The corrosion damage mechanisms of the gas pipelines in the Republic of Sakha (Yakutia)

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Abstract. The article provides examples of critical damage to a long-running gas pipeline on the territory of the Republic of Sakha (Yakutia), which arose as a result of the development of corrosion processes, discusses the mechanisms and scenarios for the development of corrosion damage in the cryolithozone conditions. Considering the processes and mechanisms, they continue for a long period of time, an increase in the number of damages to a gas main pipeline due to corrosive degradation is expected in the near future. The stage of diffuse damage during long-term operation is confirmed by the increasing loss of working capacity due to corrosion damage in the last 25 years of the pipeline operation.

1 Introduction

The Republic of Sakha (Yakutia) is the largest region in Russia, known for its sharply continental extreme climate, when in summer temperatures reach + 40 °C and in winter - 60 °C. The first cross-country gas pipeline in the cryolithozone area was put into operation in the territory of Yakutia in 1967 and is still in operation. The construction and operation carried both industrial and experimental nature given the unique climatic features of Yakutia.

The information on the operation of the pipeline, accumulated for over 50 years in unique climatic conditions, represents a significant value in the development of science and industry.

The analysis of the causes of emergency situations shows that the main defects in terms of the danger level are: defective construction and installation works; mechanical damage to pipes; defects of materials and structures caused by their long-term operation; corrosion; local corrosion caused by stray currents. Moreover, emergency situations that occurred in the conditions of Yakutia as a result of corrosion damage are rare due to the relatively dry climate.

It is known that during long-term operation of steel structures, the process of degradation of the mechanical properties of steel elements is divided into two stages: deformation aging and diffuse damage. In the second stage, after 25-35 years of operation, an intensive decrease in strength, resistance to brittle fracture and intensive formation of hydrogen traps is observed in the metal.

Due to the peculiarity of the soil associated with the presence of accumulation sites of a mixture of water and salts (electrolyte), along with the second stage of steel degradation, conditions arise for the accelerated occurrence of corrosion processes. Large current densities are created at the anode areas, which greatly increases the corrosion rate. It is also known that in permafrost soils, microorganisms can provoke corrosion by producing substances that substantially increase the corrosive activity of the soil, causing the appearance of potential differences on the metal surface and the formation of additional anodic and cathodic zones, with a further electrochemical mechanism.

The article provides examples of critical damage to a long-running gas main, which arose as a result of the development of corrosion processes, discusses the mechanisms and scenarios for the development of corrosion damage in the cryolithozone conditions.

2 Examples of incidents and accidents on cross-country gas pipeline in...
Republic of Sakha (Yakutia), occurred due to corrosive wear

In August 2006, a gas leak was detected at the 68th km of the branch pipe of Taas - Tumnus - Yakutsk gas pipeline main to the city of Pokrovsk during an industrial safety inspection. With detailed visual inspection of the leakage area, unacceptable defects such as pitting corrosion, surface blowholes, multiple cavities, and cavities up to 7 mm deep were documented.

This branch has been operated since 1968. The laying method is underground. Pipe material is St3 sp. Outer diameter is 273 mm, wall thickness is 8 mm.

Were perform the following works to define the causes of corrosion damage:
- chemical analysis and metallography confirmed the compliance of the pipe material with the existing factory certificates;
- visual examination and measuring showed the absence of a general unacceptable thinning of the walls of the pipeline. A partial absence of an insulating layer on the segment was found. Unacceptable defects such as pitting corrosion with a depth of 0.5 mm to 7 mm and a diameter of 6 mm and up to 23 mm were found on a pipe 12 m in length; 2 surface blowholes with a diameter of 10 and 12 mm; 3 cavities (P10x4, P10x5, P10x6) with a diameter of 10 mm and depths from 4 mm to 6 mm;
- the calculation of the degree of corrosion damage to the metal performed in accordance with criteria for the occurrence of the limiting state of the pipe-through corrosion damage or residual pipe wall thickness, which does not allow further operation of the gas pipeline according to the conditions of ensuring durability. Also, the calculation of the corrosion wear rate and the calculation of the residual service life of the pipeline in the presence of pitting corrosion were made.

The possibility of corrosion is determined by both internal and external factors. Internal factors: St3 has low corrosion resistance, as it corrodes not only due to oxygen, but also hydrogen depolarization, moreover, it contains S impurities in the form of FeS and MnS sulfides, which, when destroyed by corrosion, form hydrogen sulfide in the electrolyte.

Were carried out Microstructural studies on section metallographic specimen, performed matching the thickness of a pipe containing two adjacent corrosion pits. The structure of the investigated steel is ferritic-pearlitic, lamellar perlite, pronounced pearlite colonies are not observed.

The surfaces of the corrosion pits are uniformly covered with corrosive deposits (Fig. 1). Corrosion processes are characterized by a relatively uniform penetration of corrosion damage into the metal (Fig. 2), they occurred through the formation of pittings (Fig. 3), do not have signs of structural, selective and component-selective destruction, corrosion cracking, and are characteristic of oxidation processes when a metal interacts with a corrosive medium at an electrochemical corrosion mechanism.
due to damage to the insulating layer, which is characterized by the focal corrosion damage (spot corrosion and pitting corrosion). The soil corrosion in this section of the pipeline is accelerated by periodic floods affecting the area with groundwater containing nitrogen oxides, ammonia and hydrogen sulfide, which result from agricultural land treated with organic and inorganic fertilizers located near the gas pipeline.

December 2018, gas blowout with ignition took place at the 239th km of the first line of the Taas-Tumus-Yakutsk gas pipeline. This gas pipeline has been in operation since 1967. The material of the segment is 14HGS steel. Outer diameter is 529 mm, wall thickness is 8 mm.

As a result of the blowout and ignition, a crater measuring 17 * 6 meters and with a depth of about 2.5 meters was formed (Fig. 4).

![Fig. 4. The destroyed segment of "Taas-Tumus - Yakutsk" pipeline, 239 km. 1st line.](image)

The fragments of wire rod were found in the pit near the site of breakdown.

To define the causes of the accident, a number of works were carried out:

- visual examination and measuring showed that the failure occurred at the lower part of the pipe in a section of 3 successively welded pipes, each a length of 6 m, the total length of the crack and opening was 13,430 mm. Almost complete lack of insulation coating (fiberglass coated by bitumen) was found. Complete degradation of the protective material samples and non-compliance with the requirements for protecting the pipeline from corrosion was revealed;
- fractography of the fracture surface showed that corrosion damage was a stress concentrator and caused the destruction, the initiators of the formation of numerous fatigue microcracks, (Fig. 5). A crack of critical size was formed at the coalescence of fatigue microcracks, the pressure of the pumped product, led to the spread of the main crack along the base metal in both directions to adjacent pipes;

- chemical analysis confirmed the compliance of the pipe material with the existing factory certificates;
- study of the metal microstructure;
- the type of soil is defined as clay sand according to the analysis of the corrosiveness of the soil, and the low corrosivity at low temperatures, as average at 0 to 6 °C range, and low at temperatures above 6 °C;
- the results of measuring the thickness and hardness of the pipes did not reveal a general unacceptable wall thinning and deviations of hardness values from the normative values;

As a result of the research, it was concluded that the destruction of the pipeline occurred during the propagation of a main crack caused by a crack of critical size, formed by the merging of numerous fatigue microcracks. These were formed as a result of cyclic effects of temperature stresses and fluctuations of the working pressure during the operation of the pipeline on corrosion pits being stress concentrators.

The detected corrosion damage is local in nature and is found only in the source of fracture, on the rest of the 120 m long gas pipeline section extracted for replacement corrosion pits were not detected.

The occurrence of the corrosion damage took place as a result of galvanic or contact corrosion at the contact or in the immediate vicinity of the metal of the pipe and the metal of the wire rod found in the pit, which have different composition (14HGS and 08kp) and different electrochemical potential. The pipe metal served as an anode and was intensively corroded, while the metal of...
the reinforcement on which no corrosion was observed is the cathode.

Thus, the destruction of the main gas pipeline was the result of a confluence of circumstances that had been taking place for a long time, which is the damage of pipe insulation and single, difficult to detect circumstance - the interaction of a corrosion catalyst (metal reinforcement) with a gas pipe.

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Fig. 6. The pipeline destruction development scenario.

Figure 6 presents the proposed scenario for the development of a pipeline destruction in the area of the source of fracture. The gas ignition that followed the destruction of the gas pipeline came from a friction spark formed during the impact or friction of the metal fragments of the pipeline either against each other or the inclusion of pebbles in the adjacent ground.

3 Conclusion

Considering the processes and mechanisms described above, which develop over a long period of time, an increase in the number of damages to gas main pipeline due to corrosive degradation is expected in the near future. The stage of diffuse damage during long-term operation is confirmed by the increasing loss of working capacity due to corrosion damage in the last 25 years of the pipeline operation.

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