

TUBE-TO-TUBESHEET JOINTS: THE MANY CHOICES

B. J. Sanders
Consultant
307 Meyer Street
Alvin, Texas 77511

ABSTRACT

After a decision has been made to use zirconium as the material of construction for a shell and tube heat exchanger, one must take into account the process design parameters and other considerations in order to obtain the optimum mechanical design for the specific application. One of the most important steps in the mechanical design process is determining the method of attachment for the tube-to-tubesheet joint. Many of the problems which have been experienced with zirconium shell and tube heat exchangers could have been avoided by giving more attention to the selection and design of the tube-to-tubesheet joint. Some of the many factors to consider are tubesheet thickness and what type of tubesheet will be used, i.e. solid, explosion clad or loose lined. Other factors to consider are whether or not to seal weld, expand only, strength weld or use some combination of these and what should be sequence of events during proof testing and inspection.

KEYWORDS

Seal welding, tube-to-tubesheet welds, heat exchanger, mock-up, tube expansion

INTRODUCTION

Heat exchangers are widely used in many ways and are seen in many types of industrial, commercial and residential applications. Heat exchangers come in many configurations, sizes and materials of construction. Some of the various types of heat exchangers are shell and tube, plate coil, pipe coil, bayonet and air finned tube. This paper deals with the shell and tube heat exchanger which is the most commonly used type in the Chemical Processing Industry (CPI), See Figure 1.



Figure 1.

DISCUSSION

Rules for designing and fabricating the pressure containing parts of shell and tube heat exchangers are contained in the Boiler and Pressure Code of the American Society of Mechanical Engineers (ASME Code) and the general rules for design and fabrication are contained in a publication known as Standards of the Tubular Exchanger Manufacturers Association (TEMA)

The major parts of a shell and tube heat exchanger are the shell, heads, tubes, tubesheet and baffles. It is difficult to highlight the importance of one heat exchanger component above any of the others, but due to the complexities of the design and fabrication of a tubesheet and the tube-to-tubesheet joint, there are more potential leak paths at this location than with any of the other components. When zirconium is employed as the construction material the design and fabrication of the tubesheet and completing the tube-to-tubesheet joint becomes even more complicated due to the mechanical properties of zirconium and the necessary controls needed to produce a quality weld that has good ductility, corrosion resistance and strength.

OVERVIEW OF DESIGN DETAILS

Process Design

During the process design phase for a heat exchanger, several factors must be considered and these are shown in Figure 2.

TUBE-TO-TUBESHEET JOINT PROCESS DESIGN

- **Specify: Media, Flows, Temperature, Pressure**
- **Specify Materials of Construction**
- **Determine shell diameter / length**
- **Determine type of head(s)**
- **Determine shell & head nozzle size / location**
- **Determine tubing diameter / gauge (if needed)**
- **Determine required heat transfer surface**
- **Determine tubesheet hole pattern (pitch)**
- **Process design sketch**

Figure 2.

Mechanical Design

The major steps carried out during the mechanical design stage are shown in Figure 3. The weld joint for the tubesheet may be one of either a strength weld or a seal weld. Several acceptable designs for these welds are shown in Figure 4. When a strength weld is employed and properly tested it is not necessary to perform the tube end expansion step. However if only seal

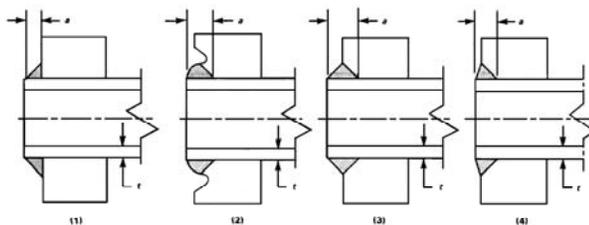
welding is done then expansion of the tube end is needed in order to achieve the required mechanical strength at the joint.

TUBE-TO-TUBESHEET JOINT MECHANICAL DESIGN

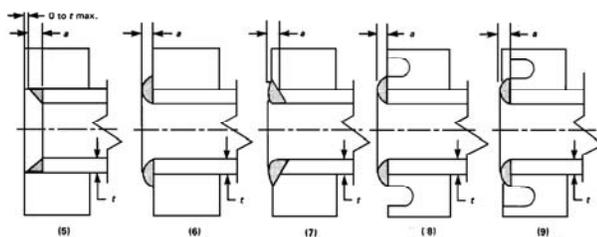
- Calculations to determine thickness for: shell, head(s), nozzles, tubing, tubesheet
- Number and location of rolling grooves
- Baffle details
- Expansion joint requirements
- General weld joint details
- Flanged joints and bolting details
- Tube-to-tubesheet joint details

Figure 3.

ACCEPTABLE TUBE-TO-TUBESHEET WELDS



Acceptable weld joints where a is not less than $1.4t$



Acceptable weld joints where a is less than $1.4t$

Figure 4.

Thermal Rating and Vibration Analysis

Thermal performance rating calculations are required in order to show that the heat exchanger will perform as expected.

A vibration analysis is a must for zirconium due to its notch sensitivity and low modulus of elasticity.

Quality Plan / Inspection and Test Plan

After the process design, mechanical design, thermal rating and vibration analysis are completed and approved, a complete and thorough quality plan and an inspection test plan must be prepared and agreed to between the purchaser and fabricator. These two documents must include all quality control steps, witness points, hold points and inspection approval points for construction and assembly of the entire heat exchanger but more especially the steps involved with the manufacture of the tubesheet and the assembly and testing of the tube-to-tubesheet joint.

TUBE-TO-TUBESHEET JOINT

Quality Plan

Quality plans can be stated in many ways and Figure 5 contains a typical one.

TUBE-TO-TUBESHEET JOINT QUALITY PLAN

- Tube-to-tubesheet mock-up (approval)
- Shop traveler
- Use of sub-vendors
- Welder qualifications
- Welding procedures
- Cleaning procedures
- Step sequence for tube-to-tubesheet joint completion including welding
- Special closefit per TEMA table RCB-7.41

Figure 5.

Inspection and Test Plan

Like quality plans, inspection and test plans can vary with heat exchanger types but major steps can be seen in Figure 6.

TUBE-TO-TUBESHEET JOINT INSPECTION & TEST PLAN

- **Inspect tubesheet blank (explosion clad)**
- **Inspect finish machined tubesheet**
- **Witness attachment of tubesheet (if applicable)**
- **Witness cleaning of tubesheet holes and tube ends**
- **Witness insertion of tubes and expansion of tube ends**
- **Witness welding of tube ends**
- **Witness air test**
- **Witness helium leak test**
- **Witness hydrostatic test**

Figure 6.

Fabrication-Inspection-Testing of the Tube-to-Tubesheet Joint

The fabrication of a heat exchanger involves many operations of forming, machining, drilling and welding in order to manufacture all of the parts, which are to be assembled to produce the final heat exchanger. Emphasis here is on fabricating the tubesheet, inserting the tube ends and securing them in the tubesheet holes whether by expanding only, welding only or a combination of expanding and welding. Tube end expansion may be done either by hydraulic means or by use of a conventional three roller expander. Welding may be done manually, with or without filler metal, or by use of semiautomatic welding equipment.

Before the fabrication step is begun, a mock-up tube-to-tubesheet joint should be assembled using the same materials and design that is proposed for the full size heat exchanger. See Figures 7 and 8 for examples of a mock-up tube-to-tubesheet joint. The proposed tube end expansion method and welding procedure should be employed and the mock-up cross-sectioned for macro examination in order to proof test all the parameters and establish the weld quality and weld penetration. In some unusual cases micro examination may also be employed to check weld quality.

MOCKUP SKETCH

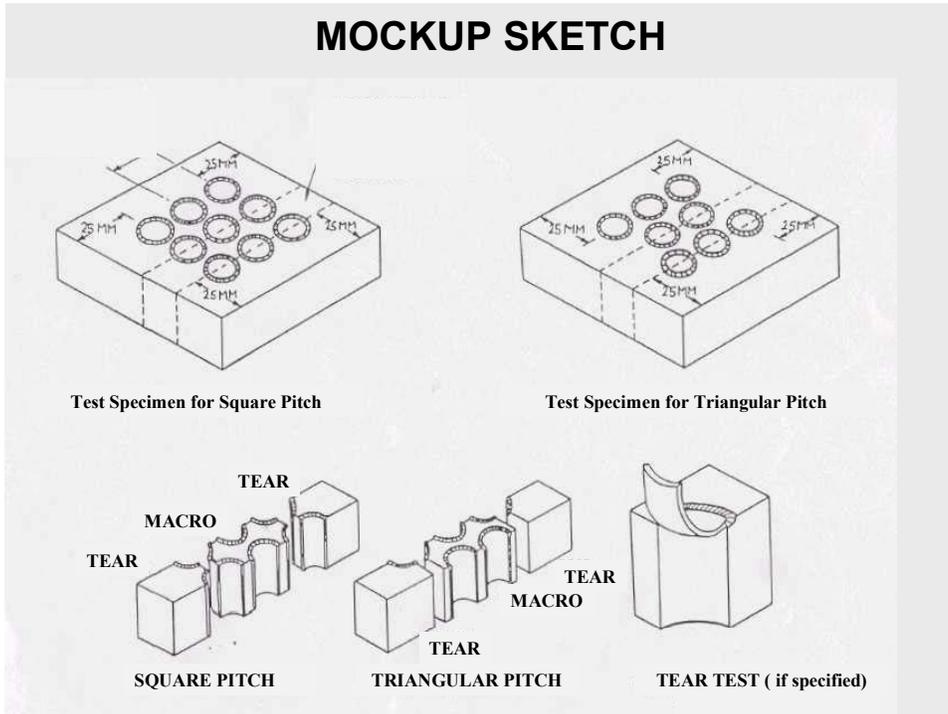


Figure 7.

SECTION OF TUBESHEET MOCKUP



Figure 8.

In my experience the most debated event in making the tube-to-tubesheet joint is the sequence in which the expansion, welding and testing is done. One camp says to weld, test the weld and then expand; another says expand, weld and then test the weld. The purchaser must ultimately make the decision for which sequence to use. Figure 9 lists the steps to follow if "weld tube ends-and then expand" is chosen as the attachment method.

If "expand tube ends-and then weld" is followed, then the steps listed in Figure 10 should be followed.

WELD TUBE ENDS-EXPAND

- Clean tubesheet holes
- Clean tube ends
- Insert tubes into tubesheet
- Weld tube ends
- Air test welds; repair as needed
- Preliminary helium test welds; repair as needed
- Expand tube ends
- Penetrant test welds; repair as needed
- Final helium test welds
- Hydrostatic test

Figure 9.

EXPAND TUBE ENDS-WELD

- Clean tubesheet holes
- Clean tube ends
- Insert tubes into tubesheet
- Expand tube ends
- Air test rolls; re-expand as needed
- Weld tube ends
- Helium test welds; repair as needed
- Hydrostatic test

Figure 10.

Preferred from Experience

The preferred method of making the tube-to-tubesheet joint is first to expand and then seal weld. When this sequence is followed a higher quality expanded joint is possible and the risk of cracking the seal weld during the expansion step is eliminated. In addition a higher quality seal weld can be made.

SUMMARY AND CONCLUSIONS

The two most important steps for accomplishing a quality tube-to-tubesheet joint are the production of a good mock-up (and adherence to the parameters established) and partnering with your heat exchanger vendor. If the purchaser and vendor communicate well and follow the agreed upon Quality Plan and Inspection and Test Plan the final product should meet or exceed expectations and during the process minimal re-work or repair will be required.

