



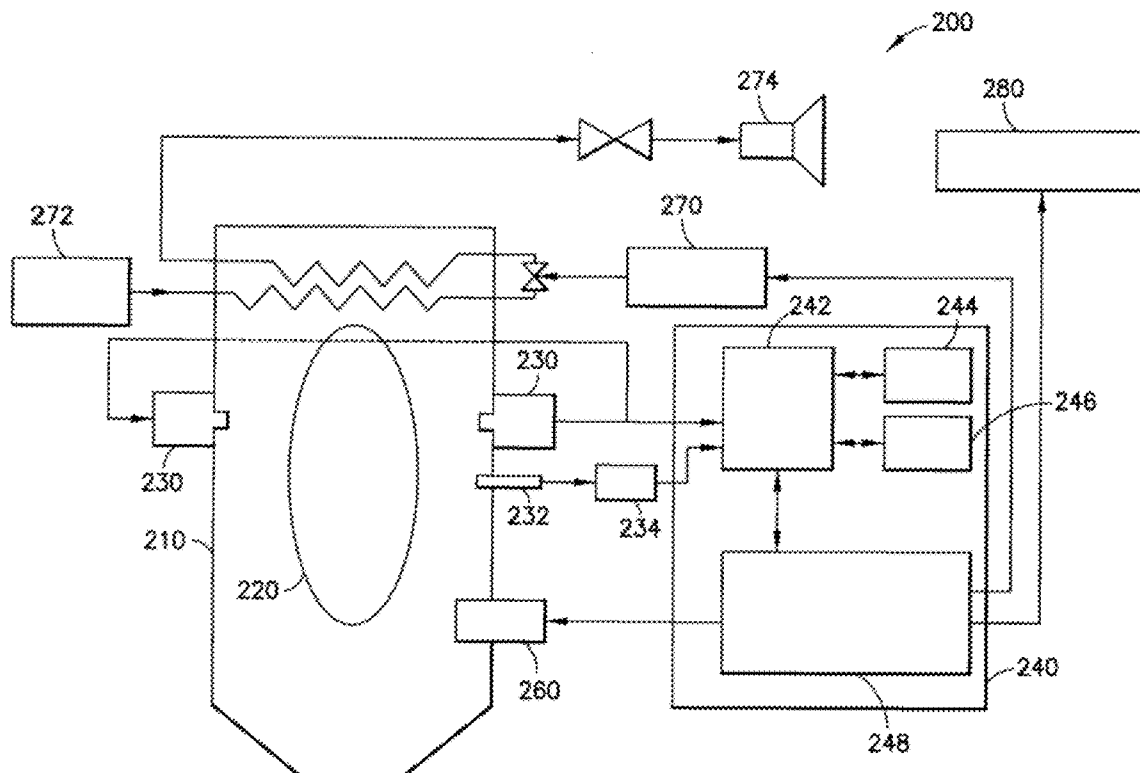
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(19) **United States**(12) **Patent Application Publication****Lou et al.**(10) **Pub. No.: US 2012/0052450 A1**(43) **Pub. Date: Mar. 1, 2012**(54) **SYSTEM AND METHOD FOR CONTROL AND OPTIMIZATION OF A PULVERIZED COAL BOILER SYSTEM****Publication Classification**(51) **Int. Cl.**
F23N 5/00 (2006.01)
F23D 1/00 (2006.01)(52) **U.S. Cl.** **431/2; 431/75; 110/347**(57) **ABSTRACT**

A control system, and method for using the same, for controlling a boiler having a furnace is provided. The system includes at least one camera positioned in visual communication with a combustion chamber in a furnace. The camera is in communication with a controller and is operable to transmit signals indicative of a parameter of a flame within the furnace. Based at least in part on the received signals, the controller generates control adjustments for one or more of the boiler components. The control adjustments are communicated to the boiler components, which in turn are adjusted to optimize the performance of the boiler and reduce pollution.

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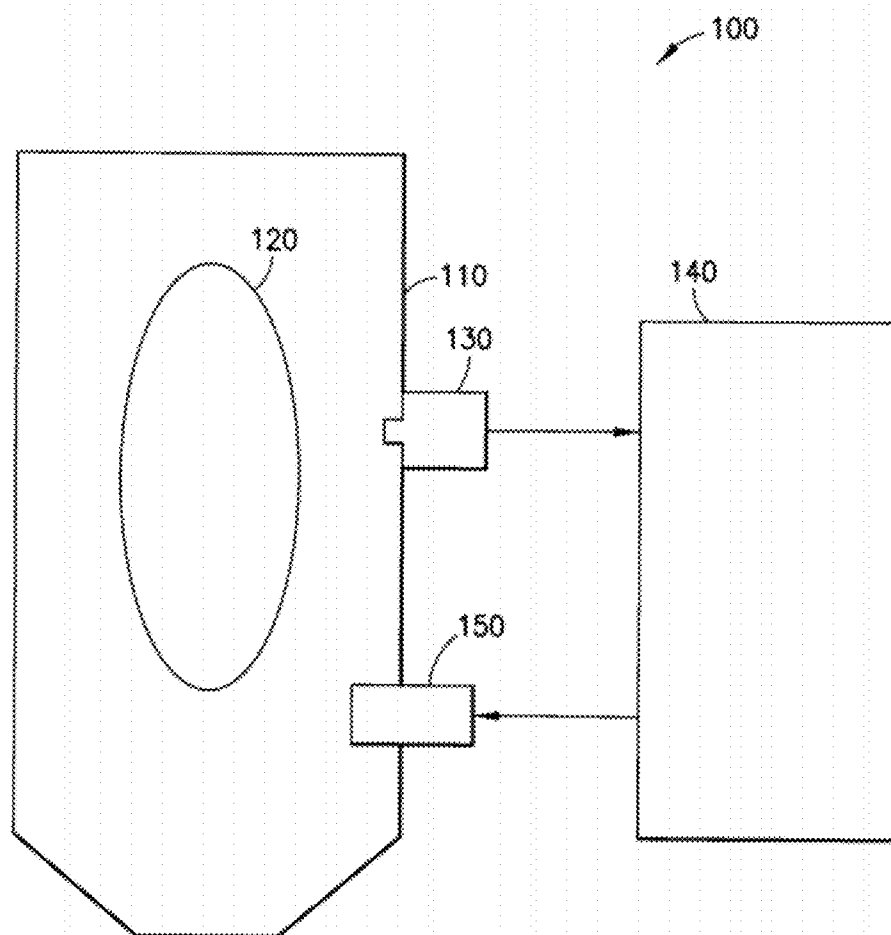


FIG. 1

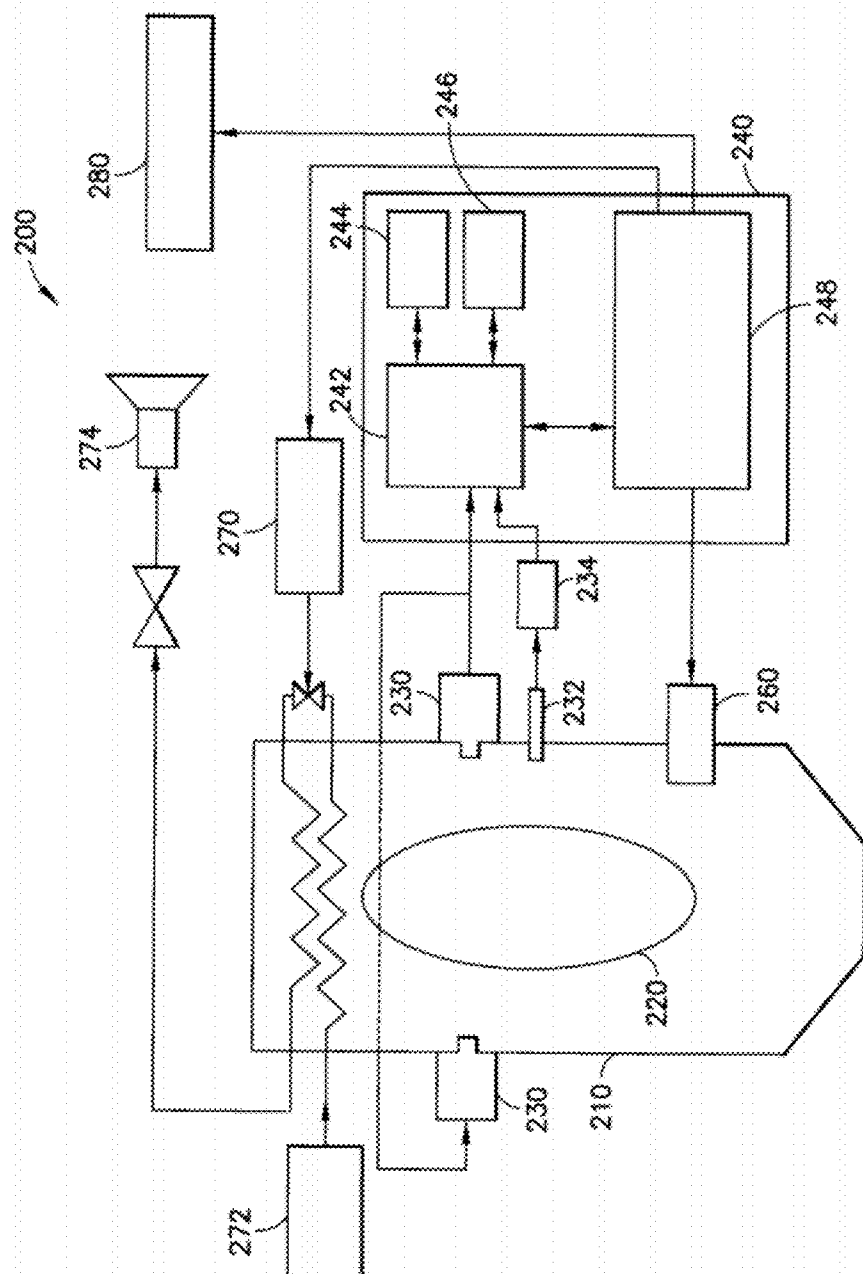


FIG. 2

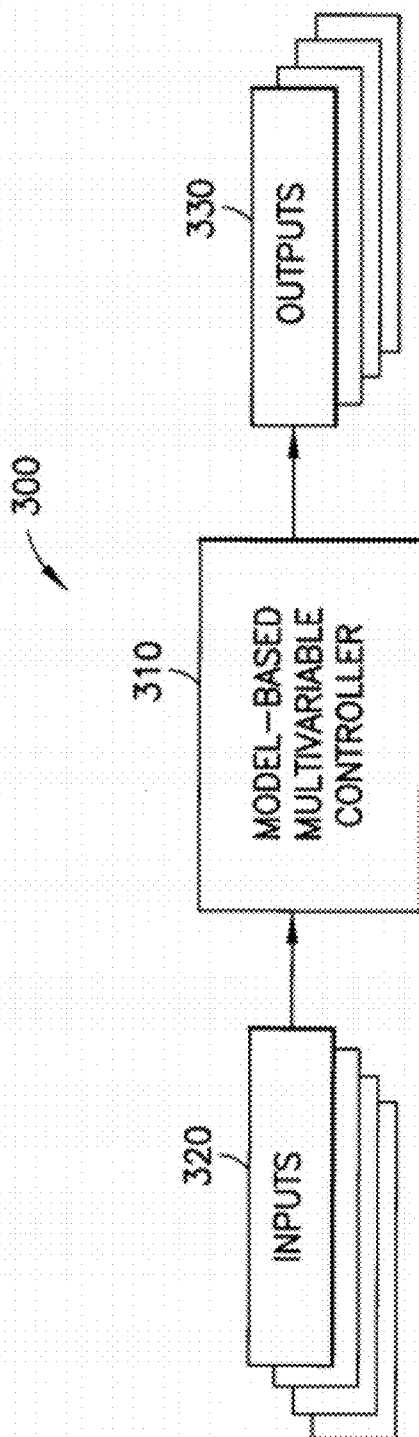


FIG. 3

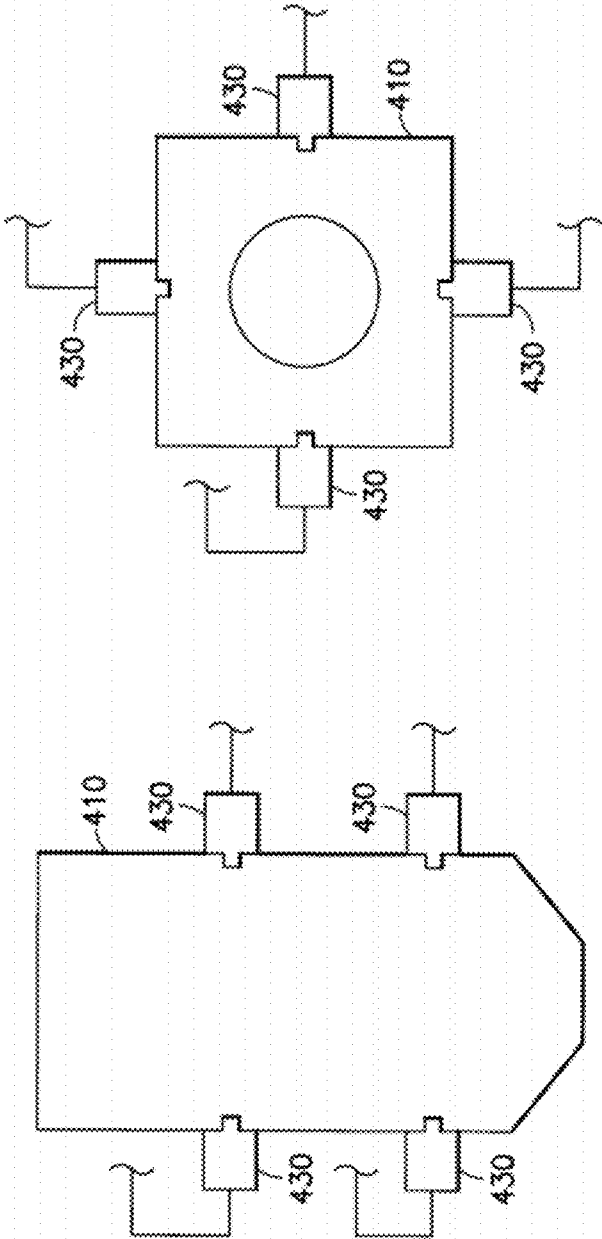


FIG.4

FIG.5

SYSTEM AND METHOD FOR CONTROL AND OPTIMIZATION OF A PULVERIZED COAL BOILER SYSTEM

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application claims the benefit under 35 U.S.C. §119(e) of Provisional Patent Application Ser. No. 61/377,637 entitled FLAME IMAGING SYSTEM BASED CONTROL/OPTIMIZATION FOR AN OXY-FIRED PULVERIZATION COAL BOILER filed Aug. 27, 2010, the disclosure of which is incorporated herein by reference in its entirety.

[0002] The present application claims the benefit under 35 U.S.C. §119(e) of Provisional Patent Application Ser. No. 61/377,676 entitled OPTIMIZATION AND CONTROLS IN PULVERIZED COAL BOILERS BY USING IMAGE-BASED TECHNIQUES OF TEMPERATURE MEASUREMENTS filed Aug. 27, 2010, the disclosure of which is incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0003] The present invention relates generally to a system and method for optimizing the control and performance of a boiler, and more specifically to a system and method for optimizing the control and performance of an oxy-fired or an air-fired pulverized coal boiler.

BACKGROUND OF THE INVENTION

[0004] A boiler typically includes a furnace in which fuel is burned to generate heat to produce steam. The combustion of the fuel creates thermal energy or heat, which is used to heat and vaporize a liquid, usually being water into steam. The generated steam may be used to drive a turbine to generate electricity. Pulverized coal is the fuel consumed to provide thermal energy for production of about 50% of the world's electric supply. In an air-fired pulverized coal boiler, atmospheric air is fed into the furnace and mixed with the pulverized coal for combustion. In an oxy-fired pulverized coal boiler, concentrated levels of oxygen are fed into the furnace and mixed with pulverized coal for combustion.

[0005] Pulverized coal boilers include multi-variable controls applicable to steam temperature controls, combustion controls, and backend controls. Backend controls are controls applied to one or more flue gas treatment systems used to treat boiler combustion gases. Such flue gas treatment systems may include but are not limited to selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), and flue gas desulfurization (FGD). Such flue gas treatment systems have a large number of known input variables that drastically affect the performance and efficiency of the treatment system and affect the emission levels achievable by the treatment system.

[0006] Boiler operation is typically monitored by measuring temperatures at metal structures in and around the inside surface of the furnace. One disadvantage of this known method is that it does not provide enough measurement data to analyze the flame and determine detailed characteristics of the flame in the furnace. (The flame is also referred to herein as "fireball" and is used interchangeably throughout this specification.) Detailed characteristics of the flame can provide further insights into combustion dynamics and is useful for improving combustion efficiency and reducing emissions.

[0007] Steam temperature control in pulverized coal boilers relies heavily on desuperheater water spray. Desuperheater water spray however, is thermally inefficient because it causes losses in both mass and energy, and has hard constraints with regard to both maximum spray flow and maximum change rate. The latter may result in ineffective steam temperature control if not properly addressed. In addition, current steam temperature control systems are mostly reactive and use feedbacks of current temperature measurements at a few points in the steam path to control steam temperature at turbine inlets. Such temperature measurement feedbacks can make steam temperature control sluggish, especially during load changes.

[0008] During load ramping periods, steam temperature variations may potentially damage pressure parts such as main steam headers, pipes, turbine inlet valves, and turbine walls. This is of particular concern when the steam pressure is high, e.g. in the case of supercritical and ultra-supercritical fossil power generation units. Another factor that sometimes restricts faster load ramping rates in coal-fired boilers is the delay between a fuel feed supply change demand to an actual fuel feed supply increase/decrease to the furnace. Physical renovations to a boiler system to avoid such drawbacks are expensive and difficult to implement.

SUMMARY OF THE INVENTION

[0009] The present invention relates to a multivariable advanced process control ("APC") system and method for using the same for improving or optimizing the performance of regulatory control systems of a boiler, and more specifically, a pulverized coal boiler. In one embodiment, the APC system includes at least one camera positioned within or in communication with the interior of the furnace of a boiler. As such, camera is operable receive one-dimensional, two-dimensional and/or three-dimensional images of combustion in the furnace and to transmit signals indicative of at least one parameter of a fireball within the furnace to a controller in communication with the camera. The controller includes one or more predictive modeling modules. The at least one camera captures measurement data pertaining to fireball characteristics including but not limited to temperature, radiant energy, and emissivity in the furnace. The controller is operable to generate multi-dimensional images of the at least one parameter of the fireball within the furnace. Software executing on the controller optimizes and controls combustion systems, steam system, and backend control systems based, at least in part, on the multi-dimensional images.

BRIEF DESCRIPTION OF THE DRAWINGS

[0010] FIG. 1 is a schematic illustrating one embodiment of the present invention.

[0011] FIG. 2 is a schematic illustrating one embodiment of the present invention.

[0012] FIG. 3 is a schematic illustrating one embodiment of the present invention.

[0013] FIG. 4 is a side view of a furnace comprising a plurality of cameras.

[0014] FIG. 5 is a top view of the furnace shown in FIG. 4.

DETAILED DESCRIPTION OF THE INVENTION

[0015] In reference to FIG. 1, a boiler control system 100 in accordance with one embodiment of the present invention is shown. The system 100 includes a furnace 110. Fuel, includ-

ing pulverized coal and air and/or concentrated oxygen, is fed into the furnace **110**. A flame or fireball **120** is generated in the furnace **110**. The system **100** includes at least one camera **130** positioned within or in communication with an interior **110a** of the furnace **110**. The camera **130** is operable to transmit signals indicative of at least one parameter of a flame, i.e. the fireball **120**, within the furnace **110**. For purposes of clarity, it should be understood that the term “positioned within the furnace **110**” requires that the camera **130** be in visual or optic communication with a combustion chamber **110b** of the furnace **110**, and does not require or exclude that the camera **130** be located in the furnace **110**.

[0016] The camera **130** is in communication with a controller **140**. The controller **140** is operable to receive signals from the camera **130**. The controller **140** may comprise a processor based computing device, such as a server. Software executing on the controller **140** processes image data captured by the camera **130** and transmitted to the controller **140**. The image data and processed images are used to calculate the fireball **120** characteristics, such as temperature profile, heat flux, and emissivity. The image data can be converted into multi-dimensional combustion temperature maps, emissivity maps, and profiles of other variables of the combustion. Based, at least in part, on the data collected by the at least one camera **130**, software executing on the controller generates control adjustments to control one or more of the boiler components to improve combustion efficiency and/or reduce emissions. The control adjustments are transmitted to and received by one or more components **150** that form part of the boiler system, steam system, or backend systems. For example, in the embodiment illustrated in FIG. 1, boiler component **150** regulates the flow rate of fuel into the boiler. The control adjustments control the one or more components **150** in order to adjust the flow rate of fuel into the boiler to achieve the desired system **100** performance optimization.

[0017] In reference to FIG. 2, one embodiment **200** of the present invention is shown. The system includes a furnace **210** in which air and/or concentrated oxygen and pulverized coal is combusted to form a fireball **220**. The system **200** includes two cameras **230** proximate to the furnace and positioned within visual or optic communication to receive image data of the fireball **220** in the furnace **210**. It should be understood that many different types of cameras **230** may be used with the present invention. For example, the system may use a camera comprising a charged coupled device (“CCD”) for receiving images. In other embodiments, the system may use a camera comprising an active pixel sensor. In some embodiments the cameras may be operable to receive infrared images. In yet further embodiments, the one or more cameras are operable to capture still images.

[0018] The cameras **230** are in communication with a controller **240**. The controller includes a central processing unit (CPU) and assorted hardware and software for operating the system **200** in accordance with the present invention. Several software modules **242**, **244**, **246**, **248** are executing on the controller **240**. The controller **240** includes an image processing, analysis and inference module **242**. Module **242** receives an image and/or a stream of images from the one or more cameras **230** and processes the images. The processed images are used to calculate fireball characteristics, such as but not limited to, temperature profile, heat flux, and/or emissivity, without using a process models or an optimizer. The module **242** generates multi-dimensional temperature maps, heat flux maps, and emissivity maps.

[0019] The calculated fireball characteristics are available for online monitoring in the form of horizontal or vertical planer profiles that may be presented in one-dimensional, two-dimensional or three-dimensional form. In some embodiments of the present invention an interface is in communication with the controller **240** and the profiles are displayed on the interface. In further reference to FIG. 2, a process model module **244** and an optimization solver module **246** are executing on the controller **240**. These modules **244** and **246** may be used to further refine the profiles of the fireball characteristics that are generated by module **242**.

[0020] In further reference to FIG. 2, a control model module **248** is executing on the controller **240**. The control module **248**, also referred to as a multivariable advanced process control (APC) system, generates optimal control adjustments to improve combustion efficiency and/or reduce emissions by optimizing control adjustments for one or more of the boiler components **260**, **270**, **280**. The furnace **210** includes a coal/air firing component **260** for feeding fuel into the furnace **210**. The control module **248** generates control adjustments for the coal/air firing component **260**. The adjustments are communicated to the coal/air firing component **260** and component **260** is controlled and operated in accordance with the control adjustments. The boiler system **200** further includes a steam temperature control component **270**. The control system **248** executing on the controller **240** generates control adjustments for the steam temperature control component **270**. The adjustments are communicated to the steam temperature control component **270** and component **270** is controlled and operated in accordance with the communicated control adjustments. For example, the steam temperature control component **270** may be used to affect the feed water supply **272**. Depending on the control adjustments, steam temperature control component **270** may be used to increase the feed water supply **272** or decrease the feed water supply **272**.

[0021] The controller **240** is further in communication with one or more backend system components **280** used to treat the combustion products or flue gas from the boiler system. Backend components are applied to the boiler system to treat combustion gases exiting through the flue. Backend components may include but are not limited to selective catalytic reduction (SCR), selective non-catalytic reduction (SNCR), and flue gas desulfurization (FGD) components. Based on the fireball characteristics, the control module **248** generates control adjustments for the one or more backend control components **280** to control and optimize their performance. The control adjustments are communicated to the one or more backend control components **280** and control the same to optimize the efficiency of system **200**. The embodiment shown in FIG. 2 further includes a flame sensor **232**. The flame sensor **232** is in communication with a processing module **234**, which is further in communication with the controller **240**. The flame sensor **232** captures a characteristic of the fireball **220**, for example its temperature, and transmits the data to the controller **240**. The data captured by sensor **232** may further be used to enhance the modeling.

[0022] In some embodiments of the present invention, the boiler system may use separate process models for the boiler system components and the backend components. In other embodiments, the present invention may employ a single integrated process model for the whole boiler island. In some embodiments, the software executing on the controller **240**, sometimes referred to as the model-based multivariable APC system, may use material models to estimate components'

and/or plant's life and use them in the cost function of its optimization problem to extend the life of components and/or increase time between required maintenance.

[0023] In one embodiment of the present invention, the one or more cameras **230** capture images of the fireball **220**. This image data is transmitted to and received by the controller **240**. Based in part on the received image data, software executing on the controller **240** estimates the location of the center of the fireball **220**. In some embodiments, the controller **240** incorporates temperature mapping in estimating the center of the fireball **220** in the furnace **210**. Based on this identified location, the controller **240** determines the elevation of the fireball **220** in the furnace **230**. Tilt controls in the furnace may be employed to adjust the elevation of the fireball **220** in the furnace **230** based in response to commands from the controller **240**. By adjusting the elevation of the fireball **220** in the furnace, the system can control the temperature of the steam and control NO_x/CO emissions. For example, the system can reduce the temperature of steam in the system by directing the center of the fireball **220** way from one or more heating coils.

[0024] In yet other embodiments, image and temperature mapping data is received by the controller **240**. Based, at least in part, on this data, the controller **240** is capable of detecting the location of the fireball **220** in the furnace **230**, and is capable of detecting a deviation of the fireball **220** from the center of the furnace **230**. To the extent the fireball **220** has deviated from the center of the furnace **220**, the location of the fireball **220** can be affected by altering the direction of air being fed into the furnace in response to commands sent from the controller **240**. By centering the fireball **220** in the furnace **230**, a more efficient operation is achieved.

[0025] In some embodiments, it is preferred to achieve a uniformly distributed temperature inside the furnace to improve control of NO_x and CO emissions and particulate matter based on different properties of the coal fuel. Image data captured by the one or more cameras is processed by the controller **240** to determine the temperature distribution in the furnace **230**. Based on this distribution, the controller **240** transmits commands to affect the air/oxidant flue gas to provide a more optimally distributed in-furnace temperature and O₂ level distribution, thereby improving control of backend emissions.

[0026] In reference to FIG. 3, a chart illustrating the inputs and outputs of the system **300** is shown. In FIG. 3, software executing on the controller **310** is referred to as the model-based multivariable controller. A number of different inputs **320** are fed into the controller **310**. The inputs may include, but are not limited to, image based fireball/combustion characteristics, steam temperature deviation, burner tilt, SH/RH spray flow, feedwater flow, flue gas temperature, flue gas NO_x, CO, SO_x levels, etc., ammonia flow (for SCR/SNCR) SCR/SNCR outlet for NO_x, sootblower, unit load, coal characteristics, ambient conditions, FGD lime/limestone flow, FGD outlet SO₂ levels, aging factors, metal stress, etc. Based on these inputs, the controller determines the optimal control adjustments **330** for different components in the system. These outputs include, but are not limited to, separator outlet enthalpy setpoint bias, coal feed bias, stoichiometry setpoint bias, O₂ setpoint, ammonia/NO_x mode, furnace DP setpoint bias, pulverizer outlet temperature setpoint, FGD dilution water flow, FGD lime/limestone slurry flow.

[0027] In reference to FIGS. 4 and 5 a side view and a top view of a furnace according to one embodiment of the present

invention is shown. Eight cameras **430** are positioned within visual or optic communication of the combustion chamber of the furnace **410**. In reference to FIG. 3 a side-view of the furnace is shown **410**. The cameras **430** are positioned on opposing interior walls of the furnace **410** at two different heights. In reference to FIG. 5, a top-view of the furnace of FIG. 4 is shown. The cameras **430** are positioned proximate to opposing walls of the furnace **410**. By including additional cameras, it is possible to improve the imaging capabilities of the system, and therefore generate more accurate multi-dimensional maps. The image data received by the cameras **430** is converted into a two-dimensional or three dimensional combustion temperature map, emissivity map, and profiles of other combustion state variables or physical parameters in coal combustion. It should be understood that many different camera configurations are possible.

[0028] In one embodiment, the present invention the control system includes a rapid load change controller (RLC). The first element in the RLC control scheme is the furnace radiant measurement system. This sensor system includes both furnace flame intensity sensor components and water wall heat flux sensor components. The radiant sensor system provides a novel input to the RLC control system's predictive steam properties (TSP) model. It is important that the radiant measuring system accurately measures the furnace flame and energy field. In order to do this, the system generates a data fusion of camera image 2-D data and point furnace wall heat flux probes. The radiant measurement system data is analyzed to compute furnace flame and energy release features. The objective is to establish a robust set of independent radiant characteristics with known high correlations to water/steam side boiler process conditions. Reference plant field data will be collected in order to determine the minimum number of radiant characteristics that form a reliable system basis set for flame/furnace state characterization.

[0029] The second element in the RLC is the Turbine Steam Parameters (TSP) predictive model. This predictive model uses the RLC furnace radiant characteristics to predict the ultimate turbine inlet steam parameters for the current fuel firing condition. It is the rapid accurate prediction from the TSP predictive model that makes more rapid control of the field firing during load change possible. The delay between the fuel delivery to the furnace and the radiant energy release is brief, for example a few seconds. The radiant energy release is an accurate instantaneous measure of the energy input to the furnace waterwalls. Therefore using this prompt radiant response to fuel firing as a model input yields a superior prediction over methods using fuel mass flow and heating value estimation. The turbine steam property predictor will also use the existing plant process measurement values to generate an adaptive error signal.

[0030] Although the present invention has been disclosed and described with reference to certain embodiments thereof, it should be noted that other variations and modifications may be made, and it is intended that the following claims cover the variations and modifications within the true scope of the invention.

What is claimed is:

1. A control system for controlling a boiler having a furnace, the control system comprising:
at least one camera positioned within the furnace, the at least one camera being operable to transmit signals indicative of a parameter of a flame within the furnace;

- a controller in communication with the at least one camera, the controller being operable to receive signals transmitted by the at least one camera;
- a control component forming part of, or in communication with, the boiler, the control component further being in communication with the controller;
- software executing on the controller for determining an adjustment for the control component based at least in part on the received signals indicative of a parameter of a flame within the furnace.
2. The control system of claim 1, wherein the boiler is an air-fired pulverized coal boiler.
3. The control system of claim 1, wherein the boiler is an oxy-fired pulverized coal boiler.
4. The control system of claim 1, wherein the at least one camera includes two or more cameras positioned at different locations within the furnace, each of the cameras being operable to transmit signals indicative of a parameter of a flame within the furnace,
- wherein the controller is operable to generate a multi-dimensional image of the parameter of the flame within the furnace.
5. The control system of claim 1, wherein the controller is operable to map combustion temperatures within the furnace based at least in part on the signals received from the at least one camera.
6. The control system of claim 1, wherein the controller is operable to map emissivities within the furnace based at least in part on the signals received from the at least one camera.
7. The control system of claim 1, wherein the controller is operable to control at least one input parameter of the boiler based on the signals received from the at least one camera.
8. The control system of claim 1, wherein the controller is operable to control at least one output parameter of the boiler based on the signals received from the at least one camera.
9. The control system of claim 1, wherein the camera comprises a CCD.
10. A method for controlling a boiler having a furnace, the method comprising the steps of:
- positioning at least one camera in the furnace;
- receiving an image of a flame with said at least one camera;
- determining a component adjustment based at least in part on the received image;
- controlling a component based at least in part on the component adjustment.
11. The method of claim 10, wherein the boiler is an air-fired pulverized coal boiler.
12. The method of claim 10, wherein the boiler is an oxy-fired pulverized coal boiler.
13. The method of claim 10, further including the step of: generating a multi-dimensional image of the parameter of the flame within the furnace.
14. The method of claim 10, further including the step of: mapping combustion temperatures within the furnace based at least in part on the signals received from the at least one camera.
15. The method of claim 10, further including the step of: mapping emissivities within the furnace based at least in part on the signals received from the at least one camera.
16. The method of claim 10, further including the step of: controlling at least one input parameter of the boiler based on the signals received from the at least one camera.
17. The method of claim 10, further including the step of: controlling at least one output parameter of the boiler based on the signals received from the at least one camera.
18. The method of claim 10, wherein the camera comprises a CCD.

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