ONTARIOPOWER GENERATION

APPLICATION OF H-VARB TECHNOLOGY TO IMPROVE COAL FLOW BALANCE AT NANTICOKE GENERATING STATION

Les Marshall, Sr. Technical Officer, Ontario Power Generation
PO Box 2000, RR#55, Nanticoke, Ontario, Canada, N0A 1L0
(519) 587 2201; les.marshall@opg.com

Prof. Abdelwahab Aroussi, Department of Engineering, University of Leicester
Leicester, LE1 7RH United Kingdom
44 116 252 2539; aa285@leicester.ac.uk

Dr. Jacob Roberts, R&D Engineer, GAIM
Hartshorne Road, Woodville, Derbyshire, DE11 7GT, United Kingdom
44 870 607 8880; jaker@greenbankgroup.com

ABSTRACT

The power generation industry is constantly challenged with the need to improve the emissions and heat rate performance of their assets. In the case of pulverized coal fired units, poor fuel balance at the burners is a relatively common issue that impedes efforts for combustion optimisation. The problem of fuel imbalance is particularly acute on units that employ splitting devices between the pulverizers and the burners.

Ontario Power Generation's Nanticoke Generating Station employs quadrafurcators (one-to-four splitters) on many of its units. These splitters boxes are arranged in the vertical, typically immediately downstream of a 90° elbow which results in exceptionally poor fuel balance - baseline measurements indicate values in excess of +/- 50% (RMS) from the mean. This translates to a number of problems including reduced flame stability and carbon conversion. The generally poor combustion conditions also require increased levels of excess air with the expected negative impact on NO_x emissions, capacity and heat rate.

In 2006, Nanticoke GS installed a Variable Area Rope Breaker (VARB) system supplied by Greenbank Energy Solutions on a single mill serving Unit 2. This technology was developed in the United Kingdom and has since been successfully installed on a number of large (500 MWe) coal-fired units configured with 3-way and 4-way splitters. The trial at Nanticoke represents the first application of the technology in North America. Initial testing of the system indicates a significant improvement in fuel distribution, reducing the imbalance to approximately +/- 15% (RMS) from the mean. The commissioning and testing of the VARB system are described in this paper.

INTRODUCTION

Nanticoke GS, operated by Ontario Power Generation, is located on the north shore of Lake Erie, approximately one hour from Hamilton, Ontario, Canada. The station is comprised of eight units, each with a nominal rating of 500 MW_e. The boilers are of the opposed-fired design and are equipped with five 10E10 ball-race pulverizers per unit. The original design of the firing system employs two large (28") outlet pipes on each mill. Each of these outlet pipes is routed to the centre-line of the boiler where a quadrafurcator is used to split each pipe into four smaller burner lines (14.25"). The resulting eight burners per mill are arranged in three rows on the front wall and two rows on the rear.

A typical Nanticoke piping configuration is shown in Figure 1. The original designers of the piping obviously expected to have problems with a strong rope formation on the outer radius of the elbow. A venturi has been used in the original design with the intention of centering the rope on the splitter box as an aid to distribution. However, in practice this venturi is simply not aggressive enough to disperse the rope. Physical and computational models as well as field measurements confirm that the rope quickly reforms on the outer wall. This results in two of the four outlet pipes being heavily loaded with pulverized fuel. Table 1 shows the results of physical modeling for one of the groups of row "A. Pipes 3 and 4 in this example are located above the outer radius of the inlet pipe elbow.

Figure 1: Original Arrangement of Nanticoke PF Distributor

Table 1: Typical Baseline PF Distribution

Parameter	Pipe 1	Pipe 2	Pipe 3	Pipe 4
Normalised Distribution (% of mean)	49%	62%	138%	152%
Group RMS Distribution	**45%**			
Maximum / Minimum Ratio	**3.1 to 1**			

THE IMPACT OF FUEL MAL-DISTRIBUTION

The impact of fuel mal-distribution on coal-fired utility units has been well documented elsewhere [1,2]. The specific issues at Nanticoke are by no means unique and may be summarized in three broad categories.

Safety

Fuel lean burners are characterized by very high local air/fuel ratios. At some point, the relatively low energy input cannot maintain the air at combustion temperatures and the flame becomes unstable. This problem is most prevalent at low pulverizer loads where the general air/fuel ratio is already high. This allows unspent fuel to possibly reignite in an uncontrolled fashion downstream of the intended combustion zone. Fuel rich burners will also tend to result in local reducing zones that can compromise the integrity of the water walls.

The possibility of unstable flames (without the use of gas igniters for support) limits the overall turndown of the Nanticoke units. Market conditions have forced the units to be able to perform two-shifting operation to meet the needs of the grid during periods of low demand.

Emissions

Fuel rich burners require that the entire boiler operate with higher levels of excess air. This in turn results in very high excess air levels at the fuel lean burners with a corresponding increase in overall NO_x emissions. In addition, unstable and/or unattached burner flames will almost certainly result in higher levels of NO_x as the combustion process occurs in a relatively uncontrolled, oxygen-rich environment.

At Nanticoke, higher levels of excess air also represent a significant challenge for the relatively small electrostatic precipitator. The original ESP was designed with a specific collection area of 245 $^{-ft}$. The shift to the use of a high PRB furnace blend has reduced the operating SCA to 209 $^{-ft}$.

Economic Performance

This includes the maximum achievable unit load, unit heat rate and carbon content of flyash (for byproduct sales) all of which can be impacted by the fuel imbalance directly or the need to maintain higher than optimal levels of excess air. The required use of auxiliary fuel (natural gas at Nanticoke) to support unstable burners at low loads would also fall into this category.

The carbon utilization performance at Nanticoke has historically been very poor. The carbons in ash (CIA) levels on bituminous coals were approximately 20%. This represents a significant energy loss and yet another challenge for the small ESP. The more recent experience with operation on a high percentage furnace blend (80% by energy) of Power River Basin (PRB) coals has improved the CIA levels dramatically. However, the current performance – about 6% LOI – is still well above industry standards in this regard.

Nanticoke currently operates with a fuel blend of 80% Southern PRB and 20% Central Appalachian bituminous coals. Blending is conducted in the furnace with the pulverizers handling only a pure parent coal by use of selective bunkering. This process has allowed the station to employ a significantly larger fraction of PRB than would otherwise be possible with traditional blending in the coal yard [3].

The move to PRB has of course also created operational issues. The larger PF particle size and higher mass flows have resulted in further degradation of the PF distribution at the splitter boxes. Fuel trials employing 100% PRB at Nanticoke were largely successful. However, a critical issue with slagging on the leading edge of the secondary superheater will restrict operation on pure PRB at full unit load. Not surprisingly, the mechanism for this slagging has been traced back to fuel rich zones created by poor fuel distribution. The issue of PF balance continues to be the major combustion related problem at the station.

SOLUTION APPROACH

Background

In 2004, development work on a new type of PF distribution device came to the attention of OPG. Greenbank Energy Solutions Incorporated (GESI), part of the Greenbank Group, had recently completed the design and development of a new type of fluidic mixing device called the VARB (Variable Area Rope Breaker). Several VARB devices had been installed in stations in the United Kingdom to assist with serious PF mass balance issues in trifurcators.

The VARB^{TM} family of devices are considered to be geometric fluidic mixers. They operate through a variety of modes and work by moving both fluid mass of air and momentum of the pulverized fuel phase. The VARB was developed by Greenbank Advanced Instrumentation and Measurement (GAIM), the research and development division of the Greenbank Group.

Operation

The solution offered to OPG was the H-VARB complete with a newly designed quadrafurcator and control gate device. This equipment was installed as part of a full scale trial of the technology at Nanticoke GS on mill 2A during its fall 2006 outage.

The H-VARB in essence operates like an aggressive non-uniform venturi. However, the design of the H-VARB overcomes many of the short comings of the non-uniform venturi. An aggressive venturi works by presenting the flow with an obstacle, which moves the pulverized fuel into the centre of the stream. A non-uniform venturi has by its nature incredibly high-pressure drop (and high wear) and does not deal with issues such as reattachment of solid phase in vertical lines or drop out in horizontal lines.

Reattachment occurs in most splitting devices due to the action of secondary flow patterns in the air and momentum of the pulverized fuel phase. This normally leads to certain devices moving a heavy rope away from the back of the pipe into the centre for only a few pipe diameters.

The H-VARB device is able to overcome the pressure drop issue by its design that allows minimal constriction of the pipe. It is also able to prevent reattachment and drop out due to its unique shape that disrupts secondary flow patterns and alters the path of the pulverized fuel. In addition the unique cross section is designed to spread the pulverized fuel in the centre of the pipe promoting mixing. The issue of accelerated pipe wear is handled by lining the internal surfaces of the device with ceramic tiling and abrasion resistant wear linings

The fluidic mixing shape is unidirectional - precise placement and orientation of the device is necessary in order to optimize operating conditions. Computer modeling is used to place the device in the appropriate location. Computer modeling is also used to optimise the shape of the VARB, which has given birth to several standard variants of the original VARB shape for special scenarios. The various shapes are tested in GAIM's scaled testing facilities to confirm and validate the computational data on the devices.
The control gate device, which is fitted after the VARB but before the splitter, is designed to fine tune the dispersed material to provide a better split and in some stations allow biasing of the pipe legs

Development

The VARB development was the product of the close association between the University of Nottingham and Greenbank Terotech LTD in the United Kingdom. This lead to the creation of the joint venture company GAIM and through use of the research environment was able to aid in the development of several important products.

The procedure involved in the development of the H-VARB began with simple concepts and looking at established devices and flow phenomena. In the development of the H-VARB particular interest was given to ways of moving material from the bottom of the pipe into the centre of the pipe and suspending it there using flow phenomena.

The next step was to model the existing geometry to replicate the pre-modification flow conditions. Then model a variety of possible designs that took advantage of these flow phenomena and test the devices computationally. This process involves various iterative modeling programs utilizing computational fluid dynamics (CFD). The most promising designs are developed further and optimized computationally.

Once the design had been optimized, several variables were chosen to be altered as part of a parametric study of the device to see how these changes affected the performance of the device. These were again modeled and computationally validated then experimentally validated on a 1/3 scaled pneumatic conveying rig.

The rig is designed to represent the same conditions in a power station and dynamically scaled to one-third the physical size. Many parts of the rig are Perspex allowing laser techniques such as particle image velocimetry and laser sheet visualisation to be undertaken to examine the flow phenomena. The rig also collects the split material into individual weigh hoppers to monitor the degree of improvement a device makes to the split.

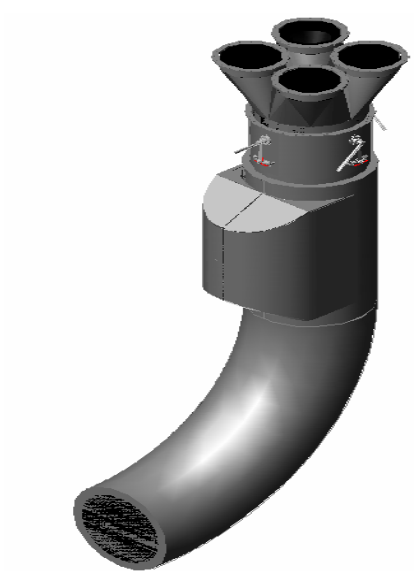
Built into this design process is constant communication with the parent company using their years of experience to advise on the practicality and function of the devices in the field and has lead to the development of the VARB™ family of devices.

COMMISSIONING AND RESULTS

The H-VARB retrofit of mill 2A was completed during an outage in the fall of 2006. The new components, shown in Figure 2, were designed to fit between the existing flanges of the original equipment. The scope of supply included two new quadrafurcators that are designed to take advantage of the diffused coal rope in the centre of the pipe work. These splitters also have the additional benefit of a lower pressure drop vis-à-vis the original devices.

The installation of the H-VARB's also included a dedicated PF-Master system (also supplied Greenbank) for monitoring pf flow conditions in the individual burner lines.

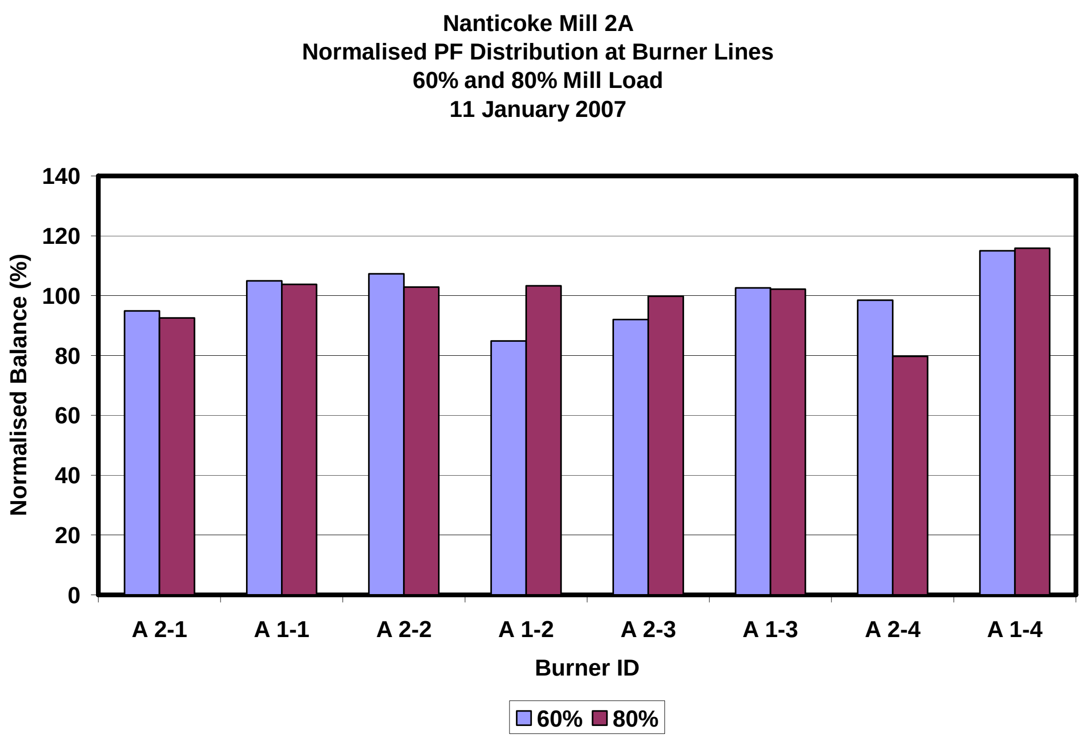
Figure 2: Configuration of H-VARB components on Nanticoke Mill 2A



The original observations of PF balance on the test mill were rather disappointing. Measurements of relative coal flow on group 2 via the PF Master system indicated very little improvement on the base case – two burners were very fuel rich while the remaining lines in that group were correspondingly fuel lean. This was also confirmed by direct visual observation of the burner fires. At this point, the commissioning team realized that the pipe layout immediately upstream of the H-VARB installation did not seem to match the configuration in the piping drawings supplied to design the system. The CFD was modified to reflect the actual piping run in the field. This new information established the "true" location of the rope at the inlet elbow to the group 2 H-VARB and the designers recommended that the VARB be rotated on it's flanges to place the rope on the "spine" of the device, per the initial design.

The impact of rotating the VARB was both immediate and positive. Control gate tuning continued using the PF Master sensors for feed back. During this period, the load on mill 2A was limited by a primary air flow issue (not associated with this trial). At the conclusion of the initial tuning runs, the burner line PF balance was on the order of +/- 10% RMS. Figure 3 shows the results for mill loads up to some 42 tonnes/hour.

Figure 3: Initial PF Balance Results for H-VARB Retrofit



Modifications to the primary air control system allowed the mill load to be increased to the throughput necessary for boiler operation at MCR. At these higher loads, two observations became readily apparent.

PF Master Signals

The PF Master sensors were installed immediately downstream of the new quadrafurcators. This location was identified as questionable by the vendor but installation in the ideal locations (straight, vertical runs) was not viable during this outage. Nevertheless, the equipment appeared to work well up to the point of increasing the mill load to maximum. At mill loads in excess of 90%, the signals became very "noisy". This scatter in the raw data in turn yielded a step change in the perception of PF mal-distribution – the calculated RMS balance changed from +/- 10% to more than +/- 20%.

This sudden change in performance seemed unlikely as the combustion performance of the unit was not observed to deteriorate. Further investigation indicated that the erratic behaviour of the PF Master signals was directly related to a small instability in the mass flow of the primary air.

Pulverizer Outlet Mass Flow Split

Nanticoke Unit 2 is equipped with 10E10 mills each of which is configured with two large (28”) mill outlet pipes. The design of the two H-VARB’s for this mill assumed an equal coal flow at the inlet of each device – an even 50/50 split at the mill outlet. Analysis of the data during tuning indicated that this was true only for the lower portion of the pulverizer load range. At mills loads in the 80-100% range, the measured PF mass flow split was seen to vary by as much as 3% (i.e. a 47/53 split). This change in mass flow is relatively minor for the VARB but the variance in flow between the two groups translates directly to a mal-distribution for the mill as a whole. This phenomenon has been observed previously at Nanticoke and is attributed to the lower air/fuel ratio (1.45 to 1 at maximum mill load) associated with higher mill loads.

Performance Analysis

The uncertainty in the PF Master signals discussed above made a complete quantitative assessment of fuel distribution problematic. The Nanticoke team was encouraged by the results observed at the low and mid-range of the mill load and considered these to be representative of the actual performance of the device. Two important qualitative indicators were then assessed for the unit 2 trial. First, direct observation of the lower furnace conditions with mill 2A in service revealed a significant improvement in the furnace environment. This region was visibly brighter when compared with the pre-retrofit case. Second and perhaps more important, the operations staff of Unit 2 have now started to employ mill 2A for low load unit operation, running the mill at the full design turndown of 2:1 without the need for auxiliary fuel support. Low load flexibility was one of the key drivers for this project.

NEXT STEPS

Based on the positive results of the single mill trial, OPG has commissioned a full boiler set of VARB devices to be installed on a single unit in the fall of 2007. Modifying all burner rows will allow for an assessment of the impact of improved distribution on the unit as a whole. This same unit will also be the host for a biomass co-firing system that will go into service in the summer of 2007. Fuel distribution at the splitter boxes is expected to be a significant problem when handling the larger biomass particles. These projects represent an opportunity to assess the impact of biomass and coal distribution on the performance of the co-firing system.

ACKNOWLEDGMENTS

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REFERENCES

[1] Cleaner Coal Technology Programme, Roshan Kamall, Department of Trade and Industry, 1 Victoria Street, London, January 2001

[2] Real Time Coal Flow and Particle Size Measurement for Improved Boiler Operation, S.Laux, J. Grusha, K. McCarthy, and T. Rosin, presented at Power-Gen 99, New Orleans, LA, November 30 – December 1, 1999.

[3] Marshall, L.W., 2005, “The Use of Selective Bunkering to Optimise PRB Utilisation at Nanticoke Generating Station”, Proceedings of Electric Power 2006.