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Jameel

(54) **COMBUSTION ROTATION SYSTEM FOR FUEL-INJECTION BOILERS**

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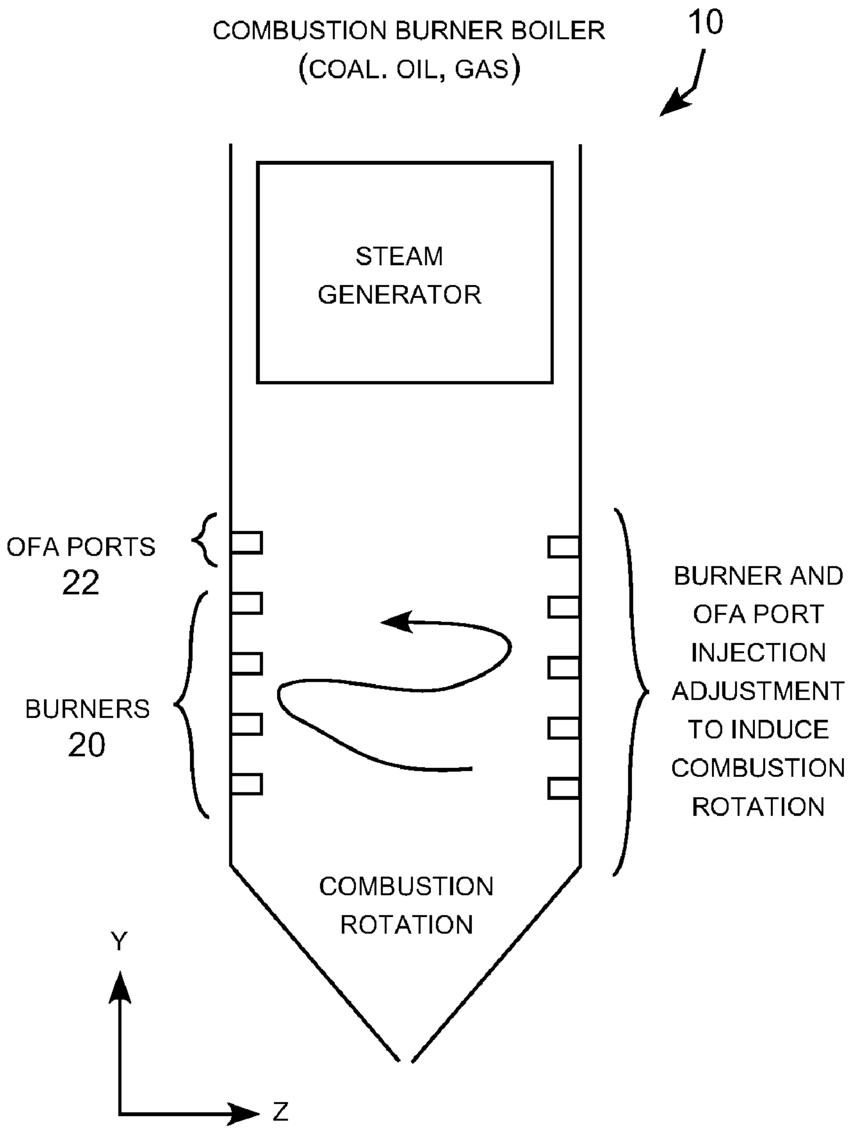
F23C 5/32 (2006.01)

(52) **U.S. Cl.** **431/181**; 431/185

(57) **ABSTRACT**

A combustion rotation system that utilizes the placement, direction, and/or unbalanced fuel injection flow rates to the burners in a fuel-injection power boiler, such as pulverized coal, oil or gas fired boiler, to achieve Inboard/Outboard (I/O) rotation of the combustion mass or other types of mixing of the combustion mass. The over fired air ("OFA") ports may also be placed, directed, and/or operated to contribute to the rotation of the combustion mass. The fuel-injection combustion rotation system may also be controlled while the boiler is operation, and controlled automatically, through a master control system. The fuel-injection combustion rotation system induces multiple vortex rotation of the combustion mass, which is more efficient and effective than attempting to rotate the entire combustion mass in a single vortex.



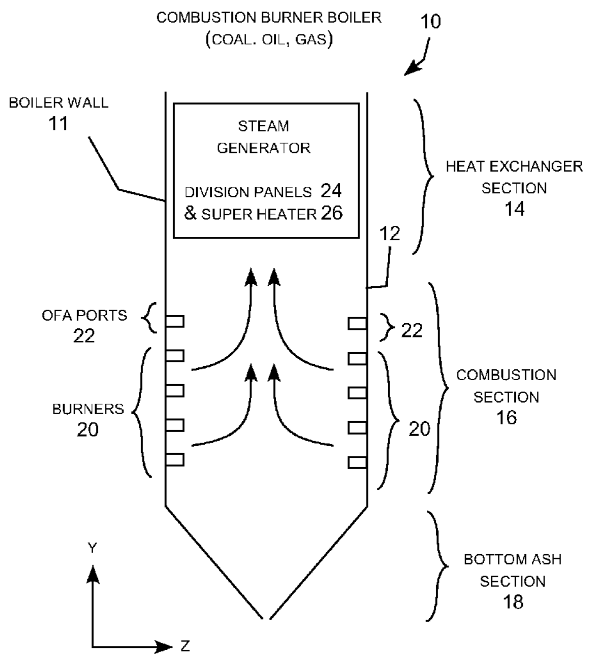


FIG. 1
(PRIOR ART)

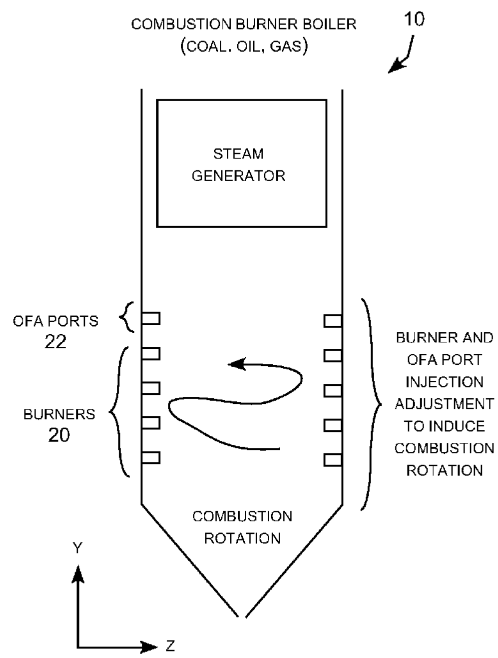


FIG. 2

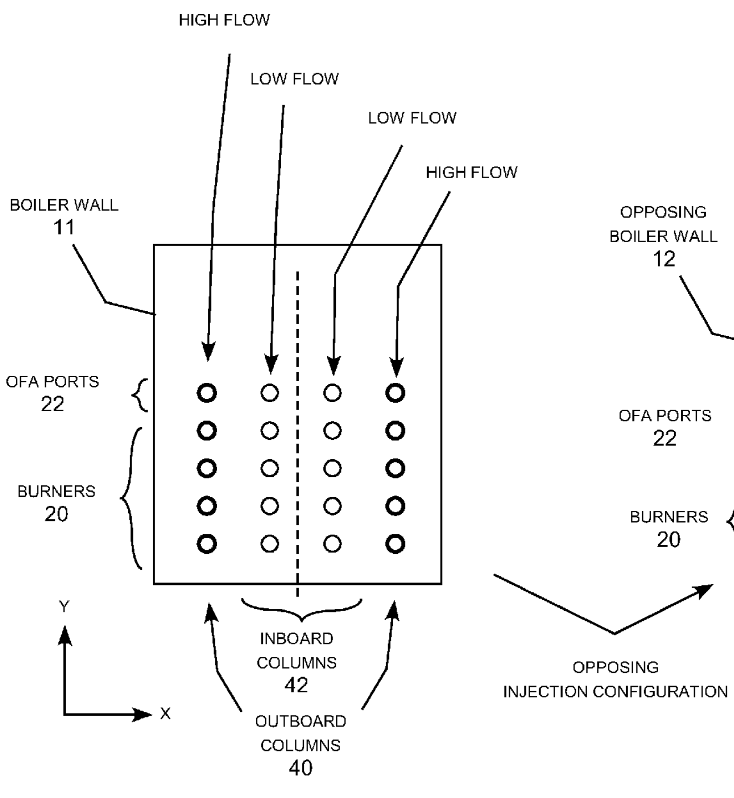

HIGH FLOW
LOW FLOW
LOW FLOW
HIGH FLOW
BOILER WALL
11
OFA PORTS
22
BURNERS
20
Y
X
INBOARD
COLUMNS
42
OUTBOARD
COLUMNS
40
OPPOSING
INJECTION CONFIGURATION

FIG. 3

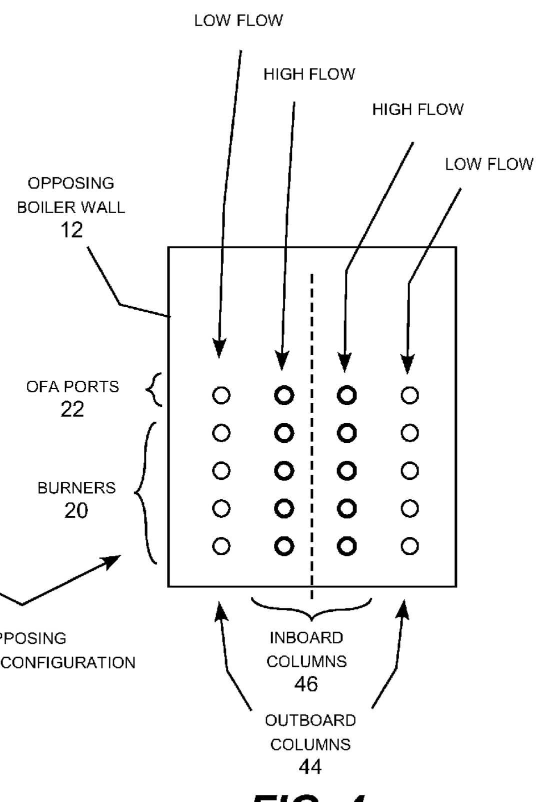

LOW FLOW
HIGH FLOW
HIGH FLOW
LOW FLOW
OPPOSING
BOILER WALL
12
OFA PORTS
22
BURNERS
20
INBOARD
COLUMNS
46
OUTBOARD
COLUMNS
44

FIG. 4

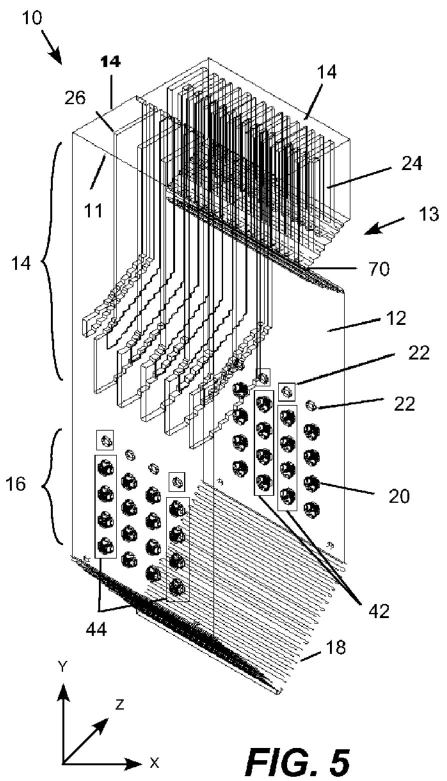

10
14
26
14
24
11
13
14
70
12
22
22
16
20
44
42
18
Y
Z
X

FIG. 5

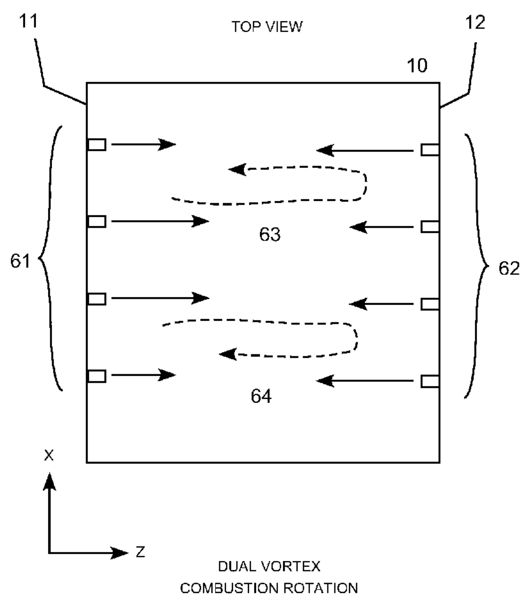

11
TOP VIEW
12
10
61
63
62
64
X
Z
DUAL VORTEX
COMBUSTION ROTATION

FIG. 6

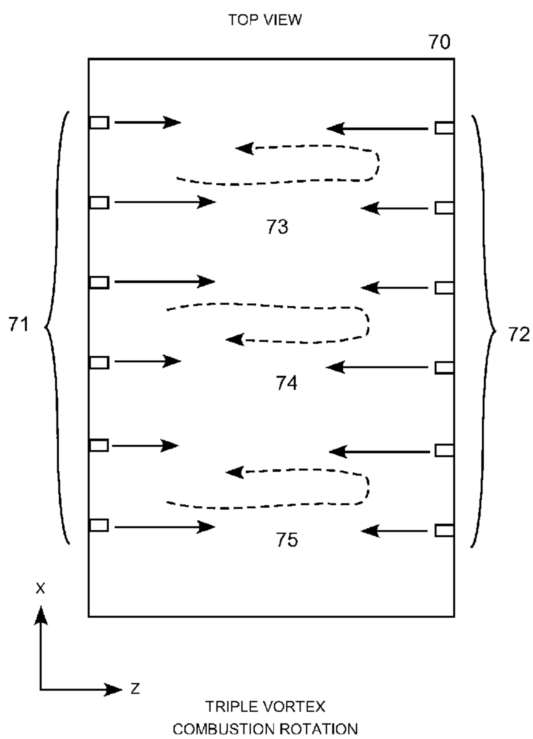

TOP VIEW
70
71
72
73
74
75
X
Z
TRIPLE VORTEX
COMBUSTION ROTATION

FIG. 7

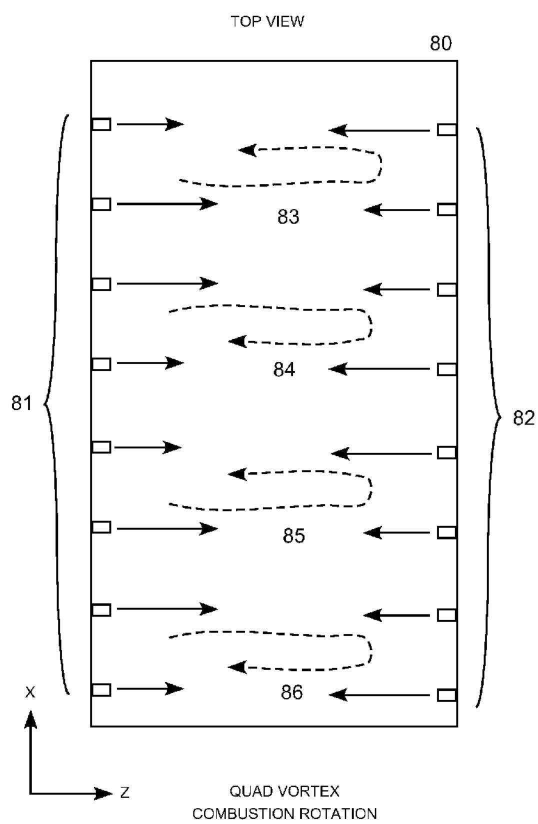

TOP VIEW
80
81
82
83
84
85
86
X
Z
QUAD VORTEX
COMBUSTION ROTATION

FIG. 8

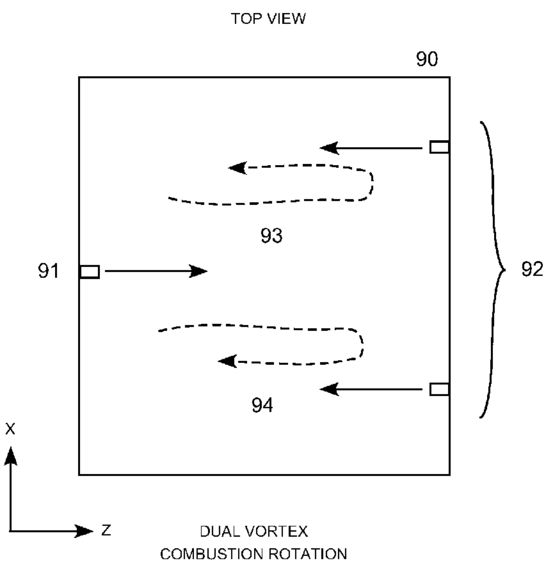

TOP VIEW
90
91
92
93
94
X
Z
DUAL VORTEX
COMBUSTION ROTATION

FIG. 9

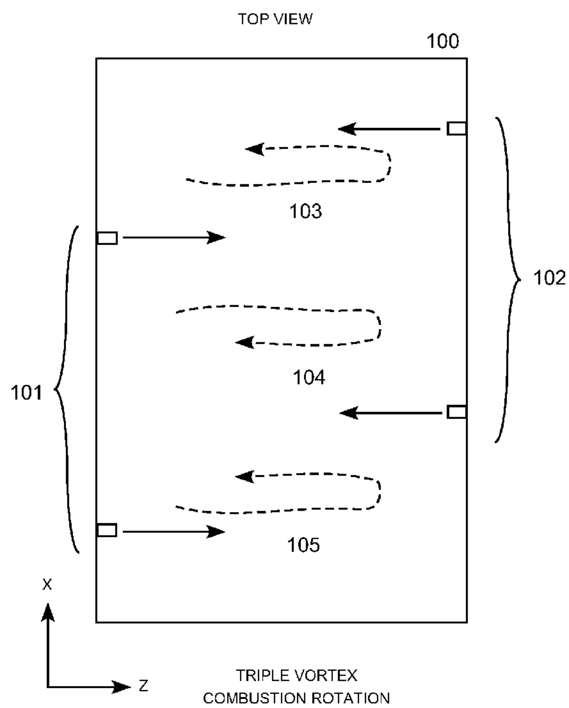

TOP VIEW
100
101
102
103
104
105
X
Z
TRIPLE VORTEX
COMBUSTION ROTATION

FIG. 10

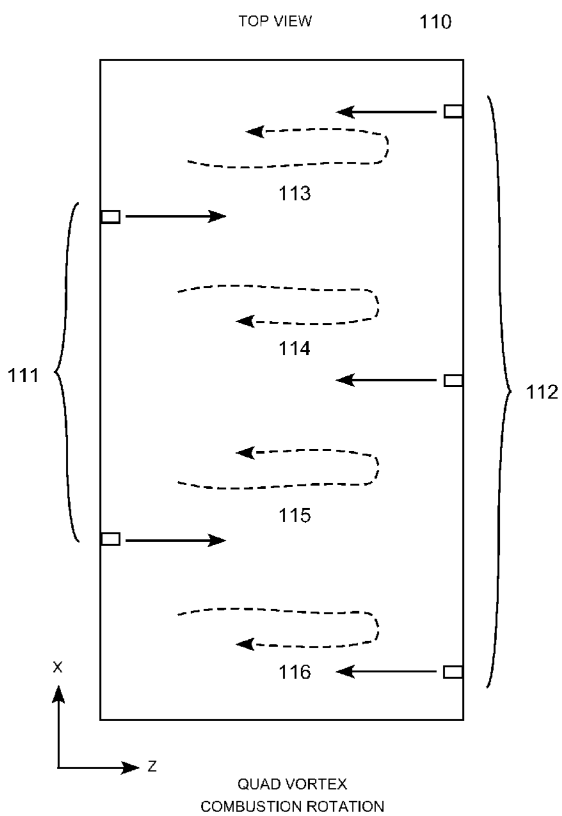

TOP VIEW
110
113
114
115
116
111
112
X
Z
QUAD VORTEX
COMBUSTION ROTATION

FIG. 11

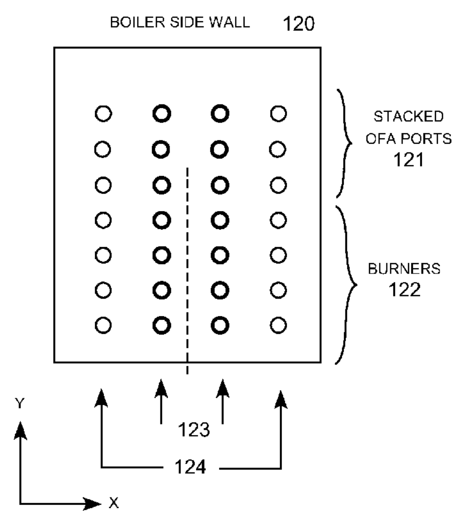

BOILER SIDE WALL
120
STACKED
OFA PORTS
121
BURNERS
122
123
124
Y
X

FIG. 12

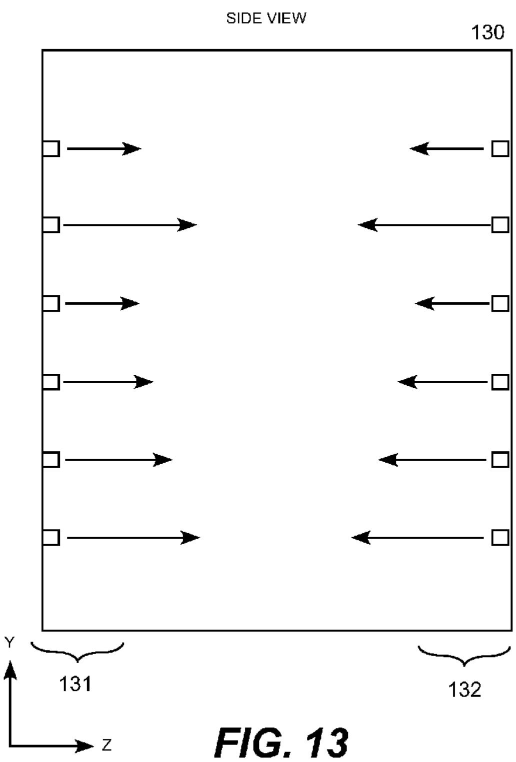


FIG. 13

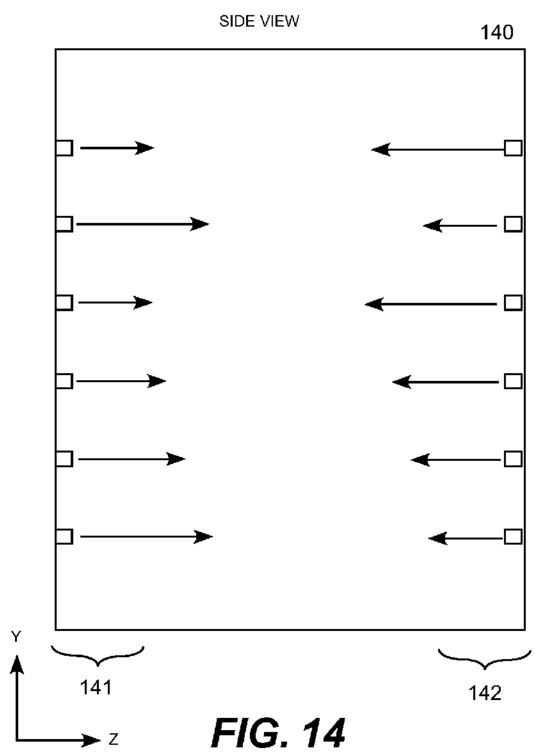


FIG. 14

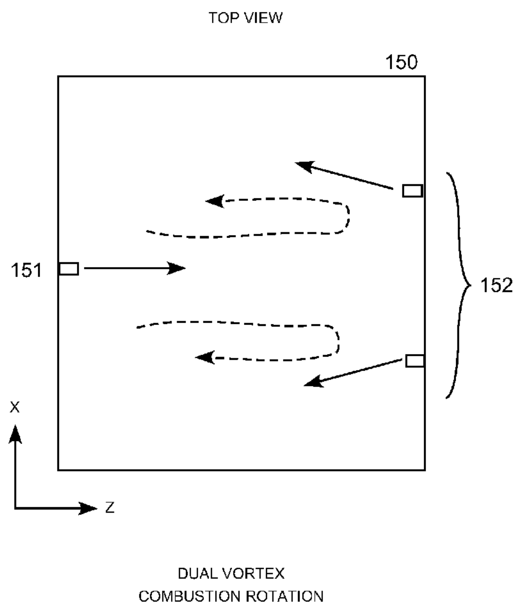

TOP VIEW
150
151
152
X
Z
DUAL VORTEX
COMBUSTION ROTATION

FIG. 15

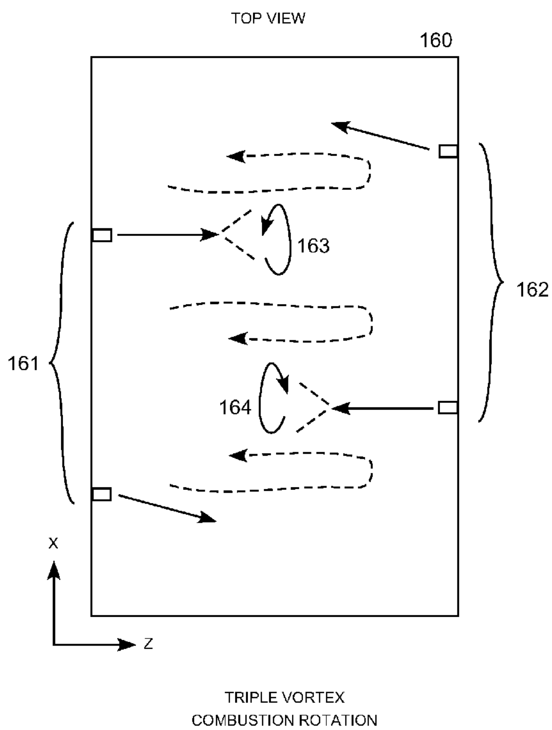

TOP VIEW
160
163
162
161
164
X
Z
TRIPLE VORTEX
COMBUSTION ROTATION

FIG. 16

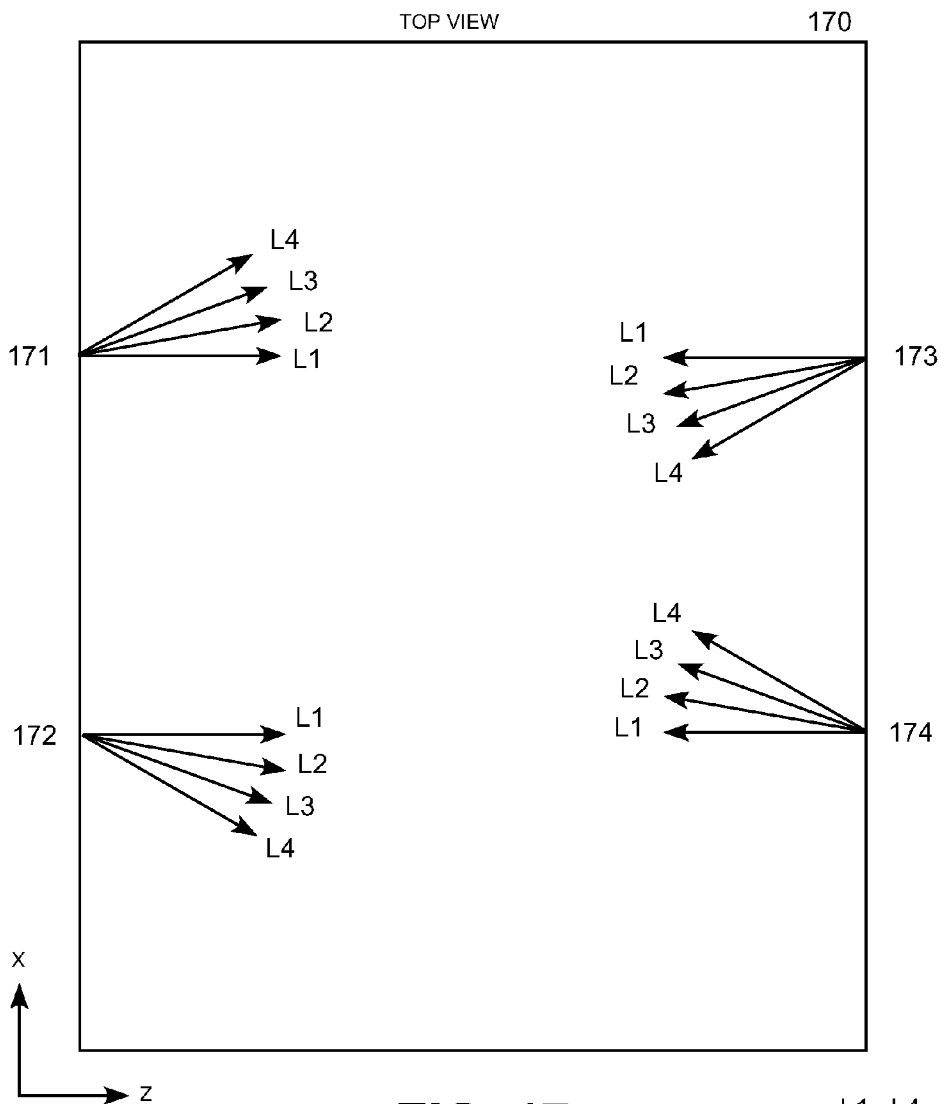


FIG. 17

L1 - L4
DIFFERENT VERTICAL LEVELS

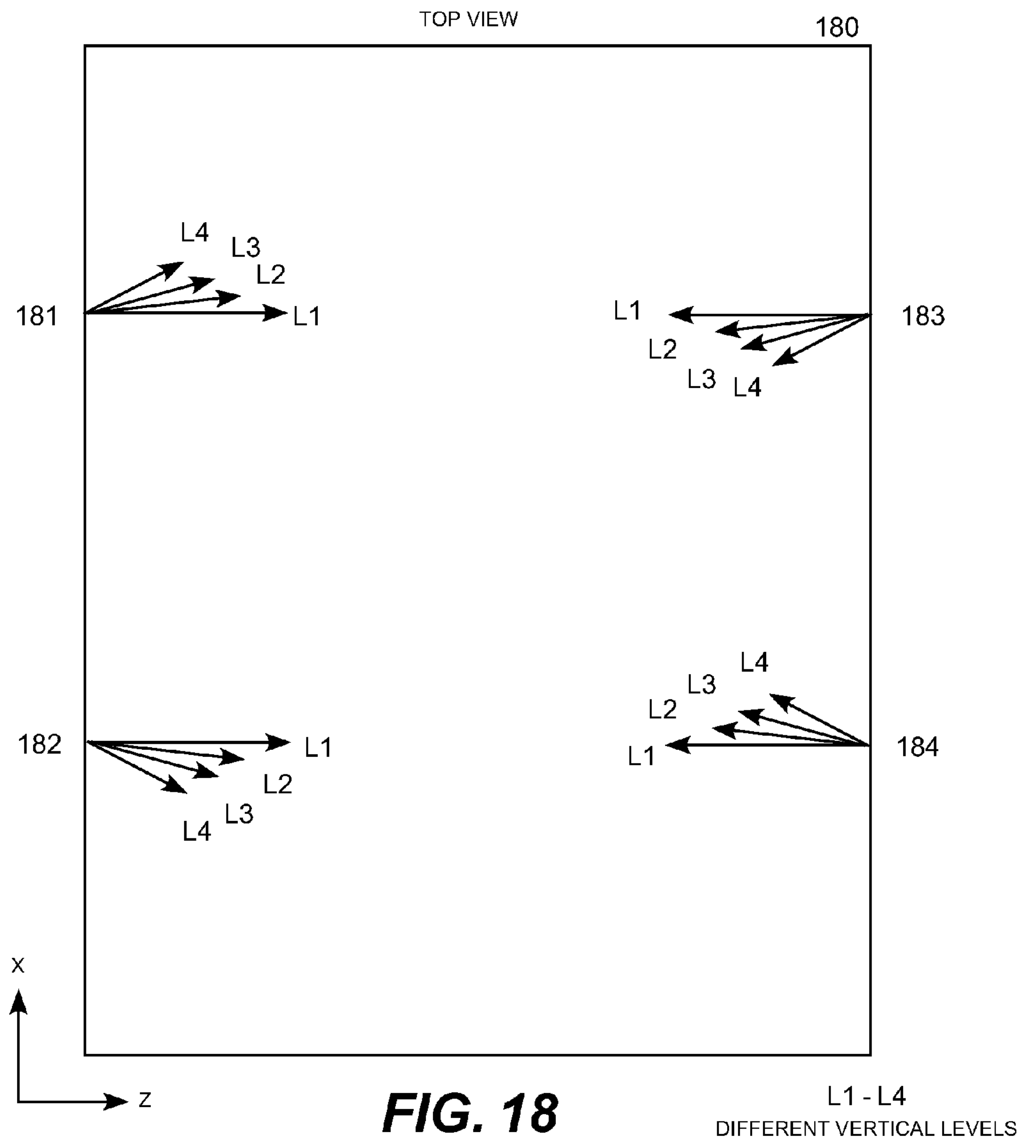

TOP VIEW
180
181
L4
L3
L2
L1
183
L1
L2
L3
L4
182
L1
L2
L3
L4
184
L4
L3
L2
L1
X
Z
L1 - L4
DIFFERENT VERTICAL LEVELS

FIG. 18

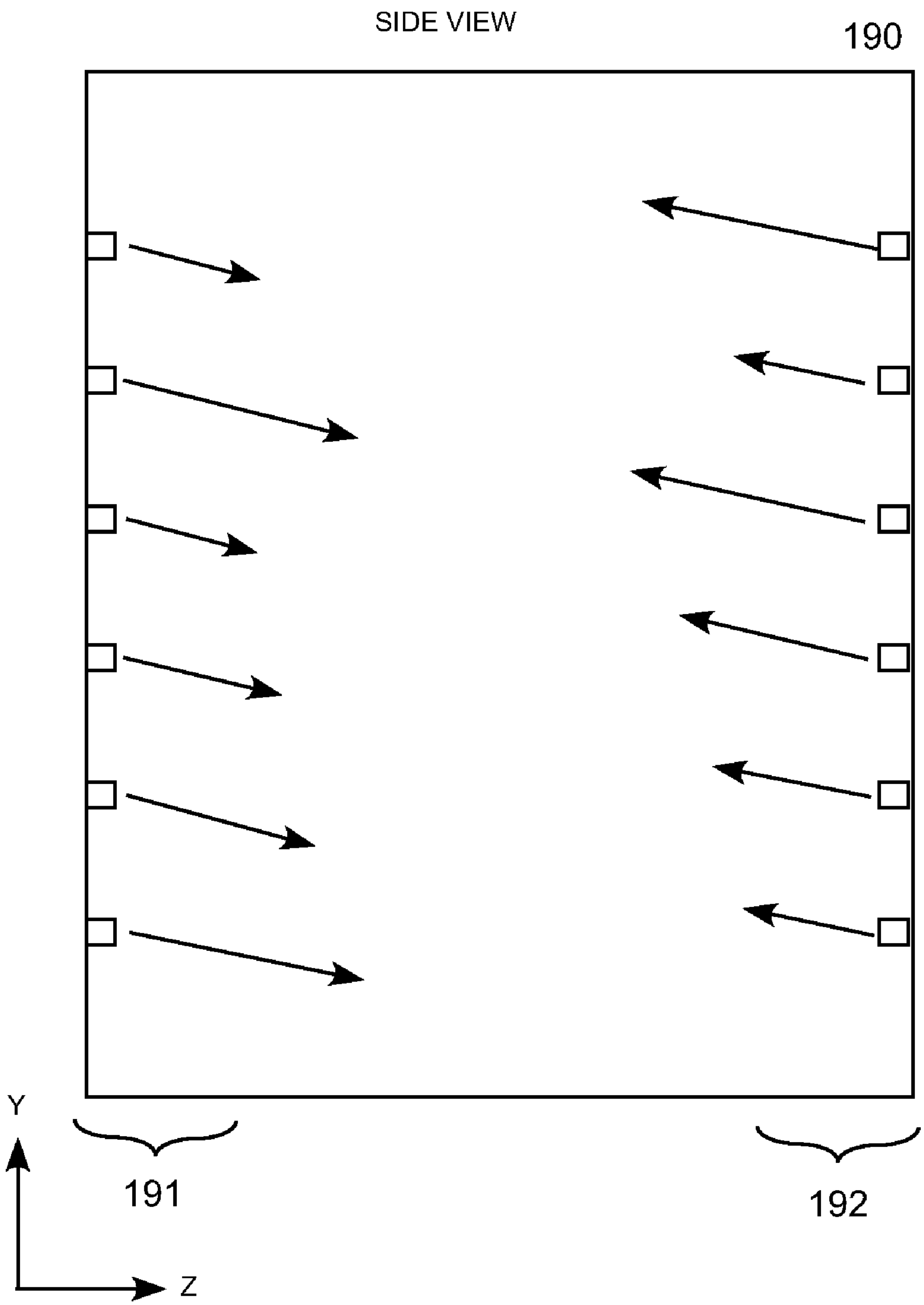
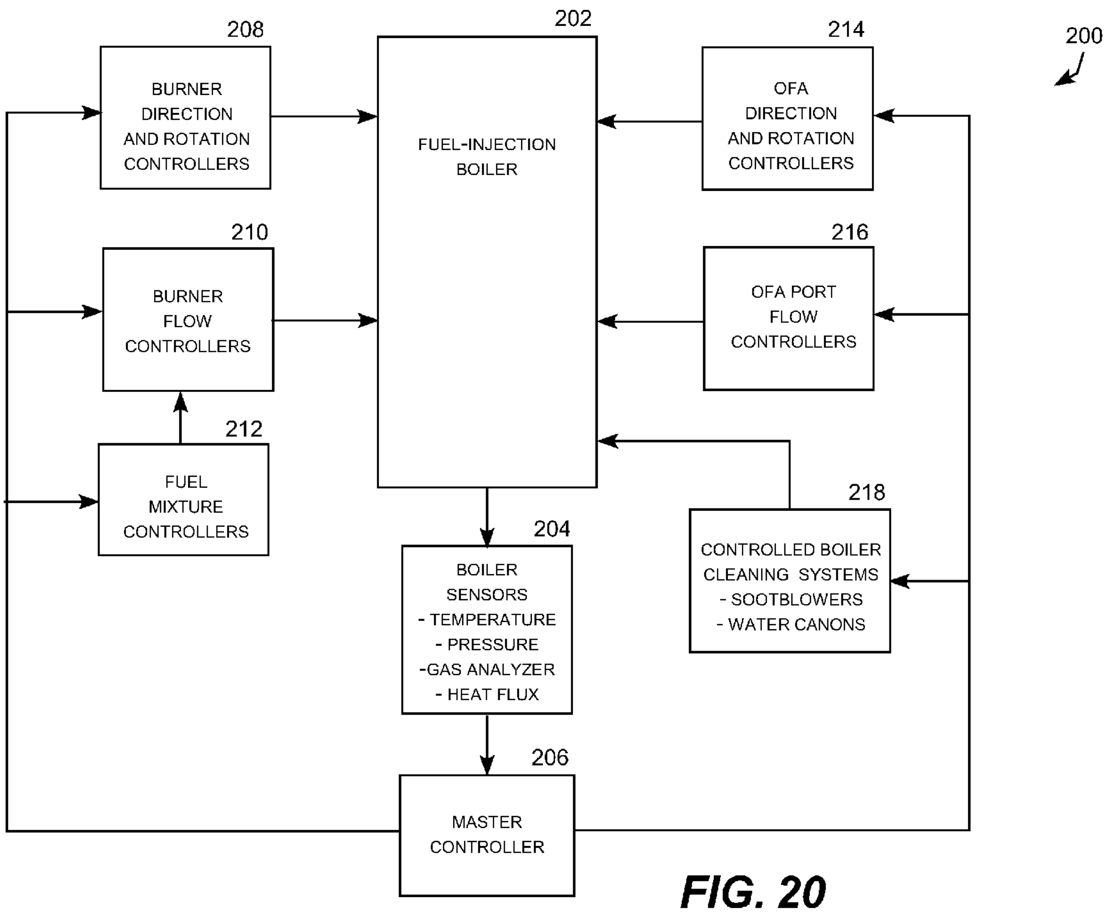


FIG. 19



200
208
BURNER DIRECTION AND ROTATION CONTROLLERS
202
FUEL-INJECTION BOILER
214
OFA DIRECTION AND ROTATION CONTROLLERS
210
BURNER FLOW CONTROLLERS
216
OFA PORT FLOW CONTROLLERS
212
FUEL MIXTURE CONTROLLERS
218
CONTROLLED BOILER CLEANING SYSTEMS
- SOOTBLOWERS
- WATER CANONS
204
BOILER SENSORS
- TEMPERATURE
- PRESSURE
-GAS ANALYZER
- HEAT FLUX
206
MASTER CONTROLLER

FIG. 20

COMBUSTION ROTATION SYSTEM FOR FUEL-INJECTION BOILERS

REFERENCE TO RELATED APPLICATIONS

[0001] The present invention claims priority to U.S. Provisional Patent Application Ser. No. 61/100,949 entitled "Method and System for Multiple Vortex Combustion Rotation in a Coal Fired Boiler" filed 29 Sep. 2008, which is incorporated herein by reference.

FIELD OF THE INVENTION

[0002] The present invention relates to industrial boilers and, more particularly, relates to a combustion rotation system for an industrial fuel-injection boiler in which the burners and over fire air (OFA) ports are located, directed and operated to induce multiple rotational vortexes in the combustion mass inside the combustion section of the fuel-injection boiler.

BACKGROUND OF THE INVENTION

[0003] For decades, industrial fuel-injection boilers have been operated with balanced fuel injection profiles that produce rising, non-rotating combustion masses inside the combustion section of the boiler. No systems are presently available for rotating or otherwise mixing the combustion mass in conventional fuel-injection boilers. U.S. Pat. No. 7,185,594 describes a combustion rotation system for a chemical recovery boiler in which supplemental air is injected into the combustion chamber to induce rotation of the combustion mass. This approach is not amenable for use in a fuel-injection boiler, such as a pulverized coal, oil or gas boiler, because injection of supplemental air to induce rotation of the combustion mass would change the air-fuel mixture in the boiler and impart other undesirable combustion characteristics. U.S. Pat. No. 5,809,910 describes a waste incinerator using over fire air (OFA) ports to rotate the combustion mass to more completely incinerate the contaminants in the waste product. This boiler is not a fuel injection boiler and describes rotating the entire combustion mass in a single vortex combustion rotation. Therefore, there remains a need for a combustion rotation system suitable for fuel-injection boilers, such as coal, oil and gas boilers.

SUMMARY OF THE INVENTION

[0004] The present invention may be implemented in a combustion rotation system in or for an industrial fuel-injection boiler with a combustion section, first and second opposing boiler walls, and a plurality of burners. Each burner is supported on the first or second boiler wall and configured for injecting a mixture of fuel and air into the boiler. Each burner has an associated fuel-injection flow rate controller. The flow rate controllers are set in a coordinated manner to impart an unbalanced fuel-injection profile to induce multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

[0005] In addition, each column of burners typically has one or more over-fire air ports located above the column of burners, and each over-fire air port has an associated flow rate controller. The over-fire air port flow rate controller may be set to impart an unbalanced air injection profile consistent with the unbalanced fuel-injection profile imparted by the fuel-injection rate controllers to assist the burners in inducing the multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

[0006] In a typical configuration, the burner locations on the first boiler wall are directly opposing the burner locations on the second boiler wall and the burners on each boiler wall are arranged into inboard columns and outboard columns. For an inboard/outboard rotational technique, the flow rate controllers are set to induce an unbalanced fuel-injection profile between the inboard columns and outboard columns on the first boiler wall, an unbalanced fuel-injection profile between the inboard columns and outboard columns on the second boiler wall, an unbalanced fuel-injection profile between the inboard columns on the first boiler wall and the inboard columns on the second boiler wall, and an unbalanced fuel-injection profile between the outboard columns on the first boiler wall and the outboard columns on the second boiler wall.

[0007] This combustion technique may be extended to boilers with larger numbers of columns of burners. In a first illustrative configuration, the number of columns on each boiler wall is four and the number of rotational vortexes is two. In a second illustrative configuration, the burners locations on the first boiler wall are directly opposing the burner locations on the second boiler wall. In a third second illustrative configuration, the number of columns on each boiler wall is six and the number of rotational vortexes is three. In a fourth illustrative configuration, the number of columns on each boiler wall is eight and the number of rotational vortexes is four.

[0008] In another combustion rotation technique, the fuel-injection lateral locations on the first boiler wall are laterally offset from the fuel-injection lateral locations on the second boiler wall to assist in the inducement of the multiple rotational vortexes in the combustion mass inside the combustion section of the boiler. In addition, one or more of the fuel-injection directions may be horizontally tilted to assist in the inducement of the multiple rotational vortexes in the combustion mass inside the combustion section of the boiler. As another technique, one or more of the fuel-injection directions may be vertically tilted to assist in mixing of the combustion mass inside the combustion section of the boiler. As yet another technique, the fuel-injection flow controllers may be set to impart a vertically unbalanced fuel injection profile along one or more of the columns to assist in mixing of the combustion mass inside the combustion section of the boiler. These techniques may be implemented individually or in various combinations to rotate and mix the combustion mass. A master controller may also be used to rotate and/or mix the combustion mass and/or actuate boiler cleaning equipment while the boiler is in operation in response to measured boiler parameters, such as temperature, pressure, gas analysis, and heat flux.

BRIEF DESCRIPTION OF THE DRAWINGS

[0009] FIG. **1** is a conceptual side view of a conventional fuel-injection boiler without combustion rotation.

[0010] FIG. **2** is a conceptual side view of a conventional fuel-injection boiler with burner ports and over fire air ("OFA") ports imparting rotation to the combustion mass inside the boiler.

[0011] FIG. **3** is a conceptual front view of a first boiler wall illustrating the burner and OFA ports on one side of the boiler.

[0012] FIG. **4** is a conceptual front view of a second boiler wall opposing the first boiler wall illustrating the burner and OFA ports on the opposing side of the boiler.

[0013] FIG. **5** is a conceptual perspective view of a fuel-injection boiler illustrating opposing placement of the burner and OFA ports.

[0014] FIG. **6** is a conceptual top view of burner ports in a first alternative fuel-injection boiler with laterally opposing burner ports illustrating the lateral placement and operation of the burner ports.

[0015] FIG. **7** is a conceptual top view of burner ports in a second alternative fuel-injection boiler with laterally opposing burner ports illustrating the lateral placement and operation of the burner ports.

[0016] FIG. **8** is a conceptual top view of burner ports in a third alternative fuel-injection boiler with laterally opposing burner ports illustrating the lateral placement and operation of the burner ports.

[0017] FIG. **9** is a conceptual top view of burner ports in a first alternative fuel-injection boiler with laterally offset burner ports illustrating the lateral placement and operation of the burner ports.

[0018] FIG. **10** is a conceptual top view of burner ports in a second alternative fuel-injection boiler with laterally offset burner ports illustrating the lateral placement and operation of the burner ports.

[0019] FIG. **11** is a conceptual top view of burner ports in a third alternative fuel-injection boiler with laterally offset burner ports illustrating the lateral placement and operation of the burner ports.

[0020] FIG. **12** is a conceptual front view of a boiler wall illustrating the vertical placement of the burner and OFA ports on one side of the boiler.

[0021] FIG. **13** is a conceptual side view of burner ports in a first alternative fuel-injection boiler with vertically opposing burner ports illustrating the vertical placement and operation of the burner ports.

[0022] FIG. **14** is a conceptual side view of burner ports in a second alternative fuel-injection boiler with vertically opposing burner ports illustrating the vertical placement and operation of the burner ports.

[0023] FIG. **15** is a conceptual top view of burner ports in a first alternative fuel-injection boiler with laterally offset and laterally directed burner ports illustrating the lateral placement, operation and orientation of the burner ports.

[0024] FIG. **16** is a conceptual top view of burner ports in a second alternative fuel-injection boiler with laterally offset and laterally directed burner ports illustrating the lateral placement, operation and orientation of the burner ports.

[0025] FIG. **17** is a conceptual top view of burner ports in a first alternative fuel-injection boiler with laterally offset and progressively directed burner ports illustrating the lateral placement, operation and orientation of the burner ports.

[0026] FIG. **18** is a conceptual top view of burner ports in a second alternative fuel-injection boiler with laterally offset and progressively directed burner ports illustrating the lateral placement, operation and orientation of the burner ports.

[0027] FIG. **19** is a conceptual side view of burner ports in as alternative fuel-injection boiler with laterally opposing and vertically directed burner ports illustrating the vertical placement, operation and orientation of the burner ports.

[0028] FIG. **20** is a functional block diagram of a fuel-injection burner with adjustable burner and OFA ports and a control system for adjusting the flow and direction of the burner and OFA ports while the boiler is in operation.

DETAILED DESCRIPTION

[0029] The present invention may be implemented in a combustion rotation system that utilizes the placement, direction, and/or unbalanced fuel injection flow rates to the burners in a fuel-injection power boiler, such as pulverized coal, oil or gas fired boiler, to achieve rotation of the combustion mass and other types of mixing of the combustion mass. The over fired air ("OFA") ports may also be placed, directed, and/or operated to contribute to the rotation of the combustion mass. For example, in a typical boiler configuration with four opposing columns of burner and OFA ports on opposite walls of the boiler, the jets are located, directed and/or operated to produce two counter-rotating inboard/outboard vortices in the combustion mass. The fuel-injection combustion rotation system may also be controlled while the boiler is operation, and controlled automatically, through a master control system.

[0030] U.S. Pat. No. 7,185,594 describes a combustion rotation system for a chemical recovery boiler in which supplemental air is injected above the combustion chamber to induce rotation of the combustion mass. While the injection of supplemental air into a chemical recovery boiler does not adversely affect the combustion process, this approach is not amenable for use in a fuel-injection boiler because the injection of additional air into the boiler to rotate the combustion mass would change the air-fuel mixture and impart other undesirable combustion characteristics.

[0031] The present invention solves this problem by placing, directing and/or controlling the air/fuel flow rate to the combustion burners involved in the combustion process to induce rotation of the combustion mass in the combustion section of the boiler without adversely affecting the air-fuel mixture. The placement, direction, and injection flow rates to the OFA ports may also be selected or controlled to assist in combustion rotation. The fuel-injection combustion rotation system induces multiple vortex rotation of the combustion mass, which is more efficient and effective than attempting to rotate the entire combustion mass in a single vortex.

[0032] As opposed to the chemical recovery boiler, a fuel-injection boiler, such as a pulverized coal, oil or gas fired boiler, introduces the fuel and combustion air through the same jet or burner. This means that one cannot just add additional air ports to rotate the combustion mass, as taught in U.S. Pat. No. 7,185,594, since this would result in an increase in the air/fuel ratio. This is not desirable because increasing the air/fuel ratio will increase the flue gas through the boiler resulting in multiple problems inside the boiler and in the back-end air pollution equipment. Altering the air/fuel ratio would also reduce the efficiency of the boiler, which is typically designed to obtain a desired air/fuel ratio prior to the injection of supplemental air for combustion rotation.

[0033] Rather than adding supplemental air to impart combustion rotation, the fuel-injection combustion rotation system utilizes the setup (i.e., placement, direction and/or flow rates) of the burners to impart combustion rotation, which is a significant adaptation and improvement over the supplemental air approach to imparting combustion rotation in a chemical recovery boiler. For some boilers, this means some burners become high flow burners while others become low flow burners. The high flow burners will flow more fuel/air than the low flow burners. In a coal fired boiler, the minimum amount of coal may be passed to the low flow burners based on the minimum allowable coal flow for the supply pipe, while the flow to the high flow burners is increased above the conventional level. This type of unbalanced fuel injection profile is quite the opposite of traditional practice where a lot of trouble is taken to balance the fuel flow to each burner.

[0034] A typical wall fired pulverized coal boiler contains multiple levels of burners on opposing walls. These burners on are arranged above each other in vertical stacks or columns and positioned so that there are similar columns of burners on opposite sides of the boiler (i.e., directly across the boiler. If the outer burners are chosen as the high flow burners, then the inner burners will be the low flow burners to impart rotation vortexes into the combustion mass. The opposite wall will have the opposite arrangement with high flow going to the inboard burners and low flow to the outboard burners. In this way the opposing jets will not interfere with each other. The resulting flow pattern produces two counter rotating inboard/outboard vortices. The spin is reinforced as the flue gases flow up and past each level of the burner and OFA jets, which are similarly operated. Even though the burner flows are biased, the total fuel flow and air/fuel ratio per level typically remains approximately the same as in the conventional balanced fuel injection technique, although these parameters may be altered and re-optimized if desired. In particular, the total fuel flow and air/fuel ratio may be optimized for efficiency, pollution control, or other desired characteristics to take advantage of the higher efficiency combustion obtained with combustion rotation.

[0035] Rotating the combustion mass significantly increases the mixing between the air and fuel, which leads to an increase in combustion efficiency enabling more complete combustion reducing the amount of carbon monoxide generated in comparison to the conventional balanced fuel injection technique. The spiraling upward movement of the combustion mass increases the residence time for the fuel in the combustion section of the boiler, enabling it to burn more completely. The improved combustion results in a greater heat release in the furnace and a reduction of un-burnt fuel in the ash. All of these are desirable improvements.

[0036] NOx that is generated as part of combustion is considered a major pollutant. Hence reducing NOx is highly desired. NOx forms through two mechanisms. One is the oxidation of the N2 in the atmosphere at high temperatures while the other is through a series of chemical reactions that combine the N in the fuel with the O2 in the atmosphere. In order to control the NOx production, combustion engineers have staged the combustion. This is done by removing some percentage of the air in the burner zone and introducing it further in the furnace. To do this, multiple openings known as air ports are made in the boiler wall. These ports are referred to as Over Fired Air ("OFA") ports. Typically these air ports are lined up vertically with the burners and are opposing OFA ports on the other side of the boiler. In the fuel-injection combustion rotation system, the certain OFA ports may be blocked off so that there are high air flow to OFA ports above the high flow burners and no flow to the OFA ports above the low flow burners.

[0037] Computation Fluid Dynamics (CFD) is widely used today to model the complex combustion and fluid flow processes in a boiler. The boiler shown in FIG. **5** was setup in a computer model and three numerical simulations were made to see the effects of the firing strategy shown in FIG. **6**. The existing setup was the base case and two other cases case 1 and case 2 were run with the firing strategy shown in FIG. **6**. Case 1 had the same air splits at every burner level and the OFA as the base case. In case 2 the air was shifted from the burner zone to the OFA zone in order to reduce the NOx. The percentage changes in the firing system and the key boiler parameters are shown below in Table 1. The primary air (1RY) carries the coal while the secondary (2RY) air provides much of the combustion air and is brought in through the burner as well.

TABLE 1

INPUT	Case 1 HI/Base	Case 1 LO/Base	Case 1 HI/LO	Case 2 HI/Base	Case 2 LO/Base	Case 2 HI/LO
Coal Flow/burner	134%	66%	205%	134%	66%	205%
1RY Air Flow/burner	134%	66%	205%	134%	66%	205%
2RY Air Flow/burner	130%	63%	205%	92%	45%	205%
OFA Flow	200%	0%		1059%	0%	

RESULTS	Case 1-Base	Case 2-Base
Gas Temp at SH exit	−2%	−1%
CO at SH exit	−73%	−33%
Nox at SH exit	13%	−47%
C in Ash(LOI)	−81%	−81%
Total Heat transfer	5%	1%

In case 1 the high flow burners (HI) flowed 34% more coal than the base case while the low flow burners (LO) flowed 34% less. The ratio between the HI and LO flow burners was 2:1. In the case of the OFA the total number of ports used was reduced from 8 to 4 hence doubling the flow per port. The enhanced mixing results in a 73% reduction in carbon monoxide (CO) and an 81% reduction of unburnt carbon in the ash. However the NOx generation went up by 13%. This is due to the fact that more of the nitrogen came in contact with the air due to the better mixing.

[0038] To offset this more of the secondary (2RY) air was move to the OFA resulting in a 159% increase in OFA. This results in substoicheometric conditions in the burner zone resulting in an higher CO at the superheater exit giving a 33% reduction versus 73% in case 1. As expected the NOx generation went down by 47% from the base case. These results show that the superior mixing of this I/O system allows one to hold the CO generation down while allowing one to move more air to the OFA elevation to reduce NOx. Without this type of aggressive mixing the CO generation will go up. This is well known to people working with combustion.

[0039] Turning now to the drawings, in which like numerals refer to similar elements throughout the figures, FIG. **1** is a conceptual side view of a conventional fuel-injection boiler **10** without combustion rotation. A Cartesian coordinate system is shown to facilitate the description of the boiler. The "x" direction is horizontal along the main boiler wall, which is into the page as shown in FIG. **1**. The "y" direction is vertical, and the "z" direction is horizontal across the boiler, as shown in FIG. **1**. The boiler **10** is vertically organized with a heat exchanger section **14** on top, a combustion section **16** below the heat exchanger section, and a bottom ash section **18** below the combustion section **16**. In generally, combustion occurs in the combustion section **16**, the combustion heat rises to heat steam generators in the heat exchanger section **14**, and the bulk of the ash falls into the bottom ash section **16**, where it is removed from the boiler. Although this layout is simplified, it is sufficiently representative of industrial boilers for the purpose of describing the present invention.

[0040] The boiler **10** includes a pair of opposing boiler walls **11**, **12** extending in the "x" direction that support a number of opposing burners **20** that inject a mixture of air and fuel, such as pulverized coal, oil or natural gas, into the combustion section of the boiler. The boiler walls also support a number over-fire air ("OFA") ports **22** that inject air into the combustion section of the boiler above the level of the burners. The burners **20** and OFA ports **22** on opposing sides of the boiler in a conventional boiler are stacked in vertical columns directly across from each other. The lower row of burners is sometimes referred to as the primary (1RY) burners, the next level is sometimes referred to as the secondary (2RY) burners, and the upper level is sometimes referred to as the tertiary (3RY) burners. In a boiler with four levels of burners, the lower pair of rows may be referred to as the primary (1RY) burners, and the upper pair of rows may be referred to as the secondary (2RY) burners. FIG. **1** shows one illustrative vertical column consisting of four burners and one OFA ports on each opposing boiler wall. Typically, there are at least four vertical columns of burners and OFA ports on each boiler wall spaced apart in the "x" direction. The inner columns are typically referred to as the inboard columns, and the outer columns are typically referred to as the outboard columns.

[0041] In the conventional fuel injection boiler, the burners and OFA ports on the first wall **11** are positioned directly across from a mirror-image set of burners and OFA ports on the opposing wall **12**, and each burner and OFA port is directed horizontally, parallel to the "z" direction at various vertical levels. In addition, each opposing pair of burners is typically operated at the same injection rate, which results in a "balanced" injection profile. Each opposing pair of OFA ports is also operated at the same injection rate in the balanced injection profile. This results in a non-rotating combustion mass that travels inward toward the middle of the boiler and upward toward the heat exchangers, as shown in FIG. **1**. The balanced fuel injection profile resulting in a non-rotating combustion mass flow pattern has been used in conventional fuel injection boiler for many decades.

[0042] The heat exchanger section **14** at the top of the boiler **10** has multiple wing walls also known as division panels **24** that come off the front walls. These act like flow straighteners that tend to destroy any rotation in the flow gas. Due to a relatively short distance from the OFA ports **22** ports to the bottom of the wing walls in a typical fuel-injection boiler, there is insufficient space to stack more than one or two levels of OFA ports between the burners and the division panels. Therefore, it is not possible to use the OFA ports alone to impart significant rotation to the combustion mass, as described for certain chemical recovery boilers in U.S. Pat. No. 7,185,594.

[0043] As shown in FIG. **2**, the present invention accomplishes the objective of rotating the combustion mass in a fuel-injection boiler by positioning, directing, and/or adjusting the flow rates of the burners **20** to impart the rotation to the combustion mass. The OFA ports **22** may also be positioned, directed, and/or operated to assist in the rotation to the combustion mass. Preferably, the burners and OFA ports are positioned, directed, and operated to impart multiple upward spiraling vortexes into the combustion mass as the combustion heat rises toward the heat exchangers. This requires deviating from the "balanced" injection profile that has been ingrained into the boiler industry for decades. A number of techniques for rotating the combustion mass have been developed, as described below.

[0044] FIGS. **3** and **4** illustrate a representative layout of burners **20** and OFA ports **22** on the opposing burner walls **11**, **12** in a fuel-injection boiler, in which each column contains four burners and one OFA port. FIG. **5** shows a perspective view of this boiler configuration, and FIG. **6** shows a top view of this boiler configuration. With reference to the Cartesian coordinate system, each boiler wall **11**, **12** lies in an "x-y" plane and they are spaced apart from each other across the boiler in the "z" direction. This representative boiler configuration includes four columns of burners and OFA ports spaced apart in the "x" direction, in which each column has four burners **20** and one OFA port **22**. The inner columns **40** on the first boiler wall **11** are referred to as inboard columns, and the outer columns **42** on the first boiler wall **11** are referred to as outboard columns. Similarly, the inner columns **44** on the second boiler wall **12** are referred to as inboard columns, and the outer columns **46** on the second boiler wall **12** are referred to as outboard columns.

[0045] FIGS. **3** and **4** illustrate a basic technique for using the burners and optionally the OFA ports to impart rotation to the combustion mass in a conventional fuel-injection boiler without making any physical alterations to the boiler. As is the case with all of the combustion rotation techniques described below, this technique can be applied to the burners alone or to the burners and the OFA ports. In addition, the longer arrows indicate higher flow rates throughout the injection flow diagrams. For this technique, the flow rates to the inboard and outboard columns are adjusted into an unbalanced injection pattern to impart rotation to the combustion mass. For example, the flow rates to the outboard columns **40** on the first boiler wall **11** are set to a relatively high flow rate (indicated by bold ports), while the flow rates to the outboard columns **44** on the second boiler wall **12** are set to a relatively low flow rate (indicated by non-bold ports). Similarly, the flow rates to the inboard columns **42** on the first boiler wall **11** are set to a relatively low flow rate (indicated by non-bold ports), while the flow rates to the inboard columns **46** on the second boiler wall **12** are set to a relatively high flow rate (indicated by bold ports). These flow adjustments can typically be implemented without changing the total mass flow rate through the boiler, although the total mass flow rate may be changed if desired.

[0046] As shown on FIGS. **3-6**, this adjustment to the fuel injection rates results in unbalanced flow injection rates between the outboard columns **40** and the inboard columns **42** on the first boiler wall **11**. At the same time, unbalanced flow injection rates a the outboard columns **44** and the inboard columns **46** on the second boiler wall **12**. This adjustment also results in unbalanced flow injection rates between the outboard columns **40**, **44** on opposing boiler walls, and the inboard columns **42**, **46** on opposing boiler walls. The top view of FIG. **6** shows illustrates the unbalanced flow injection profile **61** applied to the burners on the first boiler wall **11**, and the corresponding unbalanced flow injection profile **62** applied to the burners on the second boiler wall **12**. These injection profiles produce two counter-rotating vortexes **63**, **64** in the combustion mass.

[0047] Referring to FIG. **5**, with this arrangement the two counter-rotating vortices **63**, **64** (shown in FIG. **6**) spiral upward into the heat exchanger section **14** taking the flue gas past the division panels **24**, past what is known as the bull nose **70**, and past the pendent super heaters **26**. The flue gas then passes the heat exchanger exit **13** and continues to pass through further heat transfer surfaces.

[0048] It should be appreciated that two vortices can be created using high and low flow burner jet flows in a boiler with four columns of burners as shown in FIGS. **3-6**, whereas three vortices can be created in a boiler with six columns of burners as shown in FIG. **7** and four vortices can be created in a boiler with eight columns of burners as shown in FIG. **8**. This technique for rotating the combustion mass by adjusting the flow rates in opposing burners and OFA ports can typically be applied to existing boilers without making physical modifications to the boiler. Illustrative examples of burner and OFA port configurations with flow rates varying horizontally are shown in FIGS. **6-8**. FIGS. **9-11** illustrate laterally offset burner placement while Illustrative examples of burner and OFA port configurations with flow rates varying vertically are shown in FIGS. **13-14**.

[0049] More specifically, FIGS. **7** and **8** illustrate and expansion of the flow injection modification technique for inducing rotation of the combustion mass described with reference to FIGS. **3-6** to boilers with larger numbers of opposing columns of burners and OFA ports on opposite sides of the boiler. FIG. **7** is a conceptual top view of burner ports in a second alternative fuel-injection boiler **70** with laterally opposing burner ports illustrating the lateral placement and operation of the burner ports. The boiler **70** includes six opposing columns of burners and OFA ports on opposite sides of the boiler. FIG. **7** shows illustrates the unbalanced flow injection profile **71** applied to the burners on the first boiler wall, and the corresponding unbalanced flow injection profile **72** applied to the burners on the second boiler wall These injection profiles produce three counter-rotating vortexes **73**, **74**, and **75** in the combustion mass.

[0050] This same technique can be expanded to a boiler with eight columns of burners and OFA ports on opposing boiler walls. FIG. **8** is a conceptual top view of burner ports in a third alternative fuel-injection boiler **80** with laterally opposing burner ports illustrating the lateral placement and operation of the burner ports. The boiler **80** includes eight opposing columns of burners and OFA ports on opposite sides of the boiler. FIG. **8** shows illustrates the unbalanced flow injection profile **81** applied to the burners on the first boiler wall, and the corresponding unbalanced flow injection profile **82** applied to the burners on the second boiler wall These injection profiles produce four counter-rotating vortexes **83**, **84**, **85** and **86** in the combustion mass.

[0051] For a new plant or a plant in which physical modifications can be made, staggered burner placement can also be used to rotate the combustion mass, which can reduce the number of columns of burners required to produce the same number of vortices. For this technique, the opposing burners and OFA are not directed directly at each other, but are instead offset to induce mixing in the combustion mass. The burners and OFA ports may be strategically located horizontally (x direction), vertically (y direction), or both horizontally and vertically in addition to varying the flow rates (z direction). Strategic placement of burners can eliminate the need for low flow burners and associated piping and support structures. For example, FIG. **9** shows a dual vortex boiler utilizing three staggered (laterally offset) columns of high flow burners, FIG. **10** shows a triple vortex boiler utilizing four laterally offset columns of high flow burners, and FIG. **11** shows a quad vortex burner utilizing five laterally offset columns of high flow burners. These laterally offset, multi-vortex design alternatives are particularly attractive options for new boilers that can be originally designed to rotate the combustion mass. The staggered port profiles may be implemented with the same flow injection rate to each column or in combination with flow rate adjustment, horizontally tilted injection, and/or vertically tilted injection.

[0052] FIG. **9** is a conceptual top view of burner ports in a first alternative fuel-injection boiler **90** with laterally offset burner ports illustrating the lateral placement and operation of the burner ports. In the simplest configuration, the first boiler wall includes one column **91** of burner and OFA ports and the opposing boiler wall includes two columns **92** of burner and OFA ports. The column **91** is located laterally (x direction) between the columns **92**. This staggered port profile produces two counter-rotating vortexes **93**, **94** using only three columns of injection ports. The staggered port profile may be implemented with the same flow injection rate to each column, as shown in FIG. **8**, or in combination with flow rate adjustment. For example, the injection flows rates could be adjusted so that the flow rate to column **91** is greater than the flow rates to columns **92**, or vice versa.

[0053] This same technique can be expanded to a boiler with any number of columns of burners and OFA ports on opposing boiler walls. FIG. **10** is a conceptual top view of burner ports in a second alternative fuel-injection boiler **100** with laterally offset burner ports illustrating the lateral placement and operation of the burner ports. The first boiler wall includes two columns **101** of burner and OFA ports and the opposing boiler wall includes two columns **102** of burner and OFA ports. The columns **101** are laterally (x direction) offset from the columns **102**. This staggered port profile produces three counter-rotating vortexes **103**, **104**, and **105**.

[0054] FIG. **11** is a conceptual top view of burner ports in a third alternative fuel-injection boiler **110** with laterally offset burner ports illustrating the lateral placement and operation of the burner ports. The first boiler wall includes two columns **111** of burner and OFA ports and the opposing boiler wall includes three columns **112** of burner and OFA ports. The columns **111** are laterally (x direction) offset from the columns **112**. This staggered port profile produces four counter-rotating vortexes **113-116**. Those skilled in the art will appreciate that this technique can be readily expanded to boilers with larger numbers of laterally offset columns of burners and optional OFA ports.

[0055] FIG. **12** is a conceptual front view of a boiler wall **120** illustrating the vertical placement of the burner and OFA ports on one side of the boiler. All of the techniques described in this specification can be applied to boilers with fuel-injection burners and any number of OFA ports, including boilers with no OFA ports. The same combustion techniques can also be applied to only the burner ports or to both the burner and OFA ports in a boiler with burners and OFA ports. FIGS. **1-6** show a boiler in which each column includes four burners and one OFA port. FIG. **12** expands this concept to a boiler in which each column includes four burners and three OFA ports. Configuring the boiler with multiple columns of burners, each with multiple staked OFA ports, increases the ability to adjust the flow rates through the burners and OFA ports vertically (in the y direction) as well as horizontally (in the x direction) to impart desired mixing in the combustion mass. The flow rates through the burners and OFA (the force in the z direction) may be varied from burner to burner and OFA port to OFA port vertically (in the y direction) to impart desired mixing in the combustion mass as an alternative or in addition to varying the flow rates from burner to burner and OFA port to OFA port horizontally (in the x direction).

[0056] FIG. **13** is a conceptual side view of burner ports in a first alternative fuel-injection boiler **130** with vertically opposing burner ports illustrating the vertical placement and operation of the burner ports. A first vertical flow injection profile **131** is applied to the burners and OFA ports on the first boiler wall, and second vertical flow injection profile **132** is applied to the burners and OFA ports on the opposing boiler wall. FIG. **14** shows a second alternative fuel-injection boiler **140** a different vertical flow rate injection profile. A first vertical flow injection profile **141** is applied to the burners and OFA ports on the first boiler wall, and second vertical flow injection profile **142** is applied to the burners and OFA ports on the opposing boiler wall. Those skilled in the art will appreciate that this technique can be readily expanded to boilers with larger numbers of burners and optional OFA ports in each column, and to apply different vertical injection flow rate profiles as matters of design choice.

[0057] In addition to the techniques described above, one or more of the burners and OFA jets may be injected into the boiler at a vertically and/or horizontally tilted angle to impart desired mixing in the combustion mass. Angling the burners can be implemented in combination with staggered columns and/or flow rate adjustment to further induce mixing of the combustion mass. Examples of burner and OFA jets that are tilted horizontally (in the x-z plane) are shown in FIGS. **15** and **16**. FIG. **15** is a conceptual top view of burner ports in a first alternative fuel-injection boiler **150** with laterally offset and laterally directed burner ports illustrating the lateral placement, operation and orientation of the burner ports. In the simplest configuration, the first boiler wall includes one column **151** of burner and OFA ports and the opposing boiler wall includes two columns **152** of burner and OFA ports. The column **151** is located laterally (x direction) between the columns **152**. In addition, the column **151** is directed horizontally (z direction), while the columns **152** on the opposite side of the boiler are horizontally tilted to assist on combustion rotation. FIG. **16** shows this technique expanded to an alternative boiler **160** with two columns **161** on the first boiler wall and two columns **162** in the opposing boiler wall. Further, if the injection stream has an asymmetrical shape, such as a fan profile, the angle of the fan profile also can be rotated along the axis of injection by rotating the jet nozzle about the axis of injection, as represented by the rotational injection patterns **163** and **164** shown in FIG. **16**. Those skilled in the art will appreciate that these techniques can be readily expanded to boilers with larger numbers of burners and optional OFA ports in each column, and to apply different horizontal injection flow direction profiles as matters of design choice.

[0058] As another design option, the angle of burner and/or OFA injection can be varied from port-to-port in the vertical direction as shown in FIG. **17**. FIG. **17** is a conceptual top view of burner ports in a first alternative fuel-injection boiler **170** with laterally offset and progressively directed burner ports illustrating the lateral placement, operation and orientation of the burner ports. In this example, the first boiler wall includes two columns **171**, **173** of the burners and/or OFA ports. Each column includes ports at four vertical (y direction) levels. L**1**-L**4**. The injection direction is directly across the boiler (z direction) at L**1**, and the injection direction at each successive level L**3**-L**4** is progressively tilted horizontally (x direction) from the cross-boiler direction. A similar, complementary progressive offset injection profile is applied by the columns **173**, **174** on the opposite side of the boiler. This technique can be applied to boilers with any number of columns of burners and OFA ports, and can be combined with any of the other combustion rotation techniques. For example, FIG. **18** illustrates the combination of the complementary progressive offset injection profile of FIG. **17** with an unbalanced vertical flow rate injection profile in a boiler **180** with columns **181**-**184**.

[0059] As an alternative to, or addition to, the combustion rotation techniques described above, the burner and OFA jets may also be tilted or angled vertically (in the y-z plane) as shown in FIG. **19**. FIG. **19** illustrates the vertical injection tilt technique in combination with an unbalanced vertical flow rate injection profile in a boiler **190** with injection profiles **191**-**192**.

[0060] Those skilled in the art will appreciate that the basic concept of adjusting the burner flow rates, positions, injection angles, and nozzle rotation to rotate and otherwise mix the combustion mass may be implemented with a range of different specific burner and OFA port configurations. Those conceptual examples shown in the figures are merely illustrative. In general, the equipment required to implement these combustion rotation techniques include an air/fuel mixture and fuel injection flow rate controller for each burner to be controlled with flow rate adjustment, a fuel injection flow rate controller for each OFA port to be controlled with flow rate adjustment, jet nozzle rotating equipment for each burner and OFA port to be rotated, and jet pointing equipment for each burner and OFA port to be directionally controlled. Jet nozzles may be rotated with motor driven gear assemblies. The jet pointing equipment may include mounting structures for supporting the burner or OFA jet in a desired orientation. Directional nozzles may also be use to direct burner or OFA jets in desired directions. The directional nozzles may be rotated with motor driven gear assemblies to change the pointing directions of the jets. In general, the mounting structures and nozzles may be fixed, in which case they are physically changed to make adjustments, or these structures may be manually adjustable or motorized for remotely controlled adjustment while the boiler is in operation.

[0061] In addition, all of the injection parameters illustrated above can be changed from burner to burner and OFA port to OFA port as desired to impart mixing and rotation to the combustion mass. For example, the positions, flow rates, and angles of injection for the burners and the OFA ports can selected as design considerations for a new plant. In addition, most of these parameters can be changed for an existing plant, in some cases requiring equipment upgrades such as jet pointing equipment. Once control equipment is in place for some or all of these parameters, some or all of the parameters can be changed while the boiler is on operation, for example by turning burner and OFA jets on and off, adjusting the flow rates, and adjusting injection angles. One or more of these parameters can also be changed continually or continuously (modulated) in accordance with predefined patterns, measured performance characteristics, and/or feedback signals.

[0062] The fuel mixture supplied to the burners and boiler cleaning equipment, such as water canons and sootblowers, can also be controlled in accordance with predefined patterns, measured performance characteristics, and/or feedback signals. As shown in FIG. **20**, the burners, OFA ports, fuel mixture and cleaning equipment can all be controlled based on sensor data obtained in real time to meet or optimize desired operating characteristics. The sensor data typically includes the boiler's thermal output, temperatures, pressures, gas content, ash content, pollution emissions, and heat flux. The boiler can be controlled to optimize the thermal output while meeting pollution emission thresholds, for example NOx emission limits, and minimizing unburned carbon in the ash.

[0063] More specifically, FIG. **20** illustrates a fuel-injection boiler system **200** for a fuel-injection boiler **202**. The system **200** includes sensors **204** that monitor boiler operating parameters, such as temperature, pressure, gas analysis, and heat flux. These parameters are fed to a master controller **206**, which analyzes the performance of the boiler based on the measured parameters, predicts changed to the performance in response to changes in the burner and optionally the OFA injection profile, and the implements changes in the injection profile to optimize the performance of the boiler. The master controller **206** can be programmed to optimize the performance of the boiler while meeting pollution emission thresholds. In particular, the master controller **206** is configured to control burner one or more of the rotation and direction controllers **208**, burner flow rate controllers **210**, and fuel/air mixture controllers **212**. For the OFA ports, the master controller **206** may also be configured to control one or more of the OFA rotation and direction controllers **214** and the OFA flow rate controllers **216**. The master controller **206** may also determine from the measured parameters when the boiler is in need of cleaning and activate controlled boiler cleaning systems, such as sootblowers and water canons. In response to the measured parameters, the master controller **206** may control the cleaning of particular portions of the boiler, implement general boiler cleaning, and adjust regularly scheduled maintenance regimens. Those skilled in the art will understand that all or a portion of the equipment shown in FIG. **8** may be implemented as a matter of design choice in different plants. In an existing plant, for example, a strategic subset of the burners may be retrofitted with directional jets or nozzle rotation equipment, as desired. New plants will benefit greatly by strategically positioning the jets in laterally offset configurations during original plan construction and installing some or all of the automated combustion rotation and mixing equipment shown in FIG. **8** to provide the plant operators with rich sets of control options for optimizing the operation of the plant to achieve desired performance characteristics considering at least plant efficiency, pollution production, and cleaning regimens.

The invention claimed is:

1. A combustion rotation system in or for an industrial fuel-injection boiler having a combustion section, comprising:

a boiler having first and second opposing walls;

a plurality of burners, each burner supported on the first or second boiler wall and configured for injecting a mixture of fuel and air into the boiler;

wherein each burner has an associated fuel-injection flow rate controller; and

wherein flow rate controllers are set to impart an unbalanced fuel-injection profile to induce multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

2. The combustion rotation system of claim **1**, wherein:

the burners have locations on the first and second boiler walls;

the burners locations on the first boiler wall are directly opposing the burner locations on the second boiler wall;

the burners on each boiler wall are arranged into inboard columns and outboard columns;

the flow rate controllers are set to induce an unbalanced fuel-injection profile between the inboard columns and outboard columns on the first boiler wall;

the flow rate controllers are set to induce an unbalanced fuel-injection profile between the inboard columns and outboard columns on the second boiler wall;

the flow rate controllers are set to induce an unbalanced fuel-injection profile between the inboard columns on the first boiler wall and the inboard columns on the second boiler wall; and

the flow rate controllers are set to induce an unbalanced fuel-injection profile between the outboard columns on the first boiler wall and the outboard columns on the second boiler wall.

3. The combustion rotation system of claim **1**, wherein:

the burners on each boiler wall are arranged into columns;

each column of burners has one or more over-fire air ports located above the column of burners;

each over-fire air ports has an associated flow rate controller; and

the over-fire air port flow rate controllers are set to impart an unbalanced air injection profile consistent with the unbalanced fuel-injection profile imparted by the fuel-injection rate controllers to assist the burners in inducing the multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

4. The combustion rotation system of claim **1**, wherein:

the burners have locations on the first and second boiler walls;

the burners locations on the first boiler wall are directly opposing the burner locations on the second boiler wall;

the burners on each boiler wall are arranged into columns;

the number of columns on each boiler wall is four and the number of rotational vortexes is two, or the number of columns on each boiler wall is six and the number of rotational vortexes is three, or the number of columns on each boiler wall is eight and the number of rotational vortexes is four.

5. The combustion rotation system of claim **1**, further comprising:

a plurality of sensors for measuring boiler parameters; and

a master controller for adjusting the fuel injection profile in response to the measured boiler parameters.

6. The combustion rotation system of claim **1**, further comprising:

a plurality of sensors for measuring boiler parameters; and

a master controller for activating boiler cleaning equipment in response to the measured boiler parameters.

7. The combustion rotation system of claim **1**, wherein:

each burner has an associated fuel-injection lateral location;

wherein the fuel-injection lateral locations on the first boiler wall are laterally offset from the fuel-injection lateral locations on the second boiler wall to assist in the inducement of the multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

8. The combustion rotation system of claim **1**, wherein:

each burner having an associated fuel-injection direction;

wherein one or more of the fuel-injection directions are horizontally tilted to assist in the inducement of the multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

9. The combustion rotation system of claim **1**, wherein: each burner has an associated fuel-injection direction; wherein one or more of the fuel-injection directions are vertically tilted to assist in mixing of the combustion mass inside the combustion section of the boiler.

10. The combustion rotation system of claim **1**, wherein: the burners on each boiler wall are arranged into columns; the fuel-injection flow controllers are set to impart a vertically unbalanced fuel injection profile along one or more of the columns to assist in mixing of the combustion mass inside the combustion section of the boiler.

11. A combustion rotation system in or for an industrial fuel-injection boiler having a combustion section, comprising:

a boiler having first and second opposing walls;

a plurality of burners, each burner supported on the first or second boiler wall and configured for injecting a mixture of fuel and air into the boiler;

wherein each burner has an associated fuel-injection lateral location;

wherein the fuel-injection lateral locations on the first boiler wall are laterally offset from the fuel-injection lateral locations on the second boiler wall to induce multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

12. The combustion rotation system of claim **11**, wherein: each burner has an associated fuel-injection flow rate controller; and the flow rate controllers are set to impart an unbalanced fuel-injection profile to assist in the inducement of the multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

13. The combustion rotation system of claim **12**, wherein: each burner having an associated fuel-injection direction; and one or more of the fuel-injection directions are horizontally tilted to assist in the inducement of the multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

14. The combustion rotation system of claim **11**, wherein: each burner has an associated fuel-injection direction; one or more of the fuel-injection directions are vertically tilted to assist in mixing of the combustion mass inside the combustion section of the boiler.

15. The combustion rotation system of claim **11**, wherein: the burners on each boiler wall are arranged into columns; the fuel-injection flow controllers are set to impart a vertically unbalanced fuel injection profile along one or more of the columns to assist in mixing of the combustion mass inside the combustion section of the boiler.

16. A combustion rotation system in or for an industrial fuel-injection boiler having a combustion section, comprising:

a boiler having first and second opposing walls;

a plurality of burners, each burner supported on the first or second boiler wall and configured for injecting a mixture of fuel and air into the boiler;

wherein each burner has an associated fuel-injection direction;

wherein the fuel-injection directions are set to induce multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

17. The combustion rotation system of claim **16**, wherein: wherein each burner has an associated fuel-injection lateral location; wherein the fuel-injection lateral locations on the first boiler wall are laterally offset from the fuel-injection lateral locations on the second boiler wall to induce multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

18. The combustion rotation system of claim **16**, wherein: each burner has an associated fuel-injection flow rate controller; and the flow rate controllers are set to impart an unbalanced fuel-injection profile to assist in the inducement of the multiple rotational vortexes in the combustion mass inside the combustion section of the boiler.

19. The combustion rotation system of claim **16**, wherein one or more of the fuel-injection directions are vertically tilted to assist in mixing of the combustion mass inside the combustion section of the boiler.

20. The combustion rotation system of claim **16**, wherein: the burners on each boiler wall are arranged into columns; the fuel-injection flow controllers are set to impart a vertically unbalanced fuel injection profile along one or more of the columns to assist in mixing of the combustion mass inside the combustion section of the boiler.

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