MAIN CAUSES OF DESTRUCTION OF STEEL PIPELINES TRANSPORTING HYDROGEN SULFIDE-CONTAINING GAS

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Annotation. The article examines the main types of destruction of steel pipelines transporting hydrogen sulfide-containing gas and provides recommendations for protecting pipelines from various types of corrosion. Accumulated experience shows that the timely application of corrosion protection recommendations and monitoring of pipelines during operation reduce the costs of purchasing pipes, as well as prevent accidents associated with corrosion damage, thereby minimizing economic losses and ensuring uninterrupted operation of the systems.

Keywords: hydrogen sulfide, pipeline, steel, corrosive environment, carbon dioxide, partial pressure, delamination, cracking, pipe.

Annotatsiya. Maqolada vodorod sulfidi (H_2S) saqlovchi gazni tashuvchi po‘lat quvurlarda yuzaga keladigan yemirilishning asosiy turlari ko‘rib chiqilgan hamda quvurlarni turli xil korroziya turlaridan himoyalash bo‘yicha tavsiyalar berilgan. To‘plangan tajriba shuni ko‘rsatadiki, korroziyadan himoyalash bo‘yicha tavsiyalarni o‘z vaqtida qo‘llash va quvurlarni ekspluatatsiya jarayonida muntazam monitoring qilish quvurlarni xarid qilish xarajatlarini kamaytiradi, shuningdek korroziya shikastlanishi bilan bog‘liq avariyalarni oldini olib, iqtisodiy yo‘qotishlarni minimallashtiradi va tizimlarning uzluksiz ishlashini ta’minlaydi.

Kalit so‘zlar: vodorod sulfid, quvur, po‘lat, korrozion muhit, karbonat angidrid, parsial bosim, qatlamlanish, kreking, quvur.

Аннотация. В статье рассматриваются основные виды разрушения стальных трубопроводов, транспортирующих газ, содержащий сероводород, а также приводятся рекомендации по защите трубопроводов от различных видов коррозии. Накопленный опыт показывает, что своевременное применение рекомендаций по противокоррозионной защите и мониторинг состояния трубопроводов в процессе эксплуатации позволяют снизить затраты на приобретение труб, а также предотвратить аварии, связанные с коррозионными повреждениями, тем самым минимизируя экономические потери и обеспечивая бесперебойную работу систем.

Ключевые слова: сероводород, труба, сталь, коррозионная среда, углекислый газ, парциальное давление, расслоение, крекинг, труба.

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INTRODUCTION

Literature review. A number of fields in Uzbekistan contain hydrogen sulfide and carbon dioxide in their produced fluids, which necessitates the application of special measures during design, construction, and operation to prevent failures in pipelines and equipment caused by sulfide stress cracking (SSC) and both general and localized corrosion damage.

Pipelines transporting hydrogen sulfide-containing gas represent a complex technological system in terms of assessing their corrosion condition. This is due to the following factors:

1. Pipelines of various diameters are in operation, including both underground and above-ground sections.
2. The average service life is 20–25 years.
3. Operating conditions vary significantly. The range of working pressures is from 3.0 MPa to 15 MPa. The transported gaseous medium contains varying amounts of aggressive components, the main one being hydrogen sulfide, with concentrations ranging from 0 to 6% depending on the medium [1].

Corrosive environments containing hydrogen sulfide include gaseous and liquid media, as well as gas-liquid mixtures capable — due to the presence of hydrogen sulfide and moisture — of causing various types of damage to steel pipes and equipment as a result of electrochemical corrosion, including general corrosion, sulfide stress cracking, and hydrogen-induced delamination.

Depending on their ability to cause sulfide stress cracking in steels, as well as the intensity of their environmental impact upon release into the atmosphere, hydrogen sulfide-containing media are classified as:

- low hydrogen sulfide content environments;
- medium hydrogen sulfide content environments;
- high hydrogen sulfide content environments.

Environments with **low** hydrogen sulfide content include: • gas containing hydrogen sulfide at a concentration that results in a partial pressure of H_2S (pH_2S) in the pipeline at operating pressure ranging from 0.0003 to 0.0100 MPa (0.003 to 0.100 kgf/cm²).

Environments with **medium** hydrogen sulfide content include: • gas containing hydrogen sulfide at a concentration that results in a partial pressure of H_2S ranging from 0.01 MPa to 1.00 MPa (0.1 to 10.0 kgf/cm²).

Environments with **high** hydrogen sulfide content include: • gas containing hydrogen sulfide at a concentration that results in a partial pressure of H_2S exceeding 1.0 MPa (10.0 kgf/cm²) [2].

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Environments with a partial pressure below 0.0003 MPa (0.003 kgf/cm²) are considered not to cause sulfide stress cracking.

In addition to hydrogen sulfide (H_2S), the produced fluids from gas field wells also contain carbon dioxide (CO_2). The following relationships have been established for CO_2 corrosion in gas-condensate environments: ▪ partial pressure below 0.05 MPa → no corrosion occurs; ▪ partial pressure 0.05–0.2 MPa → corrosion may occur; ▪ partial pressure above 0.2 MPa → corrosion occurs [3].

The partial pressure of H_2S and CO_2 (in MPa) is calculated using the formula: $p = (C \times P) / 100$, where: C – content of hydrogen sulfide (or carbon dioxide) in the gas, in volume or molar percent (%); P – total reservoir pressure, MPa [2].
The destructive effect of hydrogen sulfide present in natural gas and associated liquid media manifests in two main forms: general (uniform) corrosion and cracking.

Research methodology. General corrosion occurs directly on the surface in contact with the moist environment containing H_2S, leading to thinning of pipe and equipment walls, formation of pits, deep pitting, through-wall leaks, and loss of structural strength.

This type of damage develops relatively slowly and can be monitored during pipeline inspections visually, as well as using industrial instruments that measure wall thickness without opening the pipeline (non-destructive testing methods), either from the external surface or by running in-line diagnostic tools.



Fig. 1. General corrosion 1 – uniform; 2 – non-uniform; 3 – structurally selective

Sulfide stress cracking of steels results from hydrogen charging (embrittlement) and loss of plastic properties of the metal during electrochemical general corrosion in the presence of hydrogen sulfide. This type of damage can have different mechanisms and manifest in various forms.

Hydrogen-induced delamination of steel under the influence of hydrogen sulfide can occur even in the absence of external mechanical stresses. Mechanical stresses accelerate the growth of small cracks and their coalescence into larger

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ones. Since this type of damage can develop over significant areas and spreads relatively slowly across the surface, it can be detected during pipeline inspections using ultrasonic or other instruments from the external surface or during in-line inspection.

Sulfide stress cracking manifests as the rapid (compared to general corrosion) development — under stress — of a single crack oriented perpendicular to the applied tensile stresses, with little or no development of nearby cracks. This form of damage is more typical for steels with relatively high mechanical strength and low ductility. Crack initiation and propagation occur when the stress exceeds the critical value for the given steel in the specific wet hydrogen sulfide environment. Due to its rapid development and small area of propagation, this type of damage is difficult to detect and is therefore the most dangerous.

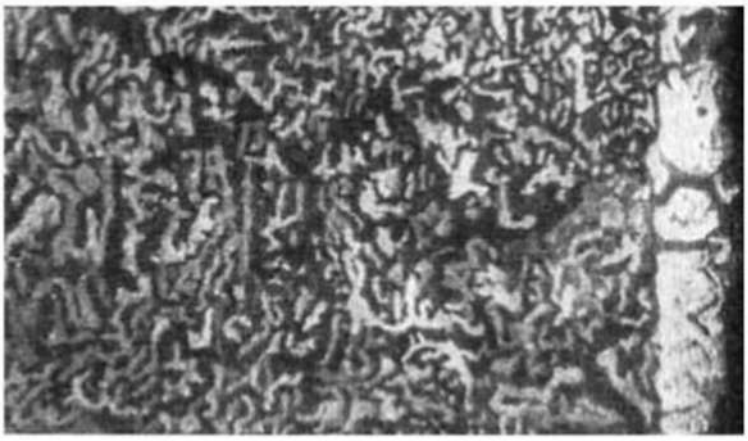


Fig. 2. Sulfide stress cracking of steel

Analysis and results. Hydrogen-induced delamination (blistering) manifests as the formation of numerous small visually detectable cracks and delaminations located in planes parallel to the pipe surface, followed by their growth and coalescence into larger cracks and delaminations. Connections between delaminations at different distances from the surface form “step-like” dangerous transverse cracks. Small blisters (“bubbles”) often appear on the metal surface due to hydrogen accumulation under pressure in subsurface discontinuities. This form of damage is more characteristic of relatively ductile carbon and low-alloy sheet steels with increased contamination by non-metallic inclusions and pronounced structural banding [4].

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Fig. 3. Hydrogen-induced delamination

Conclusion. During the design, construction, and operation of pipelines, measures must be provided to ensure protection against corrosive attack.

The main corrosion protection measures for pipelines against various types of corrosion include:

- selection of special steels and the use of pipes resistant to SSC (sulfide stress cracking) and HIC (hydrogen-induced cracking). It is generally recommended to use high-quality killed carbon and low-alloy steels for pipelines operating in hydrogen sulfide-containing media under pressure, provided their satisfactory resistance to sulfide stress cracking has been confirmed by laboratory testing (by an organization with qualified specialists and the necessary testing equipment) and validated, including weldability, through field testing at a test site or through industrial application at operating facilities handling hydrogen sulfide-containing media [4];
- use of special chemical reagents — corrosion inhibitors — to reduce the intensity of general electrochemical corrosion. The application of corrosion inhibitors can also slow down the processes leading to SSC and HIC;
- monitoring of corrosion processes and implementation of appropriate corrective measures. It is recommended to install coupon holders for general corrosion monitoring (and, if necessary, for sulfide stress cracking) at critical points.

In addition to these measures, technological solutions can be applied in production, gathering, and transportation systems to ensure liquid removal and prevent accumulation. It is recommended to maintain gas flow velocity not lower than 2.5 m/s, but — based on the operating experience of similar fields — not exceeding 11 m/s, as higher velocities can lead to increased corrosion-erosion wear.

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