

# THERMAL EFFICIENCY IMPROVEMENT THROUGH FUEL GAS RATE AND EXCESS OXYGEN CONTROL

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## Abstract

**Purpose** - Understanding the critical process variables in a system and parameters that affects those critical variables will be a strong basis in developing the process control. At the end this will deliver process stability and predictability.

**Design/Methodology/Approach** - Combustion efficiency typically indicates the ability of the burner to use fuel completely without generating carbon monoxide or leaving hydrocarbon unburned. Excess air is required to ensure a complete combustion of the fuel since a boiler firing without sufficient air or “fuel rich” is operating in a potentially dangerous condition. Getting the optimum combustion efficiency will require the accurate control of fuel gas and the air to deliver the just right amount. Field data analysis and the field experiment will be a basis to determine the applied process control works in maintaining the critical process variables.

**Findings** - Daily and seasonal changes in temperature and barometric pressure can cause effect on the critical process variables in oil-recovery steam generator, such as steam pressure, temperature, steam dryness and the excess air. Better control means improved process stability, higher production efficiency, consistent product quality, and reduced energy waste. The fact is we pay substantial dollars every time firing the unit.

**Research limitations / implications:** The accuracy of steam quality measurement and the oxygen excess analyser would affect the control capability.

**Original/Value** – Flow control valve application for the fuel gas and the variable speed drive for the air control will improve the combustion efficiency for 2.0 – 2.5%. For 50 MMBTUPD capacity steam generator unit, this will be equivalent with 30 MSCFD fuel gas saving.

**Key words:** Combustion Efficiency, Process Control, Oxygen Excess, Fuel Optimization

**Research Type:** Field Data Analysis, Field Experiment, and Research Paper

## 1. Introduction

According to Prats,<sup>[1]</sup> thermal enhanced oil recovery (TEOR) is a family of tertiary processes defined as "any process in which heat is introduced intentionally into a subsurface accumulation of organic compounds for the purpose of recovering fuels through wells."

The most common vehicle used to inject heat is saturated steam. Hot water and heated gasses have been tried, but none are as effective as quality steam. According to a 2000 *Oil & Gas Journal* survey,<sup>[2]</sup> steam enhanced oil recovery (EOR) projects accounted for 56% of the total for all tertiary enhanced recovery methods. That production rate has been essentially flat for more than 15 years. Hydrocarbon gas injection and CO<sub>2</sub> gas injection are the only other significant contributors and amount to only 17 and 24%, respectively.

Steam generators are used to produce steam for the steamflood. The most popular steam generators are the 25- and 50-MMBtu/hr units. The 25-MMBtu/hr units are used as mobile units and provide steam for cyclic-steaming or remote-injection wells. The 50-MMBtu/hr units provide steam from a central banked location, which simplifies the water- and fuel-treatment plants and the steam-distribution system.<sup>[3]</sup>

A typical steam-generator and system flow schematic is shown in Figs. 1 the convection section is designed to preheat the softened feed water, and the radiant section further heats the steam pipe for generating steam. A steam generator produces 60 to 80% quality steam, depending on the reservoir requirements.

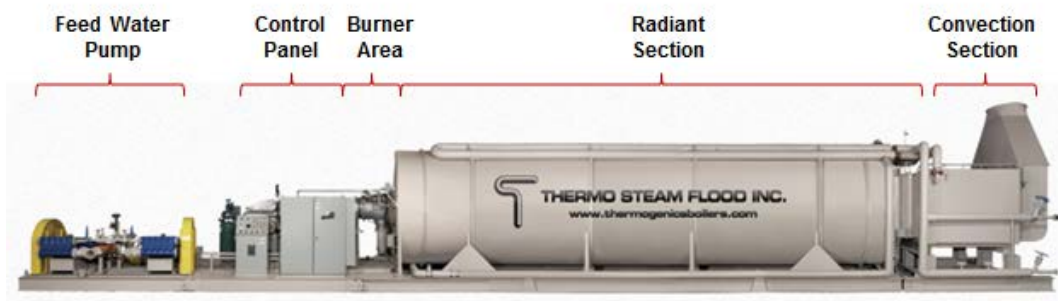


Fig. 1—A typical steam generator<sup>[4]</sup>

Steam quality is the percentage of completely dry steam present in the total steam. The suspended water droplets are present in the steam carry no specific enthalpy of evaporation and lowering the steam quality number.

Natural gas fuel is burned with controlled amount of air to ensure complete combustion and minimum pollutant. Key process variables that are measured and monitored in the process include water flow, gas flow rate, oxygen flow rate, steam temperature, steam pressure, oxygen excess, exhaust air temperature, and furnace temperature. Daily and seasonal changes in temperature and barometric pressure can cause effect on the above critical process variables. Better control means improved process stability, higher production efficiency, consistent product quality, and reduced energy waste. The fact is we pay substantial dollars every time firing the unit.

## 2. Conceptual Framework

Generated Steam with inconsistent steam quality that is injected into the reservoir results in low oil recovery. Manual control of the combustion with fixed fuel-air-ratio results in poor combustion efficiency and waste of fuel and electricity. An automatic system for control of the steam pressure, temperature, and

steam quality (dryness) during all operating conditions will increase oil recovery and minimize energy consumption<sup>[5]</sup>

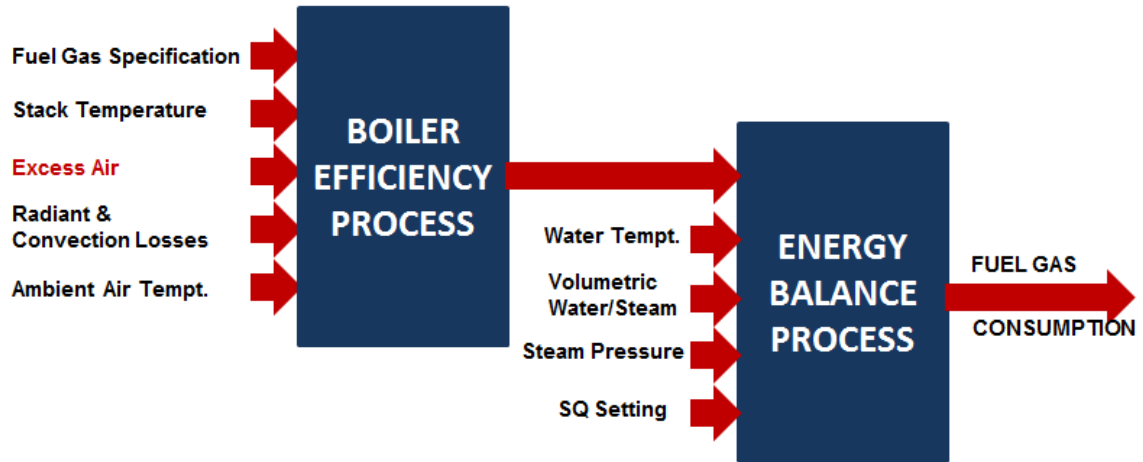


Fig. 2—Conceptual Framework of Fuel Gas Consumption Model

Boiler Efficiency is often substituted for thermal efficiency. It means any fuel-use figure must compare energy put into the boiler with energy coming out. The following are the key factors to understanding efficiency calculations:

a. Stack temperature

It is the temperature of the combustion gases leaving the boiler. This temperature represents the major portion of the energy not converted to usable output. The higher the temperature, the less energy transferred to output and the lower the boiler efficiency.<sup>[6]</sup>

b. Heat content of fuel

It is carbon to hydrogen ratio, whether the latent heat (heat required to turn water into steam) is recovered.

c. Excess air

Excess air is supplied to the boiler beyond what is required for complete combustion primarily to ensure complete combustion and to allow for normal variations in combustion. A certain amount of excess air is provided to the burner as a safety factor for sufficient combustion air.<sup>[6]</sup>

d. Ambient air temperature

Ambient conditions have a dramatic effect on boiler efficiency. Most efficiency calculations use an ambient temperature of 80 F and relative humidity of 30%. Efficiency changes more than 0.5% for every 20 F change in ambient temperature. Changes in air humidity would have similar effects; the more the humidity, the lower will be the efficiency.

e. Radiant and convection losses

Radiant and convection losses represent the heat losses radiating from the boiler. A boiler with an insulated shell will have lower surface temperatures, and therefore lower losses. Boilers operating with high surface temperatures are wasting energy every time the unit is fired.

From those parameters, the excess air control plays critical role in operations safety and fuel gas optimization. A boiler firing without sufficient air or “fuel rich” is operating in a potentially dangerous. While bringing in too much air reduces efficiency because the excess air absorbs some of the heat of combustion, and because it reduces the temperature of the combustion gases, which reduces heat transfer.

Excess air is required in all practical cases to ensure complete combustion and to allow for the “normal variations in combustion” below:<sup>[6]</sup>

- 1) The density of air changes with temperature and pressure, for instance, if pressure is fixed, the mass of air flowing will decrease when the temperature increases. The variation in the ambient temperature and humidity could easily change the air flow from excess air into deficient air or too much excess air.
- 2) In addition, other variations, such as fuel rate, could easily make effect on the air consumed and cause deficient air at some point. The excess air offers a cushion to allow variations in air conditions without affecting boiler efficiency significantly. The cushion air is not important when the boiler burner controls are sensitive enough to respond to the varying conditions.
- 3) Note that the amount of excess air is greatly dependent on the type of fuel and the type of burner. New technology burners such as low NOx burner or spud type burner require minimum excess percent oxygen to as low as 0.5 to 1%. For light oil application, pressure atomized burners will use as little as 2% minimum excess percent oxygen.

Then, understanding the fuel rate and air changes regarding the ambient temperature in normal condition will be a critical before selecting the proper control system to improve the thermal efficiency and at the end will reduce the fuel gas consumption.



Fig. 3—Design of Problem Solving Model

### 3. Methodology

The system automatically and continuously adjusts the air supply so the optimal fuel-to-air ratio is maintained at all times and under load-varying conditions. In addition, there is automatic compensation for fluctuations in fuel viscosity or BTU content, draft irregularities, changes in air density, load, temperature, humidity, and looseness in the damper and fuel valves.<sup>[7]</sup>

#### 3.1. Designing Fuel Gas Flow Control

Temperature has a greater effect on gas flow calculations, because gas volume expands with higher temperature and contracts with lower temperature. But similar to specific gravity, temperature affects flow by only a square-root factor. For systems that operate between  $-40^{\circ}\text{F}$  ( $-40^{\circ}\text{C}$ ) and  $+212^{\circ}\text{F}$  ( $+100^{\circ}\text{C}$ ), the correction factor is only +12 to -11 percent.

The old steam generator with fuel gas pressure regulator doesn't have sensitivity against the ambient temperature changes (day-night). Lower temperature at night will cause gas more dense compare to the day operation (higher temperature). With the same opening valve (at pressure regulator), the lower gas temperature (in the night) will deliver more fuel gas flow rate compare with the higher temperature in the day, as shown on the Figure 4.

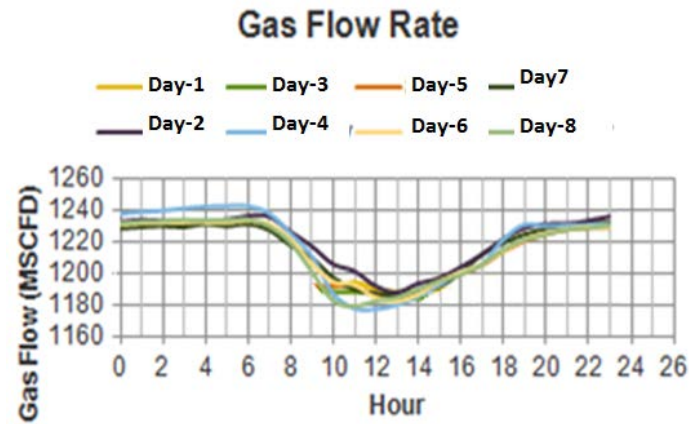


Fig. 4—Fuel Gas Flow Rate Characteristics of a Single Steam Generator at Different Days Observation

Uncontrolled fuel gas flow rate due to the temperature changes will deliver unnecessary (over-specification or waste) SQ product during the night as shown on Figure 5.

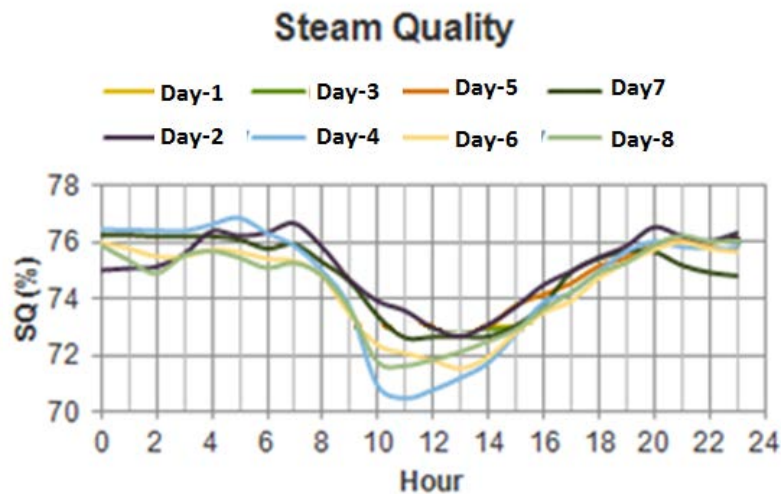


Fig. 5— Steam Quality Characteristics of a Single Steam Generator at Different Days Observation

### 3.2. Designing Air Flow Control

Myer Kutz<sup>[8]</sup> specifies a volume of 9.53 cubic feet of air for perfect combustion for every one cubic foot of natural gas. Natural gas is predominantly methane or CH<sub>4</sub>. The heating value ranges, but is typically identified as being approximately 1,000 Btu/cubic foot. Then, for every 1,000 Btu/Hr. of input rating of the appliance, it will need 9.53 cubic feet/hr of air for combustion. However, when dealing with combustion air, we also need to add excess air to assure that combustion is complete. The standard rule for engineer is to add 10 percent excess air for complete combustion of fuel-fired appliance.<sup>[9]</sup>

Understanding the manual control of excess air, we performed the field data analysis from two (2) different steam generator units. For the first unit, we conducted the observation for 17 days. And for second unit, we conducted the test for 15 days.

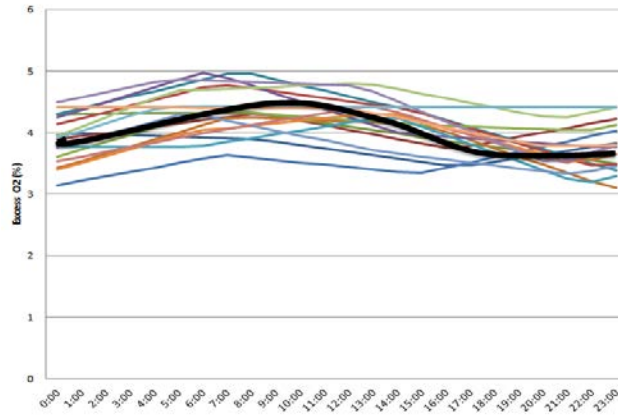


Fig. 6—Excess Oxygen Characteristics from the First Unit for 17 Days

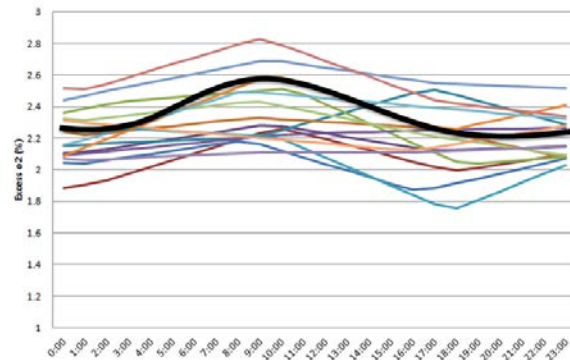


Fig. 7—Excess Oxygen Characteristics from the Second Units for 15 Days

Steam generator with manual control (fixed louver position) has no capability to control the required air flow for the combustion process. Uncontrolled air flow will cause a poor air to fuel ratio in the combustion process. Supplying less air will cause incomplete combustion and result carbon monoxide release to the atmosphere, which is a health hazard concerns. Supplying too much air will cause the heat from the combustion process will be pushed out to the stack and result poor steam generator efficiency.

Data observation indicated the manual control steam generators has more excess oxygen when the gas is at lower rate (at a day) that will cause of high temperatures stack and result poor Thermal Efficiency. The typical steam generator thermal efficiency is about 82.4 % while the best steam generator efficiency is should be 86%.

#### 4. Research Finding

It is important to provide automatic burner controls for safe and efficient operation. Improperly set operating controls cause the burner to operate erratically and stress the pressure vessel.<sup>[6]</sup>

Fuel gas pressure is critical to proper burner operation and efficient combustion. Irregular pressure leads to flame failure or high amounts of carbon monoxide. It may even cause over or under firing, affecting the boiler's ability to carry the load. Gas pressure should be constant at steady loads, and should not oscillate during firing rate changes. Usually, pressure varies between low and high fire. Therefore, readings should be compared to those taken at equivalent firing rates to determine if adjustments are needed or a problem exists.<sup>[6]</sup> For this reason, keeping the current Pressure Control Valve (PCV) at the fuel gas line is still required to deliver a constant gas pressure.



For the staged design pressure control, we changed the second stage pressure control with the flow control. We kept the pressure control on the first stage since in the conventional steam generator the pressure control is more stable under low-firing or start-up conditions.

For example, API556 suggests that one option is to use pressure control for start-up and then switch to flow control after reaching operating conditions. But the quality of modern instrumentation has changed this situation, so today, in most cases, flow control not only performs better at operating conditions, but it is also more stable under low-firing conditions and under load changes and other disturbances.<sup>[10]</sup>

The other area of performance difference between flow control and pressure control is precision of tuning. Not only is flow control easier and more accurate to tune compared to pressure control, but the temperature controller itself can also be more precisely tuned when using flow control, rather than pressure control, as the cascade secondary control loop. It is straightforward to analyse a historical dataset in spreadsheet and arrive at a very reliable value for the amount of fuel gas flow that is needed to raise a given heater charge flow rate by given number of degrees. This provides a nearly perfect gain parameter for the temperature controller (especially if a mass flow meter is used). The same cannot be said for pressure control, where the amount of flow for a given burner pressure depends upon, among other things, the number of burners currently in service.<sup>[10]</sup>

Flow Control Valve (FCV) is used to control fuel gas flow rate to maintain the Steam Quality at the set point.

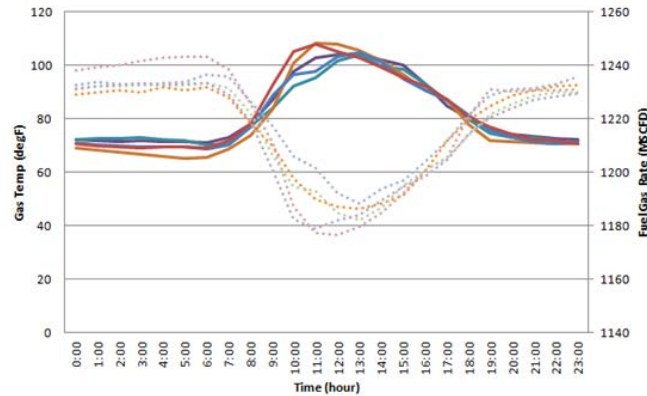


Fig. 8—Correlation between Gas Temperature and Gas Flow Rate

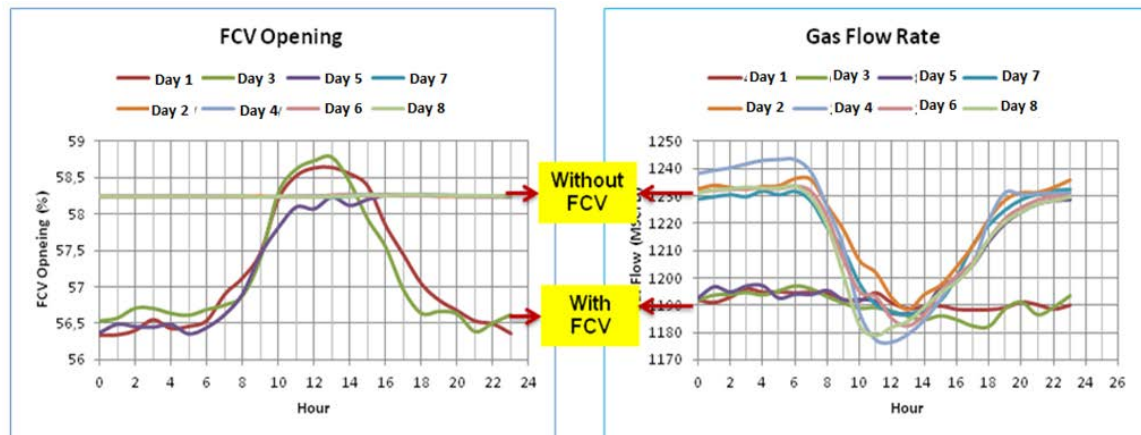


Fig. 9 – Correlation between Flow Control Valve Opening and Gas Flow Rate

As shown on Fig. 9 above, the FCV will adjust their valve opening to compensate the ambient temperature changes (day-night) that impact on the fuel gas density between day and night. Adjusting valve opening automatically will deliver the same amount of fuel gas mass rate at day and night. The same amount of fuel gas mass rate will deliver the same steam quality as shown on Fig. 10 below. This means delivering steam in stability and predictability.

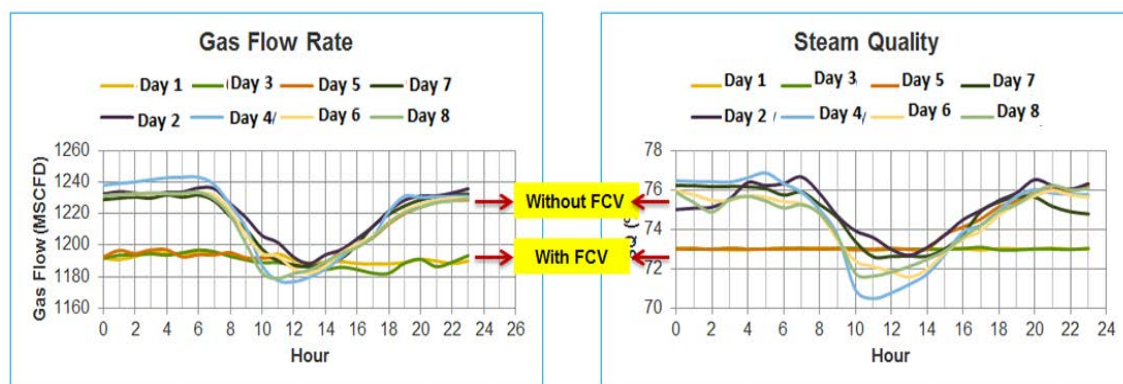


Fig. 10 – FCV Installation Effect on Gas Flow Rate and Steam Quality

Generally boilers are operated with excess air to ensure complete combustion of the fuel. Excess air at higher than optimum level results in reduced efficiency and increased NO<sub>x</sub>. Operation of burners at low excess air, say at 2 to 3% oxygen, will reduce the NO<sub>x</sub> formation. However, a minimum amount of oxygen must be maintained to avoid formation of CO and unburnt hydrocarbons. This may require the use of an oxygen trim and/or combustion control (CO) systems.<sup>[11]</sup>

Installing Variable Speed Drive (VSD) at motor blower would replace the existing mechanical linkage system. VSD is used to regulate motor blower speed to have a good air to fuel ratio for the combustion process. Supplying the right amount of air will result a complete combustion and increase the Steam Generator Thermal Efficiency as shown on Fig. 11 and 12.

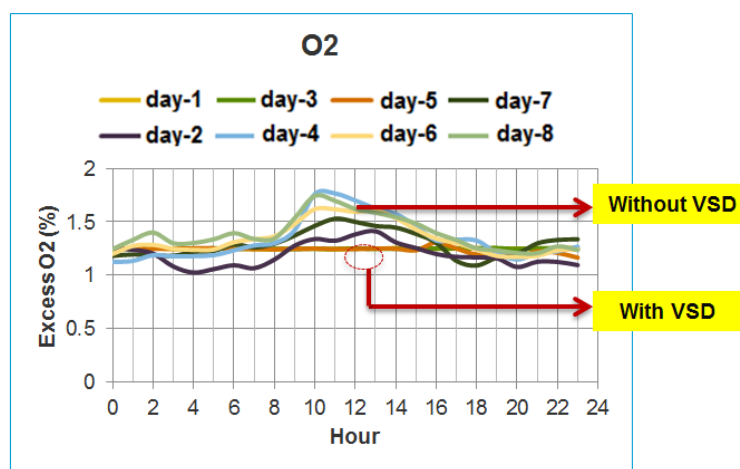


Fig. 11 – VSD Installation Effect on Excess Oxygen



We run the trial and the observation by letting the VSD worked to control the required air flow based on the excess oxygen setting at the stack starting from Day-1 until Day-3. At Day-4 to Day-8, we shut off the VSD to see the effect of no VSD on the excess oxygen output, stack temperature, and thermal efficiency. The detail of observation data is as shown on the Fig. 12 below.

Daily Average Data			
Date	Excess O2 (%)	Stack Temp (degF)	SG Eff (%)
day-1	1,25	218,28	85,06
day-2	1,25	220,5	85,01
day-3	1,24	219,05	85,04
day-4	1,28	224,03	84,92
day-5	1,28	224,03	84,92
day-6	1,33	228,59	84,82
day-7	1,35	227,64	84,84
day-8	1,39	224,07	84,92




Fig. 12 – VSD Installation Effect on Excess Oxygen, Stack Temperature, and Thermal Efficiency

## 5. Discussion and Recommendation

Flow control valve for fuel gas is easier and more accurate to tune compared to pressure control, but the temperature controller itself can also be more precisely tuned when using flow control, rather than pressure control, as the cascade secondary control loop.

By the same token, flow control lends itself to the accurate application of feed-forward, which is effective in eliminating control variance in the heater-outlet temperature caused by changes in the charge rate or temperature.<sup>[10]</sup>

Every 1% decrease in excess O<sub>2</sub> from the stack, results in as much as ½% increase in thermal efficiency. Automation plays vital role in controlling excess air and also benefits in process consistency, flexibility to load demands, ability to monitor, trend and bill the utilities in the process. When fuel composition is highly variable (such as refinery gas, hog fuel, or multi-fuel boilers), or where steam flows are highly variable, an on-line oxygen analyzer should be considered. The oxygen “trim” system provides feedback to the burner controls to automatically minimize excess combustion air and optimize the air-to-fuel ratio. It increases energy efficiency by one to two percent. For very large boilers, efficiency gains of even 0.1 percent can result in significant annual savings.<sup>[6]</sup>

The use of O<sub>2</sub> trim, only trims the amount of excess air above that required for complete combustion for a specific furnace design while not creating a fuel-rich furnace/stack environment. The burner design, fuel selection and load swing are all critical factors affecting the decision to O<sub>2</sub> trim in any given boiler. Unfortunately, high cost of purchasing and installing an oxygen analyzer discourage its use to small or medium boilers. Typically, its use is advantageous in large boilers that use between \$ 100,000 and \$1 million worth of fuel annually. But from the point of view of limiting environment emission and also to

satisfy the authority having jurisdiction, it may be appropriate to install oxygen trim for smaller boilers even though the paybacks are little longer.<sup>[6]</sup>

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