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# THE EXTREME IMPORTANCE OF TOTAL AIR & FUEL FLOW MEASUREMENT ON A 450MW B&W WALL FIRED UNIT FIRING HIGH SULFUR FUELS

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## ABSTRACT

The Economic drivers for excellence in Operations and Maintenance are improved heat rate for reduced $CO_2$, reduced production costs and reduced slagging and fouling when firing lower grade & higher sulfur fuels. Application of the fundamentals in measuring and controlling the fuel and air inputs into the furnace can and has resulted in significant improvements in plant operations. Simultaneous achievement of load response, control, reliability, stability and environmental performance at the Stanton Energy Center (SEC) demands optimization of the furnace inputs. The purpose of this paper is to serve as a case study of the extreme importance of air and fuel flow measurement and control on a 450MW B&W wall fired unit, using Unit 2 for the case study. Just for reference, the unit description is as follows:

- SEC, Unit 2 is a balanced draft, "Carolina Radiant" Boiler rated at 3,305,000lbs./Hr. SH steam flow & 1,005F .
- There are 30 B&W DRB-XCL burners; (3) levels on the front wall (A,B,C) with (2) levels on the rear wall (D,E); (6) each OFA ports on the front & rear walls.
- This boiler has (5) MPS 89N mills.
- Primary and Secondary combustion air is heated by one Ljungstrom tri-sector regenerative air heater.
- Pulverized Coal Firing is augmented by methane gas piped to the site from an adjacent municipal landfill.
- The units are also equipped with electrostatic precipitators in tandem with wet-limestone scrubbers.

**<u>The key points of the technical paper are as follows</u>:**

1. To review how the application of the fundamental essentials of combustion and implementation of proven combustion control equipment, validated repeatable air-fuel ratios, modern control theory and staging of combustion air within the furnace is essential to unit performance & reliability.
2. To review the measured and calculated airflows on a typical Low $NO_X$ Firing System using Stanton Energy Center Unit 2 as an example. To review some examples of the "best" techniques to measure, balance and control the furnace inputs. Although these are fundamental basics, the overall industry understanding of the importance of combustion airflow measurement in relationship to unit reliability is uncertain.
3. To review the reasons and need for periodic "hands on" testing and performance monitoring, ensuring proper calibration and operation of all plant related equipment.
4. To review challenges with ultra low $NO_X$ firing systems, neural networks & units firing high sulfur fuels with non-optimum inputs. Operation of todays coal fired boilers is progressing with parallel commercialization of low $NO_X$ burner technology, control systems, smart closed loop systems and neural networks.

5. To explain how the application of proven automotive technology closely parallels the optimization of large pulverized coal boilers. Improvements in pulverized coal combustion with solid fuel injection systems continue to closely rival the evolution of internal combustion engines for automobiles.

Optimizing the controllable variables for the best possible performance, fuel flexibility, capacity, environmental performance & reliability at the Stanton Energy Center can be compared to almost any fossil fuel plant. The key is to first understand the previously mentioned and frequently underappreciated essential requirements which need to be established.

**The Performance of Combustion Control Equipment**

Power plant performance and reliability, when broken down into their core constituents, can be evaluated in terms of the owner's ability to correctly and accurately measure and control equipment and their processes. These equipment and processes include, but are not limited to, combustion control equipment such as coal feeders, pulverizers, burners, forced and induced draft fans, air heaters, air dampers and processes such as primary air, secondary air, and fuel delivery systems. The ability to accurately measure and control is a function of the system instrumentation and controls, as well as the equally important controls tuning. One essential to reliable and accurate control is the ability to validate measurements, through instrument and device calibrations. Coupled with accurate calibrations of final control elements, most control variability and inaccuracy can be eliminated.

After the process measurement and control devices are correctly calibrated, the control system can also be optimized. Some older control systems are utilizing outdated control schemes in need of an update. Many improved functional control schemes can be implemented that will improve unit response and ramp rates, provide for finer control of combustion and primary airflows, fuel flows, and better excess oxygen control. In addition, the use of artificial intelligence on a modern control system is just one example of the many changes that can be implemented to improve unit control and efficiency. It should also be noted that the effective use of modern control systems are dependent on the prerequisite application of engineering fundamentals to the plant equipment. The 13 Essentials for Optimum Combustion provide some of the necessary steps to follow when applying these fundamentals.

**The Importance of Combustion Airflow Measurement**

Combustion of coal in its simplest form is converting solid coal into a gas with energy (heat) as the by-product. That which does not burn does not convert into the gas phase (ash in, ash out). The main components of coal that contribute to the flue gas are carbon, hydrogen, and oxygen. In the ideal case, the products of combustion are water ($H_2O$) and carbon dioxide ($CO_2$). Once the properties of the "as fired" coal are known, through basic chemistry one can determine how much additional oxygen is required to convert all of the hydrogen into water and the carbon into $CO_2$. Total airflow can be calculated because the mass flow of oxygen needed is approximately 21% of the mass flow of total air required. As the coal properties change, airflow requirements also change slightly. The more carbon and hydrogen bound in the fuel, the more oxygen is required to covert those quantities. This is why low Btu coal requires less air (lower air to fuel ratio) than high Btu coal (high air to fuel ratio). Approximately 850lb of air are required per million Btu. This value will differ according to such factors as the hydrogen/carbon ratio content of the fuel. Total air requirement is the most crucial in determining how the unit is run. After this is determined, the air is appropriated into the different areas of the unit: primary air, secondary air, and over-fire air. Remember that total air includes any unheated tempering air that may or may not be measured after the air heater.

Primary airflow serves the following purposes:

- Transporting the pulverized coal to the burners
- Vaporizing the moisture in the coal before combustion

Once these conditions have been met, any additional primary air will cause negative effects on fuel fineness, fuel distribution and combustion at the burner which can lead to decreased emissions performance. The typical ratio for maintaining coal velocity exiting the burner relative to the secondary air velocity around the burner nozzle on most vertical spindle pulverizer systems is 1.8 pounds of air per pound of coal. Achieving this ratio is the first step in building a primary airflow control ramp. The second requirement is to maintain minimum line velocity of the pulverized coal. The minimum velocity to entrain coal particles in an air stream is 3,000ft/min. Regardless of coal flow, maintaining this air flow rate establishes the minimum amount of primary air flow required. After minimum airflow is satisfied, the primary airflow ramp on a vertical spindle mill, such as the MPS 89's at SEC, can be optimized for a nominal 1.8 air-fuel ratio. Regardless of excess $O_2$ set-points, excess air requirements, or over-fire air, the primary airflow ratio is the same at any given coal flow. Additionally, the total primary airflow is measured and included as a percentage of the total air required for combustion.

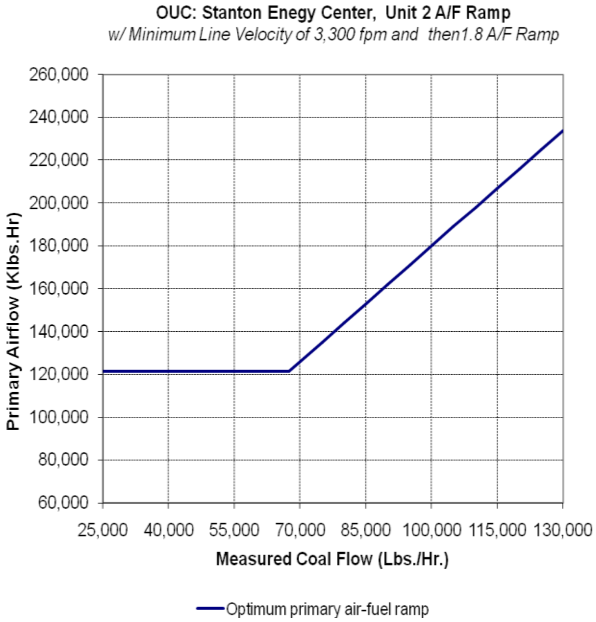


**Figure 1: Optimum primary air-fuel ramp**

The chart above depicts the optimum primary air flow curve. Active tuning of the air-fuel ramp with the fuels and/or mechanical conditions of the coal pulverizer tolerances is something rarely done. However, this task is extremely important when comprehensively evaluating mill grinding performance and/or overall combustion performance. Stanton Energy Center actively adjusts their air flow curves based on mill performance, coal quality and pulverizer rejects to maintain optimal air-fuel ratios and unit response. It should be noted that unit response at lower loads may be impacted by maintaining the minimum primary air flow (following the curve), necessitating upwards biasing of air flow at lower loads. The important point is to maintain the correct primary air flow for the conditions that exist by actively tuning the curve.

Throughout the industry, over-fire air measurement and staging for combustion and emission control is not always closely controlled. However, over-fire air is generally designed for a percentage of total airflow in the range of 10-20%. Therefore, the amount appropriated is a simple percentage of the original total value. Maintaining accurate measurement of over-fire air adds the second element of accurate combustion airflow measurement and control. After the primary air and over-fire air requirements have been met, the remaining air is introduced as secondary air. Because of the importance of stoichiometry control with high sulfur coals and the possible impacts of water wall wastage, the task of airflow measurement & control must be taken seriously. The following graph shows how the combustion air is proportioned on SEC Unit 2 at full load.

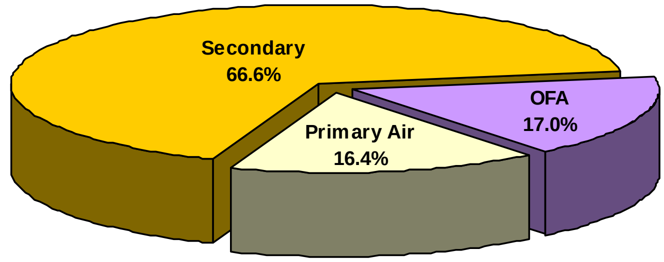


**Figure 2 - Airflow percentages to Secondary Airflow, OFA and Primary Airflow**

Theoretically, Excess Oxygen can be an indicator of combustion airflow. However, experience has shown that older units with high tramp air in-leakage infiltration upstream of the $O_2$ probes corrupts the ability to accurately determine the true amount of excess air on the unit (as tramp air in-leakage falsely represents excess air). Because of the importance of stoichiometry control and balancing of the combustion airflow, SEC and the Storm Technologies team continue to work together to periodically test, tune & optimize the combustion airflow measurement accuracy and performance. For example, **Figure 3** shows how close SEC follows the theoretical air calculations. This demonstrates the importance of accurate airflow measurement and control on a mass flow basis. Non-feedback, percentage based control systems are often vague and leave room for errors based on predetermined ranges and values.

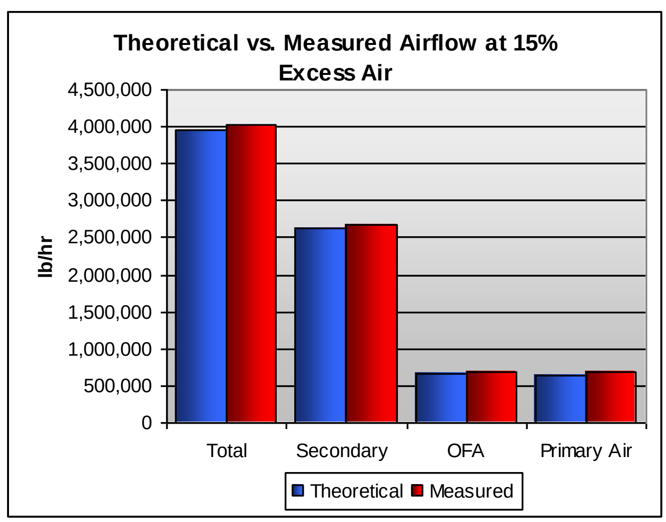


**Figure 3 - Theoretical vs. Measured Airflows (Actual) for SEC 2 at full load**

As noted previously, the measurement of each path of air supply is important. However, it is also very important that each air flow path divided up among the mills and burners are balanced. Furthermore, average stoichiometry doesn't really matter if the unit is air rich on one side and fuel rich on the other. To obtain optimum performance in the furnace, air flows and fuel flows need to be balanced within acceptable tolerances. Figure 3 shows how the minimum and maximum stoichiometry changes with increasing air and fuel imbalances.

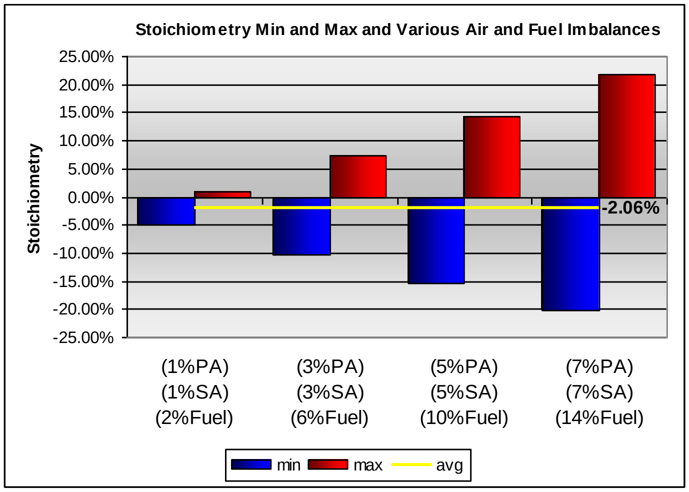


**Figure 3 - Burner Stoichiometry compared to varying fuel and air imbalances**

Primary and secondary air flows should be balanced to within ±5% of the average while fuel flow should be balanced to no more than ±10% of the average on a pipe to pipe basis. Keep in mind that 7% air imbalance and 14% fuel imbalance is a conservative number for typical air and fuel imbalances. Not surprisingly, localized high temperature zones and/or localized slagging issues are not uncommon under these conditions. This is largely due to the fact that high sulfur coals often yield high Iron in Ash levels as well. When high iron ash levels are exposed to a reducing atmosphere, slag propensity worsens. These factors clearly illustrate the need for optimizing the air and fuel inputs. Considering this, the air and fuel delivery systems must be periodically tested, tuned & optimized for best overall performance.

**Periodic "hands on" Testing and Performance Monitoring, ensuring Proper Calibration and Operation of all Plant Related Equipment**

Comprehensive diagnostic testing has been commonly used to supplement permanent plant instrumentation, and provides important feedback of opportunities for improvement. Methodically sampling representative ductwork cross-sectional areas is imperative for true indications of combustion airflow. Additionally, fuel conduit traverses are required to optimize pulverizer and burner performance. Fuel fineness also has a huge impact on fuel distribution, as the finer the particles become, the more the mixture of air and coal behaves like a homogenous gas. When fuel flow, airflow or overall stoichiometry gets out of control, secondary combustion is induced. This results in a reduction of lower furnace heat absorption, along with a corresponding reduction in the life of the super-heater and re-heater pendant sections. Because of this, periodic comprehensive testing is paramount in determining overall boiler performance. High furnace exit gas temperatures coupled with high sulfur (which is typically high in Iron) can also lead to increased slagging propensity and fouling of the heating surfaces. A reducing atmosphere with high sulfur coal and high concentration of Iron in the ash will create four adverse conditions:

1. Higher furnace exit gas temperatures
2. Increased super heater slagging
3. Increased water wall wastage
4. Low ash fusion temperatures

The 13 Essentials for Optimum Combustion outline a usable and practical approach for getting the inputs right. By applying these 13 essentials at the SEC, STI and the OUC team have combined the talents of operations and maintenance personnel and worked together to preserve and optimize plant performance. Examples of the some of the proactive steps taken by OUC to optimize performance are as follows:

- Balancing the fuel lines within ±2% clean airflow balance to equalize transport energy to each fuel line.
- Conducting periodic comprehensive mill performance tests (either quarterly or semi-annually based on the fuel quality) to optimize coal fineness and air-fuel ratios to the burners.
- Inspections with synchronization and optimization of the mechanical mill components to promote improved homogenization at the classifier outlet. As you can see within the following CFD models, clean air balance and fineness is only part of the solution when balancing fuel lines. If the classifiers are set with optimum tolerances, the classifier will serve as a homogenizer. For example, see figure 4

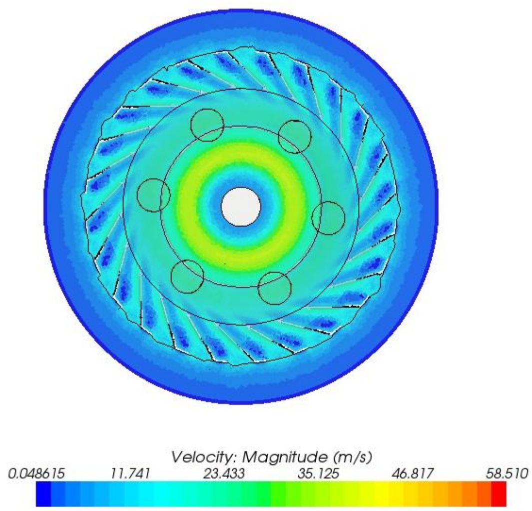


**Figure 4: CFD Model of an MPS Classifier with Optimum Mechanical Tolerances**

- Complete coal feeder calibrations and refurbishment as required.
- Semi-annual combustion airflow device calibrations.
- Water wall flue gas sampling & profiling to validate Oxidizing atmospheres on the walls. See figure 5.

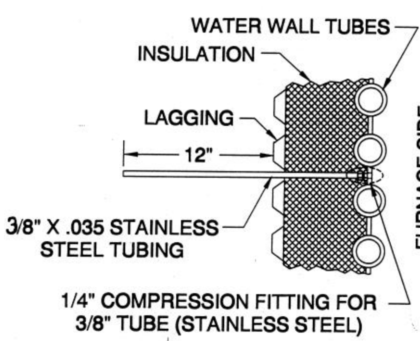


**Figure 5: Detail of furnace wall gas sample port**

- Temperature, CO, Oxygen & $NO_X$ profiles obtained with a HVT traverse, providing an indication of imbalances in air and fuel originating in burner belt zone.
- Economizer Exit Flue Gas Profiling in Conjunction with Furnace Exit HVT Traverses.
- Periodic air heater performance tests.
- Pre & Post Outage testing.

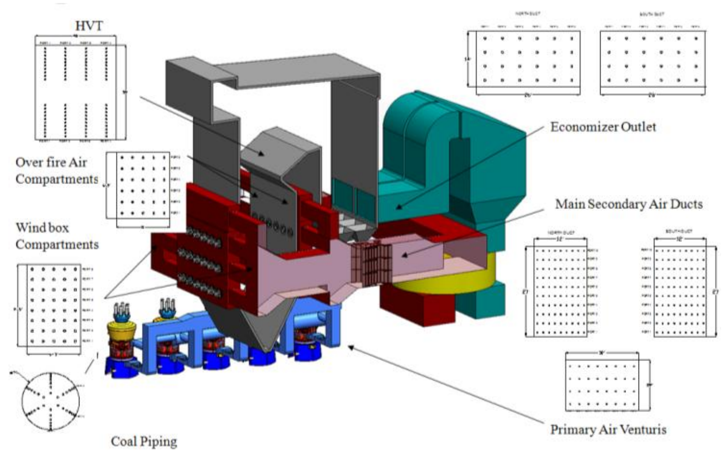


**Figure 6 – Representative testing grids used for comprehensive diagnostic testing at SEC, Unit 2.**

Although these tasks aren't easily completed, these are a prerequisite to optimum heat rate operations, while also being sensitive to the reliability and high load factor requirements of the steam generator.

**Challenges with Ultra Low $NO_X$ Firing of high Sulfur Coals with NON-OPTIMUM Inputs.**

The philosophy of operations at the SEC is reliable operation with peak environmental performance. However, the cost of this performance is absorbed in the plants flexibility to fire various spot market coals. With the evolution of Low $NO_X$ firing, the combination of staged combustion and operations with high sulfur coals has been a long time challenge, sometimes resulting in fireside corrosion and thinning of boiler tubes. This is simply corrosion by ash with low melting temperatures. Typically, higher sulfur coals correlate with increased Iron in ash contents. At the SEC, Sulfur content varies from 1.5% - 3% with Ferric Oxide in the magnitude of 20%. It is the plants experience that increases in slag propensity and/or reliability issues are correlated with the fuel inputs and therefore, to remain focused on the OUC company slogan as "The Reliable One," the plant has adopted fundamental preventative measures to optimize performance, listed as follows:

**The Pre-Requisites for Reduced Slag Operations are as follows:**

- Reducing Furnace Exit Gas Temperature below ash fusion temperature to reduce the potential for slag formation.

- Coal combustion in an oxidizing environment since the ash fusion temperature is higher in an oxidizing environment and less char is formed with complete combustion.
- Reduce combustion in the super heater which forms slag due to two factors: a.) Secondary Combustion and b.) Reduced ash fusion temperatures due to a reducing environment.
- Close review of the slagging characteristics of fuel. Coals with higher sulfur, iron and lower ash fusion temperatures will produce more slag.
- Improved fineness inherently improves fuel distribution.
- Improved fineness will reduce the formation of char, incompletely combusted carbon, and slag from ash in fuel, contributing to more complete combustion and less slag to form popcorn ash.
- The popcorn ash increases in size as sulfates form, causing fly ash to bind to the popcorn ash, leading to SCR screen plugging and/or inducing ABS plugging on the Air Heater.

## The Evolution of Control Systems mimics Automotive Technology

The evolution of power plant control systems can be paralleled with that of the automotive engine control system. In the early days, internal combustion engine controls such as ignition, timing, fuel delivery and metering, were accomplished by purely mechanical devices. Mechanical fuel pumps, mechanical fuel injection systems and carburetors were the norm. However, increasing governmental regulations for emissions brought the advent of the electronic fuel injection system, various feedback sensors and the engine control computer. Called many different names by different manufacturers, modern automobiles rely on this computer to provide accurate, repeatable and most importantly, adaptive engine control. The engine control system is a small scale example of a modern power plant control system.

While the differences between a power plant and automobiles are obvious, when considering the basic operation of each, one might be surprised to find a large amount of similarities between the two. An automobile uses an internal combustion engine as opposed to the external combustion engine found in a coal fired power plant. However, from an engineering point of view, both open systems have clearly identifiable system boundaries. It is within these boundaries that one can focus attention to find many control parallels.

Some automotive engine control systems precisely measure air input via a mass flow meter. Others calculate airflow based on engine speed, air temperature, throttle position and barometric pressure. Still others utilize engineered maps of engine volumetric efficiency, engine RPM and other parameters to determine airflow, all in an effort to calculate the correct fuel input. Variables such as inlet air temperature, coolant temperature, exhaust gas oxygen, and others are continuously monitored and considered when optimizing fuel delivery, ignition timing, emissions and overall engine performance. Actual engine performance and parameters are sometimes compared to strategic maps (or models) stored in the computer to make subtle changes to control outputs. These are just some examples of the functionality the engine control computer provides.

Some aftermarket (non-OEM) automotive suppliers have produced their own programmable computers, allowing owners to map and tune their own vehicles, optimizing their vehicles performance. The automotive racing environment is also a proving ground, providing the best tuners with opportunities to showcase their tuning skills on fully programmable computers. And the latest engine control computers learn how the operator drives the vehicle, providing adaptive controls and continuous evaluation of the best options for engine control in an infinitely variable method. These are examples of how internal combustion engine controls have evolved to provide major improvements in tuning, high performance, efficiency, emissions and cost savings to the consumer. These same changes in advanced computer controls seen in the automotive industry can be applied to a modern power plant to effect similar results.

A modern power plant control system has the ability to closely monitor and control the operation of a large pulverized coal fired boiler. However, recent industry improvements have the potential to greatly enhance the operation of these plants. The installation and application of Ultra Low $NO_X$ burners, neural networks and continuous back pass flue gas monitoring equipment can all be a great place to start on the path to improvement. Low $NO_X$ burners with the ability to precisely measure airflow, and control at each individual burner, may provide opportunity for a neural network driven control system to fine tune airflow into the boiler. However, this must be coupled with exact fuel flow measurement and control, proper furnace balance and stoichiometry can be achieved. Combining those with continuous flue gas monitoring in the exit stream, prior to leaving the system boundaries, the necessary feedback information can be provided for accurate real time control of the very dynamic external combustion process.

The adaptive nature of a neural network with model predictive control can closely mimic that of the automotive engine control system, providing changes to operational parameters in response to changing “drivers”. Some of these drivers may be operations personnel, but more importantly, responses to changes in fuel quality, equipment condition and environmental factors are necessary to remain efficient. With an increase in efficiency (i.e. better heat rate) comes an increase in reliability, as well as a reduction in fuel costs. A neural network can provide plant operators and engineer's opportunities to finely tune plant controls for optimal performance. Additionally, a regular program of combustion equipment health monitoring adds another level of performance enhancements.

Today's power plants are facing many of the same demands that the automotive industry has dealt with. Increasing pressure exists for optimal power plant performance and efficiency, while maintaining system integrity and reliability. A combined effort between power companies, OEM's and service companies can produce very positive results in these areas. With improvements in Low $NO_X$ burner development, control systems, measuring devices and third party software, many power producers can find considerable savings in annual fuel costs.

## Closing

The automotive engine control system has become increasingly complex over the last 25 years. Today's automobiles utilize highly sophisticated controls and instrumentation to provide optimal performance while offering ever increasing economy. The same can be said for the modern power plant control systems as well. If utilized, these improved controls can provide the same end results. However, as a starting point, the essentials of combustion must be applied such that the system can be treated like a solid fuel injection system. Applying the fundamentals on a large utility boiler may seem to be an onerous task. But, at the Stanton Energy Center, it has been proven that the fundamentals must be applied as a pre-requisite to advanced controls used to optimize coal fueled power generation and heat rate.

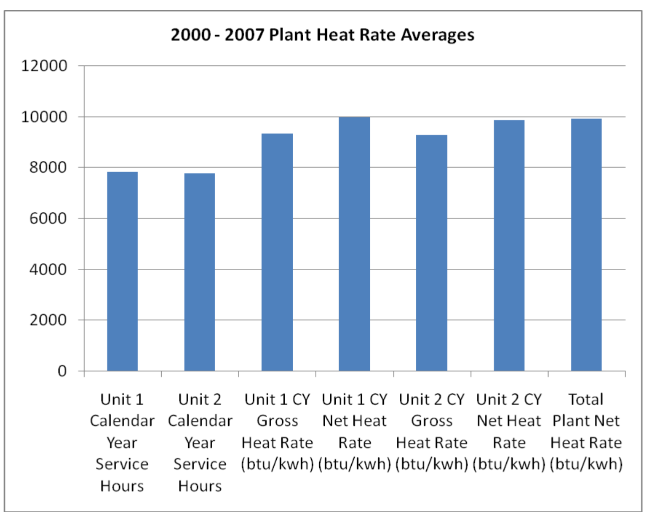


**Figure 7 – Plant Heat Rate Averages from 2000 – 2007**


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