Estimation of the Probability of Hydrogen Embrittlement of Steel Pipelines in the Operation Zones of Cathodic Stations

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Abstract—A procedure for determination of the probability of hydrogen embrittlement of steel pipes was described. The experience of the application of hydrogen sensors in selected sections of the Tyumentransgaz and Mostransgaz gas mains was generalized.

The world experience in the operation of gas mains constructed from large-diameter pipes with high parameters of a transported product attests to persistent failures caused by corrosion cracking (CC) of pipes [1-3]. Corrosion cracking is mainly observed in pipelines insulated with a polymeric tape and, less frequently, under extrusion polyethylene and partially fused epoxide coatings; in the case of small-diameter pipelines insulated with bitumen or pitch, CC is very uncommon [2]. It is also significant that CC occurs in the operation zones of cathodic protection stations (CPSs).

Many authors believe that one of the factors responsible for the tendency of steel pipelines to cracking is hydrogen resulting either from free corrosion of steel, cathodic polarization, or the activity of sulfate-reducing bacteria. It is assumed that hydrogen absorbed in steel causes its embrittlement, thus favoring the destruction of the pipe wall.

Hydrogen embrittlement of steel is a well-known phenomenon. However, data on the actual concentrations of hydrogen dissolved in the steel pipe wall of an underground pipeline under operating conditions are very scarce.

The goal of this work was to develop methods for route measurements of the concentration of hydrogen dissolved in steel in operated gas pipelines and estimate the probability of their corrosion cracking caused by hydrogen embrittlement of steel.

EXPERIMENTAL

The present work is a part of a RAO Gazprom program aimed at revealing the causes of corrosion failures especially often observed in gas pipelines of the Krasnotur’inskii junction of the Tyumentransgaz. The program was intended to fit underground pipelines with various sensors, improve the regime of electrochemical protection, and continuously monitor the corrosion state of the pipelines. For this purpose, six check and diagnosis points (CDPs) were set up at 1251, 1254, 1257, 1261, 1265, and 1269 km along the route of a six-pipeline gas main.

In addition, three control and measuring points (CPs) were set up in the Gryazovets gas line of the Noginsk section of the Kryukovskaya power line (Islavskoe village, Odintsovo district, Moscow region).

Over the period from 1994 to 1996, all gas pipelines were equipped with DH-1 hydrogen sensors (their design is described in [4]).

Sensor readings and pipe potentials (with respect to a saturated copper sulfate electrode, c.s.e.) in the CDP of the Krasnotur’inskii junction were recorded several times a day by a Pul’sar system [5]. In the Gryazovets, measurements were performed one to two times a month by laboratory workers. The test duration was not initially limited, and a large body of information is now accumulated (since November 1994).

Although we unluckily failed to continuously monitor the state of pipelines over all CDPs because of accidental damage to the pipelines during route repairs, unexpected equipment failure, etc., the gathered data are sufficient for reliable analysis and unambiguous conclusions.

RESULTS

The most complete data (since 1994) were obtained at the CP-1 (Islavskoe village). Curves of current density of hydrogen sensors' are shown in Fig. 1 (the cathodic station at the Gryazovets pipeline is (1) on and (2) off). In the normal regime of the CPS, the protective pipe potential (3) was usually no lower than −1.6 to

1 Hydrogen sensors in the gas pipelines were installed and their readings recorded by V. A. San’ko and M. A. Petrunin.
-1.9 V (without regard to the ohmic component of the measured potential). The maximum sensor current densities to a steel pipe wall was no higher than 6 to 10 μA/cm² (CPS is on). When cathodic stations were off because of power line failure (see early 1998), the hydrogen flow density into steel decreased significantly (curves 1, 2).

A monotonic dependence of the hydrogen flow density into steel on the pipe potential (as it was usually observed under laboratory conditions [4]) could not be obtained. However, this dependence is pronounced statistically. Figure 2 shows variation areas of sensor currents and pipe potentials when cathodic stations are on and off. The corresponding hydrogen sensor current densities differ by a factor of 2 to 3.

The same order of magnitude was noted for DH-1 sensor currents in the pipelines of the Krasnotur'inskii junction. Curves of the variation of hydrogen sensor currents at the CP08—125 km, recorded from 1995 to 1997, are shown in Fig. 3. The maximum sensor current density to steel were less than 12 to 13 μA/cm², mainly in summer (curves 1, 2). The measured pipe potentials ranged from -2.5 to -3.5 V (Fig. 4).

Protection potentials and hydrogen sensor currents measured at other CPs of the Krasnotur'inskii junction are not significantly different. Hydrogen sensor currents measured in June, 1996 in the above control points are given in Table 1. It follows from the tabulated data that the maximum sensor current density into a pipe wall at a hydrogen sensor membrane area of 33 cm² is less than 10 to 12 μA/cm² (pipeline 2, CP12-1257 km). It is also noteworthy that hydrogen sensor currents in very wet soils of the Krasnotur'inskii junction are somewhat higher than those in the dry sandy soil of the Gryazovets.

**DISCUSSION**

Corrosion cracking of structural metals, including carbon steels, in electrolytic media was the subject of many investigations, and the results were generalized in extensive reviews and monographs [6--8]. According to the generally accepted concepts, CC in stressed metal constructions follows the mechanisms of local anodic dissolution or hydrogen embrittlement (HE). For brevity and convenience of practical people, the first type process will be named hereafter anodic corrosion.