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# Application of New Individual Condenser Tube Circulating Water Flow and Fouling Meter in Performance Monitoring & Troubleshooting – A Case Study

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## Abstract

Low cost, reliable and accurate real time measurement of individual tube condenser cooling water flow rate, cooling water outlet temperature and tube side fouling for the purpose of condenser performance monitoring and troubleshooting is presented. The importance and the effects of these parameters on condenser performance are well understood and periodically estimated using indirect measurements such as dye dilution testing to represent average tube circulating water velocities, distributed temperature sensors in waterboxes and differential pressure measurements between inlet and outlet waterboxes. These measurements, while useful, are not always effective to identify performance inhibiting issues quickly and accurately.

This paper presents a cooperative study on the effects of circulating water flow and fouling and protective tube coatings for the purpose of condenser performance and monitoring improvement. The objective of the study was to evaluate new Circulating Water Flow and Fouling (CWFF) instrumentation [1], [2], [3] to evaluate impact of tube coating [4] on heat transfer and biofouling, and to examine the effect of other variables on on-going Microbiologically Influenced Corrosion (MIC) attack on the SS condenser tubes. However, in addition to providing useful information on the coated tubes, the study unveiled a number of other condenser performance related issues. Real-time in-situ circulating water flow and fouling data over an entire 1-year period will be presented that:

- Correlates real-time flow measurements to fouling as it occurs
- Assists in the evaluation of different circulating water pump capacities and configurations
- Identifies flow stratification within the water box and identifies whether or not waterboxes are filled
- Evaluates the heat transfer coefficient differences between the coated and uncoated tubes
- Identifies other performance related findings

 

## Introduction

Midwest Generation Joliet Station has two coal fired units, Unit 7 and Unit 8. Both units are 550 MW and are located on the Des Plaines River and have been in operation since 1963 - 1964. The circulating water system is a once through system comprised of a bar rack, traveling screens, circulating water pumps and reversible condensers. The original SS 304 condenser tubes on Unit 8 had failed due to MIC and these tubes were replaced with similar material in 2005. The root cause for the failure at that time was attributed to improper lay-up practices. In 2006, after less than a year of operation, significant MIC damage was identified during routine eddy current testing of the tubes. In an attempt to mitigate the above mentioned MIC attack, coatings have been installed on the ID of 60 leaking tubes as a test in lieu of plugging, to determine the coating life and effectiveness to prevent further MIC. The coating is installed in an ultra thin layer by pulling 2 plastic scrapers through the tubes with the coating in between. In this manner, the coating is applied and then wiped off with the intent that it will fill the pits, seal small leaks, and leave an ultra thin layer on the tube to further prevent new attacks.

Units 7 and 8 share a total of 4 circulating water pumps. All four pumps are identical in model and rated pumping capacity. The condenser configuration is presented below in Figure 1 and the tube bundle layout is shown in Figure 2. As mentioned above, the condenser is equipped with circulating water flow reversing valves, which remove the macrofouling from the tube sheet. Joliet Station experiences rapid debris (macro) fouling and therefore as a standard operation, the condenser circulating water is generally reversed on a daily cycle. The primary method for microfouling control is chlorination. Additionally, the station utilizes air drying to remove silt and biofouling by periodically taking a water box out of service and opening the doors and installing hoses connected to an air moving system that circulates warm air through the tubes and dries the fouled material to a point where it is flushed away when the water box is placed back in service. These cleaning techniques have worked well for the station. The drying method is also used for a long and short-term lay-up of the condensers.

In 2006, the station decided to test and evaluate new Circulating Water Flow and Fouling (CWFF) instrumentation to determine the cooling water velocities. MIC is most likely under stagnant conditions or operation with low or intermittent flow [7]. The objective was multifold, to measure cooling water velocities, to evaluate the impact of tube coating and biofouling on heat transfer, and to examine the effect of other variables on on-going MIC attack of the SS condenser tubes. In addition to providing useful information on the coated tubes, the study unveiled a number of other condenser performance related issues that this paper will present.

Intek's circulating water flow and fouling (CWFF) meter, patent pending, utilizes thermal sensing technology to measure the circulating water flow through unobstructed flow tube. This technology also enables quantification of heat transfer coefficient. The flow data is single or bi-directional and routed to a process computer for data logging and a range of computations. The patented *Rheotherm* measurement method that provides the basis for the CWFF has been used in thousands of installations since 1978 [5].

The important features of the CWFF are that it is highly accurate, reliable and non-invasive to the flow measurement. For most steam surface condensers used in the power industry, any flow and fouling instrument must be capable of surviving long term submersion, exposure to unfiltered circulating water, and allow ease of on-line or off-line tube cleaning methods. The CWFF is well suited to these conditions and thus is an excellent choice for the measurement. A selection of electronics options is available for temperature and fouling compensation and conditioning of the flow signal. Flow data is routed to a process computer for data storage and a range of optional output computations. The data can also be sent to an acquisition system.

The flow meters were installed in the upper bundle of one of the 4 outlet water boxes (82East) of the Unit 8 condenser. A photograph of two of the four installed meters is shown in Figure 1. Brackets anchored at two adjacent tubes were used to provide a mechanical brace from the meter to the tubesheet to overcome a concern that violent flow conditions during reverse flow could stress the adhesive used to attach the meters to the monitored tube. Meter cables were attached to tubesheet with epoxy and routed through a port in the outlet waterbox. Five thermocouples (TCs) were also installed (four of these are continuously data logged). The locations of the flow sensors and thermocouples are shown in Figure 4 and described in Table 2. Note that the sensors are installed in pairs; one monitoring a coated tube and a partnering sensor monitoring an adjacent uncoated tube. The installation locations for the CWFF sensors and TCs were carefully selected based on a critical examination of the condenser configuration, so that a very small number of key measuring points will provide data for meaningful analysis.

## Data Analysis

The CWFF meters were built and calibrated for both forward flow and reverse flow so that flow direction change can be recognized and flow rates in both directions could be measured. The data indicates that the circulating water pumps are switched at seemingly random intervals. In reality, pumps are taken off to perform system maintenance at low loads when less pumps are needed, at lower circulating water inlet temperatures, for bar rack cleaning, and waterbox drying.

Figure 5 shows two graphs of operating data (plant measured waterbox temperatures, CWFF temperatures, load, thermocouple (TC) temperatures, CWFF flow rates, and CW pump amps) with 4 CW pumps in operation in July 07 for a 1-week period. Note the temperature differentials from inlet to outlet increase for increased loads and velocity is ~7ft/sec during the forward and reverse flow conditions. This data represents measurements that are consistent with the expected operation of the unit and validates the credibility of the meters. Also note that on July 24th, the 7A CW pump was taken out of service for a short period and there is a noted decrease from ~7ft/sec to ~5.5ft/sec in all 4 of the CWFF monitored tubes.

The following sections present data that has been logged and reviewed over the past year of testing in more detail. Topics that are covered include:

- Multiple incidences of macro fouling detection and effectiveness of reverse flushing.
- Pump capacity comparisons.
- Flow stratification.
- HTC analysis of coated vs. uncoated tube.

### Multiple incidences of macro fouling detection and effectiveness of reverse flushing

Joliet Station experiences significant grass and debris run at the bar rack, plugging up the racks. Some debris makes it past the traveling screens and ends up in the condenser waterboxes. This type of fouling can become frequent during spring and summer months and was very evident from the CWFF meter data. The circulating water flow through the condenser is reversed on daily basis to remove the macro fouling of the tubesheet. The CWFF meter data illustrates how reverse flushing effectively clears the tubesheets of macro fouling debris.

As an example of one of the numerous recorded incidents, Figure 6 shows data from Sept. 15 to Sept. 25, which captures a persistent fouling event. The condenser begins to experience macro fouling on Sept 18. All of the meters have an abrupt increase in flow rate shown at "Event 'A'". The –1 flow increase is most likely due to a large amount of fouling (not in the monitored tubes) that decreased the number of tubes with clear passage causing a flow increase in the remaining unfouled tubes. The flow is switched from reverse to forward flow (at 9/18/07 10:00) and immediately the -1 meter-tube becomes increasingly plugged by debris and finally flow is reduced to zero. Notice that during this time the –2, -3 and -4 meter flow rates steadily increase thereby indicating a continued decrease of overall flow cross sectional area by additional unmonitored tubes being reduced in flow. The circulating water is again switched from forward flow to reverse flow (at 9/20/07 8:00) and the -1 meter is immediately recovered and measures flow through its tube. The meters continue to indicate tube macro fouling until the condenser flow is switched from reverse to forward flow whereby all the debris is cleared and the measured flow rates return to reasonably steady conditions. Note that the -1 and -2 flow rates are higher than the -3 and -4 flow rates preceding and following these events. This flow stratification will be discussed in the next section. Random macro fouling of this nature is typical where river water supply can be tainted with debris.

## Circulating Pump Capacity Comparison, Flow Stratification and Eductor issues

It has been noted in Figure 6 and observed in other data not shown here that the -3 and -4 CWFF meters located in the upper portion of the 82SE waterbox were often measuring lower flow rates than the -1 and -2 meters in the lower portion of the same waterbox from June 07 to December 07 and this flow stratification does not appear to be a result of fouling. This condition does not exist when 1) all pumps are on in both forward and reverse flow, or 2) either pump 7A or 7B are separately off and in the forward flow direction. Additionally, this condition does not develop when pump 7A is off and in the reverse direction; furthermore, this condition appears to correct itself (meaning -3 and -4 increase over time) with Pump7A off and during reverse flow. Figure 7 show plots used to evaluate pump capacity. Note the x-axis is consecutive chronological data points and not a time scale in order to more easily assess the configuration effect on tube flow rate. To put the data into a more manageable format, the data is separated into 4 categories and plotted. These categories are forward flow each having three pumps running with either Pump7A off, Pump7B off, Pump8A off, or Pump8B off.

The plots indicate that the CWFF sensors 3 and 4 see lower velocities than CWFF sensors 1 and 2. This may have been due to the water boxes not being totally full. The station uses service water for the waterbox priming eductors. The priming eductors remove the trapped air from the top of the waterbox thus help to maintain a full waterbox. To remove larger debris, the strainers were installed in the service water piping. The strainers were found to be plugged with debris and Asiatic clams. Therefore the water box level may not have been drawn up as high as design causing lower flows through the top tubes.

The plots also indicate that the velocities are much lower with either 8A or 8B circulating water pump off. This explains why station needs two circulating water pumps running on the unit when one of the waterboxes is being isolated. It is a common practice at Joliet Station to operate 8A and 8B pumps on Unit 8 and one of the pumps on Unit 7 prior to isolating a waterbox on Unit 8 side. The same is true for Unit 7. The increase in back pressure is very pronounced and often restrictive if there is only one pump operating on the unit when one of the waterboxes is being isolated. The likely reason for this is a restriction or imbalance in the circulating water piping system design.

One additional point to be made here is that the flow monitors detected issues before they resulted in a significant back pressure increase. In all of these cases, the back pressure increased no more than 0.30 inches above bogey. During the course of this analysis Joliet Unit 8 back pressure deviation averaged about 25 Btu/KWh. Therefore, the meters may be used as a proactive tool to help determine a back pressure issue before it becomes significant.

## HTC Comparison of Coated vs. Uncoated Tube

The single tube heat transfer coefficient can be easily calculated using the primary measurements shown in Table 1.

**Table 1: Primary measurements for HTC calculation**

| | |
|---|---|
| 1) | The tube inlet circulating water temperature |
| 2) | The tube circulating water flow rate |
| 3) | The tube length and tube OD |
| 4) | The condenser saturation temperature |
| 5) | The tube outlet circulating water temperature |

The equation used to calculate the single tube HTC is straightforwardly calculated as:

Total Heat = $U*A*\div T_{lm} = m*c_p*\div T_{cw}$

$U = m*c_p*\div T_{cw}/A/\div T_{lm}$

Where U = Heat transfer coefficient

A = Total condensing surface area

$\Delta T_{lm}$ = Log mean temperature difference

$\Delta T_{cw}$ = Circ water temperature rise

Figure 8 shows the calculated coated vs. uncoated tube heat transfer coefficient percent difference between tube pairs for a range of circulating water inlet temperatures. There were 2 different methods of coating application analyzed. The red group of trends on the plot represents a thinner coating that is applied using pulled through method. In a pulled through method, the coating is applied by manually pulling the scraper which allows a uniform coating thickness. The blue group of trends on the plot represents a coating that was propelled through the tube using vacuum, which is presumed to produce greater coating thickness because the movement of scraper is not the same as it travels through the tubes leaving thicker coating. The coating heat transfer coefficients in a pulled through method, red color, are generally from 0 to 5 % less HTC than the uncoated tube while the coating HTC in a vacuum method, blue color, is generally about 5 to 10 % lower than the uncoated tube. A very conservative error margin was calculated to be +/- 5%, and therefore the pulled through tube results in a minimal degradation on heat transfer. The pulled through method of coating is little more labor intensive but appears to pay off in terms of savings in higher HTC.

## Conclusion

This case study has shown that the CWFF technology appears to be accurate and reliable, having performed flawlessly for nearly 1-year. The meters have helped to identify new performance impacting issues and helped to identify known issues quantifiable results. Real time frequent macro fouling of the tubesheet, water box level issues, circulating water pump capacity performance and associated flow configuration impacts, and reversal flow for the purposes of debris flushing are among the practical issues that have studied. The data history from the flow meters provided the following benefits:

- Helped determine when macrofouling was becoming significant and helped evaluate the effectiveness of reversing the flow to flush away the debris.
- Indicated a flow discrepancy as various circulating water pumps were operated.
- Indicated significant flow stratification that was due to water box eductor plugging.
- Indicated that the pulled through coating application method results in a minimal effect on heat transfer coefficient.
- Continuous online flow, temperature and fouling monitoring for a 1-year period (and still running).

## References

[1] Condenser Performance Measurement Using New On-Line Condenser Tube Flow Rate and Fouling Instruments, Dr. Timothy J. Harpster and Dr. Joseph W. Harpster, EPRI 10th Balance of Plant Heat Exchanger NDE Symposium. San Antonio TX. June 2008.

[2] CWFF, a patent pending instrument assigned to Intek Inc.

[3] Air In-Leakage and Intrusion Prevention Guidelines, EPRI Technical Report Product ID 1014125, March 31, 2008.

[4] New Developments in Condenser Tube Coatings, M. Horn, G. Weber and S. Shah, presented at 2007 EPRI Heat Rate Conference, Charlotte, NC

[5] *Rheotherm* Technology. USPN 4255968 1981 Intek Inc. Westerville OH.

[6] Fundamentals of Heat and Mass Transfer, Frank Incropera and David DeWitt, John Wiley and Sons, 1981

[7] Fluid Mechanics, Frank White, McGraw-Hill Book Company, 1986

[8] Sourcebook for Microbiologically Influenced Corrosion in Nuclear Power Plants, EPRI, 1988

[9] Graphing and initial data analysis conducted by Intek using Intek's Condenser Diagnostics Toolkit, MyCondenser.com

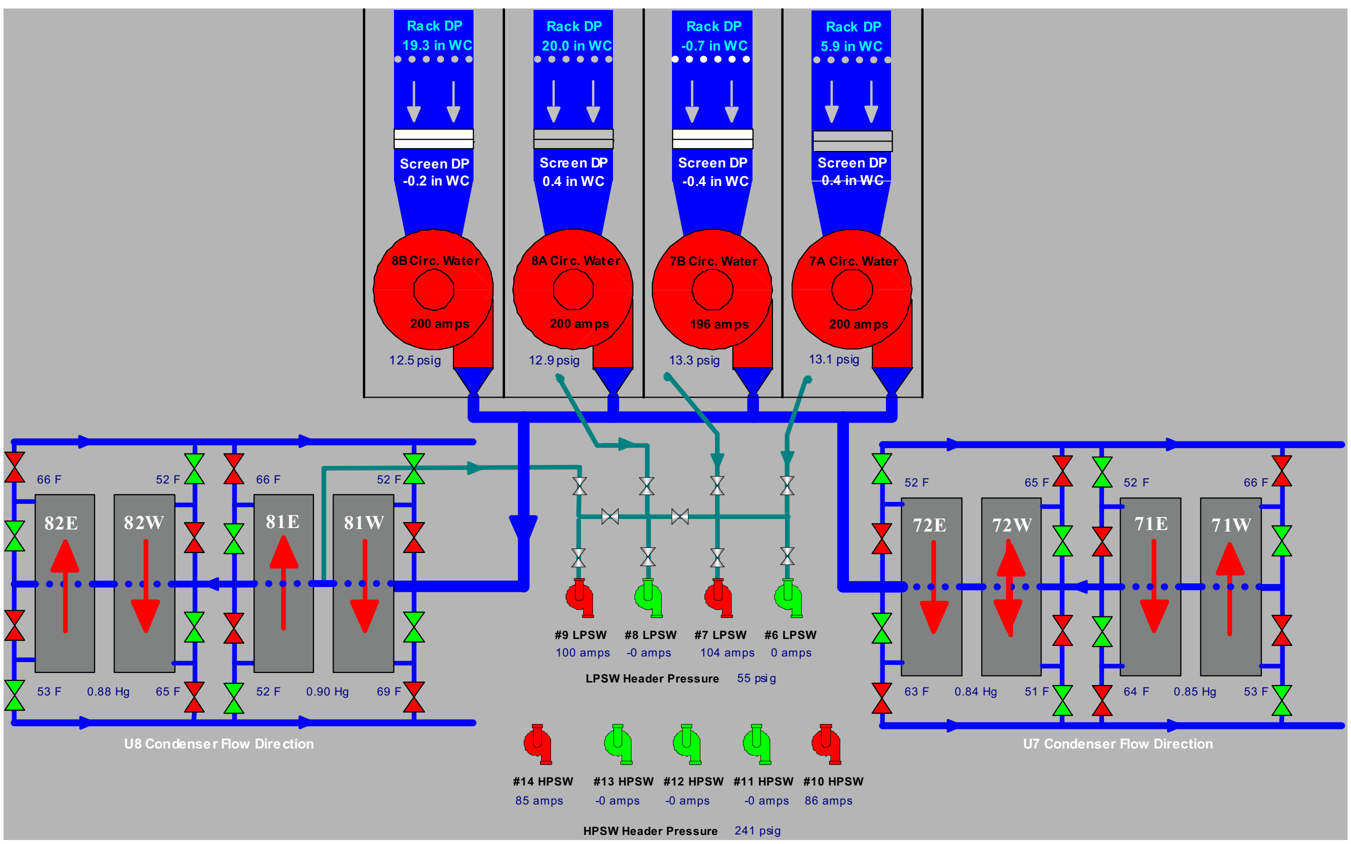


**Figure 1: Joliet Condenser Configuration**

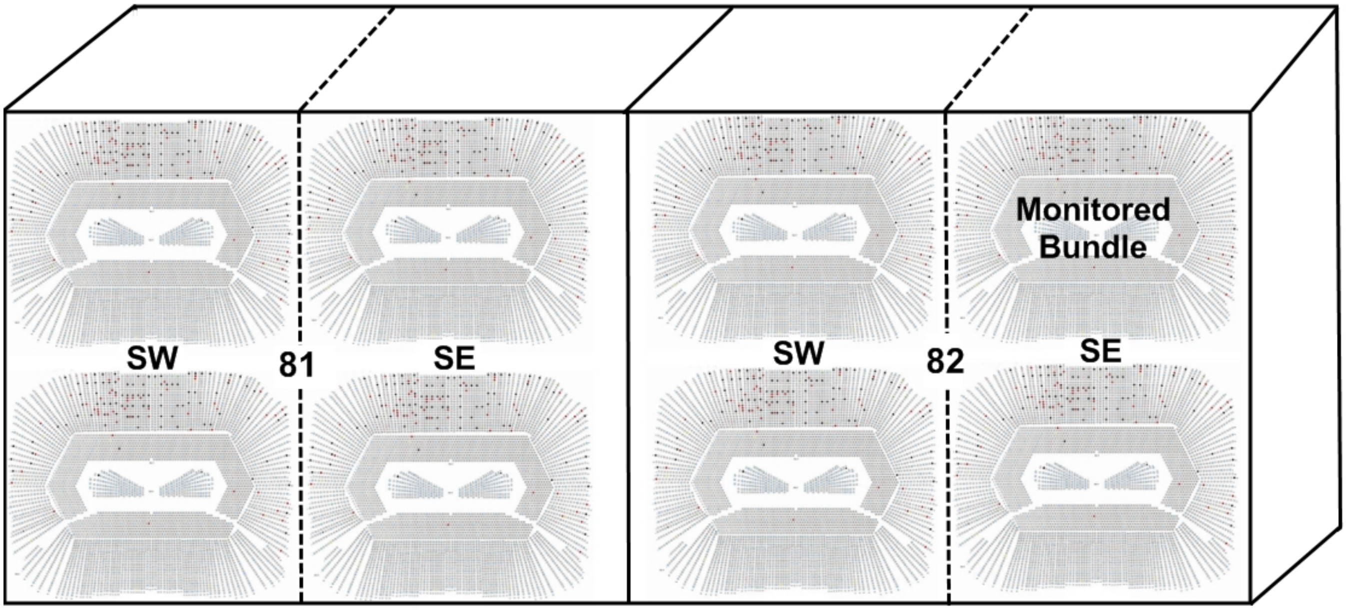


**Figure 2: South end view of Unit 8 – (Inlet of 82SE is 82NE) [9]**

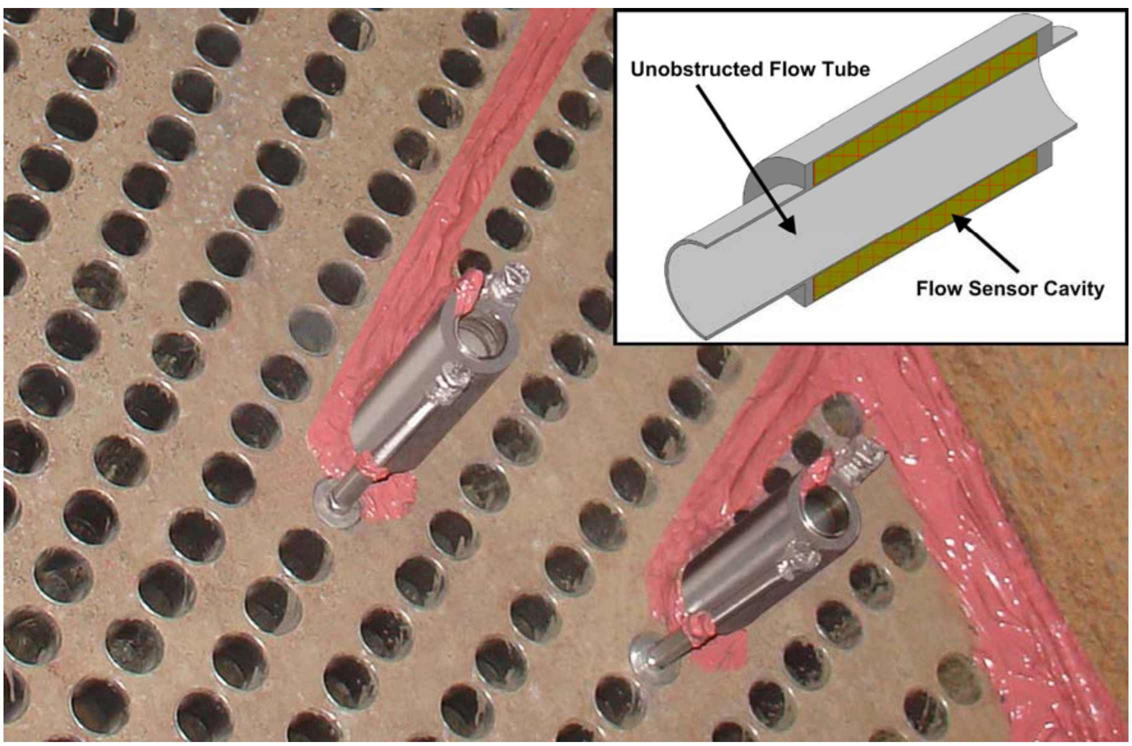


**Figure 3: Typical Flow Meter Installation**

**Table 2: CW sensor summary**

| | |
|---|---|
| **Sensor Pairs:** | |
| CWFF-1 coated condenser tube | CWFF-3 coated condenser tube |
| CWFF-2 uncoated tube | CWFF-4 uncoated tube |
| **Thermocouple Pairs:** | |
| TC-1 coated condenser tube | TC-3 coated condenser tube |
| TC-2 uncoated tube | TC-4 uncoated tube |
| TC-5 unpaired TC, not data logged, uncoated condenser tube | |

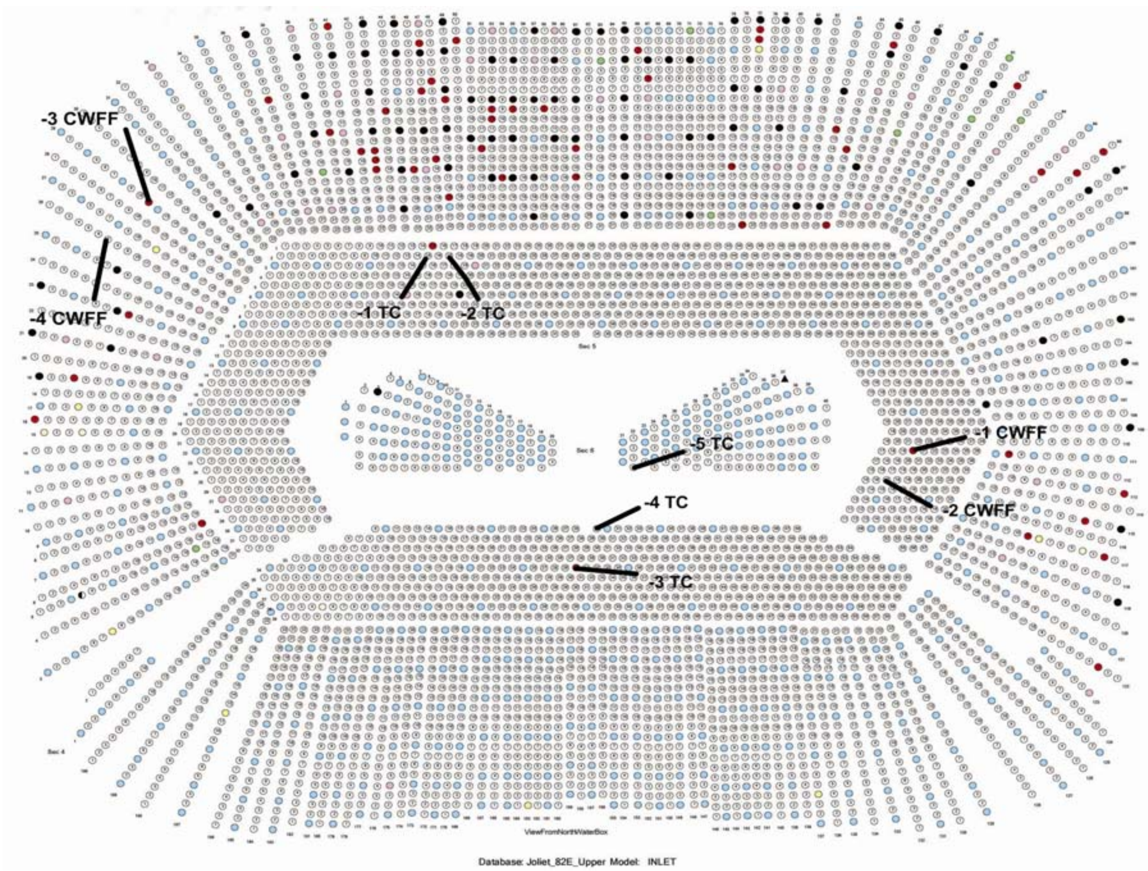


**Figure 4: CWFF and TC locations in upper 82E [9]**

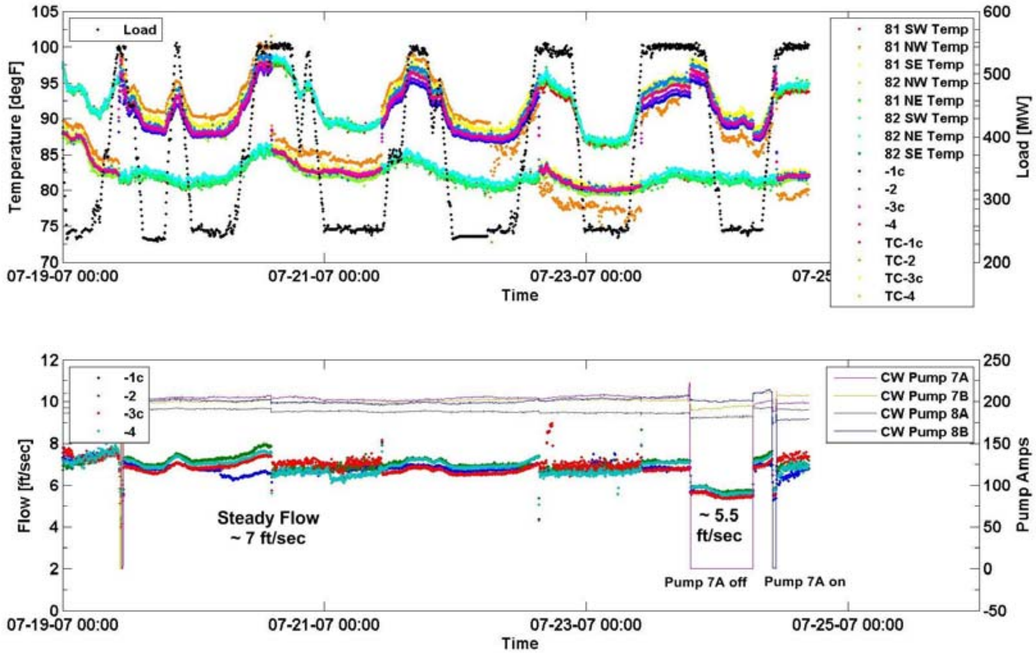


**Figure 5: CWFF meter flow velocity and temperature and other plant data [9]**

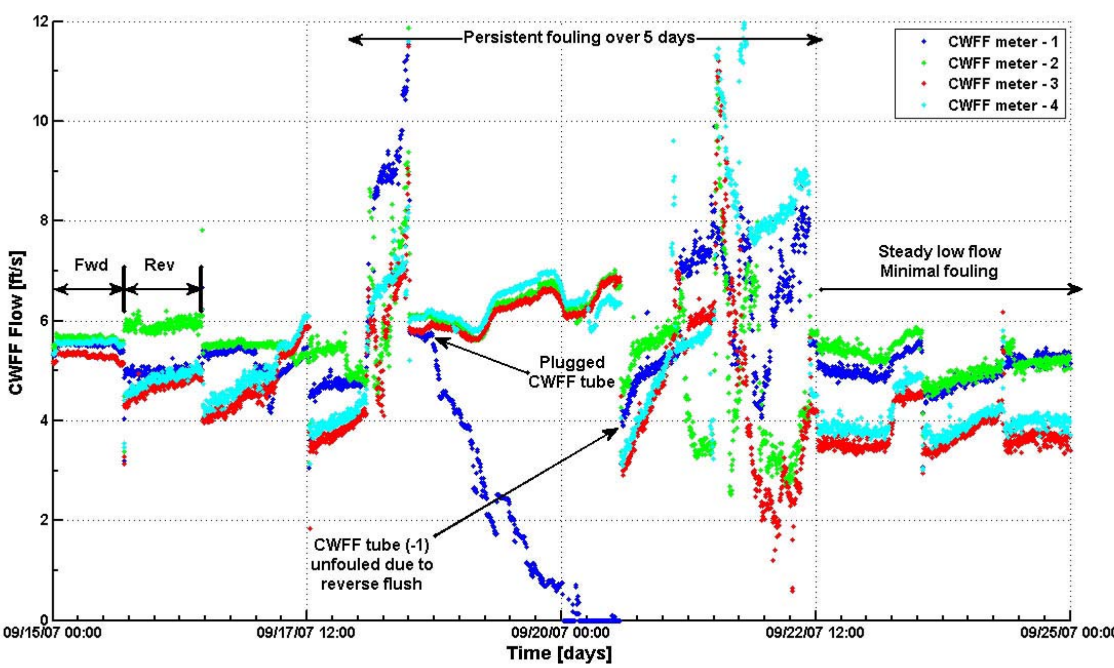


**Figure 6: Example of meter responses to macro fouling and effectiveness of reverse flushing [9]**

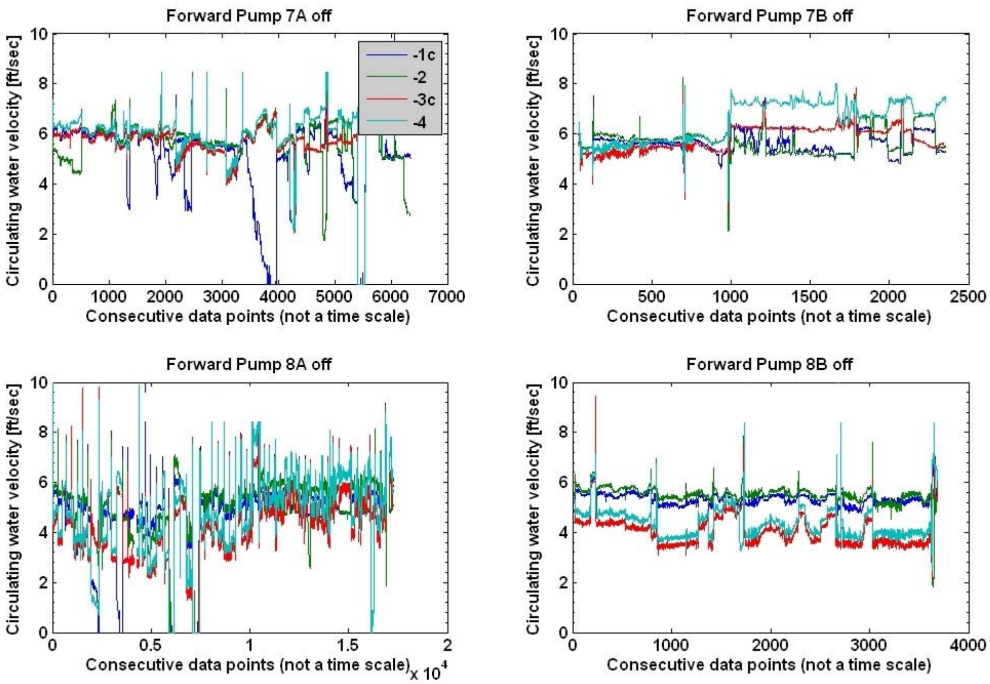


**Figure 7: Forward flow rate data for combinations of three different pumps running – sequential data point plot – steady state filtered – ~7months of data [9]**

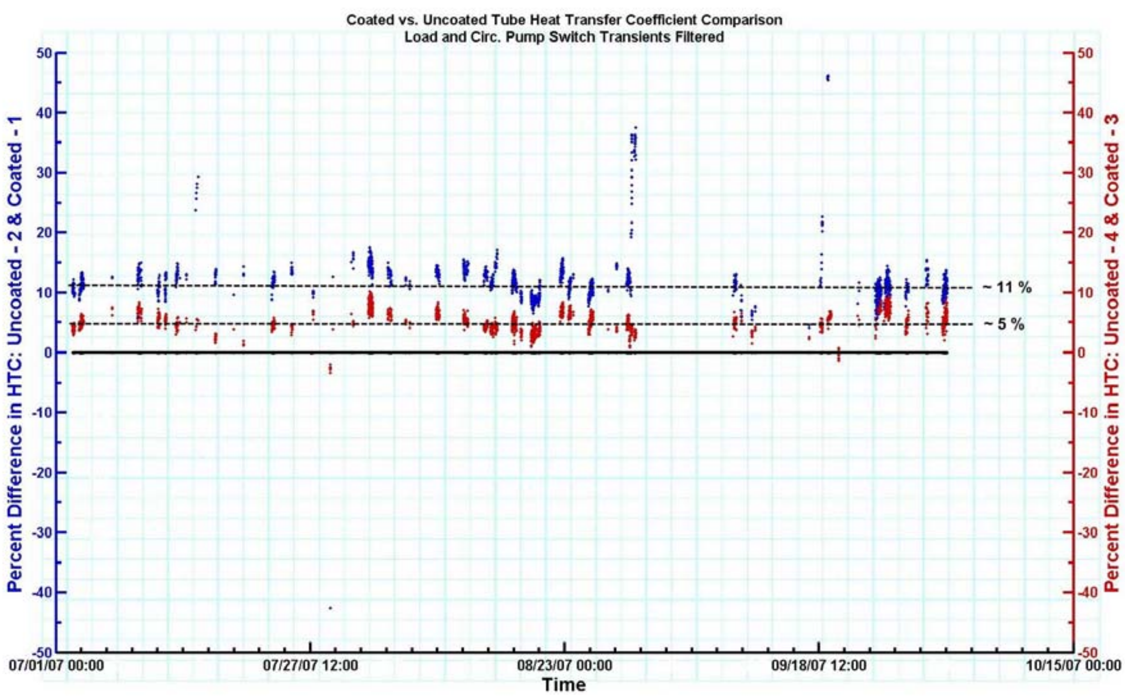


**Figure 8: HTC Comparison between the coated and uncoated tubes [9]**