PowerEnergy2017-3087

Combustion, Reliability, and Heat Rate Improvements through Mill Performance and Applying the Essentials

By: Oscie Brown, PE, SCANA (SCE&G)
Adam McClellan, PE. Storm Technologies, Inc.

Project Background

South Carolina Electric and Gas (SCE&G) Wateree Station is a pulverized coal fired power generation facility consisting of two Riley supercritical units (3,549 psi 1,005/1,005°F, 2,850 klb/hr) and two General Electric G2 tandem compound four flow three casing reheat steam turbines.

Each unit consists of three Riley double ended ball tube mills supplying 24 dual register burners arranged in a front and rear wall fired configuration. In order to meet the tightening of emissions standards, the plant has installed air pollution control devices such as low NOx burners, selective catalytic reduction systems (SCRs), Reverse Gas Fabric Filter Baghouses, Wet Flue Gas Desulphurization (WFGD) System and Activated Carbon Injection (ACI).

The use of ash has evolved over time. Wateree was the first plant to build a Carbon Burn Out (CBO) facility to reduce the flyash unburned carbon to a level that it may become a marketable product for beneficial reuse or resale. The higher carbon content of the flyash was a direct outcome of the implementation of Low NOx burners.

Wateree was designed with no significant margin in coal mill capacity, in addition, the original fuel specification was significantly higher in heating value (13,000 Btu/lb versus 12,500 Btu/lb) and Hardgrove Grindability Index (HGI 55 versus 42 HGI) which at times can cause a 30% penalty to mill capacity. The plant also receives trains with high percentages of fines. Although this smaller size improved mill throughput it also makes the fuel hold more moisture which is a significant derate to ball mills. Currently the plant burns a mix of CAPP and NAPP coals.

In order for the units to stay competitive in the current market and maintain a high position on the load dispatch list, maximum reliability and heat rates must be achieved.

Storm Technologies is an engineering firm specializing in optimizing boiler performance. Storm's philosophy for improving boiler performance starts in optimizing the inputs, starting at the pulverizer. Working in coordination, Storm Technologies and SCE&G undertook a project to improve combustion, reliability and heat rate through a comprehensive mill performance improvement program, along with applying the essentials for combustion optimization. This project consisted of firing system inspection and repair; improving pulverizer performance; installation of static-centrifugal classifiers; new inlet/outlet mill ends; fuel line air/fuel balancing; mill and airflow control curve adjustments; and validation by testing and tuning efforts.

The project was initiated due to the condition of the existing classifiers being worn to the point in which a great deal of replacement components were required or the classifiers needed a total replacement. The poor condition of the classifiers was resulting in poor fuel fineness: which was adversely impacting boiler efficiency, cleanliness and reliability. Although the focus of this narrative is performance, the classifiers and coal mills were worn to the point that coal would lay out, that the plant had many incidents of coal mill and classifiers fires & boiler explosions. Although performance & reliability improvements justified this project on an economic basis, the primary driver was the elimination this major safety concern. Since completion of the project there have been no fires in the mill.

Rather than replacing a single component a comprehensive approach was taken. Thus it was ultimately decided to install new high spin static-centrifugal classifiers in combination with a performance improvement program. This performance improvement program was a collaboration of the plant's parameters and experiences and Storm's thirteen essentials for optimum combustion for low NOx burners.

Storm's Thirteen Essentials

Combustion efficiency, boiler reliability and heat rate are interrelated as each are improved when the boiler inputs are addressed and optimized. Storm's Thirteen Essentials were applied in order to address optimizing the boiler inputs. When combustion is optimized, boiler reliability can be achieved by maintaining temperatures in the proper ranges; maintaining balanced oxygen to the proper levels throughout the furnace; and overall keeping the boiler performing to the original design conditions. Storm's Thirteen Essentials are as follows:

1. Furnace exit must be oxidizing, preferably 3% (No point less than 2%).
2. Fuel lines balanced to each burner by "clean-air" tests within ±2%.
3. Fuel lines balanced by "Dirty Air" test within ±5%.
4. Fuel lines balanced by fuel flow within ±10%.
5. Fuel line fineness shall be 75% or greater passing a 200-mesh screen. 50 mesh particles shall be less than 0.1%.
6. Primary airflow accurately measured and controlled to ±3% accuracy.
7. Primary air/fuel ratio shall be correct & accurately maintained when above minimum.
8. Overfire airflow shall be accurately measured & controlled to ±3% accuracy (Unit does not currently have OFA).
9. Fuel line minimum line velocities shall be maintained.
10. Secondary air distribution to burners should be within ±10%.
11. Fuel feed to the pulverizers should be smooth during load changes and measured & controlled as accurately as possible.
12. Mechanical tolerances of burners and dampers ±1/4" or better.
13. Consistent Fuel feed quality and consistent raw coal sizing of feed to pulverizers.

Pulverizer Performance Improvements

The Riley ball tube mills are designed so that fuel and primary airflow is fed into the mill from both ends of the mill. Each end of the mill is provided with an individual volumetric feeder, a crusher-dryer, and primary air ductwork. The mills do not have a means, such as dampers, to balance the end to end primary airflow; this balance is accomplished by assuring the system resistance and operating conditions at each end are equal. Accurate balance to each end is necessary to assure balance to each burner.

During the outage, the crusher-dryers were rebuilt and set with the proper OEM clearances and each volumetric feeder was calibrated to ensure a smooth and consistent flow of coal to maintain a consistent level of coal in each of the mills. The primary air ducts were also inspected to assure restrictions were not in place which could impact this balance. The primary airflow measurement elements were found to be partially plugged and were pulled, cleaned, reinstalled. The electronic processing units were replaced with new calibrated units form the

OEM. It was also found that the primary air duct was originally arranged with a bypass around the crusher-dryer. The original bypass was installed due to concerns with airflow capacity limitations, however airflow capacity was not found to be an issue during operation. Therefore the bypass ductwork was removed to force all the airflow through the crusher-dryer to assist with drying capacity and eliminate impacts to balance.

Pulverizer inspections were performed and the as found ball charge included a large percentage of small and misshaped balls. The decision was made to remove and classify the balls; which yielded a large percentage of balls which could not be reused. The plant used a vacuum service company to collect the balls into drums and the mill ball supplier was able to regrade at their facilities in a more efficient manner than on site grading. Small "trash" balls do little for pulverizing the fuel as they tend to ride along the bottom of the mill and are not lifted in order to provide the force and contact needed to break up the coal. Misshaped balls also cause issues as the contact points are not concentrated and reduce the ability to break the coal. Through previous experiences together, an adequate tonnage of small ball sizing was agreed upon and utilized. Storm has found a minimum ball charge of 1.2 lbs of balls per pound of air per hour fuel throughput is required. To ensure the balls maintain their shape and last as long as possible, high chrome content balls are utilized. The following size distribution was utilized in the mills.

- 25% = 1/2" to 3/4" Diameter
- 25% = 7/8" Diameter
- 25% = 1" Diameter
- 25% = 1 1/4" Diameter

A smaller average diameter ball charge allows for more contact points for the same tonnage of balls compared to a larger ball sizing. The increased number of contact points allow for more area for coal particles to be smashed between the balls. The following chart and figure illustrate the large increase in contact points for the same mass of balls when comparing a smaller diameter average ball charge to a larger size.

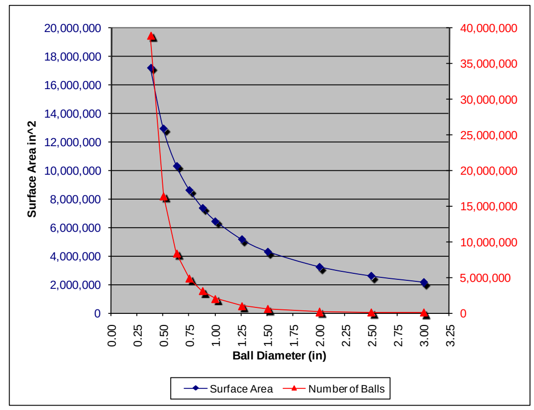

Figure 1: Ball diameter vs. surface area & number of balls

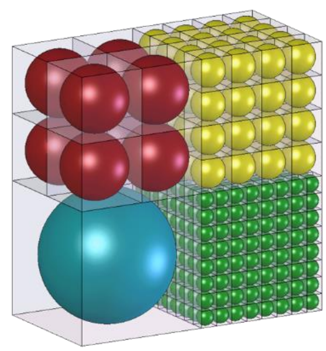

Figure 2: Comparison of large & small ball contact points

In order for a small ball charge to perform properly, the crusher-dryer must be in good condition and top size feed to the crushers should be 3/4" or less. Larger raw coal sizing greatly impacts capacity and performance. Although developed for vertical spindle mills, Storm has found the following capacity correction chart remains true for ball tube mills.

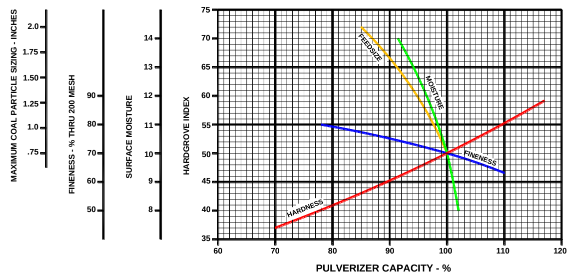

Figure 3: Capacity correction chart

In addition to reviewing the mill ball charge, mill liner conditions were measured and verified to ensure adequate lift and profile. The minimum lift of 2" and good profile are critical to mill performance and throughput by allowing for the ball charge to be lifted high enough to provide adequate crushing force. Over time the liner will become more worn on the lift side and although adequate amplitude (lift) may still be in place the profile smooths out and does not allow the balls to be adequately lifted. The profiles were measured with a gauge and found to be in excellent condition as shown if the following figure.

Figure 4: Mill liner gauge

Fuel flow measurement on ball tube mills is difficult as they operate as inventory mills. This is because the coal fed to the mill does not necessarily result in the same amount of coal exiting on a lb/hr basis and that an inventory of coal is maintained in the mill. The amount of fuel exiting the mill is controlled by the amount of airflow entering and exiting the mill as well as mill level or inventory. Therefore, the mill output is controlled by the mill's rating damper; controlling the primary air to the mill. By increasing the primary air through the mill, more coal can be transported. The level of coal in the mill is maintained by the volumetric feeders. In order to control the mill, a good indication for fuel flow exiting the mill is required. Since the primary air passing through the mill dictates the coal exiting, mill end differential pressure is utilized to provide the signal for fuel flow. The placement of the sensing taps on the mill end was critical as there are multiple flow paths and only the flow through the mill was desired to be monitored with this measurement. The following is the curve developed by testing through the load range. The absolute amount of coal exiting the mill will change with varying coal qualities and fineness levels achieved and therefore this is not an absolute curve. However the closer this curve is to the actual flow, the smoother the unit transitions. Many tests were ran at various load points on each of the mills to develop this curve.

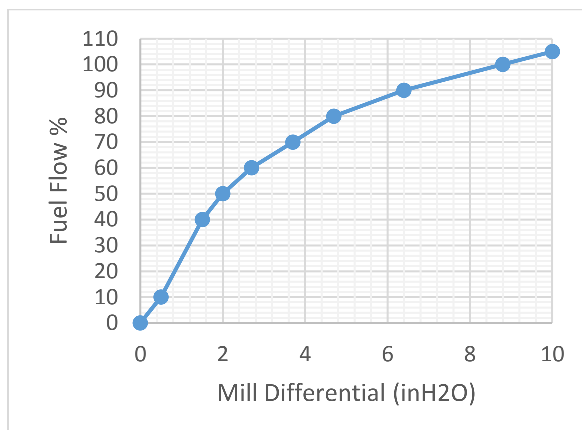

Figure 5: Fuel flow percentage vs. mill end differential

Since the airflow that enters the mill determines how much coal flow goes out, in order to have mill turn down, this airflow must be able to be lowered. However minimum fuel line velocities must be met in order to keep coal from settling out in the fuel lines and burners and sets the minimum primary airflow. In order to have turn down below this point and maintain fuel line velocities, a damper is located within the mill end that allows airflow to bypass the mill and pass directly from the inlet to the outlet of the mill, called auxiliary air. As often is the case, auxiliary air was set higher than needed when above minimum airflow, thus increasing air to fuel ratios, lowering capacity by decreasing available air through the mill, and adversely impacting fineness due to higher velocities through the classifier. By reducing the amount of bypass air, mill response time is also improved. High primary airflows also adversely impact combustion and NOx, therefore these curves were adjusted.

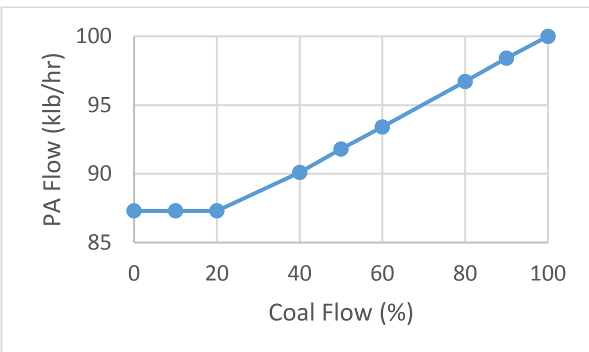

Figure 6: Primary airflow curve

All the dampers (rating and auxiliary) were characterized to linearize the damper response for each control station.

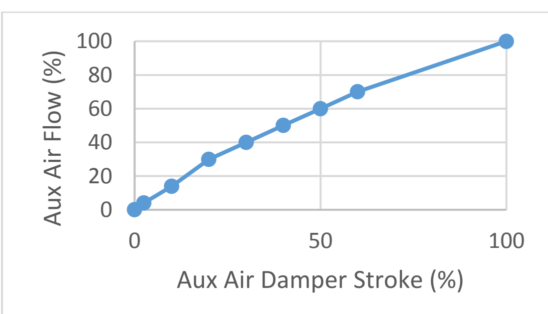

Figure 7: Example - Aux airflow vs. damper stroke

In order to improve the megawatt response, the fuel and air cross limits were adjusted and tuned. The Boiler Master was adjusted in order to provide good response to the Firing Rate Bias (Ratio of Boiler Master and Fuel Demand).

The Steam Temperature Master (Fuel to feedwater controller ratio) was adjusted for temperature control.

The O2 versus load controller was tuned and the FD fan versus boiler master set-point was also adjusted.

Mill End Overview

For the project it was decided to install new mill ends. The mill ends were designed with a vertical baffle separating the inlet and outlet. In order to increase the penetration of the entering air and lower the carrying velocities of the airflow exiting the mill, the baffles were set with the inlet area smaller than the outlet (approximately 40% inlet area/60% outlet area). As noted, this sweeps the airflow further in the mill such that the finer coal can be picked up closer to the middle of the mill. This assists with capacity, fineness and drying capacity by providing more contact with the fuel and air within the mill.

Static-Centrifugal Classifier Overview

The new Storm static-centrifugal classifiers were designed based on the specific operating parameters for Wateree Station. The mills at Wateree Station were originally designed with minimal margin on capacity and have since changed to a lower than original design heating value fuel, making the mill capacity marginal. The Storm classifier was designed for increased centrifugal spin; which increases fuel fineness by increasing the amount of coarse coal particles returning to the mill for regrinding. By improving fineness and the high spin imposed by the classifier, the fuel and air mixture at the classifier outlet is a more homogenous mixture which aids in fuel distribution to the burners. High spin is achieved with externally adjustable classifier blades. Twenty-four classifier blades are utilized in each classifier and are long straight blades with coarse particle guides. The coarse particle guides impart a downward vector to the coal particles and work towards reducing 50 mesh particles that exit the classifier. This downward vector imparted on the particles makes it difficult for the large particle to make a 180 degree turn to enter the outlet cylinder. The outlet cylinder further this by being placed with the inlet of the cylinder being below the bottom of the classifier blades. The outlet cylinder were designed so that the entrance velocities would be in the proper range as to reduce the tendency for unwanted large particle carry over into the fuel lines and ultimately the burners.

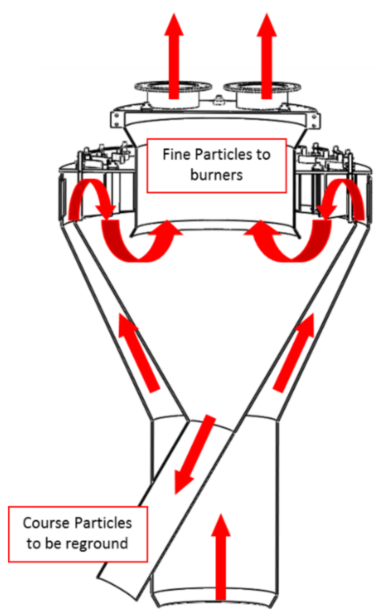

Figure 8: Coal flow through Storm classifier

Another important aspect of the classifier design is the capability to return large amounts of coarse coal particles back to the mill for regrinding. A typical recirculation of 1:4 is required to achieve adequate fineness levels, resulting in a large amount of coarse particles being returned to the mill. A smooth flow of the coarse returns from the classifier is critical. Therefore, stainless steel return lines of adequate size were utilized assuring sufficient slope and sweeping turns where required. In addition, a positive seal is required in the return line to assure airflow does not flow backwards up the return line from the mill end. When this occurs, the airflow entering the bottom of the classifier re-entrains the coarse particles and disables the classifiers ability to classify the pulverized coal. For this reason a valve called a trickle valve is utilized. Proper design of the trickle valve allows for a positive shut off. However, when enough head is developed from the coarse particles in the return line, the valve opens to reintroduce the coarse particles back to the mill. This valve must also operate smoothly such that large dumps of coarse particles are not fed into the mill at one time causing mill level swings.

Fuel Lines

The balance of the fuel and airflow to the burners is critical to boiler performance. Balance of the fuel and primary air to the burner was addressed through the installation of orifice housings for easy changing of square edged orifices in the fuel lines. Each mill is configured such that one classifier supplies the front wall burners and one supplies the rear wall burners. This arrangement results in fuel lines with various system resistance due to length of run from the classifier to the burner. Balancing the fuel lines utilizing square edged orifices in the fuel lines and verifying balance under clean conditions is the first step in achieving this balance. Test ports were also installed in order to assure accurate measurements were taken during the balancing efforts. The fuel lines were balanced at startup with clean airflow being within +/-2% pipe to pipe in order to assure equal system resistance to each of the eight fuel lines per mill.

Firing System Improvements

Before the project began flyash loss on ignition (LOI) levels were running approximately 20% unburn carbon and boiler slagging was a consistent issue. Comprehensive work was completed during the outage in order to provide the best possible conditions for maximizing combustion efficiency.

Burner inspections were completed and found that a good percentage of the burner nozzles needed to be replaced and/or repaired. Heat damage was the main cause of the burner damage found. Poor fuel and air balance were likely a culprit of the damaged in service burners, along with an insufficient amount of cooling airflow to the out of service burners. Damaged burner nozzles adversely impact combustion as the airflow and coal paths are changed at the mixing point. Deformed nozzles impact the system resistance and therefore can impact the air and fuel distribution to the burners on that mill. Burners with low primary airflow can result in flames being too close or pulled up into the burner resulting in damage. Post inspection, the damaged burners were refurbished and assured to be centered and tolerances within +/- 1/4”. The burners are also equipped with rear deflectors and conical diffusers; whose conditions were inspected and replaced as required. It was found that a few deflectors were not oriented properly (to be positioned opposite side from inlet elbow) which could cause fuel stratifications within the burner nozzle. If excessive stratifications are carried to the end of the burner nozzle this too can result in burner nozzle damage. All were assured to have proper orientation and condition following the outage.

Figure 9: Damaged burner nozzle

The burners are dual register burners in which each burner has external adjustments for an inner and outer air register. These registers adjust the proportions of airflow to the burner and impart spin. It is desired that adjustments be capable of being made when the unit is in service while monitoring the results in order to tune the boiler. By changing the proportions of inner and outer secondary air to a burner, the burner can be tuned for combustion improvements such as CO and carbon in ash or the airflow staged to tune for NOx. The inner and outer air registers were found to be bound on all burners; not allowing for any external adjustments. Cleaning within the windbox and linkage repair was completed during the outage to free the linkages and assure they were operable from the external adjustment arms.

From previous furnace testing it was found that it was difficult to supply adequate air to one side of the rear windbox. Therefore, in addition to the burner work, the windbox (secondary air) dampers were stroked and visually inspected. This inspection yielded that one set of dampers in the rear windbox was short stroked; which prohibited a full travel of the damper. Adjustments were made to the damper linkage so that the drive was permitted to allow for a full stroke. The airflow measurement devices for the secondary air to each corner of the windbox were inspected, cleaned, repaired and an initial out of service calibration performed.

Testing and Tuning Efforts

Upon completion of the outage initial testing, tuning was performed in order to address the fundamentals of combustion in order to achieve combustion optimization. Improving combustion required achieving large improvements in fuel fineness levels as well as fuel and airflow balances. Testing included primary airflow calibration, setting of the curves as noted above, mill performance testing, furnace exit and economizer outlet testing. Initial testing was performed to adjust the classifiers such that they would be close to the desired setting for both fineness and throughput. Once this was set the mill curves were then tuned as shown previously. Then final tuning for fineness was completed by making classifier blade adjustments. This was the sequence due to the fact that adjusting the classifier for improved fineness increases the recirculation rate which can impact the mill end differential vs fuel flow curve developed as well as air to fuel ratios.

Fineness was improved from 9% retained on 50 mesh and 55.5% passing 200 mesh before the outage to 0.4% retained on 50 mesh and 74.2% passing 200 mesh. However, due to capacity requirements the classifier was then adjusted to allow for margin during times when wet coal is supplied, lowering the fineness to 1% retained on 50 mesh and 69% passing 200 mesh.

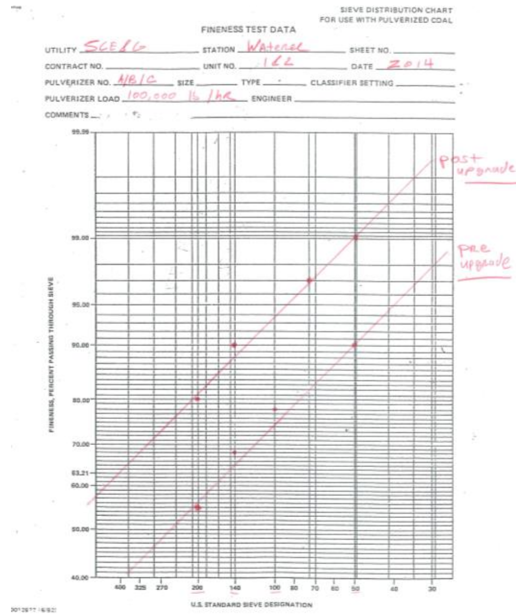

Figure 10 - Before and After Fineness

Burner tuning was then completed first by performing traverses at the furnace exit with a water cooled high velocity thermocouple (HVT) probe to assure an oxidizing furnace. Final tuning was then completed utilizing a data acquisition system in conjunction with multipoint probes at the economizer outlet. This allowed testing efforts to be completed quickly and burner changes made based on each tests' results maximizing productivity.

LOI improvements

Prior to the project, Wateree Station experienced high levels of unburned carbon. This resulted in very large boiler deposits. Following completion of the project. LOI levels ran less than half of that before, between 5-9% LOI. Boiler slagging has been reduced and is no longer an issue. SCR ash has greatly reduced where previously large buildups were found during each outage. Burner damage from outage to outage has been reduced to the point where no additional work was required from the previous outage. The plant has an onsite contractor that samples the flyash several times a shift and reports to plant operations each morning with the feed ash unburned carbon. The following figure illustrates the pre-outage LOI's of 14-21% where they now run 5-9%.

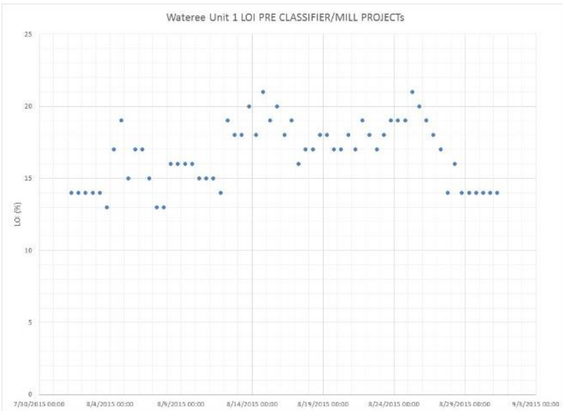

Figure 8: Pre-outage LOI levels

Average Daily Heat Rate

A BTU improvement of approximately 180 BTU/kw-hr was gained by performing this upgrade and performance program. The daily coal consumed and gross generation is recorded each day. The weighted average heat content of the coal is determined by bunker samples and analysis. The improvement of the heat rate is due to optimizing the combustion by balancing the coal flow properly and being able to run the temperatures hotter to the unit and reduce over firing of the coal mills.

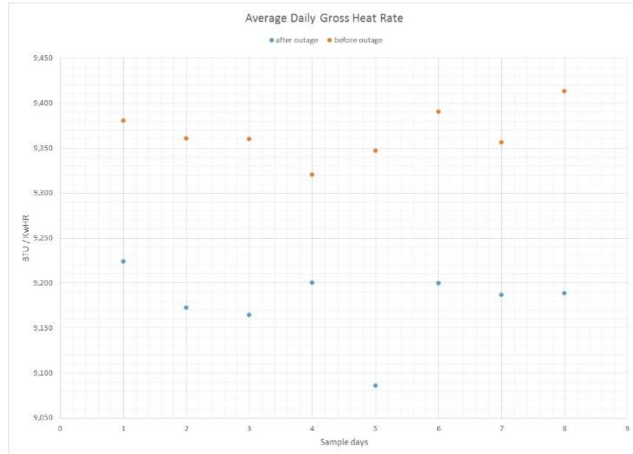

Figure 9: Average daily gross heat rate

Conclusion

Working together, SCE&G and Storm Technologies were able to address Wateree Station's issues of boiler slagging, poor fineness and high LOI levels. This was accomplished by the installation of new static-centrifugal classifiers in conjunction with implementing a comprehensive performance improvement program. This program revolved around addressing the fuel and air inputs at the pulverizer up to the firing system at the furnace. Through the comprehensive program, improvements were made to boiler performance including:

- Fineness improvements to 1% retained on 50 mesh and 69% passing 200 mesh
- Improved clean air balance of +/-2% pipe to pipe per mill
- Improved control or air to fuel ratios
- Improved LOI from 14-21% to 5-9%
- Reduced secondary combustion
- Reduced slagging
- Improvement in net heat rate of approximately 180 btu/kW-hr