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Intergranular stress corrosion cracking of steel gas pipelines in weak alkaline soil electrolytes

I.V. Ryakhovskikh[a], R.I. Bogdanov[a,*], V.E. Ignatenko[b]

[a] Institute of Natural Gases and Gas Technologies – Gazprom VNIIGAZ LLC, Moscow Oblast, Razvilka Settlement, Russia
[b] Institute of Physical Chemistry and Electrochemistry, Academy of Sciences, Leninsky pr. 31, Moscow, Russia

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ABSTRACT

The paper presents an overview of the main types of stress corrosion cracking (SCC) of pipeline steels under operating conditions of high-pressure buried gas pipelines. Up to the present time, there have been cases of transgranular cracking in gas pipelines in near-neutral pH soil electrolytes in Russian territory. The present work studies fragments of pipes containing cracks as well as soil samples at the excavation sites of gas pipelines running through the territory of the Astrakhan region. It was found that the cracks formed as a result of SCC of pipe metal and are of intergranular character of propagation. It is also established that the chemical composition of the soil along the gas pipeline differs from the previously studied compositions of corrosive environments that encourage the development of intergranular SCC of pipeline steels.

1. Introduction

Stress corrosion cracking (SCC) of pipeline steels is one of the most important problems of operation of high-pressure buried gas pipelines [1–3].

The analysis of failures and the results of diagnostic surveys of sections of gas pipelines in Russia and abroad showed that SCC occurs in gas pipelines running in different natural climatic regions constructed from pipes made by different manufacturers and differing in design and size. At the same time, the formation and propagation of SCC defects takes place on the surface of the pipes that are in contact with the soil electrolyte due to tape coating disbondment [3–5]. Depending on the composition of the electrolyte under the coating, two main types of SCC of pipeline steels are distinguished: intergranular cracking in concentrated carbonate electrolytes with high pH and transgranular cracking in dilute electrolytes with near-neutral pH (Table 1).

Currently, it is recognized that the local anodic dissolution of metal at the grain boundaries (more exactly a slip dissolution mechanism) is the prevailing mechanism of SCC propagation in pipeline steels in soil electrolytes with high pH [6, 9–12].

The majority of researchers agree that SCC in near-neutral pH environments is due to the synergistic effect of mechanical loading, hydrogen charging, and local dissolution of the metal [13–18]. The effects of these factors on SCC are interrelated and the authors consider that it is impossible to unequivocally single out the factor that exerts a dominant influence on crack growth. However, some researchers still believe that hydrogen plays a significant role in the cracking of pipeline steel in near-neutral pH electrolytes [8–19]. Other researchers believe that local anodic dissolution of the metal has a major effect on crack growth in pipeline steel in weakly acidic and neutral electrolytes [20–25]. At the same time, in [23], the authors do not completely exclude the influence of atomic hydrogen on pH-neutral SCC, which, depending on the metal potential, the pH of the solution, and the solution's ionic composition,

* Corresponding author at: Moscow Oblast, Razvilka Settlement, 115583, PO Box 130, Russia.
E-mail address: R_Bogdanov@vniigaz.gazprom.ru (R.I. Bogdanov).

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Table 1
Characteristics of the main types of SCC [5–8]

Parameter	High pH SCC	Near-neutral pH SCC
Morphology of cracks	Intergranular, narrow, without corrosion products on the crack walls. Tendency to branching. Cracks are grouped together in colonies.	Transgranular, wide cracks with etched walls. Cracks are grouped together in colonies.
Orientation on the pipe	As a rule, cracks run along the axis of the pipe and are parallel to each other	As a rule, cracks run along the axis of the pipe and are parallel to each other
Corrosive environment	Concentrated (from 0.1 to > 1.0 mol/L) carbonate-bicarbonate electrolytes with pH > 9.3	Dilute (0.001–0.01 mol/L) CO_2/HCO^{-3} electrolytes with pH 5.5 … 7.5
Corrosion potential of steel	In a narrow range of potentials around the active–passive transition	In the region of active dissolution potentials
Protective covering	Disbondment	Disbondment
Dependence of the crack growth rate on temperature	Crack growth rate increases exponentially with increasing temperature	Direct dependence is not exhibited

can inhibit or accelerate the dissolution of iron [26, 27].

Cases of high-pH SCC were reported in USA, Australia, Iran, Argentina, and Saudi Arabia [2, 4, 28, 29]. In the former USSR, high-pH SCC was observed in gas pipelines laid in the desert and semi-desert regions of Central Asia and Kazakhstan [30].

The second type of SCC of pipeline steels in near-neutral electrolytes is observed in Canada, Italy, and a number of other countries [2, 4].

On analysing soil samples taken from gas-pipeline accidents due to SCC in Russia, the morphology of the cracks in the investigated pipe samples testifies to the fact that gas pipelines are subject to neutral-pH SCC [1, 31]. At the same time, emergency failure due to SCC of pipeline steels occurred in gas pipelines running through the territories of Western Siberia, the Urals, and the northern regions of the European part of Russia [1], while in the southern regions of the country the incidence of SCC of pipeline steels in gas pipeline has not been recorded. On this basis, it was believed that in these regions there are no conditions and factors leading to the SCC of pipeline steel.

At the start of 2015, during in-line inspection and non-destructive testing of the surface of pipes in pits in one of the sections of the gas pipelines that runs through the territory of the southern region of Russia (Astrakhan oblast), > 20 pipes were found to have SCC defects with depths in the range of 1.5–5.0 mm, located from 3 to 9 o'clock position.

The territory of the investigated gas pipeline area in the Astrakhan region has a low predisposition to the SCC process. SCC defects had not previously been detected in this territory of the pipeline site.

So, for the final identification of the formation mechanism and growth of SCC defects, additional laboratory studies of metal samples of defective pipes as well as soil samples taken at the sites of this section of gas pipelines were required.

The above explains the relevance of the present work on the establishment of patterns of formation and development of SCC defects identified in the metal surface of pipes, taking into account the parameters and regional features of the operation of this gas pipeline site.

2. Materials and methods

2.1. Material

The samples were cut out from fragments of defective pipes made of X60 pipeline steel with an outer diameter of 1020 mm and a nominal wall thickness of 10 mm and isolated with a protective film coating applied in the field. The chemical composition of the steel (Table 2) was determined by spectral analysis using a Spectro Lab S emission spectrometer.

The section of gas pipeline with the identified SCC defects is located within 10 km of the compressor station. The operating period of the pipeline site before the diagnostic survey was 30 years.

According to the data provided, the examined section of the gas pipeline has the following regime characteristics:

- the average working gas pressure (P_{medium}) is equal to 4.6 MPa. Gas pressure fluctuations during operation do not exceed 10% of P_{medium};
- the gas temperature varies from 24 to 62 °C depending on the season;

The impacts not provided for by the project has not been established in the pipeline operation.

Table 2
Chemical composition (wt%) of the pipeline steel.

Elements	C	Si	Mn	P	S	Cr	Ni	Cu	Al	Ti	V	Nb
%	0.155	0.51	1.22	0.019	0.016	0.042	0.05	0.07	0.03	0.009	–	–