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RESEARCH

Heat Exchanger Tube to Tube Sheet Joints Corrosion Behavior

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A B S T R A C T

Paper presents the studies made by the authors above the tube to tube sheet fittings of heat exchanger with fixed covers from hydrofining oil reforming unit. Tube fittings are critical zones for heat exchangers failures. On a device made from material tube and tube sheet at real joints dimensions were establish axial compression force and traction force at which tube is extracted from expanded joint. Were used two shapes joints with two types of fittings surfaces, one with smooth hole of tube sheet and other in which on boring surface we made a groove. From extracted expanded tube zones were made samples for corrosion tests in order to establish the corrosion rate, corrosion potential and corrosion current in working mediums such as hydrofining oil and industrial water at different temperatures. The corrosion rate values and the temperature influence are important to evaluate joints durability and also the results obtained shows that the boring tube sheet shape with a groove on hole tube shape presents a better corrosion behavior then the shape with smooth hole tube sheet.

1. INTRODUCTION

Shell and tube heat exchangers are most commonly used in the process refinery industries due to a large ratio of heat transfer area to volume and weight. The tubes are the basic component of the heat exchanger, providing the heat transfer surface between one fluid flowing inside the tube and the other fluid flowing across the outside of the tubes. The tubes are held in place by being inserted into holes in the tube sheet and there either expanded into grooves cut into the holes or welded to the tube sheet were the tube protrudes from the surface. The main failures of heat exchangers are: corrosion of tubes and jacket, tubes blockage and failures of tube to tube sheet joints. Paper presents the studies made by authors above the tube to tube sheet fittings of heat exchanger, type BEM as classified of Tubular Exchanger Manufacturers Association, with fixed covers from hydrofining oil reforming unit, [1]. In Fig. 1 is presented the catalytic reforming unit of hydrofining oil schema were heat exchanger has position “121-S1”. Weldings between tubes and tube sheet is not recommended [2,3,4]. At studied heat exchanger the tube to tube sheet are expanded joints. The tubes and tube sheet, in addition to mechanical requirements, must withstand corrosive attack by both fluids in the heat exchanger and must be electrochemically compatible with the tube and all tube-side material [1,2,3].

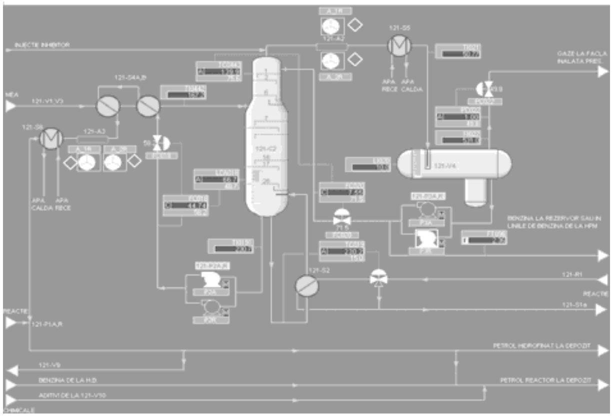

Fig. 1. Catalytic reforming unit schema.

At heat exchanger analyzed through the jacket is circulating hydrofining oil and through the tubes is circulating industrial water. In Table 1 are presented the main working conditions.

Table 1. Main working conditions

Parameter	Jacket	Tubes
Maximum working pressure, MPa	1.15	0.65
Maximum temperature, ^{0}C	70	38
Minimum temperature, ^{0}C	50	30
Working medium	Hydrofining oil	Industrial water
Danger	Toxic, inflammable	-

The mechanical process of expanding of tube comprises two distinct phases, [4]:

a) *pre expanding of tube*, that preliminary flexible flare or / and elastic-plastic the tubular element (*TE*) until it comes in contact with the wall tube sheet hole (*TP*);

b) *proper expanding of tube*, additional enlargement mainly concerned elastic-plastic, residual *TE*, while broadening mainly flexible, reversible, the holes in *TP* as shown in Fig. 2, [4].

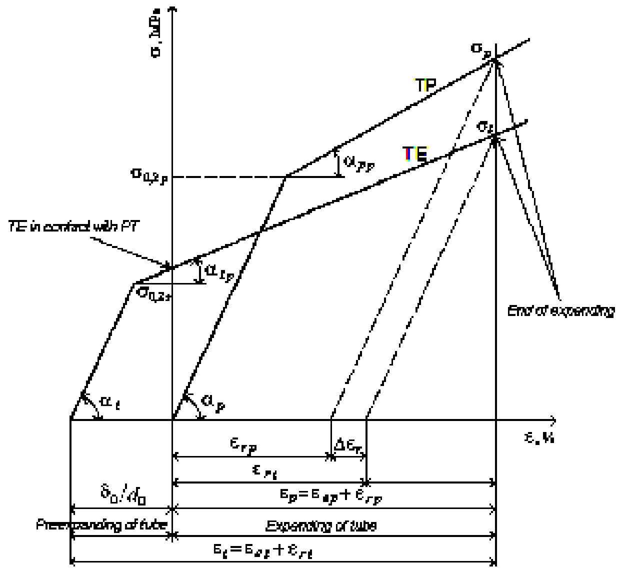

Fig. 2. Typical characteristic curves of *TE* materials and, respectively, *TP* regarded as joint materials building plastic linear hardening.

Pre expanding of tube phase corresponds to full depletion clearance of assembly $\delta_0 = 2\delta$ (Fig.3), [4].

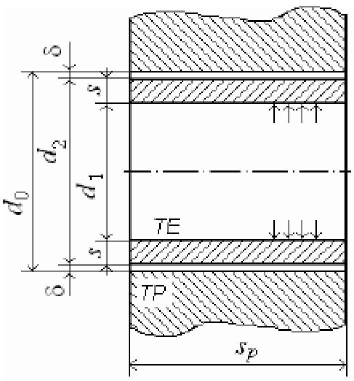

Fig. 3. Tube to tube sheet schema

The main requirement of a tube-to tube sheet joint is better to resist the axial stress, compressive or tensile, applied to tube. This happens if tube to tube sheet joints, where tubes and tube sheet are made of steel, when the hoop stress in tube sheet is higher than in tubes [4].

In order to better respect conditions of tension and compression in expanded tube to tube sheet joints the paper propose a different geometry of tube sheet which on boring surface we made a groove.

2. EXPERIMENTS

2.1 Tension and compression tests

To simulate the tube to tube sheet expanded joints were prepared samples at real joint dimensions. In Fig. 4 is presented the tube sheet sample with smooth hole tube sheet and in Fig. 5 the tube sheet sample which on boring surface we made a groove.

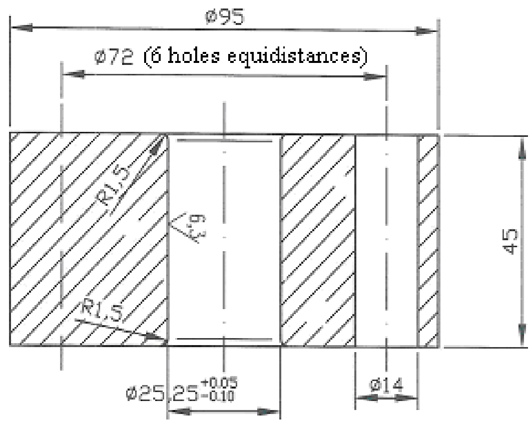

Fig. 4. Tube sheet with smooth hole tube sheet.

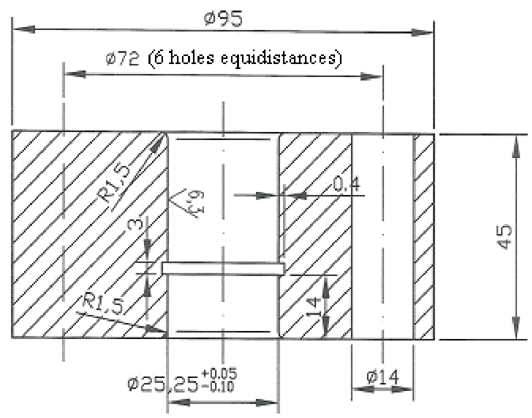

Fig. 5. Tube sheet with a groove on boring surface.

In Fig. 6 it is shown the tube samples dimensions.

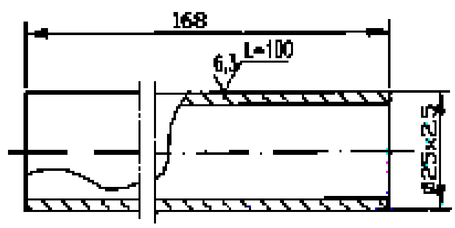

Fig. 6. Tube sample construction.

Tube sheet samples were made of steel type P355 NH, EN 10028 – 2:2009 and tubes of steel type P265 GH, SR EN 10217-5. The samples were extruded in similar conditions as real components.

The obtained assemblies were tested at tension and at compression. In Fig. 7 it is shown the tension variation vs. tube displacement in expanded joint with smooth hole tube sheet.

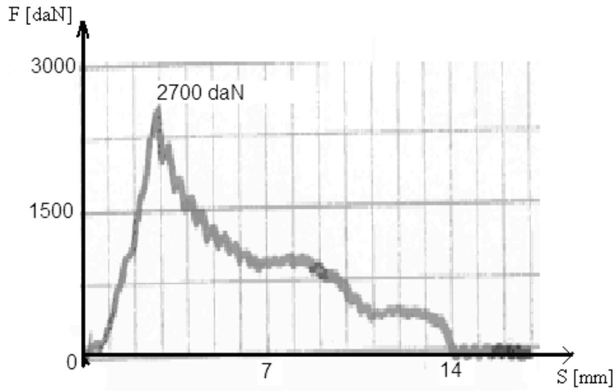

Fig. 7. Tension variation vs. tube displacement in expanded joint with smooth hole tube sheet.

In Fig. 8 it is presented the tension variation vs. tube displacement in expanded joint with a grove on tube sheet boring surface.

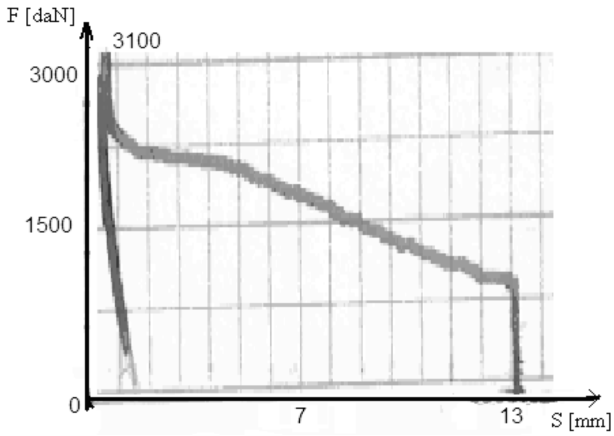

Fig. 8. Tension force variation vs. tube displacement in expanded joint with a groove on boring surface.

From Figs. 7 and 8 could be observed that the tension values were grater at expanded joint with tube sheet with a grove on boring surface. A similar behaviour was obtained at compression test. The maximum compression value obtained at expanded joint with smooth hole tube sheet was 3280 daN and at joint with a grove on tube sheet boring surface was 3350 daN.

The tension and compression results obtained confirm that model with a grove on tube sheet boring has an efforts better behavior.

Measuring the samples surfaces microgeometric parameters initial and after disassembling extruded joints by tension and by compression for the tubes that was in tube sheet with smooth hole tube sheet the roughness rise after compression and after tension than initial roughness. In Table 2 are presented the roughness modifications for tubes.

Table 2. Tubes surface roughness modification.

Type of extruded joint	Disassembling type	Roughness parameter modification, μm		
		Ra	*Rz*	*Rt*
Tubes for joint with smooth hole tube sheet	Tension	1.765	13.4	14.67
	Compression	0.445	-0.22	0.37
Tubes for joint with a grove on tube sheet boring surface	Tension	-0.051	-0.04	0.78
	Compression	-0.281	-1.96	-2.24

For the tubes that was in tube sheet with a groove on boring surface the roughness was smaller after compression and after tension than initial roughness. The tube sheet surface roughnesses were greater in case of disassembling by tension than in case of disassembling by compression for both tested geometries.

2.2 Corrosion tests

From both types expanded joints with tube sheet with smooth hole and with a grove on tube sheet boring surface were extracted samples from tube tubes active surfaces for corrosion tests. The samples were of steel type P265 GH, SR EN 10217-5. Also were tested samples extracted from tubes not used for expanded joints. Samples were named:

- "I" extracted from tubes not used for expanded joints:
- "5A" extracted from tubes from expanded joint with smooth hole tube sheet;
- "1A" extracted from tubes from expanded joint with a grove on tube sheet boring surface.

Working medium were industrial water with *pH*=7.18, *conductivity*=1524 μS/cm, total solid deposition *TDS*=42 mg/l and hydrofining oil with *pH*=5.55, *conductivity*=80pS/m, *sulphur*=1 ppm. Testing medium temperatures were 20, 40, 60 and 70 ^{0}C.

Samples have parallelepiped shapes and were machined without affecting tubes active surface. At immersion corrosion tests the corrosion rate was obtained with relation, [5]:

$$v_{cor} = 8.76 \cdot \frac{m_f - m_i}{A \cdot \tau \cdot \gamma}, \text{ mm/year} \quad (1)$$

m_f - sample final mass, g;
m_i - initial sample mass, g;
A - sample area, m^2;
τ - time, hours;
γ - specific weight, g/cm^3.

In Fig. 9 is it presented the corrosion rate variation in time at temperature of 20 ^{0}C for tube samples immersed in industrial water.

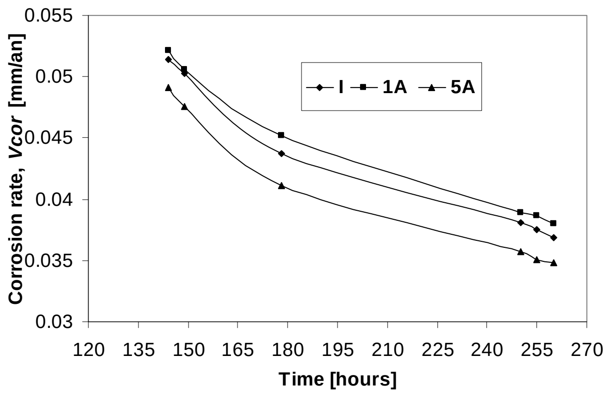

Fig. 9. Corrosion rate at 20 ^{0}C in industrial water.

In Fig. 10 it is shown the corrosion rate vs. time at temperature 40 ^{0}C, in Fig. 11 at 60 ^{0}C and in Fig. 12 at 70 ^{0}C in industrial water.

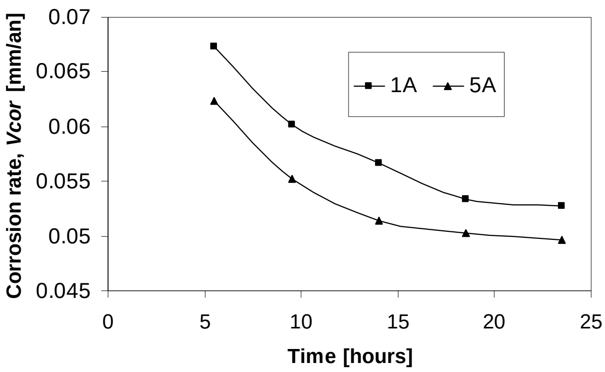

Fig. 10. Corrosion rate at 40 ^{0}C in industrial water.

From Figs. 9-12 could be observed that corrosion rate rise with temperature. Also the samples made from tube expanded joint with smooth hole tube sheet have a better corrosion behavior than samples made of tube with joint expanded having a grove on tube sheet boring surface.

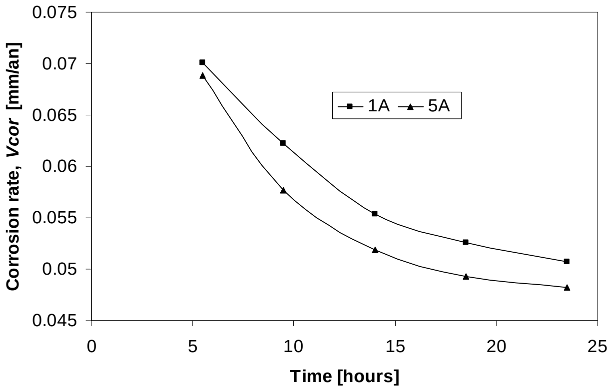

Fig. 11. Corrosion rate at 60 ^{0}C in industrial water.

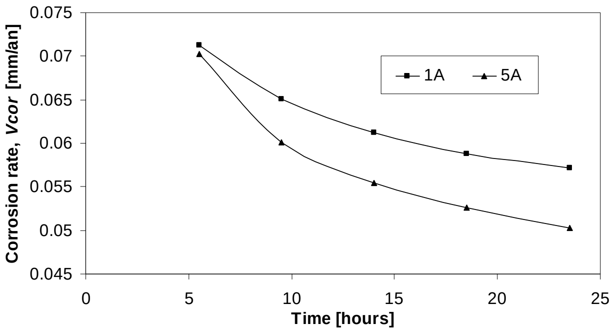

Fig. 12. Corrosion rate at 70 ^{0}C in industrial water.

In Fig. 13 it is presented the corrosion rate variation in time at temperature of 70 ^{0}C for tube samples immersed in hydrofining oil.

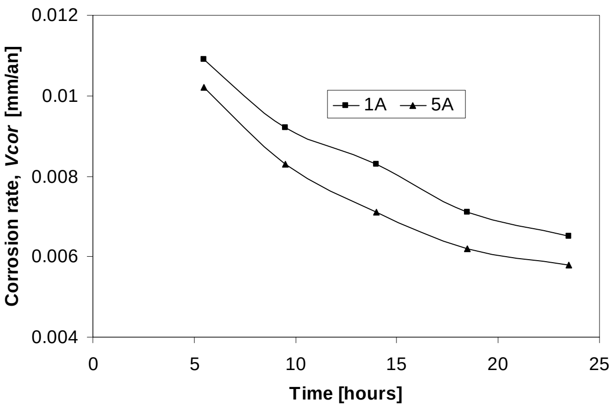

Fig. 13. Corrosion rate at 70 ^{0}C in hydrofining oil.

At temperatures of 20, 40 and 60 ^{0}C was observed a similar behaviour of corrosion rate as shown in Fig. 13. Could be observed that in hydrofining oil a better corrosion behaviour presents samples extracted from tube expanded joint with smooth hole tube sheet than samples extracted from tube expanded joint with a grove on tube sheet boring surface.

To establish electrochemical parameters, corrosion potential E_{corr}, corrosion current I_{corr} and corrosion rate v_{corr}, were extracted samples from tubes none extruded similar as from immersion corrosion tests. Specimens were machined with small cutting conditions and with cutting fluid in order to avoid the influence above metallographic structure at dimensions $\varnothing 16_{-0.1}$x3 mm. Active samples surface was polish with 500 Mesh abrasive papers.

There are several electrochemical techniques that can be used to evaluate the behavior of materials in aggressive medium such as [5,6,9]: potentiodynamic anodic, cathodic or both polarization measurements, galvanic corrosion measurements, potentiostatic measurements, linear polarization, pitting scans, Tafel plots measurements etc. Tafel plots technique quickly yields corrosion rate information. The linear portion of the anodic or cathodic polarization logarithm current vs. potential plot is extrapolated to intersect the corrosion potential line. This permits rapid, high accuracy measurement of extremely low corrosion rates. For this reason to determine electrochemical parameters we used this technique.

According to the mixed potential theory [5,6,9], any electrochemical reaction can be divided into two or more oxidation and reduction reactions, and can be no accumulation of electrical charge during the reaction. In a corroding system, corrosion of the metal and reduction of some species in solution is taking place at same rate and the net measurable current, i_{meas} is zero. Electrochemically, corrosion rate measurement is based on the determination of the oxidation current, i_{ox} at the corrosion potential, E_{corr}. This oxidation current is called the corrosion current, i_{corr}.

$$i_{\text{meas}} = i_{\text{corr}} - i_{\text{red}} = 0 \quad at \quad E_{\text{corr}} \tag{2}$$

The corrosion measurement system used was EG&G Princeton, New Jersey- model 350 that works together with compensator IR 351, [6,7,8,9].

Corrosion cell works with a saturated calomel reference electrode and specimen holder exposes 1 cm^2 of the specimen to the test solution. Using Tafel plots technique were determined the electrochemical parameters presented in Table 3. Electrochemical tests were made according to ASTM G5-94, [7] and ASTM G1-90, [8]. The reference electrode was Calomel ($Pt/Hg/Hg_2Cl_2$). For tests at 40 and 60 ^{0}C was used a thermometer and a thermostatic plate were placed corrosion cell.

In Fig. 14 it is presented the electrochemical parameters obtained by Tafel technique sample "*I*" in industrial water at 20 ⁰C.

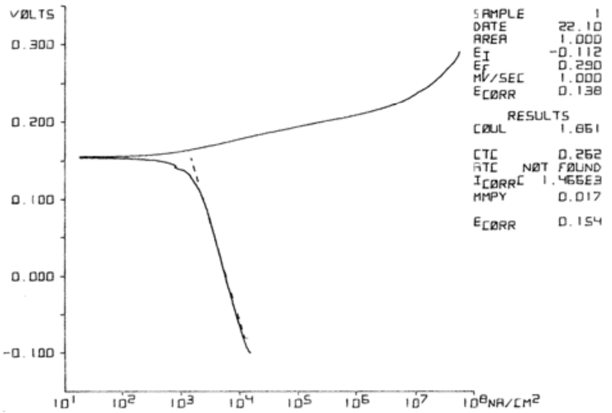

Fig. 14. Electrochemical parameters obtained by Tafel technique sample *"I"* in industrial water at 20 ⁰C.

In Table 3 are presented electrochemical parameters obtained for specimens extracted from non extruded tubes in industrial water.

Table 3. Electrochemical parameters.

Temperature T, ⁰C	Corrosion potential E_{cor}, V	Corrosion current I_{cor}, μA	Corrosion rate v_{cor}, mm/year
20	0.154	1.466	0.017
40	0.143	3.133	0.053
60	0.137	5.981	0.070

From values presented in Table 3 we could observe that the corrosion current and corrosion rate rise with temperature. The obtained corrosion rate values by immersion are proximate with values obtained by electrochemical method.

3. CONCLUSION

Tube to tube extruded joints at heat exchangers represents a critical zone for stress and corrosion.

The tension and compression tests show that proposed model of tube sheet with a grove on boring surface improve the tube to tube sheet joint.

It is recommended to disassembling the extruded joints by tension because the obtained surfaces roughness is smaller than in case of disassembling extruded joints by compression.

Because the tube sheet with a grove on boring surface rise the stress in joints, more than smooth tube sheet surface, this modify the corrosion potential and the corrosion rate is greater.

The differences between corrosion rates for two models is not significant, nevertheless the number of groves and groves dimension must be reconsidered in order to obtain a uniform stress on the entire contact surface in the extruded joint.

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