DEGRADATION OF OIL TRUNKLINE STEEL CAUSED BY INTERNAL CORROSION

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ABSTRACT

It is generally recognized that the corrosion-induced failure of oil trunklines is caused by corrosion damage of external surfaces of the pipes. However nowadays more attention is paid to the problem of the pipe internal corrosion. In this paper the problem of deterioration of the anticorrosion, mechanical and corrosion-mechanical properties of the low alloy 0.10C-Mn-Si steel after 28 years of service is considered. The problem results from the water, which comes with the transported oil and settles at the bottom part of the pipe. Three areas of the steels were investigated: the original state (specimens were cut from as-manufactured pipe), the upper area and the lower area having been in contact with the water. The following properties were evaluated for these areas: corrosion rate in residual water; impact strength; sensitivity to stress corrosion cracking in residual water at the moderate cathodic polarization determined by low rate loading of cylindrical specimens. It was found that the material of the lower pipe area has the highest corrosion rate in water. The degradation of material was confirmed by electrochemical investigations. The long service duration of the pipe caused a decrease of the brittle fracture toughness. Stress corrosion cracking tests proved that the residual water should be considered as a rather aggressive environment at the moderate cathodic polarization, and the lower area of the pipe is the weakest in respect to the stress corrosion cracking. The obtained results show that the degradation of pipes in the service means not only the corrosion damage of the inner surfaces but also the decrease of corrosion resistance of the bulk material, fracture toughness and stress corrosion cracking resistance that is caused the hydrogenation of the pipe areas contacting the residual water.

1 INTRODUCTION

The proper consideration of corrosion problem of the inner surfaces of the oil trunklines, transported the marketable oil has been not given till recently since the service failures were mostly a result of corrosion damages of an external surface of pipes. However, the inspection of inner surface of some oil trunklines carried out because of the expiration of the planned service time revealed the corrosion damages of the inner surface of pipe, especially numerous at the bottom of the pipe cross-section. An underestimation of a danger of such local damages can have the fatal consequences, such as serious financial losses and ecocatastrophes. Therefore, the study of the nature and mechanism of corrosion processes occurred on the inner surface of the oil trunklines and the development of effective measures for their suppression are of a great importance.

At present, it is recognized the presence of the residual water, deposited at the bottom of pipe cross-section at stratification of the oil-water emulsion and the presence of some water soluble compounds in oil as the main reason for corrosion of steel in oil environment. However, the nature and the mechanism of those corrosion processes have been studied insufficiently.

Slobodyan [1], Nykyforchyn [2], Tsyrulnyk [3] made an overview of corrosion and corrosive-mechanical failure of the low alloy 0.10C-Mn-Si steel used in Ukrainian oil trunklines after 28 years of operation. The virgin (as-manufactured pipe) material and the pieces cut from the top part and bottom part of the used pipe were tested.

2 CORROSION RESISTANCE

In cut out patches of the inner surface upper area (Fig. 1a), we observed numerous pointwise defects (pittings of depth 0.09-0.12 mm and several pits with an area of 0.78-0.84 mm^2). On the average, there were about 1300 pits per 1 m^2 of the surface. At the same time, in cut out patches of the lower area (Fig. 1b), the character of corrosion damage is quit different. Against the background of numerous pittings of depth 0.04-0.08 mm, there are large pitts with an area of 0.5-2.5 mm^2. We have in the mean, more than 10^5 pitting-type defects and more than 1300 pits per 1 m^2 of the surface.

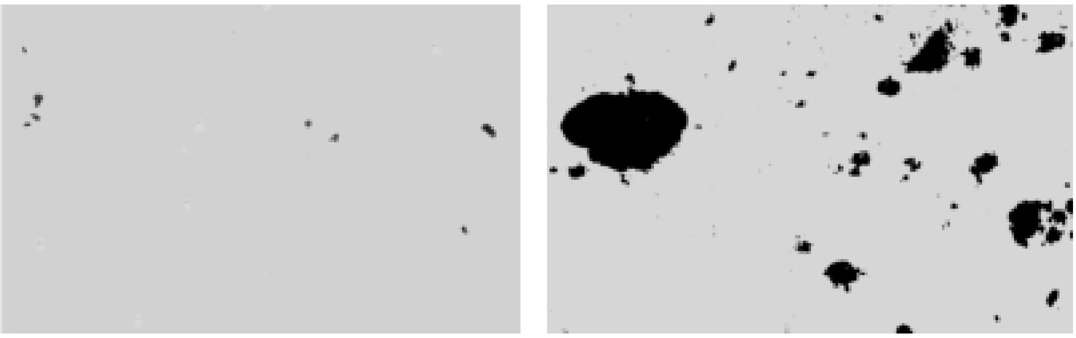
Thus, at the upper area of the pipe, whose initial thickness is 16 mm, the maximum rate of local corrosion averaged over 28 years of operation reaches 0.006 mm/year, whereas it is 0.09 mm/year at the bottom. It should be emphasized that these results are averaged over the entire period of operation because there are no annual observation data.

Corrosion rate K of pipeline steel was determined by the gravimetric method in the model environment, simulated the residual water [1]. Corrosion rate of the lower area was in 2 times and the upper area – in 1.7 times higher than for unoperated material (Fig. 2).

Electrochemical investigations confirmed the pipe material degradation in the course of service. At all rotation velocities, the steady-state potential of the lower area, measured in the residual water, was shifted into the cathodic direction in comparison with the potential for unexploited material.

The reduction processes (oxygen depolarization) on degraded steel occurred at more negative potentials and their intensity was higher than those for virgin material. The increase in rotation velocity caused the noticeable rise of sustaining diffusion current for degraded material and less pronounced for undegraded one.

The determined graphically corrosion currents confirm a presence of a differentiation in the properties of the operated and unoperated material. Corrosion rate in the first case is in 1.5 times higher. Obtained results correlate with the data of the weight tests. Difference in the corrosion rates for both materials increases essentially in the dynamic conditions and on average reaches a whole order.



a b

Figure 1: General view of corrosion damages of an internal surface of the top (a) and bottom (b) pipe parts.

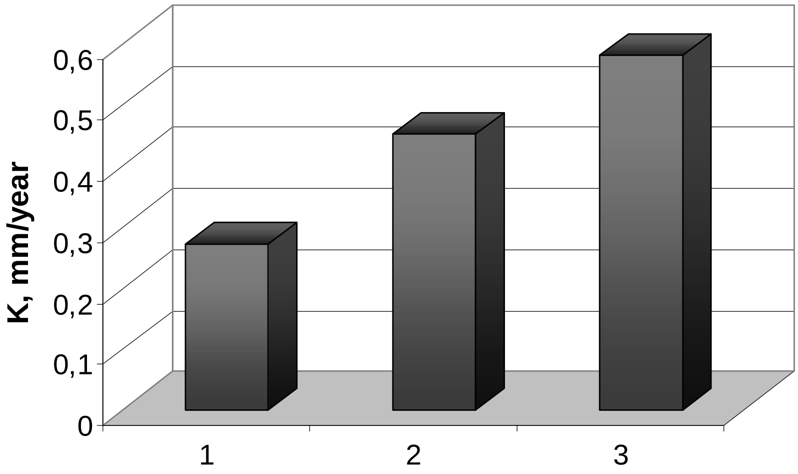


Figure 2: Corrosion rate of the virgin steel (1), upper (2) and lower (3) areas of the pipe.

3 IMPACT TOUGHNESS

The maximum value of KCV (180 J/sm^2) exhibits the as received steel, whereas in the case of the upper area of the being in service material it is twice as low (95 J/sm^2). Such a dramatic drop in the toughness is in agreement with the similar tests done by Krasowsky [4]. This indicates the common problem of the degradation of mechanical properties of the steels exploited in the oil trunklines.

FIGURE 2: The fracture of specimens cut from the pipe being in service and subjected to the toughness tests: specimen from upper (left) and lower (right) areas of the pipe.

In the case of the lower area of the pipe being in service, it has been not possible to evaluate the toughness, since the reorientation of the crack path along the pipe wall (Fig. 3). This reflects the so called hydrogen induced stratification well known defect of industrial pipe lines transporting the crude oil containing the higher amount of the hydrogen sulfide and the sulfide reduced bacteria. Therefore, the above findings, together with the results of the hydrogen extraction and permeation tests (Slobodyan [5]) confirm the role of hydrogen in the degradation of steel of the trunk-oil pipe lines.

4 STRESS CORROSION CRACKING

Sensitivity of the investigated steels to stress corrosion cracking was studied by tension with low rate of loading (10^{-7} s^{-1}) of the cylindrical specimens of 3 mm in diameter in the ground water (taken from the oil storage tank, being in service) at the moderate electrochemical polarization (at current density 0,5 A/m^2). For comparison the similar experiments were performed in air but at usual rate of loading ($3x10^{-3}$ s^{-1}). The sensitivity to stress corrosion cracking was determined due fracture analysis by factor $K = RA^c/RA^a$, where RA^c and RA^a – reduction in area of specimens tested in corrosion environment and air correspondingly.

Table 1: Reduction in area of the tested materials

Material	Test environment	RA, %	K, %
As received	air	77	55
	water	42	
Lower area of the exploited pipe	air	56	5
	water	3	

As seen in Table 1, the values of parameters *K* is 55% and 5% for the specimens in the initial state and cut out from the lower area of the pipe correspondingly.

Comparison of RA value estimated in air for as received material with that measured for the lower area of exploited pipe in aggressive environment (RA^a = 77% and RA^c = 3%, respectively) shows the possibility of drastic decrease in the resistance to brittle fracture of metal if in the course of exploitation, the conditions for the hydrogen charging to the level, similar to that obtained in the laboratory tests could occur.

As follows from the above data, the difference between resistance to stress corrosion cracking in the ground water of the exploited and of as received pipe steels has been found out. The lower resistance of the lower area of the pipe is a result of the in-service hydrogen induced degradation of the pipe steel. It means that inspection of the working surfaces of installations to detect the corrosion and mechanical damages is not enough since material can loss the previous mechanical properties, which were taking into account at engineering grounds of workability. This mainly refers to the susceptibility to the brittle cracking under the conditions of the aggressive action of the deposited water. It should be emphasized that the detrimental effect of the water would manifest itself not only during the oil-trunk pipeline standstill, when water can collect at the pipe bottom, but also during the transport of the oil, if the pipe bottom would be covered with the paraffin deposits. The break trough of the compact layer of deposits would result in the local penetration of the water to the metal surface causing the pitting and crevice corrosion, as well as the hydrogen charging of steel, and thus the further degradation of the pipe metal.

5 CONCLUSIONS

1. Presence of the deposited water is a main reason of the corrosion damages of the inner surface of oil-trunk pipelines.
2. Difference between corrosion resistance of the operated and unoperated pipe steels in the deposited water was found out. Worse corrosion resistance of the upper and especially the lower areas of the pipe is a result of the in-service degradation of the pipe steel.
3. Long time exploitation of the oil-trunk pipelines leads to the decrease in the resistance to brittle fracture of the pipe metal, as has been stated in the impact toughness tests and in the measurements of the susceptibility to hydrogen induced cracking.
4. The control of the pipelines consisting of the detection of the defects and damage has not be enough to ensure the efficient work and for the lifetime assessment of the oil-trunk pipelines.

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