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AUTOMATIC ON LINE MECHANICAL CLEANING SYSTEM FOR CONDENSERS AND HEAT EXCHANGERS

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ABSTRACT

The on-line cleaning system for condensers and heat exchangers provides a positive means for automatic cleaning on a continuous basis while plant remains "on stream" and in its full operating condition.

Condenser tube fouling contributes up to 50% of the total condenser tube heat transfer resistance. The penalties and costs associated with the operation of a fouled condenser can include increased turbine heat rate and back pressure, increased operating and maintenance costs, reduced performance and power generation output, increased outages, and loss of plant availability. Foulants such as slime, bacterial matrix, algae, silt, scale, corrosion products and mud, reduce efficiency of the best designed condenser/heat exchangers and also induces localized corrosion of condenser tubes, and eventually force a shutdown of the most sophisticated water treatment available today. In this paper the various types of cleaning systems to reduce fouling will be discussed. Northern California Power Agency's experience will be used to demonstrate the actual system at their geothermal power plants.

Introduction

Northern California Power Agency (NCPA) is a joint exercise of power agencies in the State of California and was organized in June 1968 to represent its members in the generation, purchase, transmission, distribution, interchange, pooling, and sale of electricity. NCPA's membership consists of 11 municipalities, one rural electric cooperative, and one irrigation district. NCPA power plants utilized geothermal steam from their own steam field in The Geysers, Calistoga Known Geothermal Resource Area (KGRA) in Sonoma County, California, about 70 miles north of San Francisco, at 3,000 feet above sea level elevation. NCPA operates two plants at this location. Each plant consists of two identical and independent power generating units. The total net power generation for both plants is 230 and 238 gross megawatts. The steam from an individual well is delivered to the two power plants via NCPA's integrated steam field management system. The system includes about 8-1/2 miles of pipe ranging in size from 12 inches to 48 inches in diameter which interconnect the 35 wells located on 10 scattered sites to the power plants. NCPA's steam field, a typical power plant cycle arrangement and its various operating parameters are shown in Fig. 1. Early in 1984, a series of plant performance tests were taken for identical units 1 and 2 within NCPA plant #1. Each unit was determined to be capable of operating at 116% of its nameplate capacity throughout the year. The major limiting factor to operating at this level on a continous basis without any plant outage was determined to be condenser cleaning factor (C.F.) and its fouling condition. During October 1984, the condenser C.F. for units #1 and #2 were measured routinely and found to be decreasing after they were manually cleaned. The initial C.F. for both units was measured to be at 72.3 percent. Following the initial measurement, C.F. steadily declined at a rate of approximately 1.5 to 2.0 percent each week. C.F. after 5-1/2 weeks of operation was measured at 60.8 percent, at which point unit #2 was shutdown and manually cleaned. Unit #1 was on one occasion kept in operation for 12 weeks between the two shutdowns, C.F. after 12 weeks of operation was measured to be at 53.4 percent. The decline in condenser C.F. is shown in Fig. 2.

Since Units 3 and 4 were put into operation in late 1985 and early 1986, the C.F. for both units were closely monitored. The results achieved indicated a significantly higher fouling rate for both units 3 and 4 as compared with units 1 and 2. This is largely due to the quality of steam that is for the most part delivered to this plant from neighboring steam wells. The presence of higher Hydrogen Sulfide in the steam to Units 3 and 4 has required the addition of a Hydrogen Sulfide abatement chemical to the circulating water. These chemicals include an Iron Catalyst and hydrogen peroxide. The presence of these chemicals in the condenser circulating water is the cause for a higher fouling rate.

In an attempt to predict the time when the condenser cleaning becomes necessary, the actual condenser back pressure was measured and plotted against expected back pressure indicated by the condenser manufacturer for a given heat load. Any difference in the back pressure between the measured and the designed value indicates an increase or decrease in operating C.F. with respect to the manufacturer's designed value. This comparison was used to optimize the manual cleaning cycles per year needed to prevent a significant increase in the plant heat rate, its operating costs, and loss of plant availability. Fig. 3, presents this relationship.

Alternatives Investigated

With a focus on improving the plant heat rate and increasing the plant output level to 116 percent of the nameplate capacity, NCPA investigated various alternatives to eliminate or reduce the fouling problem all of the 4 units.

Manual Cleaning System

The manual cleaning system was selected to be the only effective solution for the short term. The frequent plant shutdowns and manual cleanings proved, however, to be expensive. It was determined that the cleaning frequency of all 4 units needed to be every 8 to 12 weeks. Ideally, the units needed to be cleaned ever 4-1/2 weeks as indicated in Fig. 3.

The present cost of power to NCPA for megawatts not produced is approximately $43.50 per Mwe hr. A typical condenser cleaning for each unit takes approximately 36 hours. Therefore, for the 57 Mwe, a typical shutdown for condenser cleaning costs approximately $90,000 in power purchases. On established manual cleaning frequency of once every 8 or 12 weeks, NCPA was losing $585,000 to $390,000 per year, respectively. An additional $2500 per shutdown was also estimated for labor and materials for each cleaning cycle.

Therefore, considering all four units, the annual loss due to shutdowns for manual condenser cleaning was estimated at . . . $1,663,000 to $2,495,000 per year for a shutdown occurring every 12 to 8 weeks, respectively. There were additional costs due to increased steam consumption, since between each cleaning cycle the condenser operates in fouled condition. In addition, the condenser operated a portion of the time in a fouled condition.

Chemical Continous Cleaning System

For the purpose of evaluation, a test program was set up to evaluate the effectiveness and potential cost of a chemical treatment program. The test started immediately following the plant overhaul. The chemical treatment was implemented on Unit 1 and the results were compared with those achieved from Unit 2 where no chemical treatment was present.

For our purposes and the chemical suppliers recommendation, it was decided to use a combination of a non-oxidizing biocide and a dispersant chemical.

As shown in Fig. 2, the rate of fouling during the first two weeks of operation did not change for the condenser with chemical treatment against that of the untreated unit. During this period, the rate of C.F. for units 1 and 2 declined by 5.5 and 5.7 percent, respectively. During the third week of the test, the chemical addition was increased. The C.F. for Units 1 and 2 declined an additional 2.3 and 2.2 percent respectively by the end of the week. During the fourth week, the rate of biocide was increased fivefold. The C.F. still continued to decline. After five weeks of operation the drop in the C.F. in Units 1 and 2 was measured to be 9.2 and 11 percent, respectively.

Based on the test results, NCPA concluded that the use of the non-oxidizing agent and the dispersent chemical was not effective in controlling the condenser tube fouling. Despite the claim by one other utility to have had success at eliminating the fouling problem by using Chlorine-Dioxide, and oxidizing biocide, the cost is still a major drawback to the chemical treatment program. It is estimated that a chemical treatment program under a supply and maintenance contract for Chlorine-Dioxide addition by a supplier will cost approximately $70,000 per year for each unit. Chlorine-Dioxide use at plant No. 2 where a circular water treatment for abatement takes place, was not recommended. The total ongoing costs of $280,000 per year for all four NCPA units was considered significant. A chemical program also adds one more hazardous substance to the power plant operation and could contribute to problems of personnel safety and compliance. The risk of equipment corrosion will also be present with the use of an oxidizing biocide chemical program.

Brush and Basket on-Line Mechanical Cleaning System

This system utilizes the installation of a set of baskets, one attached at the end of each tube. One brush is inserted in each tube. During the normal condenser flow, the brushes remain in the far end of each tube at their parked position. Once a day the flow through the condenser is reversed, utilizing one single flow diverter for a series of back wash valves installed between the supply and the return line to and from the condenser.

The flow reversal through the condenser causes the brushes to travel the full length of the tube, thereby brushing each tube. The flow direction is restored back to its normal direction after a few minutes by returning the flow diverter, (or the back wash valve), back to the original and normal position. The brushes will travel back and remain at their parked position until the next cycle is repeated. A typical system is illustrated in Fig. 4. Although the brush and basket system is proven to be quite effective, back fitting the flow diverter or installing back wash valves was considered to be costly due to the NCPA plant cooling water location and other piping constraints. This option was therefore eliminated.

Sponge Rubber Ball Type On-Line Mechanical Cleaning System

The operation of this system is based on the circulation of sponge rubber balls through condenser tubes. Prior experience by other geothermal plants to eliminate fouling conditions similar to NCPA has proven this system to be quite effective, reliable and economically attractive. After careful analysis, NCPA decided to install the sponge rubber type system on all four units. A typical system is illustrated in Figure 5.

Uniquely designed, slightly oversized, elastomeric sponge rubber balls are periodically or continuously injected into the condenser inlet line and circulated through the condenser tube by the cooling water flow. The balls are designed and injected in such a way to provide uniform distribution inside the water box. Since the diameters of the sponge balls are larger than the inside diameter of the tubes, the condenser tubes are automatically kept clean by the scrubbing and wiping action of the balls which prevent the deposition of scale inside the tube surface. The balls are collected by means of a strainer installed in the 42 inch outlet pipe condenser. The balls are then circulated and reinjected back into the supply line. All NCPA units use two-pass design condensers with a split water box. Therefore each half of the condenser is equipped with its own independently-controlled ball injection and ball strainer system. The common ball circulation system is used to collect the balls from both strainers. The balls are then equally distributed and reinjected into the two supply lines. Figure 5 presents the schematic diagram for this type of arrangement. Since the condenser and the cooling water recirculation pipe materials are all stainless steel, all components of the ball system are also constructed from 316L stainless steel.

The major components of the system are the ball strainer and the control system. For this installation a double screen orientation has been selected to be the most effective system for the strainer design. The ball separation is accomplished by two half-sized elliptical screens housed in a spool piece and held in a ridged position in relation to each other, within the full diameter of the pipe section. Each screen is mounted on a shaft and can be turned to the back wash position automatically (or manually) by an exterior motorized actuator. The two shafts and the motorized actuators operate independent of each other. The two screens are situated in a manner in which each screen makes a separate hopper with each half of the pipe's cross section area. The side blank off plates are attached to the pipe directly. These plates along with the two half-sized elliptical screens provide the hopper. In addition, specially designed baffle plates are installed directly on the pipe section and the screen surface at the area where the elliptical section of the pipe faces against the curvature of the pipe. The purpose of these baffles is to eliminate the acute sitting angle between the pipe and the screen. These baffles not only eliminate the potential for the presence of dead spots where the balls could be collected and lost during backwash, but they also create a vortex and turbulent flow that forces the balls to be lifted from the screen surface and forces them towards the collector at the exit point. After leaving the strainer sections, the balls pass through a special re-circulation pump which adds sufficient pressure to the small size re-circulation flow to overcome the heat exchanger and the recirculation piping pressure drop. The balls are pumped into the ball collector and are then distributed into the injection nozzles. The ball counts are continually monitored and displayed. The ball collector is used to automatically put the ball into or out of circulation. The balls are also kept in this chamber during strainer back washing. The collector also serves as a means to replace worn out balls or add replacement balls when needed.

The screen backwashing sequence automatically starts when the differential pressure across the screen reaches a preset level. This increase in the differential pressure is caused by debris and particles usually present in the circulating cooling water. The differential pressure across the screens is continuously monitored and displayed. All balls are automatically reserved inside the collector prior to any backwashing.

All functions and operations of the ball system are controlled and displayed by means of a single central control panel using a series of PLCs. It controls the operation of each screen, the pump and the collector. The control system offers total flexibility to operate the ball cleaning system on an automatic continuous or automatic batch intermittent cycle. The system can also be manually operated at the control panel.

Equipment Cost and Plant Performance and Savings

Equipment supply and installation was awarded to a U.S. manufacturer of this type of cleaning system on a "turnkey" basis. **The final lump-sum cost to deliver, install and start up the equipment for all four NCPA units was approximately $500,000.** The first two units for plant No. 1 have been in operation since mid summer of 1986. The systems for plant No. 2 were put into operation in March of 1987. The annual operating and maintenance costs for all four units is estimated at $3,500 per year.

Unit 2 ball system was first placed in service after the condenser was manually cleaned. Prior to ball injection the condenser C.F. was measured to be 68 percent. The designed C.F. by the manufacturer was specified at 70 percent for the same given heat load. As shown in Figure 2, after injection of the ball, by the end of the first week the C.F. reached 75 percent. By the end of the second week of operation the C.F. was increased to 85 percent. As of today the system has been in operation for over 9 months and the C.F. is still holding at better than 85 percent. Ball recovery has been quite good since operation began. Recently during a plant shutdown, the condenser tubes were inspected. The pattern of tube cleanliness observed, indicated that good ball distribution has been achieved.

Recently the Unit 4 ball system was placed in service with a severely fouled condenser. Within 30 minutes of placing the ball system in service for the first time, the back pressure dropped from 3 inches of Hga to 2.1 inches of Hga, at a constant load of 57 megawatt gross. Due to this back pressure improvement, a drop in the steam flow of 30,000 pounds per hour was observed.

Savings as a result of the ball system can be measured in two ways. The first is by reduced steam consumption due to improved turbine efficiency as a result of improved back pressure. NCPA price of steam is based on a formula tied to the Gross National Product Implicit Price Deflator Index (GNPIPDI) and to the annual operating budget of the NCPA geothermal project. The latest figure calculated is approximately $1.45 per thousand pounds of steam. The immediate dollar saving realized on Unit 4 due to reduction in steam consumption amounted to $43.57 per hour or approximately $1,000 per day. It should be noted that this is the worst case. Following a manual condenser cleaning, the steam consumption would slowly increase to the above mentioned worst case. **An incremental steam savings for all four plants indicated a savings of $949,000 per year.** This takes into account the clean condition of the condenser and as it fouled over a period of time. The second way to show savings due to the ball system is the elimination of shutdown for manual cleaning. As indicated in the earlier section, the savings due to eliminating the manual cleaning once every eight weeks amounts to $2,495,000.

Since NCPA plants were capable of full load operation with a dirty condenser, a savings due to load curtailment cannot be calculated. The cost in steam consumption takes into account the same type of savings that load curtailment would.

Conclusion

The use of a sponge rubber ball type on-line cleaning system at all four of NCPA's geothermal units has eliminated the condenser fouling problem. **The favorable payback is based on the total savings of $3,444,000 per year from installing such systems which has been evaluated against the $500,000 installed cost for all systems.** The system is proven to be effective, and reliable with minimal operator involvement.

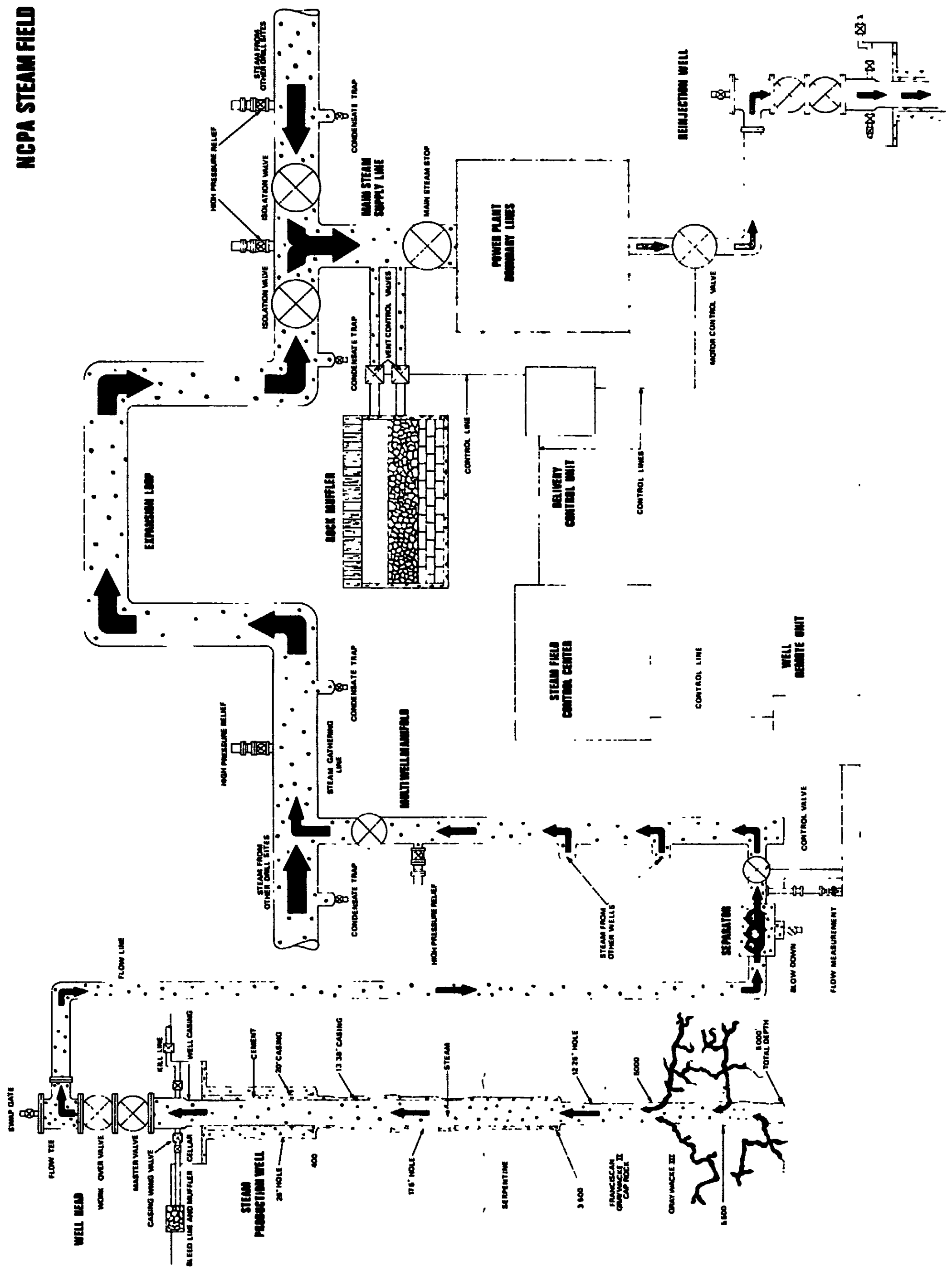

NCPA STEAM FIELD
EXPANSION LOOP
ROCK MUFFLER
DELIVERY CONTROL UNIT
STEAM FIELD CONTROL CENTER
WELL REMOTE UNIT
POWER PLANT BOUNDARY LINES
MAIN STEAM SUPPLY LINE
MULTIWELL MANIFOLD
SEPARATOR
REINJECTION WELL
STEAM PRODUCTION WELL
WELL HEAD

Fig. 1-A

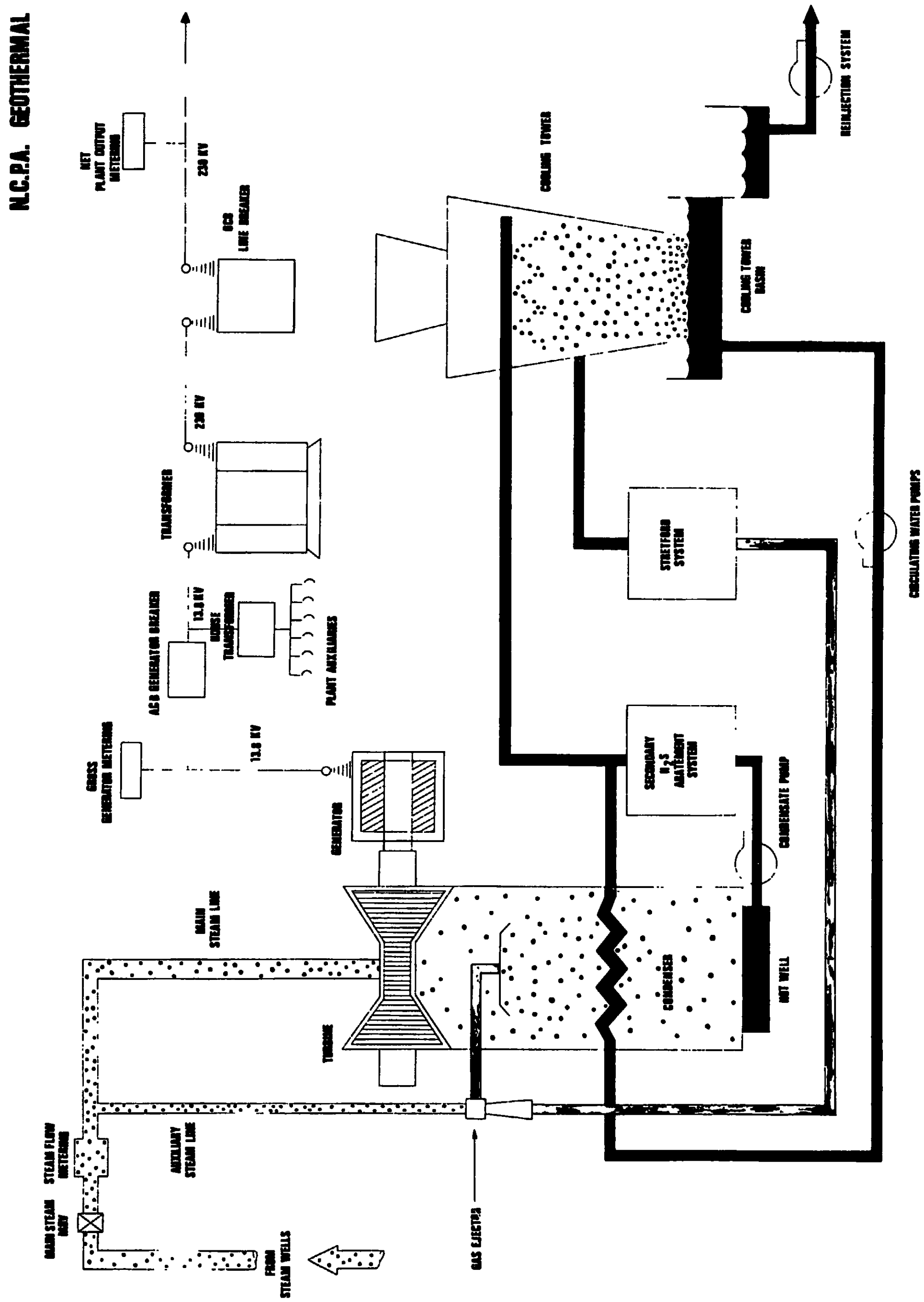

N.C.P.A. GEOTHERMAL
NET PLANT OUTPUT METERING
230 KV
OCB LINE BREAKER
TRANSFORMER
230 KV
ACB GENERATOR BREAKER
13.8 KV
HOUSE TRANSFORMER
PLANT AUXILIARIES
GROSS GENERATOR METERING
13.8 KV
GENERATOR
MAIN STEAM LINE
TURBINE
AUXILIARY STEAM LINE
STEAM FLOW METERING
FROM STEAM WELLS
GAS EJECTOR
CONDENSER
HOT WELL
CONDENSATE PUMP
SECONDARY H_2S ABATEMENT SYSTEM
STRETFORD SYSTEM
CIRCULATING WATER PUMPS
COOLING TOWER
COOLING TOWER BASIN
REINJECTION SYSTEM

Fig. 1-B

TABLE 1

NCPA GEOTHERMAL POWER PLANT OPERATING PARAMETERS

Unit No.	Date of Operation	Steam to Turbine Temp.F	Steam to Turbine P. Psig	Turbine Net Output Mwe	Turbine Steam Rate Lb/Kw Hr.	Steam to Gas Elector lb/hr	Steam to Gas Elector Psig	Condenser Design Back Pressure In. Hg Abs.	Condenser Cooling Water Flow Rate gpm
1 or 2*	Jan 1983	380	127	62	14.6	13,000	90	3.00	64,000
3 or 4**	Nov 1985	360	116	57	15.1	9,000	90	2.75	67,000

* Units 1 and 2 are identical and are located in Plant 1.

** Units 3 and 4 are identical and are located in Plant 2.

Steam moisture content and the removed non-condensibles are less than 0.1 percent and 0.4% respectively.

Fig. 1-C

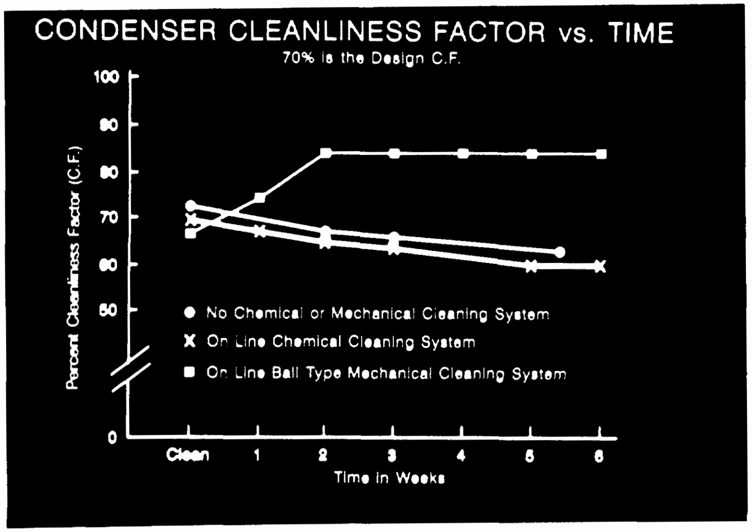


Fig. 2

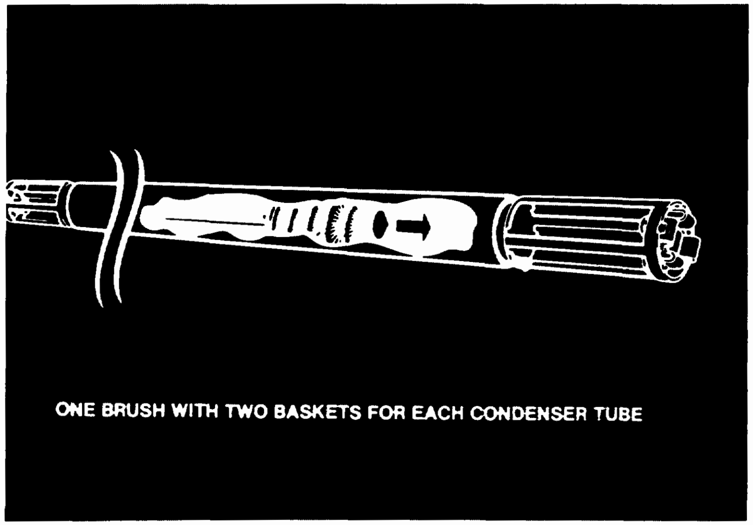


Fig. 3

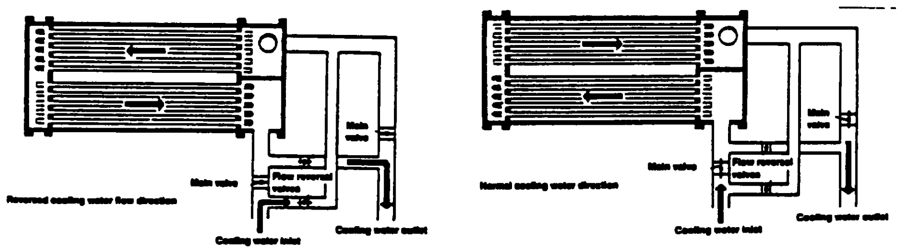


Fig. 4, Brush and Basket type cleaning system.

Source: R. Bell, et al., "State-of-the-Art Mechanical Systems for Scale and Biofilm Control." In Condenser Biofouling Control Symposium. Palo Alto, Calif.: Electric Power Research Institute, June 1985.

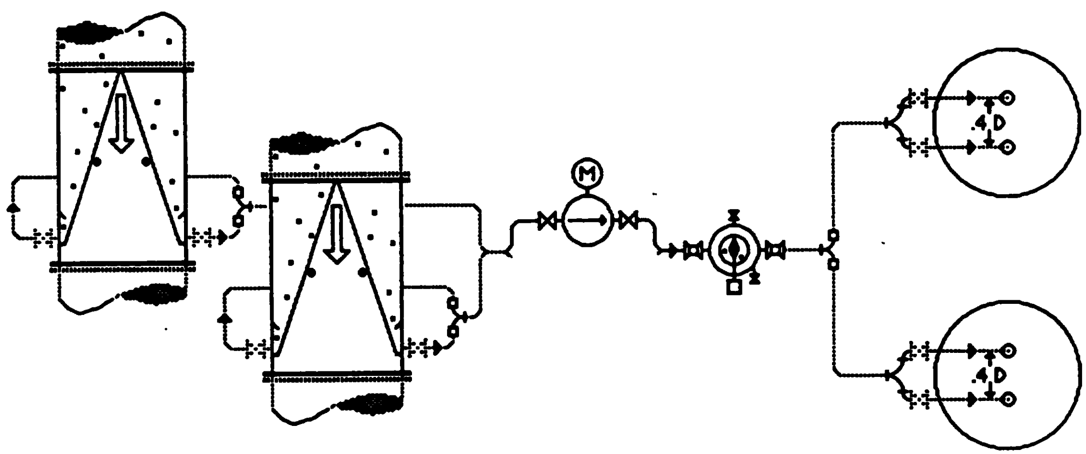
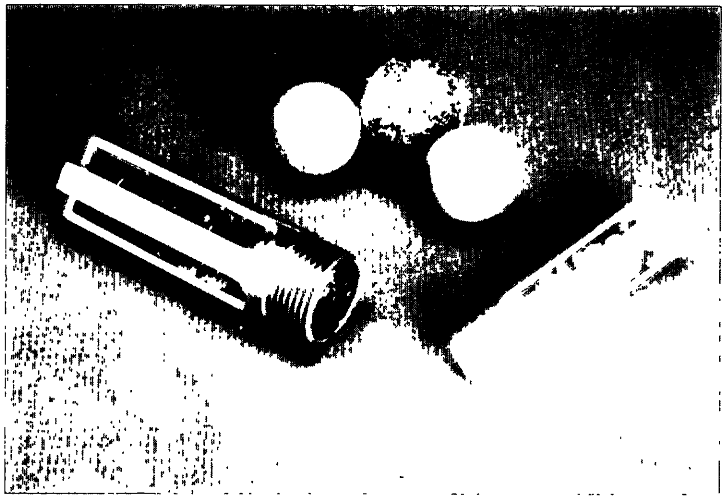
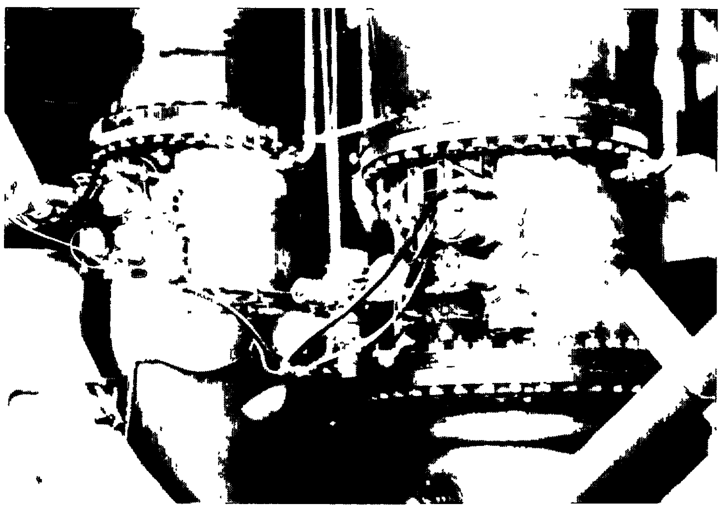


Fig. 5



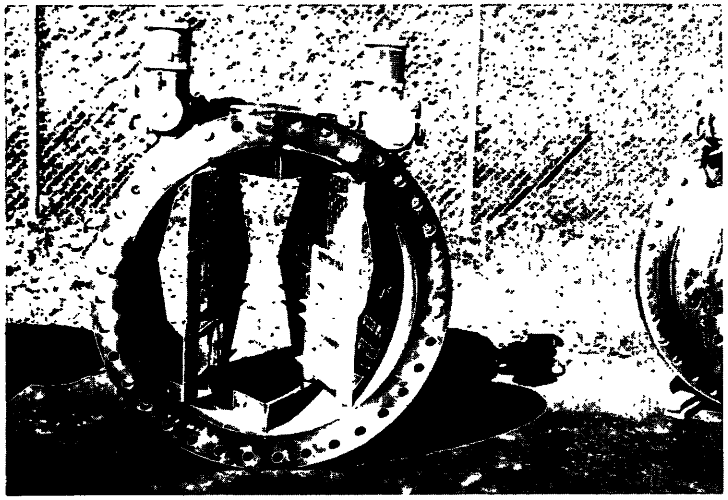
VARIOUS TYPES OF AUTOMATIC TUBE CLEANING SYSTEMS

TYPICAL BALL CLEANING SYSTEM INSTALLATION AND OPERATION

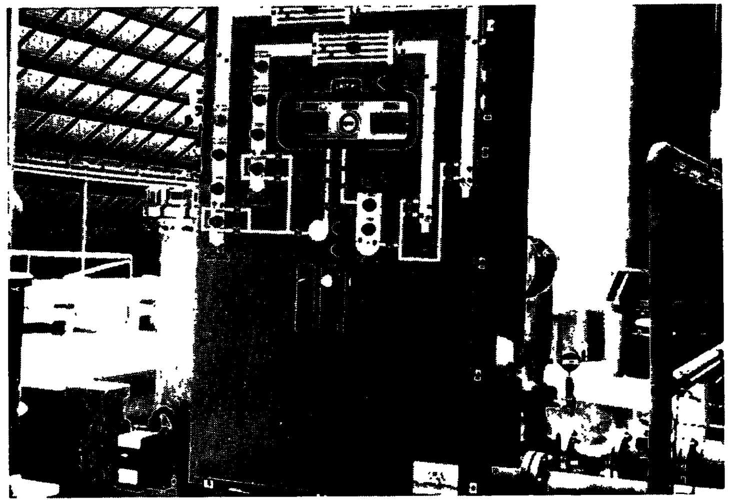


STRAINERS INSTALLED ON THE CONDENSER COOLING WATER RETURN LINES

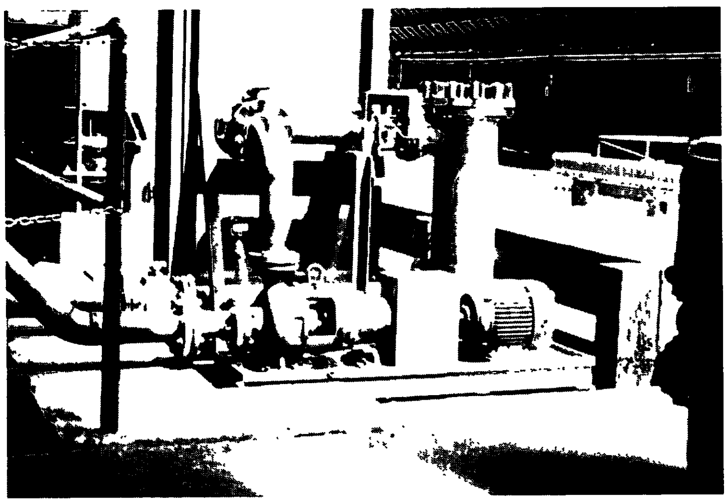
STRAINER IN A TYPICAL CLOSED POSITION TO COLLECT THE CIRCULATING BALLS



STRAINER IN A TYPICAL BACKWASH POSITION FOR CLEANING SCREEN SURFACES FROM DEBRIS



A TYPICAL CONTROL PANEL



BALL RECIRCULATION SYSTEM CONSISTING OF RECIRCULATION PUMP AND THE BALL COLLECTOR