LIFE MANAGEMENT OF FEEDWATER HEATERS AT KCPL

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ABSTRACT

In the late nineteen eighties, electric utility companies, such as Kansas City Power and Light (KCPL), recognized the viability of extending the life of power plants by repairing or replacing major components instead of building entirely new facilities. As part of a strong life management program, a life evaluation can postpone the replacement of major components to future years. A physical condition assessment is the first step in a life evaluation. It requires the following information: 1) Original design data; 2) Component operating data; 3) Knowledge of current industry practices; and, 4) Detailed component inspections. The second step in a life evaluation is an economic life assessment to ascertain the component's current loss of performance and projected life. The cost associated with operating the component in its current degraded state is then compared to the cost of repairing or replacing the component. Based on this cost comparison, a course of action is determined to optimize the component's life cycle cost. This paper describes the methodology of life management and its application to feedwater heaters at Kansas City Power and Light.

INTRODUCTION

Due to deregulation and increasing competition, it has become imperative for electric utilities to operate and maintain their facilities in the most cost effective way possible. Life management techniques have been used to evaluate the real cost of operating and maintaining feedwater heaters and thereby establishing whether it would be better to repair or replace them.

Life management of feedwater heaters has two aspects: 1) Physical condition assessment; and, 2) Economic life assessment. To assess the physical condition of a feedwater heater, both its maintenance and its operating histories, as well as its current level of performance, must be evaluated. The feedwater heater's failure mode is then determined by using a five-step approach. By fitting the feedwater heater's tube failure data with an exponential growth function, the useful life of the feedwater heater can be predicted.

After evaluating a feedwater heater's physical condition, an economic life assessment must be performed. Malfunctioning feedwater heaters can significantly affect power plant efficiency by increasing heat rate and/or decreasing generation capacity. Severe malfunction can even lead to a complete power plant unit outage. The cost associated with operating the feedwater heater in its current degraded state must be compared to the cost of repairing or replacing it. Based on this cost comparison, a strategy can be developed to optimize the feedwater heater's life cycle cost.

FAILURE MODES OF FEEDWATER HEATERS

Feedwater heaters can fail due to vibration, flashing of drain flow, inadequate level control, steam impingement, erosion, and/or corrosion. Failures have been identified in five major physical locations within feedwater heaters. These include the channel and tubes, as well as the desuperheating, condensing, and drain cooler zones.

Channel Failures

The high flow velocities on the channel side of a feedwater heater can erode the tube ends and the fillet welds connecting the tube to the tubesheet. Erosion and/or corrosion of the tube end seal weld can open a leak path between the tube hole and the tube. Bell and Diaz-Tous (1984) report that the French utilize significantly reduced inlet velocities, in the range of 1.8-2.0 m/sec, to control inlet end erosion.

Tube to tubesheet welds fail in their heat affected zone due to localized stresses. Operational, bending, torsional and tensile stresses also have the potential to propagate cracks in the welds (Yokell, 1995). Additional factors affecting tube joint failure include the following: 1) Joint type; 2) Hole preparation and drilling tolerance; 3) Tube to tubesheet configuration and joining method; 4) Tube expansion method; 5) Joint welding procedure; 6) Tube and tubesheet metal combination; 7) Pressure and temperature loading cycles; 8) Corrosivity of the tube side stream; and, 9) Tube entrance velocity.

Tube Failures

During the life of a feedwater heater, tubes can fail due to the following operational characteristics: 1) Variation in flow rate; 2) Water chemistry; 3) Corrosion; 4) Erosion; 5) Localized pitting on the tube surface; 6) Intergranular corrosion; 7) Galvanic corrosion associated with current flow; 8) Corrosion from oxygen formation; and, 9) Exfoliation of copper tubing. Tube failures in a feedwater heater can result from poor quality control during the manufacturing process. Factors of design and quality control that can result in tube failures include the following: 1) Tube position in the tube nest; 2) Impingement protection; 3) Tube support arrangement; 4) Variation in tube physical properties and chemical analysis from heat to heat, and tube to tube within each heat; 5) Residual tensile stresses in tubes which are subjected to stress corrosion cracking; 6) Corrosion and handling damage to tubes prior to installation; 7) Quality of u-tube bending and control of subsequent bend heat treatment; 8) Method of tube installation into the cage and tubesheet; and, 9) Baffle and support hole drilling;

Failures in the Desuperheating Zone

In the desuperheating zone, high steam velocities at the inlet can result in erosion of the shell, impingement plates, nozzles, baffle plates, shrouds and tubes. Erosion damage to tubes in the desuperheater may occur on either side of the inlet in the vicinity of the impingement plate. In addition, the practice of spot welding impingement plates rather than continuous welding results in greater residual stress and increases the probability of plate failure. Jacobstein et al (1981) discuss four causes of tube erosion due to steam impingement: 1) Impingement plate failure; 2) Poor impingement plate design; 3) Wet steam conditions in the desuperheating zone; and, 4) Dry steam entering the moist condensing zone at an excessive velocity.

Failures in the Condensing Zone

Tube damage just beyond the desuperheater exit can result from a wet wall condition. The wet steam can erode condensing zone tube supports by thinning their edges and enlarging the tube holes, which will create a vibration problem.

An inadequate drain inlet shield can cause tube erosion in the condensing zone on either side of the shield. Bell and Diaz-Tous (1984) report that tube damage can also occur due to high water velocity or flashing if the water level falls below the inlets of the normal and or emergency drains. In addition, inadequate venting of non-condensible gases can cause thermal performance reduction and long term corrosion in the condensing zone.

Failures in the Drain Cooler Zone

Steam entrainment in the drain cooler zone, which results from inadequate water levels in the feedwater heater, can cause tube erosion and vibration damage. Jacobstein et al (1981) report that level control problems may arise from the following: 1) Poor design of the level control system; 2) Poor maintenance of the level control system; and, 3) Inadequate normal water level.

Yokell (1995) states that uncondensed saturated steam entering the drain cooler zone, through the annular spaces between the holes in the end plate and the tubes, leads to the erosion of the holes in the end plate and baffles. Yokell (1995) also notes that failures in the vicinity of the tubesheet can result from insufficient venting of non-condensable gases.

PHYSICAL CONDITION ASSESSMENT

The objectives of a physical assessment program are to extend unit availability, minimize forced outages, identify and resolve heat exchanger problems, and predict remaining feedwater heater life (Krzywosz, 1995). The assessment of the physical condition of a feedwater heater can be performed by the following process: 1) Review maintenance, operation and design records; 2) Review current industry practices; 3) Perform visual examinations; 4) Perform non-destructive examinations; and, 5) Perform destructive examinations.

Maintenance, Operation and Design Records

The assessment of the physical condition of a feedwater heater starts with a review of available records and general operating information. Tracking the history of a feedwater heater from the first day of operation is very important. The design specifications and drawings from the original manufacturer of the heater are vital in analyzing the cause of failures and performance problems. Many failures are a result of inadequate feedwater heater design. Examples of this problem include inadequate protection against impingement at steam inlets, inadequate capacity to avoid flashing at the drain cooler inlet, and insufficient venting.

Another important document is a detailed tube plug drawing or map. Plug maps require notes regarding the date of the plugging, the location of the failure along the tube length, the reason for plugging the tube and pertinent information regarding events leading up to the tube failure.

Knowledge of the operation of the power plant and the feedwater heater system is also essential. The engineer must understand the various modes of plant operation and their impact upon the feedwater heater system. As depicted in Figure 1, feedwater heaters normally operate as counterflow heat exchangers. The feedwater first flows through the tubes of the feedwater heater that receive the lowest pressure extraction steam, then through those tubes that receive the highest pressure steam. The steam, after condensing, drains from the highest pressure heater to the lowest. In addition to normal operation, feedwater heaters can experience two other significant modes of operation: 1) Overload operation; and, 2) Low load operation.

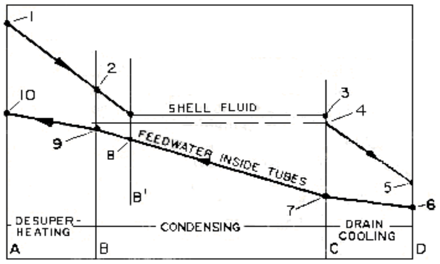

FIGURE 1. HEAT TRANSFER WITHIN A HIGH PRESSURE FEEDWATER HEATER DURING NORMAL OPERATION (Rabas et al, 1973)

Overload operation results in increased flow velocities which produce higher pressure losses than those predicted by the design specification (Yokell, 1995). These pressure losses are proportional to the velocity raised to the 1.8 power. The higher inlet flow rates also produce greater turbulence levels which result in more erosion and/or corrosion of the channels, tubesheets, tube ends, and pass partitions. In addition, the higher flow rates increase the possibility of shell-side, flow induced vibration and erosion of the shell and cage. However, the higher velocities do result in a reduction of tube fouling and an increase in heat transfer.

Low load operation may create a wet wall condition in which steam condenses on the exterior of the tubes in a desuperheater. Since the steam velocities are high in a desuperheater, the resulting high velocity condensate can lead to rapid tube erosion.

Current Industry Practices

A physical condition assessment program should take advantage of current technical developments within the power industry. Such information is available from the Heat Exchanger Institute, the Electric Power Research Institute, the American Society of Mechanical Engineers, and equipment manufacturers.

Visual Examinations

Visual inspections are the primary examinations in a physical condition assessment. This type of examination allows experienced engineers to estimate the length of time that a feedwater heater can operate in a cost effective manner. Utilizing the feedwater heater's failure and operating experience, as well as industry information, the engineer must identify and assess probable failure mechanisms.

Direct visual inspections of feedwater heaters are limited to channels, pass partition plate covers and the tubesheet feedwater face. With the use of a fiberscope or video probe, the interior of the tubes and portions of the shell can be viewed from a remote location.

Non-destructive Examinations

Non-destructive examinations are more expensive and time consuming than visual inspections, but necessary to accurately determine condition assessment. These examinations are an excellent method for predicting the remaining life of a feedwater heater. Non-destructive examinations include the following: 1) Eddy current testing; 2) Flux leakage testing; 3) Ultrasonic testing; and, 4) Sonic pulse testing.

Eddy current testing is the most common non-destructive examination used. Eddy currents produced in the tube walls are used to detect wall thinning, cracks, pits and other defects (Bell, 1995). Quantification of the defects, wall loss or pit depth can be determined by comparison of the measured signals to those obtained from standard artificially created defects. A sample representation of 10-15% should be adequate to characterize the condition of the feedwater heater (Bell et al, 1994). Eddy current testing is limited to non-magnetic and slightly magnetic alloys and it is time consuming.

Flux leakage testing, which is similar to eddy current testing, was developed specifically for the analysis of magnetic alloys (Bell et al, 1994).

Ultrasonic testing is used on thick walled tubing. This method uses reflected sound waves to very accurately determine wall thickness and material defects such as pits and cracks (Bell et al, 1994). The internal rotary inspection scan system, a form of ultrasonic testing which was developed for refineries, gives a complete picture of the tube wall. However, it is time consuming and expensive.

Sonic pulse testing, in which an acoustical pulse is transmitted from one end of a tube to the other, can be used to identify wall penetrations, obstructions and deformations of the tubes (Bell et al, 1994). The disadvantage of sonic pulse testing is its inability to distinguish the type and/or degree of the defect.

Destructive Examinations

When physical condition assessment requires destructive examinations, tubes are extracted for failure analysis. This analysis is performed by one or several of the following methods (Bell et al, 1994): 1) Atomic absorption; 2) Metallurgical chemistry analysis; 3) Measurement of significant mechanical properties; 4) Microbiological analysis; 5) Metallography; 6) X-ray diffraction; 7) Inductively coupled plasma spectroscopy; 8) Scanning auger microanalysis; 9) Electron spectroscopy for chemical analysis; and, 10) Infrared organic carbon and biochemical analyses.

ECONOMIC LIFE ASSESSMENT

The objective of an economic life assessment is to optimize a feedwater heater's life cycle cost. The economic life assessment of a feedwater heater can be performed by the following process: 1) Determine performance degradation; 2) Determine projected life; and, 3) Perform cost-benefit analysis.

Performance Degradation

Reliable feedwater heaters play a critical role in maintaining low heat rates and high availability. The North American Electric Reliability Commission identified feedwater heaters as one of the major components in power plants that show a trend of decreased availability with age (Bell and Diaz-Tous, 1984). Typically, diminished capacity is caused by fouling, bypassing in the channel, and surface area loss due to tube plugging.

As the number of tube plugs increases, the feedwater pressure drop across the heater also increases. If this pressure drop becomes too large, then it may be necessary to bypass a portion of the feedwater flow around the tube section. A bypass results in a decrease in heat transfer capacity.

Performance degradation of a feedwater heater is usually related to tube failures. Bell et al (1991) report that the tube failure rate in a feedwater heater increases exponentially with age. When the tube failure rate is allowed to reach the steep portion of the exponential curve, considerable outage time is incurred.

Two rules of thumb have been used to estimate performance degradation due to tube failure. The first rule ignores the failure of up to 10% of the tubes and then estimates that the percentage of performance degradation equals the percentage of failed tubes over 10%. The second rule estimates that the percentage of performance degradation equals the percentage of failed tubes.

Recently, Ranganathan et al (1995) developed the Heat Exchanger Workstation (HEW), a computer model to analyze the thermal performance and evaluate the failures of feedwater heaters. Based upon the feedwater heater's design specifications, HEW can be used to calculate the heater's design performance. Then by utilizing current operating data, HEW can be used to evaluate the heater's current operating performance. The feedwater heater's performance degradation can then be determined by comparing the design performance to current operating performance.

Projected Life

As discussed above and illustrated in Figure 2, the tube failure rate in a feedwater heater increases exponentially with age. Therefore, to reduce the potential for costly maintenance, it is imperative to predict when the tube failure rate will enter the steep portion of the curve. This prediction will provide lead time to plan for the replacement or refurbishment of the feedwater heater. Prediction is accomplished by fitting an exponential growth function to the feedwater heater's historical tube failure data.

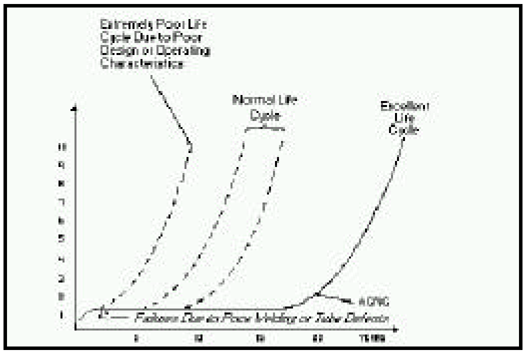

FIGURE 2. HIGH PRESSURE HEATER CARBON STEEL TUBE LIFE CYCLE (Bell et al, 1991)

Linley (1988) identified six operational and maintenance activities which could be performed to extend the life of a feedwater heater. These activities include the following: 1) Resolve failures efficiently; 2) Vent non-condensable gases; 3) Chemically treat feedwater; 4) Maintain adequate shell liquid level; 5) Establish physical condition assessment program; and, 6) Develop an accurate life projection method.

Cost-benefit Analysis

A feedwater heater has exceeded its useful life when its effect on a power generating unit's heat rate and availability becomes more costly than refurbishment or replacement. The economics of replacement includes evaluation of capital expenditure versus maintenance expense. Replacement always appears to be a quicker, easier choice but may not be the most cost effective. In the last several years, KCPL has retubed or replaced several high pressure and low pressure feedwater heaters. Significant data has been accumulated on the cost of these refurbishment and replacement projects. From this data, KCPL has determined that the costs associated with refurbishment of a feedwater heater are about half those of a full replacement. These costs include the following: 1) Either tube material or a new feedwater heater; 2) Valves and piping; 3) Insulation; 4) Control equipment; 5) Installation; and, 6) Project management.

At KCPL, in order to justify a $1,000,000 capital investment within a 10 year timeframe, benefits of $235,000 per year must be realized. These benefits are determined as the sum of the following costs on an annual basis: 1) Maintenance; 2) Predicted performance loss; 3) Down time; and, 4) Bypassed feedwater flow. Greater annual maintenance and heat transfer surface loss become acceptable as benefits required for replacement justification increase. Pearce and Willsie (1995) state that performance of feedwater heater maintenance, while the generating unit is on-line, greatly reduces down time cost and thereby extends the useful life of the feedwater heater.

CASE STUDY

The United States Energy Information Agency estimates that in the year 2010, the average age of the coal fired power plants in the United States will reach 36 years (Beckerdite, 1991). In 2010, the average age of the coal fired power plants operated by KCPL will be 39 years. In the late-eighties, KCPL began developing a life assessment and management program to study the major systems affecting the availability, reliability and efficiency of KCPL's power plants. This program analyzed KCPL's $33.5M worth of feedwater heater equipment and determine that most of the scheduled feedwater heater replacements could be delayed for a minimum of 5 years. This case study will focus on the La Cygne power plant, Unit #2, first point extraction, high pressure feedwater heater #21. This three zone horizontal hemi-head heater has a well documented maintenance history.

Physical Condition Assessment

In 1986, after nine years of operation, this feedwater heater had only one u-tube plugged. An eddy current test was performed in 1986 which revealed no significant tube wall loss. By October of 1987, 17 tubes had failed above the drain cooler inlet at a depth of 7 to 7 1/2 feet from the face of the tubesheet. A flux leakage analysis of about 10% of the u-tubes was performed approximately 2 years later which still indicated no tube wall loss.

In the spring of 1988, a maintenance project was initiated to improve the physical condition of this feedwater heater. This project included the following: 1) Review of previously plugged u-tubes; 2) Restoration of plugged u-tubes to operating service where possible; 3) Reduction of tube to tubesheet joint leakage by explosive sleeving; and, 4) Explosive expansion of tube ends to full tubesheet thickness. At the conclusion of this maintenance project, 20 tubes remained plugged and tube leaks continued to occur at periodic intervals.

By June of 1989, the number of failed tubes had grown to 30 of the 1568 total tubes. Tubes failed at an unacceptable frequency during May and June of 1990. In order to restore the heater to an acceptable level of operation, 49 u-tubes were insurance plugged. By mid-August of 1990, there were 129 u-tubes plugged, which was 8.2% of the total.

At this time, several options were evaluated to extend the life of this feedwater heater. Since most of the failures occured in the circumferential area of the tube bundle, a partial retube was found to be the most economical. In 1991, the partial retubing of 219 u-tubes in the area directly above the drain cooler inlet was completed and the heat transfer duty was restored. The intent of the partial retube was to extend the life of the feedwater heater for another 5 years.

During 1992, u-tubes were plugged at various locations within the drain cooler zone. In 1993, there were joint leaks in the retubed area of the drain cooler zone. To restore that area, 28 tube ends were rerolled and seal welded. During August and September of 1994, the feedwater heater was out of service for a total of 43 days.

Economic Life Assessment

By the fall of 1994, 4.5% of the u-tubes had failed and the feedwater heater was deteriorating rapidly. At this time, the useful life of the feedwater heater was predicted by using an exponential function to fit the tube failure data. As shown in Figure 3, this prediction indicated that 10% of the tubes would be out of service by September of 1995.

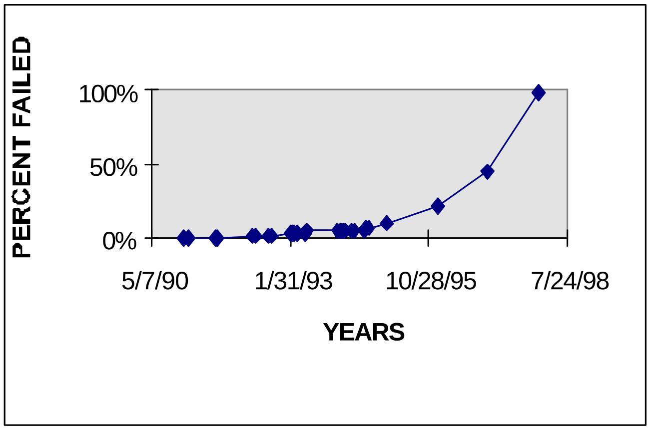

FIGURE 3. PREDICTED TUBE FAILURES FOR FEEDWATER HEATER #21

A cost-benefit analysis was performed to determine the feasibility of replacing the feedwater heater. The replacement project cost was estimated to be $1,144,000. This included a new heater built on site, new controls, valves, insulation, installation, and engineering services. To justify this replacement cost, benefits of $247,766 per year were required.

As shown in Table 1, the benefits were determined from the annual costs associated with the maintenance, performance degradation, and down time. The maintenance benefit is the average of the last three years of annual maintenance expenditures. The performance degradation benefit is the product of the heat transfer surface loss times the operation cost. The heat transfer surface loss is calculated by using the three methods discussed above in the Performance Degradation section. The operation cost is the product of three factors: 1) Power plant unit capacity factor; 2) Fuel cost; and, 3) Number of hours of operation per year. The down time benefit is the product of four factors: 1) Fuel cost; 2) Net

TABLE 1. BENEFIT ANALYSIS

	Method #1	Method #2	HEW Method
Maintenance cost benefit	\$60,381/yr	\$60,381/yr	\$60,381/yr
Effective number of tubes plugged	2%	12%	12%
Heat transfer surface loss	8, 109,220 Btu/hr	48,655,320 Btu/hr	10,500,000 Btu/hr
Operation cost	\$5000 hr/Btu x 10^{6}-yr	\$5000 hr/Btu x 10^{6}-yr	\$5000 hr/Btu x 10^{6}-yr
Performance degradation cost benefit	\$40,100/yr	\$240,600/yr	\$52,500/yr
Percent down time	33%	33%	33%
Down time cost benefit	\$137,849/yr	\$137,849/yr	\$137,849/yr
Total cost benefit	\$218,330	\$438,830	\$250,730
Benefit/cost ratio	.88	1.77	1.01

generation of the power plant unit; 3) Percentage down time incurred during the past year; and, 4) Heat rate penalty directly associated with the feedwater heater. As shown in Table 1, the benefit/cost ratio is calculated for the three methods. The numerical values utilized in the calculations shown in Table 1 were derived from the operational history of KCPL's La Cygne power plant Unit #2.

During 1994, maintenance expenses were nearly $68,000 and the heater was out of service for over 85 days. In September of 1995, the feedwater heater was replaced with an upgraded heater using T-22 carbon steel tubing. By that time, 12% of the u-tubes had failed.

CONCLUSIONS

This paper has focused on the methodology of life management of feedwater heaters. This methodology includes physical condition assessment and economic life assessment. The physical condition assessment of a feedwater heater depends upon a thorough analysis of records, technical developments and examinations. The economic life assessment of a feedwater heater includes determination of its performance degradation and projected life as well as a cost-benefit analysis of its replacement.

As illustrated in the case study, the application of this methodology has enabled KCPL to extend the useful life of feedwater heaters and thereby postpone large capital expenditures.

This paper has also presented a summary of the failure modes of feedwater heaters.

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