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Operational Efficiency Improvements Resulting From Monitoring and Trim of Industrial Combustion Systems

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Abstract

Combustion is the exothermic chemical reaction (a reaction in which heat is given off) of hydrogen and carbon atoms contained in fuels with oxygen. Excess O_2 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 (NO_2).

It is estimated that precise control of air to fuel ratio will yield 5 to 25% or more savings in heat generation. The air gas ratio can be determined by analyzing the flue gas and the mixture for combustion can be altered to produce the most clean and efficient heat for the process.

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.

Introduction

According to the Department of Energy, most high temperature direct-fired furnaces, radiant tubes and boilers operate with about 10 to 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 to 25% or more savings in heat generation. The air gas ratio can be determined by analyzing the flue gas and, with this information, the mixture for combustion can be altered to produce the most clean and efficient heat for the process. Figure 1 displays estimated volume of by product gases based on % of oxygen used when mixing with CH_4. Our studies have shown that burners are typically running with excess O_2 greater than 4% in the flue gas.

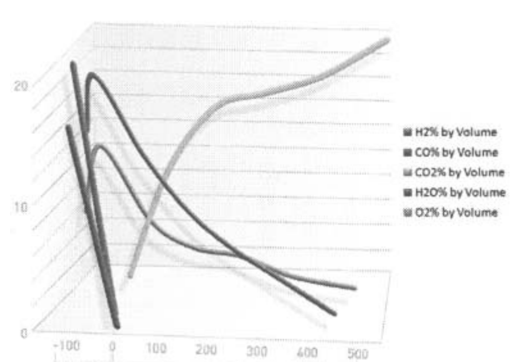

Figure 1 – Estimated products of combustion versus excess O_2.

Optimizing operational efficiency, minimizing production costs and maximizing utilization, is a competitive advantage in good economic conditions. In leaner times, it 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 Efficiency

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

For the fuels most commonly used in the US, including natural gas, propane, and fuel oils, approximately one 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, Mr. 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 in a combustion process. To determine the potential savings, you will need the following information:

Exhaust gas temperature as it exits the furnace, tube, etc.
% excess air or oxygen in the flue gas (actual)
% excess air or oxygen in the flue gas (target)

The available heat chart is shown in Figure 2.

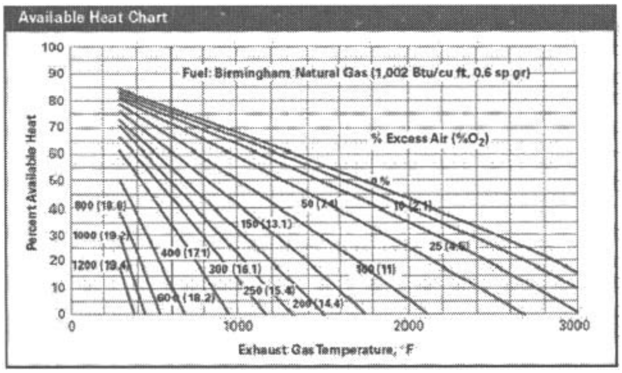

Figure 2- Available Heat Chart

Using the chart, determine the percent available heat under actual and target conditions. The intersection of the measured exhaust gas temperature and % excess air (%O_2) curves provides these values. The potential fuel savings would be calculated as follows:

% Fuel Saving = 100 x ((%AH Target - %AH Actual) / %AH Target)

Documented Savings

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

Forge Heat Furnace

A 6 mmbtu/hr open die forge reheat car bottom furnace was equipped with a high-temperature SuperOX oxygen sensor. Baseline readings of excess O_2 and fuel consumption were collected over a three month period. Based upon this data, monthly fuel consumption was determined as was the average high-temperature O_2 readings (6.5% average at 2200° F).

The controls and operation's personnel were concerned about over-trimming the excess O_2 level. Lowering O_2 levels can lead to reduced uniformity on the heated ingot. Thus, the O_2 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 has lowered his excess O_2 from 6.5% to 5.5%. After numerous runs at this O_2 level, the customer documented a 20.5% reduction in metered gas consumption. Using the data shown in figure 1, the % available heat at 5.5% O_2 and 2200F is ~25%. Similarly, 6.5% and 2200F, 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 % O_2 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.

A side benefit to the fuel savings is a documented CO_2 reduction. For each MCF CH_4 burned completely, 117 pounds of CO_2 is produced. In this particular case, the customer was able to document a reduction of 175,500 pounds or 87.75 tons of CO_2. At full utilization on this one furnace with a 1% reduction in excess O_2, 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 O_2 target, his potential CO_2 reduction is 8000+ 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 facilities. Mr. Keough recognized the value in operating burners at an optimum level to save on fuel. He also recognized the even greater value in creating operational efficiencies by increasing load throughput based on increasing the available heat produced during high fire with the optimal gas/air ratio. Mr. Keough and Applied Process challenged Super Systems with deriving a system that would monitor high fire air/gas ratios and provide operators with alarms and trending to monitor the burner performance. The two test sites demonstrated and proved out the sensor and provided the initial data regarding combustion efficiency and utilization improvement. These results led us to further testing at Queen City Steel Treating.

Queen City Steel Treating in Cincinnati, Ohio worked with Super Systems to document savings relative to varying O_2 levels in combustion exhaust gases. The tests were conducted on a batch furnace with 4 radiant tubes using the same load density with identical initial conditions. Each burner is rated 250,000 BTU/hr.

Four tests were conducted with excess O_2 levels ranging from 2 to 5%. The test results are shown in Table 1.

Table 1 – Furnace trial test results

	Test 1	Test 2	Test 3	Test 4
In (customer supplied)	4/8/2009 11:30	4/9/2009 11:40	4/22/2009 10:50	4/24/2009 12:25
Out (customer supplied)	4/8/2009 13:13	4/9/2009 13:40	4/22/2009 12:55	4/24/2009 14:35
Target % O_2	5	4	3	2
Min Temp	1137	1131	1015	1143
Target Temp	1580	1580	1580	1580
Heat up rate of change, °/min	6.75	7.31	7.34	8.82
Time to Heat, 5% or 6.75 °/min	65.67	66.36	83.75	64.78
Time to heat, 4% or 7.31 °/min	60.64	61.46	77.34	59.32
Time to heat, 3% or 7.34 °/min	58.78	59.38	74.97	57.99
Time to heat, 2% or 8.82 °/min	50.21	50.89	64.04	49.33

Denote Actual Results

Theoretical Time to Heat

Note: Test 3 come to heat longer due to lower minimum load temperature

The two significant highlights evidenced by the data are the significant improvement in ramp rate (8.82 vs. 6.75 °/min) 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 upon the 2% and 5% excess O_2 rate and was consistently more than 15 minutes.

The reduction in high-fire time reduces fuel and operating costs along with minimizing CO_2 emissions. Table 2 provides a summary of CO_2 and fuel savings for the reduction in high-fire time. The burner's total demand on high fire is 1,000,000 BTU or one (1) dekatherm. The calculations are based upon a dekatherm cost of $5 and a 90% uptime availability.

Excess O_2 level	5%	4%	3%	2%
Soak Cost per hour	$4.00	$3.48	$3.20	$2.81
CO_2, lbs per hour	97.60	84.79	77.96	68.44
Soak cost per day	$96.00	$83.40	$76.68	$67.32
CO_2, lbs per day	2342.4	2035.0	1871.0	1642.6
Soak cost per year	$31,536.00	$27,396.90	$25,189.38	$22,114.62
CO_2, lbs per year	769478	668484	614621	539597

Table 2 – CO_2 production and fuel cost

The cost to maintain temperature is reduced by 30% as are the CO_2 emissions. Over the course of one year, the savings will exceed $9,000 and 200,000 pounds of CO_2 by reducing the excess O_2 from 5% to 2% in the combustion process.

Table 3 provides a summary of the improved utilization that is achieved by reducing the excess O_2 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.

Cycle time (in hours)	3	4	5	8
15 minute savings, % of cycle	91.67%	93.75%	95.00%	96.88%
utilization improvement	109.09%	106.67%	105.26%	103.23%
Optimal Loads per year	2920	2190	1752	1095
Max increase loads per year	265	146	92	35

Table 3 – Utilization improvement

As the cycle times decrease, the utilization improvements become more significant. For a typical one hour come-to-heat and 3 hour soak (4 hour total cycle), The improvement is 6.67% and 146 additional loads per year.

Summary

Continuous monitoring and adjustment of excess O_2 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 O_2 monitoring and reduce the payback time. Even without these grants and credits paybacks are achieved from fuel savings in short periods of time 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.