WHITE PAPER:

PURE CONTROL™ O_2 COMPENSATION: TRUE EFFICIENCY & PERFORMANCE LIKE NO OTHER

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Abstract—Covers the science behind combustion control, and reasons why conventional combustion platforms have limitations in real-world installations. Also details the advances Fulton has made to counter these limitations through a precision, cutting-edge combustion system designed into its Endura+ (PURE Control™). This control platform outperforms all conventional condensing boiler platforms, providing greater efficiency, repeatability, reliability, and durability than any other.

INTRODUCTION

With the vast majority of hydronic systems now designed around condensing boilers, efficiency has become the standard expectation of commercial boiler requirements. And though several factors influence condensing boiler efficiency, prominent among them is air/fuel ratio control, which directly impacts real-world operating efficiency. But not all combustion air/fuel ratio control systems are created equal.

MODULATING BURNER TECHNOLOGY

A boiler cycle is defined as a heat demand that begins pre-purge, then trial for ignition, followed by main flame operation such that, when the heat demand conditions are satisfied, the burner safely shuts off and completes post-purge. With each cycle, the heat exchanger expands and contracts, electronics energize and de-energize, and valuable heat is pulled out of the pressure vessel during each purge. Therefore, it is reasonable to conclude that cycling should be minimized, as it wastes energy and accelerates component wear.

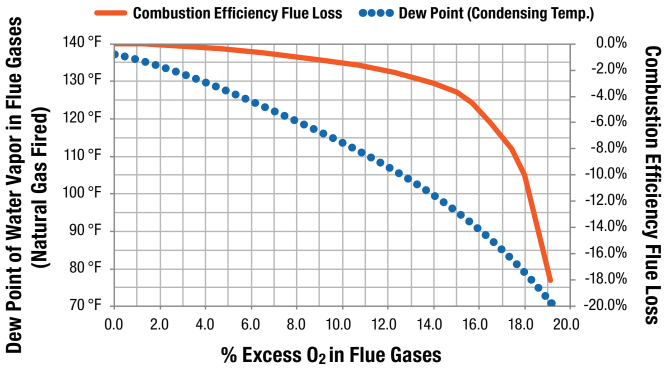
A principal method used to counteract cycling as the boiler responds to changes in load is to modulate its air/fuel ratio across increased burner turndown. (Burner turndown is the range of modulation relative to high fire.) For example, a 3,000,000 BTU/hr boiler with 5:1 turndown (600,000 BTU/hr minimum input) will cycle approximately twice per hour in a system with a 250,000 BTU/hr load, 500 gallons of volume, and a 15°F hysteresis differential. Meanwhile, the same boiler capacity with 15:1 turndown (200,000 BTU/hr minimum input) will theoretically run continuously without cycling.

PITFALLS OF HIGH TURNDOWN WITHOUT O_2 CONTROL

Every burner requires some excess air to maintain flame stability, ensure complete combustion, protect burner components, and limit emissions such as CO and NOx. The actual amount will vary, but for a typical natural gas burner found in a condensing boiler, this will often be in the range of 4-8% O_2.

Although excess O_2 is required from a practical standpoint, too much will decrease combustion efficiency and lower flue gas vapor dewpoint temperature (condensing potential), causing operating costs to rise to satisfy heat demand.

These results are graphically shown in Figure 1. Here, a 5% excess O_2 ,which is typical of high fire, results in a dewpoint of around 127°F (53°C). Therefore, for a boiler to operate in full condensing mode in this case, the heating system return water must be below 127°F.



▲ *Figure 1. Dew Point and Flue Loss versus Excess Oxygen*

As turndown ratios increase, so too do excess O_2 levels. This is a performance problem for competing boilers attempting high turndown using conventional combustion control systems, where excess O_2 levels during normal operation measure as high as 19%. (For reference, atmosphere contains approximately 20.95% O_2.) Under such conditions, the dewpoint temperature drops to nearly 70°F (21°C).

What this means for owners of these boilers is that, since it is a rarity for return water temperatures to drop as low as 70°F in a heating system, an advertised 98% laboratory thermal efficiency condition at low fire is, in real-world conditions, actually less than 85%. *The sacrifice made to achieve high turndown on conventional controls is that they effectively become non-condensing.*

NEGATIVE REGULATION AIR/FUEL CONTROL

Most condensing boilers on the market today use negative regulation ("neg-reg") combustion control, where a fan speed signal is the only means of adjusting modulation rate. These systems do not directly control the fuel flow rate; rather, the gas valve is along for the ride, tracking behind blower suction pressure. Neg-reg has the favorable benefit of generally maintaining O_2% with minor swings in air density, but the trade-off is sensitivity to changes in combustion air and stack pressures, calorific fluctuations of gas, loose repeatability tolerance, and poor resolution at low fan speeds.

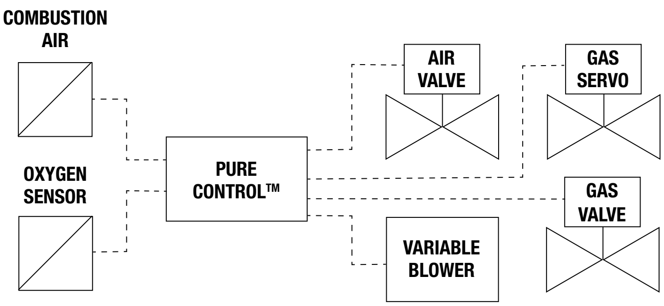
Low fan speeds are a challenge for pressure-sensing neg-reg due to the square root relationship between pressure and flow. At 5:1 turndown, only 1/25th the pressure is measured, while at 15:1 turndown that drops to 1/225th. Such low pressures negatively impact the system's ability to "track" (i.e., maintain) a stable air/fuel ratio. The "fix" is to turn the gas valve down 15:1 while only turning the fan down 5:1, which of course causes unfavorable excess air conditions, leading to poor efficiency.

Additionally, neg-reg interpolates modulation between only two combustion points: high fire and low fire. Lacking is the ability to non-linearly optimize the air/fuel ratio over the entire combustion curve. This causes all mid-fire ranges to also take an efficiency penalty, which becomes harsher as the O_2% parameter increases at low fire.

Consequently, an experienced service technician will usually commission a high-turndown, neg-reg boiler in a configuration that minimizes the risk of return trip callbacks, which is to say at a more conventional 5:1 turndown, where it is more reliable and more efficient in real-world conditions—in spite of its advertised high turndown.

PARALLEL POSITIONING AIR/FUEL CONTROL

The Endura+ with Fulton's PURE Control™ completely solves all of these concerns by eliminating neg-reg, instead using high-precision discrete air and gas servo motor control with 0.2° accuracy optimized across ten combustion points (Figure 2).

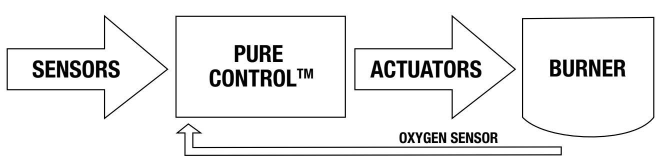


▲ *Fig 2. Parallel Positioning with O2 Compensation*

This system allows the boiler to achieve reliable turndown as high as 15:1 without resorting to excessively high O_2% levels. Additional benefits include dependable ignition, and an integrated O_2 Compensation system that automatically tunes the air/fuel ratio during operation.

O2 COMPENSATION

Using a combination of open-loop calibration and closed-loop feedback (see Figure 3) from a well-recognized automotive oxygen sensor, the O_2 Compensation system automatically tunes the air/fuel ratio, minimizing the impact of gas calorific value, draft, and air temperature. The end result is a boiler that is more forgiving of unexpected and often unpredictable operating conditions. Robustness, reliability and operational cost savings are all simultaneously optimized.



▲ *Fig 3. Closed Loop O2 Compensation*

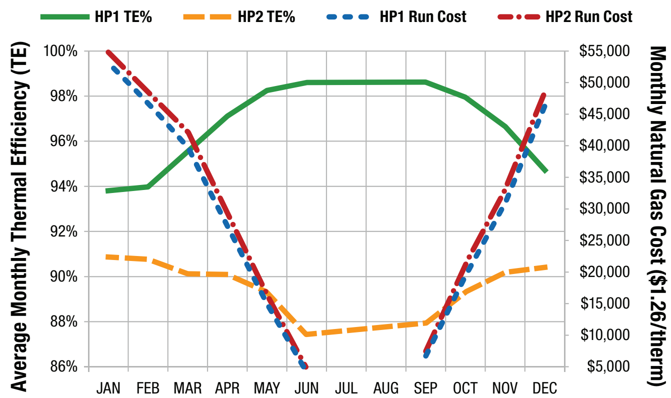
Should the oxygen sensor ever wear, or become damaged or disconnected, the boiler will not lockout, but will simply carry on normal operation and will even continue to trim using the open-loop function. Maintenance is quick and straightforward when replacing the sensor: Simply press the "Reset O_2" button on the control screen.

Note: Traditional "Oxygen Trim" systems require costly instrumentation, complicated field installation, and a lengthy commissioning procedure. None of this is required with the Fulton Endura+, where O_2 Compensation is factory mounted, configured and wired as standard.

EXAMPLE: HEATING PLANT SAVINGS

Consider an example heating plant serving a building in Boston, Massachusetts with a 8,000,000 BTU/hr load on a 7°F design day. Specified are four 3,000 MBH condensing boilers, N+1 redundancy and a 30°F delta-T, with outdoor air reset setpoints ranging from 160°F on design day to 120°F on a mild day. ASHRAE bin data is used to determine loop temperatures and burner firing rates to satisfy load.

Figure 4 compares two versions of this plant: Heating Plant 1 (HP1) utilizing PURE Control™ with O_2 Compensation, and Heating Plant 2 (HP2) with conventional negative regulation. HP1 is able to precisely optimize combustion between 5-7% O_2 at high fire and low fire, respectively, maximizing combustion efficiency and condensing potential. Combustion control in HP2 is linearized from 5% O_2 at high fire and 19% at low fire.



▲ *Figure 4. Heating Plant Comparison: Endura+ vs. Competitor*

As heating demand decreases in the shoulder months, and burner firing rates drop, it is normally expected that plant thermal efficiency will increase. However, due to the loose air/fuel ratio tolerance and high excess air levels of HP2, the opposite occurs: HP2 not only experiences lower efficiencies during peak utilization, but also suffers a significant efficiency penalty by being pulled completely out of condensing mode during the shoulder months.

In summary, the real-world efficiency of HP2 is far below advertised performance, particularly during part-load periods where the gap widens. *The difference is a cumulative $17,021 annual fuel cost savings for the heating plant with O_2 Compensation.*

A FINAL WORD ON BENEFITS TO THE OWNER

Most heating boilers are commissioned in warm weather at the end of summer. As the cooler weather of fall and winter rolls in, air density increases, which causes excess air to increase. This negatively impacts combustion efficiency and flue gas condensation dewpoint—hence, an experienced service technician will generally recommend a mid-season re-tune of the boiler. But, unfortunately, because of sensitivity to cost, this important step is often ignored.

Thus, the added importance of Fulton's PURE Control™ O_2 Compensation, as it automatically tunes the fuel/air ratio to adjust for seasonality, reducing the necessity for service trips while optimizing combustion and maximizing condensing potential for the best possible efficiency under all real-world conditions.