Study of factors enabling initiation and behavior of grooving corrosion

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Abstract. The work describes the experimental definition of the main factors that contribute to the emergence of grooving corrosion: availability of abrasive particles in flow which are transported in specific terms when they are capable of scratching the bottom generating line of a pipeline by creating stress concentrators; availability of considerable residual stresses in pipe metal; oxygen availability in reaction zone.

1 The main factors of grooving corrosion

As the operating experience shows the main reason for failures of field oil pipelines is a failure of its bottom parts due to grooving corrosion.

Despite numerous research works and developments of domestic as well as foreign authors the problem of grooving corrosion has not been fundamentally solved for the moment. Therefore this study focused on analyzing grooving corrosion mechanism and improving anticorrosive protection means, is important today.

According to the existing hypotheses, the cause of grooving corrosion is the combined effect of several factors:

- significant water cut [1];
- presence of corrosive impurities in the oil-water emulsion;
- low flow rate of oil-water emulsion (up to 1,0 m/h), which leads to the separation of the gas-liquid flow [2];
- presence in the oil-water emulsion the mechanical impurities (up to 50 g/l), which are precipitate from a solution on the bottom of the pipe and cause abrasive wearing out of the low part of pipe;
- high emulsion temperature (up to 80 °C) [3];
- presence of tensile residual stresses in the pipeline wall of metallurgical origin and of pressure of the pumped product which can cause mechanical destruction of protective films [4] and can accelerate the local electrochemical corrosion process [3];
- peeling of the protective film, which consists of oxides and carbonates of iron and calcium, due to the action of mechanical factors or as a result of mechanical and chemical dissolution of the film in places of stress state of the pipe.

2 Experimental verification of factors

In Mining University the stand (Fig. 1) have been designed and made for studying factors affecting corrosion failure speed of materials and pipelines. As expected, these factors may enable initiation and behavior of grooving corrosion, and namely:

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- composition and temperature of reaction medium;
- metal stress;
- availability of hard deposits layer on samples surface;
- availability or lack of dissolved oxygen in liquid;
- availability of abrasive effects including the surface of deformed samples exposed to residual stresses.

Fig. 1 – Schematic illustration of the test stand for determination of possible factors enabling grooving corrosion: 1 - a tank with operating medium; 2-clamps with examined samples (plates 150x50x3 mm notch of rolled pipe steel); 3- thermostating device; 4-mixer; 5-electric motor; 6-compressor.

2.1 Experimental verification based on test stand

For several series of experiments, the plates were subjected to the corrosive effects of the medium in the initial state; with scratching on their surface along or across the direction of the rolled steel plate, simulating a trace from the effects of abrasive particles; with deposition on the plate's surface the lime sediment, simulation deposits which is formed during the operation of pipelines; with a polymer coating on the surface of the plate; with the impact on the plate mechanical stresses that cause elastic and plastic deformation; with air supply to the medium.

The tank with preliminary suspended plates including the ones in clamps (Fig. 2) or bent ones with the specified residual deformation and having the notch 0,2 - 1,0 mm deep in deformed part, was filled with 3% sodium chloride solution in water simulating formation waters in the composition of oil-water emulsions transported in pipelines.

Fig. 2 – Device for loading up a sample 1- clamp; 2 - plate; 3 – insert; 4 - bolt.

The plates were placed in specially made cramp frame to create a stress-strain state. The plates were bent on the required bend deflection which was counted by device based on dial indicator (Fig. 3).

Fig. 3 – Measurement of bend deflection via device based on dial indicator

Thermostat was heated to the specified temperature (40 – 100 °C) at which it was exposure within 10 days and with continuous purging of the reaction medium with air. Upon completion of testing samples were removed, examined visually and microscopically regarding initiation of corrosion spots and repeatedly weighed. The weight change and bending deflection of plates were analyzed. Whereas it has been considered that testing of plates prestrained with bending simulate corrosion behavior of pipeline material in areas where pipe wall is under continuous mechanical stress (bends, upstream and downstream areas, passages through barriers, temperature changes, pressure of pumped medium, pulsations, etc.), and also residual stresses are taken into account in process pipeline wall.

2.2 Experimental stress test

Distribution of stresses along the length of the plates before and after immerse in the thermostat was determined using magnetic anisotropy indicator of mechanical stresses Stress Vision [5]. Measurement of the stress distribution showed that the bended plate with a notch on its deformed part lead to the appearance of increased residual stresses in the notched area. The magnitude of the residual stress increases with increasing plate deflection (Fig. 4).

Fig. 4 – Cartograms of Differences Main Mechanical Stresses on the notch area on the plate with bend deflection equal 1,01 mm (a), 1,44 mm (b), 1,92 mm (c)

The impact of corrosive medium leads to the expansion of the zone of increased stresses, which can be explained by an increase in the depth of the notch due to the corrosion destruction of the metal of its bottom part (Fig.5).

Fig. 5 – Cartograms of Differences Main Mechanical Stresses on the notch area on the plate before (a) and after (b) immersion to the corrosive medium.

As a result of experiments the relationship between the weight loss and any determined factor has not been identified, however it has been found out that for steel plates prestrained with bending and having a notch in deformed part, an aggressive media impact leads to a change of its bending deflection: for plates with a notch on external side – a decrease, on internal side – an increase. Herewith bending deflection change for deformed samples without the notch has not been observed. These conditions allow suggesting that discovered bending deflection change in deformed plates of pipe steel is caused by an increase of notch depth due to metal corrosion in bottom part with an aggressive media. Considering the notch is stress concentrator it is concluded that the corrosion has higher rate in areas where metal is affected by considerable residual stresses.

As known steel corrosion in oil-water emulsions runs as per electrochemical mechanism [3] with oxygen, thus it was possible to suggest that the second necessary factor for active metal corrosion in the notch bottom is sufficient oxygen availability in reaction zone, which was experimentally checked. In this regard the similar bent plates with the notch were soaked in boiling solution NaCl almost without dissolved oxygen and without air purging. It has been found out that in these conditions plates surface has its original surface (Fig. 6, 7), and its bending deflection remains unchanged.

Fig. 6 – Plates surface of pipe low-carbon steel after an impact of 3% NaCl solution with oxygen in reaction medium

Fig. 7 – Plates surface of pipe low-carbon steel after an impact of 3% NaCl solution without oxygen in reaction medium

3 Findings

In view of the foregoing the possible mechanism of grooving corrosion initiation and behavior may be represented as follows:

1. Abrasive particles in oil-water emulsion flowing in a pipe scratch the bottom generating line of a pipeline;

2. The bottom of scratches as stress concentrators starts corroding with higher rate increasing particularly in those pipe areas where metal is affected by considerable residual stresses;

3. Dissolved oxygen availability is a necessary condition for active corrosion process in emulsion;

4. The deeper scratches due to the corrosion process the more considerable stresses in metal of its bottom part and the more active corrosion rate. Scratches enlarge, merge with each other and turn into a groove.

Therefore in authors' opinion the main factors enabling grooving corrosion in field oil pipeline are the following:

1. Availability of abrasive particles in flow which are transported in specific terms when they are capable of scratching the bottom generating line of a pipeline by creating stress concentrators.

2. Availability of considerable residual stresses in starting pipe metal.

3. Oxygen availability in transported medium.

Development of methods for excluding these factors may prevent grooving corrosion in field oil pipelines.

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