WHITE PAPER

Return on Investment Analysis:

The Economics of Regular Condenser Maintenance

- Mechanical Tube Cleaning
- Air Inleakage Detection

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Getting To The Bottom Line

You may already suspect that your plant is not operating at peak performance. You want to incorporate the latest technologies to improve efficiency because your "gut feeling" tells you that improving your systems will have a payoff, yet you need a concrete process to justify an investment.

This White Paper summarizes a decade of research by Conco Systems, Inc. to obtain a better understanding of the behavior of steam surface condensers and their impact on your plant's bottom line. This research was followed by the development of techniques to model condenser performance, with a view to converting deviations from proper behavior to the equivalent avoided costs. Mathematical techniques were also developed to ascertain the optimum frequency of condenser cleaning to minimize these avoided costs. The full details of this work are published in a book by ASME Press, New York(1) entitled, *Steam Surface Condensers: Basic Principles, Performance Monitoring and Maintenance*.

Minimizing turbogenerator unit heat rate and maximizing generation capacity are among the guiding principles in power plant operation strategy. In fossil plants, heat rate is greatly affected by the efficiency with which the fuel is burnt. However, the heat rate of fossil plants, along with nuclear and combined cycle plants, may also be affected by the state of the condenser. Its condition is also a factor in determining whether the design MW load can be achieved.

Chapter 8 of Putman(1) outlines the variety of operating problems to which steam surface condensers are prone, principal among these being the fouling of condenser tubes with its negative impact on heat transfer rate and turbine back pressure. The condenser condition can also affect generation capacity. Air ingress into the turbine/condenser subsystem has similarly negative effects.

In this White Paper, we will discuss the thermodynamic considerations that make the condition of the condenser such an important element in determining the performance of the turbogenerator. We will also outline condenser maintenance strategies that can be adopted to minimize annual unit operating costs and, ultimately, maximize plant revenue.

Condenser operation also has a direct impact on power plant emissions. The heat rejected by the condenser is a source of thermal pollution; however, if it can be reduced by improved condenser maintenance, then the emission of carbon dioxide and other atmospheric pollutants is also reduced due to the lower consumption of fuel.

Another important condenser maintenance problem is the inleakage of cooling water into the condensate, contaminating it chemically (EPRI(2)). However, since it principally affects the corrosion of boilers and heat exchangers — and since the main topic of this document is the economics and return on investment as a result of the effect of the condenser on heat rate and/or power generation, we will not further address water inleakage here.

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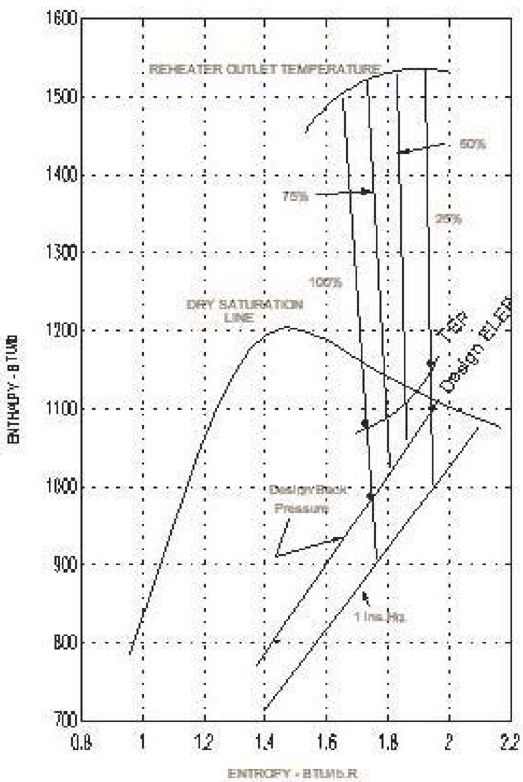
The Condenser/Turbine Subsystem

All nuclear and fossil plants are based on some variation of the Rankine Cycle — the steam/water conditions through the low-pressure stage of the turbine for a fossil-fired plant (illustrated in Figure 1).

Here, expansion lines are shown for a number of loads, steam from the outlet of the reheater passing through the intermediate and low pressure stages of the turbine and expanding finally into the condenser.



END POINT EXPANSION LINES vs. LOAD

Figure 1

During the last stage of expansion, the vapor passes through the saturation line so that the vapor entering the condenser is usually wet. As it becomes condensed, the conditions follow the constant pressure line (corresponding to the condenser back pressure) down to the liquid line (not shown). The wetness increases until the vapor becomes fully condensed.

The enthalpy of the vapor entering the condenser depends on condenser back pressure. It should be understood that the magnitude of the enthalpy drop between the reheater outlet and the condenser inlet determines the amount of energy converted to mechanical work (in this case, the generation of power).

If the flow of steam is determined at the steam generator or boiler(s), as occurs in nuclear power or combined cycle units operating in the boiler-follow mode, then raising the back pressure will reduce the amount of power generated by that fixed amount of steam. This will negatively affect unit heat rate and, in some cases, will limit the amount of power that can be generated. Conversely, a drop in back pressure will increase the amount of generated power.

In fossil-fired units, in which the load is determined by the setting of the turbine governor, an increase in back pressure will result in more steam having to be generated to support the load set on the governor. This, again, has a negative effect on heat rate. In severe cases, such as the back pressure reaching the upper limit recommended by the turbine manufacturer, the power setting will have to be reduced.

The back pressure determines the amount of latent heat (also known as condenser duty) that has to be removed for the vapor to become condensed, recovered, and then recycled back to the boiler. Meanwhile, in a clean condenser, the back pressure is determined by the duty, and by the cooling water flow rate and its inlet temperature.

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Figure 1 illustrates a design back pressure on which all the appropriate original cycle calculations were based; but the actual back pressure experienced can be lower or higher than this. For instance, it can be lower if the cooling water inlet temperature is low and the water flow is at or higher than its design value.

If the tubes in the condenser become fouled, then the thermal resistance causes the effective heat transfer coefficient of the tubes to decrease to the point where the back pressure will rise for the same duty, cooling water flow rate, and inlet temperature.

Similarly, air ingress increases the thermal resistance of the condensate film on the outside of the tubes, decreasing the effective tube heat transfer coefficient and with the same effect on back pressure. The proper management of tube fouling and air inleakage has important consequences on condenser and unit operating costs, as well as on the scheduling decisions made by the maintenance department.

Monitoring Condenser Performance

The basic principles used to calculate the performance of a condenser based on both design and current operating data are detailed in Putman.[3] One method has been developed by the Heat Exchange Institute (HEI[4]) and uses the "cleanliness factor" as the performance criterion.

The other method is that originally proposed in ASME PTC 12.2-1983 and updated in the 1998 revision of that standard[5]. Based upon the sum of thermal resistances, the ASME method calculates the clean single-tube heat transfer coefficient as a function of current operating conditions and compares this with the effective heat transfer coefficient calculated from present condenser duty.

One of the uncertainties in condenser performance monitoring is the actual value of the cooling water flow rate. The design value can be affected by the aging of the pumps or by the effects of both tube and tube sheet fouling. Putman[6] shows that a reliable estimate of the actual cooling water flow rate can be obtained from the cooling water temperature rise, together with the condenser duty calculated from the turbine thermal kit data.

The conditions that could be expected if the condenser were cleaned requires the solution of a set of nonlinear equations appropriate to the specific condenser configuration and constructing a Newton-Raphson matrix that reflects the details.

The cost that could be avoided if the condenser were to be cleaned can be estimated by using this simple equation:

$$\text{Condenser duty when fouled} - \text{The condenser duty when clean} \times \text{Fuel cost}$$

Note that this avoided cost does not distinguish between the back pressure that results from fouling or from that due to any air ingress that may be present. An estimate of the severity of air ingress can be obtained by calculating the total change in heat transfer coefficient due to both fouling and air inleakage. This can be obtained by subtracting the present single-tube U-coefficient value (U_{eff}) from that calculated if the condenser were cleaned (U_{clean}).

If this difference is small, all of the estimated avoided cost can be attributed to fouling and maintenance plans can be made accordingly. However, if the difference is substantial, steps should be taken to determine the severity of the air inleakage so the proper maintenance decision can be made.

If R_f = thermal resistance due to fouling
R_a = thermal resistance due to air ingress

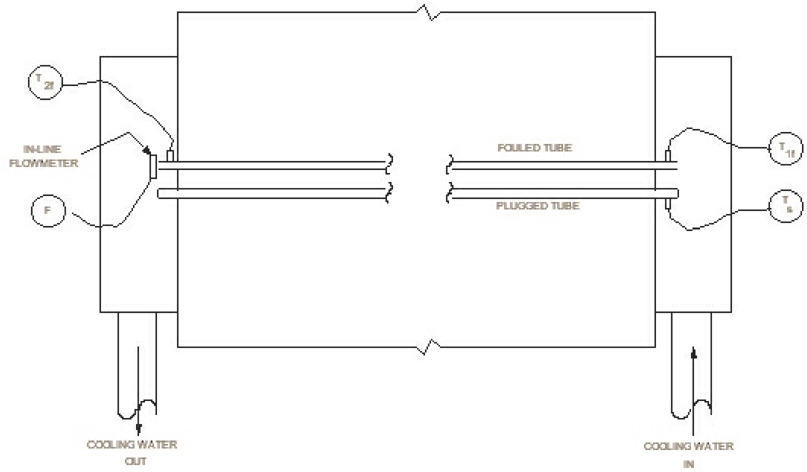
Then

$$U_{eff} = \frac{1}{R_f + R_a + \dfrac{1}{U_{clean}}} \qquad (1)$$

Clearly, if R_f, U_{eff} and U_{clean} are known, then R_a can be calculated.

Method For Estimating Tube Fouling Resistance

The principle of the method developed by Bridger Scientific under EPRI sponsorship for estimating tube fouling resistance Rf is described in EPRI[7] and illustrated in Figure 2 (where tube pairs are used).



EPRI/BRIDGER METHOD OF ESTIMATING TUBE FOULING RESISTANCE

Figure 2

One of the pair is a tube with blanked-off ends through which no water flows. The other, the fouled tube, not only has sensitive temperature measuring devices at both ends of the tube, but is also provided with a turbine-type flow meter for accurate measurement of the water flow rate through the tube.

The blanked-off tube is used to measure the mean shell temperature in the vicinity of the fouled tube so that any vapor pressure loss through the tube bundles can be accommodated. Several pairs of tubes are placed strategically in different locations within the tube bundle(s).

From the data obtained, the mean fouling resistance R_f can be estimated using the method outlined in the EPRI[7] report. The value of R_a can then be calculated using equation (1) to the left.

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Types Of Fouling Deposit

A tendency toward condenser tube fouling is a constant problem. Tube corrosion is also a concern and is sometimes initiated by fouling, as in under-deposit corrosion. The maintenance of unit performance, availability and life expectancy depends on a multi-level interaction between tube metallurgy, water chemistry, and the fouling mechanisms involved, together with the thermodynamics and kinetics of the condenser system.

In cleaning condensers over a long period of time, at least 1,000 different types of fouling deposits have been encountered. Each plant has its own idiosyncrasies and it is not unusual to find each unit within a plant behaving differently.

Furthermore, different tube materials in the same condenser also foul in different ways. For example, copper alloys in the main tube bundles foul differently than the stainless steel tubes in the air removal section.

As such, fouling deposits typically fall into five major categories:

- Sedimentary or silt formation
- Particulate fouling
- Deposits of organic or inorganic salts
- Microbiological fouling
- Macrobiological fouling

Sedimentary Deposits

Sedimentary fouling occurs when particulates entrained in the cooling water deposit on the tube walls are lower than the design value due to the water velocity. The remedy is to raise the water velocity closer to the design value.

Particulate Fouling

For particulate fouling to occur, there must already be a deposit substrate to which particulates become attached. A common substrate is bacterial slime. Once the particulates become attached, the deposit layer accumulates rapidly.

Salt Deposition

Salts of various kinds can become deposited due to changes in their concentrations. This is largely a result of the increase in water temperature as it passes through the tubes. Examples of crystalline fouling include calcium carbonate, silica, calcium sulfate, manganese, and calcium phosphate. Many of these types of fouling are difficult to remove once they have become deposited. Some salts also exhibit an inverse solubility. The solubility decreases while the temperature increases. This is especially true of calcium carbonate, the deposits of which often increase toward the tube outlets.

Microbiological Fouling

All sources of power plant cooling water contain bacteria, many of which exude a gelatinous substance that allows the bacteria to attach themselves to the tube walls. Because these slimes contain some 90 percent water, they have a high resistance to heat transfer. The organisms are often rich in metal compounds, such as those of manganese, which produce an impermeable layer and can cause under-deposit corrosion, even with stainless steels. Microbiological fouling is also sensitive to both velocity and temperature. The deposits tend to increase in thickness as the velocity falls.

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Macrobilogical Fouling

Macrobiological fouling occurs when mollusks, zebra mussels or similar aquatic organisms pass through the screens and attach themselves either to the tube sheet or to the insides of the tube walls. The reduction in water velocity not only increases the thermal resistance to heat transfer, but can also make the tubes susceptible to other types of fouling. The rate at which these fouling mechanisms develop is site-specific and depends on the chemical treatment methods that are employed. Aggressive cleaning of tubes and tubesheets is necessary to control macrofouling.

Optimizing Condenser Cleaning Frequency

Chapter 7 of Putman[1] discusses the technique for calculating the optimum cleaning frequency necessary to minimize the avoided costs incurred by fouling. The site-specific data required includes knowledge of the fouling model experienced by that particular unit, as well as understanding the historic monthly load profile and the cooling water inlet temperature profile for the unit over the past 12 months.

Some typical fouling models are illustrated in Figure 3. The mathematical relationship between fouling resistance and time must be generated. A typical load and inlet temperature profile curve is shown in Figure 4.

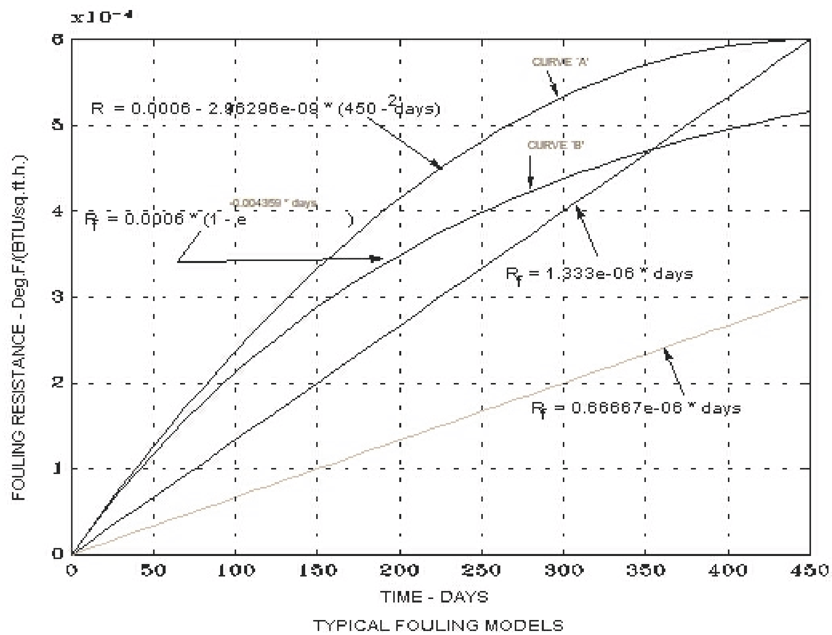

Figure 3

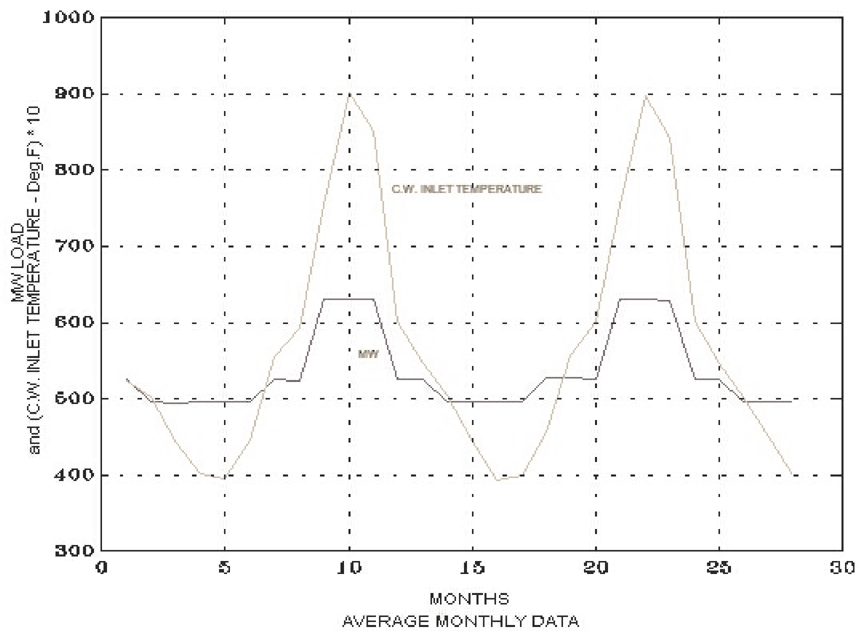

Figure 4

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Condenser duty is principally a function of generator load, cooling water inlet temperature, and its flow rate. It has been found that, at a given load, the avoided losses are a linear function of the fouling resistance vs. inlet water temperature, and a different linear function of the fouling resistance vs. load.

Given the load and inlet temperature profiles of Figure 4, and a fouling model similar to one of those shown in Figure 3, it is possible to calculate the cost of losses vs. fouling factor for each of the months in that profile. The initial data table for a typical case is shown in Table I.

An optimization program can be used to test the savings to be obtained with only one cleaning during the course of the year, and even establishes the month in which it should occur. In then calculates the savings if there are to be two cleanings during the year, and establishes the months in which they should occur. The procedure is then repeated for three and four cleanings per year.

Return on Investment

The results of a typical case are summarized in Table II. Note that additional cleanings always improve performance; but the amount of increase per cleaning decreases.

The optimum frequency selected is that which causes the incremental return on investment to match a threshold criterion (for example, an ROI of 2). In Table II, the incremental cost of cleaning is shown to be $13,500, while the corresponding incremental savings (or return on cleaning) are shown in Column 5. The maximum frequency corresponding to an ROI = 2 is

MW	CW temp, in	Duty, clean	Duty, fouled	Fouling losses	Days in month	Specific cost	Fouling resistance	Cost without cleaning
431.41	50.97	1740.28	1767.43	27.15	31	2019.96	2.5000E-05	580.74
419.38	50.09	1691.22	1716.96	25.74	28	1729.73	2.2000E-04	4,376.21
433.13	58.97	1764.12	1795.09	30.96	31	2303.42	5.0000E-04	13,244.69
448.66	62.95	1835.21	1869.92	34.71	30	2499.12	7.5000E-04	21,554.91
385.47	68.80	1598.13	1629.56	31.43	31	2338.39	9.0000E-04	24,202.36
391.87	74.61	1638.88	1674.79	35.91	30	2585.52	9.8000E-04	29,138.81
365.69	83.60	1560.22	1599.72	39.51	31	2939.54	1.0400E-03	35,156.95
318.78	84.48	1373.71	1407.65	33.94	31	2525.14	1.0400E-03	30,200.63
307.65	81.91	1321.40	1352.10	30.70	30	2210.40	1.0400E-03	26,436.38
359.23	74.74	1508.63	1540.79	32.16	31	2392.70	1.0400E-03	28,616.74
430.85	58.48	1753.99	1784.49	30.50	30	2196.00	1.0400E-03	26,264.16
443.44	51.84	1789.46	1818.04	28.58	31	2126.35	1.0400E-03	25,431.17

Yearly cost of losses — no cleanings **$265,203.74**

Table 1 — Basic Data

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	1 Cost of losses	2 Cost of cleaning	3 Total cost of fouling	4 Annual savings	5 Return on cleaning
No Cleanings	265,204	0	265,204	0	0
One Cleaning	180,469	13,500	193,969	71,235	84,735
Two Cleanings	130,214	27,000	157,214	107,990	50,255
Three Cleanings	92,133	40,500	132,633	132,571	38,081
Four Cleanings	69,522	54,000	123,522	141,682	22,611

Table II — Return on Investment Analysis: Mean Loads

shown to be three cleanings per year, since four cleanings per year would offer an ROI of <2.

Mechanical Methods For Removing Fouling

Spring-loaded carbon steel cleaners have long been recognized as the most effective tube cleaner available to the industry. They come in various forms designed for multi-deposit removal, hard deposit removal, or thin and tenacious deposit removal. Since the blades of these cleaners are spring-loaded with a determined force at the surface of contact, they can be engineered to perform the intended function while also improving the smoothness of the tube surface to restore the tube to its "as new" condition.

The earliest mechanical tube cleaners were designed for cleaning boiler tubes. It was not until 1923 that two brothers, Cecil M. Griffin and Vivian Griffin, invented the first cleaner for condensers and shell-and-tube heat exchangers. Figure 5(a), C4S, shows a current version of this cleaner, which consist of several U-shaped tempered steel strips arranged to form pairs of spring-loaded blades. These strips are mounted on a spindle. At one end of the spindle is a serrated rubber or plastic disk (developed by George Saxon), which allows a jet of water, delivered by a pump operating at 300 psig, to propel the cleaners through a tube with greater hydraulic efficiency. Figure 6(a), Model 200B Pump System, shows a typical pump, mounted on a portable skid, complete with the handheld-triggered device (Figure 6(b), also known as a water gun), which permits the operator to direct the water to the tube being cleaned.

Figure 5(a) C4S

Figure 5(b) Hex or C2X/C3X

Since the earlier cleaner designs behaved as stiff springs, loading the cleaners into the tubes was sometimes rather tedious. To speed up this operation, while also providing the blades with more circumferential coverage of the tube surface, the hexagonal or Hex cleaner shown in Figure 5(b) was developed by Saxon and Krysicki. This design not only reduced the cleaning time for 1,000 tubes, but was also found to be more efficient in removing tenacious deposits like those consisting of various forms of manganese.

Figure 5(c) CB

A later development by Gregory Saxon involved a tool for removing hard calcite deposits, which were found to be difficult to remove even by acid cleaning. This tool is also shown in Figure 5(c), CB, and consists of a Teflon body mounted by a number of rotary cutters placed at different angles, and provided with a plastic disk similar to those used to propel other cleaners through tubes. As part of a case study, cleaners of this type used on a condenser removed 80 tons of calcite material. The tool has now become standard whenever hard and brittle deposits are encountered.

Mechanical cleaners offer the most effective off-line tube cleaning method. Strong enough to remove hard deposits, they can cut the peaks surrounding pits and flush out the residue at the same time, thus retarding underdeposit corrosion. Each cleaning tool is custom-made to fit snugly inside a tube having a stated diameter and gage or wall thickness. This allows the blade contact pressure to be controlled within tolerances and also ensures that as much of the tube circumference as possible is covered as the cleaner passes down a tube of the corresponding size.

Figure 5(d) Brush

A special rig has also been developed for the heat transfer testing of tubes. In the development of these various cleaners, extensive use of this rig was made to determine the effectiveness of different cleaner designs. Not only could the incremental material removed be established for each successive pass of the tool, but the cleaner's effect on heat transfer could also be quantified for a given kind of deposit.

In some plants, it has been common practice to use compressed air with water to propel the cleaners. However, the rapid expansion of the air causes the cleaner to become a dangerous projectile when the cleaner exits the tube. The use of water alone never allows the cleaner exit velocity to rise above a safe level. Similarly, water supplied at a pressure of 300 psig is much safer to personnel than at up to 10,000 psig, which is sometimes attained when using high-pressure hydrolasing techniques.

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Figure 6(a) Model 200B Pump System

Figure 6(b) Water Gun

Another advantage of mechanically cleaning condenser tubes using water as the cleaner propellant is that the material removed can be collected in a plastic container for later drying and weighing to establish the deposit density (in grams per square foot). In many cases, X-ray fluorescent analysis of the deposit cake is performed. Experience has also shown that properly designed cleaners will not become stuck inside tubes unless the tube is damaged or severely obstructed.

Mechanical cleaners travel through the tubes at a velocity of 10 to 20 ft/s and are propelled by water delivered at 300 psig. Some of the members of a well-known family of tube cleaners have the following features:

- ***C4S***. The C4S cleaner is general-purpose and may be used to remove all types of obstructions, deposit corrosion, and pitting.
- ***C3S***. The C3S cleaner is designed for heavy duty use and is very effective in removing all kinds of tenacious deposits. Its reinforced construction also allows it to remove hard deposits, corrosion deposits, and obstructions.
- ***C2X, C3X***. These types of cleaner consist of two or three hexagonal-bladed cleaner elements, having six arcs of contact per blade. They are effective on all types of deposits, but are especially suitable for removing the thin tenacious deposits of iron, manganese, or silica found on stain less steel, titanium, or copper-based tube materials.
- ***C4SS***. While the C4SS stainless steel cleaners can be used with all types of tube materials, they were original ly developed for applications using AL-6XN stainless steel condenser tubes; however, they have also been used for cleaning tubes in highly corrosive environments.
- ***CB***. This tube cleaner was specifically developed to remove hard calcium carbonate deposits and is designed to break the eggshell-like crystalline form characteristic of these tube-scaling deposits. This cleaner has been found exceptionally helpful in avoid ing the need for alternative and environmentally harmful chemical cleaning methods, which were all that were previously available for remov ing these types of hard deposits.

Brushes

Brushes are principally intended to remove light organic deposits, such as silt or mud. They are also useful for cleaning tubes with enhanced surfaces e.g., spirally indented or finned, or those with thin-wall metal inserts or tube coatings. The brush (Figure 5(d), Brush) length can be increased for more effective removal of lighter deposits.

Cleaning Productivity in the Field

Using the methods outlined earlier in this section, it is possible for 5,000 tubes to be cleaned during a 12-hour shift, utilizing a crew of four operators with two water guns supplied from one pump. Clearly, an increase in crew size, in the number of water guns available, or in the number of mechanical cleaners supplied for the project can increase the number of tubes which can be cleaned during a shift, provided there is adequate space in the waterbox(es) for the crew to work effectively.

Some Limitations of Mechanical Cleaning Methods

Each type of off-line cleaning device has its own limitations. For instance, brushes may be effective only with the softest fouling deposits, whereas metal cleaners are more effective against tenacious foulants.

However, all methods may need assistance where the deposits have been allowed to build up and become hard. In such cases, it may still be necessary to acid-clean, followed by cleaning with mechanical cleaners to remove any remaining debris.

AIR INLEAKAGE DETECTION

Air inleakage can be inferred from an increase in the air concentration in the gases drawn off by the air-ejector system. It is often associated with an increase in condenser back pressure. Note that there is always a minimum air inleakage that cannot be eliminated.

Westinghouse Electric Corp. used to recommend that air inleakage levels be held to 1 ft^3/min per 100 MW of generation capacity, but other minima are given in the ASME and HEI standards. An increase in the dissolved oxygen concentration in the condensate can also indicate that air is leaking into the suction of the condensate pumps below the condenser hot well.

Tracer gases are used to locate the source of air inleakage, two of the most common being helium and sulfur Hexafluoride (SF_6). SF_6 was first used effectively as an airborne tracer in atmospheric research and demonstrated its greater sensitivity as a tracer gas.

Sulfur hexafluoride, discovered in 1900, is a colorless, tasteless, and incombustible gas which is practically inert from a chemical and biological standpoint. It does not react with water, caustic potash, or strong acids and can be heated to 500°C without decomposing.

Two of its common uses within the utility industry are for arc suppression in high-voltage circuit breakers and the insulation of electric cables. SF_6 also has many other uses, such as etching silicon in the semiconductor industry, increasing the wet strength of kraft paper and protecting molten magnesium from oxidation in the magnesium industry.

The fundamental property of SF_6 is that it can be detected in very low concentrations-as low as 1 part per 10 billion (0.1 ppb)-compared with the lowest detectable concentration of helium of 1 part per million above background. It was later found that on-line injections utilizing SF_6 also allowed leaks as small as one gallon per day to be detected.

Analyzer to Detect SF_6 in Condenser Off-Gas

In the early 1980s, EPRI sponsored the development of an analyzer to detect the presence of SF_6 in condenser off-gas. Known as the Fluorotracer™ Analyzer, it was based on mass spectrometer technology. Figure 7(a), Fluorotracer™ Analyzer, is a general view of the SF_6 analyzer, while Figure 8 provides a schematic flow diagram of a sampling system.

Figure 7(a) Fluorotracer™ Analyzer

Figure 7(b) SF_6 Pak

For the analyzer to detect the presence of tracer gas in the received sample, it is important that it be free from both moisture and free oxygen. This diagram shows how the off-gas sample is first cooled, then shows how the moisture is removed in a water trap and passed through a dessicant tower to remove any residual moisture. The diagrams also show how the sample is finally received by the analyzer.

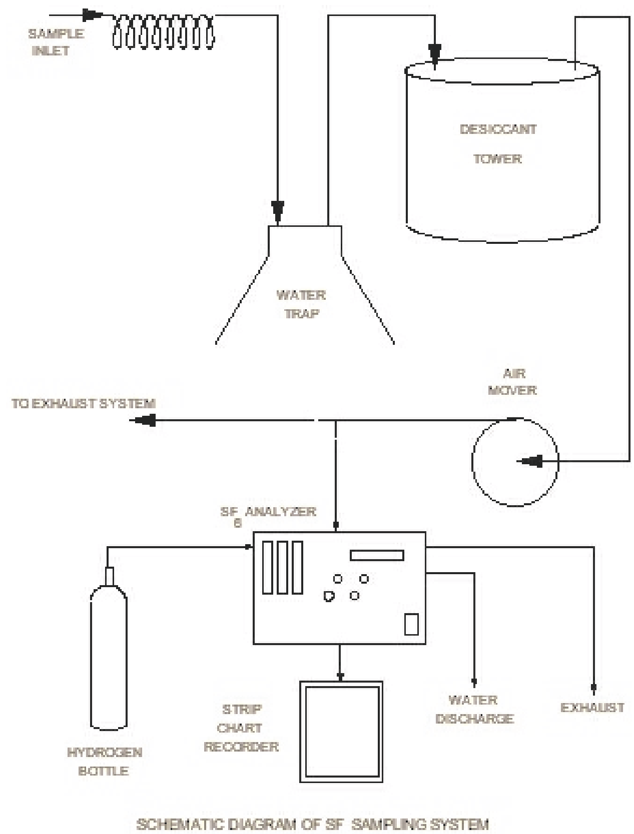

Figure 8

To remove any oxygen contained in the sample from the off-gas system, hydrogen gas is introduced into the sample stream, entering with the sample into the catalytic reactor, where a chemical reaction occurs between the oxygen and hydrogen. The moisture is removed by another water trap and dessicant tower.

The dried sample gas is then pumped into an electron capture cell, where it passes between two electrodes and is ionized by a radioactive foil. Ionized nitrogen in the sample supports a current across the electrodes, the current level being reduced in proportion to the concentration of SF_6.

An analyzer for use with SF_6 as a tracer gas is commercially available for use in both fossil fuel and nuclear generating stations. The analyzer is also provided with an SF_6 dispenser (shown in Figure 7(b) SF_6 Pak.) Weighing approximately eight pounds, the flow of the dispenser can be adjusted to obtain the SF_6 concentration needed to perform the leak detection task under current plant conditions.

Tracer gas leak detection involves a time delay between the injection of the gas and the response shown on the strip chart recorder connected to the mass spectrometer. It should be noted that, while the indicators mounted on the case of the mass spectrometer display the instantaneous values of the measurements, they are difficult to interpret without the addition of a trace from a strip chart recorder. A typical example is shown in Figure 9.

The information available from the recorder chart not only provides a hard copy for future use, but also tells technicians when they are getting close to a leak; when they have passed the leak; when they have located the leak; whether the gas is traveling to another leak; or, whether the leak is closer to the outlet end. Whether a valve is leaking at the packing, as opposed to the flange, can also be determined.

SF_6 can be used whenever helium is used; however, the reverse scenario is not true. The following are among the factors that go into the choice of tracer gas for a given situation:

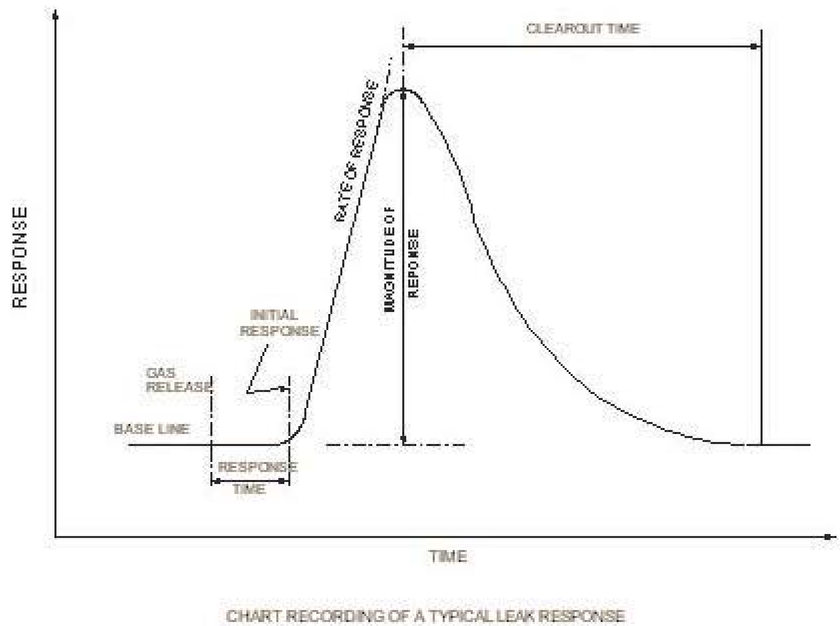

Figure 9

- ***Air inleakage into the unit***. If the unit has more than 10 ft^3/min of air inleakage, either tracer gas may be used. If the inleakage is less than 10 ft^3/min, then SF_6 should be used.

- ***Dissolved oxygen (DO)***. The standard procedure for searching for the cause of DO leakage below the water line is to use SF_6.

- ***Unit turbine power***. If the unit is running at 20 percent or greater turbine power, either tracer gas may be used. If the unit has no turbine power and cannot be brought up to any level of turbine power, then helium should be selected.

- ***Unit size***. Inspections of units of less than 50 MW capacity should always use helium.

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Air inleakage inspections are best preceded by a test shot to establish the level of any background contamination and to ensure the instrumentation is functioning correctly. It is recommended that all air inleakage inspections begin on the turbine deck, usually starting with the rupture disks. When on the mezzanine level, the tester should start spraying tracer gas at the condenser and work outward along the hood, the expansion joints, and other potential sources of air inleakage.

It is important to keep track of everything that is sprayed with the tracer gas. During a typical air inleakage inspection, it is not uncommon to spray tracer gas on literally hundreds of suspected leakage paths within the condenser vacuum boundary.

In order to isolate a leak as quickly as possible, technicians should know where they have been and what they have seen. If a large leak is found on the manway on, say, the west side of the turbine, an indication of this must be made on the strip chart recorder. When the technician goes to the west side of the condenser and sprays a suspected penetration into the condenser on the mezzanine level, the large leak could very well cause an erroneous indication of leakage there. Technicians can also waste a lot of inspection time searching for a leak that they have already found on the turbine deck. This is another reason the response time must be known.

Once the inspection results are in, it is important to understand what can and cannot be done with them. A leak detection program is useful only if there is a follow-up repair program. Both SF_6 and helium detectors give readouts, one in millivolts, the other in an arbitrary scale.

Plant personnel can determine a plan of action to repair the leaks after comparing millivolt or scale readouts. These are *relative* values, not calibrated in engineering units such as ft^3/min. It is of no importance to have exact leakage values.

Generating stations already know what their *total* air inleakage is. Because of the margin of error due to all the variables of a condenser under vacuum, quantifying leaks does not add any information to what the plant personnel already know. Therefore, it is not cost-effective. What *is* useful is the exact location of each leak and its subsequent repair and retest.

When the turbine is not under power, it is very likely that the background concentration of the tracer gas will become so high that it eliminates any chance of isolating a leak. Both air inleakage and condenser tube leakage inspections require vapor flow to carry the tracer gas out of the condenser with the rest of the non-condensibles.

If a sprayed tracer gas is sucked into the condenser, it will begin to accumulate, and the background concentration will rise and saturate the detectors. There are some occasions when, in an effort to bring a unit back up on-line as soon as possible, a station has no choice but to attempt a tracer gas inspection with the unit shut down, and many have been successful in doing so. However, a minimum 20 percent turbine power is recommended in order to perform a tracer gas inspection effectively.

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CONCLUSION

This White Paper has provided examples and guidelines to help you understand the factors that impact a return on investment analysis. These illustrations focus on the basic components necessary to understand a simple ROI analysis when considering the payback for regular condenser maintenance within your plant.

In summary, it is about operating efficiency within your plant systems — doing more with less. While it is difficult to assign a hard number to improving your plant's operating performance, you can certainly calculate how much annual revenue is at risk should you fail to keep your systems operating at peak performance.

When you are ready to investigate regular maintenance systems and options, we recommend that a more detailed assessment be performed — specific to your plant's unique requirements.

REFERENCES

1. Putman, R.E., (2001), "Steam Surface Condensers: Basic Principles, Performance Monitoring and Maintenance", publ. May 2001, ASME Press, New York, NY.

2. Condenser Inleakage Guideline, EPRI Report TR-112819, publ. EPRI, January 2000.

3. Putman, R.E. (2001), Ibid, Chapters 2 thru 6.

4. HEI (1995), "Standards for Steam Surface Condensers", 9th. edition, publ. Heat Exchange Institute, Cleveland.

5. ASME, (1998) "Performance Test Code for Steam Surface Condensers", ASME PTC.12.2-1998, publ. American Society of Mechanical Engineers, New York, NY.

6. Putman, R.E. (2001), Ibid, pp. 75-76.

7. EPRI, (1994), Instrumentation of the On-Line Condenser Fouling Monitor, EPRI Technical Report TR-109232.

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