

FAILURE OF SHELL AND TUBE HEAT EXCHANGERS FROM INDUSTRIAL COOLING WATER SYSTEMS

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Abstract: The paper presents the most frequent failures encountered in shell and tube heat exchangers used as cooling equipment in different technological processes, due to poor design, manufacturing faults, improper operating, maintenance and repairing. The conclusions of the paper are based on the monitoring of several cooling systems from chemical and petrochemical plants, power plants and oil refining facilities, during almost a decade of service.

Keywords: cooling water systems, process industries, shell and tube heat exchangers, equipment failure, corrosion, scaling, fouling.

1. INTRODUCTION

Shell and tube heat exchangers (STHE) are some of the most used heat transfer equipment in process industries (i.e. chemical and petrochemical plants, oil refineries, power plants). The STHE are widely used due to their capability to operate at high temperatures and pressures (over 500 °C and over 100 MPa), very good tightness, good thermal load and relatively low price compared with other types of heat exchangers, representing between 60 to 80 percent of the heat exchangers market [1 – 3].

In the process industries, different quantities of water are used mostly as boiler feed water or as cooling water [4]. The weight of cooling water in the global water consumption of several process industries is depicted in figure 1. In order to reduce the global water consumption, it's rerouting and/or recycling is absolutely necessary [5]. Under these circumstances, reused and recycled cooling water incorporates dissolved and suspended substances that alter its physical and chemical properties, making it dangerous for the materials used in the equipment and piping systems manufacture.

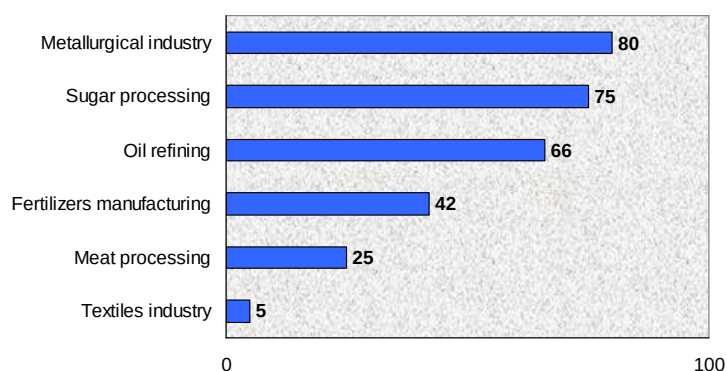


Fig. 1. Cooling water as percent of total water consumption in several process industries

The paper presents the most frequent failures encountered in STHE used as cooling equipment in different technological processes, due to poor design, manufacturing faults, improper operating, maintenance and repairing.

2. SHELL AND TUBE HEAT EXCHANGERS FOR COOLING SYSTEMS

The most popular STHE used in cooling water systems are the Tubular Exchanger Manufacturers Association (TEMA) style ones, illustrated in Fig. 2.

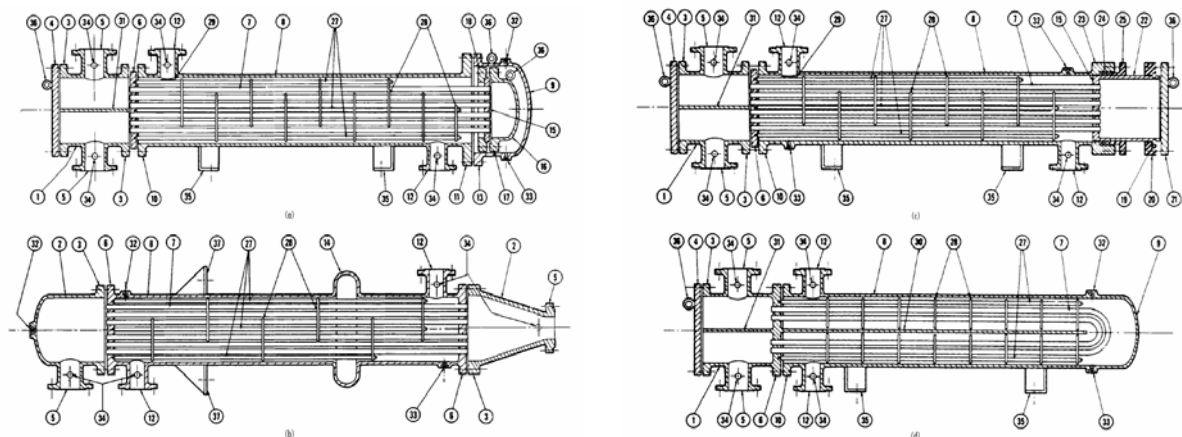


Fig. 2. Typical TEMA shell and tube heat exchangers used in water cooling systems [6]
 (a) Internal-floating-head exchanger (with floating-head backing device). Type AES. (b) Fixed-tube-sheet exchanger. Type BEM. (c) Outside-packed floating-head exchanger. Type AEP. (d) U-tube heat exchanger. Type CFU.

As a rule, the STHE of the TEMA-type AES are used for once-through and open circulated systems. The cooling water flows through the tubes and the process medium through the shell. Because the tube side of the STHE can be cleaned easier and better than the shell side, heavy fouling media are allocated to the tube side. Because of the use of corrosion-resistant materials for corrosive cooling water, it is also more economic to have the cooling water flow on the tube side. By choosing another type of STHE, the probability of leakage can be reduced by a considerable margin. Thus, there is no floating head on the U-tube type STHE and therefore no flange seal on the rear end head. The U-tube type is 10 to 15% cheaper than the floating head type.

Materials selection for STHE involved in cooling systems is a complex matter. There are two fluids (the process fluid and the cooling water) that are passing through the exchanger. In most of cases cooling water flows into the tube side, but there are situations when cooling water flows into the shell side (i.e. high pressure gas coolers). Along the mechanical strength and wear resistance, corrosion and erosion resistance have to be considered. Assuming that the process medium is not corrosive for the material of the tube bank and that possible contamination of the process is not significant, the choice of material is mainly determined by the quality of the water [7].

3. FAILURE OF SHELL AND TUBE HEAT EXCHANGERS

The failure of STHE from cooling water systems can be evidenced by several symptoms, such as:

- minimization of heat transfer capacity: the process fluid can not be cooled at the prescribed temperature;
- minimization of flow section: an increase of cooling water pressure drop across the exchanger is observed;
- mixing of process fluid with cooling water due to:
 - o perforation of tube walls;
 - o sealing gaskets leakage.

Other damages of the STHE can be evidenced only during shut downs, when the equipment is dismantled: thinning of baffles or tube walls, localized corrosive attack, solid deposits in water boxes, obstruction of tube ends with debris, leaves, foils, wooden parts, tower packing, etc.

3.1. Minimization of heat transfer capacity

The minimization of heat transfer capacity is evidenced, in most of cases, after days or weeks from starting up the plant. It is the effect of **fouling** and **scaling** that can be produced by suspended solids, precipitated dissolved solids, corrosion products or microbiological slime from cooling water. Fouling and scaling of STHE tubes is a problem of design and/or operation. To avoid sedimentation of suspended solids, water velocity in tubes has to be 1 – 2 m/s. At lower water velocities (0.9 – 1.1 m/s) large sediments can accumulate in water boxes (Fig. 2) or on baffles, if cooling water flows on the shell side (Fig. 3). Even a good design cannot avoid fouling if cooling water is not properly treated and conditioned [8] or if water flow through the exchanger is reduced [9].



Fig. 2. Sediments accumulation in water boxes



Fig. 3. Sediments accumulation at baffles

3.2. Minimization of flow section

Cooling water flow section is minimized also due to the deposits (mud, scale, slime, corrosion products) formed inside the tubes. Heavy fouling can reduce up to 100% the flow section. Usually, it is a problem of operation in conjunction with a poor water quality (elevated suspended solids). A proper treatment of cooling water, combined with periodical back wash of the exchanger can solve the problem (Fig. 4).

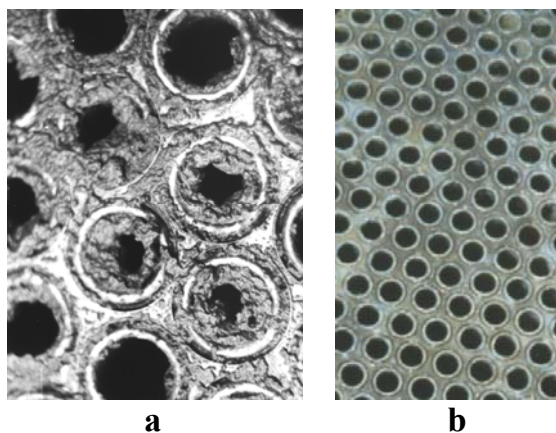


Fig. 4. Stainless steel tubing (vertical condenser) operated with untreated water (a) and with treated water (b)

3.3. Mixing of process fluid with cooling water

Several distinct problems are leading to fluids mixing: perforation of tubes, damage of tube to tube sheet joints, damage of gaskets. While gaskets damage can occur due various reasons, tubes perforation and tube to tube sheet joints damage have to be charged mainly to the **corrosion** processes.

Meanwhile **general corrosion** can be measured and failure of equipment due to this form of corrosion can be easily predicted, **localized corrosion** is more dangerous, as it cannot be observed in real time, and sudden failure of equipment can occur. If pitting tendency can be relatively measured using linear polarization resistance techniques [10], other forms of corrosion, such as selective, galvanic or microbiologically induced corrosion may be avoided only by taking proper actions starting with the phase of design and materials selection [11]. Even when material selection for heat exchangers construction is correctly performed, technological indiscipline in execution, repairing and exploitation of the equipment may lead to severe corrosion forms.

Several examples of “how not to proceed” are further outlined:

1. **Do not** use tubes made from recovered ends assembled by welding. Even when welding procedure, filler and desensitization procedure are the right ones, the welded area or its vicinity is a corrosion promoting factor, especially when the working environment is highly corrosive. A typical example was found in an oil refining facility, where a stainless steel STH was out of service in about six months (Fig. 5) [9].

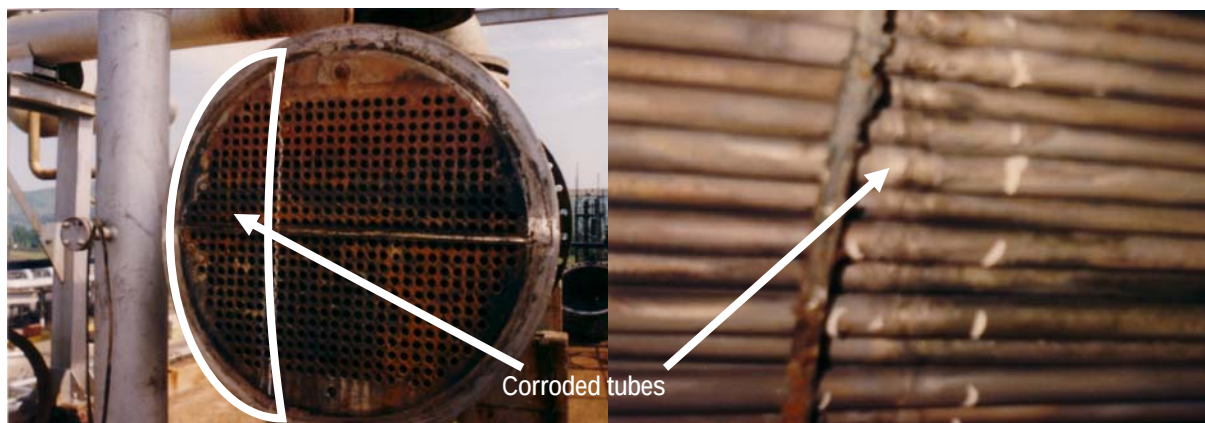


Fig. 5. Severe corroded stainless steel bundle in an oil refining facility

2. **Do not** seal stainless steel leaking tubes with carbon steel plugs. The more noble the stainless steel, the more active the formed galvanic cell is. Due to the high cathode / anode (plug / tube & tube sheet) ratio, high current densities, hence high corrosion rates will occur, as shown in Fig. 6.

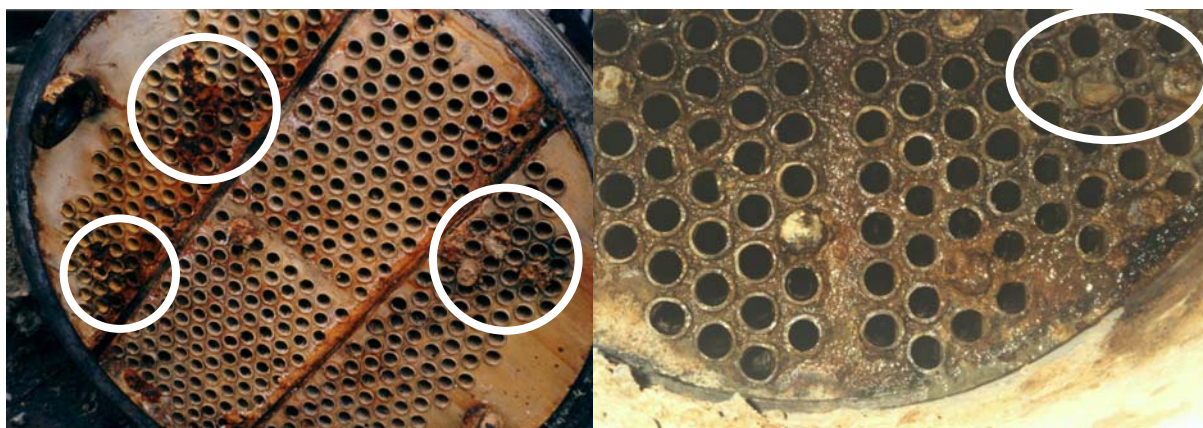


Fig. 6. Corrosive attack of the mild steel tube sheet – carbon steel plugs welded in stainless steel tubes

3. **Do not** replace mild steel bundle with nobler stainless steel bundle, if rods and baffles are made in carbon steel. In several months they will “disappear” due to galvanic corrosion (Fig. 7) [12, 13].
4. **Do not** use mild steel water boxes in contact with stainless steel tube sheets unless this situation can not be avoided. In that case use some protection: rubber gaskets to insulate stainless from mild steel, sacrificial anodes (made in zinc or magnesium – Fig. 8) placed on the mild steel walls, epoxy coatings.
5. **Do not** reduce the water flow through the exchanger in order to control the temperature of the process fluid. Use additional pipes so that part of the process fluid could by-pass the heat exchanger. The supplemental cost of the pipes, fittings and valves is cheaper than a new stainless steel bundle, or than the loss of production during heat exchanger’s mechanical cleaning time.



Fig. 7. Mild steel baffles and rods severely corroded in chemically treated water due to the contact with stainless steel tubes bundle



Fig. 8. Water box of a heat exchanger protected with zinc sacrificial anode

4. CONCLUSIONS

Failure of shell and tube heat exchangers from cooling water systems of the process plants has been analyzed. During operation, heat exchangers are subjects mainly to fouling, scaling and corrosion.

A smooth exploitation of these equipments is achieved only if proper measures are taken even from the design phase and materials selection.

The use of mixed metallurgy heat exchangers (i.e. stainless steel tubes in mild steel shells and tube sheets) can create serious problems in the running of a cooling system if some basic rules are ignored. Where combination of stainless steel tubes and mild steel shells, water boxes, baffles cannot be avoided, a proper isolation between stainless steel parts and mild steel parts is required. The use of corrosion and scale inhibitors in conjunction with sacrificial anodes (Zn or Mg) is strongly recommended.

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