ANNEX III SHELL AND TUBE HEAT EXCHANGERS FOR INDUSTRIAL ONCE-THROUGH COOLING SYSTEMS AND THE OCCURRENCE OF LEAKAGE

The design of the heat exchanger is extremely important, as it is the key element of a cooling system, where the exchange of heat takes place. From an environmental point of view it is there, where leakage from process substances to the coolant can occur. In once-through cooling systems the relevance of a well designed, operated and maintained heat exchanger is obvious. From a preventive approach attention should be paid to the issues presented in this Annex before considering a move towards an indirect (secondary) system. This Annex gives a summary of a number of important issues to take into account in the design of the commonly used shell and tube heat exchanger to avoid environmental problems [tm001, Bloemkolk, 1997]

The shell and tube heat exchanger consists of a shell, a great number of parallel tubes, tube plates (tube sheets) baffles and one or two heads. Heat exchange between the media takes place by pumping the one medium through the tubes and the other medium around the tubes. As this happens the heat is transported through the tube wall. Diagonally on the tubes are baffles. The baffles ensure a better transfer of heat (through increased turbulence of the flow around the tubes) and support the tubes. The shell & tube heat exchanger is reproduced in a picture below.

![Figure III.1: Major components of shell & tube heat exchanger](tm001, Bloemkolk, 1997)

There are a great many different types of shell & tube heat exchangers. By making the right choice from the design parameters below, the design can be adapted to the specific process and maintenance requirements:

- the type of shell and head
- the type of tube (straight or U-shaped, with or without fin)
- the size of the tube (diameter and length)
- the distance between the tubes (pitch) the configuration (lay-out)
- the number of baffles the type of baffle
- the distance of the baffle (baffle pitch)
- the number of passes through the tubes (tube passes)
- the flow pattern (counter flow, concurrent flow)
- either mechanical or not, cleaning either with (high pressure) water or not
The Tubular Exchanger Manufacturers Association (TEMA) has drafted a nomenclature for the various types of shell & tube heat exchangers. TEMA has also drafted mechanical design guidelines.

The advantages and disadvantages of the shell & tube heat exchanger are listed below.

**Advantages:**
- available for all applications
- available in almost all materials
- wide range of flows and capacities (duties)
- sturdy, safe construction
- good thermal and mechanical design methods available

**Disadvantages**
- relatively expensive per m² heat exchanging surface area
- not optimal for heat transfer
- cleaning (drawing the tube bank) of the shell side is laborious

Because of the sturdy and safe construction of the shell & tube heat exchanger, refineries prefer this type of heat exchanger. The choice of this type of shell & tube heat exchanger for once-through systems is explained further below.

### III.1 Design of the shell & tube heat exchanger for one through systems

As a rule, the shell & tubes of the TEMA-type AES are used for once-through systems. The cooling water flows through the tubes and the process medium through the shell. AES refers to the codes used to describe the different options for shell and tube heat exchangers (Figure III.2)

**Allocation media**
Because the tube side of the shell & tube heat exchanger 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.

**A-Type of front end head**
Opening the shell & tube heat exchanger for inspection and maintenance is easiest with an A-type 'front end head', because the connecting tubes do not need to be dislodged when opening this type of head. For this reason, this type of head is almost always used for heat exchangers with a "polluting" medium on the tube side.

**E-Type of shell**
The choice for the type of shell depends on the process requirements for the medium on the shell side. Usually, the E-type is chosen ("one-pass-shell").

**S-Type of rear end head**
The choice of the type "rear end head" is determined by factors relating to:
- the need to clean (mechanically or with water) the shell side
- the need to clean (mechanically or with water) the tube side
- quality of the cooling water (corrosive, scaling, etc.)
- occurrence of thermal expansion between shell and tube material
- need for counterflow
Figure III.2: Heat exchanger nomenclature (Standards of the tubular Exchanger Manufacturers Association) [tm003, Van der Schaaf, 1995]

Usually the S-type ('floating head' type) is chosen because this type can be cleaned mechanically (or with water) on both the shell and the tube side. There are also no problems with this type in the event of thermal expansion differences between the shell and tube material. However, the S-type is the most expensive type of 'rear end head'.

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III.2 Leakage in shell & tube heat exchangers

Leakage, and with it contamination of cooling water by the process medium, occurs in shell &
tube heat exchangers in most cases as a result of flaws in the tube-tube plate connection, flaws
in the tube itself and flaws in the flanged connection that separates both flows ('floating head').
Leakage can occur primarily as a result of:
1. poor design (about 30% of the cases)
2. poor manufacturing
3. operation that is not within the limits of the design (50-60%)
4. poor inspection and maintenance

1. Poor design
Because a wrong or poor design irrevocably leads to leakage, during the design phase careful
thought must be given to the design parameters below:
• choice of material
• choice of tube-tube plate connection (rolled or welded)
• choice of packing type
• type of detail on packing faces
• design of the flanges (thickness, no rotation)
• design of the tube plate (thickness, no bending)
• design of tube support

In this consideration, attention should be given to the 'operating' conditions. They are:
• occurrence of vibration
• thermal expansion differences
• flow division
• flow speeds

Poor design also includes wrong design of flow speeds and design based on incorrect data.

2. Poor manufacturing
A good design, however, is not sufficient to prevent leakage. Poor manufacturing can also lead
to leakage during operation of the heat exchangers. During manufacturing, the following aspects
play a role when it comes to prevention of leakage:
• tightening procedure of the flange bolts
• smoothness of the treatment of the packing surfaces
• tube hole diameter and tolerance in tube plates and baffles
• rolling or welding procedure for tube-tube plate connection

3. Operation that is not in keeping with the design
Operations that differ from the operating conditions for which the heat exchanger has been
designed can lead to damage and ultimately to leakage in the heat exchanger.

Different operation could be:
• thermal shocks
• 'upset' condition such as over-pressure and/or too high temperature
• increased or reduced through-flow of flows
• vibrations
• mussels in tubes (which have become detached from the cooling water tube) combined with
vibrations

In addition, incorrect treatment can occur during maintenance, for instance during cleaning of
the tubes with steam or warm water (damage as a result of thermal expansion).
4. Poor inspection and maintenance

During periodic maintenance, the heat exchanger is opened up and the tube bank is pulled, cleaned and inspected. Inspection aimed at detecting and/or preventing leaks includes control of:

- corrosion and/or erosion on the inside and outside of tubes and tube-tube plate connection
- corrosion of packing faces of the flanges
- size of tube holes in baffles (has the diameter of the openings increased in size?)
- reduced wall thickness of the tubes (special attention must be given to tube ends, tubes located at baffles and tube corners)
- bent, twisted or torn off tubes
- tubes pressing against each other, loose tubes
- bent tube plates
- small cracks (or perforations) in tubes and welded tube-tube plate connection
- smoothness and condition of packing faces

Periodic maintenance always ends with a water pressure test, whereby parts of the heat exchanger are pressurised to verify that the heat exchanger is still suitable to operate under the desired pressure levels. In this way, too, the tubes, tube-tube plate connections and flange connections are tested for leaks. To detect leaks, more accurate testing methods are also available. Air ('air and soapy water' test) or helium is used. If flaws or suspicious areas are found, their cause will need to be investigated. Once the cause has been found, corrective measures will need to be taken. If this is not done, and this applies to dealing with the cause as well as the repair of the parts, there is a large probability of (new) leaks in the future.

Corrective measures include the plugging of tubes and replacing gaskets. If a company has its own workshop, the repair work on a shell & tube heat exchanger will take one to two days. By emphasising preventive rather than corrective maintenance, leaks can be prevented. For instance, tube banks can be replaced sooner. Proper logging of maintenance works done and of the occurrence of problems enables better planning of maintenance work. It is recommended that the closing of the heat exchanger and tightening of the bolts is done under supervision to prevent future leaks. For this, a tool with a regulated momentum can be used.

III.3 Alternatives

The probability of leakage can be reduced by alternative choices of material, TEMA-type, tube plate connection, type of packing and the level of the process pressure of the cooling system.

Choice of material

Instead of carbon steel, more high-grade materials such as aluminium-brass copper nickel and titanium can be used for the water side of the heat exchanger. This will make the heat exchanger considerably more expensive than a heat exchanger whose tubes and tube plates are made of carbon steel (See also Annex IV).

Different heat exchanger

By choosing another type of heat exchanger, the probability of leakage can be reduced by a considerable margin.

Alternatives are:

- a U-tube heat exchanger
- a heat exchanger with a double tube plate construction
- both U-tube and double tube plate construction

There is no floating head on the U-tube type heat exchanger and therefore no flange seal on the rear end head. The U-tube type is 10 to 15% cheaper than the floating head type. If leakage occurs at the tube-tube plate connection in heat exchangers with a double tube plate
construction, there will be emission into the atmosphere instead of to the other medium. The double tube plate connection is fairly expensive.

**Tube-tube plate connection**
With a welded tube-tube plate connection there is a much smaller chance of leakage than with a rolled construction. Making a rolled connection into a welded connection can make existing heat exchangers better leak-proof. In this, there are two welds: a sealing weld (one layer of weld) or strength weld (usually two layers of weld). A cost indication shows that the price for a welded construction is about 9 to 11 Euro per tube higher than for a rolled construction.

**Type of packing**
With the flange seal of a floating head, the packing type can be changed. The usual types of packing, for instance an 'asbestos-free metal-wound' packing or a cam-profile packing, can be replaced by a seal with a weld ('Schweissdichtung').