Advanced Metered Combustion Control for Single Burner Industrial Boilers
(Single and Dual Fuels)

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

Bailey Controls provide advanced metered combustion control systems which can reduce the cost of steam production by as much as $0.10/Klb steam produced. These advanced controls reduce steam producton costs by allowing the boiler to operate safely and reliably at reduced excesses of excess air even though operating conditions change. Bailey's advanced controls are easily integrated into a complete control system without the need for externally hardwired signals.

Bailey Controls
Babcock & Wilcox, McDermott Company

FIGURE 1 Typical Single Burner Dual Fuel Industrial Boiler

Introduction
Summary of Features and Benefits

The Bailey advanced metered combustion control system provides the following 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 flue gas oxygen concentration. This can result in fuel savings of 0.7 cents/kBtu of steam produced 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 or without a built-in flue gas economizer, where the oxygen sensor is not available.

- Accumulator and damper characterizations at normal operating conditions, avoiding positional adjustments or where the damper characterizes on more convenient points.

- Automatic control to maintain air-to-fuel ratio for combustion control even when the oxygen measurement is not available.

- Feedforward techniques to provide rapid response for boiler load changes.

- Preprogrammed interface with a standard automatic burner management system for the boiler.

- Automatic control at the cost of achieving efficiencies by advanced control systems.

Application Description

A representative industrial boiler system is shown in Figure 1. The boiler has two separate fuel supplies, each with a flow measuring device. Combustion is provided by a forced draft fan, allowing automatic burner management system (not shown) for boiler purge and burner start-up and flame safety functions. There are many variants of these design, but most industrial boilers have these basic features.

Combustion Chemistry

Heat is added to the boiler by the combustion of the fuel. The combustion of fuel must be gas-fed, (2) the mixture of oxygen and fuel must be within the flammable range (neither too rich nor too lean), and (3) the fuel-air mixture must be above the minimum temperature. The chemistry for combustion of the carbon compounds in the fuel is as follows:

\[ C + O_2 \rightarrow CO_2 + 14.093 \text{ Btu/Btu} \]

If there is insufficient air, the carbon in the fuel is not completely burned:

\[ 2C + O_2 \rightarrow 2 CO + 3.950 \text{ Btu/Btu} \]

If the combustion of carbon generates energy, avocados are one-third of the energy produced during the combustion of carbon monoxide (CO).

Other combustion by-products are hydrogen and sulfur compounds. They react as follows:

\[ 2H_2 + O_2 \rightarrow 2 H_2O + 6*0.00 \text{ Btu/Btu} \]
\[ S + O_2 \rightarrow SO_2 + 3.983 \text{ Btu/Btu} \]

The amount of oxygen, and the corresponding amount of air required to complete the burn of 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:

\[ \text{Theoretical Air} = 1.53C + 0.3434(H/O) + 0.0429S \]

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).
Excess Air

The combust on air require d to operate the boiler is greater than the calculated theoretical air. This excess air is required because some of the combust on 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 gases.

The amount of excess air required for good combuston 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 combust on air must impart the necessary turbulence and momentum to the flame and the furnace must be sized to a ow adequate high temperature resistance for completion of the combust ion reactions.

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 sp nnng vane s and decreased burner firing rate. It s s gnificant to note the steep slope of the heat loss curve for incomplete combust ion on 2% too little air has the equiv alent effect of 20% too much air on boiler efficiency.
A properly operated commercial burner, mounted with an adequate sized furnace, is capable of operating at its rated load. However, the combustor mixture becomes too lean as excess air is added. The excess air allows more heat to be absorbed by the furnace, resulting in higher temperatures and more steam produced. The fumes from the combustion 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 turndown in the burner. The burner's operability is reduced 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 combustor on a fixed flow. This setup is established to control the concentration of oxygen in the fumes and ensure that the expected boiler operating range is achieved. The requirement for excess air above the minimum recommended can be determined by the manufacturer.

A metered combustion control system on a vertical boiler has been proven to provide 20-30% excess air. This practice can provide safety margins to accommodate changes in burner operating conditions. As ambient conditions and fuel characteristics change, the conventional control strategy requires continuous monitoring of the boiler's performance. The excess air can be adjusted as needed to control the boiler's efficiency. Changes in excess air can be expected from variations in burner operating conditions. The table below shows the relationship between excess air and boiler efficiency.

**Advanced Metered Combustion Control**

The advanced metered combustion control on a commercial burner is designed to reduce excess air used by the boiler and provide a faster response to load changes. The advanced control systems are summarized in the schematic diagram shown in Figure 3. Oxygen trim systems combine with steam pressure control and compensate for the excess air usage of the combustion process, based on the maximum operating conditions and operating hours.

The specification features of the advanced control systems are detailed in Table 3, which includes these features to be easy to order for specific units. The specification can be added to satisfy specific requirements.

**Oxygen Trim**

Zirconium oxygen analyzers have proven both reliable and cost-effective for measuring oxygen concentration on a boiler's fume gases. The output is generated from the analyzer, which is a measure of the excess air provided to the burner.

The excess oxygen is used by the advanced control system to control the oxygen content. The fuel-to-air ratio is maintained for the boiler's performance. The oxygen trim strategy is used to control the oxygen content within the furnace and stack emissions. The oxygen trim strategy depends on the boiler's design and the spec's required. The oxygen trim strategy can be taken with the boiler's operation and is based on the negative furnace pressure and the oxygen concentration.

**Oxygen Setpoint Program**

To maintain combustion efficiency throughout the boiler's range, the advanced control system uses a function on generators.
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

The oxygen setpoint program for fuel gases oxygen concentration as a function of boiler demand. A typical oxygen setpoint program for oil firing is shown on Figure 4. This program can be established to maintain excess combustion over the entire operating range by maintaining the fuel gas oxygen concentration at 1% above the point where the fuel gas carbon monoxide concentration reaches above 300 ppm.

The oxygen trim is constrained when the combustion air damper reaches its minimum position on or the boiler load falls below a user-set minimum. This feature permits automatic operation of the oxygen control during boiler startup and low load operation.

Dual Fuel Capability

The advanced metered combustion control system accommodates dual fuels from separate or simultaneous dual fuel without transfer between fuels for separate firing. All combustion features are duplicated for both fuels to automate the (different) fuel systems, even though the fuel characteristics may be significantly different. The second fuel is not utilized the advanced control automates separate combustion operation.

Simultaneous Firing

The advanced metered combustion control system permits simultaneous firing of two fuels. This feature provides for a one-to-one transfer rate from one fuel to another where the boiler is operating.

When the boiler is operating on one fuel (control station on set to AUTOMAT C mode) and the Burner Management System permits firing with the alternate fuel, the alternate fuel flow can be manually increased by the operator from the associated control station. The advanced control system...
automatically reduce the flow of the intake fuel until the control valve reaches its low fuel 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 selected for control.

Once the intake 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 intake fuel system is de-activated by the operator, the transfer sequence is completed.

**Internal Valve/Damper Characterization**

The advanced controls include two generator to near-inlet valve position on to boiler demand (fuel valve) or for gases oxygen concentration (air damper). This feature provides improved control performance over the entire operating range of the boiler by stabilizing the control system requirements.

Most boiler fuel control valves and combustor on-air damper(s) exhibit a non-linear valve characteristic (the open vs. flow rate at onsets). A characteristic ranging position can be provided for compensation for the non-linear valve characteristic and produce a near-linear relationship between the control output and the resulting flow. This permits the control to be tuned for effective performance and remains tuned over the normal boiler operating range (flow conditions do not change significantly). When a control valve position is not provided, the control must be primarily tuned to provide stable control performance over the normal operating range of the boiler. The practice permissive wide variation at onset steam pressure.

The balance advanced metered combustion control system, in conjunction with the valve, is used to be convenient. Valves are pre-approved, and 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 control and tuning constants to be applicable for a boiler oad, a low-steam header pressure condition. The valve characterizion may be provided externally to the control by mechanical valve characterizers which are provided on the valve or damper. However, it can be very difficult to measure the position of the valve or damper. The procedure must be repeated periodically to maintain the accuracy of the valve positioner. The internal valve characterizer on the advanced metered combustion control system provides a method for convenient and accurate characterization of the boiler valves and dampers.

**Flow Signal Conditioning**

Fuel is not selected for firing, the flow measurement is forced to zero. This prevents recirculation flow and transmssions to calibrate on errors from affecting combustion control.

Automatic temperature compensation on fuel and combustion air temperature is provided for gaseous fuels and combustion air. This temperature compensation reduces the effect of changes in these processes variances on excess air before an actual change in fuel oxygen concentration must be corrected by the oxygen trim controller.

**Boiler Demand Feedforward**

The advanced controls are designed to feed forward changes in boiler demand to the primary fuel control valve and the combustion air damper. The flow and oxygen trim control system then adjusts the valve position to maintain excess air consumption at a new load. This feature maintains the impact of gas fuel changes on steam conditions, sumptual on steam pressure.

**Fuel-Air Crosslimiting**

To prevent an excessive fuel ratio condition in the burner during boiler oad changes or abnormal operating conditions (e.g., a metered combustion air or fuel valve failure), the advanced control system detects the change in fuel/flow upon adequate combustion on a low steam pressure. The system partially accomplishes this by using an auctioneer signal between the combustion air demand and gaseous fuel for the fuel control system to prevent the fuel demand from exceeding the available combustion air limit.
a so part a y accomp shed by high auct oneer ng between the tota measured fue f ow and the bo er demand s gna s for the combust on a r contro er to prevent the combust on a r from fa be ow the f ow requ red for the actua fue f ow(s)

Th s cross m t ng s accomp shed n a manner wh ch perm ts up to a preset m smatch (typ ca y 5%) between the combust on a r demand and the a r f ow Th s techn que mproves bo er response to oad changes over c ass ca cross m t ng techn ques wh ch ut ze un t ga n on the cross m t ng s gna s

Fault Tolerance

The advanced metered combust on contro s nc ude severa inter ocks wh ch max m ze automat c operat on when a sensor fa ure s detected Th s feature prov des the h ghost eve of automat c contro feas b e dur ng abnorma operat ng c rcumstances

f the s gna from the steam pressure transm t ter becomes unavail ab e to the advanced controls, or becomes out of range th s cond t on w be alarmed and the BO LER MASTER stat on w l be automat ca y sw tched to MANUAL mode ho d ng bo er demand at ts prevous va ue When th s n ter ock s act ve the operator can readjust the bo er demand but the BOILER MASTER station cannot be returned to AUTOMATIC mode unti the lost s gna s restored

If the s gna from the oxygen ana yzer becomes unava abl e to the advanced controls, becomes out of range, or does not conta n the norma process noise spectrum, th s cond t on w be a armed and the OXYGEN TRIM stat on w be automat ca ly switched to MANUAL mode w th the oxygen tr m set to a preset va ue In the MANUAL mode, the operator can readjust the oxygen tr m, but the OXYGEN TRIM stat on cannot be returned to AUTOMATIC mode unti a va d s gna s restored Automat c temperature compen sa on for gaseous fues and combust on a r increases the stab l ty of the excess a r unti the oxygen ana yzer s gna s restored

f the s gna from a fue f ow transm t ter becomes unavail ab e to the advanced contro s, or becomes out of range th s cond t on w be a armed and the assoc ated FUEL contro stat on w be automat ca y sw tched to MANUAL mode w th the fue contro va ve set to tsght off pos t on The operator cannot manua y repos t on the fue contro va ve un ess the COMBUST ON A R station s set to MANUAL mode The fue contro stat on cannot be returned to AUTOMAT C mode unti the ost s gna s restored

f the s gna from the a r f ow transm t ter becomes unavail ab e to the advanced contro s or becomes out of range, th s cond t on w l be a armed and the entire combust on contro system w be automat ca y sw tched to MANUAL mode Both fue contro stat ons w be sw tched to MANUAL mode w th the fue contro va ves set to the rght off pos t on The COMBUST ON A R sta t on w be sw tched tc MANUAL mode w th the a r damper set to its prevous pos t on The BOILER MASTER stat on w be sw tched to MANUAL mode, w th bo er oad demand set at m n mum The operator can readjust the a r damper and fue va ve pos t ons, but cannot return any station to AUTOMAT C mode unti the a r f ow s gna s restored

Controller Mode Interlocks

The nd v dua cont o stat ons w th n the advanced Ba ey combust on contro s are nter ocked to nsure that they are placed n AUTOMAT C mode n the proper sequence The nd v dua FUEL and OXYGEN TRIM contro sta t on w l be automa cal y sw tched to and he d n MANUAL mode f the COMBUST ON AIR stat on s n MANUAL mode The BOILER MASTER stat on w be sw tched to and he d n MANUAL mode f both FUEL contro stat ons are n MANUAL mode On y one FUEL contro stat on can be set to AUTOMATIC mode at one t me Consequent y the proper sequence for sett ng the nd v dua control stat ons to AUTOMAT C mode is COMBUST ON A R, FUEL, BO LER MASTER, and OXYGEN TRIM

Burner Management Interface

The advanced combust on controls are con figured to interface to a standard automat c (recyc ng or nonrecycling) burner management system (as def ned by NFPA Standard 85A) The
Advanced Controls receive the following commands from the burner management system:

- SET TO LIGHT OFF POSITION
- SET TO PURGE POSITION
- FUEL A F R NG PERM TTED
- FUEL B F R NG PERM TTED

Upon receipt of the SET TO LIGHT OFF POSITION command from the burner management system, the FUEL control stations and the COMBuST ON AIR station will be automatically set to the light-off position. The nonrecirculating burner management system is used if the steam pressure is below a preset value for a recirculating burner management system.

Upon receipt of the SET TO PURGE POSITION command from the burner management system, the COMBuST ON AIR station will be automatically set to the predefined purge position. When a furnace purge is complete, the station will be automatically returned to the light-off position.

Upon removal of the SET TO LIGHT OFF POSITION command, the BOILER MASTER station set to AUTOMATIC mode. The advanced controls will automatically increase the flow of the fuel permit (and in AUTOMATIC mode) at a preset rate. As steam pressure approaches setpoint, the pressure setpoint is modulated to maintain the pressure at setpoint.

The advanced controls sent a TRIP BURNER command to the burner management system under any of the following conditions:

- Control power lost
- Burner management commands are no longer available to the advanced controls
- Burner management commands are non-existent

Advanced Controls Performance Calculations

To help document the fuel cost savings, results from the Bailey advanced metered combust on controls, the following performance parameters are automatically calculated and available forogg

- Fluegas Oxygen Concentration (%)
- Standard Deviation of Fluegas Oxygen Concentration
- Percent Utilization of the Oxygen Trim Control
- Totalized Fuel Cost Savings

Fuel cost savings are calculated from user input hours at average fuel costs for fluegas oxygen concentration (%), fluegas exit temperature (°F), and the current cost of fuel(s) ($/MBTU), fluegas exit temperature (°F) and a default oxygen concentration on the combustor.

Economic Analysis

The primary economic benefit of oxygen trim controls reduced fuel consumption for the same steam output. A 15% reduction in excess air on a 100-kilo BTU natural gas fired boiler with a $500,000/year savings is a fuel cost savings based on the following conditions:

- Steam pressure at 900°F and 900 psig
- Fuel gas temperature of 625°F
- Natural gas cost of $3.00/million BTU
- Boiler operation 24 hours/day for 350 days/year

The calculated savings shown in Figure 5.

Implementation

Bailey's microprocessor-based controls provide cost-effective and flexible control of industrial boilers. The advanced features of the Bailey control system drift free control and direct reading control adjustments, ensure rapid system startup, and enhanced long-term maintainability.

The advanced metered combust on controls discussed in this application guide can be implemented for the Bailey standard NETWORK 90 Control system module (NCOM03 or equivalent), or the Loop Command controller (CLC01 or equivalent). The advanced controls can be integrated into a complete boiler control system, communicating digitally with other Bailey control functions (e.g., automatic burner management system).
BENEFIT: Reduced Fuel Cost from reduced excess air

Bo er eff c ency change for 625°F fuegas temperature

15% decrease n excess a r

* 0.097 [% increased eff c ency] / [% decreased excess a r]
1.46% increased eff c ency

Resu t ng bo er eff c ency

80% n t a eff c ency

+ 1.46% increased eff c ency

81.5%

Fue cost savngs

{ (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 H R / DAY

* 350 DAY / YEAR

$69 600 savngs / YEAR

FIGURE 5 Economic Benefit Calculation

ment, bo er feedwater contro, furnace pressure contro, through the Ba ley nte modu e d g ta commun cat on system or commun cat ng with contro funct ons prov ded by other manufacturer s equpment through hard wired s gr a s used to prov de remote operator nterface for either the Loop Command or NETWORK 90 contro ler equpment are d scussed n the varous Ba ey Pro duct Spec if cat ons. The modu e confurat ons requ red to equpment the advanced combust on on contro s may be purchased from Ba ey Contro s. For systems configured by Ba ey, the system diskettes and documentat on will incude the con furat on. For systems not configured by Ba ley a det a ed equpment on gu de s ava able.

The features and capabilties of the av av ab e... 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 equiva ent) which provid es a contro funct ons for the bo er n th s case, add t onal nput/output modules w th be requ red w th the exact number and type depend ing on the spec f cs of the nstallat on.

Operator nterface is provid ed by the ntegra contro station for the Loop Command or f ve (5) opt ona panel mount ng Diga Contro Stat ons (NDCS03) for the NETWORK 90 contro ers Any of the Ba ey CRT based operat ons conso es can be used to prov de remote operat on nterface for e ther the Loop Command or NETWORK 90 contro ers

The features and capab ies of the ava ab e equ pment are d scussed n the var ous Ba ey Prod uct Spec f cat ons. The mod ule configurat 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 d skettes and documentat on w th nc ude the con f gurat on. For systems not configured by Ba ey, a deta ed mp ement on guide s ava ab e.

### TABLE 1 Sources of Excess Air Variations for Conventional Metered Combustion Controls

<table>
<thead>
<tr>
<th>VARIATION</th>
<th>% EXCESS AIR CHANGE</th>
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</thead>
<tbody>
<tr>
<td>Ambient air change from 40°F to 100°F at 30% RH</td>
<td>4.8%</td>
</tr>
<tr>
<td>Ambient air change from 30% to 90% RH at 100°F</td>
<td>1.8%</td>
</tr>
<tr>
<td>Natural gas source change from 1002 to 116 BTU / scfh</td>
<td>5.9%</td>
</tr>
<tr>
<td>Fuel source change from 17,600 to 18,500 BTU / b for</td>
<td>5.1%</td>
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<tr>
<td>the same spec f c grav ty</td>
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