Bailey®
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Application Guide

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Advanced Metered Combustion Control for Single Burner Industrial Boilers

(Single and Dual Fuels)

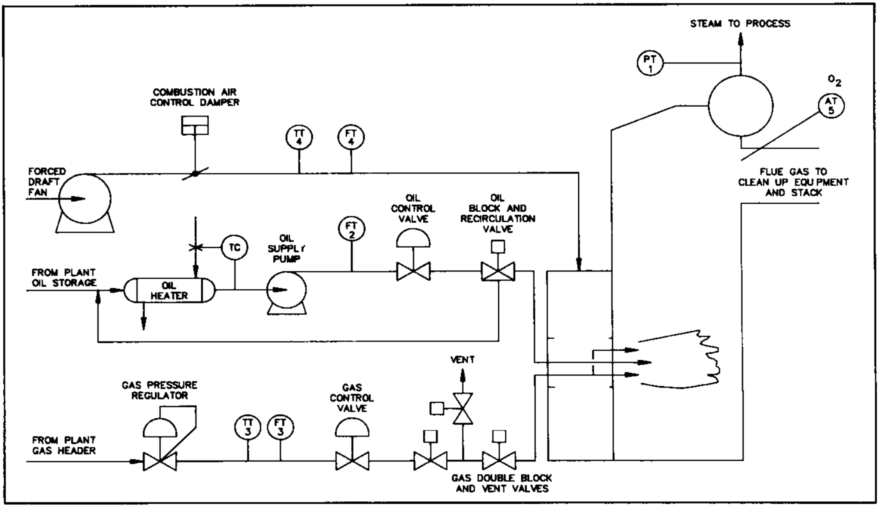

FIGURE 1 Typical Single Burner Dual Fuel Industrial Boiler

Introduction

Metered combustion control is the most widespread type of modulating control for industrial boilers. Conventional metered combustion control systems measure the flows of fuel and combustion air to the boiler, modulate fuel flow to satisfy the demand for boiler steam production, and modulate the combustion air flow to maintain the fuel/air ratio at a predetermined value. This preprogrammed fuel/air ratio often utilizes excessive combustion air and results in excessive fuel costs.

Bailey Controls provides advanced metered combustion controls which can reduce the cost of steam production by as much as $0.10/Klb steam produced. These advanced controls reduce steam production costs by allowing the boiler to operate safely and reliably at reduced levels of excess air even though operating conditions change. Bailey's unique inter-module digital communication capabilities allow the advanced controls to be easily integrated into a complete Bailey boiler control system without additional hardwiring of signals.

Bailey Controls
Babcock & Wilcox, a McDermott company

Summary of Features and Benefits

The Bailey advanced metered combustion controls provide the following specific benefits for operation of industrial boilers:

- Reduced excess air consumption throughout the operating range of the boiler. The excess air is reduced by adjusting the fuel/air ratio to maintain a preset fluegas oxygen concentration. This can result in fuel savings of 0.7 cents/klb of steam production for each percentage reduction in excess air.
- Automatic adjustment of the setpoint for flue gas excess oxygen concentration based on boiler load, boiler start up and user set constraints.
- Combustion control for boilers with either a single fuel or two fuels which can be fired simultaneously during fuel transfer.
- Automatic adjustment to alternate fuel firing.
- Automatic reversion to conventional metered combustion control when the on line fluegas oxygen sensor is not available.
- Internal valve/damper characterization for installations without characterizable valve positioners, or where digital characterization is more convenient.
- Automatic interlocks to maximize fault tolerance for loss of measurement signals and to insure proper controller modes.
- Feedforward techniques to provide rapid response for boiler load changes.
- Preprogrammed interface with a standard automatic burner management system for the boiler.
- Automatic calculation of the cost savings achieved by the advanced controls.

Application Description

A representative industrial boiler is shown in **FIGURE 1**. This boiler has two separate fuel supplies, each with a flow measuring device. Combustion air is provided by a forced draft fan and is also measured. An automatic burner management system (not shown) provides boiler purge, burner start up and flame safety functions. There are many variations to this design, but most industrial boilers have these basic features.

Combustion Chemistry

Heat is added to the boiler by the combustion of either fuel. In order for the combustion to take place (1) the combustibles must be gasified, (2) the mixture of oxygen and combustibles must be within the flammable range (neither too rich nor too lean), and (3) the fuel air mixture must be above the ignition temperature. The chemistry for combustion of the carbon compounds in the fuel is as follows:

$$C + O_2 \rightarrow CO_2 + 14{,}093 \text{ Btu/lb C}$$

If there is insufficient air, the carbon in the fuel is incompletely burned:

$$2C + O_2 \rightarrow 2\,CO + 3{,}950 \text{ Btu/lb C}$$

Incomplete combustion of carbon is generally avoided since only one third of the energy is produced during the formation of carbon monoxide (CO).

Other combustible constituents in the fuel are hydrogen and sulfur compounds. They react as follows:

$$2H_2 + O_2 \rightarrow 2\,H_2O + 61{,}100 \text{ Btu/lb H}$$

$$S + O_2 \rightarrow SO_2 + 3{,}983 \text{ Btu/lb S}$$

The amount of oxygen, and the corresponding amount of air required to completely burn a fuel (stoichiometric combustion) can be determined from the ultimate analysis of the fuel. The theoretical pounds of air required per pound of fuel can be determined as follows:

$$\text{Theoretical Air (lb Dry Air/lb Fuel)} = 11.53C + 0.3434\,(H - O/8) + 0.0429S$$

Here **C, H, O,** and **S** represent the weight percent of carbon, hydrogen, oxygen and sulfur from the ultimate analysis of the fuel (as fired).

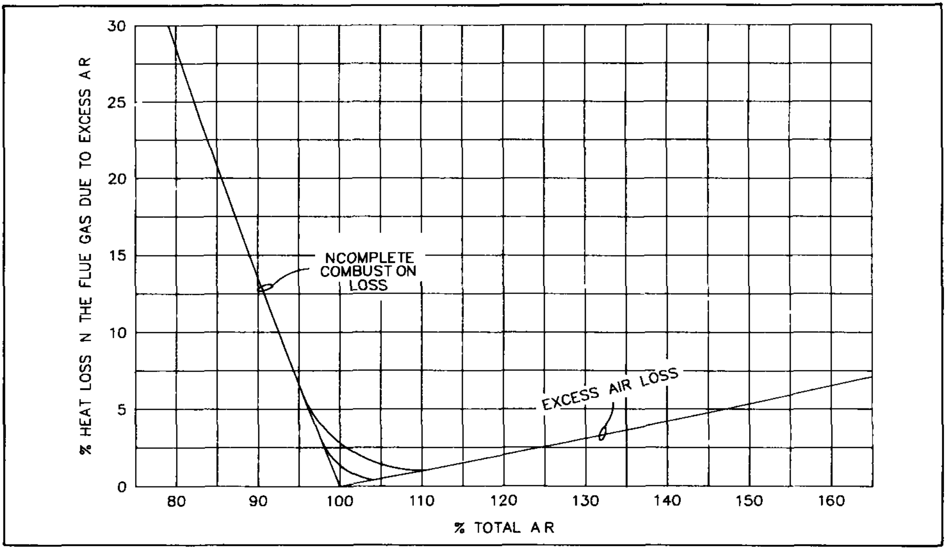

FIGURE 2 Typical Heat Loss vs Total Air Combustion

Excess Air

The combustion air required to operate the boiler is greater than the calculated theoretical air. This excess air is required because some of the combustion air supplied to the boiler will not react with the fuel before the fuel air mixture reaches the flammability limits and/or drops below the ignition temperature. Too much excess air results in excessive fuel consumption and NOx concentration in the boiler stack gas.

The amount of excess air required for good combustion in the boiler furnace is dependent upon the design of both burner and furnace. To minimize the required excess air, the fuel must be thoroughly atomized and mixed with the combustion air. Further, the combustion air must impart the necessary turbulence and momentum to the flame and the furnace must be sized to allow adequate high temperature residence time for completion of the combustion reactions.

The amount of excess air provided for burner operation has a direct impact on the cost of steam production. Reducing excess air reduces the heat lost with the stack gases by reducing the quantity of the boiler exit fluegas. Reducing excess air also reduces the power consumed by the forced draft fan. The limiting factors for excess air reduction are incomplete combustion, stack opacity and/or furnace damage from high flame temperatures.

The effects of excess air on boiler efficiency are shown in **FIGURE 2**. The rounding at the knee of the curve is related to the ability of the burner and furnace to approach stoichiometric combustion. This rounding will be increased by a dirty burner tip, low atomizing pressure, mis-aligned burner spinning vanes and decreased burner firing rate. It is significant to note the steep slope of the heat loss curve for incomplete combustion; 2% too little air has the equivalent effect of 20% too much air on boiler efficiency.

A properly operated commercial burner, mounted in an adequately sized furnace, is capable of operating with as little as 5% excess air at its rated load. However, operation at this low excess air leaves little margin for errors. If the combustion mixture becomes too rich, significantly less heat (and steam) may be generated for the same fuel consumption, furnace damage may result from high flame temperatures, and high opacity stack gases may be produced. If the combustion mixture becomes too lean, the excess air will absorb much of the heat that could have produced steam and the fluegas may contain unacceptably high NOx emissions.

Further, as the burner is reduced from its rated load, the requirement for excess air increases to maintain adequate turbulence in the burner. This requirement increases more rapidly when the burner is operated below 50% of its rated capacity.

Conventional Metered Combustion Control

In a conventional metered combustion control system, the fuel flow is modulated to maintain steam header pressure and the combustion air flow is modulated to maintain a preset fuel/air ratio. The fuel/air ratio is established periodically by monitoring the concentration of oxygen in the fluegas over the expected boiler operating range and selecting the value which keeps the excess air above the minimum recommended by the boiler manufacturer.

A metered combustion control system is normally set up to provide 20-30% excess air. This practice provides a safety margin to accommodate changes in burner operating conditions. As ambient conditions and fuel characteristics change, the conventional controls require retuning to maintain effective boiler performance. This is impractical and virtually impossible on a day to day basis. The relative magnitude of excess air changes which can be expected from changes in various burner operating conditions is shown in **TABLE 1**.

Advanced Metered Combustion Control

Bailey Controls provide advanced metered combustion controls for single burner industrial boilers which reduce the excess air used by the boiler and provide rapid response to load changes. The advanced controls are summarized schematically in **FIGURE 3**. Oxygen trim is combined with steam pressure control and several special features which utilize advanced capabilities of Bailey microprocessor based controllers to maximize functionality and operational simplicity.

The special features of the advanced controls are discussed briefly below. The flexibility of the Bailey equipment allows these features to be easily tailored for specific installations and allows additional features to be easily added to satisfy specific requirements.

Oxygen Trim

Zirconium Oxide oxygen analyzers have proven both reliable and cost effective for continuous on line measurement of oxygen concentration in boiler fluegas. The output signal from this analyzer is a measure of the excess air provided to the burner.

The excess oxygen signal is used by the advanced controls to continuously adjust (trim) the fuel/air ratio maintained for the boiler. This oxygen trim strategy maintains safe operating conditions within the furnace while minimizing both fuel consumption and stack emissions at every boiler operating point.

Successful application of this strategy depends on providing a representative flue gas sample to the analyzer. Special precautions must be taken with boilers which operate with negative furnace pressure and have significant air in leakage.

Oxygen Setpoint Program

To maintain combustion efficiency throughout the boiler operating range, the advanced controls include function generators which provide a set

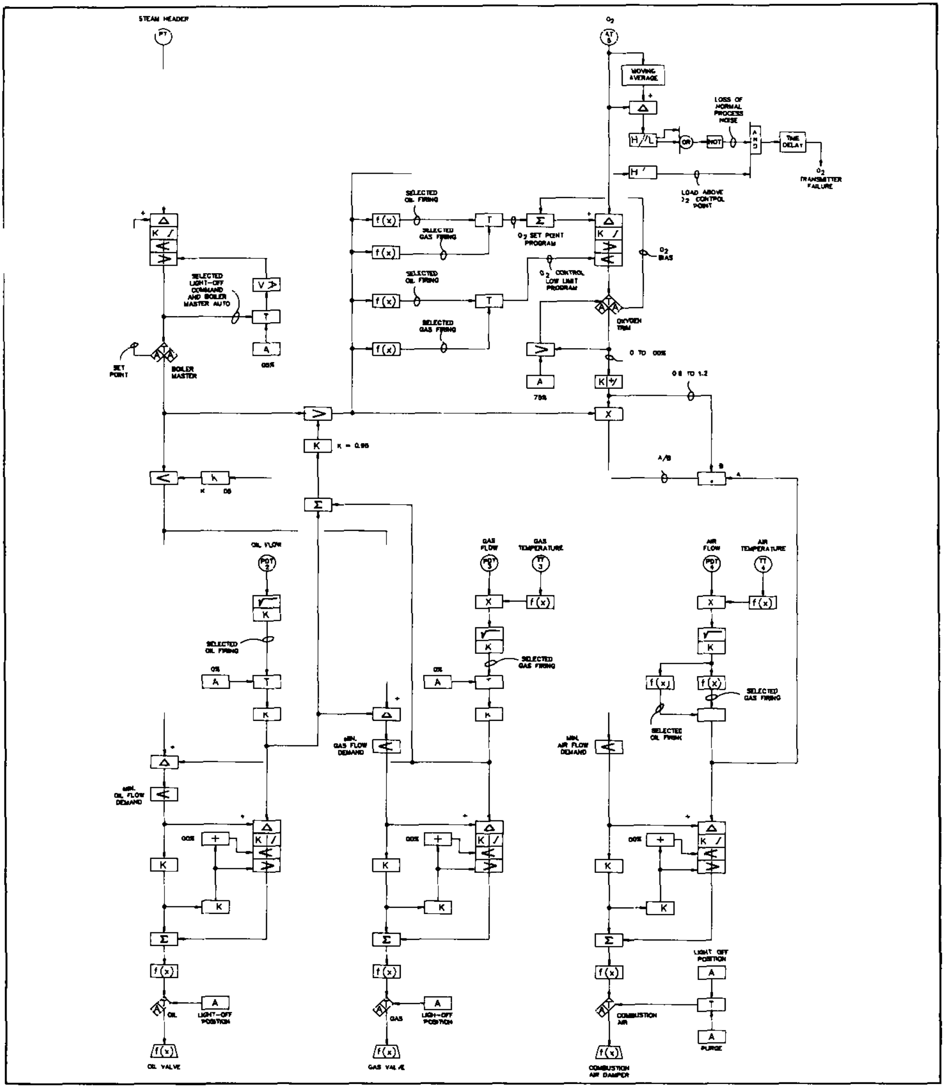

FIGURE 3   Bailey Advanced Metered Combustion Controls for Single Burner, Dual Fuel (Gas/Oil) Industrial Boilers

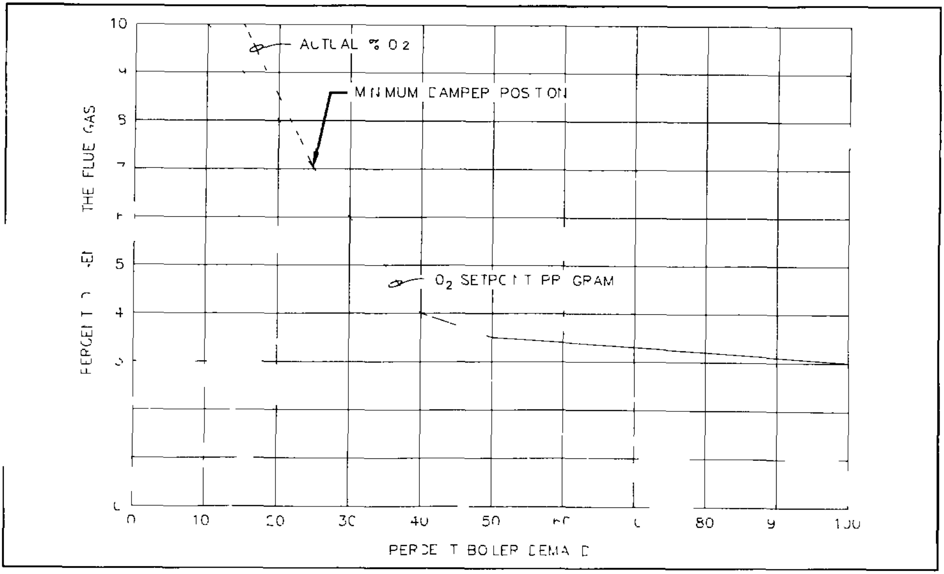

FIGURE 4 Typical Oxygen Setpoint Program for Oil Firing

po nt program for f uegas oxygen concentrat on as a funct on of bo er oad demand A typ ca oxygen setpo nt program for o f r ng s shown n **FIGURE 4** Th s program can be estab shed to *m n m ze excess combust on a r over the ent re* bo er operat ng range by ma nta n ng the f uegas oxygen concentrat on 1% above the po nt where the f ue gas carbon monox de concentrat on r ses above 300 ppm

The oxygen tr m s constra ned when the com bust on a r damper reaches ts m n mum pos t on or the bo er oad fa s be ow a user set m n mum Th s feature perm ts automat c operat on of the oxygen contro er dur ng bo er startup and ow oad operat on

Dual Fuel Capability

The advanced metered combust on contro s accommodate dua fue s f red e ther separate y or s mu taneous y dur ng a transfer between fue s

For separate f r ng a of the spec a combust on contro features are dup cated for both fue s to automat ca y prov de dent ca contro system per formance even though the fue character st cs *may be s gn f cant y d fferent f the second fue s* not ut zed the advanced contro s automat ca y d sab e the assoc ated control og c

Simultaneous Firing

The advanced metered combust on contro s perm t s mu taneous f r ng of two fue s Th s feature s prov ded pr mar y to fac tate transfer from one fue to another wh e the bo er s operat ng

When the bo er s operat ng on one fue (con tro stat on set to AUTOMAT C mode) and the Burner Management System perm ts f r ng w th the a ternate fue the a ternate fue f ow can be manua y ncreased by the operator from the assoc ated contro stat on The advanced contro s will automatically reduce the flow of the initial fuel until the control valve reaches its low fire position. The combustion air requirements for the alternate fuel are automatically provided by the advanced controls, the highest excess oxygen setpoint established for the two fuels is selected for control.

Once the initial fuel has been reduced to its minimum, the associated control station can be set to MANUAL mode by the operator, and the alternate fuel control station can be switched to AUTOMATIC mode. After the initial fuel system is deactivated by the operator, the transfer is complete.

Internal Valve/Damper Characterization

The advanced controls include function generators to linearize control valve position to boiler demand (fuel valves) or fluegas oxygen concentration (air damper). This feature provides improved controller performance over the entire operating range of the boiler by stabilizing the controller tuning requirements.

Most boiler fuel control valve(s) and combustion air damper(s) exhibit a nonlinear valve characteristic (% open vs % flow relationship). A characterizing positioner can be provided to compensate for this nonlinear valve characteristic and produce a linear relationship between the controller output and the resulting flow. This permits the controller to be tuned for effective performance and remain tuned over the normal boiler operating range (if process conditions do not change significantly). When a characterizing positioner is not provided, the controller must be loosely tuned to provide stable controller performance over the normal operating range of the boiler. This practice permits wide variations in steam pressure.

The Bailey advanced metered combustion controls provide function generators which allow the valve to be conveniently characterized so that when the control signal increases by 5%, the flow increases by 5% rather than 2% or 10% depending on the valve position. This feature permits one set of controller tuning constants to be applicable for all boiler loads, allowing the associated controller to be tightly tuned so that stable steam header pressure is maintained.

Valve characterization may be provided externally to the controllers by mechanically characterizable positioners installed on the valve or damper. However, it can be a very difficult and time consuming procedure to accurately characterize the valve positioner. This procedure must be repeated periodically to maintain the accuracy of the characterization. The internal valve characterization feature of the advanced metered combustion controls provides a method for convenient and accurate characterization of the boiler valves and dampers.

Flow Signal Conditioning

If a fuel is not selected for firing, the flow measurement is forced to zero. This prevents recirculation flow and transmitter calibration errors from affecting combustion control.

Automatic temperature compensation is provided for gaseous fuels and combustion air. This signal conditioning eliminates the effect of changes in these process variables on excess air before an actual change in fluegas oxygen concentration must be corrected by the oxygen trim controller.

Boiler Demand Feedforward

The advanced controls immediately feed forward changes in boiler demand to the primary fuel control valve and the combustion air damper. The flow and oxygen trim controls then adjust the final positions to minimize excess air consumption at the new load. This feature minimizes the impact of significant changes in steam consumption on steam pressure.

Fuel-Air Crosslimiting

To prevent an excessively fuel rich condition in the burner during boiler load changes or abnormal operating conditions (e.g. limited combustion air or fuel valve failure to close), the advanced controls limit the change in fuel flow until adequate combustion air is available. This is partially accomplished by low auctioneering between the combustion air flow and boiler demand signals for the fuel controllers to prevent the fuel demand from exceeding the available combustion air. It is also partially accomplished by high auctioneering between the total measured fuel flow and the boiler demand signals for the combustion air controller to prevent the combustion air from falling below the flow required for the actual fuel flow(s)

This cross limiting is accomplished in a manner which permits up to a preset mismatch (typically 5%) between the combustion air demand and the air flow This technique improves boiler response to load changes over classical cross limiting techniques which utilize unity gain on the cross limiting signals

Fault Tolerance

The advanced metered combustion controls include several interlocks which maximize automatic operation when a sensor failure is detected This feature provides the highest level of automatic control feasible during abnormal operating circumstances

If the signal from the steam pressure transmitter becomes unavailable to the advanced controls, or becomes out of range this condition will be alarmed and the BOILER MASTER station will be automatically switched to MANUAL mode holding boiler demand at its previous value When this interlock is active the operator can readjust the boiler demand but the BOILER MASTER station cannot be returned to AUTOMATIC mode until the lost signal is restored

If the signal from the oxygen analyzer becomes unavailable to the advanced controls, becomes out of range, or does not contain the normal process noise spectrum, this condition will be alarmed and the OXYGEN TRIM station will be automatically switched to MANUAL mode with the oxygen trim set to a preset value In the MANUAL mode, the operator can readjust the oxygen trim, but the OXYGEN TRIM station cannot be returned to AUTOMATIC mode until a valid signal is restored Automatic temperature compensation for gaseous fuels and combustion air increases the stability of the excess air until the oxygen analyzer signal is restored

If the signal from a fuel flow transmitter becomes unavailable to the advanced controls, or becomes out of range, this condition will be alarmed and the associated FUEL control station will be automatically switched to MANUAL mode with the fuel control valve set to its light off position The operator cannot manually reposition the fuel control valve unless the COMBUSTION AIR station is set to MANUAL mode The fuel control station cannot be returned to AUTOMATIC mode until the lost signal is restored

If the signal from the air flow transmitter becomes unavailable to the advanced controls or becomes out of range, this condition will be alarmed and the entire combustion control system will be automatically switched to MANUAL mode Both fuel control stations will be switched to MANUAL mode with the fuel control valves set to their light off position The COMBUSTION AIR station will be switched to MANUAL mode with the air damper set to its previous position The BOILER MASTER station will be switched to MANUAL mode, with boiler load demand set at minimum The operator can readjust the air damper and fuel valve positions, but cannot return any station to AUTOMATIC mode until the air flow signal is restored

Controller Mode Interlocks

The individual control stations within the advanced Bailey combustion controls are interlocked to insure that they are placed in AUTOMATIC mode in the proper sequence The individual FUEL and OXYGEN TRIM control station will be automatically switched to and held in MANUAL mode if the COMBUSTION AIR station is in MANUAL mode The BOILER MASTER station will be switched to and held in MANUAL mode if both FUEL control stations are in MANUAL mode Only one FUEL control station can be set to AUTOMATIC mode at one time Consequently the proper sequence for setting the individual control stations to AUTOMATIC mode is COMBUSTION AIR, FUEL, BOILER MASTER, and OXYGEN TRIM

Burner Management Interface

The advanced combustion controls are configured to interface to a standard automatic (recycling or nonrecycling) burner management system (as defined by NFPA Standard 85A) The advanced contro s rece ve the fo ow ng com mands from the burner management system

- SET TO L GHT OFF POS TION
- SET TO PURGE POSIT ON
- FUEL A F R NG PERM TTED
- FUEL B F R NG PERM TTED

Upon rece pt of the SET TO L GHT OFF POS T ON command from the burner management system the FUEL contro stations and the COM BuST O N A R sta on wil be automat ca y set to the ght off pos t on The nd v dua FUEL contro stat ons wi a so be automat ca ly set to MANUAL mode f a nonrecyc ng burner management system s used or f the steam pressure fa s be ow a preset va ue for a recyc ng burner management system

Upon rece pt of the SET TO PURGE POS T ON command from the burner management system the COMBUST ON AIR stat on w be automat - ca ly set to the predef ned purge pos t on When furnace purge s comp ete the statio wil be automat ca y returned to the ght off pos t on

Upon remova of the SET TO L GHT OFF POS T ON command f the BOILER MASTER stat on s set to AUTOMAT C mode the advanced contro s w automat ca y increase flow of the fue perm t ted (and in AUTOMATIC mode) at a preset rate As steam pressure approaches setpo nt bo er f r ng s modu ated to ma nta n the pressure setpo nt

The advanced contro s sent a TR P BURNER command to the burner management system under any of the fo ow ng condit ons

- Contro er power s ost
- Burner management commands are no onger ava ab e to the advanced contro s
- Burner management commands are ncon s stent

Advanced Controls Performance Calculations

To he p document the fue cost sav ngs resu t ng from use of the Ba ey advanced metered combust on contro s, the fo ow ng performance parameters are automat ca y ca cu ated and ava ab e for ogg ng

- Fluegas Oxygen Concentration (%)
- Standard Dev at on of F uegas Oxygen Concen tratr on from Setpo nt
- Percent Ut zat on of the Oxygen Trim Con- tro er
- Tota zed Fue Cost Sav ngs

Fue cost sav ngs are ca cu ated from user nput h stor ca averages for f uegas oxygen con centrat on (%) and f uegas ex t temperature (°F) and the current cost of fuel(s) ($/MBTU), f uegas exit temperature (°F) and norma oxygen concen trat on n the combust on a r

Economic Analysis

The pr mary econom c benef t of oxygen tr m contro s reduced fue consumpt on for the same steam product on A 15% reduct on n excess a r on a 100 k b / hr natura gas f red bo er w resu t n $69,600 / year sav ngs n fue costs Th s s based on the fo ow ng cond t ons

- Steam product on at 900°F and 900 ps g
- F ue gas temperature of 625°F
- Natura gas cost of $3 00 / m on BTU
- Bo er operat on 24 hours / day for 350 days / year

The ca cu at on of these sav ngs s shown n **FIGURE 5**

Implementation

Bai ey s microprocessor based contro ers pro v de cost effect ve and f ex b e contro of ndustr al boilers The r se f-d agnost c features drift free contro and c rect reading contro adjustments nsure rap d system startup and enhanced ong term ma nta nab ty

The advanced metered conmbust on contro s d scussed n th s app cation gu de can be mp emented n e ther two (2) standard NETWORK 90 Contro er modu es (NCOM03 or equ valent), or f ve (5) Loop Command contro ers (CLC01 or equ va ent) The advanced contro s can be ntegrated into a comp ete bo er contro system, commun cat ng d g ta y with other Ba ey contro funct ons (e g automat c burner manage

BENEFIT: Reduced Fuel Cost from reduced excess air

Bo er eff c ency change for 625°F f uegas temperature

15% decrease n excess a r

* 0 097 [% ncreased eff c ency] / [% decreased excess a r]

1 46% ncreased eff c ency

Resu t ng bo er eff c ency

80% n t a eff c ency

\+ 1 46% ncreased eff c ency

81 5%

Fue cost sav ngs

{ (100% / 80 [% n t a eff c ency]) (100% / 81 5 [% resu t ng eff c ency]) }

* 100,000 [LB steam] / HR

* 1200 [BTU heat output] / [LB steam]

* $3 00 fue cost

/ 1,000,000 BTU

* 24 HR / DAY

* 350 DAY / YEAR

$69 600 sav ngs / YEAR

FIGURE 5 Economic Benefit Calculation

ment, bo er feedwater contro furnace pressure contro) through the Ba ley nter modu e d g ta commun cat on system or commun cat ng with contro funct ons prov ded by other manufacturer s equ pment through hard wired s gr a s used to prov de remote operator nterface for either the Loop Command or NETWORK 90 con tro ler mp ementat ons

The features and capabil ties of the ava ab e equ pment are d scussed n the var ous Ba ey Pro duct Specif cat ons The modu e conf gurat ons requ red to mp ement the advanced combust on contro s may be purchased from Ba ey Contro s For systems configured by Ba ey, the system diskettes and documentat on will nc ude the con f gurat on For systems not configured by Ba ley a deta ed mp ementat on gu de s ava able

The advanced metered combust on contro can a so be mp emented w th n a NETWORK 90 Mu t Funct on Contro er (NMFC01 or equıva ent) which prov des a contro funct ons for the bo er n th s case, add t onal nput/output modules wı be requ red w th the exact number and type depend- ıng on the spec f cs of the nsta at on

Operator nterface ıs prov ded by the ntegra contro statıon for the Loop Command or f ve (5) opt ona panel mount ng Dıgıta Contro Stat ons (NDCS03) for the NETWORK 90 contro ers Any of the Baı ey CRT based operat ons conso es can be used to prov de remote operator ıterface for e ther the Loop Command or NETWORK 90 con tro er mp ementat ons

The features and capab t es of the ava ab e equ pment are d scussed n the var ous Ba ey Pro duct Spec f cat ons The modu e conf gurat ons requ red to mp ement the advanced combust on contro s may be purchased from Ba ey Contro s For systems conf gured by Ba ey the system d skettes and documentat on w nc ude the con f gurat on For systems not conf gured by Ba ey a deta ed mp ementat on gu de s ava ab e

TABLE I Sources of Excess Air Variations for Conventional Metered Combustion Controls

VARIATION	% EXCESS AIR CHANGE
Amb ent a r change from 40°F to 100°F at 30% RH	4 8%
Amb ent a r change from 30% to 90% RH at 100°F	1 8%
Natura gas source change from 1002 to 116 BTU / scfh	5 9%
Fue o source change from 17,600 to 18 500 BTU / b for the same spec f c grav ty	5 1%

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