Operational Efficiency Improvements of Industrial Combustion Systems

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Combustion-efficiency optimization results in significant operating cost savings. Payback time is short, and reduced CO₂ emissions are an additional benefit.

Combustion is the exothermic chemical reaction (a reaction in which heat is given off) of hydrogen and carbon atoms contained in fuels with oxygen. In this reaction, the carbon is oxidized to form carbon dioxide (CO₂) or, if insufficient oxygen is available, carbon monoxide (CO). If there is an excess of oxygen present, non-reacted O₂ will be in the products of combustion. Excess O₂ makes heating inefficient, thus requiring more gas for the same results. In addition, excess air also allows for the formation of pollutants such as nitrous oxide (NO) and nitrogen dioxide (NO₂). Together, NO and NO₂ make up what is referred to as NOₓ.

According to the Department of Energy, most high-temperature direct-fired furnaces, radiant tubes and boilers operate with about 10-20% excess combustion air at high fire to prevent the formation of dangerous CO and “soot” deposits. It is estimated that precise control of air-to-fuel ratio will yield 5-25+% savings in heat generation. The air/gas ratio can be determined by analyzing the flue gas. With this information, the mixture for combustion can be altered to produce the most clean and efficient heat for the process. Our studies have shown that burners are typically running with excess O₂ greater than 4% in the flue gas.

Optimizing operational efficiency, minimizing production costs and maximizing utilization are competitive advantages in good economic conditions. In leaner times, this is a basic necessity. Periodic checking and resetting of air-fuel ratios is one of the simplest ways to get maximum efficiency out of fuel-fired process heating equipment. In heat-treatment facilities, the customer would find potential efficiency improvements on generators, radiant tubes, furnaces, ovens, heaters and boilers.

The two main areas where heat-treatment facilities benefit from combustion optimization are fuel savings and throughput improvements. Combustion optimization will be reviewed first. Next, the impact these improvements have on throughput and utilization will be explored.

Combustion Optimization

Most high-temperature direct-fired furnaces, radiant tubes and boilers are designed to operate with 10-20% excess combustion
air at high fire. This excess air helps prevent the formation of carbon monoxide and soot deposits that can affect heat-transfer surfaces and radiant tubes.

For the fuels most commonly used in the U.S. – natural gas, propane and fuel oils – approximately 1 cubic foot of air is required to release 100 British Thermal Units (BTUs) in complete combustion. Process heating efficiency is reduced considerably if the air supply is significantly higher or lower than the theoretically required air.

In a September 1997 Process Heating magazine, Richard Bennett provided calculations for an available heat chart, which was republished in May 2002 by the Department of Energy. This chart is an excellent basis to determine potential savings.

Documented Savings
To illustrate the value of combustion optimization, two case studies will be presented.

Forge Heat Furnace
A 6 mmbtu/hour open-die forge reheat car-bottom furnace (Fig. 3) was equipped with a high-temperature SuperOX oxygen sensor, reference air system and 9120 oxygen controller. Baseline readings of excess O₂ and fuel consumption were collected over a three-month period. Based upon this data, monthly fuel consumption and the average high-temperature O₂ readings (6.5% average at 2200°F) were determined.

The controls and operation’s personnel were concerned about over-trimming the excess O₂ level. Lowering O₂ levels can lead to reduced uniformity on the heated ingot. Thus, the O₂ levels were lowered incrementally to ensure that no impact occurred to product quality.

At the end of the first incremental change and after process verification, the customer had lowered his excess O₂ from 6.5% to 5.5%. After numerous runs at this O₂ level, the customer documented a 20.5% reduction in metered gas consumption. Using the data shown in Fig. 1, the % available heat at 5.5% O₂ and 2200°F is ~25%. Similarly, for 6.5% and 2200°F, it is ~20%. The potential savings is ~20% [100 x (25-20)/25]. The actual results are very similar to the expected results.

For this customer, the 20.5% reduction in fuel cost corresponds to a $15,000 per year savings for this single furnace based upon its current utilization rate. At full utilization, the savings would be $53,874.

The customer has a goal of reducing the excess %O₂ several percent. At his target level, he would reduce his fuel costs by an estimated 37%. At the current utilization, the savings would be $27,750 per year. At full utilization, the savings reach $98,550 for this furnace. For all 14 furnaces in the facility, the fuel savings have the potential to exceed $1,000,000.

A side benefit to the fuel savings is a documented CO₂ reduction. For each MCF of CH₄ burned completely, 117 pounds of CO₂ is produced. In this particular case, the customer was able to document a reduction of 175,500 pounds, or 87.75 tons, of CO₂. At full utilization on this one furnace with a 1% reduction in excess O₂, the reduction would be 630,006 pounds, or 315 tons. If the customer has similar success on other furnaces and is able to achieve the O₂ target, his potential CO₂ reduction is more than 8,000 tons.

Batch Furnace Utilization and Fuel Savings
The initial R&D on batch furnaces was initiated with John Keough at his Applied Process’ Wisconsin and Kentucky

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**Table 1. Furnace trial test results**

<table>
<thead>
<tr>
<th></th>
<th>Test 1</th>
<th>Test 2</th>
<th>Test 3</th>
<th>Test 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Target % O₂</td>
<td>5</td>
<td>4</td>
<td>3</td>
<td>2</td>
</tr>
<tr>
<td>Min. Temp</td>
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<td>1131</td>
<td>1015</td>
<td>1143</td>
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<td>Target Temp</td>
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<tr>
<td>Heat up rate of change, °/min</td>
<td>6.75</td>
<td>7.31</td>
<td>7.54</td>
<td>8.82</td>
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<tr>
<td>Time to Heat, 5% or 6.75 °/min</td>
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<td>66.56</td>
<td>83.75</td>
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<tr>
<td>Time to heat, 4% or 7.31 °/min</td>
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<td>61.46</td>
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<tr>
<td>Time to heat, 3% or 7.54 °/min</td>
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<tr>
<td>Time to heat, 2% or 8.82 °/min</td>
<td>50.21</td>
<td>50.89</td>
<td>64.04</td>
<td>49.53</td>
</tr>
</tbody>
</table>

Denotes actual results  Theoretical time to heat

Note: Test 3 heat-up was longer due to lower minimum load temperature
The improved heating rate is evidenced by the data, which show the significant improvements in ramp rate (8.82° vs. 6.75° per minute) and the reduction in the amount of high-fire time. The improved heating rate shortens the time required for the load to reach heat and shortens cycle time by 15 minutes per load. This come-to-heat time was calculated based on the 2% and 5% excess O2 rate and was consistently more than 15 minutes.

The reduction in high-fire time reduces fuel and operating costs along with minimizing CO2 emissions. Table 2 provides a summary of CO2 and fuel savings for the reduction in high-fire time. The burner's total demand on high fire is 1,000,000 BTU, or 1 dekatherm. The calculations are based upon a dekatherm cost of $5 and a 90% uptime availability.

The cost to maintain temperature is reduced by 30% as are the CO2 emissions. Over the course of one year, the savings will exceed $9,000 and 200,000 pounds of CO2 by reducing the excess O2 from 5% to 2% (Fig. 4) in the combustion process.

Table 3 provides a summary of the improved utilization that is achieved by reducing the excess O2 in the radiant tubes for various cycle times. The calculations are based upon a 15-minute savings in come-to-heat time. Cycle times will impact the improvement in utilization and the number of additional loads that can be pushed through the furnace on an annual basis.

As the cycle times decrease, the utilization improvements become more significant. For a typical one-hour ramp to heat and three-hour soak (four-hour total cycle), the improvement is 6.67% and 146 additional loads per year.

### Summary
Continuous monitoring and adjustment of excess O2 levels in combustion applications provides significant fuel savings, reduced emissions and improved utilization. The savings and improvements will vary from facility to facility and from furnace to furnace depending upon how the combustion system is currently tuned and maintained.

As process temperatures increase, the fuel and emissions savings rise exponentially.

Several state governments currently offer grants and credits that help further reduce the cost of O2 monitoring and reduce the payback time. Even without these grants and credits, customers should see paybacks from fuel savings in less than 12 months along with gains in utilization.

By optimizing combustion efficiency, companies will minimize production costs and maximize utilization and have a competitive advantage over those who overlook this part of their process.

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Additional related information may be found by searching for these (and other) key words/terms via BNP Media SEARCH at www.industrialheating.com: exothermic, NOx, excess oxygen, combustion optimization, combustion efficiency, CO2 emissions.