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Factors Affecting Selection of Tubes of Heat Exchanger

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Abstract. Selecting appropriate materials for heat exchangers are included in the duties of designer and manufacturer engineers of heat exchangers. In this paper, various alloys which are used in producing tubes of heat exchangers have been studied and the water effects on them have been discussed. The operation and maintenance effects on the tubes with different alloys and the factors affecting heat exchangers design have been also presented. Further, the most appropriate selection of tube material and sheet have been introduced which is obtained with regard to these factors. The best and most suitable tube material and sheet as well as fluid optimum speed in the tube or converters shell can be selected through information presented in this article.

Keywords: sediment, fluid speed, operating conditions, water quality

1. Introduction

Designing a heat exchanger usually involves three following steps:

1-Thermal design

2- Mechanical Design

3 - Manufacturing Design

Thermal design briefly includes calculation of the thermal transfer surface for a certain flow and specific temperatures of cold and warm fluids. While in the mechanical design, exploitation temperature and pressure, corrosion specifications, thermal expansion and thermal pressure are considered. Applying physical characteristics and fluid flow in converter manufacturing design - that includes minimum or optimum cost - selecting appropriate material, sealing, determining converter internal equipment and the optimum of arrangement of tubes and shells are of the cases considered in Manufacturing Design [1]. This paper includes the special attention to selecting the most appropriate material for producing tubes and tubes sheets.

2. How to Select The Most Appropriate Material

The following three factors are considered in selecting the most appropriate tube for heat exchangers:

1-Water quality

2-How to operate and maintain

3 - Heat exchanger design

In this study, tubes made of copper alloy, type 304 and 316 stainless steel, 6 percent molybdenum alloy, Super Ferritics and titanium have been considered. Also, each of the above mentioned three factors are considered independently and without interaction among the factors. Since the unsuccessful and unexpected function of the tube in the heat exchanger can be followed by the effects of these three factors on the tube, therefore, these three factors will be studied in detail.

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3. Water Quality

The factors considered in water quality include purity, chloride level, dissolved oxygen and sulfide level, residual chlorine manganese and level, PH, temperature and capability of creating its sediment. In table (1) water contents and the drawbacks created by these contents are shown.

3.1. Water Chloride

Calcium Ions, magnesium, sodium, iron and other ions are soluble in water since do not deposit, their concentration will be increased in water boiler coolers. According to the amount of water Chloride, various stainless steel alloys are used. Type 354 stainless steel is resistant against corrosion of water with content of 200 PPm chlorides, while Type 316 stainless steel is resistant against up to 1000 PPm chloride content.

4.5 percent molybdenum alloy is resistant against water containing 2000 PPm to 3000 PPm chloride. Both 4.5 percent molybdenum alloy and duplex (a new type of stainless steel) has been applied to sea water, containing 2000 PPm chloride, but corrosion has been seen beneath the sedimentary layer on the tube body. 6 percent molybdenum alloy, Super freak and titanium are well resistant against salty water.

3.2. Oxygen and Sulfate

Soluble oxygen in water causes corrosion in the converter tubes. Sodium sulfites or corrosion preventive substances are added to the water, to reduce the amount of oxygen in it. Sulfates also produce calcium sulfate sediment by Calcium in water which is involved in creating corrosion. Tubes, made of copper alloy and stainless steel, do not act well in waters containing Oxygen of three to four PPm. Copper alloy is not resistant in dirty waters whose oxygen is constantly used for corrosion and sulphate is also present. Tubes made of stainless steel and titanium excellent material have been applied successfully to these waters.

3.3. Free Chlorine

Chlorine gas is dissolved in water and forms hypochlorite ion and hypochlorite acid which play role corrosion. Chlorine is usually added to the water to make it suitable. Copper - nickel and stainless steel alloys are both containing against water.

3.4. Heat

In the warm waters, protective film on the copper alloys is formed as quickly as five minutes at temperature of 60 degrees F. But, it happens slowly at cold water. Such a phenomenon is gradually forming on Stainless steel tubes.

3.5. PH

In water containing air and less than 5 PH, tubes will be corroded and thinned quickly, because protective film would not be easily formed on the tubes made of copper alloy. Copper alloy shows good resistance against the water whose air has been egresses and its PH is also low. Tubes made of copper - nickel or stainless steel alloy at high PH are preferred to admiral tubes (71 percent copper, 28 percent brass and 1 percent tin) or tubes made of aluminium-brass alloy which get corroded at alkaline PH. stainless steel tubes act well at less than 5 and above 9 PH.

3.6. Manganese

Manganese and iron are of the substances that Cause water discoloration during deposition. Type 304 Stainless steel tubes are not resistant in fresh water containing significant amount of manganese. However, copper alloy and more resistant alloys have acted almost well in such waters.

3.7. Sediment or Mass Absorption

Tubes sediment or Mass absorption level has an important effect on thermal transfer in heat exchangers. Creating sediment in internal surface of the tube not only reduces thermal transfer and the flow section level, but also adds to the resistance against thermal transfer. This resistance is so called Fouling factor. It is often difficult to determine the value of this parameter and it would be guessed empirically. Fouling Factor value for Shell and tube heat exchangers is given in Table (2) for several fluid samples.

Table 1-Water contents	
contents	resultant problems
Hardness	main Sedimentary materials are in thermal converters and boilers
Free and mineral acids	corrosion
bicarbonate Oxide	Corrosion occurrence especially in condensers and steam lines
PH	shows acidity or alkalinity level of water
Sulfate ion	It combines with calcium and makes calcium sulfate sediment
Chloride ion	Increases water corrosion
Na	It combines with OH and causes corrosion
Silicate	It causes deposition in boilers and cooler systems
Oxygen	It involves in deposition occurence in boilers
Hydrogen sulfide	It causes bad smell (rotten eggs) and corrosion

Table 2- Fouling factor amount a few fluid samples	
Fluid	R, W/m2
River water	3000-12000
Sea water	1000-3000
Cooler column water	3000-6000
City water (soft)	3000-5000
City water (hard)	1000-2000
Steam condensate	1500-5000
Steam (no oil)	4000-10000
Steam (with oil trace)	2000-5000
Industrial air and gases	5000-10000
Furnace gases	2000-5000
Organic Liquid- vapor and light hydrocarbons	5000
Heavy hydrocarbons	5000

4. How to Operate and Maintain

Operation procedure and having specific and determined program for Heat exchangers maintenance are of the important factors having an important effect on converter longevity. Although both factors have much influence on product cost, on the other hand, selecting appropriate alloys also leads to maintenance cost reduction.

4.1. How to Operate

Stop time of the stagnant water in the converter tubes is of the cases which should be taken into account during operation. If heat exchanger is supposed to be stopped for two three days for some reasons, its water would better be replaced with pump once a day and if it is supposed to be out of service more than one week, its water must be completely evacuated. The evacuation and water replacement operation has an important influence in tubes corrosion prevention. Because when the water is inside the converter, it would get deposited and provide the appropriate environment for the growth of bacteria. Thus, no converter should ever be left with stagnant water. Keeping water containing or even moist Converter leads to its corrosion.

4.2. Cleaning Schedule

Heat exchanger tubes cleaning schedule depends on the fluid type applied to the tube. The grosser the fluid, the sooner it gets deposited and also creates defects in the operation of the unit and operation of the converter. Thus, Converters must be opened continually and Scheduled, their water be drained and be brushed so that the sediments and fripperies would be removed in the internal surface of tubes. In this case, corrosion phenomenon will be prevented and Thermal load of the converter will be increased as well. Converter which has water containing high biological materials and sediments are should be cleaned weekly. Because if the microorganism are settled or not exited, they would cause corrosion, even in stainless steel. Although tube cleaning seems beneficial, on the other side, it should be noted that warm water produces a protective film on the surface of the tubes and mechanical cleaning of them too much can cause loss of this protective film. Thus the critical optimum period should be considered for tube cleaning.

Tubes made of copper alloy or stainless steel should be cleaned monthly or once every three months for most waters. If thermal load is not so critical, mechanical cleaning can be postponed to annually and sometimes for longer period. However, it should be acted carefully. Because if sediment remains in the tubes more than three months corrosion occurs under it.

5. Designing heat exchanger

The main factors affecting the performance heat exchanger tubes include: fluid velocity, tube diameter, converter tube shape (U or cross shape), converter layout order (horizontal or vertical), and Venting valve, material of tube sheet and channel and location order of input channel.

5.1. Fluid Velocity

High speeds increase the thermal transfer coefficient, but they are associated with pressure drop instead. Speed should be so high that could prevent from particles deposition on the one hand and on the other hand; it should not be so high that it would cause tube corrosion itself. Because high speeds reduce tube fouling. A plastic cover is often applied to the tube input to reduce corrosion rate in this place. However, high speed prevents from particles deposition or tube fouling and increases thermal transfer coefficient as well. On the other hand, it also increases pumping costs. Thus, speed would be determined considering pumping cost, tube longevity and cleaning cost against thermal load score. Design speeds are generally in accordance with the following values:

5.1.1. Liquids

Fluid velocity inside the tube is 1 to 2 meters per second for the process fluids, and 4 meters per second on maximum (if fouling reduction is needed). Velocity would be assumed between 1.5 to 2.5 meters per second for water [4].

5.1.2. Fumes

Here, velocity depends on operation pressure and fluid density:

For vacuum	50 to 70 meters per second
For atmospheric pressure	10 to 30 meters per second
For higher pressures	5 to 10 meters per second

Low values in the above range are considered for HMW materials. Consequently, if speed of less than 4 meters per second is chosen for liquids, sediments and deposited particles in the tubes to should be cleaned mechanically in a short period which reduces the life of tubes made of copper and Stainless steel. Tubes made of copper-nickel alloy accept different speeds. Although corrosion and abrasion may occur in inlet of these tubes, these alloys show a good feedback against water flow rate, after protective film has been formed and a lifetime has passed.

5.2. Diameter of Heat Exchanger Tube

Tubes of the 5/8 to 2 inches range are used. Diameters of less than 5/8 inches are preferred for higher thermal loads. Tube of larger diameters can be easily cleaned and are more appropriate for fluids which form sediment.

5.3. One Cross Exchanger or Exchanger with U Shape Tube

In converter with U shape tube, water should be very smooth and clean water (such as boiler feed water). Because mechanical cleaning of this type of tube is very difficult and perhaps impossible. Stainless steel and copper alloy tubes are suitable for these converters. On the other hand, one cross or double-cross tubes are easy to clean and they can be cleaned by a specific program. Consequently, in cases in which completely filtered water is available, using U shape tubes is permitted and in case the water contains sediment or deposit able particles, one cross or double-cross converters should be used.

5.4. Exchanger Order of Orientation

Converters, and especially condensers, are usually installed horizontally and water flows within the tubes. In such converters, copper alloy and stainless steel tubes have acted well. In conditions in which water must flow in the crust and sediment deposition cannot be prevented in the tubes at the bottom around Baffles, corrosion occurs under the sediments in these locations. Even when it is necessary for the completely smooth water to flow in the crust, tubes should be made of resistant alloy.

Condensers are sometimes located vertically and water cooler flows within the shell for the thermal transfer rate to increase. This location order of condenser causes non-condensation gases to be gathered on the top of tubes and consequently the temperature of the tube wall will become equal to the temperature of the inlet gas, which is supposed to be condensed, and consequently, it will evaporate the water and sediment will be deposited on the hot surface of the tube and will cause corrosion. The resulting sediments are also collected at the bottom of tubes and on the tube sheet or baffles. TEMA Standard suggests that these converters should be installed obliquely so that sediments could be discharged easily and their accumulation on the tube sheets would be prevented.

5.5. Venting Valve

Converters should be equipped with venting valve. Especially when water contains chlorine, Condensers should be equipped with gas venting valve to discharge the chlorine and air collected at the top of the condenser. If chlorine gas or other corrosive gases are not discharged, they will cause tube corrosion.

5.6. Tube Sheet Material

Tubes of heat exchangers are connected to two sheets called tube sheets at the two ends or in other words they are hold by these two sheets. Tubes are either welded or get clinched to these two sheets. Thus, it is important to choose an appropriate material for tube sheet which does not cause polarization.

Carbon steel, copper alloy, Metal Munoz (61 to 58 percent copper, 1 percent lead on the rest zinc), Admiral Brass and bronze aluminum are anode against copper tubes. Galvanic protection of this type of tube against tubes made of copper alloy does not remove corrosion at the inlet and outlet of tubes, but it is on an acceptable level.

Carbon stainless steel is rarely used with a tube made of copper alloy. Since stainless steel acts cathodic against copper alloy, if tube sheet is made of copper alloy and tubes are of stainless steel or titanium, corrosion occurs quickly. Since stainless steel acts cathodic against copper alloy, if tube sheet is made of copper alloy and tubes are of stainless steel or titanium, they will get polarized easily, so that the entire level inside the tube, which is cathodic, will be located against anode which is copper alloy. Cathodic protection flow should be established on the tube sheet of the copper alloy to prevent from or improve such a situation, i.e. the issue of anode – cathode.

6. Conclusion

When designing a heat exchanger is considered, designer engineer calculates the necessary level for thermal exchange and selects the heat exchanger type. He considers comparison of costs and various alternatives and selects an affordable converter which has necessary efficiency in order to select the type of heat exchanger, which of course must be based on one of the international standards such as TEMA or BS3274. Selecting tube of the suitable material is of the cases which play an effective role in cost determination. Before anything else, fluids applicable in converter should be thoroughly analyzed and factors affecting it such as creating probable sediments, PH, acidity, etc., should be specified and accordingly and based on the tables of the text, the tube material should be selected. Selecting the 4m/s speed is the most suitable speed and proper operation along with rational schedule are of the factors which are affecting the tube lifetime and do not fail the initial selection of design engineer. However, the design engineer must design the necessary filters to remove the harmful particles in the fluid – in the place of entering the fluid to the converts. During comparing studied alloys, if the design engineer concludes from his studies that he should use an alloy which is made of copper and stainless steel alloys, then, stainless steel 6 percent molybdenum, Superfreak or titanium alloys are of the best type and show high resistance against corrosion.

7. References

[1] A.J. Chapman. *Heat transfer*. The MacMillan Company N.Y., 1967.

[2] Arthur H. Tuthill. The Right Metal for Heat Exchanger Tubes. *Chemical Engineering*. 1990, 120-124.

[3] Betz. *Betz handbook of industrial water conditioning*. Inc. Betz Laboratories., 1991.

[4] J.M.Coulson, J.F.Richardson, *Chemical Engineering.* Vol.6. 1999.