A premixed combustion system includes a charge electrode, and an anchoring electrode positioned adjacent to a fuel nozzle. A charge having a first polarity is applied to the flame via the charge electrode and an electrical potential having a polarity opposite the first polarity is applied to the anchoring electrode. The oppositely-charged flame is attracted to the anchoring electrode, thereby anchoring the flame.
FIG. 3B
FIG. 4

400

SUPPORT A FLAME WITHIN A COMBUSTION VOLUME BY EJECTING A PREMIXED STREAM OF FUEL INTO THE COMBUSTION VOLUME

402

APPLY AN ELECTRICAL CHARGE HAVING A FIRST POLARITY TO THE FLAME

404

APPLY AN ELECTRICAL POTENTIAL HAVING A SECOND POLARITY, OPPOSITE THE FIRST POLARITY, TO AN ANCHORING ELECTRODE POSITIONED ADJACENT TO THE NOZZLE

406

CONTROL A POSITION OF THE FLAME WITHIN THE COMBUSTION VOLUME BY SELECTING A MAGNITUDE AND POLARITY OF THE APPLIED ELECTRICAL POTENTIAL

408
FIG. 5

500

RECEIVE AN INPUT PARAMETER

502

SELECT A FLAME LOCATION AND A CORRESPONDING VOLTAGE POTENTIAL BASED ON THE RECEIVED INPUT PARAMETER

504

506

MOVE THE FLAME TO THE SELECTED LOCATION BY APPLYING THE CORRESPONDING VOLTAGE POTENTIAL TO THE ANCHORING ELECTRODE
PREMIXED FLAME LOCATION CONTROL
CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims priority benefit from U.S. Provisional Patent Application No. 61/804,643, entitled “PREMIXED FLAME LOCATION CONTROL”, filed Mar. 23, 2013; which, to the extent not inconsistent with the disclosure herein, is incorporated by reference.

TECHNICAL FIELD

[0002] The present disclosure relates generally to combustion systems, and more particularly, to a flame control system for anchoring a flame in a premixed fuel system to a predetermined location or to a sequence of locations.

BACKGROUND

[0003] Combustion systems are employed in a vast number of applications, in industry and commerce, and in private homes. In premixed-fuel combustion systems, it is important to control a position of the flame, to prevent flashback and similar events.

SUMMARY

[0004] The present disclosure relates generally to combustion systems, and more particularly, to a flame control system for anchoring a premixed flame to a predetermined location or to a sequence of locations. According to embodiments, the location or sequence of locations of a flame in a premixed-fuel combustion system can be selected as a function of input parameters, such as, for example, equipment temperature cycle, equipment erosion control, BTU output, oxygen concentration ([O2]), oxides of nitrogen concentration ([NOx]), carbon monoxide concentration ([CO]), or flame heat output or demand, etc.

[0005] According to an embodiment, in a premixed-fuel combustion system, an electrical charge having a first polarity is applied to the flame. An anchoring electrode is held at an electrical potential having a second polarity, opposite the first polarity, which attracts the charged flame, enabling the flame to be anchored at a selected position.

[0006] According to an embodiment, a combustion system includes a fuel nozzle configured to emit a premixed fuel stream, a charge electrode positioned and configured to apply an electrical charge to a flame supported by the nozzle, and an anchoring electrode positioned adjacent to the nozzle. According to an embodiment, the anchoring electrode has a toroidal shape, and is positioned coaxially with the nozzle, a selected distance downstream therefrom. According to another embodiment, the anchoring electrode includes a plurality of anchoring electrodes arranged in radial symmetry about the nozzle. A voltage supply is configured to hold the charge electrode and anchoring electrode at respective voltage potentials.

[0007] When the anchoring electrode is held at a potential that is opposite in polarity from a charge applied to the flame, the flame is attracted to the anchoring electrode. The strength of the attraction, and thus, the position of the flame, is a function of the magnitude of the voltage difference between the charge applied to the flame and the potential applied to the anchoring electrode.

[0008] According to various embodiments, methods of operation are provided, for controlling or regulating a position of a flame in a premixed-fuel combustion system.

BRIEF DESCRIPTION OF DRAWINGS

[0009] Non-limiting embodiments of the present invention are described by way of example with reference to the accompanying figures, which are schematic and are not intended to be drawn to scale. Unless indicated as representing the background art, the figures represent aspects of the invention.

[0010] FIG. 1 is a simplified view of a combustion system with a charge electrode and anchoring electrode, according to an embodiment.

[0011] FIG. 2 is a simplified view of a system of FIG. 1, showing flame location in relation to a value of a potential applied to the anchoring electrode, according to an embodiment.

[0012] FIGS. 3A and 3B are simplified views of combustion systems with pluralities of anchoring electrodes, according to respective embodiments.

[0013] FIG. 4 is a flow chart of a method for positioning a flame within a combustion volume, according to an embodiment.

[0014] FIG. 5 is a flow chart of a method for regulating a position of a flame front, according to an embodiment.

DETAILED DESCRIPTION

[0015] In the following detailed description, reference is made to the accompanying drawings, which form a part hereof. In the drawings, which are not necessarily to scale or to proportion, 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 used and/or other changes may be made without departing from the spirit or scope of the present disclosure.

[0016] In an entrained air combustion system, a stream of fuel is emitted from a fuel nozzle into a combustion volume. The fuel stream is permitted to entrain an oxidizer fluid, such as air, in order to support combustion of the fuel stream, as a flame. In such systems, the flame front seeks a position in the fuel stream at which there is sufficient entrained oxygen and at which the fuel stream velocity does not exceed the flame propagation rate. The flame cannot move closer to the nozzle than a distance at which sufficient oxygen has been entrained to support combustion.

[0017] In contrast, in a premixed fuel combustion system, an oxidizer is mixed with the fuel upstream from the nozzle, so that combustibility does not rely on entrainment of oxygen. In a premixed fuel system, there is no inherent limit imposed by the fuel mixture to upstream movement of a flame. In such systems, care must be taken to prevent flashback, in which a flame passes upstream through the nozzle toward the fuel supply. Flashback can result in explosion or uncontrolled combustion, resulting in danger to personnel and damage to equipment.

[0018] Controlling the position of a flame during combustion to a certain area or location can provide several benefits such as, improved air/fuel mixing, improved flame stability, reduction of pollutants such as NOx and CO, and higher reliability of equipment, among others. Controlling a flame-anchoring location can be relevant in ethylene crackers, steam methane reformers and other heaters, reactors and furnaces.
used in oil and chemical processing applications. In at least some variants of these systems, a flame needs to be carefully controlled near pipes that conduct fluids to limit excessive temperatures, which can result in carbon accumulation and/or structural damage.

[0019] FIG. 1 depicts a combustion system 100, according to an embodiment. The combustion system 100 includes a combustion volume 130 in which is positioned a nozzle 102 configured to emit a premixed flow 118 to support a flame 104, and an anchoring electrode 106. A fuel conduit 120 and an oxidizer conduit 122 are coupled to the nozzle 102 via a premixing chamber 124 configured to premix fuel and oxidizer, which are subsequently ejected from the nozzle 102 and ignited within the combustion volume 130 to generate the flame 104. A charge electrode 108 is configured to apply an electrical charge to the flame 104. A voltage supply 112 is electrically coupled to the charge electrode 108 and the anchoring electrode 106 and configured to apply a first electrical potential \( V_1 \) having a first polarity to the charge electrode 108 and a second electrical potential \( V_2 \), having a second polarity different from the first polarity, to the anchoring electrode 106. According to an embodiment, the anchoring electrode 106 has an annular or toroidal shape, and is disposed generally concentrically with a longitudinal axis A of the nozzle 102 and located a selected distance downstream from the nozzle.

[0020] According to various embodiments, the first and second electrical potentials \( V_1, V_2 \) can have absolute values of greater than 1 kV, and in some embodiments, greater than 20 kV or 40 kV. The inventors have, in experimental set-ups similar to the depiction of FIG. 1, used a total voltage difference between the charge electrode 108 and anchoring electrode 106 of 80 kV, and contemplate higher voltages. According to some embodiments, the first and/or second electrical potentials \( V_1, V_2 \) can include time-varying signals, i.e., AC, AC with a DC offset, and/or pulsed DC.

[0021] In operation, the voltage supply 112 applies the first electrical potential \( V_1 \) to the charge electrode 108. An electrical charge 116 having the first polarity (positive, in the example shown) is thereby applied to the flame 104. Simultaneously, the voltage supply 112 applies the second electrical potential \( V_2 \) to the anchoring electrode 106. The opposite-polarity potential at the anchoring electrode 106 attracts the charged flame 104 to the anchoring electrode 106, such that the charged flame 104 is stably anchored proximate to the anchoring electrode 106.

[0022] It can be seen in FIG. 1 that the anchoring electrode 106 is larger in diameter than the base of the flame 104, and is positioned substantially outside the premixed flow 118. Accordingly, the flame 104 cannot actually contact the anchoring electrode 106, but is attracted to a location corresponding, approximately, to a plane defined by the anchoring electrode 106. Because the flame 104 does not make contact with the anchoring electrode 106, it does not discharge, and substantially no electrical current flows between the charge electrode 108 and the anchoring electrode 106 via the flame 104. Accordingly, although the voltage difference between the first electrical potential \( V_1 \), at the charge electrode 108, and the second electrical potential \( V_2 \), at the anchoring electrode 106, may be extremely high, the electrical power expended by the voltage supply 112 to anchor the flame 104 is very low.

[0023] According to an embodiment, the combustion volume 130 is defined in part by a conduit tube passage 110, which can include any of a variety of dielectric materials, such as refractory brick, alumina ceramic, quartz, fused glass, silica and VYCOR™, boron nitride, for example. In the embodiment of FIG. 1, the conduit tube passage 110 has a generally cylindrical shape with the nozzle 102 positioned at a closed end, the nozzle 102, the anchoring electrode 106, and the conduit tube passage 110 being substantially coaxial.

[0024] The voltage source 112 can include a separate voltage generator or regulator for each of the anchoring electrode 106 and the charge electrode 108, or the first and second electrical potentials \( V_1, V_2 \) can be produced by a common device. The fuel provided via the fuel conduit 120 can include, for example, hydrogen, and hydrocarbon gases such as methane, ethane, propane, butane, pentane, etc., while the oxidizer within the oxidizer conduit 122 can include, for example, ambient air, oxygen concentrated air; oxygen, ozone, hydrogen peroxide, etc. According to an embodiment, the conduit tube passage 110 minimizes or limits the entrainment of excess oxidizer by the premixed flow 118 by enclosing the flame 104 and nozzle 102. Preferably, the conduit tube passage 110 has a diameter that is about 1.5 to 5 times larger than a diameter of the nozzle 102. The inventors have determined that the relative diameters of the conduit tube passage 110 and the nozzle 102 affects the ability of the flame 104 to anchor. Moreover, this same diameter relationship can be applied to different shapes for conduit tube passage 110 such as ovoid, rectangular, prismatic and conical, for example.

[0025] According to various embodiments, the anchoring electrode 106 can be located in any of a number of positions with respect to the nozzle 102 and flame 104. For example, the anchoring electrode 106 can be located on the inner diameter of the conduit tube passage 110, on the external diameter of the conduit tube passage 110, or the anchoring electrode 106 can be partially or fully embedded into the thickness of the conduit tube passage 110. FIG. 2 shows, in phantom lines at 106a, an alternate embodiment in which the anchoring electrode 106a is positioned outside the conduit tube passage 110.

[0026] Anchoring electrode 106 can exhibit any of a number of different shapes, such as, e.g., squared, triangular, and other polygonal shapes, etc. Additionally, the anchoring electrode 106 can comprise a plurality of electrodes, all according to the desired characteristics of the flame 104. Voltage, charge, and/or electric fields can be applied within a plurality of waveforms and voltages/currents according to the desired flame anchoring location or sequence of locations.

[0027] According to various embodiments, the charge can be applied to the flame via a charge electrode and voltage source, as described with reference to FIG. 1. According to other embodiments, the charge can be generated by a laser beam projector, an ion generator, a corona discharge, or any other suitable means for generating a charge in the flame 104. The charge electrode 108 can be located in different positions within conduit tube passage 110, including within the nozzle 102, for example.

[0028] According to the principle of charge attraction, if the flame 104 needs to be anchored at a predetermined location within the conduit tube passage 110, then the anchoring electrode 106 can be charged at an electrical potential having an opposite polarity as compared to the polarity of the charge applied to the flame 104. As a result, the flame 104 is pulled down and anchored adjacent to the anchoring electrode 106, without making contact with anchoring electrode 106 or with any other component of combustion system 100. Conversely, if the flame 104 needs to be lifted up above anchoring elec-
trode 106, then the anchoring electrode 106 can be held at a null, ground potential or at a potential having the same polarity as the flame 104. Thus, in different embodiments, the anchoring electrode 106 can be placed in different locations in the conduit tube passage 110 and can be positively or negatively charged to repel or attract the flame 104.

[0029] Voltage potential $V_1$ and voltage potential $V_2$ can range from a few volts to several thousand volts. The magnitude of each potential can be related to the desired flame characteristics, flow rate of the premixed flow 118 and various conditions during combustion such as ambient or working pressure, temperature and the like. In addition, polarities of the charge electrode 108 and the anchoring electrode 106 can be alternating and can be synchronized according to desired flame anchoring location or sequence of locations.

[0030] According to an embodiment of the present disclosure, the performance of the flame 104 anchoring in combustion system 100 is controlled by a control system which integrates one or more sensors configured to measure one or more combustion parameters (e.g., temperature, opacity, and the like) of the flame 104, which are communicated to a programmable controller, computer, microprocessor unit, or the like, to determine the location or sequence of locations of the flame 104 within combustion system 100. Sensors can include thermal, electric, or optical sensors, etc. Additionally, sensors can measure combustion parameters such as a fuel particle flow rate, stack gas temperature, stack gas optical density, combustion volume temperature and pressure, luminosity and level of acoustics, combustion volume ionization, ionization near the anchoring electrode 106, combustion volume maintenance lockout, and electrical fault, for example.

[0031] According to various embodiments of the present disclosure, flame anchoring is suitable for a large variety of fuel and oxidizer mixes in different combustion applications. Such fuels can include, gas, liquid and solid fuels injected through a burner, an injector, or nozzle 102, for example.

[0032] FIG. 2 depicts a cross-sectional view of the combustion system 100 of FIG. 1, showing a flame-anchoring location or sequence of locations 202, 204, 206 in the combustion system 100, according to an embodiment. As noted above, FIG. 2 also shows an alternate embodiment in which the anchoring electrode 106 is positioned on the outside surface of the conduit tube passage 110. Flame-anchoring location or sequence of locations 202, 204, 206 depend on the electrical potential difference between the charged flame 104 as shown in FIG. 1 and the anchoring electrode 106, where a higher electrical potential difference results in a stronger and nearer anchoring of the flame 104 to anchoring electrode 106. For example, the flame 104 can be located at location 202 when a negative voltage of about 20,000 volts is applied to the anchoring electrode 106 (assuming a positive charge applied to the flame 104, where location 202 is slightly below an inner diameter of the anchoring electrode 106. Correspondingly, location 204 above location 202 can be achieved by the application of a negative voltage of about 1,000 volts to anchoring electrode 106, and location 206 above location 204 can be achieved when no voltage is applied to anchoring electrode 106.

[0033] Voltage potential required for anchoring the flame 104 can vary according to flow rates of fuel and oxidizer and various other conditions during combustion, such as pressure, temperature, and the like. In addition, if the flame 104 is required to be anchored in a higher or lower location or sequence of locations, then retrofitting can be achieved by relocating anchoring electrodes 106 in relation to nozzle 102.

[0034] FIG. 3A depicts a combustion system 300a using the same principle described in FIG. 1, according to an embodiment. Combustion system 300a can includes a nozzle 102, a plurality of segmented electrodes 302, a flame-charging electrode 108, and a conduit tube passage 110.

[0035] As shown in FIG. 3A, segmented electrodes 302 are located in proximity to the nozzle 102. Specifically, segmented electrodes 302 are located around the inner diameter of the conduit tube passage 110. Optionally, the segmented electrodes 302 can be located around the external diameter of the conduit tube passage 110. In another embodiment, as shown in FIG. 3B, segmented electrodes 302 penetrate the wall of conduit tube passage 110 such that an end portion of each of the plurality of segmented electrodes 302 extend into the interior of combustion chamber 130 in a position adjacent to the nozzle 102. Segmented electrodes 302 can exhibit a plurality of shapes, quantities and sizes substantially as described with reference to the anchoring electrode 106 of FIG. 1. In most respects, operation of the systems 300a and 300b of FIGS. 3A and 3B is substantially similar to the operation of the system 100 described with reference to FIG. 1, with a first voltage potential being applied to the charge electrode 108 and a second potential being applied to the plurality of electrodes anchoring 302. However, according to another embodiment, different voltage potentials can be applied between segmented electrodes 302, where such voltage potentials can allow a different flame-anchoring location or sequence of locations 202, 204, 206, and effects over the flame 104 when electrical continuity exist on the selected segmented electrode 302. When electrical continuity is interrupted in one or more of the electrodes 302, the flame 104 flows to another electrode 302 to which a local voltage is applied. Thus, the flame 104 may not be affected when the connection to ground or to a voltage source 112 of any selected electrode 302 is open so long as one of the remaining electrodes is connected to the voltage source 112. Voltage potentials $V_1$ and $V_2$ can range from a few volts to several thousand volts.

[0036] FIG. 4 is a flow chart of a method 400 for controlling the position of a flame within a combustion volume, according to an embodiment. In step 402 a premixed flow stream is ejected into a combustion volume to support a flame within the combustion volume.

[0037] In step 404 an electrical charge having a first polarity is applied to the flame.

[0038] Proceeding to step 406 an electrical potential having a second polarity, opposite the first polarity, is applied to an anchoring electrode, and, in step 408 a position of the flame within the combustion volume is controlled by selection of the applied electrical potential.

[0039] FIG. 5 is a flow chart of a method 500 for regulating a position of a flame front, according to an embodiment, in which step 508 of the method described with reference to FIG. 4 includes steps 502-506. In step 502, at least one input parameter is received. Parameters can include an equipment temperature cycle schedule, an equipment erosion control schedule or state, a measured thermal output of the flame, a burner command selected to set a thermal output of the flame, an oxygen concentration, oxide or oxides of nitrogen concentration, carbon monoxide concentration, a flame heat demand, and/or a current flame front location, for example.
In step 504 a flame front location is selected based on the received input parameter, and a corresponding voltage potential is also selected. The corresponding voltage potential can be selected, for example, by means of a lookup table, by calculation, or it can be part of a preprogrammed set of instructions for controlling the flame through a sequence of changes.

Proceeding to step 506, the flame is moved to the selected location by application of the corresponding voltage potential to the anchoring electrode. The process described with reference to FIG. 4 is performed.

According to one example, a system similar to the system 100 of FIGS. 1 and 2 is controlled to hold the flame in the position designated 202 in FIG. 2. The method described with reference to FIG. 4 (steps 402-408) is performed, except that the steps 502-506 are performed as part of step 408. The input parameter of step 502 can be a signal from a sensor configured, for example, to detect the location of the flame front. As conditions in and around the combustion volume change, they can change the behavior of the flame. Thus, if, during operation, the flame moves downstream, the sensor detects the current position of the flame, and provides a corresponding input parameter. The controller compares the input parameter with a preselected value, and determines that the flame has moved from its intended position. The controller then determines the nominal position, and calculates the value for the applied voltage potential that will cause the flame to return to the selected location. The new voltage potential is applied to the anchoring electrode, causing the flame to return to the selected position, while the input parameter from the sensor is again compared to the preselected value to confirm that the flame responded as predicted.

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

What is claimed is:

1. A combustion system, comprising:
   a fuel nozzle including a mixing chamber configured to receive a flow of fuel and a flow of oxidizer, and to eject a premixed fuel stream into a combustion volume;
   a first electrode positioned and configured to apply an electrical charge to a flame supported by the fuel nozzle; and
   a second electrode positioned and configured, when held at a voltage potential having a polarity opposite a polarity of a charge applied to the flame, to attract the flame supported by the nozzle toward a selected position without permitting the flame to discharge.

2. The system of claim 1, wherein the first electrode is positioned downstream from the second electrode, relative to the premixed fuel stream.

3. The system of claim 1, wherein the nozzle comprises the first electrode.

4. The system of claim 1, wherein the second electrode has an annular shape and is positioned coaxially with the nozzle.

5. The system of claim 4, wherein the second electrode has a diameter that is greater than a diameter of the premixed fuel stream at a point where the premixed fuel stream passes through the second electrode.

6. The system of claim 1, wherein the second electrode comprises a plurality of second electrodes positioned in radial symmetry around the nozzle.

7. The system of claim 6, comprising a voltage supply electrically coupled to each of the plurality of second electrodes and configured to apply a voltage potential to each of the plurality of second electrodes.

8. The system of claim 1, comprising a voltage supply electrically coupled to the first and second electrodes and configured to apply first and second voltage potentials to the respective first and second electrodes.

9. The system of claim 8, wherein the voltage supply is configured to hold the first electrode at the first potential, the first voltage potential having a first polarity, and to hold the second electrode at the second potential, the second voltage potential having a second polarity, opposite the first polarity.

10. The system of claim 1, wherein the combustion volume is defined, in part, by an enclosure in which the nozzle is positioned.

11. The system of claim 10, wherein the enclosure is configured to limit entrainment of ambient air by the premixed fuel stream.

12. The system of claim 11, wherein an end of the enclosure is closed.

13. The system of claim 10, wherein the enclosure is cylindrical.

14. The system of claim 13, wherein the enclosure is between about 1.5 and 5 times a diameter of the nozzle.

15. The system of claim 13, wherein the second electrode has an annular shape and is coupled to an inner surface of the enclosure.

16. The system of claim 13, wherein the second electrode has an annular shape and is coupled to an outer surface of the enclosure.

17. The system of claim 13, wherein the second electrode has an annular shape and is partially incorporated into a wall of the enclosure.

18. A method, comprising:
   supporting a flame within a combustion volume, including ejecting a premixed fuel stream into the combustion volume;
   electrically charging the flame at a first polarity;
   applying a first voltage potential to a first electrode positioned near the premixed fuel stream; and
   anchoring the flame at a selected position by controlling a degree of attraction between the first electrode and the flame.

19. The method of claim 18, wherein the controlling a degree of attraction between the first electrode and the flame includes selecting a magnitude and polarity of the first voltage potential.

20. The method of claim 18, wherein the electrically charging the flame includes applying a second voltage potential, having the first polarity, to a second electrode positioned and configured to pass a charge to the flame.

21. The method of claim 18, comprising limiting a degree to which the premixed fuel stream entrains ambient air.

22. The method of claim 18, comprising:
   receiving a flow of fuel;
   receiving a flow of oxidizer; and
   producing premixed fuel by mixing the flow of fuel and the flow of oxidizer prior to ejecting the mixture while performing the ejecting a premixed fuel stream.
23. The method of claim 18, comprising preventing a discharge of the flame while performing the anchoring the flame.

24. The method of claim 18, comprising:
   monitoring a parameter of the flame;
   comparing the parameter with a nominal parameter;
   correcting a disparity between the monitored parameter and the nominal parameter by modifying the degree of attraction between the first electrode and the flame.

25. The method of claim 24, wherein the correcting a disparity includes obtaining a new value for a magnitude and polarity of the first voltage potential, and applying the first voltage potential at the new value to the first electrode.