SOME ASPECTS REGARDING THE EVALUATION OF THE RESIDUAL LIFETIME OF SOME PIPES USED IN THE PETROCHEMICAL INSTALLATIONS V. CASE STUDY

IATAN I. RADU[1*], POPESCU C. IONEL [2], POPA T. CARMEN [3]

[1] POLITEHNICA University of Bucharest, Splaiul Independentei 313, Bucharest, sector 6, cod 06042,

[2] Project Manager, Biogas Division, Rokura SRL,

[3] VALAHIA University of Targoviste

Abstract: The paper analyses the produced stress state in a pipe system, taking into account the period of use and conservation, namely the pipe wall thinning by corrosion. It is estimated the further duration of use and the next periodic inspection for the structure safety.

Keywords: pipe, produced stress state, lifetime.

1. INTRODUCTION

In the industrial practice, the cases of appreciation of the lifetime of the mechanical structure or of a part of it, after the forecast period, are frequent. For this purpose, it is necessary to determine the appropriate measurements to establish the current geometry, on one hand, and the characteristics of the building materials, on analysis date, on other side.

Unfortunately, if the first part of the previous observation is plausible, the second, usually, is not always possible. In addition, it requires an accurate knowledge both of the normal operating conditions, and those of the conservation of the structure or of the analyzed component [1 - 8].

Therefore, to propose a finite period of use of the section of the pipe, that is the subject of this paper, the pipe wall thinning was taking into discussion, with a medium rate of corrosion, over its lifetime or that of conservation.

The storage conditions of the conservation of the section of the pipe, that is the subject of this paper, as in other cases [1 - 7], are not known with precision. The mentioned section of pipe (composed of linear sectors with the geometry $\varnothing 28-3$, $\varnothing 60-4$, respectively the leg pipes with $\varnothing 60-4$), was provided in a steam cracker, with the aim of transporting the condense between a specific machine and another connecting pipe. In the pipe,

[*] Correspondence with the author r_iatan@yahoo.com

structure there is no safety valve or elements of compensation of the thermal deformations, except its own configuration (Figure 1). During the 31 years since the release operation, on the section of pipe there has been no intervention (that is about the period of use, in essence).

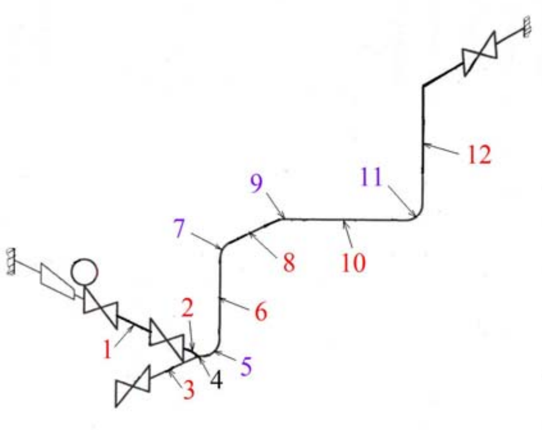

Fig. 1. The pipe route sketch.

2. INITIAL DATA

- Calculating pressure: $p_c = 1.5\,MPa$; - Working pressure: $p_l = 1.23\,MPa$; - Hydraulic test pressure: $p_h = 2.2\,MPa$; - Maximum temperature: $T_M = 200^0 C$; - Minimum temperature: $T_m = 183^0 C$; - Working environment: condensation.

The construction materials of the structure have the characteristics in the Table 1.

Table 1. The values of mechanical properties of the used materials.

Size	**M.U.**	**OLT 35 K**	**OLT 35**
Tensile strength , σ_r	N/mm^2	350 .... 450 [9, 10]	
0.2% yield at 20°C	N/mm^2	230 [10]	240 [9]
0.2% yield at 183°C	N/mm^2	194 [10]	195 [9]
0.2% yield at 200°C	N/mm^2	190 [10]	190 [9]
Maximum allowed values of the nominal design stress at 20°C	N/mm^2	146	
Maximum allowed values of the nominal design stress at 183°C	N/mm^2	129.3	130
Maximum allowed values of the nominal design stress at 200°C	N/mm^2	126.7	
Maximum allowed values of the nominal design stress in hydraulic testing and exceptional used cases	N/mm^2	207; 209.1	216; 218.2

► Maximum allowed values of the nominal design stress to the hydraulic test is calculated with the relation $0.9 \cdot \sigma_c^{20}$; $\sigma_c^{20}/1.1$,corresponding to the point 5.5.3.2 [11].

► The steel OLT 35 is according to STAS 8183-80, equivalent to the German steel St 35.8 - DIN 17175 [9], table 120 (recommended for pipe up to 580 ^{0}C temperature).

Maximum allowed values of the nominal design stress at temperature T are calculated with the relation (paragraphs 2.6.12 and 5.5.3.1 [11]):

$$\sigma_a^T = \min\left\{ \frac{\sigma_c^T}{1.5}; \frac{\sigma_r}{2.4} \right\},$$

Where: σ_c^T is the yield at temperature T .

3. THE RESULTS OF THE EXPERIMENTAL MEASUREMENTS

Before the actual measurements, we performed a visual inspection of the exterior of the pipes, uncovering the isolated areas. In the corroded portions, the pipe outer surface was machined, so that the measurement of the wall thickness can be produced. The observed defect has a reduced expansion and a small depth in these conditions where it was considered that there are no problems for a normal operation of the pipe.

The measurement of the wall thickness was performed with the T - Mike –El apparatus, by direct reading of data provided by the transducer type DA 308, having the diameter of 6 mm, with is attached to the pipe, using the coupling special grease, using an ultrasonic velocity 5730 m/s, frequency 4 MHz. The readings were made in four points, located on two perpendicular diameters, both on the linear branches of the pipe, and on the curved areas. The examination with penetrating radiations what was performed in 15% from the weld length, as the examination with penetrated liquids, have not lead to the detection of some not admitted defects.

Table 2. The results of the experimental measurements.

Measurement zones (Figure 1)	**Thickness [mm]**		**Brinell hardness[HB]**	
	Minimum	**Maximum**	**Minimum**	**Maximum**
1	4,6	4,7	-	-
2	4,4	4,8	-	-
3 *	2,5	3,8	-	-
4	4,6	5,0	-	-
5 * *	6,0	7,5	146	156
6	4,7	4,9	-	-
7 * *	5,7	6,5	-	-
8	4,2	4,5	-	-
9 * *	3,1	4,5	-	-
10	4,6	4,9	-	-
11 * *	6,1	7,2	-	-
12	4,4	4,5	122	141
* - secondary pipe; * * - elbows				

The metallographic analysis, in accordance with SR 5000/1997, SR EN ISO 634/2003, SR EN ISO 6506-1 / 2006, performed with a microscope LEITZ Wetzlar SM-LUX-HL/448020 and apparatus for hardness EQO -

Tip/59.1196, showed a predominantly ferritic structure, grain 7 and 9, with globular pearlite at the grains limit. The microscopic analysis was performed on metallographic samples, located on two areas of the pipe.

4. CALCULATING RELATIONS FOR STRESSES IN THE LINEAR ZONES [12 - 16]

The meridional stresses σ_1 these annular σ_2, and the maximum equivalent stress σ_{ech}^{III}, calculated after the third theory of resistance [16], are established with the relations:

$$\sigma_1 = \frac{p \cdot r_m}{2 \cdot s}; \quad \sigma_2 = \frac{p \cdot r_m}{s}; \quad \sigma_{ech}^{III} = \sigma_{max} - \sigma_{min},$$

where:

p is, if necessary, the calculating pressure or the pressure of the hydraulic test;

r_m – the radius of median transversal surface of the pipe;

s – the pipe wall thickness.

Note: As follows, the calculation is made for the current state of the geometry of the pipe (taking into account the wall thickness determined by ultrasound measurements - Table 2).

4.1. Solicitations in the mainline $(\varnothing\, 60 - 4)$

The minimum thickness of the wall of the mainline ($\varnothing\, 60 - 4$ - the initial state) is noted in paragraph 9, with the value of 3.1 mm (Table 2).

The radius of the median area, in this case, is:

$$r_m = \frac{60 - 2 \cdot 4}{2} + \frac{3.1}{2} = 27.55\ mm.$$

The meridional and annular stresses, respectively that equivalent, have values:

- ***for the calculating pressure:***

$$\sigma_1 = \frac{1.5 \cdot 27.55}{2 \cdot 3.1} = 6.7\ N/mm^2; \qquad \sigma_2 = \frac{1.5 \cdot 27.55}{1.1} = 13.3\ N/mm^2;$$

$$\sigma_{ech}^{III} = 13.3\ N/mm^2.$$

Note: The condition of resistance 2.6.1.2 is satisfied, considering the stipulations of the paragraph 5.5.3.1 [11].

- ***for the hydraulic test pressure:***

$$\sigma_1 = \frac{2.2 \cdot 27.55}{2 \cdot 3.1} = 9.8\ N/mm^2; \qquad \sigma_2 = \frac{2.2 \cdot 27.55}{3.1} = 19.6\ N/mm^2;$$

$$\sigma_{ech}^{III} = 19.6\ N/mm^2.$$

Note: the condition of resistance, corresponding to the hydraulic test, is satisfied (see paragraph 5.5.3.2 [11]).

For the duration of 35 years, the rate of corrosion has the value:

$$v_c = \frac{4.0 - 3.1}{35} = 0.026\ mm\ /\ year\ .$$

The thickness of the pipe wall after another 12 years will have the value $s_{12} = 3.1 - 0.026 \cdot 12 = 2.79\ mm$. In such state, the medium radius of the pipe is:

$$r_m = \frac{60 - 2 \cdot 4}{2} + \frac{2.79}{2} = 27.4\ mm\ ,$$

so that the stresses are in the form:

- ***for the calculating pressure:***

$$\sigma_1 = \frac{1.5 \cdot 27.4}{2 \cdot 2.79} = 7.4\ N\ /\ mm^2\ ; \qquad \sigma_2 = \frac{1.5 \cdot 27.4}{2.79} = 14.7\ N\ /\ mm^2\ ;$$

$$\sigma_{ech}^{III} = 14.7\ N\ /\ mm^2\ .$$

<u>**Note:**</u> The condition of resistance 2.6.1.2 is satisfied, considering the provisions of paragraph 5.5.3.1 [11].

- ***for the hydraulic test pressure:***

$$\sigma_1 = \frac{2.2 \cdot 27.4}{2 \cdot 2.79} = 10.8\ N\ /\ mm^2\ ; \qquad \sigma_2 = \frac{2.2 \cdot 27.4}{2.79} = 21.6\ N\ /\ mm^2\ ;$$

$$\sigma_{ech}^{III} = 21.6\ N\ /\ mm^2\ .$$

<u>**Note**</u>: The condition of resistance is satisfied corresponding to the hydraulic test (see paragraph 5.5.3.2 [11].

As a result, the proposed period of 12 years, for later use is justified.

The calculation thickness of the wall of the leg pipe, based on the third theory of resistance, with taking in discussion of the outer diameter d_e of the pipe, has the expression [11]:

$$s_c = \frac{p_c \cdot d_e}{\left(2 \cdot \sigma_a^T - p_c\right) \cdot z + 2 \cdot p_c}\ ,$$

where: z - the coefficient of resistance of the welded joint (*z=1*), considering seamless pipes.

With the present data, we arrive at:
- ***the mainline*** $\left(\varnothing\ 60 - 4\right)$:

$$s_c = \frac{1.5 \cdot 60}{2 \cdot 126.7 - 1.5 + 2 \cdot 1.5} = 0.35\ mm \langle\ 4\ mm\ ;$$

- ***the secondary line*** $(\varnothing\ 28 - 3)$:

$$s_c = \frac{1.5 \cdot 28}{2 \cdot 126.7 - 1.5 + 2 \cdot 1.5} = 0.16\ mm\ \langle\ 3\ mm\ ,$$

for the steel OLT 35 K and OLT 35.

4. 2. Requests in the second line $(\varnothing\ 28 - 3)$

On **the secondary line** $(\varnothing\ 28 - 3)$ - paragraph 3 (Figure 1) – the minimum thickness is 2.5 mm.

The radius of the median surface, in this case, is:

$$r_m = \frac{28 - 2 \cdot 3}{2} + \frac{2.5}{2} = 12.25\ mm\ .$$

The meridional and annular stresses, respectively that equivalent have the values:

- ***for the calculating pressure:***

$$\sigma_1 = \frac{1.5 \cdot 12.25}{2 \cdot 2.5} = 3.7\ N / mm^2\ ; \qquad \sigma_2 = \frac{1.5 \cdot 12.25}{2.5} = 7.4\ N / mm^2\ ;$$

$$\sigma_{ech}^{III} = 7.4\ N / mm^2\ .$$

Note: The condition of resistance 2.6.1.2 is satisfied, considering the stipulations of paragraph 5.5.3.1 [11].

- ***for the hydraulic test pressure:***

$$\sigma_1 = \frac{2.2 \cdot 12.25}{2 \cdot 2.5} = 5.4\ N / mm^2\ ; \qquad \sigma_2 = \frac{2.2 \cdot 12.25}{2.5} = 10.8\ N / mm^2\ ;$$

$$\sigma_{ech}^{III} = 10.8\ N / mm^2\ .$$

Note: The condition of resistance, corresponding to the hydraulic test (see paragraph 5.5.3.2 [11]) is satisfied.

For the period of existence for 35 years, the rate of corrosion has the value:

$$v_c = \frac{3 - 2.5}{35} = 0.014\ mm / year\ .$$

The thickness of the pipe wall after another 12 years will have the value $s_{12} = 2.5 - 0.014 \cdot 12 = 2.33\ mm$. In such state, the medium radius of the pipe is:

$$r_m = \frac{28 - 2 \cdot 3}{2} + \frac{2.33}{2} = 12.17\ mm,$$

so that the stresses is in the form:

- ***for the calculating pressure***:

$$\sigma_1 = \frac{1.5 \cdot 12.17}{2 \cdot 2.5} = 3.7\ N/mm^2; \qquad \sigma_2 = \frac{1.5 \cdot 12.17}{2.5} = 7.4\ N/mm^2;$$

$$\sigma_{ech}^{III} = 7.4\ N/mm^2.$$

Note: The condition of resistance 2.6.1.2 is satisfied, considering the stipulations of paragraph 5.5.3.1 [11].

- ***for the hydraulic test pressure:***

$$\sigma_1 = \frac{2.2 \cdot 12.17}{2 \cdot 2.5} = 5.4\ N/mm^2; \qquad \sigma_2 = \frac{2.2 \cdot 12.17}{2.5} = 10.8\ N/mm^2;$$

$$\sigma_{ech}^{III} = 10.8\ N/mm^2.$$

Note: The condition of resistance, corresponding to the hydraulic test (see paragraph 5.5.3.2 [11]) is satisfied.

As a result**, the proposed period of 12 years,** for later use, is justified.

5. REQUESTS IN THE ELBOWS

Restrictions: The calculations specified for elbows are valid for [11]:

- outer diameters of the pipes of which the elbows larger than 70 mm, are confectioned;

- $70 \langle d_e \langle 159\ mm$, if $\frac{R_e}{d_e} \geq 3$ or $\frac{R_m}{d_e} \geq 2$ where R_e is the radius of curvature relative to the outer diameter of the pipe, and R_m the medium radius of curvature;

- for elbows with $d_e \rangle 159\ mm$, without restricting the ratio value $\frac{R_e}{d_e}$.

Analyzing the thickness values of the walls of the four elbows (C 1, C 2, C 3 and C 4 - items 5, 7, 9, 11 - Figure 1) it appears that they are above the nominal thickness (of 4 mm for the main pipe ($\varnothing 60 - 4$)), except for the leg pipe C 2 which has at intrados 3,1 mm.

For elbows, the required minimum thickness is that derived for the straight pipes of the route that one derived above (0.35 mm).

From the analysis of the above restrictions, it is noted that the value of their outer diameter does not satisfy the respective requirements, for the effectuation of the subsequent calculations.

6. CONCLUSIONS

- The (induced) stress state in pipe, in various stages normal operating conditions, hydraulic test) shows that the equivalent stresses are under the allowed values of the nominal design stresses;

– Both the values of the maximum effective stresses, and the value of the estimated corrosion rates, in different parts of the pipe route, show the use possibility for a period of 12 years. The prescriptions of the codes concerning the nondestructive examinations and protocols of the periodic inspections will be adopted.

REFERENCES

[1]. Iatan, I. R., Unele aspecte privind evaluarea duratei reziduale de viață a unor conducte din instalațiile petrochimice. I. Studiu de caz, *Volumul Workshop "Cercetări în vederea creării unor contoare de durată de viață pentru evaluarea on-line a siguranței în funcționare a structurilor mecanice – CONDUVI"*, Slănic Moldova, 25 – 26 iunie 2008, p. 63 – 69.
[2]. Iatan, I. R., Marin Alex., Unele aspecte privind evaluarea duratei reziduale de viață a unor conducte din instalațiile petrochimice. IIa. Studiu de caz*, Al XIV Simpozion Internațional de Mecanica Ruperii*, 10 – 11 octombrie 2008, Braşov, p. 131 – 138.
[3]. Iatan, I. R., Marin Alex., Unele aspecte privind evaluarea duratei reziduale de viață a unor conducte din instalațiile petrochimice. IIb. Studiu de caz, *Al XIV Simpozion Internațional de Mecanica Ruperii,* 10 – 11 octombrie 2008, Braşov, p. 139 – 145.
[4]. Iatan, I. R., Marin Alex., Unele aspecte privind evaluarea duratei reziduale de viață a unor conducte din instalațiile petrochimice. IIIa. Studiu de caz*, Al XV-lea Simpozion Național de Mecanica Ruperii,* Sibiu, 6 – 7 noiembrie 2009, p. 111 – 118.
[5]. Iatan, I. R., Marin Alex., Unele aspecte privind evaluarea duratei reziduale de viață a unor conducte din instalațiile petrochimice. IIIb. Studiu de caz*, Al XV-lea Simpozion Național de Mecanica Ruperii*, Sibiu, 6 – 7 noiembrie 2009, p. 127 – 132.
[6]. Iatan, I. R., Popescu I. C., Carmen T. Popa, Some Aspects Regarding the Evaluation of the Residual Lifetime of Some Pipes Used in the Petrochemical Installations. Iv. Case Study, Buletinul Universității Petrol – Gaze din Ploieşti, Seria tehnică, vol. LXIII, nr. 1, 2011, p. 53 – 60.
[7]. Rusu, O., Teodorescu, M., Lascu – Simion, N., Oboseala metalelor (baze de calcul), Vol. 1, Editura Tehnică, Bucureşti, 1992.
[8]. Rusu, O., Teodorescu, M., Oboseala metalelor (aplicații inginereşti), Vol. 2, Editura Tehnică, Bucureşti, 1992.
[9]. Pavel, A., Materiale si rezistente admisibile folosite in constructia de utilaje pentru industria petroliera prelucratoare si petrochimica, Editura Didactică şi Pedagogică, Bucuresti, 1967
[10]. Slătineanu, R., Olteanu, I., Diță, Margareta, Fise de oteluri tipizate pentru constructia de masini, OTCM, Ministerul Industriei, Constructiilor de Masini, Oficiul de Informare Documentara pentru Industria Constructiilor de masini, 1984.
[11]. *** PT C10/2 – 2003. Ghid pentru proiectarea, construirea, montarea si repararea conductelor de abur si de apa fierbinte sub presiune.
[12]. Burducea, C., Leca, A., Conducte si retele termice, Editura Tehnică, Bucureşti, 1974.
[13]. Renert, M., Calculul şi construcția utilajului chimic, vol. 1, Editura Didactică şi Pedagogică, Bucuresti, 1971.
[14]. Jinescu, V. V., Calculul si constructia utilajului chimic, petrochimic si de rafinarii, vol. 1, Editura Didactică şi Pedagogică, Bucuresti, 1983.
[15]. Pavel, A., Elemente de inginerie mecanica (pentru petrochimie), Editura Didactică şi Pedagogică, Bucureşti, 1981.
[16]. Buzdugan, Gh., Rezistența materialelor, Editura Tehnică, Bucureşti, 1980.