PERFORMANCE OF WATER CANNONS AT LABADIE

Charlie Breeding/ Clyde Bergemann

ABSTRACT
Ameren’s Labadie station consists of 4 coal fired 600 megawatt size generating units. Unit 1 installed water cannon furnace cleaning devices during a spring outage this year. Water cannons were selected to clean the deposits that result from combustion of Powder River Basin (PRB) coal at the Labadie power plant. This paper describes the evaluation of methods of cleaning furnace walls and the selection, installation, and startup experience with water cannons. Cleaning the furnace results in an increase in boiler efficiency that is translated into improved heat rate and improved cost of plant operation. Benefits from water cannon installation are described along with the problems encountered. PRB fuel combustion results in tenacious deposits that inhibit heat transfer on furnace walls. PRB coal typically has a lower ash fusion temperature than bituminous coals which leads to ash slag formation in furnaces that have been changed to PRB from the fuel the boiler was originally designed for. Often the deposit from PRB fuel is of a minimal thickness, however the reflectivity of the deposit creates a high barrier to radiant heat transfer. High Furnace Exit Gas Temperature (FEGT) indicates poor heat transfer in the furnace area and this increases the formation of slag in convection passes. Cleaning of furnace surface is critical to maximizing the heat absorption of the furnace and reducing the FEGT. The increased clean capability of the water cannons compared to existing wall blowers will be compared in this paper.

INTRODUCTION
The four unit Labadie station is an AmerenUE plant with 600 Megawatt Combustion Engineering boilers. The boilers are of the tangent fired type. The first unit went into service in 1970. Recent modifications included low NOx burners, conversion to PRB coal and the addition of water cannon cleaning.

The necessity to keep power plants at top performance is more important than ever in the changing electric utility environment. Top performance means economical performance and compliance with environmental regulations. Conversion to Powder River Basin (PRB) fuel is one of the modifications Labadie has chosen to achieve top performance. PRB coal has a number of attractive attributes. It is relatively low in cost, has a low sulfur content, and there is a reliable supply. However, PRB coal has higher moisture, lower energy content, and different ash composition than eastern bituminous coal. The ash composition can result in deposits on furnace walls that are difficult to remove and impact plant operation. This is true to some extent for all coal fired boilers. Initially developed in Europe, the water cannon can remove ash deposits and help coal fired plants achieve top performance.

The first U. S installation of a water cannon furnace cleaning system was at a 550 megawatt Texas power plant burning PRB coal 5 years ago. Since that time more than 60 units in North America have installed these devices to clean the furnace area of deposits. The units represent more than 30,000 megawatts of generation. In Europe there are more than 80 plants are equipped with water cannons. This paper will describe how these systems work and review the impact of installation of water cannons and the justification used by utilities for their installation in North America. The Labadie installation provides a demonstration of cannon performance.

Furnace slagging:

The ash component of coal can leave significant deposits on the heat transfer surfaces of the furnace. In the high temperature range of the furnace slagging can be particularly tenacious and cannot always be removed by steam and air blowers. Manual lances using water had been used to clean deposits off furnace walls. The success of this technique lead to the mechanization of the lance into the water cannon. Water was also the medium used in water lances, which are a adaptation of the steam wall blowers.

Deposits are formed when the ash in the flue gas is at a temperature above its melting point. The laboratory term for the initial melting point is the initial deformation temperature. Typical values of initial deformation temperature for PRB coal
are in the 2100°F to 2200°F range. With typical gas temperatures of 2500°F in the furnace, the ash is in a semi-molten condition and when it comes in contact with furnace water walls that are at a relatively cooler temperature, a deposit is formed.

The majority of the ash passes through the boiler and is collected in the ash removal equipment (electrostatic precipitator or bag house). However, even a small portion collecting on the heat exchange surfaces can have a dramatic impact on plant performance. Not only is there an insulating effect from the deposit, but there is also a change in the emissivity of the surface. Surface emissivity is critical to heat transfer in the furnace area since most of the heat transfer is from radiant heat. The general equation for radiant heat transfer is:

\[ Q = \sigma \varepsilon S \left( T_1^4 - T_2^4 \right) \]

where:

\[ Q = Btu/hr \]
\[ \sigma = 1.71 \times 10^{-8} \text{ Btu/sq ft/hr/}T^4 \]
\[ \varepsilon = \text{emissivity factor} \]
\[ S = \text{area, sq. ft.} \]
\[ T_1 = \text{temperature of gas} \]
\[ T_2 = \text{temperature of surface} \]

Some coal such as PRB contains large levels of calcium oxide and magnesium oxide, which are major sources of the reflective property of PRB ash deposits. Calcium oxide can be in the 24% range for PRB coal when compared with 1 to 2% for eastern coals. Also, magnesium oxide is in the 5% range for PRB coal compared to about 1% for eastern coals. The normal emissivity of a boiler tube with a coating of iron oxide is from 0.85 to 0.89. However, a slag deposit can reduce this value to 0.5, and thus have a significant effect on the amount of heat absorbed by the furnace. From the radiant heat transfer equation it can be seen that this reduction in emissivity (or increase in reflectivity) would reduce heat transfer by almost half. This reduction of heat absorbed in the furnace results in hotter furnace exit gas temperatures. Less heat is absorbed by the water walls and therefore more heat must be absorbed by the superheater and reheater sections in the convection passes to maintain full load steam conditions. It is often the case that this upset in boiler balance is enough to reduce the capacity of boilers. The higher furnace exit gas temperatures usually result in hotter stack gas temperatures and therefore lower boiler efficiency. A reduction in boiler efficiency increases heat rate and therefore increases the cost of generation. The elevated temperatures of the gas leaving the furnace often results in ash entering the convection passes containing ash that is above its fusion temperature. Thus this ash will deposit on the superheat and reheat surfaces and yet further reduce the ability of the furnace to make steam conditions. High temperatures that exist in the furnace for longer time periods also result in more production of thermal NOx.

Furnace cleaning:

The traditional method of furnace cleaning is the retractable wall blower. This device is inserted into the furnace wall through an opening. The blower tube rotates while a jet of steam or air is sprayed on the furnace wall to clean off deposits. A blower typically can cover a 10-foot diameter area.

Wall blowers are often not adequate to clean boilers that are burning PRB, lignite, or other coals that form furnace deposits. Water lances were developed to clean larger areas and use a water jet as the cleaning medium. This device is a modification of the retractable sootblower. It sprays a jet of water back on to the wall it is mounted on in a spiral pattern as it is inserted into the furnace.

Water cannons spray a jet of water from an opening in the furnace wall to the opposite wall. In most installations a cannon can clean from the nose arch to the bottom slope tubes and from one side to the other. Thus 4 cannons, one on each wall, can clean an entire furnace. This is the type of installation at Labadie. A water jet of specific density, velocity and path speed is produced by a special nozzle, crosses the boiler inside and impacts on the slagged wall surface. The cleaning effect is based on the fact that the impacting water which penetrates the topmost layer and expands into steam. In this way the slag is broken up and removed from the surface.

Water cannons offer a number of advantages over conventional wall blowers and water lances. The large number of wall blowers and/or water lances requires an extraordinarily high maintenance expense. The use of steam, air, or high purity water as cleaning agents results in high operating costs. Water cannons use filtered water with a clear reduction in cost. The water cannons also allow areas to be cleaned that cannot be outfitted with wall blowers and water lances. Division walls, nose arches, and bottom slope tubes are examples of areas routinely cleaned by water cannons.

Intelligent soot blowing

The water cannon mechanism allows for 90 degrees of movement in both the vertical and horizontal planes. Variable
speed motors drive the mechanism providing for constant speed of the water sweeping across the furnace wall. The speed of the water jet moving across the wall is referred to as Jet Progression Velocity (JPV). EPRI studies (ref. 1) and actual experience indicates that the JPV is directly related to the thermal impact on water wall tubes. A JPV of 300 ft/min. results in about 100 degrees F metal temperature excursion. Computer control of the cannon operation allows for any area of the boiler to be bypassed by the cannon spray. Thus, over fire air ports, manholes, burners, and any other special area can be excluded from the water spray. Also, special zones can be created, to clean above burners, or bottom slope tubes, or any other troublesome surface.

Traditional boiler cleaning was done on a global time or condition basis. Operators monitored steam temperatures and operated the cleaning devices to control drops in steam temperature. Blowers were set up to run in a set sequence. Often blowing was set on a time basis such as every 12 hours, every shift, once per night. This type of operation often resulted in the blowing operation following a build up of deposits, it did not act to clean deposits as they occurred. When computer control is applied to boiler cleaning, we often find that the cleaning performance, measured by heat flux improvement, can double.

Water cannon systems are combined with heat flux sensors in the furnace walls to detect deposits and operate the cleaning sequence as needed to keep the furnace in a clean condition at all times. This type of computer controlled automatic system is often called Intelligent Soot Blowing. Heat flux sensors operate with embedded thermocouples in selected water wall tubes. Paired thermocouples detect the heat flux gradient in the tube. The output from the paired thermocouples is monitored and any reduction in heat flux at constant load is associated with deposits forming on the furnace surface. The sensor is also used to determine when an area is clean. With this type of system the furnace cleanliness can be optimized and steady predictable operation is assured. In addition to monitoring the heat flux, the thermal impact on boiler tubes can be monitored. With this system of monitoring and control precise cleaning can be accomplished with minimal impact on tubes. The Labadie unit has 24 heat flux sensors installed in the water walls of the boiler. The control system continuously monitors these sensors to determine the cleanliness of the water walls.

The sensors are used to represent various zones in the furnace. These zones are set up to be cleaned by the cannons when the heat flux sensors detect a decrease in cleanliness. Multiple modes of observation and analysis are used to determine when a zone should be cleaned. If the heat flux characteristic indicates that fouling has reached a certain level, then the associated zone is set into the cleaning cue for cleaning. Cleaning may also be instituted by rapid decrease in the heat flux. This occurs when deposits on the tube wall have become liquid and sinter to form a hard deposit on the wall. This sintering effect can cause a rapid decrease in heat flux and the control system monitors the sensors to detect this. Again, the associated zone is placed in the cleaning cue to be cleaned. The heat flux indication has a characteristic frequency that is related to the “flicker” of the combustion. As the sensor becomes covered with deposit this frequency is dampened. The software in the control system monitors the frequency of the sensor output and reacts to the dampened output by identifying the associated zones for cleaning. Labadie has installed 24 sensors in the water wall tubes of the boiler.

The control system is automatic in operation. Unit conditions such as load and attemperation spray flow are set up as permissive limits for cannon operation. A lower limit can be specified for load, below which the cannons do not operate. Spray flow is also a clear indicator of the condition of the convection pass superheater and reheater steam condition. At low spray flows, cannon operation is limited. Thus the control system reacts to changing unit conditions to operate the cannons when they are useful. Cannon operation has assisted Labadie in keeping the unit running for long periods of time with minimal spray flow.

Performance of Water Cannons at Labadie

Data were recalled from the PI system at Labadie to look at trends in plant parameters related to water cannon operation. The selection criteria for these data were a steady, full load on the unit and some change in the operation of the water cannons. During a recent 3-month period, there were periods when the cannons were out of service for maintenance. Data during this time were plotted to determine trends.

On January 25, 2002 the water cannons were out of service for about 5 hours for maintenance. The plots at the end of the paper relate cannon operation to unit load in Mw, Furnace Exit Gas Temperature (FEGT), and NOx.

These data indicates that without the operation of the water cannons, FEGT increased about 40°F in the 4½-hour period that the cannons were out of service. Once the cannons were placed back in service, the FEGT returned to its previous level. It is likely that FEGT would have even been hotter if the cannons had remained off for a longer period of time. As a deposit builds up on furnace walls, the water walls absorb less heat. Thus, the heat from combustion is carried further up in the boiler. Deposits on boiler walls insulate the water walls. Deposits from PRB coal have and added problem in that they are reflective of the radiant heat. This is the result of the high levels of calcium oxide and magnesium oxide in the PRB ash (ref. 2). Because radiant heat is the primary means of heat transfer in the furnace section of the boiler, the reflective nature of the ash has serious effects on heat transfer as we have discussed previously.
NOx levels increased by about 10% with the cannons off. The level of NOx reduced when the cannons were restored to service. This is likely the result of the increase in furnace temperature. Thermal NOx is created by high temperatures. It is also a function of the time that these temperatures exist. Water Cannon operation reduces the duration of high furnace temperatures. NOx levels would have increased even more if the furnace had continued to develop deposits and increase in exit temperature.

Conclusion:

Labadie experience with the cannons indicates that they effectively remove deposits that inhibit heat transfer in the furnace. The ability to maintain full load while burning PRB coal has been demonstrated. The cannons reduce furnace exit gas temperature and reduce NOx. There has been a significant reduction in maintenance requirements from the previous wall blowers and water lances. The ability to program the control system so that it is custom fit to the Labadie operation adapts the operation of the cleaning system to the conditions at the unit. The heat flux sensor information provides cleaning to the areas of the furnace that are fouled and does not clean areas that do not need cleaning.

References:
1. EPRI research project 1650-1 Report CS-4914 “Water Blowing of Fireside Deposits in Coal-Fired Utility Boilers” Nov. 1986