Environmental safety of main gas pipelines

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Abstract. Analysis of the causes of accidents indicates the prevailing influence of corrosion factors on the structural reliability of main gas pipelines. During operation, main pipelines are exposed to the in-pipe pressure of the pumped product and ground electrolytes, which leads to corrosion-mechanical damage. Moreover, these factors can act in the most unfavorable combinations. This combined action reduces the durability of the material. This leads to much faster destruction of the pipe metal. Therefore, it is necessary to monitor not only general corrosion damage, but also local damage, which, when subjected to mechanical stress, can become a source of corrosion crack. The article discusses the main factors influencing the environmental safety of main gas pipelines, as determining the required level of quality at the time of operation.

1 Introduction

The most important indicator of the environmental safety of main gas pipelines is considered to be their structural reliability – an indicator of the quality of engineering design, which is the ability to maintain these functions during operation throughout the entire service life.

According to Gazprom, the total length of the main gas pipelines is more than 160 thousand km. and they run in a variety of soil and climatic conditions. Therefore, both the economy of the Russian Federation and the environmental situation in the surrounding areas depend on the constructive reliability of the main gas pipelines.

In [1,3,8], emissions of pollutants into the atmosphere from oil and gas industry facilities account for 15.8% of their total values at enterprises of other industries.

The impact of the facilities of the gas complex on nature is due to the toxicity of natural hydrocarbons and related resources, the variety of chemicals used in technological processes, as well as the specifics of extraction, preparation, transport, storage, processing and diverse use of gas [2,4,6].

During operation, the main pipelines are exposed to the in-line pressure of the pumped product and ground electrolytes, which leads to corrosion and mechanical damage. Moreover, these factors can act in the most unfavorable combinations. This combined action reduces the durability of the material. This leads to a much faster destruction of the metal of the pipes than with the action of each factor separately. Therefore, it is necessary to monitor not only

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general corrosion damage, but also local damage, which, when applied by mechanical influences, can become a source of a corrosion crack [3,7,9].

2 Materials and methods

The analysis of the destruction of main pipelines allowed us to identify three most significant types of damage: general corrosion, fatigue low-cycle destruction, stress corrosion cracking. Of these, the most dangerous type, in particular for main gas pipelines, is stress corrosion cracking, which originates on the external exposed insulation of the pipe surface.

In connection with the above, the problem of ensuring the structural reliability and environmental safety of main pipelines in conditions of multifactorial negative impacts is an urgent scientific and practical task.

Figure 1 shows the conditions under which stress corrosion cracking occurs.

The elimination of any of these causes cannot solve the problem, since stress corrosion cracking develops with the combination of many mutually related factors, and the dominant one has not yet been established.

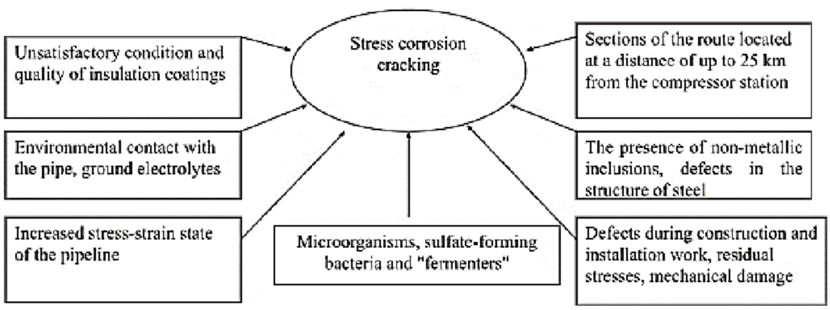

Fig. 1. Conditions for the manifestation of stress corrosion cracking on main gas pipelines.

As a result of the conducted research, it was found that all steels, without exception, are susceptible to stress corrosion cracking, therefore, only improving their grades cannot lead to a solution to the CRN problem. At the same time, the quality of pipe steels, as well as the pipe manufacturing technology in factories, play a significant role in the occurrence and development of cracks.

Obviously, among other factors, the long-term strength of gas pipelines will be significantly influenced by the design features and technological heredity of the pipe, which is due to the entire complex of sequential manufacturing techniques and assembly and welding operations of the pipeline itself. The role of these factors in ensuring the operability of the structure is different and can vary significantly depending on the specific operating conditions, in particular, on the composition of the transported product, ambient temperature, nature of loading, etc., however, it is clear that their influence on strength and durability cannot be neglected.

In [3,4,5], the patterns of behavior of low-alloy steels of strength class X70 under the simultaneous influence of an aggressive environment and mechanical loads in a uniaxial stress state were studied. The experimental samples were cut from X70 strength class tubular steel, which are used in the construction of high-pressure underground pipelines.

Studies of the nature of the origin and propagation of microcracks at the microscopic level were conducted on samples (Figure 2) cut from a pipe with a diameter of 1420x15,7 mm made of X70 steel, where a biaxial stress state was created due to the design features of the developed samples. Experimental samples have a set of structural and technological features of a real gas pipeline pipe, simulating the reserve of elastic energy of compressed gas, and in the presence of welds, they ensure the preservation of the field of residual welding stresses.

The experimental study of the stress-strain state in the pipe segment in the area of the rigid insert cut was carried out using multipoint strain measurement. Strain gauges were located in the groove zone on the inner and outer surfaces of the pipe segment. Experimental studies were carried out in order to select the optimal size of the groove in the central part of the rigid insert to determine the nature of the stress distribution over the thickness of the sample Figure 2.

Fig. 2. Sample with installed thermistors for voltage determination.

3 Results and discussion

The analysis of the obtained results indicates that in the working area of the developed sample, a biaxial stress state is simulated, a homogeneous field of tensile stresses along the thickness of the segment and the value of the elastic energy of the pumped gas, in addition, the geometric dimensions of the sample ensure the preservation of the field of residual welding stresses formed by annular and longitudinal seams.

The samples were loaded in such a way that the stresses in the working part corresponded to 0.85 $\sigma_{0,2}$ and 0.95 $\sigma_{0,2}$. By changing the parameters of the loading system, different reserves of elastic energy were given to the samples, with equal stresses in the working area. A corrosion cell with a solution simulating a ground electrolyte was installed on the working area of the samples. It was found that the nature of corrosion damage depends on the reserve of elastic energy and is a laboratory analogue of the pipe – pumped product system. In the samples with a low elastic energy reserve, the corrosion defects had the character of ulcerative corrosion with round and oval ulcers.

When testing a semi-circular sample in a carbon-containing medium, point defects form on the surface at the sites of manganese inclusions. In the resulting ulcerative lesions, acidification of the initial medium occurs and the mechanism of active anodic dissolution develops (Figure 3). However, after 4200 hours of testing, no defects were observed in the joint of the main crack. Apparently, the composition of the corrosive medium used in these laboratory tests is not capable of combining stitch ulcerative defects into one crack.

As can be seen from Figure 3, the corrosion resistance of the metal deteriorates in places of non-metallic inclusions, due to the dissolution of which line defects are formed.

Fig. 3. A colony of ulcerative lesions in the form of a point defect.

The rate of dissolution of the metal increases sharply when the external mechanical stress field increases in the studied samples, which explains the increased tendency of the deformed metal to dissolve by the accumulation of bound potential energy in it, manifested in the form of residual stresses.

When exposed to a corrosive environment, the corrosion resistance of the metal deteriorates in places of non-metallic inclusions, due to the dissolution of which stitch defects are formed. The rate of metal dissolution increases dramatically when the external mechanical stress field increases in the samples under study. This is due to the increased tendency of the deformed metal of the pipes to anodic dissolution and the accumulation of bound potential energy, manifested in the form of residual stresses throughout the pipe body.

4 Conclusion

Summarizing the above, we can conclude that the curvature, scale, technological heredity of the pipe, i.e. structural and technological factors, have a great influence on the strength and durability of gas pipelines. The role of each of them is different and significantly depends on the specific operating conditions.

Thus, according to the results of theoretical and laboratory studies, it has been established that the bearing capacity of the gas pipeline, its operational reliability are determined primarily by force factors, properties and quality of the pipe metal, as well as its ability to resist the nucleation and growth of cracks under the influence of mechanical loads and corrosive media. The deterioration of the physical and mechanical characteristics of the metal of pipes during long-term operation is due to their structural degradation and aging.

The development of stress corrosion cracking of pipe metal is facilitated by a combination of three groups of factors – the initial quality of the metal and its sensitivity to cracking; the second characterizes the appropriate level and cyclicity of tensile stresses; the third reflects the parameters of the corrosive medium, the possibility of its access and interaction with the metal surface.

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