Split Flue Modeling Techniques

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ABSTRACT

This paper provides an illustation of several techniques to calculate damper position and gas flows passing through a split backpass boiler. By more accurately predicting the gas flows and apparent damper position, a better understanding of the effectiveness of damper position can be found which can lead to more optimized boiler control. The PMAX real-time monitoring software can be used to effectively model split backpass boilers and their corresponding control systems. It can provide a real-time assessment of the effectiveness of damper position control. Constructing a PMAX model for this type of boiler requires proper and accurate instrumention, boiler geometry description, and an understanding of the PMAX code. It is important to benchmark and tune the boiler model, then to consider the modifications made since design. Upon benchmarking, the model must then be tuned for use of the live data from the DAS. Some important considerations are the effects of slagging and erosion on the stage tubing and also the dampers themselves. Alternative methods to calculate an approximate damper position and the gas flows down the respective paths will be discussed. The PMAX code also requires the input of the temperatures in and out of each stage of the backpass. Alternatives will be discussed for situations when some of these data are unavailable. Although these discussions are specific to the PMAX code, the algorithms and ideas described here may also be incorporated in a PEPSE analysis. Some of these calculations may even be better suited for the PEPSE code because of instrument inaccuracies which can be a problem for PMAX analysis and because of differences in the level of detail of the PEPSE boiler model.

1.0 INTRODUCTION

PMAX is a real-time performance monitoring and analysis system used in power plants to improve heat rate and reduce operating and maintenance costs. A PMAX model is called an "Arming Plan". The Arming Plan is a sequence of calculational modules that take the measured values from the data aquisition system (DAS) to produce calculated performance parameters.

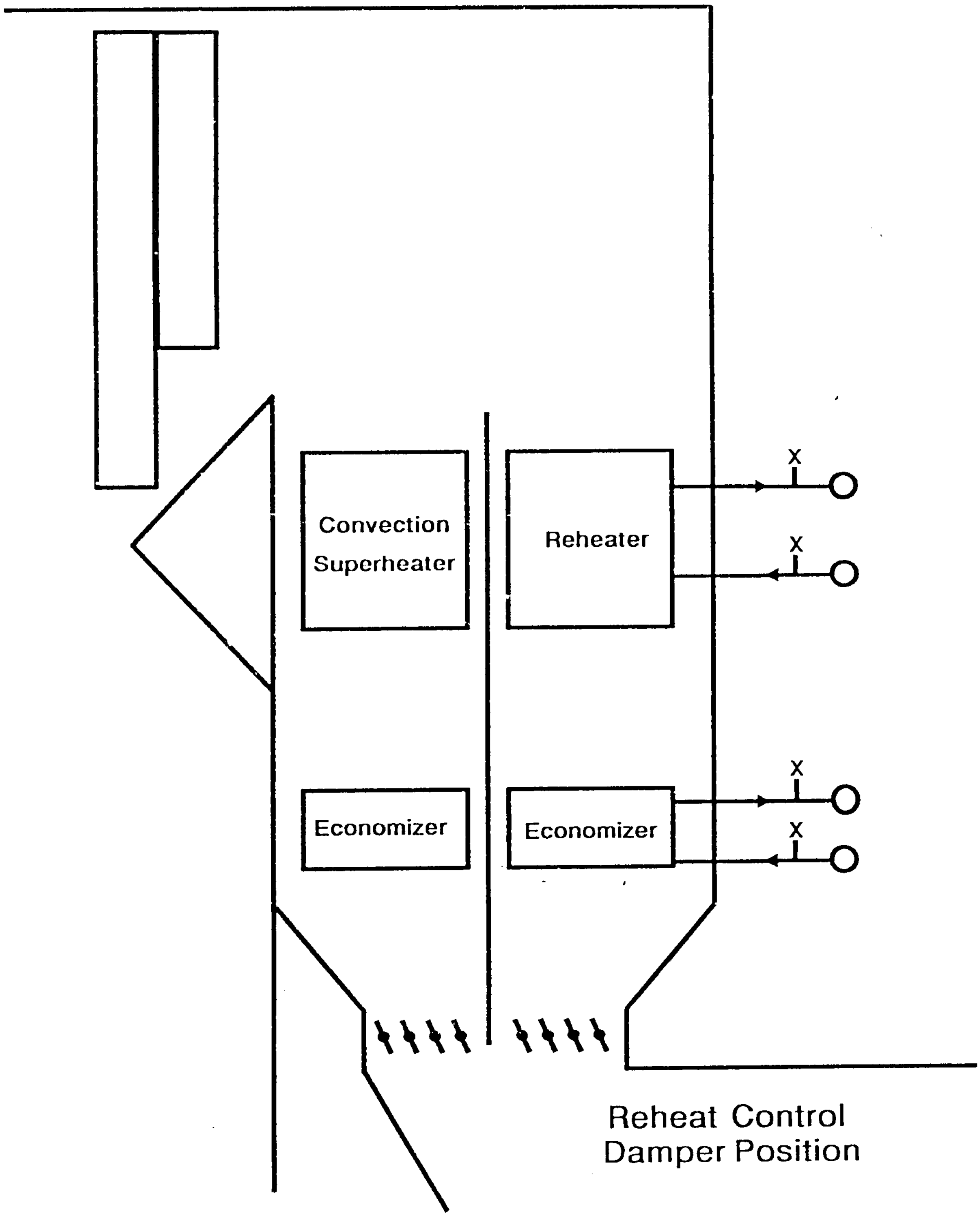
In all boilers, control of the superheat and reheat exit temperatures is very critical. Gas recirculation, attemperation, dampers, or several control mechanisms used in combination are commonly used to control temperature. By proper control of damper position and attemperation sprays, target reheat and superheat exit temperatures can be maintained. For example, by reducing the gas flow down the reheat path or increasing the reheat spray flow, the reheat steam temperature can be decreased. This paper is concerned primarily with determining the apparent position of dampers in split flue boilers and in the calculation of the respective gas flows.

There are several different types of split backpass boilers in existence and the geometry and position of the stages and tubes can vary greatly. There are boilers with one piece or multiple economizers of different geometry. In many boilers, one path contains the reheater and an economizer, whereas the other contains the primary superheater and another economizer.

The challenge in modeling these boilers is to calculate the gas flow in each passage with respect to the damper position. In PMAX, the stages are individually modeled with each stage analysis requiring the inlet and exit temperatures to be known at each header. With the split backpass configuration, a temperature measurement between the economizers is often not available and must therefore be found or estimated by other methods.

2.0 THE PMAX BOILER ARMING PLAN

The PMAX Boiler Arming Plan consists of a boiler network data set, a boiler general data set, and the descriptions of the individual stage modules in the network. When constructing a PMAX parallel flow boiler model, it is necessary to use at a minimum two individual boiler networks each including models of the components in that gas path. For example, depending on the boiler design, the first network may consist of the furnace, the secondary superheater, and the stages in the primary superheat pass. The second network contains the reheat pass and it's corresponding stages only. Within these individual PMAX stage modules there is an input for the gas flow distribution fraction. In the second boiler network (not containing the furnace), the first stage acts as a governor of flow to the following stages such that the input for the flow fraction is needed only on this first stage.



SPLIT FLUE BACKPASS BOILER

3.0 CALCULATION PROCEDURES

The following alternative methods might be applied to determine backpass damper position or flow split. In these calculations, it is assumed that the gas flow distribution is maintained by a single damper control.

<u>METHOD 1</u>: ASSUME A CONSTANT DAMPER POSITION

The damper position can be simply set and changed to a constant value via the displays and/or terminals on the PMAX system. This option can also work in conjunction with the other methods to be discussed.

<u>METHOD 2</u>: BASED ON AREA WEIGHTS

When economizer stage elements share both sides of the split path, we might use an area weight to estimate the damper position. This method may not produce the best results because the individual economizer stages are fouled differently. The calculation is as follows:

1. calculate the total backpass heat duty;

$$HD_T \cong \dot{m}_g \, Cp_g \, (T_{FE} - T_{GE}) \qquad \text{(gas side)}$$

where

$\dot{m}_g$ = mass flow rate of gas.

Cp_g = specific heat of gas.

T_{FE} = furnace exit temperature.

T_{GE} = gas exit temperature.

2. find the psh and rht stage heat duties;

$$HD_{PSH} = (\dot{m}_{FW} - \dot{m}_{BLDN}) (H_o - H_i)_{PSH} \qquad \text{(steam side)}$$

$$HD_{RHT} = \dot{m}_{CRH} (H_o - H_i)_{RHT} + \dot{m}_{RHS} (H_o - H_{RHS})$$

where

$\dot{m}_{FW}$ = mass flow rate of feedwater.

$\dot{m}_{BLDN}$ = blowdown flow rate.

$\dot{m}_{CRH}$ = cold reheat flow rate.

$\dot{m}_{RHS}$ = reheat spray flow rate.

H_o = enthalpy of outlet conditions.

H_i = enthalpy of inlet conditions.

3. calculate the individual economizer heat duties based on an area weighted average;

$$HD_{EC} = \dot{m}_{FW} (H_o - H_i)_{EC}$$

$$HD_{EC_{RHT}} = HD_{EC} \left(\frac{A_{EC_{RHT}}}{A_{EC}}\right) \qquad \text{(surface area)}$$

$$HD_{EC_{PSH}} = HD_{EC} - HD_{EC_{RHT}}$$

where

$A_{EC_{RHT}}$ = surface area of reheat side economizer.

A_{EC} = combined surface area of all economizers.

4. find gas flow distribution factors (X);

$$HD_{T_{RHT}} = HD_{RHT} + HD_{EC_{RHT}}$$

$$HD_{T_{PSH}} = HD_{PSH} + HD_{EC_{RHT}}$$

$$X_{PSH} = \frac{HD_{T_{PSH}}}{HD_T}$$

$$X_{RHT} = 1 - X_{PSH}$$

METHOD 3: DIRECT MEASUREMENT OF INTERMEDIATE TEMPERATURE (GAS OR STEAM SIDE)

First calculate the heat duties for all backpass sections, then sum the individual heat duties and divide each by the sum of the two. This calculation is as follows:

1. calculate the total backpass heat duty;

$$HD_T = \sum HD_{STAGES}$$

$$= HD_{PSH} + HD_{RHT} + HD_{ECON}$$

2. sum heat duties for each pass;

$$HD_{T_{RHT}} = HD_{RHT} + HD_{EC_{RHT}}$$

$$HD_{T_{PSH}} = HD_{PSH} + HD_{EC_{PSH}}$$

where $HD_{EC_{RHT}}$ and $HD_{EC_{PSH}}$ are directly measured.

3. calculate flow distribution factors;

$$X_{PSH} = \frac{HD_{T_{PSH}}}{HD_T}$$

$$X_{RHT} = 1 - X_{PSH}$$

<u>METHOD 4</u>: MEASURE THE INDIVIDUAL FLUE EXIT GAS TEMPERATURES

The location of the instruments is important with this option because the temperature distribution across the flue crossection may vary significantly. This method requires us to:

1. average all gas path exit temperatures and then calculate the total back pass heat duty;

$$T_{T_{GE}} = \left[\sum_{i=1}^{N} T_{GE} \right] \frac{1}{N}$$

NOTE: A flow weighted average may produce a more accurate result. This would require a method of iteration.

$$HD_T = \dot{m}_g \, Cp_g \, (T_{FE} - T_{T_{GE}})$$

2. calculate the flow distribution factors;

$$HD_T = HD_{T_{RHT}} + HD_{T_{PSH}}$$

$$X_{RHT} + X_{PSH} = 1$$

$$HD = \dot{m}_g \, Cp_g \, (T_i - T_o)$$

Substituting and solving for flow fraction gives:

$$X_{RHT} = \frac{(T_{GE_{PSH}} - T_{T_{GE}})}{(T_{GE_{PSH}} - T_{GE_{RHT}})}$$ (See Attachment)

$$X_{PSH} = 1 - X_{RHT}$$

where

$T_{GE_{PSH}}$ = gas exit temperature of PSH path.

$T_{GE_{RHT}}$ = gas exit temperature of RHT path.

METHOD 5: MEASURE THE DAMPER POSITION

Is a measured damper position from the DAS equal to the actual damper position? Under ideal conditions, assuming a newly manufactured boiler, this may be true. But with the build-up of ash and slag on the tubes and dampers, warping of the damper vanes, and inaccuracies in the measuring devices, it is likely that they are not. However, the damper position from the DAS could be used to estimate the flue gas distribution factors.

METHOD 6: PRESSURE DROP METHOD

Regardless of the geometry and size of each flue path, the pressure difference between the split flue inlet and outlet is the same. Therefore, it follows that the head loss between the two junction points will be the same in each of the gas flow paths.[1]

This calculation is very sensitive to the values of the flue form loss factors for the respective paths. These factors must be calculated by benchmarking the model with design conditions. The method is as follows:

1. set the two loss equations equal to each other;

$$h_\ell = \left(f \frac{\ell}{d} + k\right) \frac{\rho V^2}{2}$$

$$(h_\ell)_{PSH} = (h_\ell)_{RHT}$$

$$\left(f \frac{\ell}{d} + k\right)_{PSH} \left(\frac{\rho V^2}{2}\right)_{PSH} = \left(f \frac{\ell}{d} + k\right)_{RHT} \left(\frac{\rho V^2}{2}\right)_{RHT}$$

where

h_ℓ = head loss.
f = resistance coefficient.
ℓ = length.
d = diameter.
k = form loss coefficient
ρ = density.

V = velocity.

2. calculate the flow distribution factors;

lets define a composite $K = (f\frac{\ell}{d} + k)$ where K may be load dependent, which gives:

$$K_{PSH} \; V^2_{PSH} = K_{RHT} \; V^2_{RHT}$$

but

$$\dot{m} = \rho VA$$

then

$$K_{PSH} \left(\frac{\dot{m}}{\rho A}\right)^2_{PSH} = K_{RHT} \left(\frac{\dot{m}}{\rho A}\right)^2_{RHT}$$

therefore

$$\dot{m}_{PSH} = \dot{m}_{RHT} \frac{\rho A_{PSH}}{\rho A_{RHT}} \sqrt{\frac{k_{RHT}}{k_{PSH}}}$$

$$X_{RHT} = 1 \Big/ \left[\left(\frac{\rho A_{PSH}}{\rho A_{RHT}} \sqrt{\frac{k_{RHT}}{k_{PSH}}}\right) + 1\right]$$

$$X_{PSH} = 1 - X_{RHT}$$

where

A_{PSH} = cross sectional area of PSH pass.

A_{RHT} = cross sectional area of RHT pass.

METHOD 7: EXAMPLE OF AN ITERATION METHOD

This method works well when the economizer is a single, one piece unit. This requires guessing an initial flow split, then using the results from the PMAX boiler calculation to reevaluate our guess. This is an iterate method to find the flue gas distribution factors. The calculation is as follows:

1. calculate the total backpass heat duty;

$$HD_T = \sum HD_{STAGES}$$

$$= HD_{PSH} + HD_{RH} + HD_{ECON}$$

2. assuming an initial flow split, calculate the individual stage heat duties in the backpass using the output from the boiler module and, using these, calculate the new flue gas distribution factors and economizer temperatures;

$$HD_{T_{PSH}} = HD_{EC_{PSH}} + HD_{PSH}$$

therefore

$$X_{PSH} = \frac{HD_{T_{PSH}}}{HD_T}$$

$$X_{RHT} = 1 - X_{PSH}$$

Using these results, insert the calculated flue gas distribution factors into the input of the boiler modules, and recalculate, thus performing an iteration.

4.0 CALCULATION OF THE ECONOMIZER INTERMEDIATE TEMPERATURE

In order to make this calculation, the heat duties of the individual economizers must be known or estimated, and it is also necessary to know the pressure drops through these stages.

1. find the intermediate enthalpy;

$$HD_{EC_{PSH}} = m_{FW} (H_o - H_{FW}) \qquad \text{(steam side)}$$

$$HD_{EC_{PSH}} = \dot{m}_g \, Cp_g \, (T_i - T_o) \qquad \text{(gas side)}$$

$$H_o = H_{FW} + \frac{HD_{EC_{PSH}}}{\dot{m}_{FW}}$$

2. using a steam table call, find the unknown temperature;

$$T_o = f(P_o, H_o)$$

where

$$P_o = P_{FW} - \frac{\rho V^2}{2} \left(f \frac{\ell}{d} + k\right)$$

3. insert this value into the economizer boiler stage in the PMAX network.

5.0 CONCLUSION

Several alternative methods have been given to represent flow split due to damper position. Other methods for the determination of the damper position are also possible. The use of part or combinations of these methods can be easily used in the PMAX model because of the availability of logicals which may be activated and deactivated at any time.

Some of these calculations mentioned may change due to slagging and erosion, primarily where the form loss coefficients are concerned. Exit velocities could also increase because of constriction of the exit paths which may then promote premature tube failures.

Because reheat sprays are expensive, optimization of damper position and attemperation control can lead to a more efficient means of controlling temperature. In fact, some power plants have left their control dampers stationary and use attemperation only.

6.0 REFERENCES

1. Roberson, John A., Crowe, Clayton T., "Engineering Fluid Mechanics", Boston, Houghton Mifflin Company, 1985.

ATTACHMENT

$$HD_T = HD_{T_{RHT}} + HD_{T_{PSH}}$$

$$HD = \dot{m}_g \, Cp \, (T_i - T_o)$$

substituting gives

$$\dot{m}_g Cp_g \, (T_{FE} - T_{T_{GE}}) = \dot{m}_{g_{RHT}} \, Cp_g \, (T_{FE} - T_{GE_{RHT}}) + \dot{m}_{g_{PSH}} \, Cp_g \, (T_{FE} - T_{GE_{PSH}})$$

but

$$\frac{\dot{m}_{g_{RHT}}}{\dot{m}_g} + \frac{\dot{m}_{g_{PSH}}}{\dot{m}_g} = X_{RHT} + X_{PSH} = 1$$

therefore

$$(T_{FE} - T_{T_{GE}}) = X_{RHT} \, (T_{FE} - T_{GE_{RHT}}) + X_{PSH} \, (T_{FE} - T_{GE_{PSH}})$$

solving for X_{RHT} gives

$$X_{RHT} = \frac{(T_{GE_{PSH}} - T_{T_{GE}})}{(T_{GE_{PSH}} - T_{GE_{RHT}})}$$

where

$HD_{T_{RHT}}$ = total heat duty of all stages in RHT path.

$HD_{T_{PSH}}$ = total heat duty of all stages in PSH path.

$\dot{m}_{g_{RHT}}$ = mass flow rate of gas in RHT path.

$\dot{m}_{g_{PSH}}$ = mass flow rate of gas in PSH path.