How to Buy Long Lasting Closed Feedwater Heaters

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INTRODUCTION

Demand for power is a constant in the growth of the American Economy. Consequently existing steam electric plants throughout the country are in a continuing process of replacing, refurbishing and upgrading. Despite some opposition from environmental groups several new coal fired plants are well past the planning and financing process. There is also much discussion about, and feasibility studies for, constructing new and safer nuclear powered plants. In new, existing and upgraded steam power plants, closed feedwater heaters are essential to maximizing efficient use of fuel whether fossil or nuclear. The authors have previously stated that properly specified, constructed, installed and operated closed feedwater heaters should have a life of 40 years.[1]

The purpose of this paper is to guide purchasers in buying feedwater heaters through preparing procurement specifications, evaluating manufacturers' proposals and making sure that the construction meets or exceeds their specifications. Keep in mind that constructing feedwater heaters is a one-at-a-time process in which the fabricator constructs the heater from thick and heavy parts made from steel plate and forgings, using forming, tube bending, plate rolling, plasma arcing and oxyacetylene burning, drilling, machining, welding, heat treating, heavy load handling, tube-to-tubesheet welding and expanding, nondestructive testing, and similar processes throughout the construction. Therefore, factories sometimes encounter problems that require for-the-purpose solutions. This paper also describes manufacturing problems with which the authors' have dealt and suggests ways to deal with such problems when they arise.

Buying heaters requires you to thoroughly consider how your consultant and the manufacturer will assure heater quality, including monitoring by factory quality control inspectors and your own or contracted third party inspector. It is essential for you to establish a list of production hold points for your inspector to examine the manufacturer's work[*]. Purchase contracts should and usually do provide for stop work orders as required. Make sure to exercise disciplined enforcement of the hold points and be willing

[*] The authors provide their clients with a table of mandatory and optional hold points that also lists hold points that ASME Code Authorized Inspectors require.

to use a stop work orders when you think there is a problem. If you issue a stop work order, it is your obligation to work with the fabricator to resolve the problem as quickly as possible to minimize delays and cost.

WHAT YOU NEED TO KNOW WHEN BUYING FEEDWATER HEATERS

It is fundamental when buying feedwater heaters to fully understand the steam cycle and the role of feedwater heaters in reducing the heat rate. You can learn much of what you need to know of basic conceptual design by studying the Heat Exchange Institute's Standards for Closed Feedwater Heaters (HEI Closed Feedwater Heater Standards)[2]. The following brief review of the steam cycle may be helpful.*

The Basic Steam Cycle

In the basic steam cycle, steam exits the boiler/steam generator, enters the main turbine at high temperature and pressure, and expands through the turbine producing usable shaft power that is transferred to the generator to produce Kilowatts (Kw). The steam that exits the turbine exhaust is condensed to water in the main condenser and is pumped back to the boiler/steam generator which adds heat to produce high temperature, high pressure steam and the cycle repeats itself. Power plant designers use the concept of Heat Rate in establishing the economics of the plant arrangements. A simple definition of Heat Rate is the ratio of fuel energy in to the system as heat per unit of net work output as electrical power in units of Btu/Kw-h. ($\text{Heat Rate} = \dfrac{\text{Energy Input, Btu/lb of Fuel}}{\text{Power Output, Kw-h}}$)

Raising the feedwater temperature to the inlet of the boiler/steam generator improves the cycle efficiency. The higher the temperature at which you add heat to the feedwater, the more efficient is the cycle. To raise the feedwater temperature that enters the boiler/steam generator designers place heat exchangers (closed feedwater heaters) in the feedwater flow path between the condenser and the boiler/steam generator. The feedwater heaters transfer heat from steam extracted from the turbine at various pressure levels to the feedwater, thereby improving the heat rate. Most feedwater reheat arrangements also include a direct contact heater (Deaerator) to reduce the amount of dissolved gases in addition to improving the heat rate.

* This review is based upon Chapter 2 of the course notes of the authors' copyrighted course, "Closed Feedwater Heaters-Mechanical Aspects", prepared by the authors..

Another method for raising steam cycle efficiency, not discussed here, is to feed partially expanded, but relatively high pressure steam from the turbine to the boiler/steam generator which reheats it to a higher temperature. The reheated steam is reintroduced to the turbine at an appropriate lower pressure admission point where its power producing expansion is continued.

Feedwater Heater Construction Arrangements

There are three typical feedwater heater construction arrangements: (1) single zone in which steam entering the shell is condensed in the (Condensing Zone) and leaves the heater at its saturation temperature, (2) two zone constructions in where the steam surrenders its superheat and latent heat to the feedwater in the Condensing Zone before it enters an enclosed region (Subcooling Zone) where it gives up some sensible heat to the feedwater flowing through the tubes, and (3) three zone construction in which superheated extraction steam enters a Desuperheating Zone where the steam surrenders most of its superheat to the outgoing feedwater, exits into the Condensing Zone where it surrenders any remaining superheat and its latent heat to the feedwater and the condensate enters the Subcooling one where the condensate at approximately its saturation temperature surrenders some sensible heat to the incoming feedwater and leaves at a lower temperature.

All three types may be constructed for either horizontal or vertical operation. Subcooler designs for vertical channel head up and some horizontal heaters encapsulate approximately the full length of some of the tubes (partial-pass, full-length design). Subcooler designs for vertical channel down and most horizontal heaters usually encapsulate a short length of all the tubes (partial-length, full-pass design).

Heaters that receive extraction steam from the lowest pressure end of the turbine are usually single zone, condensing only heaters. If the plant operates at low loads, the extraction pressure may be so low that there is insufficient hydraulic head for a Subcooler to function. Plants designed to operate at low loads may have external Subcoolers in the cycle.

When the extraction pressure at the lowest operating load is high enough, a Subcooling zone will improve the heat rate and is usually included in the system. An exception is when the plant is arranged for condensate from the heater to be pumped forward into the feedwater stream. For this arrangement heat in the condensate enters the feedwater stream making a Subcooler inappropriate. The feedwater pump must be located so as to prevent flashing at the pump inlet.

Steam in fossil-fueled plants leaves the boiler with so much superheat that even after it has been partially expanded through the high pressure stages of the turbine there is considerable superheat - 100 °F to as much as 400 °F. When the extraction steam has enough superheat under all operating loads, including a Desuperheater reduces the amount of steam extracted from the turbine that is required to raise the feedwater temperature. The Desuperheater further improves the Heat Rate.

Parameters for Measuring Thermal Performance

Industry practice is to use two parameters to measure the thermal performance of closed feedwater heaters (CFHs). These are Terminal Temperature Difference (TTD) and Drains Cooler Approach (DCA). The Heat Exchange Institute's Standards for Closed Feedwater Heaters defines TTD as the difference between saturation temperature corresponding to the entering extraction steam pressure and the outlet feedwater temperature. It defines DCA as the temperature difference between the drains leaving the shell side of the heater and the entering feedwater on the tube side. See Figure 1.

Selecting TTD in CFHs without Desuperheaters. TTD in heaters not fitted with Desuperheaters is always positive. Turbine manufacturers' initial heat balance kits usually suggest a TTD of +5 °F, which is the value on which they base the turbine-generator output rating in Kw. However, heater optimization studies based on plant economics usually result in +2 °F TTD's being specified for horizontal heaters without DSH zones. This also applies to heaters that are installed in the vertical head up orientation. TTD less than +5°F is not recommended for vertical head down heaters because a liquid level is maintained in the bottom of the shell to maintain a liquid seal above the Subcooling zone.

Selecting TTD in CFHs with Desuperheaters. When there is a Desuperheater, the TTD is usually specified in a range of 0 to -3° F, depending on the amount of superheat available in the entering steam at the design basis load and the lowest standby operating loads considered. Table 1 has conservative values to use as a guideline based on design point basis steam extraction conditions.

The top heater TTD is unique in that it has the most effect on turbine Kw output. If the steam flow capacity in the cycle is constant, as in a fossil fueled unit where the main steam valve and the turbine design limit the amount of steam that can flow to the turbine, lowering the TTD may not improve the heat rate because the Kw loss may result in a higher heat rate. For top heaters the optimal TTD is one that balances loss of power and with fuel costs.

Table 1
***Guidelines for Selecting TTD**

Amount of Superheat available (°F)	Suggested TTD (°F)
150 – 200	0
200 – 250	-1
250 – 300	-2
>300	-3

* Heaters with 0 °F TTDs have been satisfactorily designed with = or < 150 °F of available superheat and heaters have been designed with TTDs of = or > -5 °F, but exercise caution when specifying extreme TTDs to make sure that the DSH zone will satisfy the "dry wall safety margins" at all operating loads.

Selecting TTD in CFHs when there is no Desuperheater. When the steam flow capacity in the cycle is heat input limited as in a nuclear unit where the heat input to the steam generator is held constant for optimum fuel economy, you achieve the most power generation at the lowest heat rate by providing the lowest practical TTD. This is largely dependent on fuel costs. 1,000 Kw plants can often justify TTDs of 2 °F. The drawback is that a heater with a 2 °F TTD will have 20 to 25% more heat transfer surface than one with a conventional 5°F TTD, and room to accommodate the resulting larger size may not be available.

Selecting DCAs

Most Drain Cooler (DC) designs follow the recommendations in the HEI Closed Feedwater Heater Standards. The HEI recommends that DCA not be less than +10 °F.

DCA temperatures based on heater optimization studies range from +15 °F to as low as +8 °F. DCAs in the lower end of the range can usually be justified in large heaters in nuclear plants where cascading drain flows contain considerable amounts of available heat.

Low pressure vertical head down CFHs that have large amounts of cascading drains and which do not include a DSH zone will tend go to +15 F° DCA to minimize the "dead" surface outside the DC zone.

Effects of TTD and DCA on Cycle Performance

Effect of decrease of TTD in CFHs below the top heater. Except for the highest pressure heater, a decrease in TTD of a particular heater primarily affects two heaters. As TTD in a heater below the top heater decreases, the rise in feedwater temperature increases. The increase in duty extracts more steam from the turbine. The lower steam flow through the next turbine stage tends to decrease power output. The hotter exit feedwater becomes the new inlet temperature to the next higher-pressure heater. This decreases extraction flow to the heater above the subject heater which results in increasing the amount of steam available between the two extraction points. The expansion of this additional steam at higher pressure and temperature produces a net improvement in cycle efficiency, with no change in cycle heat input.

Effect of decrease of TTD in the highest pressure CFH. Decreasing TTD at the highest-pressure heater has a somewhat different effect. When turbine steam flow is constant, the lower flow through the next turbine stage will decrease the power output. But, because the feedwater temperature to the economizer is higher and the reheater duty is lower, you have to evaluate the lower heat input to the boiler against the Kw output loss to determine the optimal TTD.

Effect of decrease of DCA in heaters below the top heater. Except for the highest pressure heater, a decrease in the DCA of a particular heater affects three heaters. The extraction steam flow to a particular heater decreases slightly as the duty in the Drains Cooling zone increases and warmer feedwater enters the condensing zone. Because less steam is extracted from the turbine, the power output increases. The additional steam flow within the next turbine stage results in a small increase in the extraction pressure of the subject heater, thereby slightly increasing the feedwater outlet temperature. The higher feedwater inlet temperature to the next higher-pressure heater results in lowering the extraction steam flow to that heater. At the same time, the cooler drains cascade to the next lower pressure heater, slightly increasing the extraction load. The net effect to the cycle is an increase in output and cycle efficiency because expansion of more steam at higher pressure and temperature produces more work. Note that there is no change in heat input.

Effect of decrease of DCA in the top heater. Lowering the DCA of the highest-pressure heater will slightly reduce the amount of steam extraction to the heater with a corresponding slight increase in power output. The reheater duty will increase slightly. However the slightly higher feedwater temperature resulting from the same type of extraction pressure increase discussed above may or may not overcome this deficit in reheater duty which impacts the heat input to the boiler. It is cycle-dependent. Nevertheless the net effect is improved cycle efficiency and output.

Effects of TTD and DCA on Performance Costs

Lowering either the TTD or DCA increases cycle efficiency. The increase usually will be manifested by either an increase in power output, a decrease in heat input, or a combination of the two. In the special case of the highest pressure heater the decrease in power output resulting from a lowered TTD must have a more than compensating decrease in heat input in order to be acceptable.

The TTD and DCA represent costs factors associated with the ability of a feedwater heater design to save fuel or to produce more power that you can apply to the design as charges or credits of performance dollar value for use in optimizing the heater performance parameters. In evaluating overall heater performance you must also consider the cost of pumping power used to force the feedwater through the tube side of the heaters. The value and the way you calculate it is cycle dependent. The pumps that circulate feedwater in heaters between the main condenser and the deaerator are usually motor-driven. The costs for driving them are the costs of auxiliary power that the condensate pumps use to overcome the feedwater heater pressure drop. For the heaters between the deaerator and the boiler/steam generator it consists of the cost of the added extraction steam required by the turbine-driven main feed-pump to overcome the feedwater heater pressure drop. With feedwater reheat cycles that do not have a deaerator the condensate pump supplies the necessary net positive suction head (NPSH) for the intermediate pressure feed-pump and/or the high-pressure feed-pump.

Combining the costs associated with heat input, power output, and pressure drop allows you to make a total evaluation of the performance parameters of a specific heater.

Buying Feedwater Heaters for New Power Plants

New Power plants are usually designed to incur the lowest cost for producing the power to be sold. The plant designers make long range estimates of the cost of fuel to make the steam and the Kw selling price for the projected life of the plant. In the United States, historically the utility owner selects the turbine-generator set and the boiler/steam generator needed to supply the steam to the turbine-generator. The Architect-Engineer (A-E) then optimizes the Balance-Of-Plant (BOP) design. In addition to the building design this includes optimizing the main steam condenser, cooling water and feedwater pumps and feedwater heaters. Requirements for buying heaters for new plants and for heaters that will replace worn out ones or for upgrading plants are similar. But unless you work for an A-E firm it is not likely that you will have much input into the process of buying the feedwater heaters for new plants. The A-E will submit its specification which includes the data sheets with which the feedwater manufacturers must work. Therefore, this work deals with buying replacement heaters.

Buying Replacement Heaters

Most power companies' engineers do not have the expertise or time to be responsible for buying replacement heaters. Consequently, common practice is to hire knowledgeable consultants to study the existing plant design, its current operating mode, effects of upgrading, and thermal and physical constraints that apply. The power company designates a responsible project engineer to work with and coordinate the various activities. The project engineer's responsibilities cover more than the heaters to be replaced. If you are the project engineer you must make available to the consultant all of the process and mechanical information about the existing heaters and plant requirements for the replacements. These consist of the following:

1. Heat balances, that show the design basis, the overload and low load conditions,
2. The original plant designer's feedwater heater specification sheets,

3. The manufacturer's feedwater heater specification sheets for the existing heater including normal operating conditions, low load conditions and overload conditions,
4. Limits of feedwater pump capacity and overall pressure drop,
5. Current operating conditions which have usually changed from the original plant design to take advantage of excess capacity margins in the installed equipment to maximize power output,
6. Drawings of the plant layout including any changes or installations of piping and equipment not included in the original construction,
7. Setting plans of the existing heaters,
8. The path and facilities for removing the heaters to be replaced,
9. The path and facilities for handling and installing the replacement heaters
10. The plant operating system including arrangements for bypassing one or more heaters and, when there are parallel strings, arrangements for bypassing a whole string,
11. Envelope limits to increasing the diameter or overall length of the heater due either to heater location or installation path to set the heater in place.

The Procurement Sequence and Time Frame

After a utility has made a decision to replace a heater or heaters, a typical procurement sequence is as follows:

Table 2
The Procurement Sequence*

Step No.	Description	Week No.
1	The station decides that it needs to replace the feedwater heater(s) that have reached the end of their service life and selects a preliminary schedule based on the next plant outage (at least 12 months ahead).	0
2	The station assigns a project manager and or project engineer, who gather as much relevant data as possible, i.e. data on operating conditions for the original design basis, current	1 through 2

* This table is based on many years of the authors' experience with American feedwater heater manufacturers. However, it is only a guide that provides a realistic time frame for procuring feedwater heaters. For a specific heater or group of heaters, there may be a different sequence and the time required to complete each item may vary as will the manufacturers' promised deliveries and slippage that may occur in the manufacturer's schedule.

Table 2
The Procurement Sequence*

Step No.	Description	Week No.
	operating conditions and projected future power upgrades	
3	The responsible engineer starts the replacement specification and details the tasks to firm up the schedule. Most utilities prefer not to use the original equipment specifications for the replacements because they are usually 25 to 30 years old. Instead they prepare new specifications that include current state of the art criteria. When in-house expertise to prepare specifications is not available, the utility contracts with a consultant who is well versed in heater design and manufacture and knowledgeable about technical heater procurement specifications. (Depending upon how the utility operates, the specification may include commercial and legal requirements in addition to technical ones.)	3 to 7
4	During preparation of the replacement heater specification, the responsible engineer details the tasks associated with the change out and firms up the required delivery schedule. Prudence requires the responsible engineer to include some margin in the schedule to allow for minor changes in the outage schedule or manufacturing errors that may need a week or two to correct. Ideally, the replacement heater(s) should be scheduled for delivery on site at least one month before the start of the outage. When requested, the consultant may make a site visit to assist the responsible engineer in verifying that there is sufficient space to install the replacement heaters and go over the plant layout to identify any interferences with which the plant must deal when installing the replacement heater.	3 to 7
5	When the specification is finished and accepted by all concerned, the responsible engineer submits it to the purchasing department which forwards it to an approved list of heater manufacturers with a request for proposal (RFP). It is prudent for the plant to require the bidders to make a site visit to verify the practicality of their offerings, but it is not always done	8
6	The manufacturers submit their bids. Purchasing submits the manufacturers' technical proposals to the responsible engineer and or consultant.	8 to 10
7	The responsible engineer or the consultant tabulates the bids and examines them for compliance with the provisions of the specification and examines them for exceptions and clarifications. This is not a straightforward process because, in order to get all the bids on a comparable basis it is almost always necessary to submit a list of questions to each manufacturer to verify acceptance of various provisions and to explain unclear parts of their proposals. It is not unusual for all of the proposals	11 to 13

Table 2 The Procurement Sequence*		
Step No.	Description	Week No.
	to be slightly different but yet all to be technically acceptable. Therefore, the responsible engineer or consultant must evaluate the order of merit of the bidders' technical proposals and submit a letter of recommendation for purchase to the purchasing department. Evaluation of the proposals may become complex if the RFP includes a request for the manufacturer to install the heaters or perform onsite work such as replacing heater bundles in the shells of heaters installed in the condenser neck.	
8	The purchasing department evaluates the commercial proposals that apply to the technically acceptable bids and, based upon the recommendations for purchase letter, issues the purchase order or contract to the successful bidder. The commercial evaluation includes not only prices but also the delivery promise, terms of payment and manufacturers' warranties. The evaluation may become complex if the RFP included a request for the manufacturing organization to install the heaters or perform onsite work such as replacing heater bundles in the shells of heaters installed in the condenser neck.	13 to 15
9	As soon as is practical after the award, the responsible engineer will schedule a meeting with the manufacturer's product engineer and the consultant to review the specification in detail. The purpose of the meeting is to reach a mutual understanding of the intent of the specification requirements and how the work will proceed to satisfy the specification's requirements.	16 to 17
10	The manufacturer submits a setting plan or setting plans to the responsible engineer and consultant. At the same time the manufacturer usually orders long delivery components such as tubes and channel and tubesheet forgings or plate	19 to 20
11	The responsible engineer and consultant review the setting plan. The responsible engineer coordinates with the plant's structural engineer to verify that the structure can support the new loads and possibly with a rigging contractor to assess how the existing heater(s) will be removed and the new ones installed. At this time the plant's piping engineer verifies that the feedwater piping will fit the replacement heater and determines if any changes will have to be made to the steam inlet piping, drains piping from the next higher heaters and condensate outlet piping and emergency drains piping. The responsible engineer returns a copy of the setting plan drawing marked, "approved" or "approved as note".	21 to 22
12	The manufacturer submits the detail drawings, bill(s) of materials, welding procedures, welders' qualifications, tube joining procedures, NDE procedures, procedures to be used	27 to 28

Table 2 The Procurement Sequence*		
Step No.	Description	Week No.
	cleaning, drying and preparation for shipment for review.	
13	The responsible engineer and/or consultant reviews and comments on the drawings and procedures. This may include some back and forth between the reviewer and manufacturer.	29 to 31
14	The responsible engineer reviews the revised detail drawings and releases the drawings for production. We recommend that the responsible engineer and consultant visit the manufacturer's facility to meet with the manufacturer's product engineer and as many of the shop manufacturing team that are available to verify that there is full agreement that the factory will meet the procurement specification's requirements.	32 to 43
15	Production commences. The manufacturer submits a milestone chart to the responsible engineer. The purchase's inspector and/or the third party inspector, contracted by the purchaser, monitors production, documenting it with photographs and possibly videos, visits the site at all predetermined hold points for witnessing, and issues reports of inspection to the responsible engineer and consultant. During construction, but before joining the tubes to the tubesheet, the factory submits sectioned tube joint mockups.	33 to 48 depending upon the manufacturer's shipping promise and progress in keeping it.
16	After code stamping, acceptance of the heater(s) cleaning, preparing for shipment the heater is loaded onto a truck or rail car and is transported to the site.	48 to 50

Preparing Specifications *

We based the following discussion on their many years of such work. The suggested outline of topics provided below may not apply to every specification for replacement heaters but it covers most things to consider.

Writing style

Writing styles differ from person to person. However, there are some basic rules for writing technical documents clearly†. The purpose of writing a procurement specification

* The recommendations for preparing specifications are based on the authors' "A Working Guide: Preparing Procurement Specification for Replacement Feedwater Heaters" and are by permission of MGT Inc, holder of U.S. Copyright Office Certificate of Registration VA1-090-595 dated July 17, 2001 and updated annually.

† See, for example, "Reporting Technical Information", by Kenneth W. Houp and Thomas E Pearsall, 4th Ed., Glencoe Publishing Company, Encino, California and similar works

is to convey as clearly as possible your station's requirement for the replacement heater(s). Bear in mind that the specification is not only a technical document but also a legal one. We recommend that you use the active voice wherever possible and pay careful attention to the rules of grammar, which provide the best framework for the specification's content. Avoid using words with which most engineers are not familiar. Here is an example from a specification that one of the authors recently reviewed, "The transition from straight legs to the extrados of each U-bend shall be uniform and free from excessive flattening, localized excessive thinning, abrupt changes in bend radius, apparent knuckles on the tube exterior, or wrinkling of the tube exterior." We leave it to the reader to look up the dictionary definition of extrados. The reviewer's comment was, "I doubt that one engineer in 10 would know the meaning of this word since neither history nor Latin studies are common to engineering education".

We recommend using simple, terse declarative statements. Here is a statement written in the passive voice, *"The feedwater heater shall be designed, fabricated, and tested in accordance with the requirements of this specification and the latest editions of the codes and standards listed below."* We rewrote it this way, *"The Seller shall design, fabricate and test the feedwater heater in accordance with the requirements of this specification and the latest editions of the codes and standards listed below.*" The passive voice locution, "The feedwater heater shall be . . ." implies but is not specific about a Seller's responsibility. Stating that "The Seller shall design . . ." clearly says that you require the Seller to take the specified actions.

We suggest that you avoid creating and referring to a series of acronyms that requires the reader to refer to a table to decipher what they mean. In a specification that the authors are currently reviewing, there is a table of more than thirty such acronyms. To review the specification we found it necessary to print the page of acronyms and their meanings so we could understand what the writer was saying. Pity the manufacturer who has to submit a proposal that must meet the requirements that has a laundry list of acronyms.

Formatting numbers

Here are good practices for formatting numbers. Use figures for units of measure and for "pure numbers" such as 6 cm, 10 N.m, 1000 Kw., a factor of 5. When you use numbers under 10 that are not associated with measurements, spell them out, for example, “There were nine people at the technical conference at which we reviewed the specification and discussed the 15 failed tubes.” Spell out definitions of units, for example, “The definition of terminal temperature difference is the temperature difference, degrees F, between the steam inlet temperature at the saturation pressure and the temperature of the outgoing feedwater.” If two numbers are adjacent, spell one out and use a figure for the other, for example six-hundred eighty 5/8” OD x 0.049” minimum wall tubes.” Customary good practice in the United States is to use a zero before a decimal point.

Some usage problems to avoid

Specification writers often do not understand the distinction between two words that sound alike but are spelled differently. An example is the words “effect” and “affect”. Affect is a verb. An example of how to use affect is, “The point at which steam is extracted from the turbine affects the feedwater heater configuration.” You may use effect either as a noun or a verb. An example of using effect as a noun is, “The effect of lowering the DCA of the highest-pressure heater is to slightly reduce the amount of steam extraction to the heater with a corresponding slight increase in power output.” An example of using effect as a verb is, “You can effect a decrease in heat rate by using extraction steam to heat feedwater to the boiler/steam generator.” If you are uncomfortable using effect as a verb, use the word achieve instead.

The words “shall” and “will” seem to confuse specification writers. Yet using them appropriately is important to convey your meaning. Here are two examples of how to use them. Example of using “shall”; “The tube manufacturer shall bright anneal the tubes in a hydrogen atmosphere.” (This tells the tube manufacturer what the manufacturer must do to conform to a requirement.) Example of using “will”: “The station will unload the heater when it arrives and place it on the turbine deck.” (This tells the reader about the station’s intention.)

Paragraph numbering

Number the paragraphs and prepare a table of contents that lists the pages on which the paragraphs appear. Here is a typical listing of topics by paragraph number in an easily followed format that you can use as an outline of what to include in your specification..

1. SCOPE

2. CODES AND STANDARDS

2.1. General

2.1.1. ANSI - American National Standards Institute
2.1.2. ASME - American Society of Mechanical Engineers, Boiler and PressureVessel Codes
2.1.3. HEI - Heat Exchange Institute
2.1.4. TEMA - Standards of Tubular Exchanger Manufacturer's Association
2.1.5. ASTM - American Society for Testing and Materials
2.1.6. Steel Structures Painting

3. REQUIREMENTS

3.1. General Information

3.1.1. Intent
3.1.2. Project location
3.1.3. Plant accessibility
3.1.4. Technical Questions
3.1.5. Commercial Questions

3.2. Performance

3.3. Conditions of Service

3.4. Technical

3.4.1. General
3.4.2. Design and fabrication codes and standards
3.4.3. Materials
3.4.4. Shells and shell covers
3.4.5. Channels and covers
3.4.6. Tubes
3.4.7. Tubesheets
3.4.8. Tube-to-tubesheet attachment
3.4.9. Baffles, support plates, and shrouds
3.4.10. Assembling bundles to shells
3.4.11. Connections
3.4.12. Vents
3.4.13. Insulation
3.4.14. Relief valves
3.4.15. Miscellaneous
3.4.16. Marking
3.4.17. Seismic

3.5. Welding

3.5.1. General
3.5.2. Weld end preparations
3.5.3. Weld repairs

3.6. Shop Cleaning

3.6.1. General
3.6.2. Acceptance criteria

3.7. Painting

4. QUALITY ASSURANCE

4.1. Quality Assurance (QA) Program Requirements

4.1.1. QA Program
4.1.2. Seller's responsibilities for suppliers
4.1.3. Notification points
4.1.4. Hold points
4.1.5. Purchaser's/Seller's quality assurance interface
4.1.6. Stop work action
4.1.7. Preproduction review
4.1.8. Submittal of manufacturing and inspection plan

4.2. Examinations and Tests

4.2.1. Tube tests
4.2.2. Forgings - ultrasonic test
4.2.3. Tubesheet weld overlay test
4.2.4. Tube and hole measurement and documentation
4.2.5. Tube-to-tubesheet welds - tests
4.2.6. Shroud tests
4.2.7. Final hydrostatic test

4.3. Inspections

4.4. Documentation

4.4.1. Records system
4.4.2. Document submittals
4.4.3. Seller's documentation
4.4.4. Final inspection and check of records
4.4.5. Shipping release
4.4.6. Documentation by the seller

5. PREPARATION FOR SHIPMENT

5.1. Drying and Nitrogen Blanketing

5.2. Packaging

5.3. Shipping

5.4. Provision for Storage

6. SUPPLEMENTAL PROVISIONS

6.1. Deviations and Nonconformances

6.2. Sub-Suppliers

6.3. Furnished by the Purchaser

6.3.1. Release for fabrication
6.3.2. Performance test

6.4. Furnished by the Seller

6.4.1. Guarantees
6.4.2. Shell relief valves
6.4.3. Tube side relief valves
6.4.4. Gaskets
6.4.5. Diaphragm seal plate
6.4.6. Vent orifice plate
6.4.7. Lifting devices
6.4.8. Tools
6.4.9. Spare parts
6.4.10. Installation, operating, and maintenance instructions
6.4.11. Drawings
6.4.12. Specification review meeting
6.4.13. Schedule

6.5. Furnished by the Bidder

6.5.1. Commercial data
6.5.2. Provisions for storage/preventive maintenance
6.5.3. Tools
6.5.4. Spare parts for operation and maintenance
6.5.5. Drawings and data
6.5.6. Schedule
6.5.7. Proposal check list

ATTACHMENTS

Attachment 1 Design Basis Data Sheet by Purchaser
Attachment 2 Maximum Overload Data Sheet by Purchaser
Attachment 3 Existing #XXX Heater Outline Drawing Provided by Purchaser
Attachment 4 Design Basis Data Sheet to be filled in by Seller
Attachment 5 Maximum Overload Data Sheet to be filled in by Seller
Attachment 6 Tube Expanding Procedure Specification (TEPS)

Most items listed are self explanatory. For some, such as paragraphs 6.5.5 Drawings and data and 6.5.7 Proposal check list, providing tables is the most effective way of communicating the station's requirements. Be as specific as possible to describe the scope of the specification and its intent (Paragraphs 1 and 3.1.1.). Here is an example of text that we have used for Paragraph 1.

This specification details the technical and quality assurance requirements for the design, fabrication, and delivery of two (2) low pressure closed feedwater heaters identified as heater Nos. 1-5A and 1-5B for the Example Station, Unit 1.

The heaters covered by this specification are replacements for existing horizontal heaters. The specification and attachments set forth physical limitations. The purpose of these documents is to allow installation of the replacement with minimum modifications to existing piping.

In addition to the heaters themselves, Seller shall furnish all of the items specified in paragraph ***6.4.***

Here is an intent statement that we have used for Par. 3.1.1.

It is the intent of this specification to describe: (1) the principal requirements and features of the equipment to be furnished; (2) the interface points that will allow the replacement(s) to be installed with minimum modifications to existing piping; (3) all of the conditions of operation that may impact the equipment design in addition to those of the design basis; (4) materials requirements; (5) fabrication and quality assurance requirements; (6) shipping requirements; and (7) documentation requirements including operating instructions and maintenance manuals complete with all relevant fabrication drawings as described in this specification.

List of Bidders

Establishing an acceptable list of bidders requires interaction between the responsible engineer, the utility's purchasing department and the engineering consultant. Manufacturers without much experience, but with acceptable facilities regularly importune purchasing departments to include them on bid lists. Laws in jurisdictions where the jurisdiction's public power district operates power plants usually require requests for proposals (RFPs) to be available to any entity capable of meeting minimum financial requirements. Many heat exchanger manufacturers have facilities where it is possible to build feedwater heaters but just a few have the required engineering and manufacturing expertise. The authors' position is that for large, high- and intermediate-pressure heaters, you should consider only those manufacturers who can demonstrate a history of having built heaters for a period of at least five years in the manufacturing facility where the heater(s) will be built and who can provide names of contacts to ask about their experiences at the stations where the heaters are installed and operating successfully for no less than two years*. These are minimums. Where the time between outages is longer than two years you may want to require longer histories and periods of successful operation. No matter what the manufacturer's history discloses we recommend investigating the financial stability of any proposed bidder on replacement heaters.

Before awarding a contract for a replacement heater or group of heaters, whether to an experienced manufacturer or to one trying to break into the field, we recommend that you have a person thoroughly familiar with heaters and shop practices visit the shop to evaluate its engineering and manufacturing facilities. Check lists for making such evaluations are available from the authors.

Although these requirements might seem to preclude considering manufacturers who have not previously built closed feedwater heaters from entering the field, we believe them to be prudent. Because there are only a few manufacturers that can demonstrate a history of successful design, construction and operation, we suggest that, if you consider a newcomer, you limit what you will allow the novice to bid on to relatively small diameter (~36"), single zone designs and low pressures.

These suggestions reflect our experience of events over several decades. It is noteworthy that over the years these companies once were heater manufacturers but now either no longer build feedwater heaters or are out of business:

- Alco, who sold off its replacement parts operation,
- C. F. Braun of Alhambra, California,
- Engineers and Fabricators (EFCO) subsidiary of Marley, to whom Westinghouse sold its feedwater heater line. Marley sold the feedwater heater operation to an employee group. Eventually EFCO went bankrupt and closed its doors, (Thermal Engineering International acquired EFCO's files.),
- Griscom-Russell who sold to Baldwin, Lima, Hamilton who went bankrupt. (Ecolaire, which was formed from the remnants of the Baldwin, Lima, Hamilton

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* During recent preparation of a specification for replacement heaters, the utility increased these times to 20 years of experience and five years of recent operation.

corporation, acquired the Griscom-Russell line and continued to sell and construct feedwater heaters by subcontracting the manufacture to heat exchanger factories, eventually purchasing Process Engineering & Machine Co., Inc. [PEMCO] where they tried unsuccessfully to continue feedwater heater production. Ecolaire was acquired by Alstom.)

- Industrial Process Engineers (IPE) who sold to a conglomerate that closed them down,
- M. W. Kellogg, who closed their shops and remained only an Architect-Engineer firm now the KBR subsidiary of Halliburton,
- Lummus, who closed their shops and remained only an Architect-Engineer firm,
- Perfex, which was bought by what is now Thermal Engineering International,
- Struthers-Wells, who sold its heat exchanger business to Struthers Industries Inc. an employee group that had bought the Struthers-Wells shop in Gulfport, Mississippi. The bankruptcy judge presided at an auction in mid April 2005 of SII which was operating in the Chapter 11 bankruptcy debtor in possession condition. Its intellectual property was purchased by TEi. The manufacturing facilities have been otherwise disposed of.

Recent developments have been the acquisition by one of the current major feedwater heater manufacturers of a second shop located in a different state from their original facility and the entry into the business of an engineering firm that acquired an excellent machine shop facility. The first manufacturer is currently building high-pressure heaters in the original shop and low-pressure ones in the second shop. The authors' experience with manufacture of low-pressure heaters in the acquired shop has not been satisfactory. The authors have done a bid review and analysis for heaters that included the latter organization's offering. However, the contract went to another manufacturer that presented the technically and commercially best bid

Evaluating Bids

Evaluating bids is a painstaking and tedious process that consists of carefully examining the technical and commercial proposals. The authors prefer to evaluate and compare only the technical proposals and leave the negotiations of prices, terms of payments, warranties and other commercial matters to the utility's purchasing department.

In doing technical evaluations, we use a template that permits ready comparison of the bidders' offerings and verification of each one's compliance with a selection of the most significant provisions of the procurement specification. Using the entries in the template we highlight the bidders' exceptions and comparisons. As we proceed down the template almost always it is necessary to discuss some of the manufacturers' responses and omissions to enable us to make a fair, balanced and unprejudiced technical evaluation. Our template provides for comparing the manufacturer's proposals for such things as:

- Dry wall margins for low load operations,
- Dome velocity
- Vibration analyses including cross-flow velocities,
- Tube-support thicknesses and spacing,
- Subcooler end plate drilling tolerances with which the manufacturer will agree to comply,
- Tube joining procedure specifications, qualification and submission of mock-up specimens for examination,
- Zonal pressure drops,
- Performance of seismic calculations,
- Similar matters

When we are finally able to state with confidence that each bid does or does not meet the requirements of the procurement specification, we can then select among those that do, the one(s) for which we provide a Letter of Recommendation (LOR).

The Post Award Conference and Successful Bidder's Site Visit

Be aware that after the purchasing department awards a contract to the successful manufacturer, the vendor's sales team that prepared their proposal will be turning over the job files to their production team who will produce the design and manufacture the heater. The job file will contain your specification listing your criteria for the design and manufacture of the heater and the final bid documents. The turnover will list those items that the sales team considered important and most likely made note of in their proposal.

In order to insure that the vendor's Product Engineer assigned to the job will adhere to the specification requirements the authors have found it to be essential to conduct a detailed review of the of the specification and the final bid documents with the Product Engineer who will be executing the terms of the contract. We have found that it is necessary to review each page of the Specification, as modified by the final bid documents, to verify that the Purchaser and the Vendor have agreed upon a mutual understanding of all of the specification requirements *before* the vendor starts the work. Often if a bidder does not make a comment about a particular requirement, those evaluating the bids will assume the vendor has agreed to the Purchasers understanding of the requirement. But if this information is not transferred to the Product Engineer he or she may not want to include the requirements especially if there is a significant cost involved.

It is best to conduct a post award specification review conference at the vendor's facility where Vendor's Product Engineer can have available his production team who will be doing various aspects of the work. The focus should be on all criteria that need clarification to make sure everyone has a mutually agreed upon understanding of the requirements listed in the specification. Schedule the post-award meeting at the time of the award allowing enough time – a week or two - for the vendor's production team to give everyone involved with the design and manufacture a chance to review the specification and bid documents. In our experience, although many vendor's suggestions have improved the original construction criteria, many more have adversely affected the service life of the heater(s) in return for insignificant cost savings.

After the post-award meeting, if you are the Responsible Engineer, revise the specification to conform to all of the agreements reached in conference and accepted as part of the vendor's proposal. Reissue the specification as soon as possible to provide guidance for those reviewing drawings and procedures that the vendor will use to manufacture the heater. A conformed specification is very useful to the Purchaser's inspector or third party inspector who will be monitoring the fabrication.

The Vendor will be issuing the Setting Plan which the Purchaser's Responsible Engineer will use to verify that all the interface points will be made in an acceptable manner. In tight fitting locations the authors suggest that the purchaser request the vendor send his field engineer a week after the receiving the drawings to assist with the interface dimensions. Steam and drain lines may need to be moved a few inches or elbows fitted to the shell to meet a steam or drain line interface dimension. The field engineer with a good understanding of the inside construction can help locate these changes in an acceptable way with a minimum impact on the heater design.

Drawing and Procedure Reviews

Drawing and procedure reviews are multifaceted processes. They consist of the following:

- Verifying that the data sheets meet all of your conditions,
- Examining manufacturer's Code calculations to make sure that they are complete and in sufficient detail to enable spot checking,
- Reviewing the setting plans and manufacturing drawings to make sure that they have all of the required information,
- Examining the manufacturers welding procedure specifications (WPSs) and the procedure qualification records (PQR's) for the WPS's and the welders' qualification records (WQRs). This requires the services of a competent welding engineer.
- Examining the manufacturer's Tube Expanding Procedure Specification (TEPS) for conformity to your specification's requirements.
- Examining the manufacturer's nondestructive examination procedures to verify that they meet the Code's requirements for qualification and that the examiners who use the procedures are qualified under the Code's rules to use the qualified procedures.
- Examining seismic calculations. Verify that these have been prepared and stamped by a registered Professional Engineer skilled in performing such calculations.
- Reviewing the manufacturer's vibration analysis.

Some important things to check on the drawings are as follows:

- Weights empty and flooded and the bundle weight.
- Reactions at the supports,
- Space required to remove the shell or extract the bundle,
- Tubesheet layout. Make sure that there are at least 3 inches of submergence of the snorkel opening below the normal liquid level,

- Annular grooving. Make sure that when the manufacturer uses hydraulic or explosive expanding the groove width is the wider of 1/4 inch or the width calculated by the formula $W= 1.56(Rt)^{1/2}$, where W is the groove width, R is the mean radius of the tube and t is the thickness of the tube, all in inches. Verify that a land of at least 3/8 inches separate the annular grooves from each other.
- Impingement protection extending at least 1 inch in every direction from the intersection of a 120 degree included angle cone tangent to the inside of the steam and drains inlet nozzles and line of site of incoming steam and drains missing the peripheral tubes. Require the manufacturer to show these graphically or by calculation,
- Make sure that a reference point on the drawing will be accessible on the heater after installation,
- Verify the positions of all nozzles,
- Verify that level connections are located where they will not cause false readings,
- Compare the bill of materials with the specified material list,
- Verify that the tube bending schedule matches the tubesheet layout.

The Factory Visit

There are two purposes for factory visits. The first is to assess the facilities and capabilities of the manufacturer, or if a well-known manufacturer has established a new facility to assess it. The second is to meet with the project manager and discuss the drawings that you have reviewed in your office and resolve any problems that your office review has disclosed.

Assessing facilities and capabilities of manufacturers and shops requires many years of experience and thorough familiarity with acceptable and unacceptable shop practices. Although the authors have available check lists for surveying shops, we strongly recommend that only a very experienced inspector perform such evaluations. Do not rely on the fact that the shop has authorization to apply ASME Code symbol stamps; many shops that have such authorization know little or nothing about the intricacies of feedwater heater design and construction.

We recommend that before any factory visit to discuss drawings and procedures, you first review these in your office. If you have a consultant who does such reviews, be sure that the consultant has received and reviewed a complete set of documents and provided a tabulation of comments and findings. When you meet with the project manager or engineer, require the shop to have available a complete set of drawings, bill of materials, procedure specifications and every thing that you intend to discuss. Make sure that the factory superintendent, the manufacturer's sales and thermal engineers will be available for discussion as needed before you schedule a meeting.

Monitoring Production

When your own company does not have an inspector thoroughly versed in feedwater heater construction and shop practice, we recommend hiring a third party inspection agency experienced in performing such inspections. Provide a copy of the procurement specification and a complete set of the drawings, procedure specifications and shop's Standard Operating Procedures that you have approved. Be sure to keep the inspector apprised of any revisions. The procurement specification has the list of hold-witness points that you established when writing the specification. Be cautious about waiving any of these points.

The inspection agencies with which we are familiar provide the responsible engineer and the consultant with summary and detailed reports of each inspection, documented with digital photographs. This provides a reasonably complete record of the construction of the heater(s). The reports and photographs make it possible for the consultant to recommend corrective actions when there are nonconformance reports (NCRs) and to suggest when the nonconformance is acceptable without further action.

Nonconformances and Actions to Take

Each heater is custom built. Heaters constructed from the same set of drawings and bill of materials almost never have identical dimensions. One might be built with the shop issuing no NCRs while others have many. The list of things that can go wrong during manufacture is extensive. Although we have seen all of the following during our years of experience with feedwater heaters, most production progresses reasonably smoothly with few or insignificant NCRs. Here is an incomplete list of NONCONFORMANCEs taken from our personal observations and inspectors' NCRs followed by recommended actions. Before you agree to a corrective action, have the manufacturer submit a repair procedure for your review. The NCRs and accompanying actions are broken down into drilling/machining problems and fabrication/assembly ones.

Drilling and machining nonconformances

NONCONFORMANCE Tubesheets drilled to the incorrect drilling template.

ACTION The action to take depends upon the type of error. Require the manufacturer to replace tubesheets that are drilled with narrower ligaments than specified. If the error is simply due to a rotated pitch, and the ligament widths are acceptable and the incorrect pattern is identical in the tubesheet, tube supports, baffles and end plate and the tube bending pattern matches the incorrect template, such an error is acceptable. However, require the manufacturer to demonstrate that the error will not affect performance, that the impingement protection is adequate and that there is no line-of-sight contact between incoming steam and peripheral tubes. Reject tubesheets when the error requires a smaller-than-specified innermost tube bending radius.

NONCONFORMANCE Tubesheets drilled with extra holes.

ACTION One would think that the programs for drilling tubesheets, support plates and baffles used to control the drilling template would be checked and double checked to make sure that just the right number of holes is drilled in each part and that the drilling templates are identical. However, sometimes a tubesheet is drilled with extra holes. This is acceptable provided that additional U-tubes to the required bending radius are available and that identically placed holes are in the baffles/supports. Absent these conditions, require the manufacturer to plug extra holes in the tubesheets. Make sure that the manufacturer submits a satisfactory plugging procedure.

Our preference for plugging extra holes in the tubesheet is for the manufacturer to press fit a round bar of material compatible with the tubesheet material into the hole such that there is a set back of approximately 1/4 inch below each tubesheet face and then filet weld plug to the clad face with cladding material and to the rear face with low hydrogen wire. After the AI has inspected the filet welds, require the manufacturer to fill the space with weld wire and grind the filler metal smooth and flush with the tubesheet face.

NONCONFORMANCE Tubesheets drilled with fewer holes than the drawings call for.

ACTION Although, it seems incredible that a tubesheet drilling template may be shy of all the holes required to accommodate the U-tube schedule, it has happened. Here there are two choices: (1) insist on the additional holes, and (2) accept the template as is and demand a credit for the cost of the drilling of the holes, the tube material, bending cost, U-bend installation and joining of the tubes to the tubesheet. For the first alternative, the manufacturer will have to make sure that the tube support/baffle drilling template matches that of the tubesheet. The second alternative is acceptable because almost invariably, there is more than adequate surface without the missing tubes to meet the guaranteed performance. Keep in mind that the common belief is that credits for reduced requirements are nearly always smaller than the cost for additions and extras.

Putting the tubesheet back up on the drill is time consuming and runs the risk that the missing holes will not match the tube bending schedule. Omitting a tube or two does not ordinarily affect the performance or life of the heater. If the manufacturer is willing to guarantee the performance and offers a suitable price reduction, it may be best to accept having one or two less U-tubes. Require the manufacturer to provide as-built drawings and revised data sheets for all conditions of operation. If you decide to require the manufacturer to drill the missing holes, be sure to monitor very closely that the additional holes are properly located.

NONCONFORMANCE Tubesheets in which the tapped holes for tie rods have been on the wrong face

ACTION It is very embarrassing for a manufacturer to learn that the tapped holes for the tie rods have been situated on the wrong face of the tubesheet. The only fix for improperly situated tie-rod holes is to plug them with weld metal and grind the surface smooth. When the tubesheet is clad with alloy metal, make sure that the repair procedure is subject to the same essential variables as the procedure for cladding the tubesheet. Be sure to verify that the tie-rod holes drilled into the back face of the tubesheet and tapped are properly located.

NONCONFORMANCE Tubesheets where the drill operator spotted the holes in the wrong place. (See Figure 2.).

ACTION Manufacturers' faces are red when the tubesheet holes have been spotted incorrectly as shown on Fig. 2. It was difficult to understand how the illustrated error took place because presumably the manufacturer programmed the drilling template into the digitally controlled drilling machine. Obviously the manufacturer did not check the output. There are four possibilities for dealing with the situation shown in Fig. 2: (1) puddle up the depressions with weld metal using a repair welding procedure acceptable to your welding engineering group and the ASME Code authorized inspector and grind the welds flush with the tubesheet face, and (2), assuming that it was the back side of the tubesheet that was incorrectly spotted, and providing that there is sufficient tubesheet thickness to meet the ASME Code requirements for tubesheet thickness and corrosion allowance, machine the damaged face flush, (3) accept a thinner tubesheet and lower maximum allowable operating pressure (MAWP) or (4) replace the tubesheet. For alternative (3) you have to balance the cost of the delay in manufacture against the disadvantage of the lower MAWP. For alternative (4) you will have to plan to accommodate the delay in delivery that replacing the tubesheet will incur.

The action taken for the pictured nonconformance was to examine the calculated tubesheet thickness and specified corrosion allowance. Fortunately, there was sufficient metal to allow machining away the depressions

NONCONFORMANCE Tubesheets in which the number and diameter of oversized holes exceeded the permissible tolerances or vary in diameter through the tubesheet thickness.

ACTION Except for very thick tubesheets (in the range of 20 inches), specifications should require TEMA special close fit drilling. For 5/8 and 3/4 inch diameter tubes ordinarily used in feedwater heaters, special close fit drilling diameter is 0.633 inch and 0.758 inch respectively with a tolerance of plus or minus 0.002 inch with 4% of the holes allowed to be 0.01 inch oversize.

Although you would expect the holes to be uniform in diameter through the tubesheet thickness this is not always so. Thick tubesheets are usually forged material such as SA-350 Grade LF2. The hardness of thick forgings varies somewhat through the thickness, generally being harder near the tubesheet faces and softer in the material between. When the pressure on the drill and drilling speed are suitable for the hard regions, they may not be just right for the soft region. Although the drill bit is designed to find a true path perpendicular to the tubesheet faces it may deflect. The result is that there is usually some non-uniformity in the diameter of the hole throughout the thickness of the tubesheet. As long as substantially all of each hole is within the specified drilling tolerance, this deviation will not affect the utility or life of the heater. Consequently we usually accept holes that exceed the allowable tolerance when the excess is the lesser of 1/2 inch or 10% of the tubesheet thickness.

If the measurements exceed these limits, the manufacturer must take some corrective action. This usually consists of puddling the offending holes with weld wire, re-drilling and reaming. Examine the situation very carefully before accepting such repairs and make sure that the Authorized Inspector has accepted the repair procedure. If the variation in diameter of holes in the tubesheet is extreme the manufacturer must replace the tubesheet.

When holes exceed the permissible 0.01 inch oversize or when more than 4% of the tubes are 0.01 inch oversize, require the manufacturer to plug the holes with weld metal and redrill to the permissible tolerance. Be sure to further inspect the tubesheet. If the number of 0.01 inch oversized holes substantially exceeds 4%, or if there is a substantial number of holes that exceed the 0.01 inch permissible tolerance, consider requiring the manufacturer to replace the tubesheet.

NONCONFORMANCE Thick tubesheets with unacceptable drill drift.

ACTION Although most manufacturers drill thick tubesheets with Lahr or similar drilling machines in which the spade type drill finds its way through the thickness of the tubesheet with minimum drift, this can happen. There is no good fix when the exit side of tubesheet hole is unacceptably offset from the entrance side (drill drift exceeds the specified tolerances) other than to replace the tubesheet. If the unacceptable drill drift occurs in only two holes as verified by 100 percent measurement, it is acceptable to plug the holes.

Do not let anyone talk you into a fix such as expanding for only 2 inches behind the front face weld because not expanding for the full depth leaves a crevice with unpredictable results such as crevice corrosion. Full depth expanding when there is substantial drill drift is impractical.

NONCONFORMANCE Tube hole surfaces unacceptably rough.

ACTION When the tubesheet hole roughness is beyond the limits of workmanlike drilling or when there are scratches or gouges, especially spiral or axial ones, require the manufacturer to run a finishing reamer through the holes to establish an acceptable finish. When the tool used for machining annular grooves into the tube holes is improperly sharpened it may create grooves of uneven depth or width other than specified or leave some upset metal on the hole edges. When inspection reveals upset metal at the groove edges, require the manufacturer to remove it with a finishing reamer.

NONCONFORMANCE Failure to relieve backs of tubesheet holes.

ACTION Require the manufacturer to relieve the hole edges.

NONCONFORMANCE Annular grooves of incorrect width and or depth.

ACTION Require the manufacturer to re-groove holes of uneven depth or improper width.

NONCONFORMANCE Extra and incorrectly placed annular grooves.

ACTION Improperly placed annular grooves will not affect the quality of the heater provided that the grooves are not placed closer than 5/16 inch apart nor closer than 5/16 inch to the interface between the tubesheet cladding or in it or closer than approximately 1/2 inch to the inner tubesheet face. Occasionally the drill bit drags some metal in the hole and it creates an additional annular groove. This is acceptable providing the additional groove is located reasonably between the two tubesheet faces, is not closer than 5/16 inch to any of the intentionally machined grooves and is not more than 0.025 inch deep at its deepest point.

NONCONFORMANCE Subcooler endplate drilling template that does not match that of the tubesheet and tube bending schedule.

ACTION When the Subcooler endplate drilling template does not match the bending schedule and tubesheet drilling the best solution is to require the manufacturer to scrap it and drill a replacement that does match. An interesting solution for this nonconformance that one manufacturer insisted on was to progressively drill the Subcooler baffles so as to divide the difference across the straight length of the tubes. Our client accepted this solution because not doing so would have caused the heater to be delivered too late for installation in the remaining outage time. We required the manufacturer to perform finite element analysis of the loads and stresses on the tubes to demonstrate that they were acceptable.

NONCONFORMANCE Oversized holes in the endplate that exceed the permitted tolerance.

ACTION In the specifications that we write, we require all Subcooler endplates to at least 3 inches thick and drilled to the TEMA Special Close Fit tolerance except that 100% of the holes must meet the tolerance, i.e. we do not allow 4% of the holes to be 0.01 inch over tolerance. The purpose is to prevent steam intruding from the condensing zone into the Subcooler which can lead to baffle erosion and vibration damage. Oversized holes defeat this purpose and are especially undesirable near the top of the endplate where there is substantially no hydrostatic head to suppress flashing.

The drilling operator has to be especially careful to properly sharpen the drill bits and to operate the drill at the correct rotational and axial travel speeds. Occasionally an operator drills a hole in the endplate oversize. The fix for this problem is for the manufacturer fit a sleeve tightly into the end plate and to weld both ends with full penetration welds and then ream the sleeve to the required diameter and tolerance. We have had manufacturers accept this repair procedure after some reluctance only to tell us how well it turned out.

NONCONFORMANCE Extra holes in tube supports and baffles

ACTION Extra holes in support plates in tube supports cause no problems as do one or two extra holes in some of the cross-flow baffles. However, if all of the baffles have been drilled with extra holes, it is effectively a leak past the cross flow baffles that may affect the coefficient of heat transfer in the DSH or DC zones. Either require the baffles to be replaced or repaired, or require the manufacturer to demonstrate by calculation that the flaw will not affect the guaranteed performance. If you accept extra holes in tube supports and baffles, be sure to get as-built drawings for your files.

NONCONFORMANCE Incorrect baffle drilling template that does not match the tubesheet and Subcooler endplate drilling.

ACTION Require the baffles to be scrapped and replacement ones drilled to the correct template.

NONCONFORMANCE Oversized baffle holes.

ACTION When you inspect baffles and support plates, measure a reasonably statistical number of holes at random to verify that they are not oversized. At the same time check to be sure that baffle cuts are on the centerline of the row of holes at the distance of the specified percent cut off (See below.). Verify that the holes have been deburred on both sides of the baffles and support plates. (See below.) There is no economical way for manufacturers to deal with support plate and baffle holes that are oversized other than to scrap the faulty supports/baffles and replace them with properly drilled ones. If there are only a very small number of oversized holes, the manufacturer may try to plug them with weld wire and redrill to the proper size. Be especially suspicious of such a procedure because the welding is very likely to cause distortion of the surrounding holes. Make sure to verify that there is no distortion. If there is, reject the baffle or support plate and require replacements drilled to the correct hole sizes. Failure to do so is practically a guarantee of future vibration problems

NONCONFORMANCE Improperly located support plate/baffle cuts.

ACTION Support plate and baffle cuts should be on the centerline of a row of tubes. Deviations leave sharp spikes of metal subject to corrosion and which may gouge the tubes. Require the manufacturer to re-cut the support plates/baffles on the centerline of the appropriate row. Be sure that the as-built drawings show where the support plates/baffles are cut.

NONCONFORMANCE Failure to relieve support plate/baffle holes.

ACTION Require the manufacturer to relieve both sides of the support plate and baffle holes to prevent gouging the tubes.

Fabrication and assembly problems

Here is a short list of fabrication and assembly problems and suggested actions.

NONCONFORMANCE Weld metal clad tubesheets that fail the UT examination.

ACTION Require the manufacturer to machine out the discontinuities, reweld and retest before drilling.

NONCONFORMANCE Long, tie rods in which rod lengths have not been welded together with full penetration welds.

ACTION When you review the weld map, make sure that lengths of round bar welded together to make the required tie rod length are beveled, welded with full penetration welds and the welds ground flush with the parent metal. Tie-rod joining welds that are not full penetration may not affect assembling the shell to the bundle. However, in the event that you have to pull the shell off the bundle, our experience is that filet welds will break, allow the tube supports and baffles to tilt and damage the tubes. Therefore, if there is any evidence of tie rods joined by welds that are not full penetration ones, require the welds to be ground out and replaced with full penetration welds.

NONCONFORMANCE Distorted impingement plate supports resulting from poor welding control.

ACTION The action to take depends upon how badly the support bars are distorted. If there is adequate room between the impingement plate and underlying tubes, despite the ugly appearance, no action is required. In a recent inspection of a bundle under fabrication we found impingement plate supports to be so badly bent from the heat of welding that the impingement plate was so close to some of the tubes that small thermal deflections would have caused it to rub on the tubes.

NONCONFORMANCE Omitted seal rings.

ACTION Although it seems to be unbelievable, we encountered a situation in which the manufacturer had omitted the seal rings shown on the drawing. The manufacturer had to disassemble the heater and install seal rings. Note that the welds of the seal rings to the shell should be full penetration welds.

NONCONFORMANCE Shell girth weld crowns not ground flush where tube supports must pass during bundle insertion.

ACTION The girth weld crowns must be ground flush wherever the tube supports will cross. Inadequate girth weld grinding will reveal itself as difficulty in stabbing the bundle into the shell or pulling the shell over the bundle. Specify that during bundle insertion or shell pulling the manufacturer stop work and investigate why excessive force is being required. This requires disassembling the shell from the bundle, inspecting inside the shell and grinding down any welds that are impeding assembly. (See below for excessive force during assembly.)

NONCONFORMANCE Misplaced nozzles.

ACTION Misplaced feedwater nozzles can be disastrous when installing replacement heaters. However, short of building a new channel, there is little that you can get the manufacturer to do. Your inspector should verify the location and placement of the feedwater nozzles at the earliest possible time to allow the field installation crew to adjust the feedwater piping.

The manufacturer can usually cap badly misplaced shell side nozzles and install replacements at the correct locations. However, if this is not possible, require the manufacturer to cut out the incorrectly placed ones, roll a section of plate of the same thickness as the shell to the inside shell radius and insert a circular patch welded in place by full penetration welds. Be sure that the patch weld is fully radiographed or examined by ultrasound. Also make sure that the manufacturer has submitted a repair procedure to the AI and that the AI has accepted it.

NONCONFORMANCE Incorrectly located supports and trunnions.

ACTION There is no easy fix for incorrectly located supports and trunnions. The manufacturer has to remove them without damage to the shell and channel and reinstall them at the proper locations. Quick fixes such as wider saddle base plates are unacceptable.

NONCONFORMANCE Scale not completely blasted from the shell interior.

ACTION Your inspector should thoroughly examine the completed shell interior after grit blasting to make sure that all scale is removed and all grit has been cleaned out of the shell. This requires entering the shell and examining under strong light. If the scale has not been completely removed by the grit blasting, require either grinding the offending spots or re-blasting.

NONCONFORMANCE Scratched or dented tubes.

ACTION In a recent construction the third party inspector found that some of the U-bends had unacceptable scratches. We required the manufacturer to progressively remove the tubes and inspect them together with the representative of the tube mill that supplied them. The mill accepted responsibility and made special efforts to replace them quickly to avoid a production delay.

On another occasion, because of difficulty in aligning the bundle centerline with the shell centerline during pulling the shell over the bundle, some tubes were slightly dented by tube supports that hung up on the shell. UT examination of the tubes showed no wall loss. Because of the installation schedule the purchasing station accepted the unit with the few slightly bent tubes. If you encounter such a situation, be sure to have this noted on the maintenance documents and mark the bent tubes for trending during eddy current examinations.

NONCONFORMANCE Tubes not bent to the correct bend radii.

ACTION It is not likely that the manufacturer will notice that the tubes are not bent to the tolerances shown on the bending schedule until installing them. The workers install the tubes with the smallest bend radius first. They will encounter progressive difficulty as the tube ends traverse the cage until they jam. That is why tube loading should always be a hold point so the inspector can put a stop to forcing the tubes through the cage by leather- or rubber-headed mallets, blows to wooden stakes or worst hammering the U-bends.

When it becomes apparent that the work force is having difficulty loading the innermost tubes issue a stop work order pending measuring the bending pattern. Require the manufacturer to rebend the tubes to the appropriate radii.

NONCONFORMANCE U-tubes inserted into the wrong end-plate and or baffle/support plate holes.

ACTION Especially in large bundles, it is easy for workers loading U-tubes to misalign them. Your inspector and the manufacturer's inspector should be present when loading starts to verify that the tubes are going into the correct holes. Require the manufacturer to remove misaligned ones and install them in the appropriate holes.

NONCONFORMANCE Excessive force required to pull the shell over the bundle or to insert the bundle into the shell causing support plates to bend and dent the tubes, and skid bars to cripple.

ACTION Pulling shells over bundles is a tedious job that requires great skill, patience and care. To fully understand what the work force must contend with try to be present at least once during the pulling of the shell over a bundle. In any event the shell pull should always be a hold/witness point for your inspector.

Before commencing and during a shell pull, the workers align the centerlines of the bundle and shell as precisely as possible. They also exercise great care to make sure that the vertical and horizontal centerlines of the shell cross section and bundle cross section are aligned with each other. Considering that the bundle is flexible but heavy and that relative to it, the shell is rigid but may sag slightly out of round and that the clearances between the tube support ears and shell are small, it is a tribute to manufacturers' skills that they consistently assemble shells to bundles without damaging the bundle parts or gouging the shells.

Typically, the manufacturer provides a reaction beam or plate against which the channel butts. The shop crew strings cables from a winch bolted to the base of the reaction plate around the trunnions. They fit adjustable supports under each side of the tube supports to enable adjusting the vertical fit of the bundle to the shell. The work force also uses overhead cranes to adjust the vertical position of the shell relative to the bundle. Skid bars on the bottom of the bundle rest on the inside of the shell. Most manufacturers lubricate the parts that have to slide over each other with a customer-approved lubricant.

Sometimes a shell pull is very hard. In your specification require the manufacturer to stop the shell pull upon encountering an unusually difficult shell pull to investigate the cause instead of using maximum brute force that can cause hidden damage. The decision to stop work and investigate must be the manufacturers. However, a representative of your station should be present during such investigations.

NONCONFORMANCE OF TUBE JOINT MOCKUP Undersized tube-to-tubesheet welds, incomplete penetration of grooves by tube metal, discontinuities between the expanded length of tube and hole.

ACTION We recommend that most tube-to-tubesheet welds have a leak path equal to the thickness of the tube wall. Manufacturers may accomplish this with single-pass autogenous welds, but usually achieving a 1t leak path requires two-passes and the use of filler metal. The purpose of the 1t leak path is to provide leak tightness, not to ensure that there is adequate joint strength – during pushout tests most of the time tubes will fail before the tube. Always require the manufacturer to submit a sectioned and polished tube joint mockup. Examine the weld size under 10x or greater magnification to verify that the manufacturer's tube welding procedure specification (WPS) produces the 1t leak path.

If the welds are undersized or the tube metal does not bottom out in the grooves, or if there are substantial discontinuities in the interface between the tube and hole, reject the specimen and require preparation of a replacement to ensure tube-to-tubesheet joint integrity.

NONCONFORMANCE Tube-to-tubesheet welds did not pass the gas-bubble test or leaked on hydrostatic testing.

ACTION Do not accept a procedure that simply adds weld metal to seal the leak. Require the manufacturer to trepan out the flawed welds to the root, reweld and retest.

NONCONFORMANCE Wrong process used for expanding tubes into the tubesheet.

ACTION Your specification and the subsequent agreement with the manufacturer about the tube expanding process should be very clear. It is not acceptable for a manufacturer to roller expand when the specification calls for hydraulic or explosive expanding. Witness the preparation of the mockup specimen to make sure that the manufacturer is using the agreed-upon process. Make it a hold/witness point for the commencement of tube expanding to avoid having the manufacturer use the wrong process. Bear in mind that if tubes have been roller expanded, the process is irreversible.

NONCONFORMANCE Flaws in welds of skirts to tubesheets.

ACTION Flaws in welds of skirts to tubesheets are hard to detect unless the skirts are welded to hubs on the back faces of the tubesheets, allowing for double butt welding and radiographic examination. In many designs the rear face of the tubesheet is machined to receive the skirt cylinder and the weld is essentially a single-Vee weld in which the root is backed by tubesheet metal. Inclusions and cracks may not show up until the hydrostatic test when there is weeping through the weld.

For such situations, require the leak area to be ground out to the root with the flaw chased in both directions as far as it goes. Require the manufacturer to use the same weld wire as was used for the original skirt-to-tubesheet attachment. Do not permit the repair to proceed until the AI has approved a written repair procedure. If your company has a welding engineering department, require their review and approval of the repair procedure before the manufacturer proceeds with the repair. Make sure that the repair heat treatment and nondestructive examination of the repair are acceptable to the AI and your welding engineering group.

NONCONFORMANCE Improperly cut impingement baffles in flash chamber.

ACTION During a review of a picture that a third party inspector took, we noticed that the impingement baffle in front of the end of the bundle in a flash chamber had no substantial opening to the bundle. If we had not caught the error, the drains from the previous heater would have backed up. Be sure to review all manufacturing drawings thoroughly before approving them.

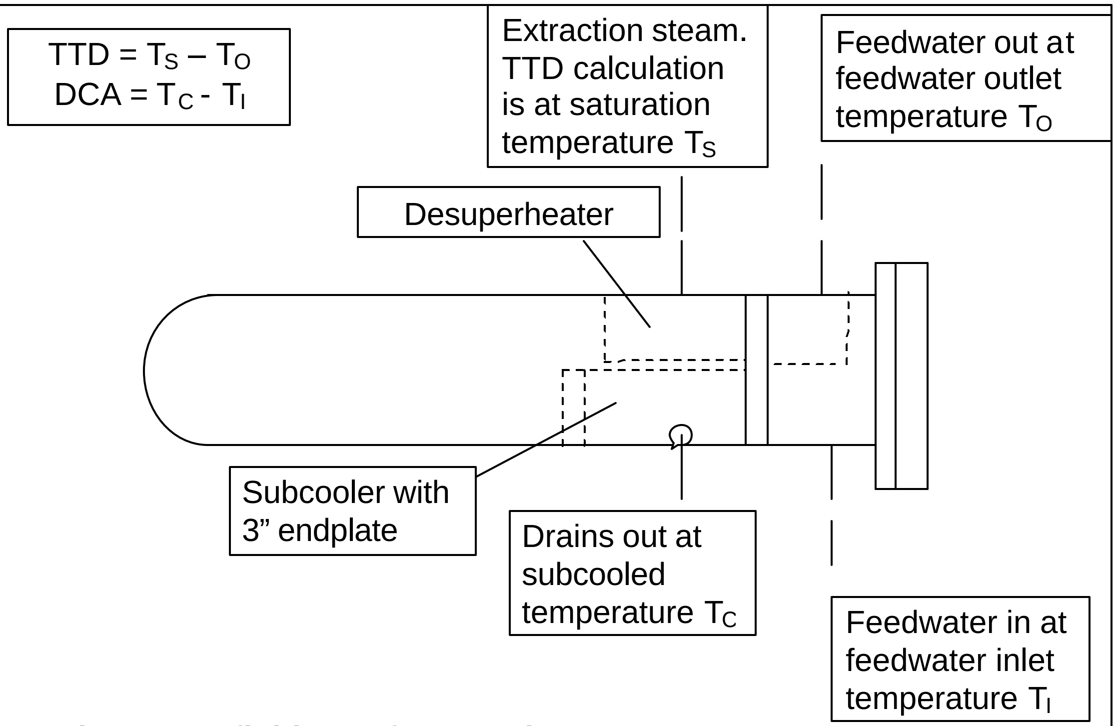
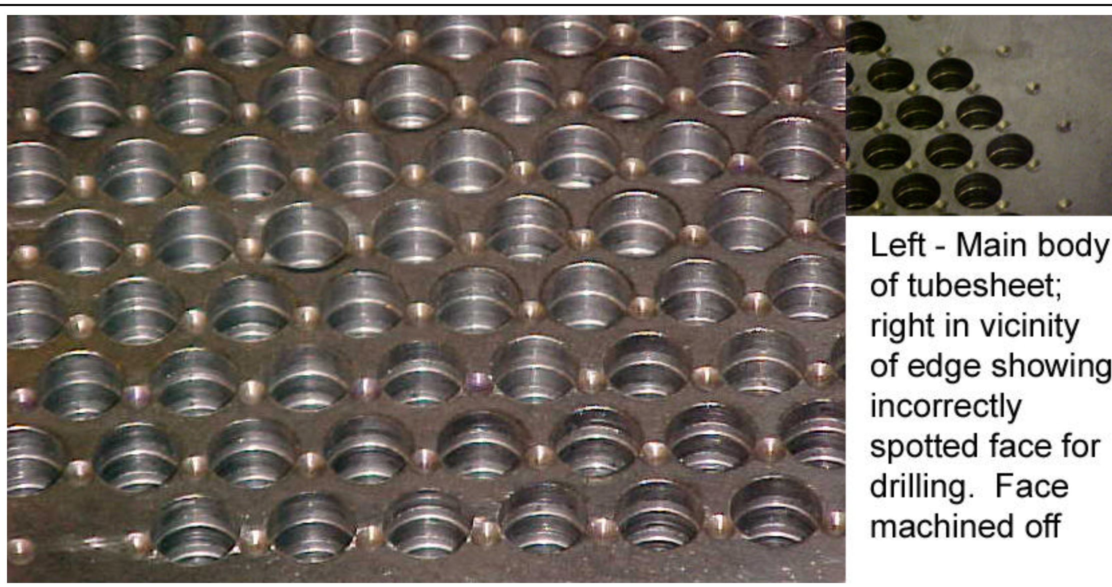


Figure 1 Definitions of TTD and DCA



Left - Main body of tubesheet; right in vicinity of edge showing incorrectly spotted face for drilling. Face machined off

Figure 2 Incorrectly spotted tubesheet face before repair procedure.