COMBUSTION ENGINEERING BOILER - CONVECTION SURFACE STUDIES AN ANALYTICAL METHOD

William T. Brockman, P.E.

Kentucky Utilities Company

ABSTRACT

Based on test and computer boiler model observations, certain boiler operating responses to heat transfer surface changes appear to be linear and repeatable. These observations have been applied in graphical form to develop a method of predicting, with reasonable accuracy, the convective surface area changes required to concurrently achieve desired main and reheat steam temperatures, spray flow and burner tilt position. This graphical analysis has evolved into a mathematical linear analysis which uses the results of PEPSE boiler model output as input data.

This paper presents the observations, graphical interpretation and the mathematical analysis developed by Kentucky Utilities performance engineering to analyses surface alterations of controlled tilt Combustion Engineering Boilers. In addition, the results of a test conducted by the author of this paper and EI International Inc. using the new block controls to solve this type of boiler problem are presented at the back of the paper.

A SCENARIO

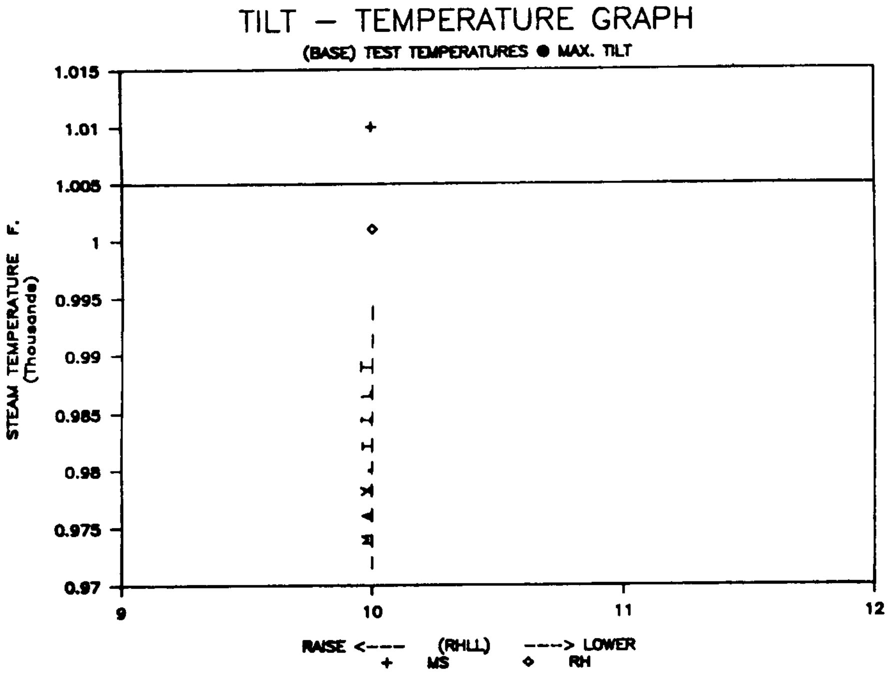
Because of regulations governing emission standards, the coal for certain boilers was changed. This has caused some operating problems in the furnace and convective pass of one boiler in particular. The new coal ash properties are outside the limits of this boilers design. Where slagging used to occur is no longer occurring and the furnace fouling has declined. Now the boiler is too large. At first this sounded good, but now the tilts are completely elevated to their blocks. The superheat sprays are running at a quarter of a million lbs/hr. The tilts are effectively non-operational and any further control of reheat temperatures must be done by biasing burner levels. The excessive spray is causing high turbine deposits and loss of generation. The fuel contracts are long term and locked in. The utility company decides to study the boiler to see what surface changes could be made to correct the off operating conditions.

INTRODUCTION

This paper is not a thesis on how to use PEPSE boiler models. Rather, it is a description of boiler responses to changes of tilt position, spray flow and convective heat transfer surface alterations, and in particular, surface changes toward the back of the convective gas pass. This is usually a good location for such changes due to the physical accessibility of the area for men and equipment and the reduced scaffolding requirements. In addition, changes to surface areas of reheat finishing pendants, superheat rear pendants and horizontal superheaters show good response to desired changes in boiler operating temperatures. This is not to say that other boiler locations would not be as effective. It is assumed the performance engineer has built a PEPSE boiler model and has verified its operation. It is also assumed the engineer has a good set of test data of the boiler - turbine steam cycle to initiate the analysis. Burner tilt emulation is use extensively in the analysis presented in this paper. Superheat and Reheat gas pass louver regulation could likely follow these same principles.

BOILER OPERATING LINEARITY

Lets begin by assuming some data, then further on we will drop the data and simply describe responses. From the case described in **A SCENARIO,** we know that the tilts are completely elevated and the superheat spray is at 250000 lb/hr. Also, lets say the superheat steam temperature is 1010.0 F and the reheat steam temperature is 1001.0 F from test data. By assigning the PEPSE boiler model water wall component (RHLL) equal to 10 feet, lets say, then any lowering of tilt position will increase the length of this RHLL value. The exact correlation of RHLL in feet to burner tilt angle in degrees can be obtained from boiler tilt tests. A good way to describe these initial conditions is to locate these temperatures on a tilt - temperature graph, using RHLL for the x axis. **(graph 1)**



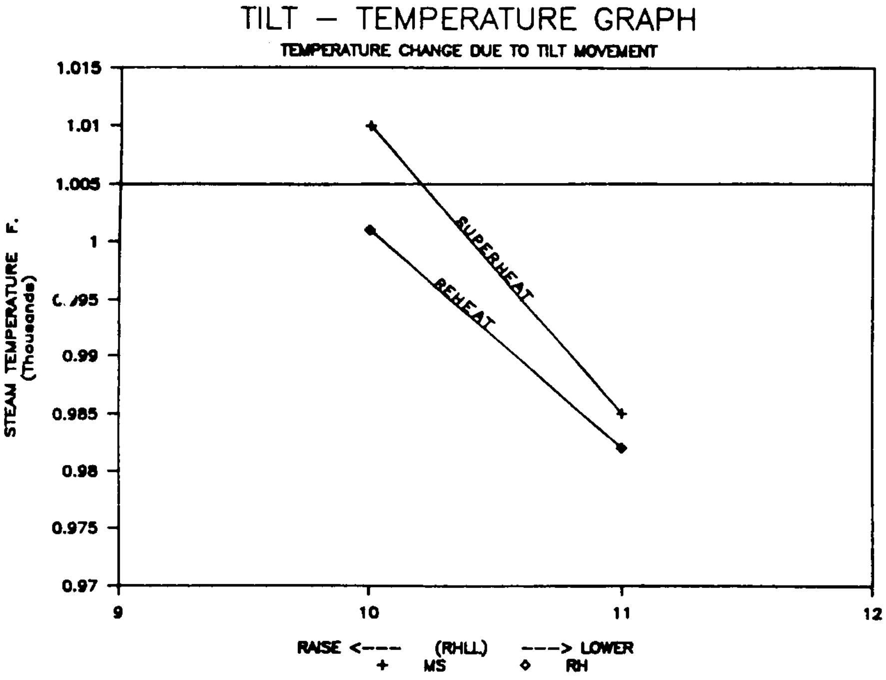
graph 1

Using the PEPSE boiler model balanced to the base or initial test data in full design mode, we want to see what effect there will be by lowering the tilts by a small amount and balancing the firing rate to maintain steam production. Note that spray flow and steam flow remain constant. Lets lower the tilts by 1 foot RHLL and note the new temperatures.

Superheat temperature = 985.0

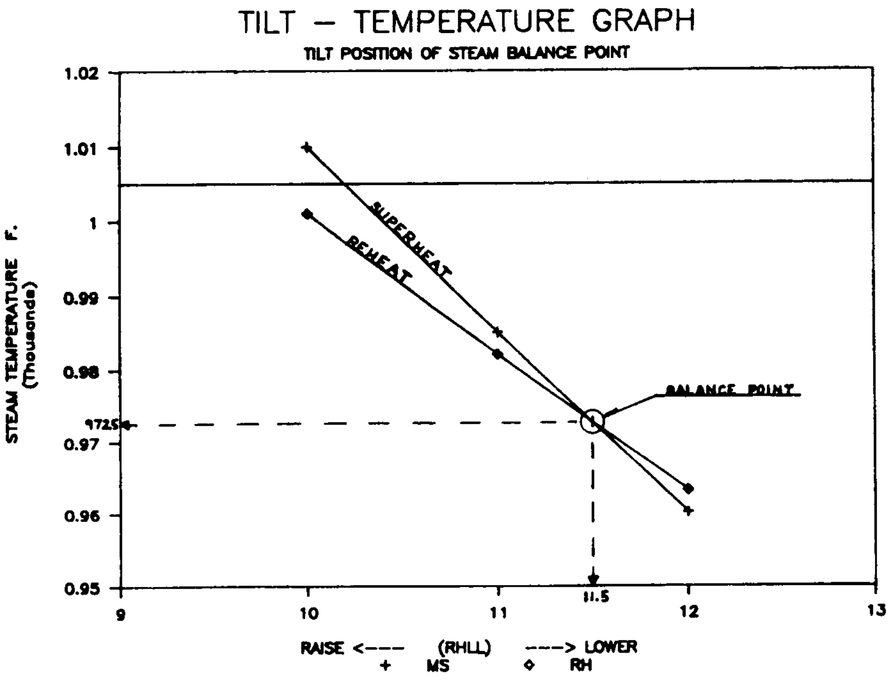
Reheat temperature = 982.0

By plotting this data we will see what has occurred. **(graph 2)**



graph 2

These results are a fictitious state, since sprays would not remain constant, nor would feedwater or cold reheat steam temperatures. However, by examining these results, we can deduce that at some lower tilt position, the two steam temperature lines would cross. We can extend these lines to estimate what tilt position would give us equal steam temperatures under these initial conditions. **(graph 3.)**

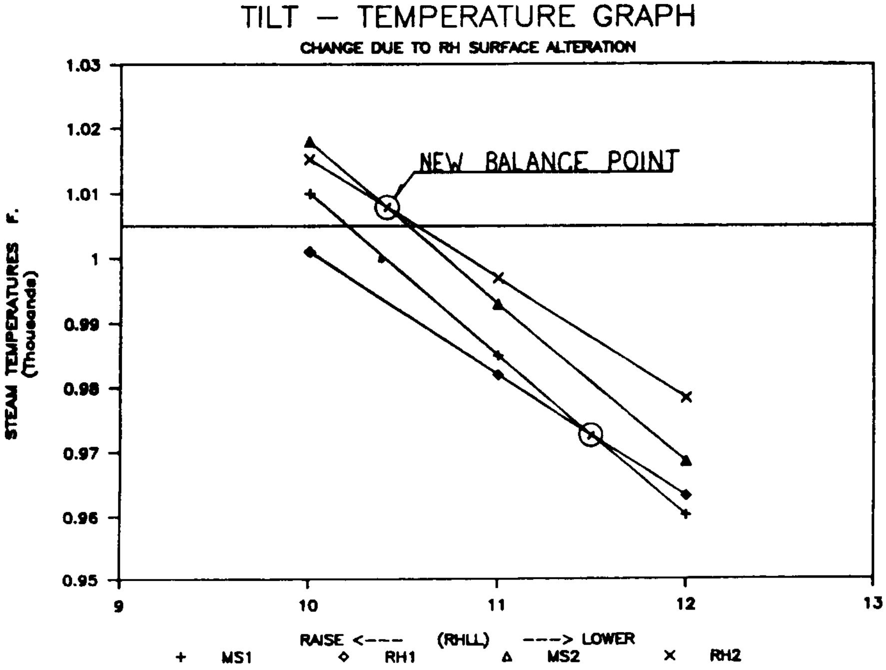


This indicates that if all flows were held constant at the boundaries and the only variables changed were the tilt position and firing rate, then both superheat and reheat outlet steam temperatures would be equal at approximately 972.5 F with a tilt position of 11.5 feet RHLL. Indeed this could be verified for this test case by setting the boiler model tilt component RHLL to 11.5 feet and running the model. The point being made here is that both **steam temperatures have been found to be directly proportional to tilt position** provided all inlet boundary conditions are held constant. The point where both steam temperatures are equal takes on a very significant meaning. This point is what I choose to call the **BALANCE POINT.**

CHANGE OF REHEAT SURFACE AREA

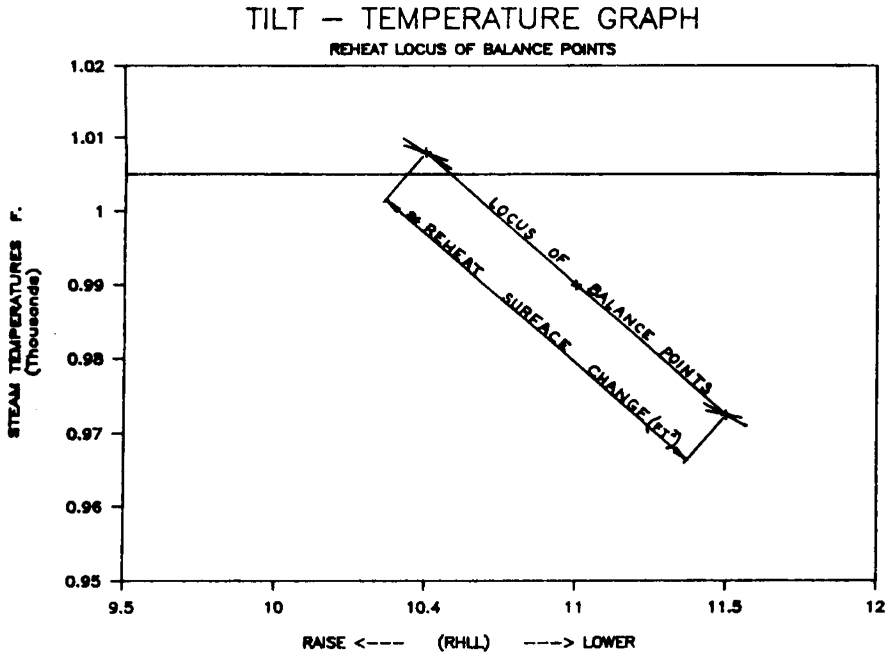
What will happen if we change surface area or heat transfer coefficient for a given reheat component in the convective pass. If we add a small amount of surface to, say, the reheat finishing pendant we see a rise in reheat steam temperatures as we would expect. We also see a rise in the superheat steam outlet temperature, but to a far lesser extent then the reheat. Essentially what occurs is first a rise in heat absorption in the reheat finishing pendant. This causes a lowering of the burner tilts and a reduction of firing rate. If this were all that occurred there would be a reduction in final superheat steam temperatures. However, because of the increased heat absorption in the reheat component, the gasses to the economizer are cooler, causing cooler feedwater to pass to the furnace. Because of this, the firing rate must now increase above its previous level to make up the heat deficit, causing a slightly higher main steam temperature from where we began.

If we plot a typical response to change in burner tilt position after reheat surface is added, we would see something similar to this graph. **(graph 4.)**



graph 4

After examining this graph we can note some interesting characteristics of the superheat and reheat steam temperature lines. In addition to the relative increase in reheat and superheat temperatures at any given tilt position, we also note that the temperature lines are parallel to their previous lines prior to the surface addition. This **PARALLEL AND LINEAR** characteristic of tilt - temperature lines has been found to be almost universally true. However, the most interesting and useful feature of these new lines is the change of location of the balance point. **(graph 5.)**



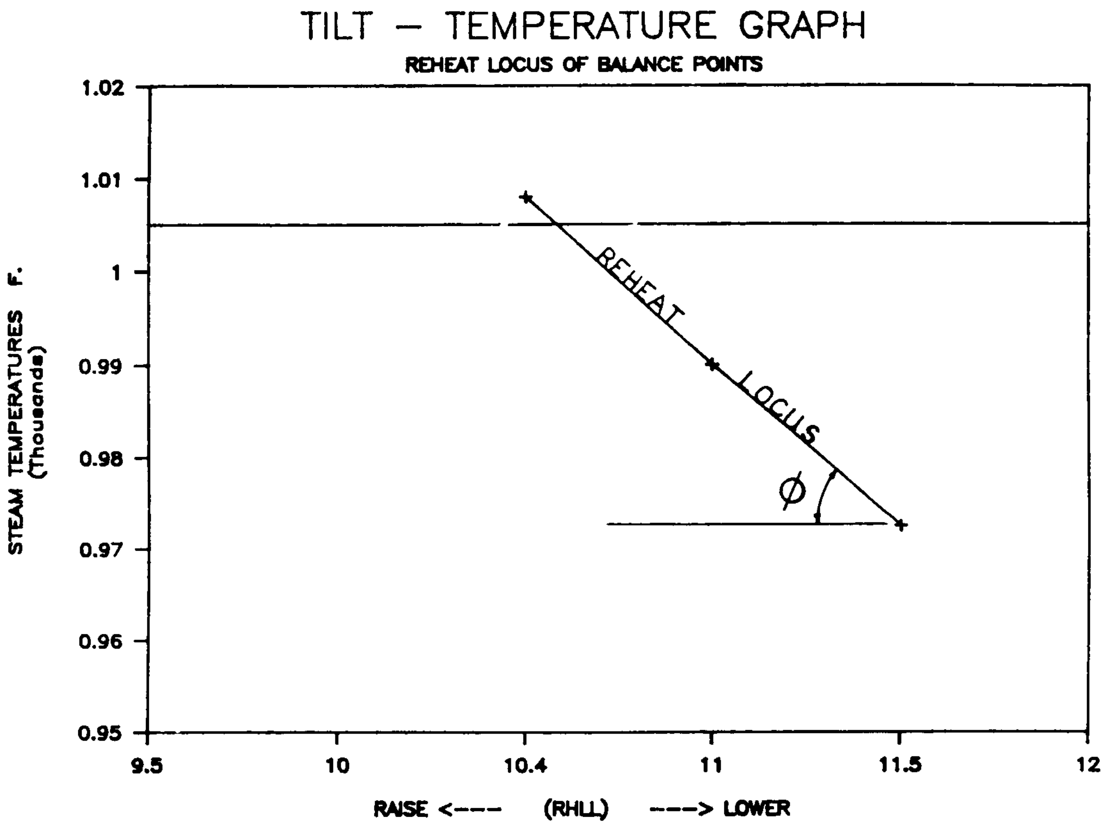
graph 5

Essentially what we see is that for reheat surface addition, the balance point moves to a higher temperature at a relatively higher tilt position. Also, it has been observed that the change of location of this balance point with further additions or deletions of this reheat surface area will cause all subsequent balance points to fall upon a straight line which passes through these two initial points. From this we can conclude that the relative distance between any two balance points along this line is directly proportional to the change of surface area of this reheat component. This line of balance points for the reheat surface change takes on special importance and is given the title **REHEAT LOCUS OF BALANCE POINTS.**

A useful characteristic of this LOCUS line is that this line can be moved with changes in spray or superheat surface area, but in every case it has been found that the resulting new REHEAT LOCUS OF BALANCE POINTS is parallel to the old line, provided the test case (ie. input boundary conditions and steam flows) remain constant. Thus it can be said that the relative angle that the reheat locus line makes with horizontal on the tilt temperature graph is constant for this test case, and will remain constant regardless of where this line is moved to on the tilt temperature graph. This characteristic becomes instrumental in the final solution of the surface analysis. **(graph 6.)**

CHANGE OF SUPERHEAT SURFACE

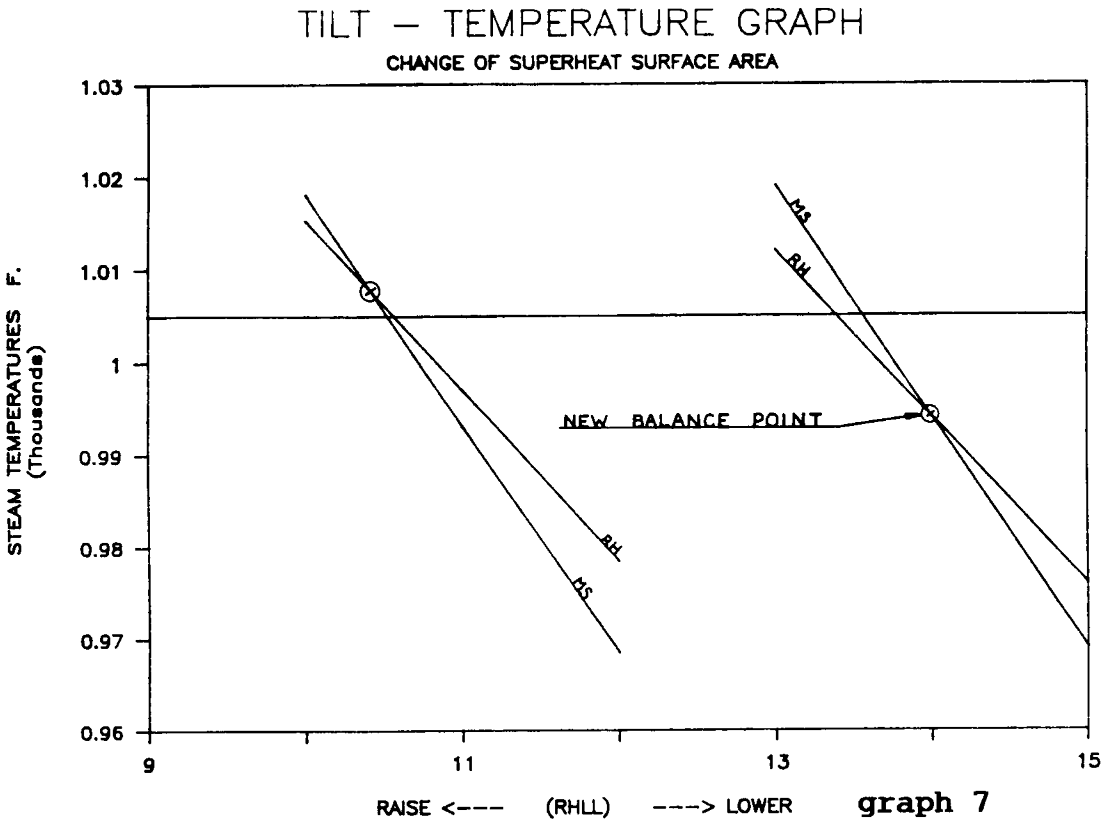
We can now select a superheat component to examine changes of surface area. In doing this, we want to keep the reheat surface modifications fixed. The only other values we need to change are the tilt position and firing rate. The superheat



graph 6

component I generally select for alteration is either the SUPERHEAT REAR PENDANT or the SUPERHEAT REAR HORIZONTAL ASSEMBLIES. For purposes of this analysis, either choice will perform equally well.

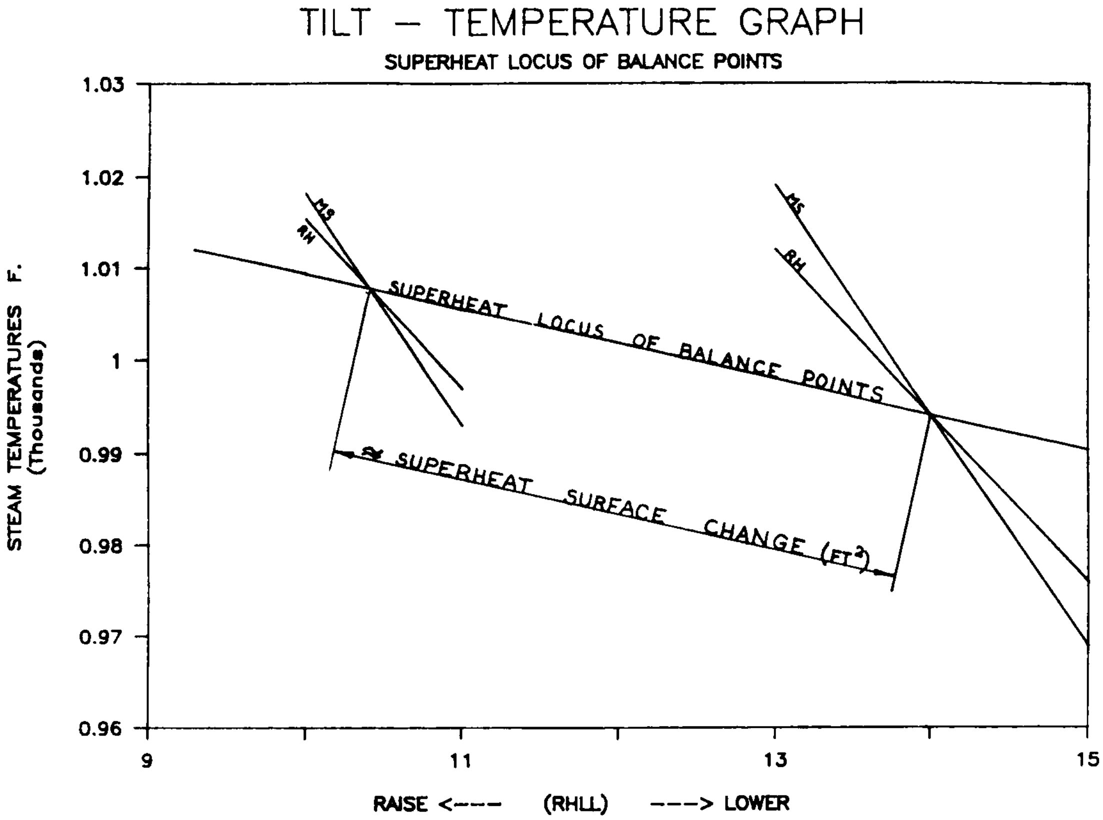
Lets assume we start by adding, say, 50% more surface to the superheat rear pendant. Provided the superheat sprays are held constant, we see an expected increase in the superheat main steam temperature and about an equal amount of increase in the reheat steam temperature. Now if we traverse the tilts over a small range while adjusting the firing rate, we can get a tracing of the new tilt-temperature lines due to change of superheat steam surface. **(graph 7.)**



graph 7

Again we observe the parallel relation of the respective superheat and reheat tilt-temperature lines. We also note that the new balance point is at a lower temperature and also at a lower tilt position. Again, as was the case with the reheat surface, we find that subsequent increases or decreases of superheat surface area produce balance points that fall on a straight line that passes through the initial and the new balance point. Thus we can conclude that changes in superheat surface area for this component is directly proportional to the relative distance between respective points along this line. This line is appropriately called the **SUPERHEAT LOCUS OF BALANCE POINTS.** Contrary to the REHEAT LOCUS line, the SUPERHEAT LOCUS line does not always remain parallel. However, that is of little concern for this analysis since we have already established two dimensional movement over the surface of the tilt-temperature graph.

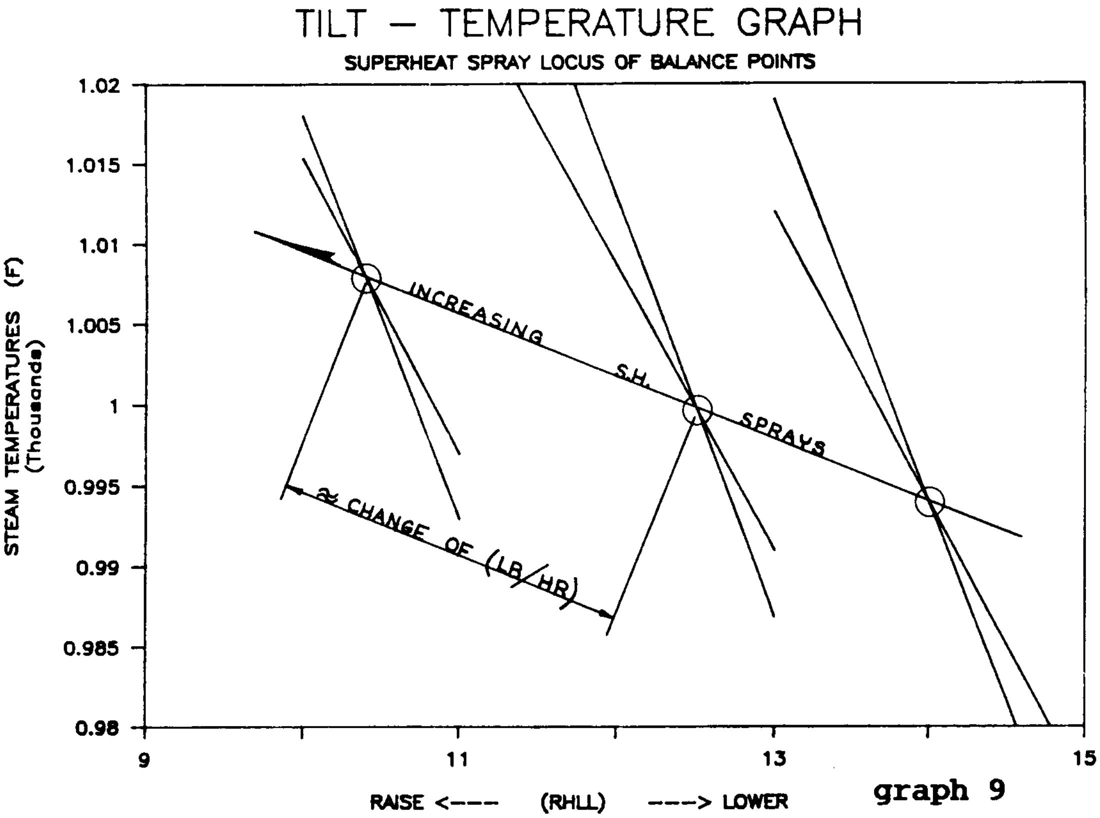
(graph 8.)



graph 8

CHANGE OF SUPERHEAT SPRAY FLOW

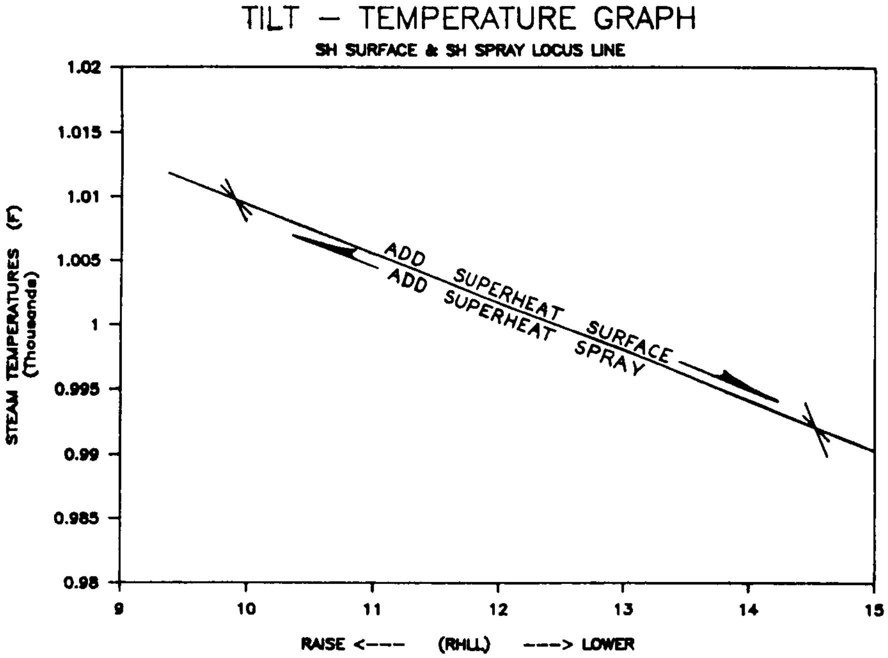
A very interesting phenomena occurs with the addition or reduction of superheat spray. If we hold the surfaces constant and, say, increase superheat spray, we must then back down on feedwater inflow to the economizer in order to maintain constant main steam flow to the turbine. By doing this, we are reducing the amount of steam production in the furnace water walls. This is because in general, superheat spray is admitted to the boiler after the steam drum discharge. This causes a slight reduction in firing rate, cooling of the gas pass, reduction of dry gas losses and at the same time causes the tilts to elevate because there is a slight cooling of the reheat steam temperature. If traverse the tilts as before and plot the tilt-temperature lines for this process, we note the change to the boiler operating states. **(graph 9.)**



graph 9

As superheat sprays are increased with main steam flow held constant, we see that the resulting balance points again fall on a straight line. This movement indicates that as spray is increased, the balance points increase in temperature at a higher tilt position. Because of the linearity, we can again conclude that the relative length along this line is directly proportional to the amount of increase or decrease in spray flow. However, the most interesting property of this SUPERHEAT SPRAY LOCUS OF BALANCE POINTS is that it overlays almost precisely the SUPERHEAT LOCUS OF BALANCE POINTS and for all practical purposes is the same line. This means that with respect to balance points, addition of superheat spray is the opposite of adding superheat surface.

(graph 10.)



graph 10

ESTIMATION OF REQUIRED SURFACE CHANGES

Using the observations presented in this paper, it is possible to determine fairly accurately the superheat and reheat surface changes required in a boiler to achieve a desired tilt position and spray flow and make balanced steam temperatures from any given initial test case.

REQUIREMENTS

- A good set of test data at the desired boiler load.
- A PEPSE boiler model balanced to the test data in full

design mode, with tilt emulation for Combustion Engineering boilers

- A minimum of 6 computer model runs if you do not desire to change superheat spray and superheat surface simultaneously, otherwise 8 runs will be the minimum.

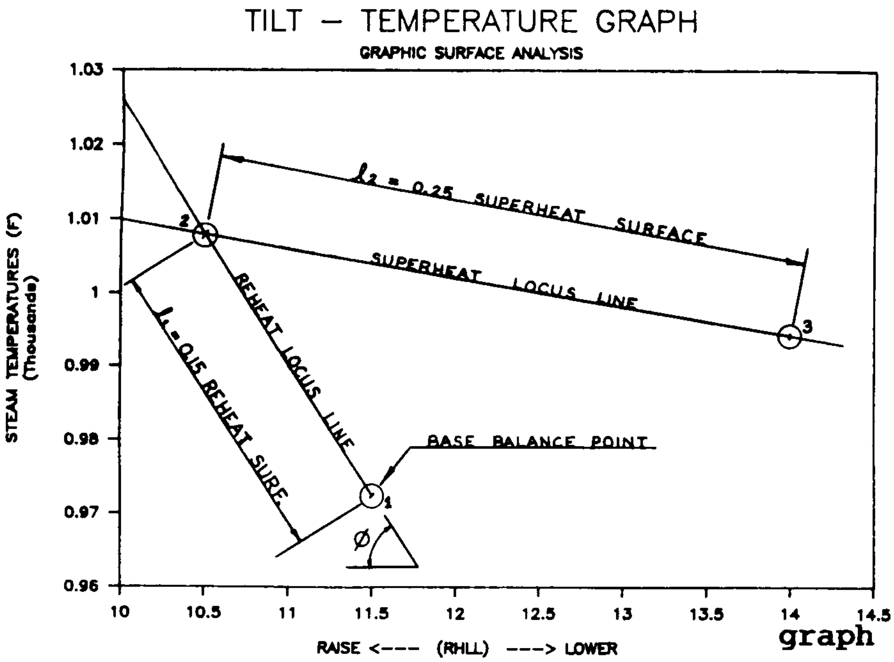
GRAPHIC ANALYSIS

1) Using the initial (base) test data, vary the tilts while controlling the firing rate, and by linear intersection, determine the initial balance point. (TILT-TEMPERATURE point where both the superheat and reheat temperatures are equal)

2) Add or delete an arbitrarily small amount of reheat surface area for a selected reheat component, say, 15% of the initial area. Again vary the tilts while controlling the firing rate and graphically locate the new balance point.

3) Leaving the reheat surface fixed as applied to point #2, add or delete a small amount of superheat surface for a selected superheat component, say, 25% of the initial area. Using the procedure used for the reheat surface, locate the third balance point on the tilt temperature graph. **(graph 11)**

4) Using a ruler or other scale, measure the relative length between points 1 and 2 for the reheat surface. Set up a ratio between this length and the associated surface area change,



graph 11

such as, one inch = 5260 square feet, etc. Do the same between points 2 and 3 for the superheat surface area. Also measure the angle that the reheat locus line makes with horizontal. θ

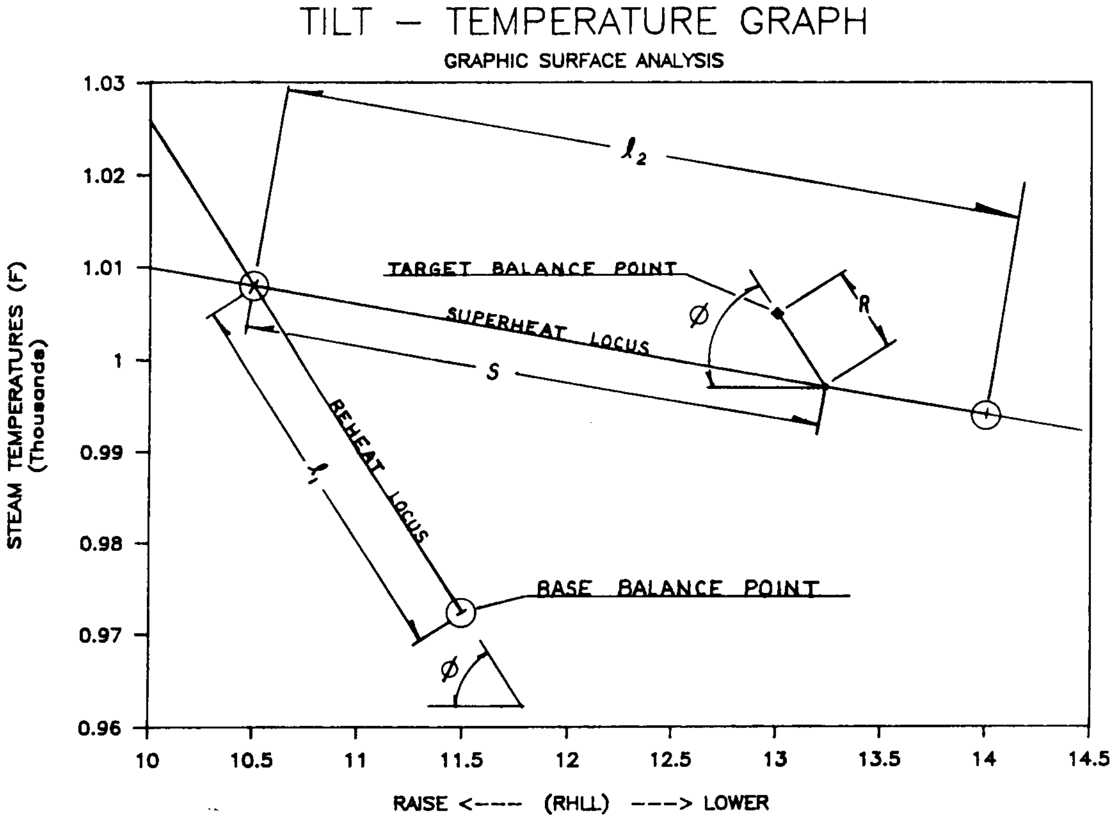
5) Select a target point on the tilt - temperature graph, say, 1005 degrees temperature at a balance point at 13 feet tilt position (RHLL). This will be point 4 on the graph. **(graph 12.)** From this extend the line (R) at the angle (θ) until it intersects line 2 - 3. Measure the length (R) and (S) and calculate the resulting surface changes for their respective surface ratios.

6) If it is desirable to alter superheat spray, it is necessary to run a fifth point on the tilt - temperature graph, correlating a change of spray flow to line length as was done in steps 1, 2 and 3. The graphical procedure in steps 4 and 5 are the same.

From the above analysis:

REHEAT SURFACE CHANGE = $(l_1 + R)/l_1 \times 0.15$ percent of area

SUPERHEAT SURFACE CHANGE = $(S \times 0.25)/\ l_2$ percent of area



graph 12

MATHEMATICAL PROCEDURE

Steps 1,2,3,5 and 6 are identical, however for more precision, the linear analysis is as follows. The only difference is that the tilt positions and temperatures are used in the calculations as x and y data values.

example, point 1 (T,F)= (tilt value 1, temperature value 1) etc.

T = Tilt value

F = Temperature (Farenhite)

$$m_1 := \frac{F_1 - F_2}{T_1 - T_2}$$ = Slope of reheat locus line.

$$l_1 := \sqrt{\left[T_1 - T_2\right]^2 + \left[F_1 - F_2\right]^2}$$ = = Length of reheat locus line.

$$m_2 := \frac{F_2 - F_3}{T_2 - T_3}$$ = Slope of superheat locus line.

$$l_2 := \sqrt{\left[T_2 - T_3\right]^2 + \left[F_2 - F_3\right]^2}$$ = Length of superheat locus line.

F_t = Target balance point temperature

T_t = Target balance point tilt position

$$B_t := F_t - \left[T_t \cdot m_1\right]$$ = y intercept of resulting reheat target line.

$$XP := B_t - \frac{F_2 - \left[T_2 \cdot m_2\right]}{m_2 - m_1}$$ = Intercept (x value) of resulting reheat target line and the superheat locus of balance points.

$YP := \left[XP \cdot m_1\right] + B_t$ = Intercept (y value) of resulting reheat target line and the superheat locus of balance points.

$l_R := \sqrt{\left[T_t - XP\right]^2 + \left[F_t - YP\right]^2}$ = Length of resulting reheat line.

$l_3 := \sqrt{\left[XP - T_2\right]^2 + \left[YP - F_2\right]^2}$ = Length of resulting superheat locus line from point 2 to the intersection of the reheat resulting line.

DEFINITIONS

DRH = Amount of reheat surface change used in step 2 to determine the balance point #2 from point #1.

DSH = Amount of superheat surface change used in step 3 to determine the balance point #3 from point # 2.

DSP = Amount of superheat spray change (lbm/hr) used in step 6 to determine the balance point #4 from point #3, if that option is desired.

THEN :

1) The amount of reheat surface change required from the base test is: $= \left[\dfrac{l_R \cdot DRH}{l_1}\right] + DRH$

And if $YP > F_t$ then $= DRH - \left[\dfrac{l_R \cdot DRH}{l_1}\right]$

2) The amount of superheat surface change required from the base test is: $= \dfrac{l_3 \cdot DSH}{l_2}$

3) If superheat surface was held constant and only superheat spray was used to establish point #3, then the amount of superheat spray change required from the base test is:

$$\text{SPRAY FLOW} = \frac{l_3 \cdot DSP}{l_2}$$

4) If the option was chosen to change both superheat surface and spray flow, then the length of Locus of Balance Point line correlating to the change of spray flow (DSP) is:

$$l_4 := \sqrt{\left[T_4 - T_3\right]^2 + \left[F_4 - F_3\right]^2}$$

And the required superheat spray change with a change of superheat surface from the base test is:

$$\text{SPRAY FLOW} = \frac{\left[l_2 - l_3\right] \cdot DSP}{l_4}$$

RESULTS

FINAL COMPONENT REHEAT SURFACE = BASE TEST REHEAT SURFACE + (1)

FINAL COMPONENT SUPERHEAT SURFACE = BASE TEST SUPERHEAT SURFACE + (2)

FINAL COMPONENT SUPERHEAT SPRAY = BASE TEST SUPERHEAT SPRAY + (3) OR (4)

The intention of presenting these equations is to allow the engineer to more accurately calculate the results via, say, a basic program. The accuracy of the results depend upon how accurately the balance points were determined. These in turn are effected by the control of the firing rate and weather cold reheat and feedwater temperatures are scheduled as a function of main and reheat steam temperature.

A MUCH EASIER WAY - PEPSE BLOCK CONTROLS

In May 1987 and again in July 1988, Kentucky Utilities Company chose to perform extensive boiler surface studies on Combustion Engineering boilers. These studies were performed on E.W. Brown Unit 3 in 1987 to correct excessive spray and high tilt position. Then in 1988, studies were performed on Ghent Unit 2 to bring up low steam temperatures and lower the tilt position. The Ghent 2 surface modification has not yet been performed.

The 1987 E.W Brown Unit 3 study took four months to complete and over 200 PEPSE boiler model runs. Controls on these PEPSE runs were used extensively for adjusting firing rate, but were not powerful enough to resolve the surface modification problems. It was during this time that the majority of the boiler surface analysis technique was developed. This technique was then used with PEPSE during the Ghent Unit 2 study in 1988 with great success. Four different surface changes with tilt correlation and variable loads were analyzed. This effort took over four weeks and about 30 PEPSE computer runs.

In October 1988, I attended an EI International Boiler Modeling Seminar. Mr. Eric Hanson of EI mentioned the development of a powerful block control that could possibly perform the entire surface analysis in one PEPSE run. When I returned to work, I contacted Eric and we agreed to run a boiler test using the block control. The test involved a typical set of boiler data altered to require surface changes to superheat and reheat convective pass assemblies to achieve rated steam conditions. In addition, I scrambled the tilt position by setting it at full positive angle. Using PEPSE with the previous controls, this problem would have been difficult to solve. Using PEPSE with the surface analysis described in this paper, the problem could be solved with a minimum of 8 to 10 PEPSE runs.

After reviewing the test case and specific details of the boiler model, the block controls were set to simultaneously solve the reheat and superheat surface changes while the tilts were adjusted to zero degrees elevation. At the same time, the drum pressure was held constant and the firing rate was controlled to maintain constant steam production. Mr. Gene Minner then ran the model and the block controls resolved the test case to tighter than specified tolerance (+ - 2.0 degrees F.) in 87 iterations. This took about 30 minutes, and the resulting surface changes compared very closely with the surface analysis presented in this paper.

The new block controls are available with the 1988 PEPSE update. This new control application will prove to be a very significant and powerful tool in computer modeling analysis.

CONCLUSION

It is not very often that a utility company will take on the task of performing boiler surface analysis to correct off operating conditions. Usually this task is contracted back to the OEM or a consulting engineering firm. The resulting modification project will be expensive and time consuming, as will be the engineering effort involved. The PEPSE code in conjunction with the new block controls and/or the analysis presented in this paper, gives the utility engineer a very useful tool to either perform this work in-house, or to verify the work performed by the contracted engineering firm. The cost savings in either case can be very significant.