Method of Determining the Sizes of Corrosion Defects of Elements of Marine Oil and Gas Industrial Constructions on the Basis of Data on Temperature Contrasts

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Abstract. Offshore oil and gas platforms located on offshore fields are exposed to various stresses, the most intense of which is corrosive. Corrosion caverns arising in different areas of offshore oil and gas structures cause local stress concentration, and can cause overstresses of structural elements with its subsequent destruction. The most dangerous are corrosion defects "V"-shaped, capable of increasing the value of operating stresses more than 2 times. The article presents the results of experiments and a method of estimating the size of corrosion defects on the basis of data on the difference between defect-free and corrosion-affected areas. The use of this technique will allow to determine the sizes of corrosion damages with high efficiency and to estimate their influence on the safety of operation of offshore oil and gas platforms.

1. Introduction

Having established the thermal conditions on the outer and inner walls of the structural elements of offshore oil and gas facilities, let us turn to the consideration of an equally important phenomenon, namely, the appearance of a temperature contrast in areas with defects. On the basis of this phenomenon, a new scientific direction has been developed-thermography, which studies the differences in temperature fields between defective and defect-free sections of the material of various elements, and on the basis of an analysis of the data obtained, they conclude that the size of the defects.

Various authors predicted the appearance of this method for complex diagnostics of offshore oil and gas facilities and showed the advantages of this method in comparison with other methods of nondestructive testing. However, specific results and formulas allowing to determine the size and assess the danger of the detected defects in the marine oil and gas field structures have not been developed.
2. Analysis of existing researches

According to the authors of [1, 2] thermography with the method of sufficient accuracy, it is possible to identify corrosion defects, namely, in the planar form and the maximum depth projection, according to the formula, determine:

\[
\frac{\Delta L}{L} = 1 - \frac{T_{nd}}{T_d},
\]

where: \( \Delta L \) - depth of corrosion defect, \( L \) - wall thickness, \( T_d \) и \( T_{nd} \) - temperature in the defective and defect-free zones.

This formula is given in [1]. According to this formula, the ratio of temperatures in the defect and defect-free zones, i.e. The temperature contrast is always a constant.

However, the experiments carried out by the author showed some deviation from the results obtained in [2]. In figure 1 shows graphs of the temperature variation in the region simulating a single corrosion defect, and in the defect-free region that have been subjected to the heat flux. In the author's opinion, the temperature contrast of the defective and defect-free zones will depend on the power of the heat flux, i.e. the ratio of the density of the heat flux to the duration of its effect on the sites under study.

This conclusion is well confirmed by experiments conducted by the author. An experimental model was developed simulating corrosion lesions with various depths and surface dimensions. To satisfy the similarity condition of the experiment, these defects were filled with iron oxide. The photograph of the experimental setup is shown in figures 2 and 3. A heat flux of different density was directed to the defects. In all cases, there was a significant discrepancy between the rate of temperature growth in the defective and defect-free zones figure 5. Especially sharply there was a drop in temperature in the defective zone after the heating ceased.

![Figure 1](image1.png)

**Figure 1.** Graphs of temperature variation in defective (SP 1) and defect-free (SP 2) regions.

3. Aims and objectives of the research

The author poses the following questions:

- Determine whether the value of the temperature contrast is a constant value that does not depend on the duration of the exposure and the density of the heat flux.
- Determine whether it is possible to conduct thermal control of offshore oil and gas facilities due to the action of only solar radiation, or it will be necessary to apply the forced heating method (active thermal control method).
- Establish a relationship between the temperature contrast, the dynamics of heat flux and the depth of corrosion defects.
4. Justification of conditions of the experimental research
An experiment was carried out to solve these problems. Consider the effect of heat flow on a single defect.

Figure 2. Experimental sample (with a non-continuous layer of corrosion).

Figure 3. General view of the experimental setup.

Figure 4. Experimental sample (with a continuous layer of corrosion).

Figure 5. An experimental sample observed through a thermal imager.

A thermal constant flow was sent to the defect, which revealed the following. Because the defect is modeled by a "V" or "U" shaped groove filled with oxide, then the maximum temperatures were reached at its apex middle figure 6. If the defect is removed from the center to its boundaries, the temperature tends to align with the defect-free surface. In addition, the ratio of the dynamics of temperature growth when the defect and defect-free zone is heated is not a constant value. In addition, the following feature was noted. After the heat flux ceases, a sharp drop in temperature occurs in the defect zone. Even taking into account that the temperature in the defect zone was much higher than the surface temperature of the defect-free zone, the rate of its fall after stopping the heating of the decrease was significantly higher. And after a certain period of time, the temperatures were equalized, and then the temperature in the defect zone decreased below the values of the defect-free zone. When cooling the sample, small values of the temperature difference, close in their values to the noise, were noted. Considering the peculiarities of the application of methods of forced and free heating, it can be said
that the most obvious defects were found during forced heating, which is explained by a higher temperature contrast.

Figure 6. Temperature distribution by defect.

To obtain a practically applicable formula for estimating the depth of corrosion defects, let us carry out the following experiment. In the wall of a pipe with a diameter of 133 mm and a wall thickness of 8 mm (with a uniform corrosion layer), drill holes of various diameters simulating corrosion damage in depth that were filled with $\text{Fe}_2\text{O}_3$. The relationship between the following parameters is studied:

- The ratio of the depth of corrosion damage to the wall thickness.
- Dynamics of the influence of heat flow ($\Delta Q \cdot \Delta t$).
- Temperature ratio of defect-free and corrosion-damaging sections (temperature contrast).

Calculation of the density of heat flow taking into account the duration of its effect is carried out in accordance with the methodology given in [1]. The density of the heat flux was calculated with respect to the defect-free zone of the metal. The experiment was carried out 6 times with respect to each point. The results of the experiment are shown in figure 9.

Figure 7. Arrangement of points simulating corrosion defect on the experimental sample.

Figure 8. Analysis of the thermal state of the experimental sample through a thermal imager.
Figure 9. The results of the temperature measuring points, simulating corrosion defects.

Table 1. Characteristics of the points simulating the corrosion defect on the experimental sample.

| SP | 1     | 2     | 3     | 4    | 5     | 6     | 7     | 8     | 9     |
|----|-------|-------|-------|------|-------|-------|-------|-------|-------|
|    | Ø8x3  | Ø8x4,5| Ø8x1,5| Ø6x3 | Ø8x4,5| Ø6x1,5| Ø4x3  | Ø4x4,5| Ø4x1,5|

We will process the experimental data. We calculate the density and dynamics of heat fluxes, as well as temperature contrasts for each of the samples simulating corrosion defects.
Table 2. Results of the experiment. Sample No. 1 (point No. sp 1). The hole diameter modeling the corrosion defect is 8 mm. The depth of the hole is 3mm.

| Duration of exposure to heat flow, s | 0   | 15  | 30  | 45  | 60  |
|-------------------------------------|-----|-----|-----|-----|-----|
| Dynamics of heat flow (W / [s·m²])  | 0   | 1040| 968 | 895 | 822 |
| The temperature of the defect-free surface, °C | 28  | 32  | 34  | 36  | 38  |
| Temperatures in the defect zone, °C  | 28  | 46  | 52  | 55  | 59  |
| Temperature contrast                 | 0   | 0.30| 0.35| 0.35| 0.36|

Table 3. Dependence of the defect contrast on the depth of the defect (the average values are shown from the results of 6 experiments).

| Diameter and groove of the hole modeling the CD | Equivalent defect volume, mm² | Dynamics of the influence of heat flow, W / s·m² |
|-----------------------------------------------|-------------------------------|-----------------------------------------------|
|                                               |                               | 1040 | 968 | 895 | 822 |
| Ø8x1.5                                        | 75                            | 0.27 | 0.29| 0.29| 0.30|
| Ø8x3                                          | 151                           | 0.30 | 0.35| 0.35| 0.36|
| Ø8x4.5                                        | 226                           | 0.33 | 0.37| 0.36| 0.38|
| Ø6x1.5                                        | 42                            | 0.24 | 0.26| 0.27| 0.27|
| Ø6x3                                          | 85                            | 0.26 | 0.28| 0.28| 0.29|
| Ø6x4.5                                        | 127                           | 0.27 | 0.29| 0.29| 0.29|
| Ø4x1.5                                        | 19                            | 0.20 | 0.19| 0.18| 0.20|
| Ø4x3                                          | 38                            | 0.22 | 0.23| 0.22| 0.23|
| Ø4x4.5                                        | 57                            | 0.24 | 0.24| 0.25| 0.27|

5. Results of the experimental research

As a result of the pilot study, the following is established:

- The magnitude of the temperature contrast is greater the deeper the defect and the greater its geometric dimensions in the projection.
- The magnitude of the temperature contrast is affected not only by the depth of the defect, but also by its dimensions in the projection to the area. For example, the defect 8x1.5 and 4x4.5 have the same temperature contrast 0.27. Therefore, the author proposes to introduce the notion of an "equivalent volume" of a defect.

We shall calculate the formula from the experimental values obtained, which will describe the relationship between the equivalent volume of the corrosion defect and the dynamics of the heat flux and the temperature contrast:

$$V_{aeq} = k_1 D^2 + k_2 D + k_3 C^2 + k_4 C + a$$

(2)

where: $V_{aeq}$ - equivalent defect volume; $D$ - dynamics of heat flow; $C$ - temperature contrast; and constants $k_1 = 0.00463937$; $k_2 = -8.70561$; $k_3 = 132.525$; $k_4 = 1432.5$; $a = 3748.46$. 


This formula is valid for the dynamics of heat flow in the range from 55 W/s·m² to 69 W/s·m² and at temperatures of the base metal from 28 °C to 38 °C, and the corrosion defect from 28 °C to 60 °C and a wall thickness of 8 mm.

Most often, the corrosion caverns have a projection approximating to a rounded one (a circle, an ellipse, etc.), the area of the projection of the corrosion defect can be visually assessed using a thermal imager, then knowing the equivalent defect volume it becomes possible to calculate its depth. According to the author, the most dangerous in terms of stress concentration will be a defect of the "V" shape. The volume of such a defect can be described by the formula:

- for the case of corrosion defects with the shape of its projection on a plane close to the circumference (OD):

$$V_{\text{def}} = \frac{1}{3} \pi r^2 l$$

(3)

where: $V_{\text{def}}$ - equivalent defect volume; $\pi=3,14$, $r$ - defect radius, $l$ - defect depth

- for the case of corrosion defects with the shape of its projection on a plane close to an ellipse (ED):

$$V_{\text{def}} = \frac{1}{3} \pi h b l$$

(4)

where: $V_{\text{def}}$ - equivalent defect volume; $\pi=3,14$, $h$ и $b$ - semiaxis of the elliptical base of the defect, $l$ - depth of the defect.

Then the formula for estimating the depth of the OD defect will be in the form:

$$l = \frac{3V_{\text{def}}}{\pi r^2} = \frac{3(k_1D^2 + k_2D + k_3C^2 + k_4C + a)}{\pi r^2}$$

(5)

where: $l$ - defect depth; $V_{\text{def}}$ - equivalent defect volume; $\pi=3,14$, $r$ - defect radius, $D$ - dynamics of heat flow, $C$ - temperature contrast, and constants $k_1=0,00463937$; $k_2=-8,70561$; $k_3=132,525$; $k_4=1432,5$; $a=3748,46$.

And for an ED defect:

$$l = \frac{3(k_1D^2 + k_2D + k_3C^2 + k_4C + a)}{\pi h b}$$

(6)

where: $l$ - is the depth of the defect, $h$ and $b$ - are the semiaxes of the elliptical base of the defect, and the remaining values are the same as in the previous formula.

6. Conclusions
The method of estimating the temperature state of structural elements and welded joints of marine stationary platforms is developed and on this basis the emerging temperature stresses are investigated.

It should be noted that experiments with a grid of holes deposited according to the scheme in figure 6, which were carried out on samples of pipes with different wall thicknesses, revealed the dependence of the temperature contrast on the thickness of the pipe walls. In all cases, the temperature contrast was determined not only by the defect volume, but also by the dynamics of the heat flux and the wall thickness of the pipe.

The magnitude of the temperature contrast is not constant and depends on the volume of the corrosion defect and the dynamics of the heat flux.

It is expedient to carry out the thermal control of offshore oil and gas facilities by an active method.

The greatest danger from the standpoint of stress concentration are defects having a large temperature contrast and a smaller area of their projection onto the plane.
The relationship between the temperature contrast, the dynamics of the heat flux effect and the volume of corrosion defects for samples with a wall thickness of 8 mm is established.

7. References
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