THE INSPECTION AND EVALUATION OF THE TECHNICAL ESTATE OF A RECIPIENT AFFECTED BY CORROSION USING THE API RP 579 STANDARD, CONCEPTS OF BROKING MECHANICS AND THE PRINCIPLE OF CRITICAL ENERGY

ULERIU COSTEL DORINEL*

CNCIR S.A.,Str. Fluviului, nr. 16, sector 1, Bucuresti

Abstract: The inspection and estimation of the length of residual life of the equipment under pressure affected by corrosion, represents a subject of a greater importance. The paper presents several general problems of the API 579 standard, an overview of the methods necessary to be done for the technical assessment of the equipment under pressure, and also the evaluation of the technical estate of a recipient affected by corrosion using the standard API RP 579, concepts of the broking mechanics and the critical energy principle.

Keywords: duration of residual life, local corrosion, critical energy, critical thickness of profiles

1. INTRODUCTION

Managing equipment integrity is essential to the safe, reliable operation of process plant equipment. Fitness – for – service (FFS) assessment is a multi – disciplinary approach to determine whether a structural component is fit for continued service. In 2000, the American Petroleum Institute (API) published API 579, a Recommended Practice for FFS assessment [1]. In 2007, API joined forces with the American Society for Mechanical Engineers to produce an updated document with the designation API 579 – 1/ASME FFS - 1.This document contains Fitness-For-Service *(FFS)* assessment procedures that can be used to evaluate pressurized components containing flaws or damage. If the results of a fitness-for-service assessment indicate that the equipment is suitable for the current operating conditions, the equipment can continue to be operated at these conditions provided suitable monitoring/inspection programs are established. If the results of the fitness-for-service assessment indicate that the equipment is not suitable for the current operating conditions, calculation methods are provided to relate the component.

2. LEVELS OF ASSESSMENT, INSPECTION METHODS, CORROSION ASSESSMENT

The API/ASME fitness–for–service standard provides three levels of assessment:
- Level 1. This is basic assessment that can be performed by properly trained inspectors or plant engineers. A level 1assessment may involve simple hand calculation;
- Level 2. This assessment level is more complex than level 1, and should be performed only engineers trained in the API/ASME FFS standard. Most level 2 calculations can be performed with a spreadsheet;

*Corresponding author, email: uleriudorinel@yahoo.com

- Level 3. This is the most advanced assessment level, which should be performed only by engineers with a high level of expertise and experience.

The Fitness-For-Service assessment procedures are organized by flaw type and/or damage mechanism.An overview of the procedure is provided in the following eight steps:
- Step 1 – Flaw and Damage Mechanism Identification;
- Step 2 – Applicability and Limitations of the FFS Assessment Procedures;
- Step 3 – Data Requirements:The data required for a FFSassessment depend on the flaw type or damage mechanism being evaluated;
- Step 4 – Assessment Techniques and Acceptance Criteria;
- Step 5 – Remaining Life Evaluation;
- Step 6 – Remediation;
- Step 7 – In-Service Monitoring;
- Step 8 – Documentation: Documentation should include a record of all information and decisions made in each of the previous steps to qualify the component for continued operation.

Defect location, size, orientation and shape need to be characterized to assess current equipment condition, fitness for service, and remaining life. The suitability of a particular technology or technique must fully be understood for specific damage mechanism. This requires application specific techniques that provide technical merit through a combination of appropriate technology, procedure selection, and personnel qualification. When considering NDE techniques for specific damage attributes, a selection can be made from one of three general groupings:
- surface techniques – offering only general detection and length/width sizing. These include visual inspection, liquid penetrating examination, magnetic particle examination, eddy current, alternating current field measurement;
- volumetric techniques – offering varying degrees of quantitative information on flaw size, location, orientation. Volumetric techniques include radiography and ultrasonic inspection.

API 579 procedure makes reference to several types of damage. The majority of them can be due, or influenced by, corrosion. They are: thickness reduction, localized thickness reduction, pitting, blister/delaminating, cracks. Each form of damage can be due to different corrosion mechanisms. Corrosion allowance is estimated as an increase of the requested component thickness, and depends on the desired service life. API 579 are three sections that address corrosion: Section 4 – assessment of general metal loss; Section 5 – assessment of local metal loss; Section 6 – assessment of pitting corrosion.

3. THE INSPECTION AND EVALUATION OF THE TECHNICAL ESTATE FOR A RECIPIENT AFFECTED BY CORROSION ACCORDING TO API RP 579

As a result of an internal revision, at a stable recipient under the GPL pressure for storing having the maximum admissible pressure 1.68 MPa, TS = -40÷50°C, it has seen that the interior surface is affected by a uniform corrosion, the thickness of the coating being of 13.3 mm. In addition on one of the shells there was discovered a powerful corroded zone with the dimensions s = 100 mm and c = 80 mm. The material from which it is executed the recipient is BH 47 S. The recipient falling due to the technical checks, was made to work in 1979 and according to the present records in the recipient book there can be seen the fact all along the cycle of functioning there were no restoration works for the elements submitted to the pressure and no other events were registered (accidents, damages and others) able to affect the structural integrity of the recipient. On the occasion of technical checks there were examined at the interior 100% welded tights with fluorescent magnetic particles [2], acceptance level 1, by an authorized laboratory ISCIR with result – admitted, there were no default indications. There were also done hardness trials. The registered values of the hardness are situated within admissible boundaries. The difference between the hardness of the obtained values within the base material, the thermal influenced zone and the material of surplus is under 100 units. On this occasion there have been done metal graphical examinations aiming to put into evidence the morphology of the phase changes from the material, the determining of the dimension of the grains, of the eventual normal structures. According to the results presented in Figure 1, there were put into evidence normal structures, ferrite – perlitic, the score granulation 7÷8. There were no defaults identified in the material, micro –cracks, lack of homogeneity.

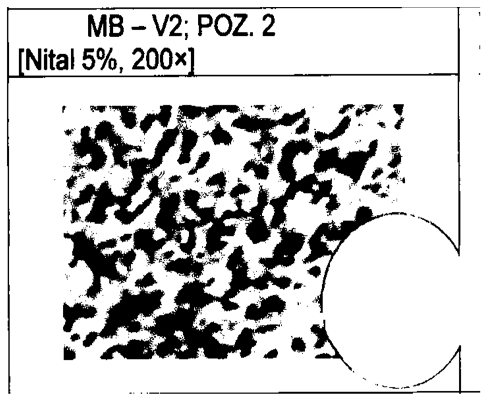

Fig. 1. Dimensions of the grains.

The severely corrosion affected area was examined with penetrating liquids and ultra sounds by an authorized ISCIR laboratory with the result – admitted, there were no default indications. The corrosion is in base metal and does not cross any welds. The following parameters apply:
- the maximum operating pressure (p) is 1.68 MPa;
- the inside diameter (ID) is 2968 mm, so the inside radius (R_i) is 1484 mm;
- the wall thickness is 14 mm, where there is no corrosion loss;
- the 10-year future corrosion allowance (FCA) is 1.2 mm;
- the material is BH 47S, the allowable stress (S_a) is 233 MPa;
- the weld efficiency factor (E) is 1.00;
- the minimum distance of the flaw from a major structural discontinuity (L_{msd}) is measured and found to be 400 mm.
- c - Circumferential dimension of the region of local metal loss (mm).

Wall thickness in the corroded region is measured at points on a 20 mm grid. To determine the critical thickness profiles through minimum values in the longitudinal (M) and circumferential (C) directions, as illustrated in Table 1.

Table 1. Inspection data (mm).

Longitudinal inspection planes	Circumferential inspection planes						Circumferential CTP
	C_1	C_2	C_3	C_4	C_5	C_6	
M_1	13.30	13.30	13.30	13.30	13.30	13.30	13.30
M_2	13.30	10.46	8.65	9.35	10.20	13.30	8.65
M_3	13.30	9.75	8.42	9.50	10.45	13.30	8.42
M_4	13.30	9.90	8.90	10.65	10.80	13.30	8.90
M_5	13.30	13.30	13.30	13.30	13.30	13.30	13.30
Longitudinal CTP	13.30	9.75	8.42	9.35	10.20	13.30	

The minimum measured thickness (t_{mm}) is thus mm. The tasks are determine if the vessel is acceptable for continued operation based on a API RP 579 level 1 assessment and to estimate the remaining corrosion life of the vessel.

First, use the standard code formulas to compute minimum required wall thickness values as follows [1]:

$$t_{min}^{c} = \frac{p(R_i+FCA)}{S_a \cdot E - 0.6 \cdot p} = \frac{1.68(1484+1.2)}{233-0.6 \cdot 1.68} = 10.75\ mm \tag{1}$$

$$t_{min}^{l} = \frac{p(R_i+FCA)}{2S_a \cdot E + 0.4p} = \frac{1{,}68(1484+1.2)}{2 \cdot 233+0.4 \cdot 1.68} = 5.34\ mm \tag{2}$$

The minimum wall thickness (t_{min}) is 5.34 mm.

Compute the remaining thickness ratio (R_t), as follows:

$$R_t = \frac{t_{mm}-FCA}{t_{min}} = \frac{8.42-1.2}{10.75} = 0.67 \tag{3}$$

Obtain the factor Q from table 4.4 of API RP 579 using $R_t = 0.67$ and $RSF_a = 0.9$, or compute Q as follows:

$$Q = 1.123 \cdot \left\{\left[\frac{1-R_t}{1-\frac{R_t}{RSF_a}}\right]^2 - 1\right\}^{0.5} \tag{4}$$

Factor Q, conform according to reference table API RP 579 and calculated according to the above formula has a value of :

$$Q = 1.123 \cdot \left\{\left[\frac{1-0.67}{1-\frac{0.67}{0.9}}\right]^2 - 1\right\}^{0.5} = 0.96 \tag{5}$$

Determine the length for thickness averaging (L), as follows:

$$L = Q\left(ID(t_{min})\right)^{0.5} = 0.96\left(2969.4(10.75)\right)^{0.5} = 171.52\ mm \tag{6}$$

Since the minimum required thickness for longitudinal stress = 5.34 mm < 7.22, evaluating the circumferential extent of flaw is not required. Because s which is the actual length of the region of corrosion, is 100 mm < L = 171.52 mm, check the criteria of paragraph 5.4.2.2. d of API RP 579:

$$R_t = 0.67 > 0.2$$

$$t_{mm} - FCA = 7.22\ mm$$

$$1.8(ID \cdot t_{min})^{0.5} = 284.6\ mm < L_{msd} = 400\ mm$$

In addition, check the criterion of paragraph 5.4.2.2. g of API 579 for c. Using figure 5.7 of API RP 579, R_t = 0.67 > 0.2 at c/ID = 0.26.

4. WHERE THE COMPUTATIONS AIM CONCEPTS OF BREAKING MECHANICS AND THE PRINCIPLE OF THE CRITICAL ENERGY

Data and calculation hypotheses:

- t = 13.3 mm, minimum thickness of the a cylindrical wrap;
- D_0 = 2968 mm, inside diameter of the recipient;
- P = 1.68 MPa, calculation pressure;
- TS = 50°C calculation temperature;
- z = 1, resistance coefficient of the welded parts;

Material BH 47 S, under stationary conditions is characterized by:

- Minimal value of breaking resistance, $R_m = 560$ N/mm^2;
- Value of the conventional limit of laminimal elasticity of 0.2 %, $R_{p0.2} = 460$ N/mm^2;
- $P_{cr} = 0.7$ – participation compared to the critical estate;
- The meridional direction is characterized by $l_{cr} = 0.8$ mm;
- The ring tension $\sigma_\theta = 179$ MPa;
- $\sigma_{cr} = R_m = 560$ MPa;

Aiming the relation [3]:

$$P_T = \left(\frac{\sigma}{\sigma_{cr}}\right)^2 + \frac{l}{l_{cr}} \tag{7}$$

in which σ is applied effective tension (uniformly distributed); l – the effective length of the crack; σ_{cr} – critical tension or the tension in which, under tracking conditions, produces the breaking of the material with no cracks; l_{cr} – the critical length of the crack, corresponding to the tension σ or the length of the crack which is dangerous for the studied body.

It results, the critical semi - length along the generator, under soliciting conditions:

$$\overline{l_{cr}} = l_{cr} \cdot \left[P_{cr} - \left(\frac{\sigma_\theta}{\sigma_{cr}}\right)^2\right] = 0.8 \cdot \left[0.7 - \left(\frac{179}{560}\right)^2\right] = 0.47\ mm$$

Observation: Any crack with the length risks to continuously extend itself at the smallest growth of the tension above $\sigma_\theta = 179$ MPa.

The admissible length of the crack:

$$l_{ad} = \frac{l_{cr}}{c_l} = \frac{0.47}{4} = 0.1175\ mm$$

in which c_l represents the coefficient of surety against the critical length of the crack.

So, there are admitted cracks with the meridional length of.

In the direction of thickness, considering at a first approximation that lcr = t = 13.3 mm one obtain:

$$\overline{l_{cr}} = l_{cr} \cdot \left[P_{cr} - \left(\frac{\sigma_\theta}{\sigma_{cr}}\right)^2\right] = 13.3 \cdot \left[0.7 - \left(\frac{179}{560}\right)^2\right] = 7.95\ mm$$

It is known that, if $l_{cr} \geq t$ the crack along the whole thickness – and, consequently, the loss of the tightness, *leak – before – break* – is produced before the instable extinction of the crack. Because $l_{cr} \leq t$, there is the danger of a sudden extinction of the crack which has the length greater than 7.95 mm.

Under the conditions in which the ring tension $\sigma_\theta = 179$ MPa apply suddenly (through shock) the critical length of the crack is calculated as follows [3]:

$$\overline{l_{cr}} = l_{cr} \cdot \left[P_{cr} - \left(\frac{\sigma_\theta}{\sigma_{cr}}\right)^2\right] \tag{8}$$

where $\sigma_{cr} = \sigma_{rd} = \sigma_r(1 + k_d)$, in which $k_d = 0.43$.

We get $\sigma_{cr} = 560(1 + 0.43) = 800.8\ MPa$.
After replacing it results:

$$\overline{l_{cr}} = 0.8 \cdot \left[0.7 - \left(\frac{179}{800.8}\right)^2\right] = 0.52\ mm$$

4. CONCLUSIONS

Since the publication of the original API 579 procedure in 2000, fitness-for-service assessment has seen widespread application in a range of industries that rely on pressure equipment. Various NDE methods can be used to characterize the condition of material in operating equipment. The information on flaw type, size, and location then can be used in engineering fracture mechanics models to evaluate equipment integrity and remaining life. Based on the results of this Level 1 assessment per API 579, the corrosion flaw is found to be acceptable. The material from which the recipient is built up, steel BH 47S, containing carbon < 0,19%, cannot have martensitical structures, which evolves in time, so there cannot appear fragility phenomena which would limit the use time. Because the metallographic analyses conclude that in the steel which has been analyzed there were detected normal structures, ferrite - perlitical, and the granulation having 7 ÷ 8 points, observed in these structures, one can say that the material presents good mechanic characteristics of resistance, motif for which it can be exploited further on.

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