Study of Condenser Retubing

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Abstract

The surface condenser on RG&E Russell Station Unit 4 has 13% of the tubes plugged and is scheduled for retubing. The condenser currently has Admiralty metal tubes, which have been subject to ammonia attack in the air removal section. Several alternative tube materials were evaluated for cost, thermal performance and corrosion resistance. PEPSE was used to compare the heat transfer performance of Admiralty, copper/nickel, titanium and SS304 replacement tubes in the existing condenser. The results of the heat transfer analysis are the subject of this paper. The study concluded that 90/10 copper/nickel provided the best combination of properties for replacement tubes.

Introduction

Rochester Gas and Electric Corporation, with corporate headquarters in Rochester, New York, serves 300,000 customers in the upstate New York area. RG&E electric generating plants include a 500 MW nuclear plant, five (5) coal fired units with a total output of 350 MW, hydro-electric stations on the Genesee River with 50 MW, and two (2) 18 MW peaking combustion turbines. RG&E is also a partner with neighboring utilities for 200 MW of oil fired generation and 150 MW of nuclear. The RG&E system peak electric demand occurred in 1991 with 1297 MW.

Background

RG&E Russell Station Unit 4 went on line in 1957. It is rated at 80 MW, with a Combustion Engineering single reheat boiler and General Electric turbine. The condenser, supplied by Allis-Chalmers, is a deaerating type with two water passes and a divided waterbox. There are 6240 admiralty metal tubes, 7/8 inch OD by 18 BWG wall, 28 feet long. The tubes are rolled into Muntz metal tubesheets. A triplex low pressure feedwater heater is mounted in the condenser neck. Circulating water is supplied from Lake Ontario. Stress corrosion cracking on the outside of the tubes has occurred on many tubes in the air removal sections of the condenser. This has been attributed to ammonia attack from the hydrazine water treatment. Tube leaks have been common in the past few years, and 13% of the tubes have been plugged. A decrease in condenser performance due to the reduction in surface area has not been detected, but tube leaks have resulted in poor boiler water chemistry and increased water treatment costs. Because Unit 4 is expected to operate for another

25 years, it was decided to retube the condenser during a scheduled maintenance outage.

Study of Retubing Options

RG&E considered several alternate materials for retubing the condenser, including admiralty, copper/nickel, titanium and stainless steel. The criteria for evaluating these materials include cost, corrosion resistance, bio-fouling resistance and heat transfer properties. Because the existing tube sheets and internal tube support plates are to be retained, the change in weight of the tubes, the potential for tube vibration and the ability to roll the tubes into the tubesheet were also reviewed during the evaluation.

Study of Heat Transfer Properties

A PEPSE model for the condenser and for the turbine had been previously developed for this unit. The turbine model was run with the condenser both in HEI mode and in Simplified Design mode to compare predicted unit performance with operating data. Operation was reviewed at several different loads and at varying circulating water temperatures. We found better correlation with the condenser in the Simplified Design mode, and so that was used for the heat transfer analysis. No models were run with the condenser in Full Design mode, as we felt the additional data input did not improve the reliability of the results.

The heat transferred in the condenser is calculated from the following equation:

$Q = UA \times A \times \Delta T$

Q = Heat transferred, BTU/Hr

UA = Overall heat transfer coefficient, BTU/Hr Ft2 F

A = Heat transfer surface, Ft2

T = LMTD, F

The heat transfer surface is fixed by the dimensions of the tubes in the condenser. The Log Mean Temperature Difference is not assigned a variable name in PEPSE, so operations were included to calculate the LMTD for this study. The following equation was used:

$\Delta T1 = T\ steam - T\ water\ out$

$\Delta T2 = T\ steam - T\ water\ in$

$LMTD = \Delta T1 - \Delta T2\ /\ \ln\ (\Delta T1/\Delta T2)$

The overall heat transfer coefficient in the condenser is determined from the five (5) thermal resistances across the tube: Tube outside fouling + outside film + tube wall + inside film + inside fouling = total thermal resistance. The outside and inside fouling are typically characterized by reducing the overall coefficient by 15%. The outside and inside film coefficients should be the same for all tubes with the same dimensions, regardless of tube material. Therefore the effect of wall thermal resistance on the overall heat transfer coefficient can be calculated. The effect of the heat transfer coefficient on overall condenser performance and unit performance is more difficult to predict, and we relied on the PEPSE analysis for this information.

The wall resistance does not have a variable name, so it was calculated with operations using the equation in the TEMA standards:

$r = t \times d / 12 \times k \times (d - t)$

r = Tube wall resistance, Hr Ft2 F / BTU

t = Tube wall thickness, Inches

d = Tube outside diameter, Inches

k = Tube material thermal conductivity, BTU / Hr Ft F

The values of thermal conductivity for the tube materials varied somewhat among the sources. The following properties were utilized for this study:

Material	Conductivity, k at 100 F
Admiralty	64
Cu Ni 90/10	26
Cu Ni 70/30	17
Titanium	12
SS 304	8.7

The condenser sub-model was used to evaluate the heat transfer coefficients with the various materials. This provided sufficient data for analysis in a model that was easy to run.

The typical resistances calculated by PEPSE are shown below for .875 OD by 18BWG admiralty tubes with 70 F circulating water. This assumes that there is only one tube in the condenser, and there is no flooding penalty. Note that the tube wall resistance contributes approximately 6% to the overall resistance.

	Resistance Hr Ft2 F/BTU	Conductance BTU/Hr Ft2 F
Outside Film	.00042	2375
Tube Wall	.000068	14800
Inside Film	.00066	1525
Overall	.00115	870
85% Cleanliness		740

The same condenser with 90/10 Cu/Ni tubes, .875 OD by 18 BWG results in the performance as follows. Note that the tube wall resistance contributes approximately 14% to the overall resistance.

	Resistance Hr Ft2 F/BTU	Conductance BTU/Hr Ft2 F
Outside Film	.00042	2375
Tube Wall	.00017	5875
Inside Film	.00066	1525
Overall	.00125	800
85% Cleanliness		675

The same condenser with 90/10 Cu/Ni tubes, .875 OD by 20 BWG (a more typical wall thickness) results in the performance as follows. Note that the tube wall resistance contributes approximately 10% to the overall resistance.

	Resistance Hr Ft2 F/BTU	Conductance BTU/Hr Ft2 F
Outside Film	.00042	2375
Tube Wall	.00012	8325
Inside Film	.00066	1525
Overall	.00120	825
85% Cleanliness		700

The same condenser with SS304 tubes, .875 OD by 18 BWG results in the performance as follows. Note that the tube wall resistance contributes approximately 30% to the overall resistance.

	Resistance Hr Ft2 F/BTU	Conductance BTU/Hr Ft2 F
Outside Film	.00042	2375
Tube Wall	.00046	2175
Inside Film	.00066	1525
Overall	.00154	650
85% Cleanliness		550

The same condenser with SS304 tubes, .875 OD by 22 BWG (a more typical wall thickness) results in the performance as follows. Note that the tube wall resistance contributes approximately 20% to the overall resistance.

	Resistance Hr Ft2 F/BTU	Conductance BTU/Hr Ft2 F
Outside Film	.00042	2375
Tube Wall	.00026	3900
Inside Film	.00066	1525
Overall	.00130	750
85% Cleanliness		640

In an actual steam surface condenser, there are many rows of tubes, and condensed steam falling from tubes high in the tube bundle will insulate the lower tubes. The average outside film coefficient will be reduced, though the other thermal resistances remain unchanged. This reduction in the outside coefficient is called the flooding penalty.

The same condenser with admiralty tubes, .875 OD by 18 BWG, with the flooding penalty included results in the performance as follows. Note that the tube wall resistance contributes approximately 4% to the overall resistance.

	Resistance Hr Ft2 F/BTU	Conductance BTU/Hr Ft2 F
Outside Film	.00090	1113
Tube Wall	.000068	14800
Inside Film	.00066	1518
Overall	.00162	615
85% Cleanliness		522

The same condenser with 90/10 Cu/Ni, .875 OD by 20 BWG, with the flooding penalty included results in the performance as follows. Note that tube wall resistance contributes approximately 7% of the overall resistance.

	Resistance Hr Ft2 F/BTU	Conductance BTU/Hr Ft2 F
Outside Film	.00090	1114
Tube Wall	.00012	8325
Inside Film	.00070	1424
Overall	.00172	581
85% Cleanliness		494

The same condenser with SS304 tubes, .875 OD by 22 BWG, with the flooding penalty included results in the performance as follows. Note that the tube wall resistance contributes approximately 14% to the overall resistance.

	Resistance Hr Ft2 F/BTU	Conductance BTU/Hr Ft2 F
Outside Film	.00089	1120
Tube Wall	.00026	3900
Inside Film	.00072	1381
Overall	.00187	535
85% Cleanliness		454

The overall cycle performance was then calculated for the three different tube materials. The data from the condenser sub-model was incorporated into the turbine model. The gross generation, gross cycle heat rate and condenser backpressure were evaluated at circulating water inlet temperatures from 40 F to 70 F. The results are as follows:

	70 F Circulating Water		
	Admiralty 18 BWG	90/10 Cu/Ni 20 BWG	SS304 22 BWG
UA, BTU/HR-FT2-F	522	494	454
LMTD, F	17.9	18.9	20.5
Backpressure, In Hg	1.99	2.04	2.14
Heat Rate, BTU/KWH	7874	7880	7892
Generation, KW	82536	82456	82324

	40 F Circulating Water		
	Admiralty 18 BWG	90/10 Cu/Ni 20 BWG	SS304 22 BWG
UA, BTU/HR-FT2-F	452	439	397
LMTD, F	20.9	21.5	23.7
Backpressure, In Hg	0.83	0.85	0.91
Heat Rate, BTU/KWH	7826	7822	7818
Generation, KW	83072	83080	83118

Conclusion

The reduced thermal conductivity of 90/10 Cu-Ni and SS304 do affect the overall condenser performance at the higher circulating water temperatures. The heat rate degradation utilizing 90/10 tubes versus the admiralty tubes results in an incremental annual fuel cost of $3000, and a $9000 incremental cost with the SS304 tubes. It is also apparent that condenser backpressures below 1 inch HG do not result in a unit performance improvement.

Summary

RG&E selected 90/10 Cu-Ni for the replacement tubes for the condenser. This material offers the best resistance to stress corrosion cracking, which has been the cause of most of the tube failures to date, and the improvement in boiler water chemistry will offset the small loss in thermal performance.

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References

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