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Controlling Air Heater Pressure Differential through Dynamic Speed Control and Targeted Deposition Depth

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ABSTRACT

As demands for increased NOx reduction collide with aging catalyst, higher ammonia slip and higher sulfur fuel, management of air heater differential pressure is becoming a major source of operational concern. Despite the best efforts of plant operating departments, and the latest technological developments aimed at controlling all manner of fouling related issues, many plants still experience nagging and expensive air heater fouling problems. Following installation and commissioning of SCRs on both operating units, Duke Energy's Belews Creek generating station experienced similar, recurring air heater fouling issues.

To combat the negative effects of air heater fouling without sacrificing plant NOx performance, the station's engineering group developed a novel and reliable method for on-line cleaning of even the most tenacious deposits. This method involves integrated control of the rotational velocity of the air heater rotor with respect to the stationary position of its dual-media retractable sootblowers.

This presentation will discuss the evolution and development of the technology at Belews Creek along with lessons learned during the process. It will also discuss case studies taken from additional installations at plants beyond Belews Creek. Specific attention will be paid to additional findings derived from dynamic speed control (DySC). These include; 1) on-line control of condensate deposition depth (and air heater differential pressure) through coordination of the rotor speed with pre-air heater condensable data and, 2) reduced particulate opacity spikes generally caused by air heater cleaning.

INTRODUCTION

Much has been written and presented about the negative effects of sulfuric acid and ammonium bisulfate vapor in the flue gas stream from the economizer outlet to eventual gas discharge from the stack. As the installed base of Selective Catalytic Reactors (SCR) and Wet Scrubbers (FGD) increases, and as plants subsequently move to higher sulfur coal for economic value, these problems have become increasingly evident. One of the most immediate and apparent problems is the deposition of sticky condensable material in the air heater baskets leading to increased pressure differential and possible pluggage.

Historically (meaning before the advent of ammonia based DeNOx controls) coal fired generating stations maintained their air heater outlet gas temperature in accordance with Average Cold End Temperature (ACET) guidelines. The ACET figure is based on the average value between the cold air inlet to the air heater and the cold end gas outlet temperature. For example, an air heater with a cold air inlet of 100˚F and a cold end gas outlet temperature of 300˚F would have an ACET value of (100˚F + 300˚F)/2 = 200˚F.

The actual required ACET value is a direct function of the level of SO_3 in the flue gas stream entering the air heater. Since free SO_3 combines with free flue gas water vapor to form sulfuric acid vapor at temperatures below 400F, the goal is to keep the outlet gas temperature above the dewpoint of the acid vapor. However, several studies of the condensation mechanism of sulfuric acid vapor suggests that the vapor preferentially condenses on the cold metal plates, and that maintenance of the air heater basket metal temperatures is more critical to the fouling mechanism than the actual gas temperature itself.

COLD END DEPTH CONSIDERATIONS

In the mid-1980s EPRI commissioned a project to Lehigh University to develop a rigorous heat transfer model applicable to all rotating media air heaters. The output of the model, among other things, defines the maximum and minimum metal temperatures present at any depth, as defined from the gas side cold end outlet. Intuitively, the minimum metal temperature at any depth will be at the point where the media first rotates in from the cold air side, and the maximum metal temperature at the same depth will be at the point just before the baskets transition from the flue gas side back into the cold air side.

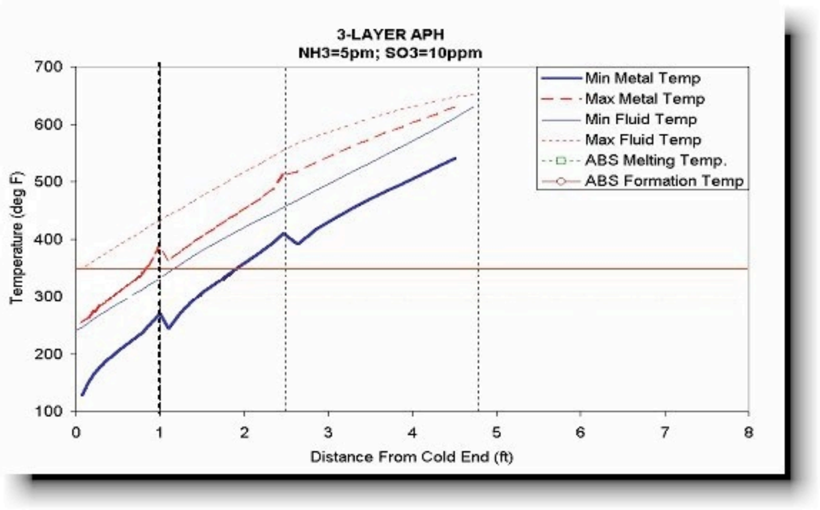


Figure 1 - Typical Three Layer APH Model Output

What is interesting to note is that most air heaters exhibit a maximum metal temperature, at 12" from the cold end outlet, of between 300˚F and 310˚F. 310˚F corresponds to an SO_3 content of 65ppm. Without the presence of the SCR as a secondary SO_3 source, and assuming a 1% furnace conversion of SO_2 to SO_3 then this would mean that all acid deposition from readily available US high sulfur coals would occur in the last 12 inches. Historically, most pre-DeNOx air heaters employed 12" cold end baskets.

With the advent of ammonia based DeNOx equipment, under-utilized ammonia now enters the air heater along with the SO_3 and water vapor. Depending on the reaction temperature and ratio of free ammonia to free SO_3, either ammonium sulfate or ammonium bisulfate is formed during the air heater gas transition. As with sulfuric acid vapor, the ammonium bisulfate vapor will condense out on the cold metal plates at a temperature consistent with the concentration of the vapor. For reference purposes ammonium bisulfate (ABS) is a solid at 297˚F, generally forms a condensate layer at a temperature between 300˚F and 350˚F, and then evaporates back into its constituent components at temperatures between 450˚F and 500˚F. All of these temperatures are dependent on the concentration of the ABS vapor.

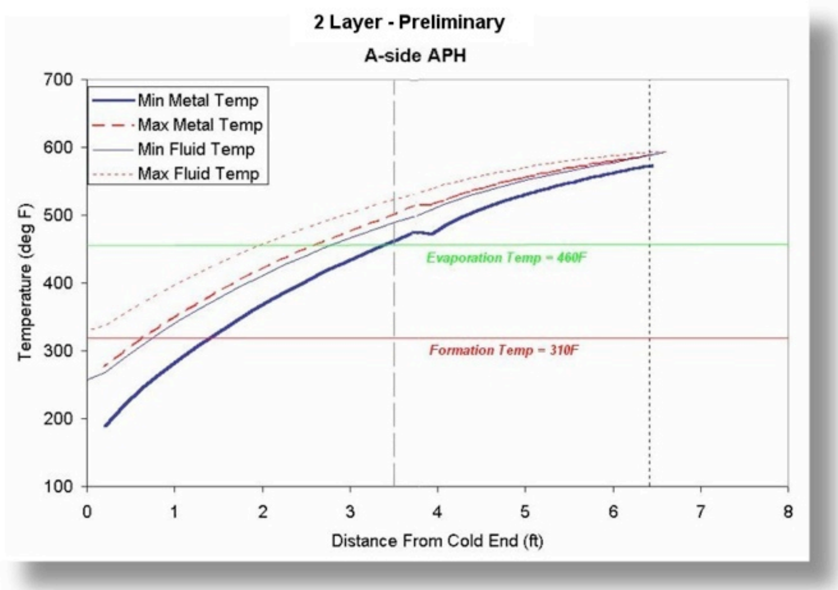


Figure 2 - Typical ABS Tolerant Air Heater Model Output

As can be seen from the above air heater metal temperature graph, the new ABS tolerant baskets often have cold end depths exhibiting maximum metal temperatures in the 450˚F to 500˚F range. This temperature is consistent with self evaporation of any condensed ABS.

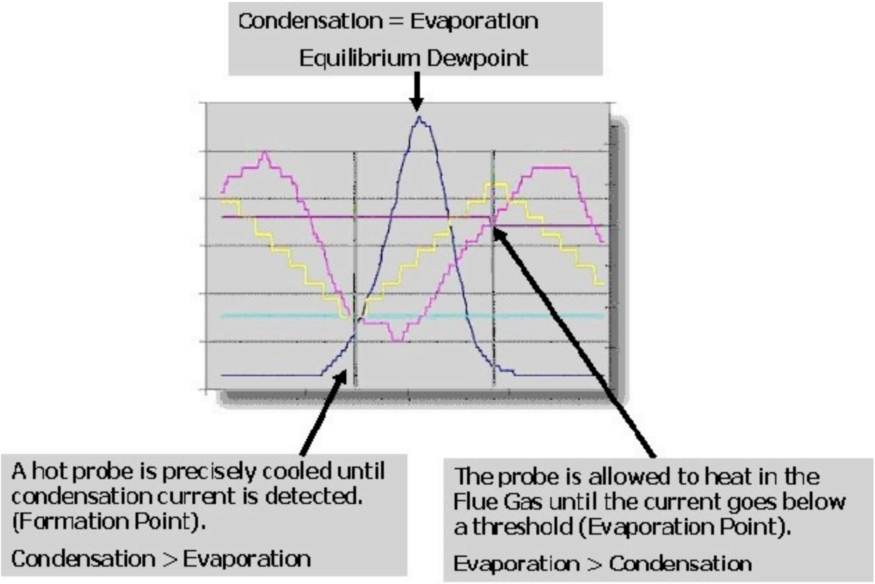
The key, then, to controlling air heater cleanliness (and pluggage) is to keep the evaporation temperature of the condensable material below the maximum metal temperature at the inlet to the cold end layer, and to keep the formation temperature of the condensable material as close to the cold end outlet as possible. This can be accomplished by one, or both, of the following actions:

- Maintain the concentration of the condensable material so that deposition occurs in a targeted, cleanable, depth. This can be accomplished by controlling the ammonia injection rate so that the total ABS concentration at the AH Inlet matches the desired deposition concentration, and
- Maintaining the metal temperatures so that the Maximum cold end metal temperature exceeds the measured condensable Evaporation temperature. This can be accomplished by controlling the air heater heat transfer rate (steam coils, bypass dampers, etc.) or by adjusting the minimum and maximum metal temperatures by controlling the air heater rotational speed. We refer to this second process as Dynamic Speed Control or DySC.

THE PROCESS TOOLS

Condensables Measurement Instrument

The AbSensor - Condensables measurement device uses a kinetic algorithm to detect condensables related temperatures. These temperatures are labeled as Formation Temperature and Evaporation Temperature as seen in the figure below.



Condensation = Evaporation
Equilibrium Dewpoint

A hot probe is precisely cooled until condensation current is detected. (Formation Point).

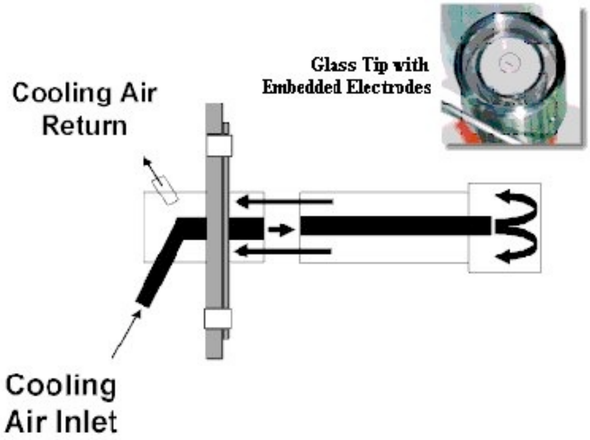
Condensation > Evaporation

The probe is allowed to heat in the Flue Gas until the current goes below a threshold (Evaporation Point).

Evaporation > Condensation

The Breen Energy AbSensor - Condensables measurement device consists of a highly polished glass surface with electrodes embedded therein. The kinetic algorithm then varies the cooling flow rate to the back of this glass tip to change the temperature of the glass surface which sits in the flue gas. At the beginning of a measurement cycle the tip temperature is high enough to not cause any material to condense. The tip temperature is then varied at a controlled rate creating a temperature dynamic similar to the metal plates in the Air Heater. When the temperature of the tip is sufficiently low, material begins to condense on the tip and a current is recorded by the device. This temperature is noted as the **Formation Temperature**. The cooling air to the tip is then reduced in a controlled fashion and the tip temperature begins to rise.

As long as the tip temperature is below the equilibrium dewpoint, more material continues to condense on the tip thereby increasing the current as measured by the device. As the tip temperature crosses the equilibrium dewpoint, the material starts to vaporize faster than it condenses and the total material on the tip begins to go down. This results in the current going down until it goes to 0. The temperature at which the current goes back to 0 is noted as the **Evaporation Temperature.**



A great deal of information can be determined from the Formation (FmT) and Evaporation (EvT) temperatures of condensable material. For the purposes of this discussion the following is important:

- When the differential between FmT and EvT is less than 30 degrees, the condensed material is essentially a single compound and the dewpoint is, for all practical purposes, the average of the two values,

- When the differential between FmT and EvT is greater than 30 degrees, the condensed liquid contains more than one compound.
- In all cases, we interpret the dominant species in the condensable to be determined by its EvT and the relative concentration by the FmT.

Dynamic Speed Controller

Following implementation of SCRs for NOx control, the engineering staff at Duke's Belews Creek generating station noticed an unacceptable rate of increase in the pressure differential across their air heaters. While this was not unexpected, demands on plant NOx reduction targets did not allow a great deal of flexibility in ammonia injection rates.

During a high pressure water wash to remove ABS deposits, plant engineers noticed that the majority of the fouled gas passages were near the circumference of the air heater rotor. Further study revealed that the residence time of each individual gas passage over the cleaning media nozzle decreased linearly with the distance of the passage from the axis of the rotor.

In 2006 a process was developed that allowed the plant to insert the cleaning sootblower to a specific (or indexed) position and then adjust the rotational speed of the rotor to provide the same localized residence time as was determined when the sootblower nozzle was closest to the wheel's axis. Sequential indexing and readjustment of rotational speed led to patent filings for an on-line cleaning process known as DySC.

TARGETED DEPOSITION DEPTH

Armed with the knowledge of actual condensables concentrations (Evaporation Temperature) a strategy was created to provide an intuitive feedback to the plant operators. This feedback assumed a desired deposition depth and called that the "Target" or "Zero" depth. This depth is actually determined based on historical analysis of the plant's air heater cleaning process and determining the tolerable depth where condensable formations can occur and still be removed by the sootblowing system.

Once the target depth has been determined, an algorithm is placed in the DCS logic that translates measured formation temperatures into actual deposition depths. This algorithm is based on the site specific air heater heat transfer model and determines the depth where the measured formation temperature intersects the minimum metal temperature curve.

If the actual deposition depth matches the targeted deposition depth then the depth deviation factor is zero. If the actual deposition depth is deeper than the target, the differential (in inches) from target is determined and reported back to the operator. A similar, though negative, deviation is reported when the actual deposition is closer to the cold end outlet than targeted. Data for a three day period is shown below:

Figure 3 - Three Day Targeted Depth Comparison

Several items are noteworthy from the above data:

- The targeted depth is shown at 14 inches.
- The "B" side deviation value is fairly stable compared to the target zero.
- The "A" side deviation is close to the target at low load conditions but departs dramatically at high load conditions. Using the 14 inch base depth, depositions as deep as 34+ inches were reported on two occasions.
- The more stable "B" side actually shows deposition below the target at high loads and above the target at low loads. This is likely due to changes in boiler O2 and resultant SO3 between the two load conditions.
- While it cannot be seen from the data, a catalyst replacement was conducted recently.

Figure 4 below shows the same data from the same air heater during the peak NOx months last summer, and before the catalyst replacement.

Figure 4 - Two days of Target Depth Comparison

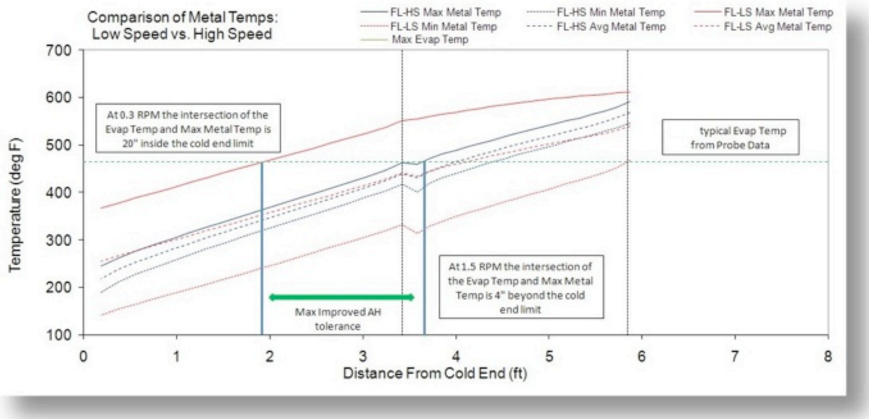
Several items are noteworthy from the above data:

- The targeted depth is now shown at 20 inches. This is due to the excess ammonia slip resulting from the aged catalyst
- The “A” side deviation value is no fairly stable compared to the target zero.
- The “B” side deviation swings from several inches below target at light loads to 15+ inches above target at high load. Considering that the target is 20 inches this results in deposition as high as 36 inches into the air heater, approaching the cold end entry point.
- Historically, the “B” side air heater showed the higher differential pressure

DYNAMIC SPEED CONTROL

Once the variable speed drive mechanism is in place for the DySC cleaning process it can be further employed to adjust the maximum metal temperatures with a much smaller impact on heat rate.

The following graph shows the relative min/max metal temperatures for an ABS tolerant air heater as calculated by the heat transfer model. The difference between the two graphs is the rotational speed. Full speed at this site is 1.5 RPM and the minimum speed shown is for 0.3 RPM. It should be noted that the minimum speed is used in the DySC cleaning process when cleaning the circumference baskets, but is not generally reached when dynamically adjusting metal temperatures.



At 0.3 RPM the intersection of the Evap Temp and Max Metal Temp is 20" inside the cold end limit

At 1.5 RPM the intersection of the Evap Temp and Max Metal Temp is 4" beyond the cold end limit

Figure 5 - Rotational Speed Comparison

What can be seen from this graph is the following:

- Slowing the rotation speed changed the average metal temperature about 40F
- Slowing the rotational speed changed the maximum metal temperature at the cold end entrance by over 100F,
- Slowing the rotational speed changed the depth at which the ABS evaporation temperature was crossed by almost 24 inches,
- Data is not available to show the effect of the change in average metal temperature on average air outlet temperature, but it is assumed that it will drop. This drop can be made up with steam coils if they are present. Utilizing the two in combination can produce the desired change in gas side metal temperature at a fraction of the steam cost using steam coils alone, and have zero impact on the air side temperature.

SUMMARY

Using closed loop control of both ammonia injection rate and air heater rotational speed can provide positive benefits to the plant:

- Automatic, side to side, biasing of ammonia injection rates to achieve a stable deposition distribution,
- Monitoring the change in targeted deposition depth can provide a clear indication of changes in catalyst activity,
- Automatic adjustment of air heater rotational speed can change the depth of ABS fouling deposits, making on-line cleaning more effective,
- Automatic adjustment of air heater rotational speed can improve heat rate by minimizing the amount of steam or bypass needed to achieve proper air heater performance.