DIABLO CANYON UNIT 1

FEEDWATER HEATER RETUBING STUDY

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Presented at: Energy Incorporated
PEPSE® Users Group Meeting
November 2, 1983

ABSTRACT

The object of this study was to check the thermal performance results of a vendor's retubing analysis on the feedwater heaters at Diablo Canyon Unit 1. The tubing replacement is being considered because copper in the tube material contributes to the corrosion of the Inconel 600 tubes in the steam generators. The cost of retubing feedwater heaters would be significantly less than the replacement of a steam generator.

To check the vendor feedwater heater thermal performance results, six feedwater heater models were set up and then analyzed using the design mode of the PEPSE code written by Energy Incorporated. These models were set up to match as closely as possible the design specification sheets provided originally with the heaters. Stainless steel tubes were then replaced in the models and again PEPSE was used to analyze the new performance. The change in performance differences between the two models was then compared to the performance differences predicted by the vendor. The loss of performance predicted in the PG&E models was much larger than that predicted by the vendor. PG&E informed the vendor of these results and asked them to recheck their calculations. The vendor rechecked their calculations and found several errors. Since that time the vendor has provided PG&E with new thermal performance estimates. The revised vendor performance estimates have been found to be in strong agreement with the PG&E estimates.

INTRODUCTION

For several years the utility industry has been aware of corrosion problems in steam generators in PWRs. This concern has led Pacific Gas and Electric Company (PGandE) to consider various methods of reducing these problems. One of the methods is to replace the feedwater heater tubing with less corrosive materials. At present, PGandE is considering the replacement of its copper-nickel and admiralty feedwater heater tubes with stainless steel tubes in order to reduce corrosion problems with the Inconel 600 tubes present in the steam generators.

Unfortunately, stainless steel tubing has a lower thermal conductivity than the copper-nickel tubes. To compensate for this, the stainless tubes can be manufactured with a larger inside diameter while keeping the same outside diameter. Thus, by reducing tube wall thickness, some of the thermal losses may be recouped by taking advantage of the greater strength of stainless steel. Still, even a small reduction of efficiency in the feedwater heating system can mean a significant dollar cost in electrical output of the plant. For this reason, PGandE requested that the vendor evaluate the effects of retubing the feedwater heaters.

PGandE received an evaluation from the vendor which summarized the effects. The most significant of these effects were increases in Terminal Temperature Difference (TTD) and Drain Cooler Approach temperature difference (DCA), and the reduction of pressure drop through the feedwater heater tubes. To check the vendor's results, PGandE used the feedwater heater design mode of the PEPSE code (Energy Incorporated).

The resulting analysis on retubing was intended to be a check on the vendor's results, not a complete design analysis. Thus, several simplifying assumptions were made in the modeling of the feedwater heaters. The models were set up to match the performance shown on the design specification sheets provided initially with the heaters. Once good agreement was established, the stainless steel tubes were substituted and the new thermal performance values were calculated. The differences between these cases were then compared to the differences predicted by the vendor.

When the comparison was made, there were discrepancies between the PGandE and vendor results. The vendor was contacted and informed of our results. Upon checking, the vendor discovered several errors in its calculations. The vendor recalculated its predictions, and produced a new set of thermal performance estimates. These estimates were then in close agreement with the PGandE estimates.

Model Description and Methodology

In order to perform the analysis on the feedwater heaters, six types of heaters had to be modeled. Models were set up to match the design specification sheets that were provided with the heaters. A schematic of the PEPSE Design Mode Feedwater Heater Model used is shown in Figure 1.

Most of the input data used for the models were found on the specification sheets. Additional data was provided by the feedwater heater manufacturer.

To match the performance on the specification sheets several assumptions were made:

1) There was negligible pressure drop in the shell side of the condensing section.

2) The inlet conditions were set to the values given on the design specification sheets.

3) Hydraulic and heat transfer bypass factors were used to match performance of the drain cooling sections.

4) Feedwater pressure drop through the tubes of the as-built models was matched to the specification sheet values using the feedwater outlet nozzle loss coefficient.

The first assumption was made because the heater manufacturer assumes negligible pressure drop in the condensing section. This assumption also simplified the modeling effort since several variables affecting pressure drop were difficult to determine. For instance, the flow areas around hydraulic baffle plates were not readily available, hence by assuming no pressure drop in the condensing section we were able to set these values to zero.

The second assumption was made to provide consistent inlet conditions for all of the heaters. This assumption includes controlling the condensing section pressure inside the shell using the inlet nozzle loss coefficient. PGandE has not yet operated Diablo Canyon so actual operating data was unavailable.

The third assumption became necessary since it was extremely difficult to match the drain cooling section performance. Input variables such as baffle spacing, flow area, and drain cooling envelope wall thickness were not readily available. In order to compensate for this lack of modeling information, the hydraulic and heat transfer bypass factors were used as "fudge factors". It was assumed that the shell side pressure drop in the drain cooling section could be controlled quite effectively using the hydraulic bypass factor. The drain cooler approach temperature difference ($DCA = T_{Drain\ outlet} - T_{Tube\ inlet}$) was controlled using the heat transfer bypass factor. These bypass factors were calculated using controls and fixing the pressure drop and DCA to the specification sheet values. The assumption that the bypass factors calculated in the as-built cases can be substituted into the retube cases is reasonable. The bypass factors are primarily dependent on the flow paths and shell side dimensions in the drain cooling section. These flow paths remain unchanged in the retube cases since the shell side dimensions remain unchanged. Thus it was assumed that these bypass factors remained unchanged. When the PGandE retube cases were compared to the vendor's revised predictions, the results using these factors were in reasonable agreement with the vendor.

The last assumption was made because we were primarily concerned with the difference in pressure drop the increased inside diameter of stainless steel tubes will cause. We controlled the overall pressure drop in the as-built cases by having PEPSE calculate the feedwater outlet nozzle loss coefficient to give us the specification sheet pressure drop. When we used this coefficient in the stainless steel cases, the difference in pressure drop was entirely due to the larger inside diameter of the stainless steel tubes.

The results of the as-built modeling are shown in Table 1. The results are consistent between both the vendor and the PGandE models. Since we were concerned with the effects of retubing, the as-built models for both PGandE and the vendor were considered as control cases for the respective comparisons.

It should also be noted that both PGandE and the vendor consider the terminal temperature difference as follows:

$$TTD = T^*_{shell\ inlet} - T_{tube\ outlet}$$

$T^*_{shell\ inlet}$ was assumed to be the saturation temperature at the operating pressure of the heater.

Tube Replacement

Only a few modifications to the inputs for each of the feedwater heater models needed to be made. These changes involved input regarding the replacement stainless steel tubes. The new thermal conductivities, tube inside diameters, and feedwater inlet temperature were substituted into the respective as-built models. It was assumed that the pressure inside the condensing section would remain the same as the as-built cases. All of the controls were taken out of the stainless tube models except the condensing section shell side pressure, and the shell and drain (if applicable) inlet enthalpies. The values calculated for feedwater outlet nozzle loss coefficient and both bypass factors were substituted in their respective models.

Discussion of Results

The results of the retubing analysis are shown in Table 2. The expected increases in TTD and DCA are shown along with the decrease in pressure drop in the feedwater heater tubing. The condensing section overall heat transfer coefficient is included because it is a good indication of model consistency. Since the feedwater heater models used by PGandE and the vendor are not identical, it is difficult to say exactly what the specified values of these various performance parameters should be. However, the effects of retubing should be consistent with respect to both sets of models. Hence, relative changes in each set of models were compared.

To make the evaluation, PGandE compared the changes retubing made in the PGandE model results, while the vendor did the same with their models. Thus the evaluation is a comparison of the predicted change in thermal performance caused by retubing.

The initial comparison of the changes in TTD and DCA showed significant differences between the vendor and PGandE. These differences were then reported to the vendor. The vendor inquired what values PGandE had calculated for TTD and DCA in our as-built cases. Since our as-built cases closely matched their as-built cases they decided to recheck their replacement tube calculations. Upon checking, they found that they in fact had made some errors. Thus, they provided PGandE with revised estimates of the thermal performance effects.

The revised predictions by the vendor were in much closer agreement with the PGandE predictions. The change in TTD's all matched within a tenth of a degree. The DCAs are also in good agreement. PGandE predicts slightly higher DCAs in feedwater heaters three and four, but the difference is at most one degree.

The pressure drop predictions between the vendor and PGandE were also very close. It should also be noted that although increased inside tube diameter does reduce the pressure drop in the tubes, its effect on overall system performance is minor.

The heat transfer coefficients in the condensing section decreased in almost identical amounts which also indicate reasonable results.

Using these comparisons, PGandE concluded that the vendors revised thermal performance results were indeed a good indication of the thermal effects of retubing PGandE feedwater heaters with stainless steel.

SUMMARY

The study consisted of modeling the feedwater heaters as-built and with stainless steel replacement tubes. The models were then analyzed using the PEPSE thermal analysis code written by Energy Incorporated. The results from this analysis were compared with the results predicted by the vendor. Since the results were in disagreement, the vendor rechecked its calculations and found some errors. The vendor then provided PGandE with revised thermal performance estimates which were in close agreement with the PGandE estimates.

In conclusion, it has been shown that the PEPSE design mode is a viable way of checking vendor thermal performance estimates concerning hardware modifications at power plants.

REFERENCES

1. C. P. Rhodes, PEPSE Feedwater Heater Retubing Study, Calculation File 821215-0, Pacific Gas and Electric Co., December 1982.

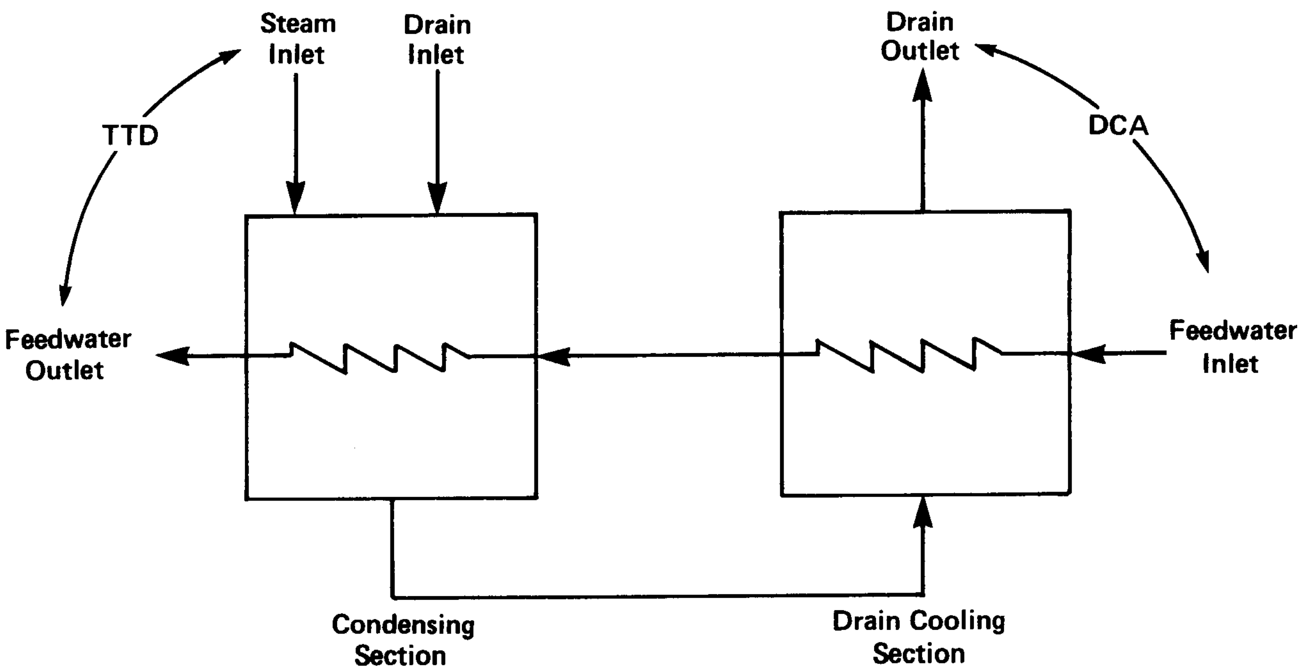
2. Kettenacker, Minner, Klink, PEPSE Manual Vol. I: USER INPUT DESCRIPTION, Energy Incorporated, January 1979.

3. Kettenacker, Minner, Klink, PEPSE Manual Vol. II: ENGINEERING MODEL DESCRIPTION, Energy Incorporated, December 1981.

4. Salisbury, Steam Turbines and Their Cycles, R. E. Krieger Publishing Company, 1950.

FIGURE 1

PEPSE FEEDWATER HEATER MODEL



Terminal Temperature Difference (TTD)

$$TTD = T_{\text{Steam Inlet}} - T_{\text{Feedwater Outlet}}$$

Drain Cooler Approach Difference (DCA)

$$DCA = T_{\text{Drain Outlet}} - T_{\text{Feedwater Inlet}}$$

TABLE 1

COMPARISON OF PEPSE FEEDWATER HEATER MODELS
TO THE DESIGN SPECIFICATIONS (AS BUILT)

	AS BUILT Feedwater Heater	TTD °F	DCA °F	Steam Inlet Mass Flow (lbm/hr)	Steam Inlet Enthalpy (BTU/lbm)	Drain Inlet Mass Flow (lbm/hr)	Drain Inlet Enthalpy (BTU/lbm)	Drain Outlet Enthalpy (BTU/lbm)	Tube ΔP PSIA
1	ABC								
	PEPSE	5.7	10.0	394885.	1147.79	320077.	460.72	349.6	4.7
	VENDOR	6.0	10.0	392817.	1147.79	320077.	460.72	349.4	4.7
	(% difference)	(5.)	(0.0)	(0.53)	(0.0)	(0.0)	(0.0)	(0.06)	(0.)
2	ABC								
	PEPSE	5.7	N/A	257372.	1109.68	7422.	1196.06	341.5	0.
	VENDOR	6.0		256998.	1109.68	7422.	1196.06	341.4	0.
	(%difference)	(5.)		(0.15)	(0.)	(0.)	(0.)	(0.03)	(0.)
3	ABC								
	PEPSE	3.7	10.0	193329.	1207.88	N/A	N/A	234.4	1.7
	VENDOR	4.0	10.0	192225.	1207.88			234.4	1.7
	(% difference)	(7.5)	(0.0)	(0.57)	(0.)			(0.)	(0.)
4	ABC								
	PEPSE	3.7	10.0	194120.	1114.5	192225.	234.3	180.17	2.8
	VENDOR	4.0	10.0	193039.	1114.5	192225.	234.3	180.04	2.8
	(% difference)	(7.5)	(0.0)	(0.56)	(0.)	(0.)	(0.)	(0.7)	(0.)
5	ABC								
	PEPSE	5.1	10.0	143055.	897.99	384115.	179.0	144.4	1.8
	VENDOR	5.1	10.0	143387.	897.99	384115.	178.9	144.4	1.8
	(% difference)	(0.0)	(0.0)	(0.23)	(0.)	(0.)	(.06)	(0.)	(0.)
6	ABC								
	PEPSE	5.1	N/A	241826.	910.14	527502.	144.4	139.3	0.1
	VENDOR	5.0		243666.	910.14	527502.	144.4	139.3	0.0
	(% difference)	2.0		(0.76)	(0.)	(0.)	(0.)	(0.)	-

TABLE 2

RESULTS OF FEEDWATER HEATER RETUBING STUDY

Feedwater Heater	VENDOR INITIAL PREDICTIONS TTD °F	DCA °F	Tube ΔP PSIA	Condensing HTC (BTU/HR-FT²-°F)***	VENDOR REVISED PREDICTIONS TTD °F	DCA °F	Tube ΔP PSIA	Condensing HTC (BTU/HR-FT²-°F)*	PG&E PEPSE PREDICTIONS TTD °F	DCA °F	Tube ΔP PSIA	Condensing HTC (BTU/HR-FT²-°F)*
1 ABC												
As Built	6.0	10.0	9.1		6.0	10.	9.1	821	5.7	10.0	9.1	827
Stainless Steel	7.2	10.5	5.8		8.4	11.9	6.6	710	8.2	11.8	6.6	711
(Change)	(1.2)	(.5)	(-3.3)		(2.4)	(1.9)	(-2.5)	(-111)	(2.5)	(1.8)	(-2.5)	(-116)
2 ABC												
As Built	6.0	N/A	6.1		6.0	N/A	6.1	849	5.7	N/A	6.1	854
Stainless Steel	7.8		5.3		8.2		5.3	748	8.0		5.4	748
(Change)	(1.8)		(-.8)		(2.2)		(-.8)	(-101)	(2.3)		(-.7)	(-106)
3 ABC												
As Built	4.0	10.0	7.3		4.0	10.0	7.3	875	3.7	10.0	7.3	898
Stainless Steel	6.4	10.4	6.2		6.7	11.3	6.2	713	6.4	12.0	6.2	724
(Change)	(2.4)	(.4)	(-1.1)		(2.7)	(1.3)	(-1.1)	(-162)	(2.7)	(2.0)	(-1.1)	(-174)
4 ABC												
As Built	4.0	10.0	6.7		4.0	10.0	6.7	779	3.7	10.0	6.7	787
Stainless Steel	(6.2)	10.1	5.7		6.5	11.4	5.7	645	6.2	12.4	5.7	647
(Change)	(2.2)	(.1)	(-1.0)		(2.5)	(1.4)	(-1.0)	(-134)	(2.5)	(+2.4)	(1.0)	(-140)
5 ABC												
As Built	5.1	10.0	7.8		5.1	10.0	7.8	711	5.1	10.0	7.8	714
Stainless Steel	6.6	10.3	7.0		6.8	11.8	7.0	622	6.9	11.7	6.5	618
(Change)	(1.5)	(.3)	(-.8)		(1.7)	(1.8)	(-.8)	(-89)	(1.8)	(+1.7)	(-1.3)	(-96)
6 ABC												
As Built	5.0	N/A	9.5		5.0	N/A	9.5	630	5.2	N/A	9.5	625
Stainless Steel	5.0		7.9		6.8		7.9	544	7.0		7.7	547
(Change)	(0.)		(-1.6)		(1.8)		(-1.6)	(-86)	(1.8)		(-1.8)	(-78)

*This is the calculated overall condensing section heat transfer coefficient.

**This data was not available from the initial VENDOR proposal.