Temperature factors effect on occurrence of stress corrosion cracking of main gas pipeline

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Abstract. The purpose of the article is to analyze and compare the data in order to contribute to the formation of an objective opinion on the issue of the growth of stress corrosion defects of the main gas pipeline. According to available data, a histogram of the dependence of defects due to stress corrosion on the distance from the compressor station was constructed, and graphs of the dependence of the accident density due to stress corrosion in the winter and summer were also plotted. Data on activation energy were collected and analyzed in which occurrence of stress corrosion is most likely constructed, a plot of activation energy versus temperature is plotted, and the process of occurrence of stress corrosion by the example of two different grades of steels under the action of different temperatures was analyzed.

1. Introduction
Over the period of many years of operation, the main gas pipeline has been subjected to a large number of internal and external influences, as a result of which various defects appear. One of the main defects on the main gas pipelines is stress corrosion cracking (SCC), as a result of which, according to different authors, up to 50% of all main gas pipelines fail. The appearance of stress corrosion on the main gas pipeline is associated with a combination of various factors. The study of the effect of temperature as a separate factor will help us to understand the process of occurrence of stress corrosion on the main gas pipelines.

In 2001, due to stress corrosion, 41.93% of main gas pipelines went out of operation, while they are revealed only on pipelines with a large diameter (from 720-1420 mm). [1] The main problem of studying the issue is that stress corrosion cracking appears only for a certain time. The bulk of the work is meant for the period from 7 to 24 years.

2. The assay of influence of the temperature factor on the failures of main gas pipelines because of stress corrosion according to company “Severgazprom”
According to the data on the distribution of emergency destruction of the linear part of the main gas pipelines of company “Severgazprom” [2], a histogram of the dependence of the number of accidents due to stress corrosion on the distance from the compressor station was constructed (Figure 1). Sections 115 km long were considered on the linear part of the underground main gas pipeline. The steel grade was 17G1S, the diameter of the pipes ranged from 1020 mm to 1420 mm. [3]
After analyzing the distribution of temperature along the length of the main pipeline during the winter and summer periods, graphs of the dependence of the number of accidents on stress corrosion against temperature were plotted. The temperature intervals at which the main gas pipelines were operated ranged from +60 °C to +25 °C in the summer, from +30 °C to -30 °C in the winter. (Figures 2, 3)

**Figure 1.** Dependence of defects due to stress corrosion on the distance from the compressor station

**Figure 2.** Exponential approximation of the dependence of the density of accidents due to stress corrosion on the temperature in summer
Figure 3. Exponential approximation of the dependence of the density of accidents due to stress corrosion on the temperature in winter

As a result of the analysis of the graphs, it can be concluded that high temperatures have a significant negative impact on the condition of pipelines, in particular, gas pipelines operating at high temperatures are much more susceptible to stress corrosion.

3. The study of the dependence of the activation energy required for the occurrence of stress-corrosion defects on the temperature

An important factor for investigating the dependence of stress corrosion on temperature is the activation energy. The activation energy is the minimum amount of energy necessary to form stress corrosion. As a result of the analysis of the research of A G Gareev, a histogram of the dependence of activation energy on temperature was constructed (Figure 4).

Figure 4. Histogram of dependence of activation energy on temperature

The formula of Chuchkalov and A G Gareev was used to calculate the activation energy, (1):

\[ y = 0.9717e^{0.0115x} \]

\[ R^2 = 0.4702 \]
where $T$ - absolute temperature, K;
$R$ - universal gas constant, $\frac{J}{molK}$;
$\delta$ - pipe wall thickness, mm;
$a$ - empirical coefficient characterizing the parameters of SCC;
$t$ - gas failure time, years;
$b$ - the duration of the formation of a near-electrode medium, years;
$\sigma$ - stress, MPa;
$\sigma_t$ - yield strength of steel, MPa;
$Q$ - activation energy, $\frac{kJ}{mol}$;
$\nu$ - effective crack growth rate, $\frac{mm}{years}$. [4]

Comparing the results of A G Gareev with the work of M V Chuchkalov, it is possible to plot the dependence of the activation energy on temperature with the temperature range from 0 °C to +70 °C (Figure 5):

**Figure 5.** Exponential approximation of the dependence of the activation energy on temperature

The range of operating temperatures at which measurements were taken varied from + 25 °C to + 50 °C. As to steel X70, the studies were carried out on a sample that was cut near the colony of stress-corrosion cracks. A solution of 1N NaCO$_3$ + 0.5N NaHCO$_3$, which is most often used to model the conditions of occurrence of stress corrosion, was chosen as the electrolyte. The results show that at lower temperatures, more energy is needed to generate stress corrosion than at high temperatures — to overcome the energy barrier. [5]

The comparison of the studies of M V Chuchkalov and A G Gareyev revealed that as the temperature increases, the activation energy necessary for the process of occurrence of stress corrosion decreases.

4. Comparison of the susceptibility of steel grades to stress corrosion under the influence of different temperatures
The last point of the work was the study of two graphs (Figures 6, 7) constructed from the slow strain rate testing results for longitudinal welds of X60 and X65 steels in a brine solution saturated with H2S at a temperature of + 25 °C, + 37 °C and + 50 °C. According to the first graph, when the temperature was changed from + 25 °C to + 50 °C, the susceptibility to stress corrosion increased from 0.85 to 0.87 for steels X65, and to 0.9 — for steels X60. [6, 7] This indicates a direct effect of temperature as a detrimental factor, which increases the susceptibility of the metal to stress corrosion. Analysis of the second graph allows us to conclude that when the temperature upsurges from + 25 °C to + 50 °C, the ability of the metal to absorb hydrogen increases 2.5 times for X65 steels and for X60 steels, and the growth of the hydrogen concentration uplifts the risk of stress corrosion. [8-10].

Susceptibility to stress corrosion was calculated using the following formula (2):

$$I_{SCC} = \frac{R_{air}-R_{H2S}}{R_{at}} \cdot 100\%,$$

(2)

where $R_{air}$ and $R_{H2S}$ — loss of metal in air and in H2S solution [11].

Figure 6. Dependence of the susceptibility to stress corrosion on temperature

Figure 7. Dependence of the hydrogen uptake on temperature
5. Conclusion
As a result of this work, the authors have found a clear dependence of the occurrence of stress-corrosion on the gas mains on temperature. The assay of influence of the temperature factor on the failures of main gas pipelines because of stress corrosion shows a reduction in the number of accidents in the course of temperature decrease (near compressor stations, where gas main pipelines are under maximum operating temperature, density of accidents per kilometer reaches 1.6, and at a distance of 115 kilometers from the compressor station accidents density is more than 0.8). The study of the dependence of the activation energy on the temperature demonstrates a clear decrease in activation energy due to the temperature rise (at a temperature of 0 °C it is necessary to overcome the energy barrier of 44 kJ / mol, and at a temperature of +70 °C — activation energy of only 4.5 kJ / mol, which increases the risk of growth of SCC on parts with higher temperature. The results of the comparison of the susceptibility of steel grades to stress corrosion under the influence of different temperatures show an increase in the susceptibility of metals to stress corrosion as the temperature rises (from +25 °C to +50 °C, the susceptibility to stress corrosion increased from 0.85 to 0.87 for steels X65 and to 0.9 for steels X60). These results indicate a clear effect of temperature on the occurrence of stress corrosion.

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