“FEEDWATER HEATER REPLACEMENT ANALYSIS AND JUSTIFICATION”

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INTRODUCTION

As older fossil fuel and nuclear utility plants receive life extensions, many components such as feedwater heaters (FWH) are operating longer than the original designers expected. Often, plant managers are faced with the prospect of continuing to operate with a problem FWH or to replace it with a new one. As consultants, we are often asked to project remaining useful life of a heater and to make a recommendation whether to replace a FWH or not. As heaters age and fail, engineers are challenged to economically justify decisions to either repair or replace problem heaters. Even when replacement is deemed imminent, determining the most optimum schedule to replace, involves another set of variables to consider.

The determination of FWH remaining useful life is very subjective, since most assessment techniques can only state for certain the current condition of the heater, and not predict the future. For instance, even a heater with a relatively low amount of pluggage can fail catastrophically if subjected to the wrong conditions. Typical trends in plots of current number of tubes plugged versus time depict a flat incubation period, and then at some point, the rate of failure increases exponentially.

Therefore, the decision of “if and when” to replace a FWH must be quantified in terms of economics. This is a more practical method, and one that is better understood and accepted by Utility management. Such an evaluation is typically driven by two factors, 1) the risk and potential ramifications of continuing to operate with an older/damaged FWH and 2) replacement heater cost. In order to evaluate both factors, the risk must be expressed as a financial value so that it can be properly accounted for in the economic analysis. Quantifying the risk shall be addressed later; first it is important to understand the basic economic principles of net present value. This is the Industry accepted method of how these cases are normally presented to Utility Management.

ECONOMIC ANALYSIS

Net present value (NPV) or net present worth (NPW) is defined as the total present value of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects. For each option available, the total of the expected costs in each future year is discounted back to its present value at an assumed rate of return, and then they are summed. Typically, the option with the lowest NPV is selected.

NPV can be expressed as the sum of the terms $C_t / (1+i)^t$ where:

t = the year of the cash flow
C = sum of cash flow for future year t
i = the discount rate (rate of return)

Many spreadsheet programs have the ability to automatically calculate NPV, and are typically used in such evaluations. Therefore, the question for the plant engineer/manager becomes one of how to estimate the costs of a replacement FWH project as opposed to how to estimate the cost of not replacing a FWH over future years. Each of these are addressed below.

REPLACEMENT FWH GUIDELINES AND ESTIMATING COSTS

It is typically difficult for Plant Engineers to justify replacement of a problem FWH based solely on reduced thermal performance. Except for the first point heater, it is almost impossible to equate the incremental loss in heat rate cycle efficiency to the total replacement heater cost. Loss in individual heater thermal rise will always be made up by the next downstream heater, minimizing the effect on the overall cycle.

Historically, FWHs were considered for replacement when about 10% of its tubes became plugged. This was an accepted “rule of thumb” utilized by most utility generating plants. Over the years the industry has learned that, while the percentage of tubes plugged is important, there are other factors that must be considered as well. The magnitude and severity of experienced tube failures, the rate at which failures are occurring, the overall age of the heater, the condition of pressure boundaries such as the heater channel and shell, as well as the deterioration/failure of other internal components such as the shrouds, baffles and tube supports, are all important elements that need to be evaluated and in some way quantified. Another important consideration sometimes overlooked, is the evaluated susceptibility for continued problems that can directly affect overall heater reliability. This can only be qualified by an in-place, comprehensive Failure Cause Analysis (FCA) program. One must establish root causes and contributing factors to damage and failures to determine if any remedial actions are possible to preclude future failures. Sometimes it is simply inherent in the heater design and/or the materials of construction for the given application. In any event, a FWH is normally considered for replacement when the risk to continue operating it becomes too great, either from a financial standpoint or a safety standpoint.

The results of the FCA program should help dictate the need for design and material improvements in the technical specification for the replacement FWHs. In many cases, this results in a change to the tube material of the heater, and as a result, to the overall heat transfer surface and physical size of the heater. This is especially true for older FWH designs in some plants where low-pressure (LP) FWHs tubed with copper bearing alloys are typically being replaced with heaters tubed with TP-439 ferritic or TP-304L stainless-steel tubing in order to arrest copper carryover into the turbine. In high-pressure (HP)

FWHs, older carbon steel tubed FWHs are being replaced with T-22 alloy steel or specific grades of stainless-steel tubes.

The overall performance requirements may have also changed. Many units, both fossil and nuclear have been or are currently planned for uprated conditions, which include turbine modifications to increase load and efficiency, with consequential higher duties imposed on the feedwater heater strings. Higher heater loading, changes in modes of operation and new design guarantee points present other variables that also must be considered as a part of the replacement heater evaluation program. In some cases, performance uprates provide added incentive to help justify more reliable replacements sooner, rather than later. Sometimes replacement of an older genre FWH with a more robust state of the art design can help improve overall plant heat rate and generate slightly higher Unit loads. If this is the case, then this savings and/or higher revenues should also be considered in the economic analysis.

When evaluating the cost of a replacement FWH, it should first be decided if a tube material change will be required, as that can have a significant impact on the size of the replacement heater. If there is little available space for growth of heater, then the guarantee design point of the heater may have to be adjusted in order to meet the physical constraints. In some cases, size restrictions could require a slight reduction in thermal performance (temperature rise across the heater or TTD) as a trade-off to using a less susceptible tube material, in exchange for better heater reliability over the long term. Given the original heater data sheet and the new desired tube material, FWH rating engineers are able to calculate the required surface area and physical size for the replacement heater. Typical budgetary replacement cost for a FWH can be estimated by the total surface area required. For example, recent estimates by manufacturers of state-of-the-art HP FWHs are in the ballpark of \$50 to \$75/ft^2 for T-22 Alloy steel tubes, while some LP stainless steel tubed FWHs have been recently approximated at \$40 - \$65/ft^2. The price can vary widely depending on the type of unit (fossil or nuclear), channel closure (full access or hemi head) and materials of construction. Of course, the cost of the replacement FWH is only part of the total replacement project. The total budgetary amount must also include the removal of the existing heater and installation of the new heater. This is always Plant and Unit specific; however, a typical installation cost may be close to if not exceed the cost of the replacement heater. Therefore, if the replacement heater costs \$1,250,000, then the cost to remove the exiting heater and install the new one is estimated as an additional \$1,250,000. However, this value can be significantly lower or higher depending on such details as Nuclear vs. Fossil, HP vs. LP, horizontal vs. vertical, the external limits and hindrances at the job location, the complexity of the overhead crane lift, the required rigging, available space, and any required modifications in piping-up the replacement FWH.

A few other associated costs that should not be overlooked when budgeting for the replacement project involve estimating any desirable system modifications, and/or control hardware and instrumentation improvements. Also, costs for contracted consultants providing technical staff support functions and quality assurance inspections and evaluations should also be an integral part of the overall replacement project budget.

With regard to lead-time and project schedule, FWH manufacturers are currently able to provide delivery of new FWHs in about 12 months. This lead-time could be longer depending on current tube delivery schedules. This should be taken into account when planning for FWH replacement, and the replacement technical specification document should be finalized about 14 months prior to when the heater is required to be on site, allowing about 2 months for the solicitation and evaluation of bids, and the selection of the successful Vendor. Major planned outage schedules are another important consideration (i.e. time required to change-out the heater(s) vs. planned outage window available). The duration of the planned outage must be of sufficient length to support the change-out and all the associated modifications, etc. Even prerequisite items such as crane availability within the outage schedule can become a significant issue in planning when to replace.

RISKS OF NOT REPLACING A PROBLEM FWH

When confronted with the potential need to replace a FWH, usually the short-term alternative option is not to replace it now; hoping that by conducting immediate repairs as required, one could postpone the replacement for a period of time. It may be impractical to assume that this approach could be successfully used repeatedly over the remainder of the expected Plant/Unit life. Depending on the history of the FWH, there could be several risks in delaying its replacement. When evaluating risk, typically the two ends of the spectrum are evaluated, what is the most probable outcome, and what is the most severe outcome. Usually for a FWH, the most severe outcome is catastrophic failure that results in the heater being condemned, or unreliable and unavailable. Depending on the FWH’s location in the cycle and the limitations of the system configuration, this can have significant financial impact on the generating Unit. The most probable events are typically based on the heater’s maintenance history, and understanding the active failure mechanisms that exist inside the heater. In some cases, the Station may have no idea of active mechanisms or root causes for the heater failures they are experiencing. Under these circumstances, risks for continued operation are a “crap-shoot” and are purely speculative at best.

When trying to determine overall risk, it is helpful to develop a matrix which evaluates the severity and probability for several different scenarios. An example matrix is offered as follows:

Probability Severity	Likely to occur immediately	Probably will occur in time	May Occur in time	Unlikely to Occur
Catastrophic Failure/Personnel Safety	6	5	4	3
Major Failure to FWH/ Major Revenue Loss	5	4	3	2
Minor Failure to FWH/ Minor Revenue Loss	4	3	2	1

Typically, if the combination of the two factors (severity and probability) is too high, then the risk is too great. In the above matrix, it may be decided that a scenario that has a score of 4 or higher may be too risky unless other methods are put into place to mitigate the risk. If this is not possible, then the heater should be replaced.

Note that risks should also include abnormal modes of operation when the Unit is forced to run with specific heaters or heater strings out of service. Overload impositions on the Boiler, Turbine and upstream and downstream FWHs must be considered and in some ways quantified financially. This is discussed in more detail in later subsections.

If the risk to continue to operate the FWH is safe and acceptable, then a financial estimate of those risks should be made in order to evaluate the cost to repair versus the cost to replace.

TYPICAL MAINTENANCE / INSPECTION COSTS

Plant management must become familiar with the FWH’s maintenance history and typical maintenance costs. Obviously, forced outage maintenance work is much more expensive than the same performed during planned outage situations. This is especially true for all base-loaded Nuclear plants. Emergency work typically performed over reduced-load timeframes must also contend with issues related to whether it is safe to work within the confined space of a leaking FWH with the Unit still on-line. Utility plant policies have varied greatly on this issue over the years, however, it appears that lately most Utilities will not allow their station mechanics to work inside these channels without a double block and bleed isolation valves configuration on the feedwater side. For this reason, isolated heater strings containing at least one leaking FWH may sometimes be forced to remain out of service for a longer period of time, awaiting the next available opportunity to take the whole Unit off-line to repair a single tube leak. The costs and risks associated with this type of forced mode of operation must be quantified and a part of the overall financial evaluation.

Also, the actual maintenance cost to plug one tube can vary widely, depending on the orientation, access and type of plug used. For example, FWH’s that have a welded torus ring or welded diaphragm for channel access typically will cost more per maintenance incident to open and close than a heater with a bolted and gasketed access. Costs associated with manway access heaters are also different than full access channels. Additionally, if explosive plugging is required, this usually requires mobilization of a crew from a licensed/approved vendor, the cost of which can vary greatly depending on how much notice is given to the vendor and how far they must travel. Most people estimate that a single tube failure can cost anywhere from $5,000 to $20,000 to repair, just in direct maintenance costs.

Some utilities conduct routine condition assessment evaluations such as ECT and visual inspections on a predetermined schedule, while others only conduct such evaluations based on necessity. Regardless, the lifecycle maintenance costs should also be considered when evaluating repair versus replacement options, typically, older FWHs require much more frequent inspections, whereas new heaters can be expected to last between 5 to 10 years before any significant maintenance/inspections occur. Again, depending on the utility’s location and vendors the costs for such inspections can typically range anywhere from $10,000 to $40,000, depending on the tube material, heater access and amount of the heater to be tested.

If a FWH develops a significant internal problem which requires a part of the shell to be removed and then rewelded in the field, it is not uncommon for such maintenance activities to exceed $100,000 in cost.

A somewhat simplistic method to estimate the annual maintenance costs for a problem in future years is to come up with a weighted average for different maintenance costs based on probability.

ADDITIONAL COSTS ~ OPERATING WITH FWH'S OUT OF SERVICE

Depending on the location of the FWH within the heat cycle (i.e., LP vs. HP) and the plant specific configuration of the FWH (i.e., single string vs. dual string), the impact of operating with a FWH out of service can vary greatly. If the FWH does not have an individual bypass, and requires that a full string of FWHs be placed out of service when a failure occurs, this can result in a load reduction and lost revenue for the plant. There may be turbine load limitations applicable for certain combinations of FWHs out of service. Additionally, the loss of a FWH may result in an overload condition on the remaining FWHs or over-firing of the Boiler due to colder inlet temperatures. All of these potential limits and restrictions that ensure the safe non-damaging operation of continuing to run with certain heaters unavailable need to be identified, and quantified. A cost estimate for these potential additional expenses should also be included in the economic analysis. These costs can be estimated by assuming that the existing FWH will fail or be non-operational for a certain number of days or percentage of time throughout the year. In the case where this results in a load reduction, then the number of lost MW times the sales rate per MW should be used. In the case where an overload condition on other FWHs or over-firing of the Boiler occurs, then it may be prudent to estimate the need for additional maintenance on those components due to the FWH being out of service. Many of these estimates will be plant specific and should be determined with the assistance of operations managers and performance engineers. Where applicable in instances of load deduct potentials, penalties for replacement power costs should also be included in the economic analysis.

CASE STUDY

A 345 MW fossil unit consists of a single HP FW string, #5, #6 and #7 HP FWHs, with #7 being the top point heater. Each FW heater may be individually bypassed. The #7 FWH is 20 years old with carbon steel tubes, is approximately 8% plugged. The Unit is only expected to operate for an additional 20 years. Management needs a decision whether to replace the heater now or continue to operate the FWH until end of unit life.

It is estimated that a replacement #7 FWH will cost approximately $1,180,000. With no major anticipated problems an additional $1,250,000 is estimated to install the replacement. It is also estimated that the replacement of the #7 FWH will result in a 2 degree increase in Economizer inlet temperature which would result in a savings of approximately $29,000 per year.

If the heater is not replaced, it is estimated that the FWH may experience 2 maintenance events per year. Based on historical data, it is estimated that there is a 75% chance that the heater may develop a tube leak, which usually costs the plant $20,000; A 20% chance that several leaks may develop, resulting in the need to also perform ECT, visual or other non-destructive testing, which usually costs the plant $70,000, a 4% chance that the shell may become thinned, requiring a patch repair, that is estimated at $130,000, and a 1% chance that a significant internal problem could occur that requires removal of the shell for access and repairs, estimated at $250,000. As discussed earlier, it may be convenient to estimate the future maintenance costs based on an average value of 0.75*20,000 + 0.20 * 70,000 + 0.04*70,000 + 0.01 * 250,000 or $36,700 per event, which results in $73,400 for the year. These costs are expected to increase by 10% every 5 years. If a new heater is purchased, it is expected to have no maintenance events for the first 10 years, 1 event per year from years 10-15 and 2 events per year for years 15-20.

For cost projection purposes, the #7 heater is estimated to be out of service 10% of the time for the first year, and then increases 1% per year up to an estimated 30% in year 20. With the #7 heater out of service, over-firing of the boiler results in increased fuel costs of $3000 for each percent of the time the heater is out of service (i.e. $30,000 in year one). Additionally, if the #5 or #6 heater is also out of service, the unit must be derated by 30MW. This is estimated to occur 1% of the time for the first year up to a total of 5% in year 20. This loss in load is estimated to be about $50,000 in year one and increases proportionally. If the heater is replaced now, similar costs are expected to accrue starting in year 16.

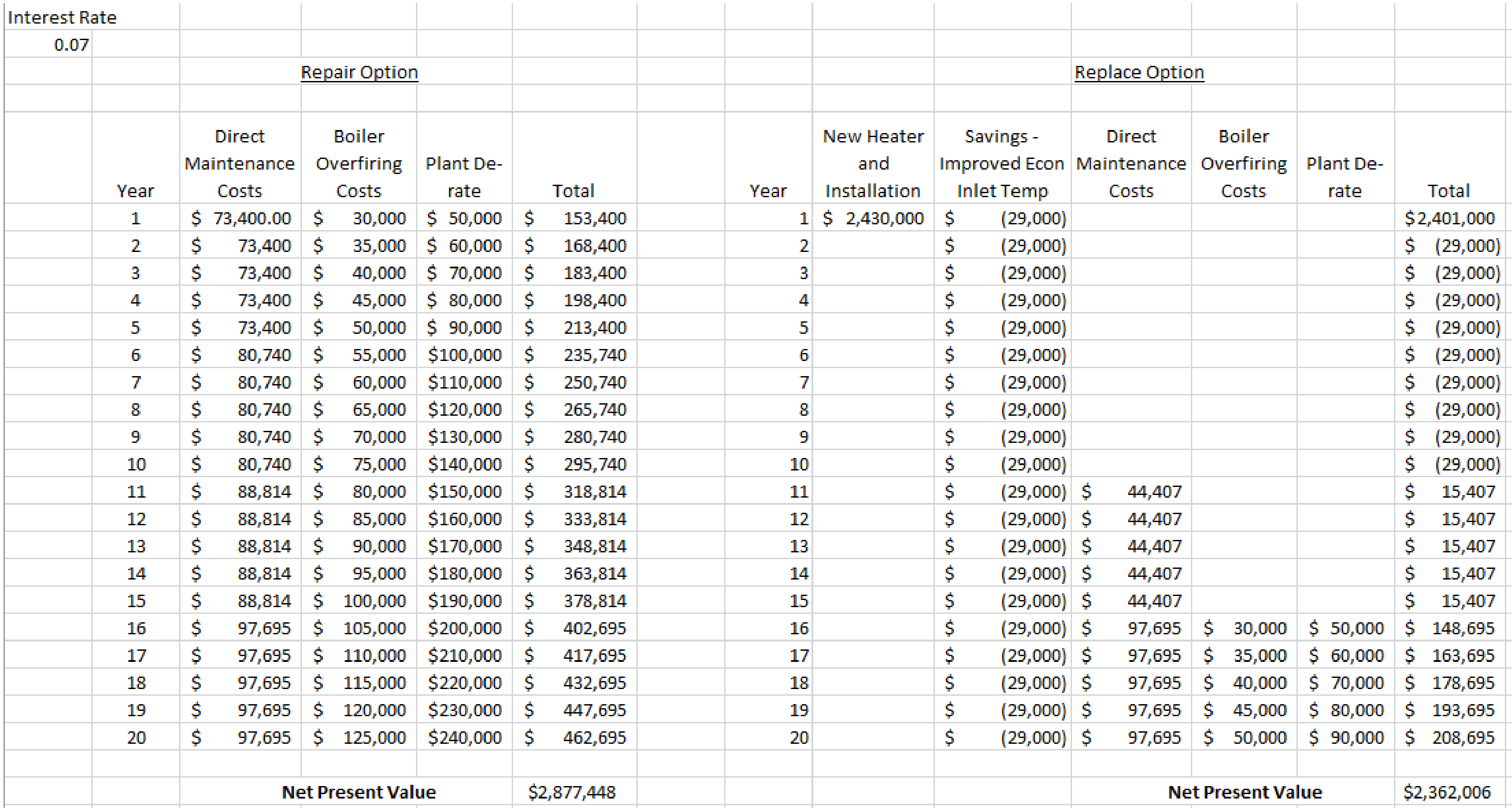
The above data may be placed in a spreadsheet as shown in Figure 3. From the economic analysis, it can be seen that it is less expensive in the long run to replace the heater instead of continuing to operate with the exiting heater.

CONCLUSION

Several factors must be taken into account when determining whether to continue operating a troublesome and unreliable FWH, or replace it. Economic analysis can often be used to determine potential cost savings to the utility by replacing a FWH sooner rather than later, however, a full understanding of the maintenance and operating costs may be required. A comprehensive program that includes periodic condition assessment in support of failure cause analysis should be implemented so that an analysis of all of the associated risk elements related to continued operation can be quantified. Increasing operational and maintenance costs projected over time, will help to justify the need to replace a FWH, and future outage window limitations will provide the optimal and most practical scheduling parameters for the FWH change-out. The determination of the contributing factors associated with failure events and their root causes will provide the basis for required design modifications and adjustments for materials of construction to prevent similar failures from occurring in the replacement.

Figure 1 – A FWH with 28% tubes plugged

Figure 2 – Unloading a Replacement FWH



Interest Rate
0.07

	Repair Option						Replace Option					
Year	Direct Maintenance Costs	Boiler Overfiring Costs	Plant De-rate	Total		Year	New Heater and Installation	Savings - Improved Econ Inlet Temp	Direct Maintenance Costs	Boiler Overfiring Costs	Plant De-rate	Total
1	$ 73,400.00	$ 30,000	$ 50,000	$ 153,400		1	$ 2,430,000	$ (29,000)				$2,401,000
2	$ 73,400	$ 35,000	$ 60,000	$ 168,400		2		$ (29,000)				$ (29,000)
3	$ 73,400	$ 40,000	$ 70,000	$ 183,400		3		$ (29,000)				$ (29,000)
4	$ 73,400	$ 45,000	$ 80,000	$ 198,400		4		$ (29,000)				$ (29,000)
5	$ 73,400	$ 50,000	$ 90,000	$ 213,400		5		$ (29,000)				$ (29,000)
6	$ 80,740	$ 55,000	$100,000	$ 235,740		6		$ (29,000)				$ (29,000)
7	$ 80,740	$ 60,000	$110,000	$ 250,740		7		$ (29,000)				$ (29,000)
8	$ 80,740	$ 65,000	$120,000	$ 265,740		8		$ (29,000)				$ (29,000)
9	$ 80,740	$ 70,000	$130,000	$ 280,740		9		$ (29,000)				$ (29,000)
10	$ 80,740	$ 75,000	$140,000	$ 295,740		10		$ (29,000)				$ (29,000)
11	$ 88,814	$ 80,000	$150,000	$ 318,814		11		$ (29,000)	$ 44,407			$ 15,407
12	$ 88,814	$ 85,000	$160,000	$ 333,814		12		$ (29,000)	$ 44,407			$ 15,407
13	$ 88,814	$ 90,000	$170,000	$ 348,814		13		$ (29,000)	$ 44,407			$ 15,407
14	$ 88,814	$ 95,000	$180,000	$ 363,814		14		$ (29,000)	$ 44,407			$ 15,407
15	$ 88,814	$ 100,000	$190,000	$ 378,814		15		$ (29,000)	$ 44,407			$ 15,407
16	$ 97,695	$ 105,000	$200,000	$ 402,695		16		$ (29,000)	$ 97,695	$ 30,000	$ 50,000	$ 148,695
17	$ 97,695	$ 110,000	$210,000	$ 417,695		17		$ (29,000)	$ 97,695	$ 35,000	$ 60,000	$ 163,695
18	$ 97,695	$ 115,000	$220,000	$ 432,695		18		$ (29,000)	$ 97,695	$ 40,000	$ 70,000	$ 178,695
19	$ 97,695	$ 120,000	$230,000	$ 447,695		19		$ (29,000)	$ 97,695	$ 45,000	$ 80,000	$ 193,695
20	$ 97,695	$ 125,000	$240,000	$ 462,695		20		$ (29,000)	$ 97,695	$ 50,000	$ 90,000	$ 208,695
		Net Present Value		$2,877,448						**Net Present Value**		$2,362,006

Figure 3 – Example NPV Analysis