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Some Aspects Regarding the Evaluation of the Residual Lifetime of Some Pipes Used in the Petrochemical Installations. IV. Case Study

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Abstract

The paper examines the induced stress state in a section of pipe with an intermediate leg pipe, 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 possible controls for the structure safety.

Key words: *pipe, induced stress state, lifetime*

Introduction

The research of a possible extension of the use life of a component of the petrochemical installations, which worked a certain period and another period stated in conservation, raises some difficult problems to solve. This observation is conditioned of the practical details, not always conclusive, regarding the normal working, on the one hand, and the storage conditions, on the other hand [1-5]. The known procedures for estimating the lifetime of the mechanical structures, found in the specialty literature [6-7], based on material characteristics, didn't led to limited periods of time. As such, it has taken into consideration, in this case, the pipe wall thinning, with an average speed of corrosion, throughout the expressed duration, in working or in storage. The storage conditions of the section of pipe, that is the subject of this paper, as in the other cases [1-5], are not known with precision. The section of pipe, that is the subject of this analysis, was provided in a steam cracker, with the task of downloading the pressure of the working

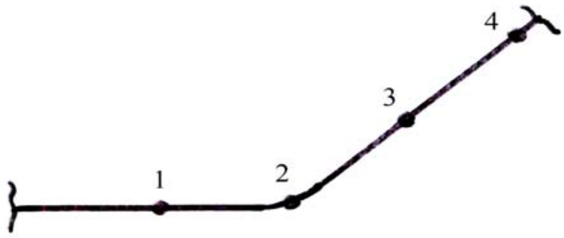

Fig. 1. Section of pipe

environment from a upstream vessel, into the atmosphere, through a purge valve. The structure consists of two straight sections, joined by a leg pipe at 120 ^{0} (fig. 1). During the 31 years since the release working, the section of pipe, there has been no intervention (that is the period of use, in essence).

Initial data

The table 1 specifies some of the characteristics of the construction materials used to make the section of the pipe, and the admissible resistances (stresses), according to the accepted norms.

Table 1. The characterization of the construction materials

Size	M.U.	OLT 35 K	OLT 35
Breaking resistance, σ_r	N/mm^2	350.... 450 [8, 9]	
Yield limit at 20°C	N/mm^2	230 [9]	240 [8]
Yield limit at 250°C	N/mm^2	170 [9]	165 [8]
Yield limit at 280°C	N/mm^2	152 [9]	150 [8]
Admissible resistance (stress) at 20°C	N/mm^2	146	
Admissible resistance (stress) at 250°C	N/mm^2	$113{,}3/96{,}3^{\bullet}$	$110/93{,}5^{\bullet}$
Admissible resistance (stress) at 280°C	N/mm^2	$101{,}3/86{,}1^{\bullet}$	$100/85^{\bullet}$
Admissible resistance (stress) on hydraulic test: $((0{,}9\cdot\sigma_c^{20})\,;(\sigma_c^{20}/1{,}1)$	N/mm^2	207; 209,1	216; 218,2

Note: The equalizing of the mentioned steels is: OLT 35 - STAS 8183 / 80 with P 235 TR 2 – SR EN 10216 – 1 / 2003; OLT 35 K – STAS 8184 / 84 with P 235 GH – SR EN 10216 – 2 /2003.

The working environment characteristics circulated through the pipe section have the values:
- working pressure: $p_l = 1{,}23\ MPa$;
- calculation pressure: $p_c = 1{,}5\ MPa$;
- hydraulic test pressure: $p_h = 2{,}2\ MPa$;
- maximum temperature: $T_M = 280\ ^0C$;
- minimum temperature: $T_m = 250\ ^0C$;
- working environment: condensation.

►The admissible resistance (stress) on hydraulic test, calculated with the equation $\sigma_c^{20}/1{,}1$, corresponds to section 5.5.3.2 [10].
►The steel OLT 35 is conform STAS 8183-80, the equivalence to the german steel St 35.8 OLT 35 – DIN 17175 [8], the table 120 (recommended for pipes having the temperature bellow 580 ^{0}C).
Note: The admissible resistances at temperature T are calculated with the relation (sections 2.6.12 and 5.5.3.1 [10]):

$$\sigma_a^T = \min\left\{\frac{\sigma_c^T}{1,5}; \frac{\sigma_r}{2,4}\right\}, \tag{1}$$

where σ_c^T is the yield limit at temperature T.

The admissible stresses values, marked with "$\bullet$", represent the calculated values taking into account the influence of the weld quality coefficient, equal to 0.85, respectively:

$$\left(\sigma_a^T\right)^{\bullet} = 0,85 \cdot \sigma_a^T . \tag{2}$$

The straight sections of pipe and the leg pipe are characterized by $\varnothing\, 219 \times 7$.

The experimental measures results

Before the actual measurements were performed a proper view of the exterior of the pipe, discovering the isolated areas.

In the corroded sections the polishing of the outer surface of the pipe was take place, so that the measurement of the wall thickness can be produced. The observed defects had reduced expansion and a little depth, stage where it was considered that there are not problems for a working of the pipe.

Table 2. The experimental measures results

Measuring zones (fig. 1)	Thickness [mm]		Brinell hardness [HB]	
	Min.	Max.	Min.	Max.
1	6,2	6,5	132	140
2	6,0	7,2	91	108
3	6,0	6,4	-	-
4	8,2	8,4	-	-

The wall thickness measurement was performed with the T - Mike – El apparatus, by direct reading the provided data offered by DA 308 transducer, with 6 mm in diameter, attached to the pipe by using the coupling special grease, the ultrasonic speed 5730 m/s, frequency 4 MHz.
The penetrating radiation examination was performed in 15%, and penetrating liquids examination, didn't led to the detection of some no admitted defects.

Table 3. The chemical composition of the steels used for pipe

Area Measurement (fig. 1)	Chemical element [%]									
	C	Si	Mn	P	S	Cu	Ni	Cr	Mo	V
1	0,11	0,21	0,80	0,020	0,025	0,23	0,30	0,20	0,01	$\langle$ 0,01
2	0,12	0,20	0,75	0,020	0,025	0,07	0,30	0,07	0,01	$\langle$ 0,01

Note: Compared with the reading values of standards there is an appropriate classification of the chemical composition, except for manganese (manganese containing standardized 0.35 ... 0.60%) which is in excess of the existing pipe.

The metallographic analysis, in accordance with SR 5000/1997, SR EN ISO 634/2003, SR EN ISO 6506-1 / 2006, performed with the microscope LEITZ WETZLAR SM-LUX-HL/448020 and the apparatus for hardness EQO - Model/59.1196, showed a predominantly ferrite structure, grain 7, with globular pearlite, at the grains limit, on the linear left section of the pipe and ferrite-pearlite, easy needle, in its leg pipe area.

In the mentioned areas the minimum and maximum hardness values had been find out and specified in the table 2.

Calculation of the stresses characteristic to the linear areas [11-15]

The meridian stresses σ_1, those annular σ_2, and the maximum equivalent stress, calculated after the III resistance theory [15] are determined by the relations:

$$\sigma_1 = \frac{p_c \cdot r_m}{2 \cdot s}; \quad \sigma_2 = \frac{p_c \cdot r_m}{s}; \quad \sigma_{ech}^{III} = \sigma_{max} - \sigma_{min}, \tag{3}$$

where p_c is, after case, the calculation pressure or hydraulic test pressure; r_m – radius of the median surface of the pipe; s – pipe wall thickness; σ_{max}, σ_{min} – maximum, respectively minimum pressure, deduced by calculation.

Note: In what follows, the calculation is made for the current state of the pipe geometry (taking into account the wall thicknesses by measurements determined with ultrasound).

The calculation thickness of the wall pipe, based on the III theory of resistance, taking into discussion the external diameter d_e, has the expression [10]:

$$s_c = \frac{p_c \cdot d_e}{\left(2 \cdot \sigma_a^T - p_c\right) \cdot z + 2 \cdot p_c}, \tag{4}$$

where z is the coefficient of resistance of the welded joint ($z = 0,85$, considering pipes without weld), σ_a^T – admissible resistance (stress) of the pipe material at working temperature. The above expression is valid for the wall thickness of the leg pipes belonging pipe route, too.

The value follows:

$$s = \frac{1,5 \cdot 219}{\left(2 \cdot 101,3 - 1,5\right) \cdot 0,85 + 2 \cdot 1,5} = 1,9 \ mm \ \langle \ 7 \ mm . \tag{5}$$

From the data analysis provided by the Bulletin of the thickness examination with ultrasounds, we notice the minimum thickness of 6 **mm**, so that the average radius has the value:

$$r_m = \frac{219 - 2 \cdot 7}{2} + \frac{6}{2} = 105,5 \, mm \ . \tag{6}$$

The effect of the calculation pressure ($p_c = 1,5 \, MPa$):

The stresses have the values:

$$\sigma_1 = \frac{1,5 \cdot 105,5}{2 \cdot 6} = 13,2\ N/mm^2 ; \sigma_2 = \frac{1,5 \cdot 105,5}{6} = 26,4\ N/mm^2 ; \qquad (7)$$

$$\sigma^{III}_{ech} = 26,4\ N/mm^2 . \qquad (8)$$

Note: The condition of resistance 2.6.1.2 is satisfied, considering the stipulation of section 5.5.3.1 [10].

The effect of hydraulic test pressure ($p_h = 2,2\ MPa$ **)**

The stresses have the values:

$$\sigma_1 = \frac{2,2 \cdot 105,5}{2 \cdot 6} = 19,4\ N/mm^2 ;\ \sigma_2 = \frac{2,2 \cdot 105,5}{6} = 38,7\ N/mm^2 ; \qquad (9)$$

$$\sigma^{III}_{ech} = 38,7\ N/mm^2 . \qquad (10)$$

Note: The condition of resistance adequate the hydraulic test (see section 5.5.3.2) is satisfied.

The estimating of the residual life of service

Accepting the average corrosion speed corresponding to 35 years of the existence pipe (18 years working and 17 years in conservation), with the value:

$$v_c = \frac{7-6}{35} = 0,029\ mm/an , \qquad (11)$$

and proposing a further using of 12 years, the defect depth a_{12} will reach:

$$a_{12} = (7-6) + 0,029 \cdot 12 = 1,35\ mm , \qquad (12)$$

corresponding, in this way, a wall thickness of 7 – 1,35 = 5.65 mm and an average radius of the pipe cross section:

$$r_m = \frac{219 - 2 \cdot 7}{2} + \frac{5,65}{2} = 105,33\ mm . \qquad (13)$$

The effect of the calculation pressure is reflected of the stresses values developed in this phase:

$$\sigma_1 = \frac{1,5 \cdot 105,33}{2 \cdot 5,65} = 14,0\ N/mm^2 ;\ \sigma_2 = \frac{1,5 \cdot 105,33}{5,65} = 28,0\ N/mm^2 ; \qquad (14)$$

$$\sigma^{III}_{ech} = 28,0\ N/mm^2 . \qquad (15)$$

Note: The condition of resistance 2.6.1.2 is satisfied, considering the provisions of the section 5.5.3.1 [10].

The effect of hydraulic test pressure is reflected in the existence of the following stresses:

$$\sigma_1 = \frac{2{,}2 \cdot 105{,}33}{2 \cdot 5{,}65} = 20{,}5\ N / mm^2 ;\ \sigma_2 = \frac{2{,}2 \cdot 105{,}33}{5{,}65} = 41{,}0\ N / mm^2 ; \quad (16)$$

$$\sigma_{e\,c\,h}^{III} = 41{,}0\ N / mm^2 . \quad (17)$$

Note: The condition of resistance corresponding to the hydraulic test (see sections 5.5.3.2 [10]) is satisfied.

Requests in the leg pipe C 1 (section 2 - fig. 1)

Restrictions: The calculations shown below are valid for [10]:

► leg pipes with external diameters of the pipes which are made larger than 70 mm;

► $70 \langle d_e \langle 159\ mm$, 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 average radius of curvature;

► for leg pipes with $d_e \rangle 159\ mm$, without restricting the value $\frac{R_e}{d_e}$.

The stresses developed in the wall leg pipe are established with the relations:

$$\sigma_{i\,m} = \frac{p_c \cdot \left(d_e - s_i^{\bullet} - s_e^{\bullet}\right)}{2 \cdot s_i^{\bullet} \cdot z} \cdot \frac{2 \cdot R_e - 0{,}5 \cdot d_e + 1{,}5 \cdot s_i^{\bullet} - 0{,}5 \cdot s_e^{\bullet}}{2 \cdot R_e - d_e + s_i^{\bullet}} + \frac{p_c}{2} \leq \sigma_a^T , \quad (18)$$

for intrados, respectively:

$$\sigma_{e\,m} = \frac{p_c \cdot \left(d_e - s_i^{\bullet} - s_e^{\bullet}\right)}{2 \cdot s_e^{\bullet} \cdot z} \cdot \frac{2 \cdot R_e + 0{,}5 \cdot d_e + 0{,}5 \cdot s_i^{\bullet} - 1{,}5 \cdot s_e^{\bullet}}{2 \cdot R_e + d_e - s_e^{\bullet}} + \frac{p_c}{2} \leq \sigma_a^T , \quad (19)$$

for its extrados.

In the above equalities the notations were used: R_i, R_e – radii of curvature of the leg pipe referring to the inner diameter, respectively to the outer diameter; $s_i^{\bullet}, s_e^{\bullet}$ – resistance thickness at intrados, respectively the extrados of the leg pipe.

The minimum thickness of the wall:

$$s_c = \frac{1{,}5 \cdot 219}{2 \cdot 101{,}3 - 1{,}5 + 2 \cdot 1{,}5} = 1{,}6\ mm \langle 7\ mm , \quad (20)$$

in the case of the section pipe where no belt weld, respectively the wall thickness (1.9 mm) above established, in the conditions to the existence the weld belt.

For this leg pipe $R_e / d_e = 1{,}5$, is known where from, for $d_e = 219\ mm$, we obtain $R_e = 328{,}5\ mm$.

For the leg pipe C1 where $s_i^{\bullet} = 7{,}2\ mm$, $s_e^{\bullet} = 6{,}3\ mm$ the correct sizes are deducted:

$$d_e^{\bullet} = 219 - 2 \cdot 7 + 2 \cdot 6{,}3 = 217{,}6\ mm ;\ R_e^{\bullet} = 1{,}5 \cdot d_e^{\bullet} = 1{,}5 \cdot 217{,}6 = 326{,}4\ mm . \quad (21)$$

Therefore, the stresses developed in the intrados and the extrados of the leg pipe have the values:

$$\sigma_{i\ m} = 27{,}3\ N / mm^2\ ;\ \sigma_{e\ m} = 22{,}0\ N / mm^2\ , \tag{22}$$

corresponding to the calculation pressure, namely:

$$\sigma_{i\ m} = 40{,}0\ N / mm^2\ ;\ \sigma_{e\ m} = 32{,}3\ N / mm^2\ , \tag{23}$$

for the hydraulic test pressure.

Note: It appears that the stresses in the leg pipe intrados are higher than those of extrados. However, it is noted that the conditions of resistance, specific to the two load cases, are discharged.

Conclusions

Comparing the values of the maximum equivalent stresses with admissible resistances, there is a small application of the section of pipe, which indicates an important reserve of the portent capacity of the pipe; this status indicates that the initial sizing was done with sufficient coverage; accepting a progressive thinning of the pipe wall or of the leg pipe present in the route, a future use is warranted for a period of 12 years, with expertise appropriate rules. An average speed of corrosion, under conditions of imperfect preservation and of a working with static loads was taking into account. Obviously, in the analysis the current features of the construction material are not known, mechanical tests on samples taken from the structure being unrealizable, which is why the argument requires some caution in subsequent duration of use. For the induced stress state was envisaged the wall thinning intensity, similar to previous conditions, although it requires more care to protect the section of the pipe.

When the working restored the hydraulic test is recommended ($p_h = 2{,}2 MPa$) and, possibly, an analysis by strain gages for stress analysis or by finite element method for assessing the applications for the entire pipe, in appropriate circumstances leaning on the ends of the section, which was not taken into present study.

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Unele aspecte privind evaluarea duratei reziduale de viață a unor conducte din instalațiile petrochimice. IV. Studiu de caz

Rezumat

Lucrarea analizează starea de tensiune într-un tronson de conductă cu un cot intermediar, ținând seama de perioada de utilizare şi de conservare, respectiv de subțierea peretelui țevii prin corodare. Se estimează durata ulterioară de utilizare şi controalele posibile, pentru siguranța structurii.