstract; paragraphs [0153], [0154], [0163]; figures 3,6b.	1,3-17,32,34-41,43,45-48,51-59,61 2,18-31,33,42,44,49,50,60,62-65
Y	US 5,498,154 A (VELIE et al.) 12 March 1996 See abstract; column 3, lines 6-35; figures 3,4.	1,3-17,32,34-41,43,45-48,51-59,61
Y	US 2007-0026354 A1 (BRANSTON et al.) 01 February 2007 See abstract; paragraph [0028]; figure 2.	15
A	US 2007-0020567 A1 (BRANSTON et al.) 25 January 2007 See abstract; paragraphs [0028]-[0030]; figure 1.	1-65
A	JP 2001-056120 A (MATSUSHITA ELECTRIC IND. CO., LTD.) 27 February 2001 See abstract; paragraphs [0016], [0017]; figure 1.	1-65

☐ Further documents are listed in the continuation of Box C. ☒ See patent family annex.

* Special categories of cited documents:
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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents,such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search 12 September 2013 (12.09.2013)	Date of mailing of the international search report **13 September 2013 (13.09.2013)**
Name and mailing address of the ISA/KR Korean Intellectual Property Office 189 Cheongsa-ro, Seo-gu, Daejeon Metropolitan City, 302-701, Republic of Korea Facsimile No. +82-42-472-7140	Authorized officer HAN Joong Sub Telephone No. +82-42-481-5606

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/US2013/043635

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