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On-Line Mechanical Tube Cleaning for Steam Electric Power Plants

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Final Report

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ABSTRACT

In July 1991, Superior I.D. Tube Cleaners, Inc. (SIDTEC™) received a grant through the Department of Energy and the Energy Related Invention Program to conduct a long term demonstration of a proprietary technology for on-line mechanical condenser tube cleaning in thermal power plants on open or once-through cooling water systems where the warmed condenser cooling water is discharged through a canal. The purpose of the demonstration was to confirm and establish the use of this mechanical method as an alternative to the application of chemical biocides in condenser cooling water for the control of biofouling, the growth of micro-organisms which can reduce a unit's operating efficiency.

The SIDTEC on-line mechanical tube cleaner, the Rocket™, is used to physically remove accumulated deposits on the water side of the main steam condenser, and the non-intrusive tube cleaner recovery system, the Skimmer™, is used to recover and recirculate tube cleaners. The periodic circulation of tube cleaners can maintain optimum condenser cleanliness and improve unit heat rate.

Results of the periodic cleaning can be measured through the monitoring of various physical parameters and operating conditions of the generating unit as a function of time. In the absence of sophisticated instrumentation or to augment its use, both on-line and off-line video borescope inspections are used to verify the results.

Beginning in August of 1991 at the Austin Power & Light Co., Decker Station and continuing at the TU Electric Martin Lake Steam Electric Station in April 1992, through the present, the SIDTEC Condenser Maintenance Service has maintained condenser cleanliness, eliminated the use of biocides at the Martin Lake plant, and has improved heat rate in excess of 1.5%.

Thermal power plants which discharge condenser cooling water through a canal now have a viable alternative to the chemical treatment of condenser cooling water, whether the principal foulant is biofouling, chemical scaling, silting, or a combination of the three. At prices competitive with scale inhibitors, and a fraction of competing mechanical systems, this technology is provided as a service requiring no capital investment; minimal retrofit modifications to plant structures or equipment; can be installed and maintained without a unit shutdown; does not add any restrictions in the cooling water system; and is environmentally benign.

INTRODUCTION

In 1992, the electric utility industry operated 2,564 steam electric generating units in 951 plants with a combined generating capacity of 592,405 Mw. These plants use a vast amount of water to remove the last unusable heat in the steam cycle with a variety of cooling water schemes. The majority of these plants (63%) are on open, once-through or mixed mode systems, taking water from surface sources, such as lakes, rivers, estuaries, oceans, and cooling ponds. Unlike cooling towers, which are basically closed systems, the open systems are able to treat the cooling water only once, immediately before use.

The largest shell and tube heat exchangers are the main steam condensers utilized in the conventional boiler/steam turbine-based Rankine cycle. Condensers in large base load units can contain upwards of 30,000 tubes with an effective surface area of 450,000 ft², or over ten football fields. Through these tubes pass the cooling water, often in quantities exceeding 400,000 gallons per minute (gpm). In the process, the temperature of the water may increase 10° or more. This environment is ideal for organic growth, the precipitation of chemical salts (scale) and the deposition of silt and other particulate matter.

Identification of the Problem

A mechanical tube cleaner can maintain optimum heat transfer in a shell and tube heat exchanger by removing or preventing the accumulation of organic and/or chemical scale deposits which act as an insulator to heat flow and a source of corrosion of the tube material. Studies conducted by the Electric Power Research Institute (EPRI), the Tennessee Valley Authority (TVA), Mississippi Power Co., Duke Power, and the Potomac Electric Power Co. have demonstrated the economic impact of condenser fouling. Biological fouling has been the focus of major industry studies and is deemed responsible for a 3.8% overall loss in availability of U.S. plants generating 600 Mw or more. The costs resulting from condenser tube failures is in the billions of dollars.

For plants on open cooling water systems, EPRI surveys show microscopic growth (bacteria, algae, etc.) to be the dominant problem plaguing over 70% of the plants experiencing biofouling problems. Besides inhibition of heat transfer, fouling of tube affects material integrity through general corrosion, erosion, and pitting. Condenser replacements can cost upwards of \$5 million through either re-tubing or through modular units .

Biofouling Control

Methods for controlling water side fouling in steam electric generating plant cooling systems fall into two major categories: chemical and mechanical.

The uncontrolled growth of invertebrate aquatic animals in power plant cooling systems causes problems. Not only in heat transfer capability, but also pumping pressures and energy requirements are increased due to the higher wall friction and reduced cross sectional area. In extreme situations the biofouling on the inlet side of the circulating water system may even impair the ability of the pumps to deliver sufficient cooling water or restrict circulating water flow through the condenser by blocking tubes, reducing the effective heat transfer surface area. In addition, macrofouling can increase microfouling, increase the erosion-corrosion rate, promoting corrosion where it did not previously occur, contribute toward stress corrosion cracking or sulfide pitting, and providing conditions conducive towards under-deposit attack.

The primary method of biofouling control used by utilities has been chlorination. Seventy-eight per cent of the installed capacity of all U.S. steam plants use chlorine or chlorine dioxide to the cooling water intake. Another 10% use bromine in some form along with a reduced amount of chlorine. These discharges are restricted by the Federal Water Pollution Control Act of 1972 and the Clean Water Act of 1977 (see 40 CFR 423). According to the EPA, current technology makes possible either total elimination of the use of chlorine for biofouling control or permits a substantial reduction of its use.

Mandated to meet technology based effluent limitations by minimization in 1984 and dechlorination by 1985, the past decade has seen much activity in alternate biocides and chlorination techniques. Chlorine minimization involves optimizing operating efficiencies while limiting chlorine levels in plant effluent to 0.2 mg/l. While this technique has shown good results, changing water quality makes it difficult to standardize treatment programs.

Targeted chlorination has recently been promoted by EPRI as an alternative chlorination technique. It involves the application for short periods of time (minutes) of a strong chlorine solution (10 ppm FAC from the nozzle resulting in 1 ppm exposure at the tubes) sequentially to a selected fractional area, one after another until the entire tube sheet has been contacted. At any given time, the high concentration of FAC exiting the small proportion of tubes contained in the selected area being chlorinated constitutes a flow that is very small relative to the unchlorinated flow from the other parts of the condenser. Thus, the concentration of TRC

in the chlorinated flow is rapidly reduced both by dilution and by the demand of the unchlorinated flow.

Chlorination-dechlorination commonly involves the use of sulfur-based compounds such as sulfur dioxide or sodium sulfite to reduce residual chlorine. Retro-fit costs are high with total evaluated costs ranging from \$400,000 to \$1,500,000. In addition, chlorinated organics, such as chloroform, are not removed by dechlorination.

Alternative oxidizing chemicals have also received considerable attention. Chlorine dioxide is produced at the point of use by reacting chlorine with sodium chlorite. It is relatively pH-insensitive, does not react with ammonia, and its concentration decreases rapidly because of photochemical decomposition. However, it is five times as expensive as chlorine. Bromine chloride, which releases bromine to form hypobromous acid (a very strong biocide), can be used with similar chemical feed systems as chlorine while its cost is two or three times that of chlorine.

Brominated propionamides are a new category of oxidizing toxicants for microbial control of cooling water. The DBNPA (2,2-diobromo-3-nitro propionamide) molecule selectively brominates or oxidizes specific substrates within the microorganisms and is sometimes categorized as an oxidizing-type microbiocide.

Corrosion Control

Corrosion takes many forms and in many cases is a direct result of microbiological activity. Cooling water systems are also prone to other deposits: mineral scale and suspended matter. These deposits usually occur first in the heat exchangers, where the temperature is the highest and solubilities are lowest.

By far the most common scale in cooling water systems is calcium carbonate which is formed by the breakdown of calcium bicarbonate, a naturally occurring soluble salt. The degree of scaling depends primarily on the levels of calcium hardness and bicarbonate alkalinity in the cooling water. The rate of calcium bicarbonate breakdown increases with pH and temperature. Other scales include calcium sulfate, calcium phosphate, magnesium silicate, manganese oxides, and silica.

Deposit control can be in subsaturated or supersaturated conditions using a variety of mechanisms: inhibition, through ion-particle or ion-surface interaction; dispersion, through particle-particle interaction; or solubilization, through particle-surface interaction. Sometimes, the only technique available is to remove that constituent before use. Silica scale must be prevented by keeping its concentration below its solubility level since there are no known silica-solubilizing chemicals.

The organo-phosphorus chemicals act as inhibitors. Phosphonates, such as AMP (amino-methylene phosphonic acid) and HEDP (1-hydroxy-ethylidene-1, 1-disphosphonic acid) inhibit or distort crystal growth sites and are normally used in cooling tower-based cooling water systems. The nonorganic polyphosphonates, hexameta, tripoly, and pyro phosphonphates are more common in once-through systems when scale and iron need to be controlled.

Polymers act as dispersants. The polyacrylates are used in either the salt or acid form with molecular weights from 1000 to one million. Since suspended solids have a tendency to agglomerate and settle out in low flow/heat transfer areas, dispersants are used to keep these particles in suspension. Anionic polymers impart a negative charge to the particles and the system surfaces, causing them to repel each other.

The third group allows the scale to form, but uses crystal modifiers, such as polymaleic acids and sulfonated polystyrenes, to distort the resulting crystal structure, changing the scale to a nonadherent sludge. These sludge fluidizers are applied in concentrations of 0.5-5 ppm and are termed surfactants, for surface-active-agent.

Heat Rate and Efficiency Improvements

Steam turbines are a venerable workhorse in both large and small power plants and industrial steam systems. During the past decade, virtually every turbine component has been studied exhaustively to determine how design refinements can improve overall machine performance. All that has been learned in the areas of life extension, repair technology, performance monitoring and diagnostics, and machine protection has been applied to new design and construction. The steam condenser and the auxiliary heat exchangers have become focal points of attention in the power industry's effort to obtain more efficient utilization of fuel.

The most effective way to improve heat rate is to improve turbine performance. The heart of better turbine performance is maintenance of design back pressure. Back pressure is a function of condenser efficiency. When the circulating cooling water produces an absolute pressure at the turbine flange that induces choking flow, the optimum heat rate is obtained. At a pressure above or below that point, there is a loss in heat rate. This is because at choking flow the steam passing through the turbine exhaust annulus has reached sonic velocity. When that occurs, no additional energy can be imparted to the turbine by further lowering the absolute pressure. Improved heat rates can result in both increased generation capacity and reduced fuel requirements. But maintenance of

efficient heat rejection depends largely on the maintenance of a high state of cleanliness of the condenser tubes.

The Invention

SIDTEC has developed an on-line mechanical tube cleaner for maintaining optimum heat transfer in shell and tube heat exchangers common to the electric utility, refining, and petrochemical industries. Made from a rigid polymer body and an elastomeric disk or cleaning element, the tube cleaner circulates with the condenser cooling water removing or preventing the accumulation of organic material and/or chemical scale on the inside diameter (I.D.) of heat exchanger tubes.

SIDTEC Rocket™ Tube Cleaner

SIDTEC Saturn™ Tube Cleaner

To date, the sponge ball has been the state-of-the-art in on-line mechanical tube cleaning. Used in automatic tube cleaning systems (ATCS), also referred to as sponge ball or ball and screen systems, open cell sponge balls circulate through shell and tube heat exchanges and are retrieved by mechanical strainers placed in the outlet conduits, generally immediately downstream of the waterbox.

In extensive pilot plant testing, the SIDTEC tube cleaner has outperformed the sponge ball in longevity, cleaning efficiency, and flexibility for a variety of fouling and operating conditions.

The SIDTEC tube cleaner also has applications beyond the water side of a heat exchanger and into the hostile environment. Standard sponge balls are limited to use in water under 200° F. and in relatively clean water. Special application sponge balls for seawater desalination plants are available to 285°F. The presence of hydrocarbons and other

contaminants cause the open cell material to deteriorate rapidly. The SIDTEC tube cleaners could be designed to 600° F. utilizing modern elastomers and stainless steel bodies.

The Condenser Maintenance Service

Webster's American Heritage Dictionary defines the verb "skim" as "to remove floating matter from (a liquid)." In this application, it is a separation technique recovering less than one part per million.

The ability to skim is dependent on the density contrast between the tube cleaner and the warmed cooling water, the current velocity, the presence of turbulence, and the angle at which the boom intersects the current. The figure below shows the basic concept of skimming.

After the cooling water is discharged from a typical ten foot concrete conduit at about ten feet per second, the twenty fold expansion into the canal reduces the average current velocity to between one and two feet per second. The turbulence involved with this expansion gradually subsides until all the water is basically moving in the same direction, at a constant velocity. Local variations will exist due to the non-uniform sides of the normally earthen banks and other turbulence inducing factors.

Wind is perhaps the most common influence on these localized eddies and current perturbations. The vector diagram in the above figure depicts the interaction of the main current with the variable wind-induced surface current. When a boom is tensioned in the canal, the smooth inside surface of the boom acts as a dam. Normally, a very small pressure drop exists between the inside and outside of the boom, less than a tenth of an inch of water (<0.10 "H₂O"). This imbalance forces the resultant current to dive below the shelf of water traveling parallel to the boom.

This downward current in the immediate vicinity of the skimming boom defines the minimum density contrast between the tube cleaner and the warm cooling water. The "rate of rise" of a tube cleaner is a measure of the vertical velocity due to the difference in specific gravity and is on the order of a few tenths of an inch per second (positive to float, negative to sink). The optimum density contrast is one that will not effect the equal distribution of the cleaners at the inlet tube sheet, but will have the fastest rate of rise in the canal.

The boundary between this shelf and the main body of water is defined by a shear zone and can be observed under proper wind and water conditions. The width of this shelf constantly varies in this dynamic system of wind and water, but is fairly uniform under a constant angle of boom to current. It therefore becomes important to keep this relationship as stable as possible.

For years, one method employed was a system of "breaker" booms parallel to the skimming booms. Offset ten to twenty feet, these booms interrupt the wind generated surface current and mix it back into the main body of water. The space between the booms is kept sufficiently small so the distance (fetch) is too small to re-establish a surface current. At the same time, the space must be wide enough to allow tube cleaners that have also been mixed back into the main body of water to re-surface inside of the skimming boom.

The system of booms are set downstream of the discharge structures to gradually guide the cleaners to the end of an elongated "V" where a mechanical device, the tube cleaner recovery unit (TCRU), retrieves the tube cleaners and all other floating material.

Typical boom configuration and canal profile

The dimensions of these canals have been designed to the maximum circulating water capacity of the combined units. The current velocities are in the range of one to two feet per second to minimize bank erosion. Canals can also have concrete or rip-rap banks, especially on turns and corners. Additional booms are used to shield the cleaners from the banks of the canal and out of stagnant or slower moving water.

A Skimmer consists of a set of modified oil spill control booms placed in the discharge canal; a recovery unit to collect and separate the tube cleaners from debris; a pump to convey the cleaners; some form of line to transport the cleaners to the intake structure or other injection point; and a distribution network for multiple-unit injection. All equipment is off-the-shelf material with minor modification or small scale fabrication.

A pontoon-mounted traveling screen, the TCRU has a site-specific debris rejection scheme with pumps to provide water for the high pressure sprays and for conveying the cleaners to the shore.

At the approach to the TCRU, the skimming booms narrow to the width of the traveling screen. A set of parallel booms, five to twenty feet long, connect the TCRU to the skimming booms. The approach booms are positioned to remain vertical and semi-rigid to accommodate small movements by the TCRU due to wind loading.

Once the cleaners and all other floating material reach the traveling screen, any object less than the pitch of the screen flows through and is not processed. Lifter bars are placed at intervals along the traveling screen to assist round and linear objects onto the screen. An overhead flap is located where the screen breaks over to a flat area to re-position linear objects sub-parallel to the bars of the screen. The forward spray station removes filamentous material, foam, small fish, twigs, leaves, etc. through the bars of the screen and washes any material off the tube cleaners. Everything remaining proceeds up to the end of the conveyor.

When the screen rolls around the drive roller, another water spray forces all remaining objects off the screen. A counter-rotating series of notched disks spaced slightly larger than the greatest diameter of a tube cleaner removes large debris. The tube cleaners can either free fall into the sump to be pumped back to shore, or an additional sorting scheme geared to the unique size and shape of the cleaners can remove other similarly sized objects, such as pecans.

In conclusion, SIDTEC believes there are several advantages relative to current technology:

- The Skimmer™ Tube Cleaner Recovery System is economically viable where a sponge ball system may not be. A three-unit site on a fresh water lake in Central Texas had an estimate for \$300,000 per unit for a sponge ball system, plus an additional \$400,000 per unit for debris filter. Although a rigorous engineering study has yet to be completed for this site, a SIDTEC system servicing three units at other locations have been installed for less than \$200,000.
- One recovery system can service all units on a common discharge canal. At the site mentioned above, a sponge ball system would require six strainer sections, twelve pumps, three sets of instrumentation, and extensive modifications to retrofit. In contrast, a SIDTEC system would require one set of recovery booms, one tube cleaner recovery unit (TCRU), three pumps, one instrumentation package, and the piping for the cleaner distribution lines to the intake structure.
- The system is non-intrusive. No plant shut-down can occur due to a malfunction of the recovery system. A Texas utility with an ATCS had a 530 Mw unit shut down for six months due to a damaged strainer section restricting the cooling water flow. Lost generating revenue in this instance was in excess of \$30,000,000.
- It can be installed and serviced while the unit(s) is at full load. Base-load units often are operating continuously except for scheduled outages to allow for routine maintenance, repairs or upgrading systems, often at intervals up to eighteen months. These long periods between off-line condenser maintenance, either mechanical or

chemical, increases the need for on-line cleaning. Additionally, the narrow window during an outage leaves limited time for an extensive retrofit of an ATCS and places a huge demand on plant and contract personnel, often working 24 hours a day. If the schedule for coming back on-line is not met, all the potential savings that justified the system in the first place can be lost. In addition, repairs to a sponge ball system may be postponed for months, waiting for the next scheduled outage, while the condenser cleanliness continues to decline.

- It can recover from a variety of fouling catastrophes. Twice SIDTEC has been called upon to clean fouled condensers at Martin Lake, unit 3 in 1988, and units 1 & 2 in 1992. In each case, the system was installed and cleaners circulated, all while the unit was under normal operating conditions, which is generally full load. Also in 1992, SIDTEC began a test of the abrasive tube cleaners to remove the remnants of a partially successful chemical cleaning. Over a seven week period the normal weekly maintenance of 100,000 tube cleaner passes were increased to approximately 100,000 per day. Video inspections of the condenser during the February 1993 outage showed remarkable improvement in condition of the tubes.
- No constriction or pressure drop is introduced in the circulating water piping. The presence of the ATCS strainer section increases the pumping requirements of the circulating water system. This increase costs the plant thousands of dollars per year in lost net generating capacity.
- No debris is recycled in the SIDTEC system. Although a debris filter reduces the problem, recycling debris is inherent in a sponge ball system. Any particle larger than the bar spacing and smaller than the tube I.D. is either stuck in the strainer section, decreasing the free available area of the screen, or is continually recirculating in the system along with the sponge balls but providing no benefit.
- All equipment is located outside congested plant areas, making a retrofit simple by comparison to a sponge ball system. At Martin Lake, an operational tube cleaning system was installed with no permanent modification to existing plant equipment or cooling water piping.

THE METHOD

Early during the preparation of the ERIP budget and work plan, the selection of a site to host the demonstration presented SIDTEC with a "Catch-22" situation, no one wanted to commit to the project before the funding was secured and funding could not be secured without a site. Finally in February 1992, the plant manager at the City of Austin (Texas) Power & Light Decker Generating Station, agreed to host the demonstration.

Decker

This plant is operated by the municipal utility of the state capital of Texas and home of the University of Texas. Due to the strong influence of students and state government employees, the city council banned the use of biocides in the treatment of condenser cooling water, without regard to the lack of alternatives or impact on operating efficiencies. In 1984, SIDTEC approached the utility to do the original development work on the tube cleaning technology, without success. Seven years later, and following a change in management, SIDTEC was able to return to the Decker station.

Due to the excellent work by our invention coordinator and the anticipation of the grant award, much of the mobilization work was in progress by the time funding was approved in late July 1991. In four weeks, equipment was ready to be moved on site in Austin.

The Decker Generating Station is what is known as a "summer peaking unit." Ninety per-cent of its yearly generating capacity is produced between May and September. Unit 2 being the more efficient of the two units is the first unit brought on-line. Once the South Texas Project, two - 1,100 Mw nuclear units, became commercial, the capacity factor at this plant has been very low. This actually worked to our advantage most of the time because we were able to have unprecedented access to the condenser and cooling water system. However, on occasion we had to remind ourselves the production of electricity was the priority, not skimming tube cleaners.

Decker Unit 2 is a 400 Mw, natural gas-fired unit which has a 200,000 sq ft condenser, with 17,060, 1", 20 BWG (0.930" I.D.) 90-10 copper-nickel tubes. Cooling water flow in unit 2 is 236,000 gpm, for a combined flow of 468,000 gpm when both units are operating.

The month of September was spent assembling skimming boom and making the first boom set in the canal. The TCRU was moved into position, the water supply and return hose was placed in service, and the initial testing of the system began.

On September 20, the first test of the system was conducted by recirculating the tube cleaners directly back to the discharge structure. The skimming system was fine tuned in this manner, prior to injecting cleaners into the cooling water system and through the condenser. In preparation for the first full scale circulation test, the condenser tube sheets were cleaned of foreign debris and all other obstructions removed from the inlet and outlet waterboxes. On October 9, 1991, an off-line video borescope inspection was conducted on fifteen tubes whose location was marked on a tubesheet map for re-inspection following cleaning. The tubes were fouled with an organic-silt matrix deposit.

Following the first set of circulation tests which completed 180,000 total passes or approximately ten passes per tube, a video borescope inspection of the same fifteen tubes revealed excellent results. Results were shown to plant management with the remark that they had never seen the tubes this clean.

Testing continued throughout October and November, improving the operation of the skimming system with the final boom set, as shown below, brought a recovery efficiency approaching 100%.

Decker Generating Station - Plant Lay-out

By November, it was becoming apparent that one of the goals of the grant could not be attained at the Decker station, demonstrable results of the tube cleaning process through plant performance. While before and after video borescope inspections were clear evidence the process could clean condenser tubes, the instrumentation of the unit was not sufficient to show any improvement in operating parameters, primarily condenser back pressure, or Δt , the temperature rise across the condenser. However, November also brought the first contact by the TU Electric Martin Lake Steam Electric Station to discuss installing a skimmer before the summer of 1992.

One of the remaining goals to accomplish at Decker was a distribution test. If tube cleaners of appropriate density are mixed uniformly in the cooling water, each tube will receive the proportionate number of tube cleaners as the flow through that tube.

A condenser waterbox forms the transition from a circular conduit to the rectangular tube sheet. There are two waterboxes for Decker Unit 2. The waterboxes are designed with the intent that each tube has an equal amount of water flowing through it. In the real world it does not quite work out that well. Again, quantitative data is difficult to obtain, but studies have been done. Depending upon inlet and outlet waterbox geometry flows can vary significantly. Arkansas Power & Light Nuclear One actually had flow in the opposite direction in some peripheral tubes.

In January, a distribution test was conducted in Unit 2 using 24 wire baskets mounted to the outlet tube sheet. These baskets are 3 1/4" in diameter and approximately 18" deep. An anchor bolt runs down the center of the basket and is fixed to the outlet tube sheet using an open tube. This leaves the six surrounding tubes open for cleaner collection. Since the baskets were manufactured for a condenser with a slightly different tube pitch, some of the tubes were blocked by the edge of the basket. While this was considered a perturbing influence for the test, it provided added support to the distribution theory since every tube obstructed by a basket had a tube cleaner stuck in a tube.

Prior to the distribution test, the condenser was cleaned of obstructions from the inlet waterbox. The outlet tube sheet was also cleaned and the twenty-four mounting posts were installed in a somewhat random pattern. The twenty-four baskets were divided equally between the four tubesheets. The mounting posts were long pieces of 3/8" all-thread with a long donut of polyurethane, slightly smaller than the tube I.D., between two washers and nuts. The nut on the end of the rod to be inserted into the center tube was immobilized so that the nut outside the tube could be tightened, expanding the polyurethane donut, and anchoring the rod in place. The six neighboring tube were blown out using SIDTEC tube cleaners and high pressure compressed air to clear any unseen obstructions. The baskets were placed on the mounting posts and fitted to the outlet tube sheet.

The next day, 6,600 tube cleaners were circulated from 11:30 a.m. to 5:00 p.m. with just the circulating water pumps from Unit 2. Throughout the test, marked cleaners were timed for computing average cycle times. It is estimated that between 125,000 and 145,000 total tube passes were made. Assuming 130,000 passes for 20,000 tubes, each tube should have received 6.5 tube cleaners, or each basket should contain 39 cleaners.

On January 8, the outlet waterboxes were entered to count cleaners and remove the baskets. All twenty-four baskets were intact and

contained cleaners. Some of the baskets were not seated properly and obstructed one or more of the six tubes inside the basket. It was assumed for computational purposes that the first tube cleaner through the tube blocked it off and no other tube cleaners came through the tube. In some other cases, a tube cleaner was poised at the outlet tube opening, but was not interfered by the basket. These cleaners may have been in the basket, but moved about as the condenser was drained. Therefore, the total number of cleaners recovered in that basket was increased proportionate to the number of tubes blocked. For instance, basket #1 had 34 tube cleaners recovered in the basket. Two tubes were blocked and two tubes had cleaners lying in the tube outlet, so the revised total was 49 ($34 \times (1 + (2 \times .16)) + 4$). These revised totals were normalized to 39 and the results plotted and contoured. The contoured tube sheets are below. After the test was completed, 5,700 cleaners were recovered at the TCRU and another 850 in the baskets and water boxes (~99.2% recovery).

Results of Decker Unit 2 Distribution Test

The test results are divided into five levels: baskets which received greater than one and one-half times the normalized value through baskets which received less than half the normalized value. Each side of the condenser received nearly 50% of the total number of cleaners.

Reviewing the test results, one immediately observes a non-uniform distribution. The white boxes are the location of the collection baskets. The values ranged from 0.31 to 1.96. In distribution tests conducted at the Georgia Power Co. Plant Scherer in 1986 in an ATCS, there was as much as a ten to one variance in the distribution of sponge balls. Without multiple tests and more sophisticated data collection and reduction techniques, no definitive conclusions can be reached. However, due to the similarities of the pattern between the north and south waterboxes, it is believed that the results are heavily influenced by the hydraulic distribution of the water flow. Due to the presence of a large butterfly valve located near the base of the waterbox, in the open position, it may act as a turning vane, disturbing the desired water flow. Perhaps an artifact of the data points or the contouring technique, it appears the two waterboxes are approximate mirror images of each other. A full scale display of the results are included in the Appendix.

Martin Lake Steam Electric Station

In February, the SIDTEC DOE Invention Coordinator met with John Tsou and Michael Miller in the EPRI offices in Palo Alto, California. The purpose of the meeting was to familiarize EPRI management with the work SIDTEC had completed in Austin and the possibility of continuing the demonstration at the TU Electric Martin Lake plant. Two units at Martin Lake have the instrumentation required to make more meaningful measurements with regard to the benefit of on-line mechanical tube cleaning.

Since a field test of the skimming technology in 1988 at this plant, Martin Lake has continued to struggle with the condenser maintenance program. The conditions in the Martin Creek Reservoir require the plant to walk a fine line in their cooling water chemical treatment program. If they over chlorinate, manganese oxides are precipitated onto the stainless steel tube by the oxidizing action of the chlorine. These deposits initiate galvanic corrosion cells, leading to under deposit pit corrosion. If they under chlorinate, biofouling reduces the heat transfer coefficient and the condensing efficiency of the condenser, requiring more fuel for each kilowatt of electricity.

The Martin Lake management was concerned about the increasing frequency of off-line acid treatments. These operations require the isolation of the condenser from the cooling water system and foamed acid pumped through the condenser. This treatment generally costs between \$50,000 to \$70,000 per unit and does not provide any long term protection.

The Martin Lake representatives were confident of the technology but needed to know more about the economics of a long term installation.

It was suggested that the money spent on a chemical cleaning could be used to defray the costs to install a complete SIDTEC system. Then a monthly maintenance program could be structured to replace the chlorine costs for the rest of 1992, while tests were conducted to show benefit. The spring outages were to begin April 6 and 26, with bids due by March 6.

Over the next two weeks, a proposal was prepared and a demonstration conducted in Austin for Messrs. Baum and Jones. The proposal called for two condenser cleanings and a maintenance plan initiated in conjunction to the spring outages for Units 1 & 2 in April.

On February 7, in conjunction with a DOE Commercialization Workshop held in Austin, a demonstration at the Decker Station was conducted for Annette Argall, of the Texas Department of Commerce, and Harold Livesay and David Lux, representing the Oak Ridge National Laboratory.

On March 6, SIDTEC met with representatives of Martin Lake Technical Services, Purchasing, and Operations to review the proposal and establish the fine points of the contract. The two major points to be agreed upon were the electrical power supply and the participation of EPRI in the evaluation process. A verbal purchase order was issued with a deadline of April 20 established to coincide with the spring outage. Following the initial circulation test, the on-line cleaning would take place following the outage when the unit came back on line.

Immediately following this meeting, plans were put in place for the initiation of this project. Between March 9 and 13, the SIDTEC equipment and office was removed from the Decker Creek plant and transported to Martin Lake. The rest of the month was spent preparing additional equipment, fabricating the additional skimming boom, preparing the banks of the discharge canal, siting the water plant, and putting the first booms in the water.

The installation at Martin Lake was unlike any other project SIDTEC had ever attempted. In a 40 working days, one system had to be removed and other, three times as large, had to be installed, with no room for error. Having had previous experience at this site, it was decided to move the recovery point further down the canal to get away from the 30 degree curve. A project schedule was prepared prior to leaving Austin and several major milestones needed to be accomplished in a stepwise fashion.

- 1) Boom systems in place: skimming, bank protection and environmental.
- 2) Water plant assembled prior to TU power hook-up.
- 3) TCRU modifications completed when water and power are ready.
- 4) Cleaner injection system in place before deadline.

Unlike the rectangular, concrete canal in Austin, this site has earthen banks with a severely eroded surface. Originally, a 3:1 slope, the banks are now highly irregular with undercut banks. Bank protection booms, offset a few feet, roughly parallel to the bank, attempt to keep the cleaners in the flow and minimize wave action along the shoreline. One end of the boom also extends out into the main channel of the canal to keep the cleaners in the fastest moving water.

The skimming booms form a long "V" and are 900' long on each side. Wing booms parallel the skimming booms are 100' long and provide the final approach to the TCRU. The canal at this point is about 250' wide.

The environmental boom is downstream from the TCRU and collects cleaners not processed by the TCRU, washed over the booms during heavy weather, or in the case of a catastrophic failure of the boom system during circulation, prevents additional loss. A fixed screen retains the cleaners along with other surface debris and is cleaned out on a regular basis.

The completed system was in place and operational on April 19. The following fold-out shows the system as deployed at Martin Lake plant in the top photo, and the Decker plant in the lower right-hand corner.

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2 units, 710 Mw, 500MGPM

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RESULTS

Unit 2 came down on schedule April 6 and during the two weeks prior to the first circulation test, the maintenance grating was removed from the inlet and outlet waterboxes. Debris was cleaned off the inlet tube sheet and damaged tube ends were repaired to allow the free exit of cleaners. On April 21, cleaners were injected and the first one recovered at the TCRU had a thick accumulation of black matter around the cleaning element, visual evidence of biofouling removal.

The TU management satisfied with the initial results, made the decision to circulate cleaners through Unit 1 just before the unit came down for its outage. The computed condenser cleanliness was below 65% and on-line condenser inspections with a video borescope confirmed the tubes were heavily fouled.

On April 24, cleaners were injected in Unit 1 at 9:45 a.m. The output from the Plant Monitoring Workstation is below. Three curves are plotted: load (Mw), condenser backpressure (in/Hg), and condenser cleanliness (%).

Results of Plant Monitoring Workstation - April 24, 1992

When evaluating the performance of a machine the size of a steam electric power plant, there is no one gauge to measure its efficiency. Several performance parameters are interdependent, so many factors need to be observed under constant operating conditions. A computed condenser cleanliness can have over twenty variables. One, condenser backpressure, is dependent on load (steam flow), inlet water temperature, cooling water flow, air in-leakage, condenser cleanliness to name but a few.

With this in mind, the graph of data from April 24 is still impressive. Curve 1 is load, it remains fairly constant except between 1 p.m. and 10 p.m., so the other two curves become meaningless. It is significant the backpressure (curve 2) and condenser cleanliness (curve 3) show immediate improvement and continue to improve throughout the test.

In lieu of a chemical cleaning of Units 1 & 2, an on-line mechanical cleaning of the units were part of the original contract. This required 560,000 "single element passes" through each condenser, or approximately twenty passes per tube. On May 8 and 9, Unit 2 was cleaned upon completion of its scheduled outage. Unit 1 followed on May 18 and 19.

On May 21, a meeting was held to establish the test protocol to determine the benefit of an on-line tube cleaning system. John Tsou with EPRI, John Westcott with Power Technologies, Inc., John Rawley with TU Electric Research and Development, other plant personnel discussed what data was to be collected, how it would be processed, and who will be responsible for various parts of a report to be published by EPRI. Following the meeting, the chlorination program for Unit 1 is terminated.

The weekly maintenance program officially started on June 2 with 100,000 passes in Unit 2. Unit 1 was to be run without chlorine or mechanical tube cleaning until operations saw an impact in condenser performance.

Unit 3 was not been part of the original agreement since no outage was scheduled and the condenser and waterboxes could not be prepared for regular circulation. But on June 12, a brief weekend outage allowed access to the cooling water system and 60,000 cleaners were circulated to mark the tubes. Following a video borescope inspection to establish the base-line condition, unit 3 started on a regular maintenance schedule.

Unit 1 finally began to show the effects of five weeks without chlorination or on-line mechanical cleaning in early July. Discussions with the TU Electric Operations, Maintenance, and Technical Services departments were held to determine when and how to intervene. One aspect of the test protocol which had not been seriously studied was the range of the number of single element passes necessary to maintain adequate cleanliness. The 100,000 passes per week was a number more or less picked out of the air as a conservative starting point. If it was found

to be inadequate, the number of passes would be increased. Half way through the peak fouling months, 100,000 passes per unit per week maintained a high level of condenser cleanliness.

An on-line video borescope inspection of Unit 1 confirmed biofouling in place. On-line video inspections have played an important part in evaluating the effectiveness of the technology. Since the circulating water system operates with a siphon to reduce pumping requirements, the outlet water box, as shown below, is under a partial vacuum. So opening a valve to atmosphere, draws air in instead of blowing water out. This fact allowed the easy insertion of a $\frac{3}{4}$ " tube through the outlet water box and into the opening of a condenser tube. A 50' fiber optic video probe could then be pushed through the conductor tube reaching upwards of two-thirds of the length of the condenser tube. A TV monitor and videotape recorder allow on-line viewing, as well as valuable historical data. With this access to the condenser, much of the guess work was eliminated. This method is currently covered by a U.S. Patent assigned to TU Electric.

On-Line Video Borescope Inspection

Following the inspection, it was decided to circulate 40,000 cleaners to determine if the unit instrumentation could register any improvement. Following circulation, perhaps a 1% improvement was indicated, but it is unsure whether that magnitude of change could have been discriminated from the noise in the data. So the next morning, the

on-line video borescope inspection was repeated and an additional 66,000 passes were made to achieve the nominal 100,000 level. Further passes did not improve the calculated condenser effectiveness, so complete recovery to values in May was not possible. While the lake temperature has risen significantly since then, the calculated condenser cleanliness, in theory, should have taken that into account.

Concurrently, an on-line video borescope inspection of Unit 3 showed a persistent discoloration of the condenser tubes. While it was not suspected this was a new deposit, an additional 268,000 passes were run to determine if any appreciable difference could be detected.

Following another on-line inspection, some improvement was noticed, but overall the stains remained. Without having pulled a tube for a more rigorous inspection and testing, it was assumed the deposits were remnants of previous scaling and probably could not be removed without abrasive cleaners. The conditions was monitored throughout the rest of the year.

Following completion of a complete fouling cycle, more data became available to look at the trends established between 1991 and 1992. The graph below shows the magnitude of the economic benefit of a clean condenser.

Seasonal Heat Rate Penalty and Lake Temperature

Lake water temperature is seasonal, as one would expect. As the ambient temperature increases, the ability of the lake to reject heat decreases. During the summer months, the lake water temperature can approach 100°F. The most influential factor affecting a condenser's backpressure is the temperature of the cooling water. At this location, during the summer, a unit will experience a higher than normal backpressure, increasing the unit's heat rate or decreasing the efficiency. This graph essentially shows that over the bulk of the 1992, the plant experienced as much as a 1.5% improvement in unit heat rate from the previous year. The difference between these two heat rates is in the neighborhood of a \$1,000,000 savings in fuel costs.

In December, a test of the abrasive cleaning elements was started in Unit 3. An ineffective acid cleaning job sometime ago had left an intermittent orange to brown, streaky stain on the condenser tubes. Numerous on-line video borescope inspections since March have shown that it was resistant to the normal (non-abrasive) material in use. To reduce the potential of sub-deposit pit corrosion, an extended test with the abrasive cleaning element was proposed. The unit was scheduled for an extended outage in February 1993, so after six weeks of intensive cleaning, an extensive inspection could determine the effectiveness of the abrasive cleaning elements.

Throughout January, on-line video borescope inspections were conducted periodically, but progress on the removal of the manganese scale was inconclusive, since this particular on-line video borescope technique cannot re-inspect the same tube on different inspections.

Martin Lake Main Steam Condenser Waterbox Configuration

With the unit 3 outage, off-line video inspection of the condenser enabled TU personnel to evaluate the condenser cleanliness. The condenser is split in halves, with each half condensing steam from one half of the low pressure turbine. Each half in turn has two water boxes, and each waterbox has two tube bundles, as shown on the preceding page.

The results of the test using the abrasive cleaning elements was very encouraging. The "A", "B" and "C" waterboxes were exceptionally clean, almost "as new" condition. The "D" waterbox had some remnant stain, but TU personnel inspecting the condenser were satisfied the manganese had been removed.

For the first year of operation, tube cleaners were injected into the condenser cooling water (CCW) system via a four inch, polyethylene pipe into the suction bell of one CCW pump per unit, as shown below. While this method minimized the modifications to the CCW system and did not require an additional pump to overcome the discharge head of the CCW pump, other considerations made this technique undesirable for a long term installation.

Martin Lake Tube Cleaner Injection Methods

The intake structure pump pit also contains pumps for other systems. The auxiliary cooling water pump supplies water for lube oil coolers, hydrogen coolers, soot blowers, and other small heat exchangers throughout the plant which typically have smaller tube sizes, 5/8" and 3/4" being common. Service water pumps also occupy some of the same bays and supply water to fire control systems, the sewage treatment plant, and the flue gas desulfurization "scrubbers."

Approximately six months out of the year, during the warm weather, all three circulating water pumps are operating. The other six months of the year, two of the pumps supply condenser cooling water. In September 1992, an operator unilaterally decided it was time to turn off one CCW pump concurrent with a cleaning operation. Without the water being drawn into the CCW pump, the cleaners floated upward, entering the auxiliary cooling water system. Several thousand tube cleaners were dispersed throughout Unit 2. This occurrence gave added importance to injecting tube cleaners into the pump discharge plenum.

The large axial flow CCW pumps move a tremendous volume of water, but the discharge head is only in the 6 to 10 psig range. An access pipe was put in place during the unit 3 outage in February. A source of high pressure water was available off the service water system, so a hydraulic pump was obtained to convey the tube cleaners from the "cleaner feeder" to the pump discharge plenum. Water at 125 psig enters a volute through an orifice creating a suction with a 10 psi discharge head. The new system works very well. Additional ports were added for Units 1 & 2 during their fall outage in October and November, 1993.

CONCLUSION

In the Special Terms and Conditions set forth by the Project Description, SIDTEC was to perform the following tasks to demonstrate and test the "patented system and determine its effectiveness against biofouling." Some paraphrasing is used for brevity and clarity.

- 1) Redesign the TCRU to match the needs of the Decker station.
- 2) Perform revisions to the mechanical systems.
- 3) Purchase all hardware and supplies to test the system.
- 4) Load and move equipment to site.
- 5) Assemble cleaning system at the test site. Checkout system and test for design flaws. Perform final diagnostics and optimize overall system performance.
- 6) Conduct condenser tube cleaning test.
- 7) Perform monitoring and follow-up work to complete Task 6. Repeat tests over varying conditions as appropriate, maintaining daily logs.
- 8) Perform off-line condenser inspections and record results.
- 9) Organize data into technical report that documents test, test conditions and system effectiveness.
- 10) Disassemble test equipment.
- 11) Submit progress and financial reports quarterly. Submit a final report at the end of the grant period that summarizes the technical accomplishments and the next steps for commercialization.

With the completion of this report, all tasks have been completed. An extension of the grant period was obtained in January 1993, so the results of the EPRI report could be included. Unfortunately, Power Technologies, Inc. has spent over a year on the data reduction portion of the report and has not adequately responded to numerous requests for explanation by EPRI, TU Electric and SIDTEC. However, technical papers have been presented at the EPRI Condenser Technology Conference in St. Petersburg, the Edison Electric Institute (EEI) Prime Mover Conference in Peoria, the EEI Chemical Users Group in Denver, the Plant Design and Operations Committee meeting in Corpus Christi, and several TU Electric intra-plant meetings. A copy of the EPRI paper is included in the Appendix.

Tasks 1-8 were completed at both Decker and Martin Lake. Video borescope inspections, both on-line and off-line, at both plants confirmed that the SIDTEC Rocket tube cleaner is effective in removing the soft biological fouling. In addition, anecdotal evidence indicates the SIDTEC method to tube cleaner injection, along with tube cleaners of appropriate density, relative to the inlet cooling water temperature, provide adequate

distribution where all open tubes receive an adequate number of cleaners per unit time to maintain optimum condenser performance.

The Martin Lake plant terminated the use of gaseous chlorine or other biocides for biofouling control in Unit 1 in May, 1992, in Unit 2 in June, 1992 and in Unit 3 in July, 1992. Condenser cleanliness problems and the heat rate penalties or load limitations experienced in the years prior to 1992 have not reoccurred. A maintenance contract has been completed for 1993 and secured for 1994. Discussions have taken place with the TU Electric Production Engineering Department for implementing this technology in an additional eight or nine generating stations.

The test of SIDTEC abrasive tube cleaners has shown that thin hard scales can be removed in place, eliminating the need for expensive off-line chemical cleanings and disposal of large quantities of acid. A proposal has been submitted to the Illinois Power Clinton Power Station, a 990 MW boiling water reactor to remove 20 mils (0.020") of calcium carbonate which remains following a mechanical cleaning during the third refueling outage. The scale inhibitor chemical treatment used since has not permitted any further deposition, but the remnant scale remains. The proposal suggests an intensive on-line cleaning program prior to the next refueling outage. This technology also has the attraction to eliminate the use of chlorine in this 750,000 sq ft stainless steel condenser.

A proposal has also been submitted to the Florida Power & Light St. Lucie Plant, a two-unit 855 Mw pressurized water reactor. Frequent off-line cleanings are required to remove the silt in one-quarter of the condenser at a time. Environment restrictions on biocides limit the application of chlorine to one two hour treatment per waterbox every four days. Biofouling becomes the glue for the accumulation of fine suspended particles.

Other responses to inquiries and proposals are being prepared for the San Antonio City Public Service Board Deely and Sommers plants, the New England Power Co. Brayton Point Station (the largest coal-fired plant on the east coast), and the Commonwealth Edison Joliet 29 Station.

In addition, SIDTEC has, at this writing, has agreed to terms for the purchase of company assets by Betz Laboratories, Trevose, PA. Over the past year, the success demonstrated at Martin Lake has attracted the attention of the main suppliers of condenser cooling water programs for open cooling water systems. We feel the expansion to this technology will be intricately linked to acquisition by a major industry player who has, not only the capital necessary, but also the contacts and industry credibility. The Power Division of the Betz Water Management Group can provide those attributes. An \$800 million dollar company, Betz maintains a leadership position in all facets of industry where this technology is applicable.

APPENDIX 1: Distrubtion Test Data, Decker Unit 2

Basket No.	No. of cleaners	No. of tubes	No. of cleaners	Revised No.	Normalized No.
	in Basket	Blocked/Plugged	in tubes	by formula	to 39
South Side					
1	34	2	2	49	1.26
2	25	2	0	35	0.91
3	25			25	0.64
4	32			32	0.82
5	12			12	0.31
6	36			36	0.92
7	36			36	0.92
8	27	1		33	0.83
9	24			24	0.62
10	48	1		57	1.46
11	46			46	1.18
12	13	1		16	0.41
	358	49.79%		401	48.75%
North Side					
13	25	1		30	0.77
14	42			42	1.08
15	12			12	0.31
16	21			21	0.54
17	30	1	3	39	1.00
18	55	2	1	76	1.96
19	40	1	1	49	1.25
20	37	1	2	46	1.18
21	32			32	0.82
22	5	3		11	0.27 *
23	40		2	42	1.08
24	22			22	0.56
	361	50.21%		422	51.25%
Number of cleaners recovered in condenser				746	

* - Maybe artificially low due to number of block tubes

Location of Distribution Test Collection baskets, Decker Unit 2

Decker Unit 2 South Waterbox - Outlet Tube Sheet

Contoured Distribution Plot, 1= 39 tube cleaners per basket

Decker Unit 2 North Waterbox - Outlet Tube Sheet

Contoured Distribution Plot, 1= 39 tube cleaners per basket

Appendix 2

A NEW APPROACH TO ON- LINE MECHANICAL CONDENSER TUBE CLEANING

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A NEW APPROACH TO ON-LINE MECHANICAL CONDENSER TUBE CLEANING

ABSTRACT

For many years, condenser biofouling has been difficult to prevent/control. The benefits of maintaining clean condenser tubes to the efficient operation of steam electric power plants include:

1. Prevention of Heat Rate Degradation
2. Extended Condenser Tube Life
3. Elimination of Outages to Clean the Condenser

TU Electric's Martin Lake Plant has been utilizing an innovative on-line mechanical tube cleaning system since April 1992 to maintain condenser cleanliness while eliminating the use of chlorine to control biofouling. The system is operated as a tube cleaning service; therefore, no capital investment or plant retrofit was required. The system was installed while the units were operating at base load.

The results of the on-line cleaning effectiveness were determined by the EPRI Plant Monitoring Workstation, installed test grade instrumentation, and on-line video borescope tube inspections.

A NEW APPROACH TO ON-LINE MECHANICAL CONDENSER TUBE CLEANING

INTRODUCTION

On-line condenser tube cleaning systems have been established in the marketplace since the 1970's. Varying degrees of success have been realized with each of these different systems.

Closed loop cleaner circulation systems around the condensers have had some limited success. High maintenance costs and unit outages required for system repair (in the absence of inlet and outlet isolation valves) are the major disadvantages.

Conventional chlorination of the circulating water to control biological growth is probably the most widely employed process of maintaining condenser cleanliness. Typically, the growth rate of the biofouling is merely controlled to allow operation between condenser cleanings (either mechanical or chemical). Limitations on free available chlorine at discharge outlets to a cooling pond and the deposition of manganese oxide scale on the condenser tubes, limits this method in its full potential to control biofouling at this plant.

TU Electric's Martin Lake Plant has three 750 MW lignite-fired supercritical units with each main condenser containing 28,512 - 1" 22 BWG stainless steel tubes. Control of biofouling was maintained by chlorination. Every two to three years, a chemical cleaning was required to remove the manganese oxide deposits which precipitated onto the tubes as a result of the chlorine in reaction with the cooling pond water. To limit this occurrence, a chlorination minimization program was initiated. However, biofouling would overwhelm the minimization process leading to a rapid increase in chlorination levels. The condenser would then experience the dual problem of manganese deposits and biofouling. As a result, concern mounted over the corrosion potential of these deposits and the cost of repeated off-line chemical cleanings.

An additional problem encountered during the cycles was the degradation of condenser effectiveness. With the presence of the biofouling and manganese deposits, the heat transfer of the condenser tubes would progressively worsen, resulting in high backpressures and high hotwell temperatures.

TU Electric sought an alternate solution to the conventional chlorination and chemical cleaning cycles that had been employed and found a new process that provided for on-line condenser tube cleaning which had the potential to eliminate chlorination. This patented process utilizes on-line mechanical tube cleaners and a non-intrusive tube cleaner recovery system. The cleaner recovery system utilized at this site requires that the effluent cooling water be discharged through a canal or a flume. The first full-scale field demonstration of this process was rigorously tested at the Martin Lake Plant. It is supported by the Department of Energy through the Energy Related Invention Program. To evaluate the effectiveness of the process, the EPRI Plant Monitoring Workstation (PMW) and on-line video borescope (VBS) inspections were used. Data was gathered on-line for the condenser performance calculations on the PMW. The VBS provided visual documentation of the effectiveness of the process on a periodic basis.

METHOD

The tube cleaning system consists of on-line mechanical tube cleaners and a tube cleaner recovery system. The two-part construction of the hard body tube cleaner permits the specific gravity of the cleaner relative to the cooling water temperature/salinity to be adjusted for local operating conditions. The wear resistant materials of construction provide a long life with consistent performance (See Figure 1). The cleaning element, an elastomeric disk, determines the level of cleaning and can be made abrasive for attacking tough chemical scales. The design of the cleaner provides for self-alignment for passage through the condenser tubes.

Figure 1

The tube cleaner recovery system consists of modified oil spill recovery booms, a tube cleaner recovery unit, and means to recirculate the recovered cleaners. In most cases, the cleaners can be hydraulically conveyed to an injection point upstream of the inlet condenser waterboxes. The intake structure at Martin Lake permitted the easiest access to

the condenser cooling water system (See Figure 2). Injecting cleaners at the intake structure ensures that the tube cleaners will be evenly distributed throughout the volume of cooling water. It is well understood that the hydraulic distribution in condensers is not equal, but using this approach, each tube will receive a number of tube cleaners proportionate to the water passing through it.

Discharged into the canal, the tube cleaners gradually rise to the surface when the turbulence subsides and the flow becomes essentially laminar. Once on the surface, the system of skimming booms channel the cleaners to a common collection point. The tube cleaner recovery unit is a pontoon-mounted traveling screen. It retrieves the cleaners, rejects any floating debris, and conveys the cleaners to shore for either direct re-injection or to be manually carried to the intake structure.

RESULTS

From the very beginning, the Plant Monitoring Workstation and on-line video borescope (See Figure 3) inspections were the backbone for evaluation of the tube cleaning process. Before the first tube cleaners were ever circulated, a visual base-line condenser condition was established with the VBS. These inspections were facilitated because the outlet waterboxes are under partial vacuum. An existing blind flange allowed entry into the waterbox below the centerline of the tubesheet. A ten foot length of 7/8" tube was inserted through a ball valve and mated with a tube opening. The VBS was then inserted into the condenser tube using this "bridge" through the outlet waterbox. Using this method, over half of a randomly selected condenser tube could be inspected and videotaped for later viewing and documentation. This technique, used many times with excellent results, is a patented process by TU Electric.

Cleaners were circulated through Unit 2 before its scheduled outage in the spring of 1992. The condenser was severely fouled and a chemical cleaning was planned during the outage. Condenser performance results were recorded by the PMW during the initial circulation of tube cleaners. Condenser effectiveness was calculated and plotted on a graph¹ (See Figure

¹ This graph was presented in a paper, "Utility Experience with the EPRI Plant Monitoring Workstation", by Steve Williams at the EPRI Heat Rate Improvement

4) along with unit load and condenser backpressure. The immediate improvement in the calculated effectiveness and condenser backpressure was significant. In addition, many tube cleaners recovered in the canal had a ring of black material lodged between the body and the tube cleaning element as visual evidence of biofouling removal.

Being very encouraged by the initial test results on Unit 2, the decision was made to cancel the condenser chemical cleaning during the unit outage. Additionally, tube cleaners were injected into the Unit 1 condenser prior to the spring outage in lieu of chemical cleaning. Similar results were realized.

By circulating tube cleaners through the units before the outage, obstructions which prevented the tube cleaners from passing through waterboxes and condenser tubes were identified. The areas found were damaged tube ends, grating for maintenance in the inlet waterbox, and vent and drain valve penetrations in the waterbox. Screens were placed over these valve penetrations, the grating was removed, and the tube ends were repaired during the outage. Additionally, the tubes were visually inspected using the VBS.

Upon completion of the outages, an on-line mechanical cleaning was performed on Units 1 and 2. Tube cleaners were circulated until no further improvements in calculated condenser effectiveness could be determined by the PMW. At intervals, the VBS was utilized to record visual conditions of the tubes. These inspections confirmed that the process was successful in removing the soft biofouling. The cleaning elements being used at this time were the non-abrasive type. The time frame to achieve a stable condenser effectiveness was approximately three weeks for each unit with a combined number of tube cleaner passes exceeding 1,200,000 for both units. Chlorine injection at the intake was continued on both units during this mechanical cleaning process. Unit 3 was initiated in a similar fashion to Units 1 and 2 during May 1992.

To provide for one of the objectives of the evaluation program, chlorination was suspended on Unit 2 but continued on Units 1 and 3. The intent was to compare the effectiveness of the process on condensers with chlorination to a condenser without chlorination.

Conference, Birmingham, AL, November 1992.

Unit 2 continued operating without chlorine or mechanical cleaning for six weeks until the calculated condenser effectiveness had degraded 5% from its clean condition. On-line mechanical cleaning was resumed and performance was restored with approximately 100,000 tube cleaner passes. This process confirmed the ability to recover from any unforeseen biofouling episode, temporary interruption of the cleaning service, or extended periods of bad weather.

The results of this test also revealed that the condenser effectiveness was not influenced by the absence of chlorine as long as weekly mechanical tube cleaners were utilized. VBS inspections revealed that no biofouling growth began on Unit 2. It was concluded that chlorination was not required with this process. Chlorination was thus eliminated on the condenser for all three units.

After six months of weekly condenser cleanings, the process had demonstrated the ability to prevent tube biofouling, but the manganese oxide deposits had not been removed. The next step was to determine the ability of the process to remove these manganese oxide deposits. Abrasive cleaning elements were installed on all cleaner bodies. A continuous run of abrasive cleaners was started on the Unit 3 condenser with a total of 2,347,000 single element passes being completed with progressive removal of the manganese oxide deposits tracked by the VBS. Removal was accomplished within five to six weeks. The manganese oxide deposits on Unit 1 and 2 condensers were removed in a similar manner.

Currently all three unit condensers are operating in a clean state exclusively by injection of the tube cleaners at a rate of 100,000 single element passes per week per condenser. Condenser effectiveness factors are remaining constant.

ECONOMIC EVALUATION

Evaluation of the test results on the PMW reflect several interesting facts. Generally, summer lake temperatures at the condenser inlet have approached 100F. During the summer of 1992, after each condenser had been cleaned, the heat rate penalty attributed to the high lake water temperature and fouled condenser tubes was drastically reduced as compared to the summer of 1991 (See Figure 5). An average of approximately 100 Btu/kWh reduction in unit heat rate was realized from July through August. Translating the com-

parison of 1991 to 1992 yearly heat rate data projects a potentially large yearly savings in fuel costs.

Additional savings were realized since chlorine was no longer utilized in the once-through cooling water. No chemical cleaning of the condensers is expected in the future at the two to three year intervals. These combined cost savings more than made up for the initial cost and monthly maintenance expense of this process application at Martin Lake.

CONCLUSION

On-line mechanical tube cleaning for power plants with open cooling water systems discharging effluent cooling water through a canal is provided as a contract service. The condenser tube cleaning system requires no capital investment and minimal plant modifications. If, for whatever reason, performance does not equal expectations, the service can be discontinued without the need to remove or write off expensive equipment. Other advantages include:

1. Chlorination and/or other chemical treatment of condenser cooling water can be reduced or eliminated.
2. Unit heat rate can be improved.
3. Corrosion potential is reduced by eliminating powerful oxidants and tube deposits.

An Electric Power Research Institute report is being prepared by Power Technologies, Inc. This report will cover the technology, operations, and economic impact of the condenser tube cleaning system on TU Electric's Martin Lake Plant condenser performance during the summer and fall of 1992.

Circulating Water System and Discharge Canal

Figure 2

On-line Video Borescope Inspection

Figure 3

Plant Monitoring Workstation, Initial Start-up
Figure 4

Figure 5

Appendix 3: Glossary

BWG - British Wire Gage, a common measurement for the wall thickness for heat exchanger tubes, e.g. 18 BWG=0.049", 22 BWG=0.028"

Cleaning effectiveness - a quantity to compare tube cleaners. The cumulative sum of flowing pressure drops, $\sum \Delta p_f$, or the area under a decline curve.

Closed cooling water system - a recirculating cooling water system serviced by either a natural draft or forced (mechanical) draft cooling tower. A large central station may circulate as much as 500,000 gal/min, with 10,000 gpm lost through evaporation. Blowdown is a continuous release of water to limit the buildup of dissolved solids and could approach 50,000 gpm for this unit, and is replaced with "makeup" water.

Condenser-Located at the exhaust end of the turbine, a surface condenser is a shell and tube heat exchanger used to extract the last unusable heat generated in the steam cycle. Since a pound of steam occupies sixty times the volume of a pound of water at atmospheric

pressure, a vacuum is created by the condensation of the steam back to the liquid phase, or the condensate. This very pure distilled water is kept free of contaminants to prevent problems developing in the boiler and turbine. With an effective surface area of several hundred thousand square feet, rolled into small diameter tubes, steps must be taken to maintain the integrity of the condenser to prevent air in-leakage and condensate contamination. Some common parts are identified below.

Distribution - the degree of even coverage of tube cleaners over the condenser tube bundle. Under ideal conditions, all tubes will receive an equal number of tube cleaners per unit time. In ATCS, the close-coupling of the ball injectors do not allow adequate distance for the tube cleaners to be dispersed in the inlet cooling water.

Elastomer - any various polymers having the elastic properties of natural rubber, primarily, but not limited in this use, polyurethane.

Flowing pressure drop, Δp_f - a measured quantity in "H₂O which is an indication of the cleaning effectiveness of a tube cleaner.

Heat rate - a measure of generating thermal efficiency for producing electricity, or the amount of energy input in BTU's to produce one kilowatt-hour (kwhr) of electrical energy output. Computed by dividing total BTU content of fuel burned for electric generation by the resulting net kwhr generation.

"H₂O - inches of water. A measure of pressure or "head." 12 "H₂O = 1 ft of head = 2.31 psi

Megawatt - Abbreviated Mw-1,000 kilowatts. If a unit's name plate rating, or the continuous full-load capacity, is 350 Mw, it is supplying the power for approximately 60,000 people.

Neutral buoyancy - having the same density or specific gravity as the host fluid, normally water. Fresh water at 40°F. has a specific gravity of 1.000. Condenser cooling water can vary from 0.990 (fresh water @ 112°F.) to 1.026 (salt water at 40°F.) For a specific temperature and salinity, a SIDTEC can be designed for neutral buoyancy by properly balancing the body and cleaning element dimensions with the material of construction, polypropylene (s.g.=0.910) to ultra-high molecular weight polyethylene (s.g.=0.935) for body material and polyurethane (s.g.=1.18+) has for cleaning elements. Loading the polyurethane with filler material has added to its flexibility to incrementally increase its density.

Once-through - a circulating water system which withdraws condenser cooling water from a body of water to be used only once. Commonly a river, ocean, or some other saline body of water. Some fresh water lakes, most notably the Great Lakes, fit this category. However, many power plant cooling ponds or lakes more closely the "open recirculating" category.

Open cooling water system - a circulating water system which withdraws cooling water from a surface body of water and discharged to the same or like body of water. May be a recirculating system, typified by a cooling pond, or "once-through." Cooling towers may be located along a discharge canal to reduce summer cooling water temperatures.

Orientation - the orientation of a SIDTEC tube cleaner is governed by a spatial relationship between the cleaning element and the dimension of the cleaner body with respect to the tube I.D. Without proper orientation, the cleaning element is not in circumferential contact with the tube surface.

Peaking duty - a typical summer day system-load demand curve is shown below, as is the load supplied by the mix of power plants. All power not generated by base-load units is supplied by peaking units, usually the least efficient fossil-fired units or those designed for cycling duty, i.e. gas turbines or pumped-storage hydro.

Pressure drop - pressure loss due to drag of the boundaries on the flowing fluid. Common turbulence inducing piping elements; expansions, contractions, elbows, tees, valves, all produce pressure drops. In the case of the strainer section in an ATCS, the pressure drop is between one-half and one psi.

Rankine cycle - a thermodynamic fluid cycle that combines expansion, compression, heat input and heat rejection. The initial pressure of the steam is raised and the condensation process that accompanies heat rejection continues until the liquid saturation point is reached. At the end of the cycle, condensate is pumped back to the boiler to begin the cycle again.

Simple Rankine Cycle

Skimmer - the non-intrusive tube cleaner recovery system. Modified oil spill control booms are used to separate mechanical tube cleaners using a small density contrast between the cleaner and the heated condenser cooling water

Tubesheet - (see condenser) the vertical surface separating the waterbox and the shell side of the condenser. More than an inch thick, thousands of tubes are rolled or welded in place to provide a seal between the shell-side vacuum and the outside pressures.

Waterbox - (see condenser) the transition piece between the circulating water conduit and the condenser tube bundle.

Zero discharge - a term for enhanced pollution control in plant design. Plant wastewaters, sewage-plant effluent, boiler blowdown, and steam condensate are frequently used as cooling tower makeup. Cooling tower blowdown is reprocessed by lime-softening, reverse osmosis or ion exchange to remove hardness, silica, and dissolved and suspended solids before being returned to the circulating water system.

40 CFR 423 - Environmental Protection Agency, Code of Federal Regulations, Title 40, Current Federal Register, Part 423.

Steam Electric Power Generating Point Source Category.

The EPA regulations in this section are "applicable to discharges resulting from the operation of a generating unit by an establishment primarily engaged in the generation of electricity for distribution and sale which results primarily from a process utilizing fossil-type fuel (coal, oil, or, gas) or nuclear fuel in conjunction with a thermal cycle employing the steam water system as the thermodynamic medium."

Section 423.11 list specialized definitions for total residual chlorine (TRC), once through cooling water, recirculated cooling water, 10 year/24 hour rain fall event, blowdown, average concentration, free available chlorine (FAC), and coal pile runoff.

Section 423.12 state the "effluent limitations guidelines representing the degree of effluent reduction attainable by application of the best practical control technology currently available (BPT)."

- 1) pH of all discharges, except for once through cooling water shall be in the range of 6.0-9.0
- 2) No discharge of polychlorinated biphenyl compounds (PCB's)
- 3) Sets quantity of pollutants for low volume waste sources
- 4) Sets quantity of pollutants for fly ash and bottom ash transport water
- 5) Sets quantity of pollutants for metal cleaning wastes
- 6) Sets quantity of pollutants discharged in once through cooling water, **average concentration of 0.2 mg/l FAC**
- 7) Sets quantity of pollutants discharged in cooling tower blowdown
- 8) FAC nor TRC may be discharged from a unit for more than 2 hr/day
- 9) Sets quantity of pollutants for coal pile runoff, except when associated with a 10 year/24 hour rainfall event

Section 423.13 sets effluent limitation guidelines by the application of best available technology economically achievable (BAT).

Section 423.14 sets effluent limitation guidelines by the application of best conventional pollutant control technology (BCT).

Section 423.15 defines the New Source Performance Standards (NSPS).

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