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Mechanics and material aspects in serviceability prediction of the heat exchangers

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1. Introduction

A heat exchanger (HE) is a device that is used to transfer heat between two or more fluids, between a solid surface and a fluid, or between solid particles and a fluid at different temperatures and in thermal contact. HE are used in a wide variety of applications (Fig. 1). These include power production; process, chemical and food industries; electronics; environmental engineering; waste heat recovery; manufacturing industry; air-conditioning, refrigeration, and space applications. Two of the most popular types of HE are the shell and tube and the plate heat exchanger. Shell and tube HE are ideal for applications with extremely high flow rates, temperatures and pressure loads. Plate HE are ideal for applications where temperature and pressure demands are not that high and there is very little particle debris or build-up in the fluid. The number and size of the plates are determined by the pressure drop, temperature requirements, flow rate, and physical properties of the fluids.

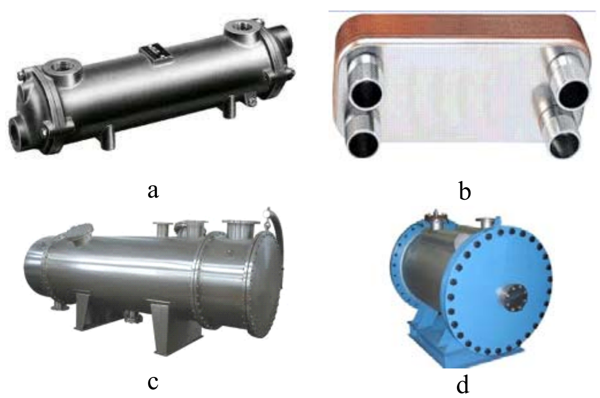

Fig. 1 Samples of industrial heat exchangers: a – tube HE, b- brazed plate HE, c – shell and tube HE, d – spiral plate HE

A HE works by transferring a given heat flux without mixing the material flows for the product and the cooling or heating media. The heat transfer performance is maximized by making the wall thickness as small as possible, increasing the area of the heat transfer surface, and using materials of high thermal conductivity.

Some inherent limitations of the plate HE are caused by plates and gaskets as follows. The plate exchanger is capable of handling up to a maximum pressure of about 3 MPa gauge but is usually operated below 1.0 MPa gauge. The gasket materials restrict the use of polymer asbestos fibre materials in highly corrosive applications, they also limit the maximum operating temperature to 260°C but are usually operated below 150°C to avoid the use of expensive gasket materials.

In our previous paper [1] we explain the impact of fouling and corrosion on heat transfer and pressure drop in HE. But some aspects of uncertainty associated with all the factors contributing to HE element's failure and fouling, and especially corrosion rates are of important to evaluate.

The principal types of fouling encountered in process HE includes: particulate fouling, crystallisation fouling, corrosion fouling, biological fouling and chemical reaction fouling [2 - 4]. In most cases, it is unlikely that the fouling is exclusively due to a single mechanism and in many situations one mechanism will be dominated. Reduced efficiency of the HE due to fouling represents an increase in fuel consumptions with repercussion not only in cost but also in the conservation of energy recourses.

In corrosion fouling, the HE surface itself reacts with the process fluid or chemicals present in the process fluid. Its constituents or trace materials are carried by the fluid in the exchanger and it produces corrosion products that deposit on the surface. Hence, corrosion fouling could be considered as chemical reaction fouling in which heat transfer fouling affects the exchanger mechanical integrity.

Corrosion fouling is dependent on the selection of exchanger surface material and can be reduced or avoided with the right choice of materials (such as expensive alloys) if the high cost is warranted. Corrosion fouling is of significant importance in the exploitation of the boiler and condenser of a fossil fuel-fired power plant. It should be noted that although growth of corrosion influenced deposit has a detrimental effect on heat transfer, this influence is less important than fouling caused by particulate fouling of corrosion products formed elsewhere within the system.

Serviceability of the HE includes factors such as durability, leak proofing, cracking, throughput, corrosion resistance. Safety and reliability of all the components in HE production are of paramount importance, with both being controlled by quality, corrosion resistance, microstructural stability and mechanical properties of the material. With increasing safety demands, corrosive conditions becoming more complex and material selection becomes more and more an optimization problem.

2. Determination of the representation parameters

The first stage of selection the material is the analysis of operating conditions of designed apparatus and possible types of losses of their efficiency in order to determine the required properties and level of the endurance criteria values. The second stage consists of examining the properties of the existing materials in order to select compositions satisfying the service requirements. The same stage includes analysis and development of production technology and treatment of composite materials. The third stage is aimed at developing composite materials, procedures of laboratory investigations, and evaluation of the properties of the produced materials to determine their correspondence to the application criteria and specific service conditions. Analysis of the technical state of the HE which failed during tests is used as a basis for determining the main requirements of the properties of the materials from which they are produced and for practical recommendations for the application of materials with higher service reliability.

Materials selection for shell and tube or plate heat exchangers focuses primarily upon the plates, tubes and gaskets. Since these items significantly effect first cost and equipment life, this produce should receive special attention [1]. Tubing made with high strength low alloy steels, e.g., AISI 316 (Cr 16.9 %, Ni 12.6 %) and AISI 304 (Cr 18 %, Ni 8 %) are used to construct gas and oil pipelines for conveying pressurized hydrocarbons over long distances. The main causes of the damages are stress corrosion cracking, wall thickness reduction and the pressure of stress concentrators.

There has been a trend to improve the material mechanical properties in terms of yield strength and corrosion resistance [5, 6]. In the last three decades, the steel yield strength has been increased from 250 MPa to more than 760 MPa. The most common plate materials are stainless steel (AISI 304 or 316) and titanium. Plates made from incoloy 825, inconel 625 and hastelloy C-276 are also available. Nickel, cupronickel and monel are rarely used. Carbon steel is not used, due to low corrosion resistance for thin plates. Graphite and polymer plates are used with corrosive fluids.

Selection of materials is the main factor in fouling in HE systems. Steels are not generally suitable for water duties; although austenitic stainless steels possess an excellent resistance to general corrosion, they are susceptible to the localized corrosive attacks, such as pitting corrosion, inter-granular corrosion and stress corrosion cracking in chloride containing environments. Corrosion related failures of welded austenitic stainless steel components are still very common in engineering structure.

Duplex alloys are not usually suitable, though some manufacturers claim that super-duplex alloys may be used at temperatures up to around 50°C, or even as high 80°C with cathodic protection [7]. Traditionally, bold copper based alloys were used in various water applications. It is important to note that stainless steels have a higher modulus of elasticity than copper alloys and are stiffer. This minimizes the impact of vibration. Most manufacturers offer the alloys listed bellow: 304 stainless steel, 316 stainless steel, titanium, tantalum, incoloy 825 (alloy 825 is a nickel-iron-chromium alloy with additions of molybdenum, copper and titanium), hastelloy, inconel 625 (inconel 625 is a nickel-chromium-molybdenum alloy with an addition of niobium), aluminium bronze, monel (alloy based on nickel and copper). As for ranking our stated alloys with respect to corrosion resistance, that is not simple either, as each alloy's resistance will depend on the environment.

The nominal chemical composition of alloys used for plates and tubes of HE are presented in Table 1.

Table 1

Chemical composition of alloys used in HE systems (%)

Material	C	Co	Cr	Fe	Mn	Ni	Mo	Si	Cu	Al	W
Steel 304	0.08		18		2	8		0.75			
Steel 316			16-18.5		< 2	10-14	2-3				
Hastelloy C-276	0/03	2.5	14.5-16.5	4-7	1	55	15-17	0.75			3-4.5
Monel 400				2.5	2	63min.	15-17		28-34		
Incoloy 825	0.02			22min.	1	38-46	2.5-3.5	0.08		0.2max	
Inconel 625		1	19.5-23.5	5	0.5	58min.			1.5-3		
Aluminium Bronze	0.3 0.05 0.1		20-23	0.5-6	0.5-3	0.8-6	2.5-3.5 8-10	0.5 0.5 0.5 1.5	Bal.	0.4max 5-11	

In addition, a large number of optional alloys is available by special order. Most manufacturers will quote either 304 or 316 stainless steel as the basic material. For direct use in geothermal applications, the choice of materials is generally a selection between 304 stainless steel, 316 stainless steel and titanium. The selection between 304 and 316 is most often based upon a combination of temperature and chloride content of the geothermal fluid. Titanium is only rarely required for direct use applications. In applications where the temperature/chloride requirements are in excess of the capabilities of the grade 316 stainless steel, titanium generally offers the least cost alternative.

Table 2

Thermal and mechanical characteristics of alloys used in HE systems

Material	Specific heat J/kg · K	Thermal conductivity, W/m · K	Yield stress σ_y, MPa	Ultimate stress σ_u, MPa	Elongation δ_5, %	Hardness, HV
Stainless steel 304	500	16.2	290	621	55	220
Stainless steel 316	500	16.2	290	579	50	217
Hastelloy C-276	427	11.1	345	793	60	188
Monel 400	427	21.8	269	565	45	137
Incoloy 825	439	12.3	310	690	45	155
Inconel 625	410	9.8	483	896	50	183

Austenitic stainless alloys with higher chromium and molybdenum contents could be also recommended for this application. These alloys, however, are generally not available as standard HE materials as is titanium. Table 2 presents chemical and mechanical characteristics of alloys used for heat exchangers designed mainly for specific environment.

To avoid untimely damage of HE, it is very important to choose properly not only the material, but also geometrical parameters (first of all the thickness) of plates, tubes and connecting pipes of HE [8, 9]. For this reason, a HE tube which has a high tensile strength, excellent process ability and good thermal conductivity is strongly demanded for thinning of the HE tube. In this respect, there is a definite relation between the tensile strength of a HE tube and its thickness.

For example, when the operating pressure of a cooling medium in a HE tube is set to be p, the outer diameter of the HE tube is set to be D, the tensile strength of the heat exchanger tube (in the longitudinal direction of the HE tube) is set to be σ_u and thickness of the HE tube (bottom thickness in the case of the inner helically grooved tube) set to be t, and p is expressed as follows

$$p = \frac{2\sigma_u t}{(D - 0.8t)} \quad (1)$$

Then, from Eq. 1, t may be expressed

$$t = \frac{Dp}{(2\sigma_u + 0.8p)} \quad (2)$$

showing that the larger the tensile strength of the HE tube, the smaller the thickness. When the HE tube is actually selected, tensile strength and thickness of HE tube is calculated by further multiplying the operating pressure p of the above cooling medium with the safety ratio n (normally, from about 2.5 to 4.0) is used.

Incidentally, a large tensile force is exerted upon the HE tube of a HE by the operating pressure p of a cooling medium in the circumferential direction of the tube (also referred to hoop direction) rather than in the longitudinal direction of the HE tube. For this reason, in the breakdown of the HE tube, the tensile strength, exerted on the circumferential direction of this HE tube, causes cracks in the HE tube, leading to breakdowns in many cases. Therefore, in order to improve the fracture strength of the HE tube, the restraint of crack generation in the HE tube is important against the tensile strength exerted upon the circumferential direction of this HE tube.

On the other hand, in the prior art for improving the fracture strength of the tube, cracks cannot be restrained which are generated by the tensile strength applied to the circumferential direction of the tube such as a particularly thinned copper alloy tube, so that the fracture strength for the HE tube cannot sufficiently be improved.

Practically it is possible to manufacture first section, which receives fluid at a first temperature, of HE from the first material and the second, which discharges the fluid at a second temperature, from a dissimilar second material, having higher acidic corrosion resistance.

3. Failures and corrosion influence to heat exchangers

Some of the criteria for selecting materials used for HE are corrosion resistance, strength, heat conduction, and cost. Corrosion resistance is frequently a difficult criterion to meet. Damage to HE is frequently difficult to avoid. Some common causes of failures in HE are listed below: pipe and tubing imperfections, welding, fabrication, improper design, improper materials, crevice corrosion, design errors, improper operating conditions, pitting (fouling), stress-corrosion cracking, corrosion fatigue, general corrosion, erosion corrosion.

Corrosion must be considered for any HE, although corrosion may not be a concern for some application. The cost of corrosion is always more significant than just the replacement of the HE or element [10]. Process down time, change out cost, accessing the equipment and pressure testing are all additional costs of corrosion.

A practical engineering way to account for a uniform corrosion process is to use a power law to model the loss of wall thickness with the time of exposure. The general form of the corrosion power law is written as

$$t_c = kT^n \quad (3)$$

where t_c is the thickness of the corrosion layer, T is the elapsed time and k and n are the corrosion constants to be evaluated by fitting Eq. (3) for corrosion data [11]. For atmospheric pressure the mean and standard deviation are, respectively 0.066 and 0.037 for the multiplier k, and 0.53 and 0.14 for the power n.

Because of corrosion, the expected life of carbon steel HE is about 5 years or even less. An alternative to the HE with carbon plates is a unit fabricated by using AISI 316 stainless steel, with an estimated life of 15 years.

In general, heat exchanger companies will not make material recommendations to guard against corrosion because the source of corrosion can vary and change also; the fluid chemistry and environment can change over the operating life of the exchanger, even just for short periods of time (such as a spike in water chemistry). There are, however, generally accepted materials that are used for most common applications. The factors affected corrosion: fluid chemistry, fluid (or metal temperature), fluid flow rate, metal or combination of metals, metal working (forming or welding), fouling, film formation. The factors to consider to minimize the effect of corrosion: material selection, material coating, material thickness, heat exchanger type, dry heat exchanger when not in use.

In heat transfer plates, independently of the type of steel, corrosion pits appear mainly at the tops of corrugations. The role of sites of their initiation is played by nonmetallic inclusions of complex oxides (Al, Si, Ti, and Mg) and oxysulfides (Ti and Ca).

The corrosion allowance for brazed and gasketed plate HE is much smaller than for shell and tube HE, because the plates are very thin compared to the tube thickness. The ability to transfer heat in plate HE can be reduced caused by precipitation of contents of the water and deposition of impurities. Heating of the water with high hardness (> 2 mmol/l as calcium carbonate) above 55°C will cause extensive precipitation of lime (Ca^{2+}) and this will appear as a layer of lime on the plate surface [12].

Standard value of water hardness in Europe is between 0.89 – 2.68 mmol/l.

Fig. 2 Outside surface of the damaged connecting tube due to corrosion influence

Corrosion, pitting of plates' metal surfaces and the build up of "crud" occurs because the quality of the city plumbing water being used is poor or the flow rate is too low or unstable. Enlarged quantities of oxygen, chloride, nitrate, sulphide, water hardness, iron content in the water stimulate corrosion process. Our experience shows, that corrosion damages occur not only inside or outside of heat exchanger, but also in the connecting pipes. Fig.2 shows typical corrosion damage of connecting pipe under the bracket which is used to stay heat exchanger and to avoid deformations of pipes and junctions.

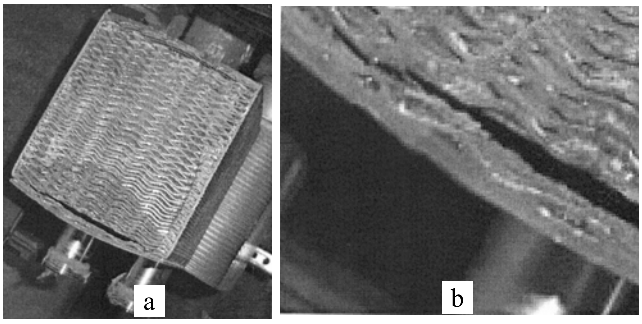

Fig. 3 Damaged copper brazed plate HE due to higher pressure than approved and corrosion of cooper caused by poor water quality or aggressive liquid: a – general view; b – closer view of the defect

Fig. 3 shows damaged copper brazed HE with plates' material of stainless steel 316. The damaged HE was in operation for approximately 2 years before being removed from service. There is a typical defect of brazed plate HE caused by poor water quality or aggressive liquid and higher pressure than approved where external leakages are observed. During the examination the heat exchanger has been cut into two parts. The reinforced end plates with plate thickness 3 mm show deformations with max height of 5 mm on both end plates. The appearance of the external leaking indicates high tensile stresses in the leaking areas. This damage the cooper brazing and the strength in the areas with the highest tensile stresses reduced, typically in the corners or the middle of the end plates. The examination also shows another defect. Cooper brazing has disappeared in the space between the plates on the secondary side of HE. Degrading of cooper in the space between the plates reduces the strength as there is no longer any brazing to keep the heat transfer plates bonded together. It also causes external leaking as the cooper in the edges of the plates is sealing the HE. Our experience shows, that tap water temperature below 55°C will limit the risk of stress corrosion of stainless steel and hot water pitting of copper. Copper can disappear either caused by poor water quality or caused by an aggressive flushing liquid. Flushing should take place in the shortest possible time period and only until all scaling and deposits are removed. Flushing can remove the deposition and increase the ability to transfer heat, but it can also cause reduction of the life of the HE. It is very important that the HE is thoughtfully flushed with clean water immediately after cleaning. If this is not done deposits of flushing liquid can corrode the plates and the copper brazing material.

To consider flushing aspects of brazed and gasketed plate HE it is necessary to accent that gasketed plate HE can be easily opened for mechanical cleaning, gaskets replacement, reduction or extension of the number of plates, whereas, for brazed plate HE only chemical cleaning is possible.

Maintenance instructions of heat network and heat consumption devices require that HE for domestic hot water preparation should be flushed every four years. Furthermore, strength and leakage tests of heat network pipelines should be done every year.

Cleaning method selected should be the one that is not only able to handle effectively the type of fouling experienced with that heat exchanger, but also results in minimum annual maintenance and downtime costs.

4. Experimental results

One of the factors causing the corrosion of the HE elements is trivalent iron Fe^{3+}, which is named as one of the main destructive impurities of the domestic water. It is known, that the concentration of trivalent iron in the water has direct influence on the corrosion rate [13, 14]. The mechanism for forming corrosion material is metallic Fe firstly oxidized to Fe^{2+} by dissolved oxygen present in the water, then, released into water, and further oxidized to trivalent iron Fe^{3+}, forming solid $Fe(OH)_3$, which can accumulate on the inner wall of connecting pipe and on the plates of the HE.

Research was conducted to determine the influence of the iron impurities in the water on the corrosion-caused defects of the brazed plate HE.

The plates of the exploratory HE were made of the grade 316 stainless steel and copper brazed (Cu 99.9%), while the connecting pipes of the HE were made of the low carbon steel (C<0.2%). It was observed visually, that during the exploitation of HE, an intense corrosion process of the steel and copper brazed joints occurred (Fig. 3). The samples cut out of the HE showed the corrosion / precipitation on the inner plates' surfaces, copper brazed joints and on the connecting flanges. The external surface of the cooper joints at the location of the pinhole leaks was covered with reddish, green and brown corrosion products.

Therefore, for electrochemical investigation the grade 316 stainless steel, low carbon steel and copper were selected and the electrodes were made of the mentioned materials. The test electrodes were mechanically polished by emery paper of different grades, degreased in acetone, washed with distilled water and dried. Then they were immersed into the tankage filled with the test solution of known concentration of the trivalent iron or without it. It is important to mention the fact, that electrochemical investigation also provides information about metals corrosion melting in case of two different metals contact. It is known, that during the contact of two different metals, causing galvanic coupling, the metal with lower corrosion potential anodically melts (corroded). During the investigation iron concentration in the water was varied from 0 up to 100 mg/l. Permissible iron concentration in the drinking water should not exceed 0.2 mg/l [15]. Value of pH during the investigation with trivalent iron 0, 0.1 and 0.5 mg/l concentrations was approximately 5. In case of higher concentration (100 mg/l) of trivalent iron, the value of pH was decreased to 2.8. The corrosion rate was determined gravimetrically. It was defined by the experiments (Table 3), that in pure water the galvanic coupling of grade 316 stainless steel and Cu stimulates the corrosion of the steel, but in case the trivalent iron was emerged into the water, the situation was changing conversely, i.e. due to contact corrosion the melting process of the copper, which was used for HE plates‘ brazing, was observed.

Table 3

Corrosion rate in the metals (galvanic couplings)

Metal, (galvanic coupling)	Corrosion rate, $V_{corr.}$ g/m^2 per 24 hours			
	Concentration of trivalent iron Fe^{3+}, mg/l			
	0 mg/l	0.10 mg/l	0.50 mg/l	100 mg/l
Copper	0.81	1.38	2.63	4.65
Low carbon steel	1.28	2.15	3.84	
Stainless steel 316	0.15	0.09	0.06	
Cooper - stainless steel	0.25 (melts AISI 316)	0.03 (melts Cu)	0.06 (melts Cu)	5.32 (melts Cu)
Stainless steel 316 - low carbon steel	1.95	2.92	4.23	8.78
Cooper - low carbon steel	2.83	4.26	6.58	12.50

While Fe^{3+} concentration in the water is increased, the copper contact corrosion rate intensifies. The same situation is with low carbon steel. Under direct electric contact with stainless steel or Cu, the corrosion of low carbon steel becomes more intensive and results more iron ions impurities in the water. Interestingly, that increase of Fe^{3+} concentration in the water reduces corrosion rate of the stainless steel.

As was mentioned before, material coating is one of the factors to minimize corrosion influence on material. Coating is the most convenient method for preventing corrosion/fouling of steel surfaces, storage tanks, surfaces of pipelines, ship bottoms and their super structures.

Noble metal clad systems are materials having a relatively inexpensive base metal covered with a corrosion resistant metal. Selection of the substrate metal is based on the properties required for a particular application. For example, when strength is required, carbon steel is frequently chosen as the substrate. The cladding metal is chosen for its corrosion resistance in a particular environment, such as seawater, high temperature, sour gas. Clad metals of this type are typically used in the form of stripe and plate. A wide range of corrosion resistance alloys clad to steel substrates have been used in industrial applications.

Our examination was done with the stainless steel 304 as a clad on low carbon steel tube. An experimental definition of engineering load-displacement *(F-Δl)* curves obtained from a tensile tests was done for low carbon steel and stainless steel clad on low carbon steel (Fig. 4) connecting tubes. The tubes were of a circular cross-section with an outer diameter of d = 0.055 m, the wall thickness of tubes was 5.5 mm and 1.5 mm, respectively. Tensile tests at room temperature of the service exposed tubes were performed using 500 kN "Amsler" testing equipment. Standard tensile specimens were made of the longitudinal direction of the tubes, which were used for HE connecting; flow media - steam at temperature 200°C, exploitation time - 5 year.

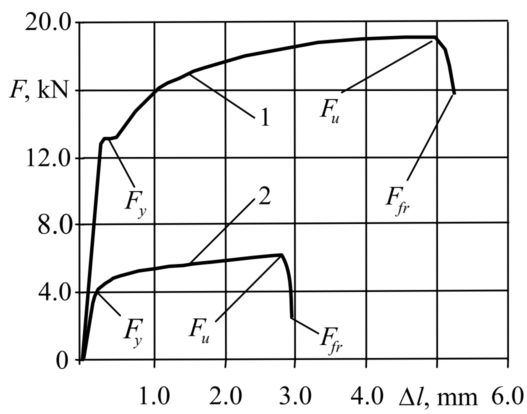

Fig. 4 Engineering F-Δl diagrams obtained from a tension tests for low carbon steel tube *1*, and for coated tube *2,* where F_y – yield force, F_u – ultimate tensile force, F_{fr} – fracture force

Tensile tests were carried out on the tube metal only from the longitudinal direction of the service exposed tubes. The ultimate tensile stress (UTS) occurs where the nominal stress curve shows a maximum. In our case UTS for coated tube is 584 MPa, and for low carbon steel tube 550 MPa. For the 0.2% offset yield stress, we extrapolate a line with the same slope as the linear regime (which is equal to the Young's modulus) until it intersects with the curve. The stress at this intersection is the 0.2% offset yield stress, i.e. 421 MPa for coated tube and 360 MPa for law carbon steel tube.

Furthermore, coated connecting tubes were subjected to standard metallographic examination and hardness measurement. Hardness is a mechanical parameter which is strongly related to the structure and composition of the solids. Furthermore, microhardness is not only a mechanical characteristic routinely measured but it has also been developed as an investigation method of structural parameters in recent years [16]. Fig. 5 shows the cross section of coated low carbon steel tube and indents of microhardness testing procedure. The term "microhardness" usually refers to indentation hardness tests made with loads that do not exceed 1000 g. We provided testing experiments with loads 100 g and 200 g.

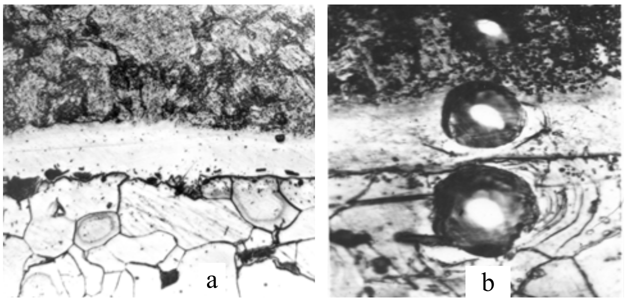

Fig. 5 Photomicrographics of the cross section of the tube (low carbon steel and clad - stainless steel), polished and etched (x500): a – before, b – after the microhardness testing procedure

Microhardness testing provides an alternative means of assessing changes in mechanical properties [17]. It can be done quickly and efficiently, without need for a large volume of sample material. While the yield stress of the thin damaged layer in coated tube cannot be measured directly, microhardness tests can easily be with high precision. With a hardness distribution in the different zones of coating substrate system, the yield stress is expected to change with depth. In practice it is very difficult to obtain experimentally the depth and local hardening distribution of the tensile strength. Here it is approximately calculated according to empirical relations. Fortunately, good linear relationships have been found between the tensile strength and the hardness, the distribution of which can easily be measured. The ultimate tensile strength can be calculated by the following equations

$$\left.\begin{aligned}\sigma_y &= 3.29HV - 47(\text{MPa}) \text{ for } HV \le 445\\ \sigma_y &= 4.02HV - 374(\text{MPa}) \text{ for } HV > 445\end{aligned}\right\} \quad (4)$$

and in the case constructed the stress-strain curve of the material by using the stress levels from the hardness values and the strain values appropriate to the cones indentation angles,

$$\left.\begin{aligned}\sigma_y &= 0.32H_{120}\\ \sigma_y &= 0.25H_{172}\end{aligned}\right\} \quad (5)$$

where H_{120} and H_{172} are equivalent stress and strain to strength and yield in uniaxial tensile stress-strain curve.

Both the yield strength and tensile strength of steels exhibited the linear correlation with the hardness over the entire range of strength values. Hardness and tensile strength are indicators of a metal's resistance to plastic deformation. From the hardness value the yield strength σ_y can be calculated [18]. For n>2, where n is material strengthening coefficient,

$$\sigma_y = \frac{HV}{2.9\left[1-(n-2)\right]}\left[\frac{12.5(n-2)}{1-(n-2)}\right]^{n-2} \quad (6)$$

If $n < 2$, then Eq. (6) is reduced to

$$\sigma_y = \frac{HV}{3} \quad (7)$$

The values of the yield strength as estimated in the present case are calculated by Eqs. (6) and (7) respectively.

While hardness measurements are inexpensive, quick and easy to perform, a tensile test uses expensive equipment and needs a lot more material to be performed. Furthermore, hardness measurements can be done in sites and are virtually nondestructive.

5. Conclusions

The heat exchanger must be maintainable, resist fouling and corrosion, must satisfy the process applications and withstand the service conditions of the plant environment.

1. Having aim to prolong the operating time of the copper brazed plates HE, focus should be given on reducing the concentration of the iron iones in the water (should not exceed 0.1 mg/l). If mentioned above concentration is exceeded, due to the potential difference between the stainless steel and copper, in this case the copper is the corroded element.

2. The experimental investigation has indicated that clad on inner surface of the tube improves the corrosion resistance, increases both the tensile strength of material and durability of operating.

3. The ductility and strength (measured by a tensile test), related hardness properties and fracture toughness are the three most frequently required materials properties. Service behavior such as wear resistance, corrosion is usually inferred from other tests.

4. The factors which lead to a degradation of cladding properties (the cladding embrittlement, deterioration of corrosion resistance, the additional stresses formation) are to be related to void swelling in cladding materials as well as to fouling-induced segregation.

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MECHANINIŲ PARAMETRŲ IR MEDŽIAGOS ĮTAKA ŠILUMOKAIČIŲ FUNKCIONALUMUI

R e z i u m ė

Straipsnyje pateikiama šilumokaičių funkcionalumui, ilgaamžiškumui ir patikimumui įtakos turinčių veiksnių analizė. Daug dėmesio skiriama korozijos įtakai parenkant medžiagas šilumokaičių šilumos mainų plokštelių ir vamzdžių gamybai. Pateikta dažniausiai pasitaikančių šilumokaičių defektų, sukeltų korozijos ir kitų neigiamų veiksnių, pavyzdžių. Atlikta šilumokaičių plokštelių gamybai naudojamų medžiagų cheminės sudėties, mechaninių ir šiluminių charakteristikų analizė. Išnagrinėta šilumokaičių jungiamųjų vamzdžių padengimo įtaka eksploatacinėms savybėms ir ilgaamžiškumui. Nustatyta, kad geležies priemaišos vandenyje skatina šilumokaičių varinių suvirinimo siūlių koroziją. Atlikti jungiamųjų vamzdžių, pagamintų iš skirtingų plienų, įtempių ir deformacijų eksperimentiniai tyrimai, tempimo diagramos, išmatuotas padengto vamzdžio skerspjūvio mikrokietumas, įvertintas ryšys tarp įtempių ir medžiagos kietumo.

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MECHANICS AND MATERIAL ASPECTS IN SERVICEABILITY PREDICTION OF THE HEAT EXCHANGERS

S u m m a r y

This paper presents the analysis of the factors which influence the operation, durability and reliability of heat exchangers. Major attention was devoted to the corrosion influence while selecting the materials for manufacturing heat transfer plates and tubes of heat exchangers. The paper presents the examples of the mostly occurring defects in the heat exchangers due to corrosion and other negative factors. Analysis of the chemical composition, mechanical and thermal properties of plates for heat exchangers was done. Coating influence as performance parameters and durability of connecting tubes of heat exchangers were developed. Negative role of iron impurities in the water for corrosion of copper brazed junctures in HE was determined. An experimental investigation of stress-strain for different steels of connecting tubes, microhardness tests of cross-section of coated tube, relationship between tensile strength and hardness of material were also estimated.

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ВЛИЯНИЕ МЕХАНИЧЕСКИХ СВОЙСТВ И МАТЕРИАЛА НА ФУНКЦИОНАЛЬНОСТЬ ТЕПЛООБМЕННИКОВ

Р е з ю м е

В настоящей работе приведен анализ факторов, влияющих на функциональность, долговечность и надежность теплообменников. Большое внимание уделено процессу коррозии при подборе материалов, используемых для производства теплообменных пластин и труб теплообменников. Приведены примеры наиболее часто возникающих дефектов теплообменников из-за коррозии и других негативных факторов. Проведен анализ химического состава, механических и тепловых характеристик материалов, используемых для изготовления пластин теплообменников. Исследовано влияние покрытия соединительных труб теплообменников на их эксплуатационные свойства и долговечность. Определено негативное влияние примесей железа в воде при коррозии медных сварных швов в теплообменниках. Представлены экспериментальные диаграммы растяжения труб, изготовленных из разных сталей, составлены диаграммы прочности, определена микротвердость сечения покрытой трубы, учтена взаимосвязь между предельными напряжениями и твердостью материала.

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