Furnace Air Leakage Modeling

Gerald Weber

Commonwealth Edison Company

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G.E. Weber and
S.J. Gronwold
ComEd
Fossil Division
1411 Opus Pl. - Suite 250
Downers Grove, Il. 60515

Abstract

In this paper an air heater is modeled in both the PEPSE performance mode and the reference based predictive mode (RBPM) to determine the cause of a high air heater gas outlet temperature problem. The air heater model utilized is a portion of a performance mode boiler model for a 230 MW pulverized coal boiler. Using the boiler performance mode model and some minor component additions, the root cause for the high gas outlet temperature is found and determined to be furnace air leakage. This effect is simulated by utilizing the boiler model and associated controls to mix air into the flue gas as it enters the primary superheater.

Introduction

Maintaining and controlling air heater gas outlet temperature near its optimum point is important for maximizing boiler efficiency and precipitator performance. A precipitator performs best at a certain gas inlet temperature that is a characteristic of the ash resistivity profile of the coal being burned. For most low sulfur Western coals, a lower inlet gas temperature leads to better precipitator performance. The boiler efficiency effect is also important. Every 40^0F rise in the air heater gas outlet temperature reduces boiler efficiency by 1.0%. Typically when burning Western coals, a rule of thumb is that lower air heater gas outlet temperature is better for both boiler efficiency and precipitator performance. Often when the stack gas temperature increases, the initial investigation focuses on the air heater.

This paper discusses the utilization of PEPSE to analyze a high air heater gas outlet temperature problem for a 230 MW pulverized coal boiler with a rotary regenerative air heater. The gas outlet temperature was about 50^0F above design. The plant requested an analysis to determine the need for air heater replacement. This unit was designed for high sulfur (>3%) Illinois coal but was converted to low sulfur (<1%) Western coal about twelve years ago. This conversion has significantly changed the amount of air preheating required. When a unit burns high sulfur coal, the air heater gas outlet temperature must be maintained at a higher level than when a low sulfur coal is burned. This is due to the coal's ash chemistry as well as acid dew point considerations. Therefore when a lower sulfur coal is burned, the requirement for air preheating diminishes.

To simulate the boiler operation, a performance mode boiler model was constructed. The performance mode, as opposed to design mode, is proper in this case because the steam/water and air temperature profiles were known for this boiler. Therefore the heat transferred to each major boiler section is measured directly. A performance mode boiler model requires less than half of the time that a design mode boiler model takes to construct. This makes performance mode the method of choice when a plant requires a quick answer to a question and the heat transfer is measured as in this case. Even though there is some accuracy lost in the "what if" analysis, often this loss will be insignificant depending on the desired end result. The performance mode model may be converted to design mode in the future if necessary. The performance mode boiler model is illustrated in Fig. 1.

Analysis

The actual vs. design air heater data is presented below.

Table 1: Actual vs. Design Air Heater Data

	Design	Actual	
		RH	SH
Air Heater Gas Inlet Temperature (°F)	660	651	623
Air Heater Gas Outlet Temperature (°F)	290*	345	330
Air Heater Air Inlet Temperature (°F)	150	74	74
Air Heater Air Outlet Temperature (°F)	585	572	550

* corrected for 6% air heater leakage

Since the unit is now burning Western coal, a lower cold end average temperature is permitted. Therefore, the actual air heater air inlet temperature is 76°F cooler than design. Notice that even though the air inlet temperature has been reduced, the gas outlet temperature is about 50°F higher in the actual case.

A PEPSE performance mode boiler model was constructed for the above boiler to verify the design data. All design water/steam temperatures, air heater air and gas inlet and air outlet temperatures, boiler excess air, and fuel analysis and flow were input to the model. Note that in the initial model, the air heater is in performance mode. The fuel flow for each furnace was controlled to produce the design air heater gas inlet temperature, with air preheating used to match air heater air inlet temperature. With the air heater temperatures controlled at design, the gas temperatures throughout the back pass were very close to the design data provided by the manufacturer. This verified the design values. This is generally good modeling practice because it provides a base point from which to compare actual data.

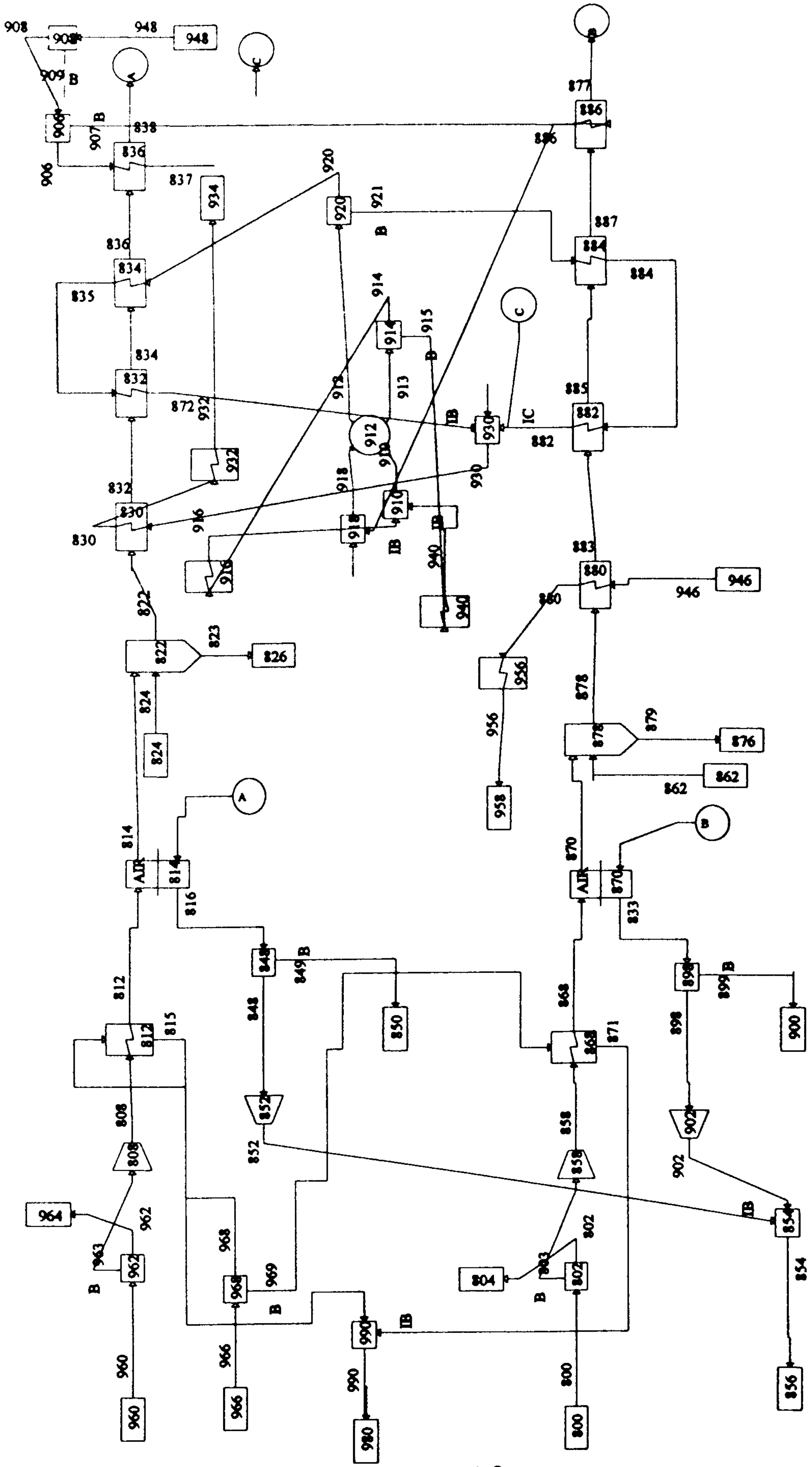

Figure 1: PEPSE Boiler Model

In order to match actual air inlet conditions, the PEPSE model is modified to reflect the 74°F air heater air inlet temperature. This is accomplished by putting the air heater in Reference Based Predictive Mode (RBPM). The difference between RBPM and performance mode is that in RBPM the air heater air and gas outlet temperatures are determined based on design heat transfer data. In the performance mode, the modeler specifies the air outlet temperature, and the only calculated temperature is the gas outlet. The RBPM allows PEPSE to use off design gas and air inlet conditions to determine what the outlet conditions would be if the air heater were performing to specification. The revised model results are presented in Table 2 below:

Table 2: PEPSE Results For the Air Heater Reference Based Predictive Mode(RBPM)

	Design Data in RBPM		Actual Measurements	
	RH	SH	RH	SH
Air Heater Gas Inlet Temperature (°F)	660	660	651	623
Air Heater Gas Outlet Temperature (°F)*	**230**	**230**	**345**	**330**
Air Heater Air Inlet Temperature (°F)	74	74	74	74
Air Heater Air Outlet Temperature (°F)	570	570	572	550

* corrected for 6% leakage

The results illustrate that the air heater gas outlet temperature is above design even when the inlet air temperature matches the current measured conditions. They also illustrate that the air heater gas outlet temperature was not 50°F greater than design, but about 100°F greater. The next task was to calibrate the PEPSE performance mode boiler model to match the actual measured conditions.

To further analyze the problem, the boiler model was then executed in a similar manner to the above design data application. For this case actual steam/water and air heater air inlet temperatures, coal analysis, and excess air measurements were utilized to calibrate the model. We controlled the fuel flow to obtain the correct air heater gas inlet temperature. Note that the air heater was modeled in performance mode for this case. The actual measurements and PEPSE performance mode results are listed below in Table 3:

Table 3: Actual Measured Data vs. PEPSE Model Results

	Actual Measurements		PEPSE	
	RH	SH	RH	SH
Economizer inlet gas temperature (°F)	NA		916	920
Economizer inlet water temperature (°F)	467	467	467	467
Economizer outlet water temperature (°F)	550	550	550	550
Air Heater Gas Inlet Temperature (°F)	651	623	651	623
Air Heater Gas Outlet Temperature (°F)	**345**	**330**	**244***	**234**
Air Heater Air Inlet Temperature (°F)	74	74	74	74
Air Heater Air Outlet Temperature (°F)	572	550	572	572

* corrected for 6% leakage

Notice the air heater outlet gas temperature discrepancy between the PEPSE results and actual measurements. The PEPSE model was calculating about a 100°F lower outlet gas temperature. Note that the PEPSE model results shown in Table 3 correlate with the RBPM results presented in Table 2. All thermocouples pertaining to the air heater were then checked and found to be accurate to within 10°F. Therefore, comparing the results presented in Table 2 with those in Table 3, we can conclude that the air heater is operating near its design condition and was not the major contributor to the high outlet gas temperature problem.

The next possible cause investigated was furnace air leakage. This suspicion occurred for two reasons. If we compared the actual data PEPSE results in Table 3 with the design data PEPSE results in Table 1, we found that the air heater air side temperature increase was about 45 °F greater than design while the gas side temperature drop was 100 °F lower. The governing equation for heat transfer in the air heater is:

$$[M(C_p)dT]_{air} = [M(C_p)dT]_{gas}$$

where:
M = mass flow rate
C_p = specific heat at constant pressure
dT = temperature difference

To support an energy balance, if the gas side temperature drop is lower than design and the air side pickup is higher, an increase in gas mass flow is suspected. The other reason for the suspicion was the economizer heat transfer was about 50% greater than design. This also pointed toward a gas side flow difference. To simulate this effect, we installed an air source and a mixer just after the secondary superheater and after the pendant reheater. To determine the amount of air leakage necessary, we installed a control that adjusted the air leakage until the measured value of air heater exit gas temperature was achieved. This control was in addition to the existing control that adjusted the coal flow until the air heater gas inlet temperature was achieved. The adjusted PEPSE model is shown in Figure 2. The controls for one of the furnaces are listed below:

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** CONTROL FUEL FLOW FOR 651 F AIR HEATER GAS INLET ON RH SIDE
840100 WWVSC 862 651.0 1.0E-3 1.0 TT 877 (Control fuel flow from #862 to achieve 651 F at
stream #877)
840106  7                     (Start control at 7th iteration)
840107  0.5                   (relaxation)
840109  80000.0  130000.0     (Minimum and maximum values)
** CONTROL LEAKAGE FOR 330 F AIR HEATER GAS OUTLET
840200 WWVSC 2  330.0 1.0E-3 1.0 TT 833  (Control air flow from #2 to achieve 330 F at
stream #833)
840206 7                      (Start control at 7th iteration)
840207  0.5                   (relaxation)
840209 220000.0  100000.0     (Minimum and maximum values)
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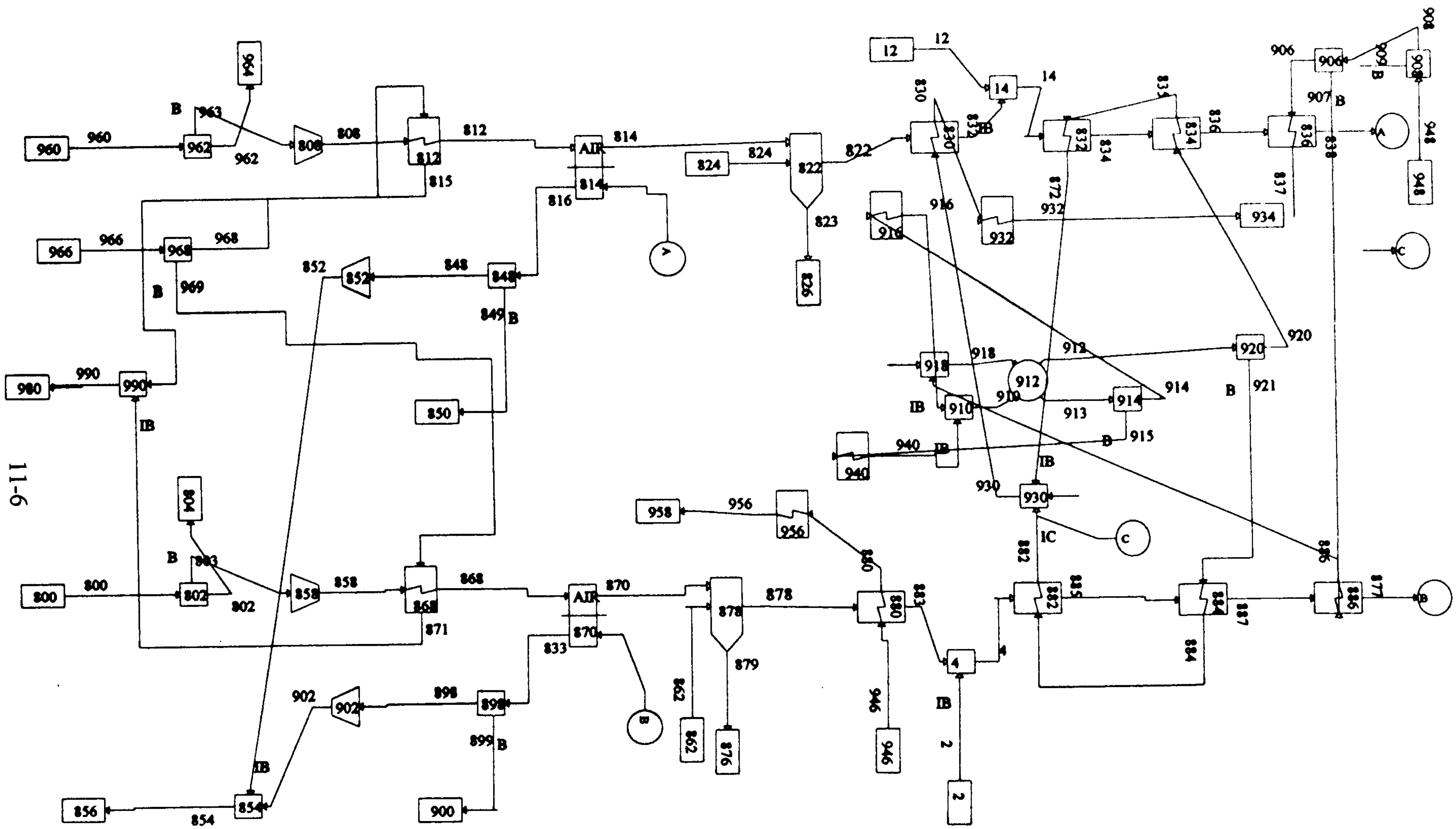

Figure 2: PEPSE Boiler Model Modified To Include Air Leakage

The PEPSE results illustrated that the necessary air leakage flows to achieve the measured temperatures were about 350,000 lb/hr for the reheat furnace and 400,000 lb/hr for the superheat furnace. This is about 25% and 30% of total air flow in the reheat and superheat furnace respectively. Since these values seemed very high, the PEPSE calculated air heater exit gas flows were compared with the induced draft fan curves to verify that the gas flow had increased. The PEPSE calculated gas flow corresponded to a 102% of the design gas flow for the fans. Plant personnel verified that this was occurring because when the unit burned higher moisture fuel than normal, the induced draft fans were operating at maximum capacity. In fact, the fans often derated the unit by about 10 MW. Operators at the plant also verified that the flame in the furnace often appeared smoky, implying that adequate combustion air was not being provided in the furnace.

The boiler, furnace and convection pass were walked down and inspected for air infiltration. No problems that could have caused this level of air leakage were found. However, during the next unit outage plant personnel inspected the penthouse above both the SH and the RH furnace and found that the floor had significantly deteriorated. Because the unit was required for service the next day, the floor could only be temporarily repaired, but a longer outage was scheduled at a later date. Table 4 below shows full load air heater data that was recorded the next day:

Table 4 Full Load Air Heater Performance After Repair

	Design Data in RBP Mode		Actual RH	Actual SH
Air Heater Gas Inlet Temperature (°F)	660	660	640	630
Air Heater Gas Outlet Temperature (°F)	230*	230*	292	280
Air Heater Air Inlet Temperature (°F)	74	74	63	67
Air Heater Air Outlet Temperature (°F)	570	570	535	536

* corrected for 6% air heater leakage

The temporary fix corresponds to about a 1.3% increase in boiler efficiency. There are also additional savings due to the reduction in auxiliary power necessary for the induced draft fans, and the replacement power cost for the frequent precipitator and induced draft fan deratings that were eliminated by the lower gas temperature. Although the problem was not eliminated entirely, the temporary fix is currently producing significant savings.

Conclusion

This paper has illustrated how a relatively simple PEPSE model can be utilized with some small modifications to solve a major air leakage problem. When the air heater gas exit temperature increases, often the first possible cause suspected is the air heater itself. A performance mode PEPSE boiler model and its associated features, like air heater performance and RBP modes, provide a method of analyzing this effect to determine the possible causes. The PEPSE model cannot replace all plant testing and measurement but may be utilized along with existing instrumentation to determine the instruments' validity and narrow the possible causes of a problem so the plant can quickly take corrective action.

References

Minner, G.L. et al, **PEPSE Volume I,** Haliburton NUS Corporation, 1996

Reynolds and Perkins, **Engineering Thermodynamics,** Wiley and Sons, 1979