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The Equivalence of the Assessment Procedures API 579 and ASME B31G

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Abstract

This paper deals with the description of a method of transforming the results of an oil pipeline inspection, using fitness for service procedures. The inspection results were evaluated by the method of ASME B31G standard and the transformation is done in the specific assessments of the standard API 579 using a computer program developed in Matlab *[12]. The results are compared using the maximum allowable working pressure defined by each of the two methods.*

Key words: *oil pipeline inspection, fitness for service*

Introduction

While an equipment (pressure vessel, pipe, tank, etc.) is wearing down under pressure, the operator must decide whether it can continue to work safely, reducing the working parameters or stopping the equipment and refurbishing it, avoiding injury of the personnel or other persons, and unexpected environmental accidents [3, 6, 7].

The Method Fitness for Service (FFS) provides the means by which the operator can take these decisions based on reliable engineering knowledge [1, 2, 5]. The FFS method is based on the analysis of efforts, requiring information about: the operating conditions, knowledge about the state of the pipe (nondestructive testing) and the properties of the material of which it is built [2, 6, 11, 14, 18]. The analysis of the state of stress can be done based on design codes [1, 2, 4, 7, 9, 11, 14] or using the finite element method (FEM) [8, 9, 15].

There are several ways to assess the defects by means of the FFS method of which the most known are: API 579, ASME B31 G and DNV RP F101 [18-20]. The standard API 579 includes three levels of evaluation. The level of conservatism decreases with the level of assessment, but more data is required for analysis. In the method API 579 the defects are evaluated by categories (1228 pages) versus B31G (58 pages), the steps in the evaluation (calculation methods) being more clear. As specified in B31G, a level 1 assessment with API 579, reduced to its simplest form is similar to a level 1 assessment with B31 G. Also the assessment with API 579, at level 2, reduced to its simplest form is similar to level 2 of the evaluation with B31 G.

This paper is based on a scientific research contract [10]. As required by the beneficiary, the results of the inspection of an oil pipe (by magnetic flux method) rated by specific procedures of standard B 31 G, were reviewed with the specific procedures of API 579 standard. The review refers only to the corrosion defects. The comparison was made on level 1 because the method of inspection did not provide a description of the defect matrix (a grid should be established to obtain thickness readings) necessary for a level 2 assessment (evaluation possible with the ultrasonic inspection method, but more expensive than the inspection method with magnetic flux [5, 17]). The authors propose a method of implementing the measurement results (PIG-MFL) in the specific assessments of the API 579 standard.

The Working Method

We use a set of geometric data obtained by an inspection with magnetic flux carried out by the company that performed the testing services [21]. These data were evaluated using a computer program of the Rosen Company; this program includes a set of rules based on the standard ASME B31G/2009. The company that carried out the inspection sent to the operator of the transport system a list of faults highlighted based on the following priority criteria:

Rule 1 Faults at which the maximum depth is greater than or equal to 80 % of the wall thickness.	*Rule 3* Defects at which the ratio *ERF* = *MAWP* / P_{safe} are between 0.95 and 1.
Rule 2 Defects at which the ratio *ERF* = *MAWP* / P_{safe} is greater than or equal to 1.	*Rule 4* Faults at which the maximum depth is between 20 % and 80 % of the wall thickness.

The maximum pressure at which the pipeline can work safely is estimated with the following formulas (B31 G):

$$P_{1safe} = \begin{cases} 1.1 P_{design} \dfrac{1-0.67\frac{c}{t_n}}{1-0.67\frac{c}{M_1 t_n}}, z \le 20 \\ 1.1 P_{design}\left(1-\dfrac{c}{t_n}\right), z > 20 \end{cases}, \tag{1}$$

$$z = \frac{L^2}{D \cdot t_n}, \tag{2}$$

$$M_1 = \sqrt{1+0{,}8z} \quad . \tag{3}$$

The burst pressure is expressed in several relationships [11, 16, 17], is to [19]:

$$P_{1burst} = \begin{cases} 1.1 SMYS \dfrac{2t_n\left(1-0.67\frac{c}{t_n}\right)}{D\left(1-0.67\frac{c}{M_1 t_n}\right)}, z \le 20 \\ 1.1 SMYS \dfrac{2t_n}{D}\left(1-\dfrac{c}{t_n}\right), z > 20 \end{cases} . \tag{4}$$

Also, the maximum safety pressure is (modified B31G):

$$P_{2safe} = MAWP\left(1+\frac{10000}{145 \cdot SMYS}\right)\frac{1-0.85\frac{c}{t_n}}{1-0.85\frac{c}{M_2 t_n}} , \tag{5}$$

the expressions for the bulging stress magnification factor depending on the values of the *z* parameter :

$$M_2 = \begin{cases} \sqrt{1-0.6275z-0.003375z^2}, z \le 50 \\ 0.032z+3.3, z > 50 \end{cases} . \tag{6}$$

For this variant (modified B31G), the burst pressure is:

$$P_{2burst} = \frac{2t_n}{D}\left(SMYS+\frac{10000}{145}\right)\frac{1-0.85\frac{c}{t_n}}{1-0.85\frac{c}{M_2 t_n}} \tag{7}$$

The acceptance criteria according to [19] is to use the relations (4) or (7) and impose a higher value to these pressures than the product *SF* x *SO*. As we see, the highlight of defects in [21] is made by the rules 1-4 with a more pronounced practical character: deep defects and defects signaling that the operating pressure is close to the safety pressure (*ERF* near 1). The recommended safety factor is the ratio of the test pressure of the pipeline relative to the operating pressure P_O.

These data of the pipeline can be assessed on the basis of the standard API 579, calculating the maximum working pressure (see comments in the Tab. 4, column 6) and a comparison between the methods can be made. Given the large volumes of the matrix (64000 x 19), an evaluation method based on Matlab program was developed [12]. Inspection reports [21] were made in the form of an Excel file as in Table 1.

Table 1. The Excel file with the results of inspection of the pipeline [21].

reference distance of fault [m]	**distance of defect to welding** [m]	**number of joint / joint length**	**distance to equipment** [m]	**wall thickness** [mm]	**reference distance** [m]	**clock orientation of defect**	**type of defect**	**size of defect**	**length of fault *L*** [mm]	**width of defect *l*** [mm]	**max. depth of fault** [%]	**average depth of fault** [%]	***ERF* repair factor**	**inside / outside wall**	**comment**	**classification of location**	**group**	**group identification**
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19

From these data only the corrosion defects were retained on a selective column 8 from Table 1. From this table for the fault analysis (according to API 579/2007), only the following columns have been preserved (Table 2).

Table 2. Columns stored for the analysis of corrosion defects

Column	Significance	Column	Significance
1	reference distance of fault [m]	5	clock orientation of defect
2	distance of defect to welding [m]	6	length of fault *L* [mm]
3	distance to equipment [m]	7	width of defect *l* [mm]
4	wall thickness [mm]	8	maximum depth of fault [%]
		9	average depth of fault [%]

In this selection we have taken into account the large amount of data (one additional line / column involves smaller posibilities of storage / handling) and only data strictly necessary for analysis and reporting defects were kept. These data are imported into Matlab software as data matrix. For example, a matrix of four lines, which has 9 columns (according to Table 2) is shown in Table 3. Further we constructed a matrix for the analysis of data, according to API 579 ([18] Sections 4 and 5). The structure of this matrix is presented in Table 4, accompanied by the explanations. The details referring of the implementation and the instructions of the achieved program are presented in [12].

Table 3. Data matrix called *data1*

	C1	C2	C3	C4	C5	C6	C7	C8	C9
D1	-1.38	80	14.64	10.30	15.02	13	34	6	4
D2	-1.39	80	14.64	10.30	16.02	11	18	14	10
D3	-1.88	80	14.64	10.30	17.02	98	54	5	1
D4	-3.13	80	14.64	10.30	18.02	13	18	8	6

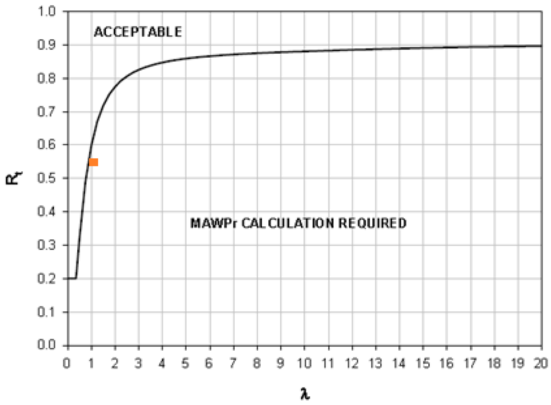

Fig. 1. Checking the longitudinal extension of the defect as [17].

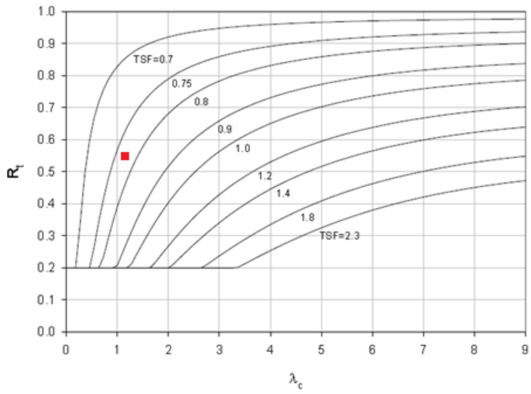

Fig. 2. Checking the circumferential extension of the defect as [17].

Table 4. The elements of the analysis matrix (matrix lines correspond to the minimal description of the defect obtained during the inspection).

<table>
<tr><th>Column</th><th colspan="2">Response / Content</th></tr>
<tr><td>1</td><td colspan="2">In this column enter the value 1 (b1 (i, 1) = 1) if all checks:
$$R_t \geq 0.20 \quad (8)$$
$$t_{mm} - FCA \geq 2.5 \text{ mm} \quad (9)$$
$$L_{msd} \geq 1.8\sqrt{D_i \cdot t_c} \quad (10)$$
are fulfilled and 0 otherwise (b1 (i, 1) = 0).</td></tr>
<tr><td rowspan="9">2</td><td colspan="2">In this column enter the code (one of the numbers 1 to 8) which describes the size of corrosion defect as follows:</td></tr>
<tr><td>b1(i,2) = 1</td><td>General {[$W \geq 3A$] and [$L \geq 3A$]}</td></tr>
<tr><td>b1(i,2) = 2</td><td>Pitting {([$1A \leq W < 6A$]and [$1A \leq L < 6A$] and [$0.5 < L/W < 2$]) and not ([$W \geq 3A$] and [$L \geq 3A$])}</td></tr>
<tr><td>b1(i,2) = 3</td><td>Axial grooving {[$1A \leq W < 3A$] and [$L/W \geq 2$]}</td></tr>
<tr><td>b1(i,2) = 4</td><td>Circumferential grooving {[$L/W \leq 0.5$] and [$1A \leq L < 3A$]}</td></tr>
<tr><td>b1(i,2) = 5</td><td>Pinhole {[$0 < W < 1A$] and [$0 < L < 1A$]}</td></tr>
<tr><td>b1(i,2) = 6</td><td>Axial slotting {[$0 < W < 1A$] and [$L \geq 1A$]}</td></tr>
<tr><td>b1(i,2) = 7</td><td>Circumferential slotting : {[$W \geq 1A$] and [$0 < L < 1A$]}</td></tr>
<tr><td>b1(i,2) = 8</td><td>Another case</td></tr>
<tr><td colspan="3">The geometric parameter is defined as follows: if $t_n < 10$ mm then $A = 10$ mm, if $t_n \geq 10$ mm then $A = t_n$, according to [21].</td></tr>
</table>

3	If we have a groove like flaw on local loss of material LTA, the condition (11) is evaluated: $$g_r \geq (1 - R_t)\, t_c \qquad (11)$$ and the result is passed in column 3, b1 (i, 3) = 1 if YES is met, or b1 (i, 3) = 0 if NOT is met; also we use this column to the assessment of overall loss of material type, in this case if the condition (12) is satisfied the result is b1 (i, 3) = 1: $$t_{mm} - FCA \geq \max\,(0.5t_{min};\, t_{lim}) \qquad (12)$$ where $$t_{lim} = \max\,(0.2t_n;\, 2.5\text{ mm}) \qquad (13)$$ or b1 (i, 3) = 0 if NOT satisfied (using the same column for different purposes).
4	This column stores the maximum allowable working pressure *MAWP*, b1 (i, 4) = *MAWP* expressed in MPa.
5	The result of the evaluation with Fig. 1, taken from API 579 (original figure 5.7 of [18]): b1 (i, 5) = 1 if the longitudinal extension check is accepted, b1 (i, 5) = 0 otherwise (if the fault is of type local metal loss LTA). The verification is done using the function that describes the curve which separates the fields acceptable / unacceptable in Fig. 1 rel. (22). Also, the use of this column is to verify the condition: $$t_{am} - FCA \geq t_{min} \qquad (14)$$ b1(i,5)=1 if checked, is true, b1(i,5)=0 if checked (14) is false , in the case of the general metal loss type defect (GML).
6	In this column the value of working pressure is written down if the longitudinal extension of the defect is unacceptable, by Fig. 1 above b1(i,6) = *MAWP* if $RSF \geq RSFa$ or b1(i,6) = *MAWPr* if $RSF < RSFa$. In the case of the GML type of defect, in the column 6 it is written the value of the pressure recalculated with the average thickness of the pipe minus the corrosion allowance $t_{am} - FCA$ [18].
7	If the conditions for the circumferential extending of the defect (local loss of metal type) are met: $\lambda_c \leq 9$ (15) $\frac{D_i}{t_c} \geq 20$ (16) $0.7 \leq RSF \leq 1$ (17) $0.7 \leq E_L \leq 1$ (18) $0.7 \leq E_C \leq 1$ (19) then b1(i,7)=1, otherwise b1 (i, 7) =0. The column has no significance to the GML defect type.
8	In this column, the result of the verification of the circumferential extension of the defect with Fig. 2 (original figure 5.8 of [18]) is recorded: b1 (i, 8) = 1 the check of the circumferential expansion met, b1 (i, 8) = 0 check of circumferential expansion unfulfilled. Column has no significance to GML defect type.
9	In this column, if the analized defects are forming a group: b1 (i, 9) = 1 if the defect is part of a group, b1 (i, 9) = 0 if the defect is not part of a group. Rule of interaction of the defects according with [20]: two individual defects interact with metal loss and will be grouped when the axial distance between the edges of defects with loss of metal is smaller than the smallest circumferential length of the fault and the distance is less than the smallest width of the defects.
* The relationships used for columns 1 and 3 to 8 are according to the verification procedure [18], sections 4 and 5, and for the column 2 according to [21].	

Conclusions

Based on the above proposed method (according to the procedures specified in API 579) all the corrosion defects were verified, except the cracking of the pipe. An example with some results of execution of the Matlab program [12] is presented in Table 5. Further these results were imported in Microsoft Excel to make a comparison in Table 6. Total faults count is 165 458. The marked corrosion defects count is 90 167, with 377 defects rejected by specific aspects of API 579 method for the following reasons:

- Type 1 fault, the conditions of the characterization of the defect type overall loss of material (see Column 2, Table 4), if not fulfilled (12);

Table 5. The result of the Matlab program execution

Verifications (8-10)	**Defect size**	**Verification groove like flaw (11) or condition (12)**	***MAWP*, MPa**	**Verification axial extension fig. 1 (it includes verifications (8-10) or condition (14) at GML**	**Maximum working pressure *MAWP* or *MAWPr***	**Conditions (15-19) at circumferential extension**	**Verification Fig. 2 circumferential extension (15-19 are included)**	**Belonging to a group of defects**
1	4	1	9.89	1	9.89	1	1	1
1	2	0	9.89	1	9.89	1	1	1
0	1	1	9.89	1	9.79	0	0	1
1	2	0	9.89	1	9.89	1	1	1

Table 6. The Excel file filled with data analysis and comparison elements

Values of MFL inspection									**Calculated values Matlab program conforming to [18]**									**Compa -ration**	
Reference distance of fault [m]	Distance of defect to welding [m]	Distance to equipment [m]	Wall thickness [mm]	Clock orientation of defect	Length of fault L [mm]	Width of defect 1 [mm]	Maximum depth of fault [%]	Average depth of fault [%]	Verifications (8-10)	Defect size	Verification groove (11) or condition (12)	*MAWP*, [MPa]	Verification fig. 1 (LTA) or (14) at GML	*MAWP* or *MAWPr* [MPa]	Conditions (15-19)	Verification with fig. 2	Group of defects	*Rc*1[-]	*Rc*2[-]

Table 7. The defects of corossion

No.	**The depth of loss of metal**	**Total**	**Corrosion defect inside the wall**	**Corrosion defect on the outside wall**
1	≥ 90	0	0	0
2	80 – 89%	50	0	50
3	70 – 79%	24	0	24
4	60 – 69%	77	0	77
5	40 – 59 %	483	18	465
6	20 – 39 %	2.971	708	2.263
7	10 – 19 %	21.024	13.243	7.781
8	5 – 9 %	65.159	43.556	21.603
Total		**89.788**	**57.525**	**32.263**

- Type 2 fault, local thin area, one of the following conditions is not fulfilled: (8-10), (15-19) , the verification of circumferential extension;
- Types 3 or 4 LTA with groove like flaw, one of the following conditions is not fulfilled: (8-11), (15-19), the verification of circumferential extension.

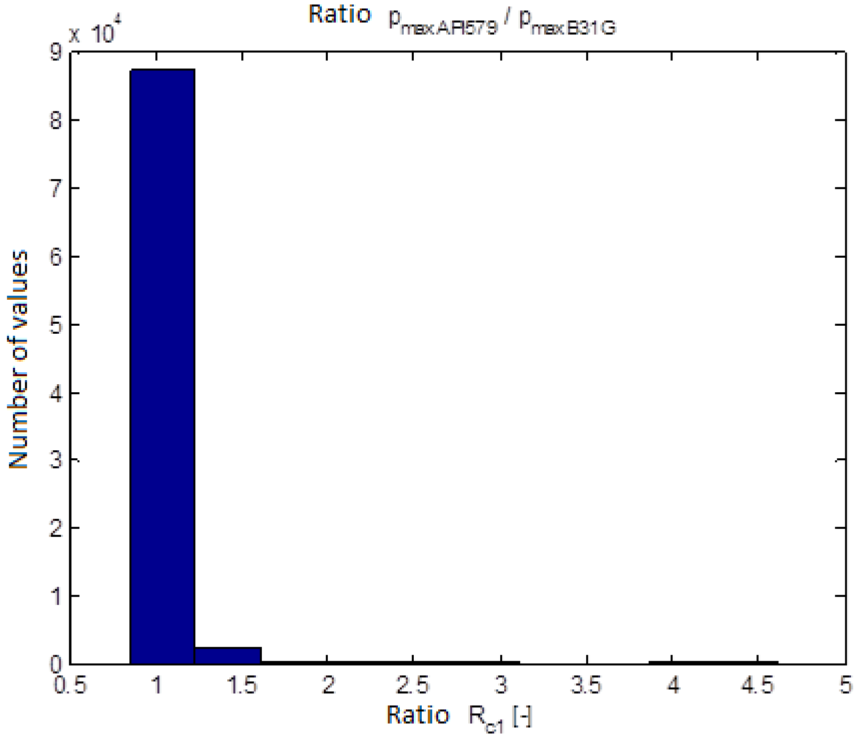

Fig. 3. Representation of values of ratio R_{C1}, mean value 0.9947

Only two circumferential slotting defects type 7 (Table 4) were found that could be analyzed in accordance with Section 9 of API 579 (crack). The 89 788 remaining defects are characterized in Table 7. As points of comparison we used the maximum pressure at which pipeline can work calculated according to API 579 (column 6 of Table 4), $Pmax_{API\ 579}$, B31 G formula (1) and modified G B31 (RSTRENG) formula (5). The following ratios were considered:

$$R_{C1} = \frac{Pmax_{API\ 579}}{P_{1safe}} \tag{20}$$

$$R_{C2} = \frac{Pmax_{API\ 579}}{P_{2safe}} \tag{21}$$

The two ratios (20), (21) are represented in Fig. 3 and 4. You can see the overlap between the values of the maximum working pressure of the standard methods B 31 G and API 579. Given that the results concerning the values of working pressure in the presence of the defect are the same and the method of [19] involves using a single formula, we recommend the using of this standard at a level 1 evaluation. The method of [18] is more selective, 377 defects are rejected based on the reasons given above. However, their number is small, a 0.4 % of the total. From a practical point of view, a program at level 1 as in [21] provides a very good guidance to the operator of the pipeline system on cases that have to be analyzed. The calculation of the factor *ERF* (103 values are into the interval [0.9 to 1) and 52 values are greater than 1 for the case shown in Table 6) constitutes an additional element for this guidance. Working methods of level 1 are conservative and therefore it benefits from using a more accurate evaluation to save of labor and materials in the replacing of sections of the pipe [10], using methods of level 2 or 3.

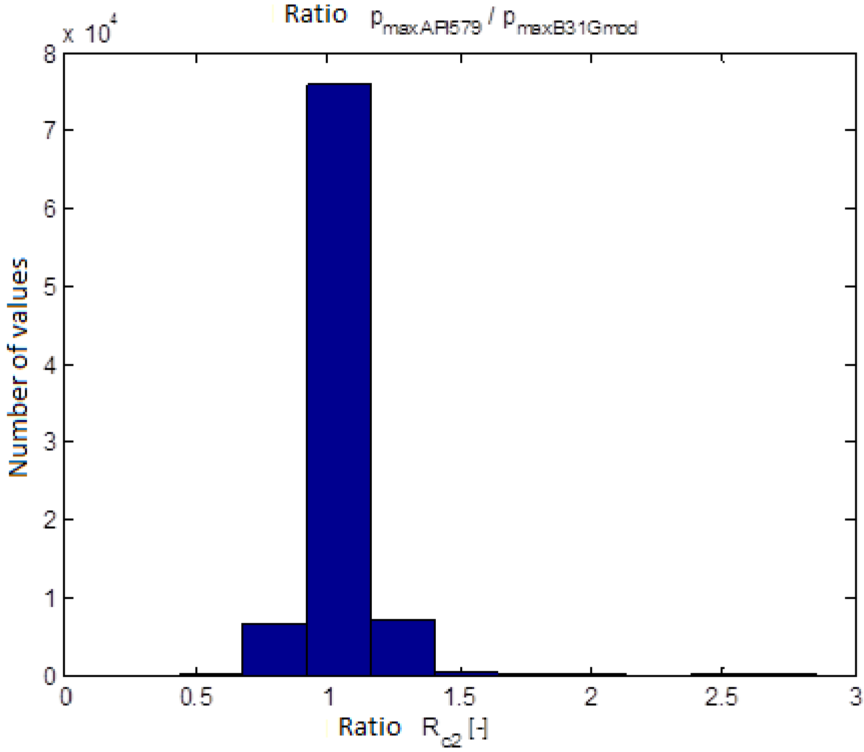

Fig. 4. Representation of values of ratio R_{C2}, mean value 0.9947.

The assessment at level 2 and 3 involves the use of computer programs, which are provided in [10] by the construction of some programs in Visual Basic for the level 2 and the FEA modeling in Cosmos Solid Works for the level 3 (nonlinear analysis). Another aspect that needs attention is the actual pressure in the pipe, at the location of the fault. Thus, if in the starting point of the pipeline the pressure is high, it decreases because of the pressure loss, and again we have a reserve that can be used. A final recommendation is required: no replacement of a pipeline section without an analysis of level 2 or 3 should be made.

List of Notations

c – maximum depth of the region of local metal loss [mm]
c_s – safety coefficient for pipe material [-]
D_e – outside diameter of the pipe [mm]
D_i – inside diameter of the pipe [mm]
E_c – circumferential weld joint efficiency [-]
E_l – longitudinal weld joint efficiency [-]
ERF – estimated repair factor, *ERF* = *MAWP*/ *Psafe* [-]
F – applied net-section axial force for the weight [N]
FCA – future corrosion allowance applied to the region of local metal loss [mm]
L – axial length of the defect [mm]
L_{msd} – distance to the nearest major structural discontinuity [mm]
LOSS – amount of uniform metal loss away from the local metal loss location at the time of the assessment [mm]
M_i – bulging stress magnification factor, i = 1,2 [-]
MWP – maximum working pressure [MPa]
MAWP – maximum allowable working pressure [MPa]
MAWPr – reduced permissible maximum allowable working pressure [MPa]
M_t – Folias factor [-]
p – working pressure [MPa]

P_{design} – design pressure (safety factor 0.72) [MPa]
PO – operating pressure, may equal *MAWP* or *MWP* [MPa]
P_{safe} – safe operating pressure [MPa]
R_i – inside radius of pipe [mm]
R_m – average radius of the pipe [mm]
RSFa – allowable remaining strength factor [-]
RSF – computed remaining strength factor based on the meridional extent of the LTA [-]
R_t – remaining thickness ratio [-]
S_a – allowable stress determined based on the original construction code of component [MPa]
SF – estimated failure stress level [MPa]
S_{flow} – flow stress [MPa]
S_O – hoop stress at the operating pressure, calculated as $P_O D/2t_n$ [MPa]
SF – safety factor [-]
t_n – nominal wall thickness [mm]
t_{am} – mean wall thickness measured [mm]
t_c – corroded wall thickness away from the region of local metal loss [mm]
t_{min} – minimum required thickness for the component that governs the *MAWP* calculation [mm].

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Echivalenţa dintre procedurile de evaluare API 579 şi ASME B31G

Rezumat

Articolul prezintă o metodă care permite transformarea rezultatelor unei inspecţii de la o conductă de petrol prin procedura "Fitness For Service". Rezultatele inspecţiei au fost evaluate prin metoda din standardul ASME B31 G şi transformarea este făcută prin metodele standardului API 579 utilizând un program realizat de autori în Matlab *[12]. Metodele de evaluare sunt comparate utilizând presiunea maximă admisibilă de lucru stabilită prin fiecare dintre cele două metode.*