The present invention monitors and controls various operation/process variables of a furnace or boiler, which may be, for example, fuel flow, fuel pressure, air flow, box pressure, feed outlet temperature, etc., and reacts to certain operation issues. A method and system is provided for monitoring and controlling the operation of a furnace in real-time which may prevent unnecessary tripping of the furnace.
FIG. 3B

326
Is Box Pressure Back to Normal? YES

328
Is excess O2 Back to Normal? NO

330
Is Fuel Pressure Back to Normal? NO

332
Is Fuel Pressure Back to Normal? NO

334
Is High Constraints for Air Flow and O2 Set? NO

336
Is High Constraints for Fuel Flow and Heat Temp Set? NO

338
Is Low Constraints for Fuel Gas Flow and Feed Out Temperature? NO

340
Remove High Constraints for Air Flow and O2

342
Remove High Constraints for Fuel Gas Flow and Feed Out Temperature

344
Remove Low Constraints for Fuel Gas Flow and Feed Out Temperature

-1

-1
Initialization

Obtain PV and OP Data for Air Flow

Calculate:
\[ dOP = \text{ABS}(OP_t - OP_{t+1}) \]
\[ dPV = \text{ABS}(PV_t - PV_{t+1}) \]

Is \( dOP > OP_{\text{Max}} \)?

NO

Is \( dPV \leq PV_{\text{Min}} \)?

NO

Air Flow Controller Turned to Manual Mode, Operator Notified

Fuel Gas Flow Controller Turned to Manual Mode, Operator Notified

Air Flow Controller Remains in CAS Mode

Set:
\[ OP_{t+1} = OP_t \]
\[ PV_{t+1} = PV_t \]
\[ i = 0, 1, 2, \ldots, n \] (sampling interval)

FIG. 4
Initialization

Obtain PV and OP Data for Air Flow

Calculate:
\[ dOP = OP_i - OP_{i-1} \]
\[ dPV = PV_i - PV_{i-1} \]

Is \( dPV > PV_{\text{maxA}} \) and \( dOP \leq OP_{\text{minA}} \)?

Yes

Air Flow Controller Turned to Manual Mode, Operator Notified

No

Is \( dPV < PV_{\text{maxA}} \) and \( dOP \geq OP_{\text{minA}} \)?

Yes

Fuel Gas Flow Controller Turned to Manual Mode, Operator Notified

No

Air Flow Controller Remains in CAS Mode

Set:
\[ OP_i = OP_{i-1} \]
\[ PV_{i+1} = PV_{i+1} \]
\[ i = 0, 1, \ldots, n \] (sampling interval)

FIG. 5
Initialization

Obtain PV and OP Data for Fuel Gas Flow

Calculate:
\[ dOP = OP_1 - OP_{\text{cur}} \]
\[ dPV = PV_1 - PV_{\text{cur}} \]

Is \( dPV > PV_{\text{MaxF}} \) and \( dOP < OP_{\text{MinF}} \)?

Air Flow Controller Turned to Manual Mode, Operator Notified

Fuel Gas Flow Controller Turned to Manual Mode, Operator Notified

Set:
\[ OP_{b+1} = OP_b \]
\[ PV_{b+1} = PV_b \]
\[ i = 0, 2, \ldots, n \] (sampling interval)

FIG. 6
Initialize Air/Fuel Ratio Using Current Filtered Air/Fuel Ratio

Obtain PV and OP Data for O2 Controller

Is O2 Analyzer Out of Range and DCS See Bad PV?

Calculate the Trimmed Air/Fuel Ratio

Is OP > OP_{maxop} or OP < OP_{minop}?

Is O2 Analyzer Issue?>?

OP is close to its maximum or minimum limit, Operator Notified

Operator decide to Reset Or Not?

Air Flow Controller Turned to Manual Mode, Operator Notified

FIG. 7
FIG. 8A

Feed Out Temperature
Fuel Gas Flow
Air Flow
Excess O2

Excess O2 was below zero % for about 8 minutes.
FIG. 8C

Increase in Fuel Gas Pressure due to increase in Fuel Gas Flow. With no constraints in place, the furnace tripped.

Decrease in feed out temperature

Air Flow

Furnace tripped on High Fuel Gas Pressure
Feed Out Temperature varied from 364 °C to 384 °C to 370 °C

Feed Rate Variation from 75 KBD to 45 KBD to 60 KBD

Excess O2
FIG. 8E

Before: Mean = 2.8
Standard Deviation = 0.6

After: Mean = 2.46
Standard Deviation = 0.29

Low Combustion Efficiency

Desired O2 Range

Low Excess O2
Box Pressure Controller OP is 105% (Loss of Control), however the furnace box pressure was still contained below zero after implementing our invention.
As a result of an increase in feed, the fuel gas flow and pressure increased. However, the constraints in the invention did not allow the fuel gas pressure to reach the fuel gas pressure high trip point.
FURNACE COMBUSTION CROSS LIMIT CONTROL WITH REAL-TIME DIAGNOSTIC FEATURES

FIELD OF THE INVENTION

[0001] The present invention relates to a method and system for monitoring and controlling the operation of a furnace. More specifically, the invention relates to a method and system for operating a furnace, which may be a component in a process for refining hydrocarbons, to run substantially continuously and close to maximum capacity safely, reliably and efficiently.

BACKGROUND OF THE INVENTION

[0002] Industrial furnaces, such as those used in hydrocarbon refineries, use conventional cross limit controls that are intended to run in automatic mode and be monitored by a human operator. However due to limitation of equipment capacities, field instrument issues, fluctuations in operation variables, including ambient temperature, feed flow rate, fuel pressure, fuel flow rate, fuel quality, air flow rate, etc., some of the controllers in the control system are mostly operated in manual mode. The term “furnace” used herein includes furnaces and fired heaters. When a certain operation variable changes, the human operator is trained to react by adjusting other operation variables to compensate for the change, in order to help maintain the furnace or boiler running within the range of safe operating conditions. However, when the furnace is operated manually, the furnace is sometimes supplied with either too much or too little air for O2 requirement. When there is not enough air in the furnace, some fuel is left without being fully combusted in the furnace. When there is too much air in the furnace, the excess air cools down the furnace which reduces the furnace’s efficiency. Further, in manual mode, the furnace box pressure may be allowed to increase beyond a certain threshold, thereby tripping the furnace. The furnace can also trip if the fuel gas pressure is too high or too low based on the predetermined set values. Other issues that can cause the furnace to trip or otherwise disrupt the operation of the furnace include transmitter malfunction and valve stiction. Any one of the above identified issues may prevent the furnace from running continuously in auto mode and/or at close to its maximum capacity. Every time a furnace trips, the furnace needs to be restarted and the start-up time for an industrial furnace can be lengthy. Therefore, the tripping of a furnace not only interrupts the operation of the furnace itself, but can also cause significant delays in a process wherein the furnace is a component thereof.

[0003] In the prior art, there are some cross limit control patents relating to furnaces and boilers, which are designed to handle some special operating condition. For example, U.S. Pat. No. 4,369,026 describes a cross limit control design for controlling the fuel flow and an oxygen-containing fluid to a combustion process, in which it employs a positive polarity limiter and a negative polarity limiter to maintain the fuel/oxygen ratio for a combustion process. U.S. Pat. No. 4,064,698 gives a boiler combustion control method in power plants with fuels having variable heating values. U.S. Pat. No. 6,984,122 shows a combustion control with temperature compensation. U.S. Pat. No. 4,498,863 gives a design for the combustion control with feed forward function. U.S. Pat. No. 4,473,490 demonstrates a control of a reforming furnace.

[0004] For the constraint methods in process control schemes, which are used to ensure safety of process operations, the method of setting fixed high/low limits on controller output (OP) is generally used. Since there are variations in operation conditions, normally, these kinds of limits are very conservative. In the multivariable process control methods, including the multivariable model predictive controllers, most implement the constraint functions by changing the related other controlled variable inputs based on the process model relationships. Since the process dynamic responses are normally not quick enough, there are always required more safety rooms for any constraints, which result in the constraints being somewhat far away from the optimum constraint limits to avoid the possible process trips. Therefore, the fixed limit method and the method of getting the constraint by changing other controller inputs are not the optimum constraint methods, that is, the both methods cannot maximize the furnace capacity.

[0005] In the area of valve stiction detection, one U.S. Pat. No. 8,145,328 is found to detect the valve stiction using controlled variable (PV) and controller output (OP), in which a filter and a mathematic analysis technique are employed to determine whether there is valve stiction or not. Comparative studies of the valve stiction detection have been described by Garcia, et al (2013), Choudhury, et al (2006), Nallasivam, et al. (2010), Singhal and Salisbury (2005), Chitralekha, et al (2010) and Zakharov, et al (2013). All those studies have required the several cycles of valve PV and OP data to detect the possible valve stiction, that is, before determining whether the valve is stiction or not, the methods in those papers need the data that valve stiction at least happens several times. In the furnace operation situation, it may cause furnace trip or O2 deficiency (safety problem) when there is a big stiction issue such as 10% valve stiction if the valve stiction detection methods in those papers are used. Thus, those methods presented in those papers cannot be used in the real-time/online valve stiction detection to prevent the upset or trip caused by the valve stiction.

[0006] A few valve compensation methods are given by Cuadros, et al (2012) and Mohammad and Huang (2012) to reduce the effect of valve stiction. However, those methods are effective only for this kind of valve stiction caused by friction nonlinearity around 0% valve opening. In most cases, the valve stiction can happen at any percent of valve opening, then, those methods can only extend the stiction happening period and cannot reduce/remove the effect of the stiction. Therefore, those methods are difficult to use in the furnace combustion control.

[0007] The literature on fault detection and diagnosis schemes is very extensive. There are three main approaches to fault detection and diagnosis, namely, the model-based method, the knowledge-based method, and the statistical analysis method. The model-based method is the conventional method of fault detection which uses static or dynamic models of the process such as Samy et al (2011) and Insermann (1984). When the process models are unknown, the knowledge-based method can be used to detect faults (Frank, et al 1990)). Statistical analysis method is simple and effective for specific faults, including frequency analysis method, data characteristic analysis method, partial least-squares (PLS) analysis and principle-component analysis (PCA) analysis methods (Gertler, et al 1999)). Those methods are very effective for the faults happened comparatively slowly.
However, for the sudden big changing fault, the methods may have some time delay to find it.

[0008] In the conventional furnace cross limit control, O₂ controller normally trims the air to fuel ratio from minimum to maximum (10 to 20), which means that if the O₂ analyzer fails, it may cause a big upset or unit trip. For the furnaces used in the oil sands industry, the O₂ analyzer is not very reliable due to the harsh operating conditions. Thus, the effect of O₂ failure is one of the big concerns in furnace operation.

[0009] However, no literature was found to handle the furnace operation with real time dynamic constraints to deal situations such as high box pressure, high/low fuel gas pressure; with real time valve stiction detection; with real time transmitter failures detection and/or with real time dynamic trimming of air to fuel ratio.

SUMMARY OF THE INVENTION

[0010] A novel cross limit control scheme is developed to handle the process and/or mechanic issues existed in furnace combustion such as the limitation of equipment capacity, partial plugging in air inlet/Outlet line, transmitter failure and valve stiction, and to ensure that the furnaces can safely run at/close its maximum capacity. The novel cross limit control scheme of the present invention focuses on one or more of the following criteria:

[0011] (1) Real-time dynamic constraints for fuel gas high/low pressure, box pressure high and low excess O₂ protections.

[0012] Currently, there are several ways to run furnaces, for example:

[0013] (a) Air and fuel gas are both in manual control mode. In this way, the furnace outlet temperature cannot maintain its desired setpoint when feed flow changes;

[0014] (b) Air is in manual control but fuel gas is cascade to temperature control. This method may cause that either O₂ is too high or O₂ goes to deficiency when feed flow suddenly increases, thus, the furnaces either lose their efficiency or go to unsafe operation condition;

[0015] (c) Furnace is controlled by the conventional cross limit control scheme. In this case, the furnace may trip at high box pressure or high fuel gas pressure when the box pressure or fuel gas pressure is on the high limit if feed flow increases or some other operational condition(s) changes;

[0016] (d) Furnace is maintained by using a multivariable model predictive control scheme. As mentioned in the Background of the Invention, this kind of control cannot maximize the furnace’s capacity.

[0017] In the invention of the real-time dynamic constraints, the fuel gas pressure high/low constraint values and the box pressure high values can be changed in a computer system. For the case of high box pressure protection, the maximum allowed box pressure value is pre-defined by operation and can be changed from DCS (Distributed Control System) system. When the box pressure reaches the allowed maximum value, current controller’s outputs (OPs) will be set as the controller’s maximum OP limits for fuel gas flow controller and temperature controller. Thus, the fuel gas flow cannot increase any more but can decrease. It prevents the possible furnace trip on high fuel gas pressure.

[0019] For the case of low excess O₂ protection, the minimum excess O₂ value is predefined by operation and can be changed from DCS system. When the excess O₂ reaches the minimum value, current controller’s outputs (OPs) will be set as the controller’s maximum OP limits for fuel gas flow controller and temperature controller. Thus, the fuel gas flow cannot increase any more but can decrease. It prevents the possible furnace trip on high fuel gas pressure.

[0020] When the box pressure is back to normal (less than the allowed maximum box pressure), the high limits on air and O₂ controllers will be removed. When the box pressure, fuel gas pressure and excess O₂ are back to normal, the high limits on fuel gas and temperature controllers will be released.

[0021] For the case of low fuel gas pressure protection, the minimum allowed fuel gas pressure value is pre-defined by operation and can be changed from DCS (Distributed Control System) system. When the fuel gas pressure reaches the allowed minimum value, current controller’s outputs (OPs) will be set as the controller’s minimum OP limits for fuel gas flow controller and temperature controller. Thus, fuel gas flow cannot decrease any more but can increase. It prevents the possible furnace trip on low fuel gas pressure.

[0022] When the fuel gas pressure is back to normal (greater than the allowed minimum fuel gas pressure), the low limits on fuel gas and temperature controllers will be removed.

[0023] Note that for the same pressure constraint, the OP maximum/minimum limits will be different due to the variation of environment temperature and operating conditions. The real-time dynamic constraint can catch the limit changes since all the limits are dynamically set using the current OPs whenever any constraint conditions reach. Therefore, the invention ensures the furnace can operate at its maximum capacity more safely, reliably, and efficiently.

[0024] (2) Real-time valve stiction detection.

[0025] Valve stiction is a common issue in furnace operation. Valve stiction may be defined as the prescience of non-linear behavior in a valve. This is attributed to static friction in the valve, which impedes the motion of the valve until a force sufficiently great can overcome the static friction. If the valve stiction is great enough, it may trip the furnace when the valve stiction happens.

[0026] For the valve stiction detection method of the present invention, OP_max is defined as the maximum allowed controller opening change during a sampling time period. PV_max is the possible minimum flow change when the controller opening changes the amount of OP_max. OP_max and PV_max are chosen so that, when the controller suddenly opens or closes the amount of OP_max, it will not cause operational problems, and the controlled variable’s (PV) change is at least larger than the amount of PV_max. When the change of a controller opening (OP) is larger than OP_max during the sampling time period but the change of the controlled variable (PV) is smaller than PV_max, then one can conclude that the valve stiction exists since the OP change doesn’t get the
response of PV. This method doesn’t need to wait for actual valve stiction to occur and, thus, it prevents the possible furnace trip.

(0027) (3) Real-time transmitter failure detection.

(0028) Transmitter failure is another common issue in furnace operation. If a transmitter fails, it causes furnace upset or trips.

(0029) In furnace operation, the slow fuel gas or air transmitter failure generally will not cause a large disruption since those kinds of failures can be compensated by temperature or O2 controller. But a sudden big change of transmitter reading may cause the furnace trip.

(0030) The transmitter failure detection method of the present invention is mainly used to find a sudden change of the transmitter readings due to transmitter failure. The present transmitter failure detection method defines that PV_{max} is the maximum controlled variable (PV) change during a certain time period. OP_{min} is the required minimum controller opening change when the PV changes the amount of PV_{max}. PV_{max} and OP_{min} are chosen by that, when the PV suddenly increases or decreases the amount of PV_{max}, the OP change is at least larger than the amount of OP_{min}. When the change of PV is larger than PV_{max}, during a certain time period, but the change of OP is smaller than OP_{min}, then it concludes that the transmitter fails since the PV change is not caused by the OP change. This method can quickly catch the sudden transmitter failure, and thus reduces the effect of transmitter failure on the furnace operation.

(0031) (4) Real-time dynamic trimming of air to fuel ratio.

(0032) The conventional O2 control generally aims at air to fuel ratio from minimum air requirement to maximum air requirement (10 to 20). Since the reliability of O2 analyzer is one of the problems in furnace control, the present design trims the air to fuel ratio within predefined small range. Thus, if the O2 analyzer fails, the effect of the failure will be greatly reduced. If the O2 analyzer is out of range and shows a poor PV, the new control will set the air flow controller and fuel flow controller in manual mode. If the air to fuel ratio is outside the predefined range, the air and fuel gas controllers will also be set to manual mode and operator notified. If the output (OP) of the O2 controller is greater than OP_{max} or less than OP_{min}, where OP_{max} and OP_{min} are the predefined maximum OP and minimum OP, the new control method will inform the operator and operator can decide whether the O2 controller is needed to reset its function or not. When O2 control is reset, its OP is set at 50%, and air to fuel ratio is initialized and set equal to the actual filtered air to fuel value at that time.

(0033) (5) Furnace box high trim control.

(0034) This control function provides a further over pressure protection. When the furnace box pressure is larger than a predefined value, the controller starts to reduce the fuel gas flow which eventually results in reduction in air as well by O2 controller. Thus, the furnace box pressure will decrease and controlled.

(0035) Thus, in one aspect, a method for monitoring and controlling the operation of a furnace in real-time is provided, comprising:

(0036) obtaining a measurement of a controlled process variable (PV) from a measuring device that senses the PV in a controlled process;

(0037) obtaining an output reading (OP) from a controller that is in an auto-mode and is continuously controlling the controlled process by maintaining the PV within a desired range;

(0038) determining whether there has been a change (dPV) in the PV relative to a previously obtained controlled process variable (PV_{prev}); and

(0039) determining whether or not dPV was initiated by the controller.

(0040) In one embodiment, the method further comprises switching the controller from the auto-mode into a manual mode if it was determined that dPV was not initiated by the controller. In another embodiment, if dPV was not initiated by the controller, the method further comprises sending a signal to an operator alerting the operator that the controller has been switched to the manual mode.

(0041) In one embodiment, the controlled process variable (PV) is selected from the group consisting of box pressure, fuel gas pressure, O2 concentration, valve stiction, air flow transimion, and fuel gas transmission.

(0042) In another aspect, a novel cross limit control scheme is provided, comprising one or more of the following:

(0043) a real time dynamic constraint method for fuel gas high/low pressure, box pressure and low excess O2 protection;

(0044) a real-time valve stiction detection method;

(0045) a real-time transmitter failure detection method;

(0046) a real-time dynamic trimming of air to fuel ratio; and

(0047) a furnace box high trim control.

BRIEF DESCRIPTION OF THE DRAWINGS

(0048) Referring to the drawings wherein like reference numerals indicate similar parts throughout the several views, several aspects of the present invention are illustrated by way of example, and not by way of limitation, in detail in the figures, wherein:

(0049) FIG. 1 is a typical schematic of a furnace in communication with the control system of the present invention.

(0050) FIG. 2 shows a functional block diagram of the novel cross limit control with the dynamic constraints and diagnosis features.

(0051) FIGS. 3A and 3B illustrate a decision flow diagram of the methodology for setting the dynamic high/low constraints based on the box pressure and fuel gas pressure.

(0052) FIG. 4 is a decision flow diagram of the methodology for the detection of and response to air valve stiction.

(0053) FIG. 5 is a decision flow diagram of the methodology for the detection of and response to air flow transmitter issues.

(0054) FIG. 6 is a decision flow diagram of the methodology for the detection of and response to fuel gas transmitter issues.

(0055) FIG. 7 is a decision flow diagram of the methodology for the detection of and response to oxygen analyzer issues.

(0056) FIGS. 8a to 8c are graphical representations of sample data collected from the operation of a furnace used in a process of refining hydrocarbons, without the system of the present invention.

(0057) FIGS. 9a to 9d are graphical representations of sample data collected from the operation of a furnace used in a process of refining hydrocarbons, with the system of the present invention.
DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0058] The detailed description set forth below in connection with the appended drawings is intended as a description of various embodiments of the present invention and is not intended to represent the only embodiments contemplated by the inventor. The detailed description includes specific details for the purpose of providing a comprehensive understanding of the present invention. However, it will be apparent to those skilled in the art that the present invention may be practiced without these specific details.

[0059] The present invention relates generally to a method and system for monitoring and controlling the operation of a furnace or boiler. More specifically, the present invention monitors and controls various operation variables of the furnace or boiler, which may be for example, fuel flow, fuel pressure, air flow, box pressure, feed outlet temperature, etc., and reacts to certain operation issues. The figures and description herein describe the present invention in relation to the operation of a furnace. However, the present invention may be configured for monitoring and controlling the operation of a boiler.

[0060] As used herein, a “controlled process variable” or “PV” refers to a process variable that is controlled by a controller used to continuously or automatically maintain the controlled process variable or PV within a desired range. Examples of controlled process variables useful for monitoring and controlling the operation of a furnace or boiler include, but are not limited to, temperature, pressure, flow rate, oxygen (O₂) concentrations, and the like.

[0061] As used herein, a “measuring device” refers to a device that senses a process variable through the medium of a sensor or other measuring element. Examples of measuring devices include, but are not limited to, flow meters, pressure sensors, O₂ analyzers, stiction detectors, and the like.

[0062] As used herein, an “output reading” or “OP” refers to a reading or output given by a controller that is controlling a process, which reading or output is useful to troubleshoot and diagnose issues.

[0063] Referring to FIG. 1, a system includes a furnace 10 having a combustion chamber 12, a flue stack 14, and a pilot light 15. The furnace is configured to receive fuel from a fuel source via a fuel supply line 16. In one embodiment, the fuel is natural gas or a natural gas mixture. However, other types of fuel may also be used. The furnace can also receive air from an air source via an air supply line 18. In the embodiment, the air provides O₂ as a mixture of O₂ and at least one other gas. An air valve 19 may be included to control the supply of air into the furnace. In the illustrated embodiment, the furnace is used to heat a feed, which may be a hydrocarbon mixture, to or close to a desired temperature. The feed is fed into the furnace via a feed-in line 20 and heated feed exits the furnace via a feed-out line 22. Although the embodiments described herein relate to a furnace for heating feed, it can be appreciated that the system of the present invention may be used for other furnaces.

[0064] Flue 14 allows any exhaust from the combustion chamber to exit directly into the surroundings, but flue gas may include a valve 24 for selectively blocking off the flue such that exhaust cannot exit directly. In the illustrated embodiment, an optional heat exchanger 26 is provided in air supply line 18 to warm up the air supply with the furnace flue 14 via lines 28 and 30. When valve 24 is closed, exhaust from the combustion chamber cannot exit the flue directly and is forced to flow to the heat exchanger via line 28. Heat exchanger 26 extracts heat from the exhaust to warm up the ambient air that is fed into the furnace. Supplying the furnace with warm air, rather than ambient air, helps improve the furnace’s efficiency. The cooled exhaust then flows out of the exchanger via line 30 back to flue 14 where it is allowed to exit into the surroundings. Heat exchanger 26 is not necessary for the operation of the furnace but may be optionally included to help improve the efficiency of the furnace, based on ambient air temperature.

[0065] The system includes a plurality of monitoring devices, including for example meters, transmitters, transducers, analyzers, etc. for monitoring various operation variables. In the illustrated embodiment, the system has a first flow meter 32, and a pressure transmitter 34 in fuel gas line 16 to measure the flow rate and pressure of the fuel gas, respectively. A second flow meter 36 is installed in line 18 for measuring the air supply flow rate into the furnace. A pressure transmitter 38 is provided for measuring the box pressure of the combustion chamber. An O₂ analyzer 40 is installed inside flue 14 for measuring the level of O₂ in the exhaust. Line 20 includes a third flow meter 42 for measuring the flow rate of the feed input, and line 22 includes a temperature transmitter 44 for measuring the temperature of the feed output. Flow could be measured by orifice type differential pressure measurement or vortex type devices. Temperature—Temperature could be measured by resistance temperature detectors or thermocouple type devices. Pressure—Pressure could be measured by diaphragm capsule type devices. O₂ Analyzer—O₂ analyzer could be measured by Zirconium Probes or Paramagnetic type devices.

[0066] The readings obtained by the monitoring devices may be sent in the form of a signal, whether by wire or wireless connection, to a control system for display and/or further processing in real-time. The values of the operation variables generated by the signals from the monitoring devices may be presented to an operator of the furnace by the control system via a graphical user interface.

[0067] Referring to FIG. 1, fuel gas line 16 and air supply line 18 have flow controllers 35 and 37, respectively, for varying the flow rate in each of the lines. Flow controllers 35 and 37 are in communication with the control system such that the control system can control the flow valve 17 and air valve 19.

[0068] FIG. 2 shows a sample graphical user interface 100 that may be used with the system for displaying/selecting/controlling the various operation variables by the operator. Referring to FIG. 2, Box 102 is Air Flow Outlet Temperature controller. Box 116 indicates initialized Air to Fuel Ratio from the actual Air to Fuel ratio at the time the application turned ON. Box 104 is Trimmed Air to Fuel Ratio calculated based on initialized Air to Fuel ratio trimmed by Excess O2. Box 108 is Air Demand Calculation Block. Box 115 is O2 Trim. Box 124 is Fuel Calculation block as per A/F Ratio Box 104 and as per the Air Flow value 114. Box 110 is High Pressure trim. Box 106 is Fuel Demand Calculation block. Box 114 is Air Flow Controller. Box 112 is Fuel Gas Flow Controller. This figure also has various selectors to ensure constraints are in place to avoid nuisance trips and smooth control of all the process variables of the furnace. Three values are shown in all the controller boxes (Box 102, Box 112, Box 114 and Box 115). These values indicate PV—Measured Process Variable; SP—Desired Set Point for the Pro-
cess Variable; and OP—Controller Output that drives the final control element to achieve the Process Variable close to the Set Point.

[0069] In one embodiment, a target temperature for the feed output is set at a temperature $T$. When the temperature measured by temperature transmitter 44 is below temperature $T$, it is an indication that the furnace is not supplied with sufficient fuel and air to heat the feed to the desired temperature. In this situation, the box 102, Feed Outlet Temperature Controller of the control system reacts by calculating an appropriate amount of increase in the air supply required first (to ensure the excess O2 level is maintained) and feeds that value to Box 108, Air Demand. As the air flow starts increasing, the box 124 Fuel as per NF Ratio feeds the signal to Box 106, Fuel Demand that sends the signal to Box 112, Fuel Gas Flow controller, taking into account other real-time variables, such as the box pressure (box 110), Trimmed A/F Ratio (box 104) and the High Selector 126 and Low Selector 128. When the temperature measured by temperature transmitter 44 is above temperature $T$, it is an indication that the furnace is supplied with more than sufficient fuel and air to heat the feed to the desired temperature. In this situation, the box 102, Feed Outlet Temperature Controller of the control system reacts by calculating an appropriate amount of decrease in the fuel gas supply required first by Low Selector 128 and feeds that value to Box 106, Fuel Demand. As the fuel gas flow starts decreasing, the value selected by High Selector 126 is fed to the box 108, Air Demand which in feeds the decreased air flow requirement to Box 114, Air Flow controller.

[0070] Initially the A/F Ratio 116 is set based on the actual air/fuel ratio in the time that the application is turned on. The A/F ratio can change as the quality of fuel fluctuates, even if the fuel flow rate remains constant. More specifically, more air is required if the fuel contains a higher portion of combustible components (i.e. “higher quality” fuel), and vice versa. For example, a fuel supply that contains 100% pure natural gas requires more air (i.e. a higher NF ratio) to fully combust than a lower quality fuel supply that contains 80% natural gas. The system allows for the automatic adjustment of the A/F ratio when the fuel quality fluctuates, which will be described in more detail herein below. Preferably, the amount of air supplied to the furnace should be slightly more than the amount required to completely combust the fuel in the furnace, and there should not be too much excess air to leave a cooling effect on the furnace, both of which should be taken into account in the A/F ratio used by the system.

[0071] In the sample embodiment illustrated in FIG. 2, the A/F ratio is shown in box 104. Therefore, when an increase in the fuel flow rate is detected, the control system automatically sends a signal to controller 37 to increase the air flow rate in order to maintain the A/F ratio. In the sample embodiment, box 108 shows the required air flow rate calculated based on the measured fuel flow rate and the A/F ratio, and a signal is sent to the air flow controller to increase the air flow rate to the required rate accordingly. In some cases, the quality of the fuel source can fluctuate, which affects the amount of air required to react with the fuel even if the fuel flow rate remains constant. In one embodiment, the level of O2 in the exhaust stream in the 14 is determined by analyzer 40 and is shown in box 115. The level of O2 in the exhaust is an indication of the actual amount of air that was consumed in burning the fuel supplied to the furnace. The initial A/F ratio is based on the fuel quality or a hypothetical presumed fuel quality and air quality at the time when cross limit controller is turned on. The A/F ratio may subsequently be adjusted based on the reading of the O2 analyzer in the flue. For example, a high level of O2 in the exhaust indicates that the fuel quality has decreased since the A/F ratio was last set or is lower than the presumed value because the combustion of the fuel is not using up most of the air supplied to the furnace. In this situation, the system will react by lowering the A/F ratio through O2 controller 115 based on the O2 level measured in the flue, in order to reduce the amount of excess air in the furnace. If the analyzer shows that there is almost no O2 in the exhaust, which may indicate that the fuel quality has increased, the system may react by increasing the A/F ratio through O2 controller 115 such that more air is fed into the furnace while the fuel flow rate remains unchanged. The adjusted A/F ratio is shown in box 104.

[0072] Referring to both FIGS. 1 and 2, an embodiment of the system is configured to monitor and control the fuel gas pressure. Depending on the type of furnace and the type of fuel, there is usually a safe range of fuel gas pressures within which a furnace can operate without tripping. In the illustrated embodiment of the system, the high and low limits of the safe fuel gas pressure range can be set at boxes 118 and 120, respectively, and these limits may be preset by process safety personnel in the control system and the furnace operator can vary the control set point within these high and low limits. Interface 100 may also display, in box 122, the real-time fuel gas pressure that is measured and transmitted by indicator 34.

[0073] The system may also be configured to monitor and control the box pressure. The furnace should be operated at a box pressure slightly below the atmospheric pressure to prevent flue gas leakage to the surroundings, and above a certain minimum pressure to minimize air leakage into the furnace from the surroundings, which reduces furnace efficiency. If the box pressure is too high, the furnace can trip. If the box pressure is too low, the furnace can implode. Interface 100 may display, in box 110, the real-time box pressure that is measured and transmitted by indicator 38.

[0074] Referring to FIGS. 3A and 3B, in one embodiment, the system of the present invention is configured to set the real-time dynamic constraints for high box pressure and high/low fuel pressure protections. This design allows the furnace to safely run at/close to its maximum capacity. The fuel gas pressure and box pressure of the furnace are continuously monitored by the system in a process 300. At step 302, the system gets its initialization for dynamic constraint function. At step 304, the system obtains respective PV and OP for fuel gas flow, box pressure and O2.

[0075] In the first stage from step 306 to step 324, it sets the constraints if the operation conditions are abnormal. At step 306, the system checks the box pressure, and if the box pressure is too high and is larger than a predefined value $P_{\text{box max}}$, the system then sets the high constraints for air flow at step 314, $O_2$ at step 316, fuel gas flow at step 318, and feed temperature at step 320, and goes back to step 306. Otherwise, it moves to the next stage. At step 308, the system checks the excess $O_2$, and if the $O_2$ is too low and is less than a predefined value $O_{2\text{min}}$, the system then sets the high constraints for fuel gas flow at step 318 and feed temperature at step 320, and goes back to step 304. Otherwise, it moves to next stage.

[0076] At step 310, the system checks the fuel gas pressure, and if the fuel gas pressure is too high and is larger than a predefined value $P_{\text{Gp max}}$, the system then sets the high con-
straints for fuel gas flow at step 318 and feed temperature at step 320, and goes back to step 304. Otherwise, it moves to next stage. When the system sets the high constraints, the air flow and fuel flow are not permitted to increase any more but can be decreased. The box pressure and fuel gas flow constraints help to prevent the high box pressure and high fuel gas pressure in tripping the furnace. A sharp increase (sometimes also referred to as a “spike”) in the box and fuel gas pressures may be a consequence of a huge increase in the flow rate of the feed input. A spike in the box and fuel gas pressures may cause the furnace to trip. By restricting the air flow and fuel flow rates from increasing when the box pressure or fuel gas pressure is already very high, the system may prevent tripping of the furnace at high box pressure or high fuel gas pressure.

When the box pressure is too low, the control system sends a message to the panel operator for his intervention. Referring to FIG. 2, in one embodiment, if the box pressure increases too high to reach a predefined value, the Box 110 will start to decreases the fuel flow rate and air flow rate will follow to decrease through the Box 115 O₂ controller.

[0077] At step 312, the system checks the fuel gas pressure and, if the fuel gas pressure is too low and is less than a predefined value PV₃Pₐ₈₉₆₉₉, the system then sets the low constraints for fuel gas flow at step 322 and feed temperature control at step 324, and goes back to step 304. Otherwise, it moves to the next stage. The low constraint restricts the fuel flow rate to the current level so that the fuel gas flow cannot be reduced any more but can increase. By restricting the fuel flow rates from decreasing when fuel gas pressure is already very low, the system may prevent tripping of the furnace at low fuel gas pressure.

[0078] In the second stage from step 326 to step 344, the system releases the constraints if all the conditions in above are back to normal. If the box pressure is back to normal and is less than a predefined PV₃Pₐ₈₉₆₉₉ at step 326, then the high constraints on air flow and PV are released at step 340 if there are high constraints for the air flow or O₂ at step 334, and goes back to step 304. Otherwise, it also goes back to step 304. If the box pressure is back to normal, it checks to see if O₂ is back to normal or not, i.e., O₂ is larger than a predefined (normal) value O₂₉₉₉₉. If the O₂ is back to normal, the system goes to step 330. Otherwise, it goes back to step 304. At step 330, if the fuel gas pressure is back to normal and is less than a predefined PV₃Pₐ₈₉₆₉₉, then the high constraints on fuel gas flow and feed temperature are released at step 342 if there are high constraints for the fuel gas flow or feed temperature at step 336, and goes back to step 304.

[0079] At step 332, the system checks whether the fuel gas pressure is recovered from low pressure or not. If the fuel gas pressure is back to normal, i.e., it is larger than a predefined value PV₃Pₐ₈₉₆₉₉, then the low constraints on fuel gas flow and feed temperature are released at step 344 if there are low constraints for the fuel gas flow or feed temperature at step 338, and goes back to step 304.

[0080] In one embodiment, the system of the present invention is configured to detect stiction in air valve in a process 400 as shown in FIG. 4. At step 402, the system gets its initialization for the valve stiction detection. At step 404, the system obtains respective PV and OP for air flow. Step 406 calculates the OP and PV differences dOP and dPV between the current time and previous nᵣ controller’s sampling time. Here, PV is the controlled process variable and OP is the controller’s output.

[0081] At step 408 and step 410, the system checks whether the air flow reading at meter matches the air flow controller output level or not, i.e., dOP is larger than a predefined OP value OP₉₉₉₉₉₉₉, but dPV is less than a predefined PV value PV₉₉₉₉₉₉₉. If the air flow meter reading matches the controller output level, then air flow controller is allowed to continue to be in CAS mode at step 416 (i.e. controlled by the control system) and restarts the process at step 404. Here, CAS means cascade mode for a controller. Otherwise, it sets air flow and fuel gas flow controllers in Manual mode. If the air flow meter reading does not match the controller output level, which indicates that there may be valve stiction, the system then switches the air flow controller at step 412 and the fuel gas controller at step 414 to manual mode (i.e. controlled manually by the furnace operator), and also sends notifications to the operator warning that the controllers have been switched to manual mode and/or air valve requires checkup or maintenance. In one embodiment, the warning notification is sent by way of a pop-up window in the user interface or another display visible to the operator. Steps 412 and 414 may be implemented substantially simultaneously. In manual mode, the operator controls the air flow and fuel gas flow controllers, and can manually adjust the air flow rate and the fuel gas flow rate. At step 418, it swaps data to save the previous 1ⁿ to ⁿ⁻¹ sampling OP and PV data.

[0082] For example, if air flow valve has 8% valve stiction, when it requires to increase or decrease air flow, the air controller will start increasing or decreasing its output until the output increases or decreases to 8%, then the valve will suddenly open or close at least 8%, which may cause the furnace trip at high box pressure or cause the furnace running at the O₂ deficiency situation.

[0083] With reference to FIGS. 1 and 5, the system may be configured to detect malfunctioning of the air flow meter in a process 500. As described above, air flow meter 36 measures the amount of air that flows into the furnace. The amount of air flowing into the furnace is controlled by controller 37, which controls valve 19. At step 502, the system gets its initialization for the air flow transmitter failure/spike detection. At step 504, the system obtains respective PV and OP for air flow. Step 506 calculates the OP and PV differences dOP and dPV between the current time and previous nᵣ controller’s sampling time. Here, PV is the controlled process variable and OP is the controller’s output.

[0084] When flow meter 36 detects a change in the air flow rate, the system checks whether the air flow change was initiated by the controller 37 at step 508 and step 510, i.e., dPV is larger than a predefined PV value PV₉₉₉₉₉₉₉, but dOP is less than a predefined OP value OP₉₉₉₉₉₉₉, or dPV is less than a predefined PV value PV₉₉₉₉₉₉₉, but dOP is larger than a predefined OP value OP₉₉₉₉₉₉₉. If the change was initiated by the controller 37, then the system allows the air flow controller and fuel gas controller to remain in CAS mode at step 516 and the system restarts process 500 at step 504. If the change was not initiated by the controller 37, which may indicate that the air flow meter is malfunctioning and giving false readings, the system then switches the air flow controller 37 at step 512 and fuel gas flow controller 35 at step 514 to manual mode and also sends a notification to the operator warning that the air flow controller and fuel gas flow controller have been switched to manual mode and/or air flow meter 36 requires checkup or maintenance. The warning notification may be sent by way of a pop-up window in the user interface or another display visible to the operator. In manual mode, the
operator controls the air flow controller and can manually adjust the air flow rate. In this situation, from the moment when the air flow controller is switched to manual mode, the system ignores the air flow meter readings so that they are not relied upon to change other operation variables. At step 518, it swaps data to save the previous 1st to nth sampling OP and PV data.

[0085] For example, if the system relies on a false reading that indicates a 20% sudden increase in the air flow rate, but in reality the air flow rate has not changed, then the system will react by instructing air flow controller 37 to try to decrease the air flow rate by 20%. Such an unwarranted decrease in the air flow rate would lead to air deficiency in the furnace, which is unsafe operation and may trip the furnace. Therefore, switching the air flow controller to manual mode when there is a potential malfunctioning of the air flow meter helps prevent the furnace from tripping due to a false air flow rate reading.

[0086] With reference to FIGS. 1 and 6, the system may be configured to detect malfunctioning of the fuel gas flow meter in a process 600. As described above, fuel gas flow meter 32 measures the amount of fuel gas that flows into the furnace. The amount of fuel gas flowing into the furnace is controlled by controller 35, which controls valve 17. At step 602, the system gets its initialization for the fuel gas transmitter failure/spike detection. At step 604, the system obtains respective PV and OP for fuel gas flow. Step 606 calculates the OP and PV differences dOP and dPV between the current time and previous nth controller’s sampling time. Here, PV is the controlled process variable and OP is the controller’s output.

[0087] When flow meter 32 detects a change in the fuel gas flow rate, the system checks whether the fuel flow change was initiated by the controller 35 at step 608 and step 610, i.e., dPV is larger than a predefined PV value PV_max_OP, but dOP is less than a predefined OP value OP_max_OP or dPV is less than a predefined PV value -PV_max_OP, but dOP is larger than a predefined OP value -OP_max_OP. If the change was initiated by the controller 35, then the system allows the fuel gas flow controller and air controller to remain in CAS mode at step 616 and the system restarts process 600 at step 604. If the change was not initiated by the controller 35, which may indicate that the fuel gas flow meter is malfunctioning and giving false readings, the system then switches the air flow controller 37 at step 612 and fuel gas flow controller 35 at step 614 to manual mode and also sends a notification to the operator warning that the fuel gas flow controller and air flow controller have been switched to manual mode and/or fuel gas flow meter 32 requires checkup or maintenance. The warning notification may be sent by way of a pop-up window in the user interface or another display visible to the operator. In manual mode, the operator controls the fuel gas flow controller and can manually adjust the fuel gas flow rate. In this situation, from the moment when the fuel gas flow controller is switched to manual mode, the system ignores the fuel gas flow meter readings so that they are not relied upon to change other operation variables. At step 618, it swaps data to save the previous 1st to nth sampling OP and PV data.

[0088] For example, if the system relies on a false reading that indicates a 20% sudden decrease in the fuel gas flow rate, but in reality the fuel gas flow rate has not changed, then the system will react by instructing fuel flow controller 36 try to increase the fuel flow rate by 20%. Such an unwarranted increase in the fuel flow rate would lead to air deficiency in the furnace, which is unsafe operation and may trip the furnace. Therefore, switching the fuel gas flow controller to manual mode when there is a potential malfunctioning of the fuel gas flow meter helps prevent the furnace from tripping due to a false fuel gas flow rate reading.

[0089] In one embodiment, the system is configured to determine the reliability of the O2 analyzer reading in the flue stack. Referring to FIGS. 1 and 7, O2 analyzer 40 provides the system a measurement of the O2 level in the exhaust. Due to the location of the analyzer in the furnace, the analyzer can sometimes intermittently coated with debris from the exhaust and may be cleared subsequently, which may cause the analyzer to give inaccurate and fluctuating readings.

[0090] In a process 700, the system checks the O2 analyzer readings. For example, if according to the air flow rate and Air/Fuel (Air/Fuel) ratio there should be more (or less) O2 in the exhaust than the level indicated by the analyzer, it is likely that the analyzer is intermittently coated with debris and subsequently cleared which provides an inaccurate and fluctuating O2 level reading. At step 702, the system initializes air/fuel ratio by using current filtered air/fuel. At step 704, the system obtains respective PV and OP for the excess O2. At step 706, it checks O2 analyzer’s reading range with a predicted level determined from the other operation variables, such as air flow rate as measured by flow meter 36 and the fuel flow rate as measured by flow meter 32. If O2 reading is out of the defined range and DCS detects a poor PV, it will set the air flow control to manual mode and operators notified at step 716. If the O2 level indicated by the analyzer is much higher or much lower than the predicted O2 level, since the system design restricts the ratio trimmed Air/F Ratio to a predetermined smaller range than the normal full range, thus, it prevents the ratio from fluctuating by large magnitudes. In the standard cross limit control, the O2 controller generally trims the air/fuel ratio from 10 to 20. Thus, when the O2 analyzer fails or suddenly big change, it may trip the unit. Referring to FIGS. 2 and 7, O2 controller just trims the initial air/fuel ratio with a predefined small range such as ±1.5 around the initial air/fuel ratio. So, when the O2 analyzer fails, the effect on the furnace will be greater reduced. In this design, when O2 controller reaches its maximum or minimum output, the value of air/fuel ratio can be reset so that O2 controller recovers to its maximum regulating ability. At step 710, the system calculates the trimmed air/fuel ratio. From step 708 to step 714, the system checks whether the OP of O2 controller is too high (larger than a predefined value OP_max_OP) or too low (less than a predefined value OP_min_OP), if the OP is in the normal range, then it goes back to step 704. If the OP is out of the normal range and is caused by the fault O2 analyzer, it sets the O2 controller to manual mode and notifies the operator. In step 718, operator decides whether resets the O2 controller (goes back to step 702) to set the OP back to the normal range or remains the operation condition (goes back to step 704) when the OP is out of the normal range.

[0091] FIG. 8a illustrates the effect of a sharp spike in the fuel gas flow rate on the level of excess O2 in a furnace operating without the control system of the present invention. It can be seen that at around 8:50 hour, the feed temperature 810 dropped, which caused the fuel gas flow rate 812 spike, while the air flow rate 814 remained substantially constant. The spike in the fuel gas flow rate resulted in an inversely proportional spike in the level of excess O2 816 to zero for about 8 minutes. As discussed above, a significant drop in the level of excess O2 close to zero causes the furnace to run in the unsafe condition.
In contrast, it can be seen in FIG. 9a that changes in fuel gas flow rate have minimal effect on the excess $O_2$ in a furnace that uses the system of the present invention with the feed out temperature controller 910 and excess $O_2$ controller 916 in Auto Mode. More specifically, even the air controller’s OP (output) 918 was fully opened (105% opening) at later two periods, i.e., the air flow 914 reached its maximum rate, but the fuel gas flow 912 cannot be increased when the air flow 914 was limited, thus, the excess $O_2$ PV (process value) 916 is controlled very close to the excess $O_2$ SP (set point).

FIG. 8f illustrates the effect on the furnace box pressure from changes in the air flow rate supplied to a furnace when operated without the control system of the present invention. Without the control system of the present invention, the effect of changes in air flow rate on box pressure is not considered. Therefore, the air flow rate does not have any restriction based on the box pressure. An increase in the air flow rate 822, while the fuel gas flow rate 826 remained substantially constant, caused a corresponding increase in the level of excess $O_2$ 828 and positive box pressure 824 in FIG. 8f which means the furnace is running in an unsafe operation condition. It should also be noted that the box pressure controller 820 was fully open (105%) to try to operate the furnace box pressure at its set point (~0.20 PSIG), however, even at these conditions, the controller was not able to control box pressure.

In FIG. 8f, the box pressure controller’s output 820 was always 105%, i.e, there was no any more control on high box pressure due to the equipment capacity limitation. The air flow rate 822 was about 15MSCFD and it increased to about 20MSCFD from around October 23 to around October 25. The data shows that the box pressure 824 increased in substantially the same time period from ~0.08 to 0.11. The air flow rate 822 decreased between October 25 and October 26, from 20MSCFD to 16MSCFD. As a result, the box pressure 824 dropped from 0.12 to ~0.07. As can be seen from the graph, the box pressure 824 was positive for about two days since box pressure controller 820 had lost control.

In contrast, it can be seen that in FIG. 9b, when a furnace is controlled by the system of the present invention and operating close to maximum operation conditions, the air flow controller and fuel gas flow controller has restriction regarding the box pressure. If the box pressure is proceeding to reach a predefined value, the application will dynamically set constraints on the fuel and air controller to limit them increase any further thus preventing the potential trip. It can be seen in FIG. 9b when the box pressure 920 reaches the predefined value (~0.05 PSIG) the fuel flow 922 and air flow 924 are restricted so that the box pressure 920 cannot increase any further, which may have a slight overshoot, while the box pressure’s output 926 is 105% (fully open). Further, if the box pressure is still increasing, the control application will start trimming the fuel which eventually results in reduction in air as well. It is worthwhile to note that the $O_2$ 928 was well maintained.

FIG. 8c illustrates the effects of changes in fuel gas flow rate on other operation variables in a furnace operating without the control system of the present invention. The temperature 830 dropped from 328 Deg. C to 279 Deg. C between around 16:12 hour to 16:26 hour. Consequently, the decrease in the temperature resulted in that fuel flow 832 increased from about 0.3 MSCFD to 0.8 MSCFD. $O_2$ 834 decreased from about 7% to 0% and fuel gas pressure 836 from about 14 PSIG to 38 PSIG. Therefore, the furnace tripped on high fuel gas pressure. It should be noted that the Excess $O_2$ level 834 was close to zero prior to furnace trip, which was an unsafe operation condition.

In contrast, as shown in FIG. 9c, when a furnace is controlled by the system of the present invention, changes in the feed flow rate or feed outlet temperature do not significantly affect other operation variables. The increasing requirement for the fuel gas flow rate 932 resulted in similar increase in the air flow rate 938 and fuel pressure 936. Since the air flow rate changes with the fuel gas flow rate in accordance with the A/F ratio, the level of excess $O_2$ 934 in the furnace remained substantially constant.

And the fuel gas flow was dynamically constrained whenever the fuel gas pressure was above the predefined value (33 PSIG). Thus, furnace has not ripped on high fuel gas pressure even with increased demand in heat duty. Further, the feed output temperature 930 also remained substantially constant.

FIG. 8d illustrates the effect of the feed output temperature from changes in the flow rate of the input feed in a furnace that operated with the existing controls in the control system in manual mode prior to implementation of the present invention. The initial feed input flow rate 840 was about 75 KBPD and it was gradually reduced to about 45 KBPD from around 23:00 hour to around 8:00 hour. The data shows that the feed output temperature 842 increased from around 1:00 hour to around 9:00 hour by about 20° C. The feed input flow rate was then increased from about 45 KBPD at about 12:00 hour to about 60 KBPD at 16:00 hour. The feed output temperature decreased from around 9:00 hour to about 17:00 hour by approximately 10° C. As can be seen from the graph, the feed output temperature was significantly affected by changes in the feed input flow rate.

In contrast, it can be seen in FIG. 9d that changes in feed input flow rate have minimal effect on the feed output temperature in a furnace that uses the system of the present invention with the feed out temperature controller and excess $O_2$ controller in Auto Mode. When the feed rate 940 slowly changed from 65 KBPD to 55 KBPD, the feed outlet temperature PV 942 was well maintained. The sudden variation of feed rate from 55 KBPD to 40 KBPD within 15 minutes had little effect in the feed outlet temperature (within 6 Deg. C) and in excess $O_2$ PV (max 0.8% change) 944 as could be clearly seen from this trend.

FIG. 8e illustrates the excess $O_2$ comparison with one year data before using the system of the present invention 850 (blue line) and one year data after using the present invention 852 (red line). Before using the present invention, the mean value of excess $O_2$ was 3 and the standard deviation of excess $O_2$ was 0.6, and a lot of high excess $O_2$ causing low combustion efficiency and some low excess $O_2$ which could result in unsafe operation. After using the present invention, the mean value of excess $O_2$ was reduced to 2.5 and the standard deviation of excess $O_2$ was reduced to 0.3, and the excess $O_2$ was mostly in the desired range of excess $O_2$ increasing the combustion efficiency and completely eliminating the low excess $O_2$ which can result in unsafe operation.

As shown by the sample data collected from the furnaces, one of which operated with the control system of the present invention and the other without, it can be seen that the control system helps prevent significant fluctuations in the operation variables during the operation of the furnace. The control system also helps prevent the furnace running in the
unsafe operation situation. The control system may further help diagnose certain problems with the furnace by monitoring the various operation variables and assist in preventing tripping of the furnace.

[0103] From the foregoing description, one skilled in the art can easily ascertain the essential characteristics of this invention, and without departing from the spirit and scope thereof, can make various changes and modifications of the invention to adapt it to various usages and conditions. Thus, the present invention is not intended to be limited to the embodiments shown herein, but is to be accorded the full scope consistent with the claims, wherein reference to an element in the singular, such as by use of the article “a” or “an” is not intended to mean “one and only one” unless specifically so stated, but rather “one or more”. All structural and functional equivalents to the elements of the various embodiments described throughout the disclosure that are known or later come to be known to those of ordinary skill in the art are intended to be encompassed by the elements of the claims. Moreover, nothing disclosed herein is intended to be dedicated to the public regardless of whether such disclosure is explicitly recited in the claims.

REFERENCES


We claim:
1. A method for monitoring and controlling the operation of a furnace in real-time, comprising:
   (a) obtaining a measurement of a controlled process variable (PV) from a measuring device that senses the PV in a controlled process;
   (b) obtaining an output reading (OP) from a controller that is in an auto-mode and is continuously controlling the controlled process by maintaining the PV within a desired range;
   (c) determining whether there has been a change (dPV) in the PV relative to a previously obtained controlled process variable (PV, previously) obtained from the measuring device;
   (d) determining whether or not dPV was initiated by the controller.

2. The method as claimed in claim 1, further comprising:
   (e) switching the controller into a manual mode if it is determined that dPV was not initiated by the controller.

3. The method as claimed in claim 2, further comprising:
   (f) sending a signal to an operator alerting the operator that the controller has been switched to the manual mode.

4. The method as claimed in claim 1, wherein the controlled process variable (PV) is selected from the group consisting of box pressure, fuel gas pressure, O2 concentration, valve stiction, air flow transmission, and fuel gas transmission.

5. A method for monitoring and controlling the operation of a furnace in real-time, comprising:
   (a) obtaining a measurement of a controlled process variable (PV) from a measuring device that senses the PV in a controlled process;
   (b) obtaining an output reading (OP) from a controller that is in an auto-mode and is continuously controlling the controlled process by maintaining the PV within a desired range;
(c) determining whether there has been a change (\(dPV\)) in the PV relative to a previously obtained controlled process variable (\(PV_{r}\)) obtained from the measuring device;
(d) determining whether there has been a change (\(dOP\)) in the OP relative to a previously obtained output reading (\(OP_{r}\)) obtained from the controller; and
(e) determining whether \(dPV\) is less than or greater than a predefined maximum controlled process variable (\(PV_{max}\)) and whether the \(dOP\) is less than or greater than a predetermined minimum output reading (\(OP_{min}\)) in order to determine whether a change in the process was initiated by the controller.

6. The method as claimed in claim 5, further comprising:
(f) switching the controller from the auto-mode into a manual mode if it is determined that the change in the process was not initiated by the controller.

7. The method as claimed in claim 6, further comprising:
(g) sending a signal to an operator alerting the operator that the controller has been switched to the manual mode.

8. The method as claimed in claim 5, wherein the controlled process variable (PV) is selected from the group consisting of box pressure, fuel gas pressure, \(O_2\) concentration, valve stiction, air flow transmission, and fuel gas transmission.