# Performance improvement opportunities during a condenser retube

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This article reports on fixes made to a chronically under-performing condenser during a condenser retube resulting in nearly a 1.0"Hg decrease in back pressure on the turbine. The project scope included a basic engineering evaluation in 2008, advanced engineering evaluation and installation of unique test grade instruments and testing in 2009, the condenser retrofit in Q4 2010 and post retrofit testing. For reference, a condenser pressure reduction of 0.1"Hg per 1GW Rankine cycle unit is $150,000/yr in fossil fuel savings or $1,000,000/yr in extra power generation revenue [1]. The performance of the condenser is presented before and after the upgrade showing significant backpressure reduction and heat transfer improvement.

It will be shown that 30% of the effective condensing surface area (or similarly, an additional 30% average heat transfer coefficient) was unlocked by activating the previously idle surface area of this under-performing 1980s vintage condenser.

Historically two options have been available to power plant engineers faced with an underperforming condenser: replace the entire condenser via a modular bundle replacement, and/or replace the tubes with a more favorable heat transfer material. A third option is now available that offers great cost advantages. Condenser retrofit methods that better manage steam, condensate and non-condensable flows can recover underutilized surface area thereby effectively increasing the capacity of a condenser without adding tubes. This option can be deployed during or without a retubing outage and has dramatic impacts on condenser performance. Considering a retrofit option concurrent with a retube is an opportunity that should not be missed. This is especially the case with condenser designs prior to the year 2000.

A stepwise process is used to determine if a condenser will benefit from the installation of a retrofit. This allows plant engineers to understand the potential benefits of continuing the process prior to moving on to a subsequent step. The following sections of this article will describe this process and the results that were achieved implementing this process.

## Basic Engineering Evaluation

The goal of a basic engineering evaluation is to determine the best clean condition performance of the equipment using OEM instrumentation. ASME PTC 12.2 [2] provides standards for bulk parameter measurements and overall performance quantification. The analysis usually concludes with quantifying the chronic excess back pressure and its impact on power generation efficiency, i.e. gross heat rate.

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Although it is often found that 30-40-year-old OEM instrumentation has unacceptable uncertainties for performance monitoring, the quantified excess back pressure is a decent estimate and provides a basis for determining if corrective action is justifiable.

A basic evaluation was performed in 2008 on Minnesota Power's Boswell Energy Center's 560MW unit 1980 Ingersoll-Rand condenser. Data from 2006 to 2008 was evaluated. Excess condenser pressure was estimated to be about 1.0"Hg in the second stage condenser and 0.5"Hg in the first stage condenser under near full load and clean tube conditions. This data shows a heat transfer of ~60% of the design value. A drawing review concluded that the condenser was a good candidate for modification due the condenser's inefficient non-condensables removal design. An instrumentation package was recommended for quantifying the recoverable heat transfer and aid in the retrofit design.

## Instruments for Condenser Analysis

Excess back pressure is the sum of contribution from several root-cause factors and has been summarized in previous publications and in the EPRI Guidelines [3]. These root causes are: internal tube fouling (microfouling), plugged tubes (plugged or obstructed due to macrofouling), low cooling water flow, steam side air storage and steam side condensate inundation. Quantifying the impact on backpressure of individual root causes requires advanced evaluation using additional instrumentation for directly measuring heat transfer. Appendices in the ASME PTC 12.2 standard also provide general guidelines for measuring fouling and air storage (also known as air binding). The instruments and methods presented in this article represent state of the art measurement of heat transfer for large scale shell and tube condensers. The quantification of fouling and air binding is essential for improvement via the shell and tube condenser retrofit process. This section presents the instrumentation used in this continuous monitoring program for advanced evaluation.

**Figure 1**
*Example Condenser Monitoring System (CMS)*

**RheoVac® Condenser Monitor (RVCM)** [4]. This instrument is installed between the condenser and the vacuum equipment and provides non-condensable and water vapor flow rates in the air off take piping of a condenser.

**Rheotherm® Cooling Water Flow and Fouling Meters (CWM)** [5] [6]. These instruments are installed at selected tube locations in the outlet waterbox, as shown in Figure 1. They measure tube flow rate and cooling water outlet temperature. These unique instruments provide measurements necessary to accurately map critical regions of a tube bundle for determination of the tube heat transfer coefficients and to quantify fouling.

**Submersible high density temperature arrays (HDTA).** These instruments are installed on the face of the outlet tubesheet or along the ID of selected tubes (between the inlet and outlet tubesheet). They allow for direct measurement of the heat transfer in thousands of locations within the condenser which can then be used to evaluate and advance the design of the heat exchanger. The sensor density is tailored to the project goals and have been installed as high as 1 sensor per 15 tubes on a 30,000 tube 1GW condenser.

**Bulk cooling water flow rate.** Differential pressure instruments are calibrated and used to monitor cooling water flow rate. An engineering evaluation is used to ensure proper location and protection for long-term reliable flow measurement. The instruments are calibrated using test methods such as dye dilution, velocity traverse or CWM average tube flow.

Bulk test grade measurements. Steam pressure, steam temperature and condensate temperature sensors are used to provide accurate bulk measurements as necessary since OEM equipment rarely meets current monitoring standards.

All instruments communicate with the RheoVac Supervisory Control and Data Acquisition (SCADA) system that can serve data to a plant DCS. An example of a complete Condenser Monitoring System (CMS) would include instruments selected to address specific engineering study requirements such as shown in Figure 1.

These instruments effectively put a microscope on the condenser and provide engineers with detailed, continuous diagnostic data giving them evidence of the deficiencies that exist and providing insight for modifications that should and can be made to improve the performance of the condenser.

## Advanced evaluation - A program to improve heat transfer

Using the instruments presented above, advanced evaluation of many condensers has revealed several common causes, as well as some unique ones, that contribute to low heat transfer coefficients. Unique causes include low cooling water flow, various types of cooling water side fouling, low waterbox fill levels, Scaling, low non-condensable vacuum equipment capacity, high air in-leak and other causes familiar to most plant personnel. Common causes include configuration-caused heat transfer losses such as poorly managed steam, condensate and non-condensable flows, and promotion of air storage (a phenomenon generally referred to as air binding). These common causes can be monitored using the aforementioned instruments and can be eliminated by retrofit methods.

In 2009, the instrumentation package described above was installed at Minnesota Power's Boswell Energy Center for an advanced performance evaluation. The left image in Figure 2 shows the heat transfer performance profile for the condenser. This figure is created using in-situ measurements. The data is measured in real-time, can quantify the regions of underperforming heat transfer, and is the state of the art method of implementing the ASME PTC 12.2 air binding measurement. The colors represent the percent heat transfer derived from HEI formulas for the heat transfer coefficient. A red color (around the perimeter) represents an area of the tube bundle that is transferring 100%, whereas a yellow color (interior) represents an area that is only transferring 70% of the HEI derived value. Areas of depressed heat transfer are caused primarily by air binding and/or, to a small degree, by condensate inundation. It was concluded that nearly all, 38% of the ~40% degradation, was a result of the condenser's configuration-caused inefficient removal of non-condensable gases. A condenser retube is an ideal opportunity to correct configuration deficiencies and recover effective surface area.

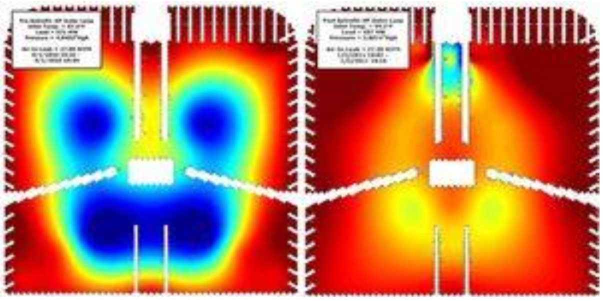

**Figure 2**
***Heat transfer percent performance profile before retrofit (left) and after retrofit (right)***

This profile along with years of evidence of an underperforming condenser, despite low air in-leakage and negligible fouling, provided justification for installing a retrofit during an upcoming retube. The projected benefits from the retrofit included lower condenser operating pressure, reduced condensate dissolved oxygen, and a greater immunity to air in-leakage events.

### Retrofit installation

The modification included placing baffles, pipes and other standard fluid transport structures using patented methods that were engineered to better manage steam, condensate and non-condensable flows. The retrofit was installed by the retubing contractor and was completed mostly in parallel with the retubing effort.

### Post retrofit performance

Following the modernizing retrofit of the condenser, including a conventional retubing, several months of data were collected to identify and quantify the condenser's new behavior. When the unit was brought on line following the retubing outage in January 2011, a change to lower condenser pressure and dissolved oxygen was promptly noted. Air in-leakage was quantified using the RVCM [4] to be 28 SCFM and condenser pressure was between 1.25 and 2.0"HgA. During this period, the condenser cooling water temperature differential was 21 °F with greatly reduced thermal stratification. The average cooling water flow rate measured by 16 CWM meters [7] [6] was 6.9 ft/sec - as expected from the circulating water pump rated capacity. It should be noted that a ball cleaning system had been in use from prior to 2006 to present to maintain tube cleanliness, the plugged tube count prior to the retrofit and retube was less than 2% and wall loss was the primary reason for retubing.

The right side of Figure 2 shows the heat transfer performance profile for the condenser after the retrofit. Comparing the left and right images of Figure 2, notice that many more tubes have higher heat transfer performance. This indicates that the retrofit eliminated the air bound zones within the condenser. Figure 3 shows a comparison of operating condenser pressure as a function of inlet cooling water temperature. The comparison data shows for pre-retrofit Admiralty tube condenser data is shown in the upper curve (2006 - 2010), and post-retrofit Admiralty tube condenser data in the lower curve (2011 and 2017).

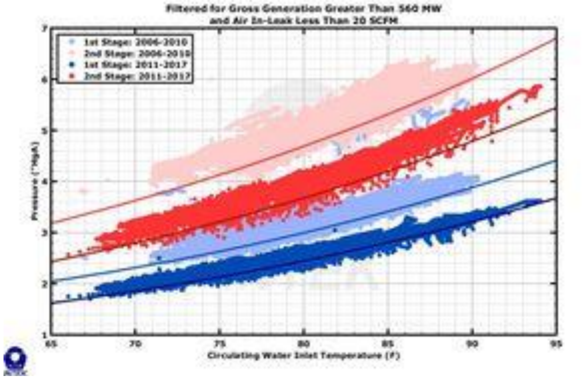

**Figure 3**
***Measured pressures pre-retrofit and post-retrofit***

Cost benefit studies have been conducted for this condenser modification work. Payback has been determined to be 1-2 years and is dependent on the benefits that are quantified. If one considers fuel savings, additional generation at heat input limited conditions and maintenance reductions, a one-year payback period is easily projected.

## Heat rate improvement/increased capacity analysis

The heat rate improvement was evaluated using two different methods. The first method approximates heat rate reduction using the original turbine heat rate correction curve as a function of condenser pressure. This method estimated the annual heat rate reduction to be ~80 Btu/kWh depending on normal swings in unit operating load, which correlates to ~0.8% heat rate reduction. This method neglects secondary benefits of the retrofit.

A second method approximates the heat rate reductions by evaluating EPA Continuous Emissions Monitoring (CEM) data. Figure 4 is CEM data showing a total unit heat rate normalized to the year before the retrofit. Concurrent with the condenser retrofit work in 2010, the HP turbine was replaced with a dense pack. The plant reported that the dense pack contributed to ~7% heat rate reduction (see Figure 4). The condenser pressure reduction contributed -1% heat rate reduction with some additional unknown heat rate reduction due to secondary effects such as increased immunity to air in-leak.

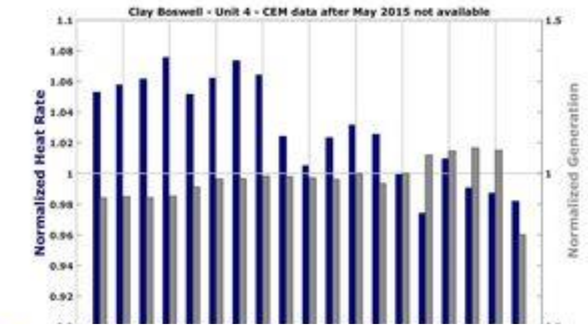

**Figure 4**
***CEM unit heat rate data - normalized to year of retrofit (2010)***

## Conclusion

Condenser performance is limited in a wide range of the condenser designs that are in operation today. A detailed monitoring approach to independently measure root causes for degradation allows plant engineers to determine what degradation mechanisms are economically justifiable to repair. A stepwise program developed to evaluate condensers for their improvement via retrofit methods is available as described in this article. This technology can permit a 30% or more increase in the amount of steam that a condenser could accommodate and reduce turbine exhaust pressure with a payback of 1-2 years.

## References

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