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RECOMMENDATIONS FOR THE USE OF PIPES AND FITTINGS IN THE CONSTRUCTION OF PIPELINES TRANSPORTING HYDROGEN SULFIDE-CONTAINING GAS

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Introduction. The article provides recommendations for the selection and application of pipes and fittings for pipelines transporting hydrogen sulfide-containing gas. It specifies requirements for pipes regarding strength category, yield strength, carbon equivalent, and the content of non-metallic inclusions in the pipe metal to ensure the safety and reliability of pipelines during operation.

These recommendations are based on the need for pipes and their welded joints to resist brittle fracture in aggressive environments containing hydrogen sulfide with carbon dioxide impurities in wet hydrocarbon media at temperatures up to +60°C. The goal is to reduce the risks of leaks, failures, accidents, and to minimize repair and maintenance costs during operation.

Keywords: pipe, hydrogen sulfide, pipeline, steel, strength, toughness, chemical composition, carbon equivalent, sulfide stress cracking (ssc), hydrogen-induced cracking (hic), non-metallic inclusions, post-weld heat treatment of welded joints.

Literature reviyew

Currently, great attention is paid to ensuring the reliability of pipelines operating in contact with corrosive hydrogen sulfide-containing environments during the transition of national standards such as GOST, API, ASME to the development of global ISO standards, including those for pipe products of the metallurgical industry and fittings for pipelines. This is accompanied by the development of new materials (steels) with higher required properties (strength, viscoplastic, resistance to sulfide stress cracking, etc.), guiding designers toward the use of higher-quality products that meet ISO requirements.

At the same time, the introductory sections of ISO, API, ASME standards, as well as NACE MR0175/ISO 15156 (formerly NACE TM-01-77, TM-02-84, etc.), warn that the application of these standards does not guarantee reliable accident-free operation of pipelines, which depends on many specific operating conditions [1].

These recommendations for the selection and application of materials for pipes operating in hydrogen sulfide-containing environments (hereinafter referred to as the Recommendations) are intended for steel pipelines transporting hydrogen sulfide-containing media.

The main measures to protect pipelines and equipment from corrosion damage and sulfide stress cracking, implemented during design, construction, and operation, are as follows:

1. At the design stage — determination of the partial pressure of hydrogen sulfide in the gas (the higher the gas pressure in the pipeline, the higher the penetrating ability of hydrogen sulfide into the pipe metal and its welded joint).
2. At the design stage — development of design measures to reduce the partial pressure of hydrogen sulfide in the gas (pressure reduction by throttling, etc.).
3. At the design stage — hydraulic calculations to determine the required pipe diameter ensuring effective removal of liquid with contaminants at gas transport velocities not lower than 2.5 m/s

but not more than 11 m/s, as higher velocities can lead to increased corrosion-erosion wear and detachment of the inhibitor coating layer.

4. During design, construction, operation, and repairs — use of pipes and fittings in sour-resistant execution, namely: a) for pipelines with diameters up to 457 mm — seamless sour-resistant pipes made of carbon and low-alloy steel are recommended; b) for pipelines with diameters from 508 to 1020 mm inclusive — pipes made of carbon and low-alloy steel, electric-welded straight-seam with one double-sided longitudinal weld, welded by submerged arc welding. The use of spiral-seam pipes for transporting hydrogen sulfide-containing media is not permitted [2]. c) use of fittings in sour-resistant execution that have undergone factory heat treatment.
5. During construction, operation, and repairs — compliance with operational control requirements for welding operations, assembly, and welding of pipe joints and pipes with fittings, as well as post-weld heat treatment, based on developed requirements for technological maps of operational quality control for welding and heat treatment (developed/approved by welding production specialists of enterprises — basis for development of technological maps: requirement of ShNK 3.01.01-03, clause 7.5) [3]. The use of pipes previously in service for the manufacture of spools, transition rings, fittings, and installation of transitions is not permitted [4].
6. Application of internal surface protection of pipelines using corrosion inhibitors or special coatings.
7. Use/application of a system for monitoring corrosion processes and corrosion cracking.

Research Methodology

Final recommendations for the application of pipes, fittings, shut-off and control valves in corrosion-resistant execution are developed by the design organization or the leading research institute, taking into account requirements for resistance to sulfide stress cracking (SSC) and hydrogen-induced cracking (HIC).

For the construction of pipelines operating under pressure in hydrogen sulfide-containing media, high-quality killed carbon and low-alloy steels should generally be used for pipes and fittings (tees, elbows, reducers, caps), whose satisfactory resistance to sulfide stress cracking has been established by laboratory tests (by an organization with appropriate specialists and necessary testing equipment) and confirmed, including field welding, by testing under industrial conditions at a test site or by industrial application at operating facilities with hydrogen sulfide-containing media.

When selecting pipes and fittings for transporting hydrogen sulfide-containing gas, special attention should be paid to the following:

1. It is recommended to select the strength category by type, for example:
   - for seamless pipes made of steel grades 20 and 12GF according to TU 14-3R-77-2004, API 5L PSL2 Annex H: BNS, X42NS, X42QS, X46NS, X46QS, X52QS;
   - for seam pipes made by submerged arc welding with one longitudinal weld — strength classes K48, K50, K52, X42SS (MS), X46SS (MS), X52SS (MS) according to TU 1381-046-05757848-2009, API 5L PSL2 Annex H: X42MS, X46MS, X52MS (nominal yield strength not exceeding 360 MPa) and carbon equivalent not exceeding 0.38% to minimize the risk of failure due to corrosion.

Hydrogen sulfide in the transported gas (product) also causes corrosion cracking of pipes and welded joints. The failure mechanism is complex and depends on a number of technological factors: temperature, medium pH, metal structure and hardness, stress level, partial pressure of H_2S, etc. The use of pipes with higher strength above X52 according to API 5L PSL2 Annex H with a carbon equivalent above 0.38% increases the likelihood of failure of butt welded joints under such conditions [5].

2. The carbon equivalent, calculated by Formula 1, should not exceed 0.38%.

(The formula is typically the IIW carbon equivalent:

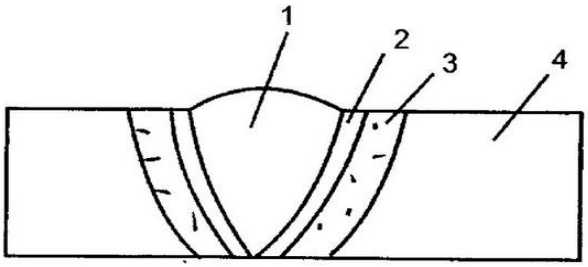
$$CE = C + Mn/6 + (Cr + Mo + V)/5 + (Ni + Cu)/15,$$

though not explicitly shown in the text.)

The carbon equivalent is an important indicator determining steel weldability, and its low value is necessary to prevent cold cracks. The higher the carbon equivalent, the higher the risk of forming hardened structures in the heat-affected zone (HAZ) during welding, which leads to reduced ductility and crack formation. The lower the carbon equivalent, the better the weldability and higher the cracking resistance, allowing selection of the optimal welding mode and technology, minimizing the risk of cold cracks and other defects in the welded joint.

For example, at one large field, production of hydrogen sulfide-containing raw materials began on September 11, 2013, and field operation was suspended on September 24 after gas leaks were detected from a Du 711 mm pipeline. Considering that the pipeline material was made of steel with a high strength class L415MCS (X60MS), with the carbon equivalent content exceeding 0.38%, a significant portion of the failures occurred in the girth welds [6].

For each specific field and gas pipeline, a separate "Instruction for Welding Technology and Post-Weld Heat Treatment" should be developed, taking into account the gas properties and local conditions [7].



1- Welded joint
2- Melt zone
3- Weld heat-affected zone
4- Item

Fig. 1 — Diagram of a welded joint

When placing orders for pipe products, a number of additional requirements must be imposed regarding metal cleanliness — non-metallic inclusions such as oxides, sulfides, silicates. This is because the pipe metal operates in aggressive conditions, where the aggressive environment can accelerate corrosion processes, especially in field pipelines where the transported products/fluids contain aqueous media with sulfates and chlorides, which are also activators of steel corrosion in addition to aggressive gases H_2S and CO_2 under conditions of elevated temperature of the transported medium.

Corrosion damage to the metal is inevitable, particularly its resistance to pitting/through-wall corrosion initiated by H_2S and CO_2, sulfide stress cracking, and biocorrosion [8].

The norms for contamination by non-metallic inclusions (NMI) in steel for pipes with specified chemical composition and mechanical properties are established by agreement between the manufacturer and the customer (ratings: average/maximum) for sulfides, oxides (stringer, point), silicates (brittle, plastic non-deformable). Data on non-metallic inclusions are recorded by the pipe supplier in quality certificates for pipes under contract conditions and requirements in the form of a table titled:

Metallographic properties

Contamination of steel metal for pipe products and fittings by non-metallic inclusions according to the scale of GOST 1778 (ISO 4967-79) is recommended not to exceed the values indicated in Table 1 [9].

Table 1 — Contamination of metal by non-metallic inclusions

Type of inclusion	Average rating (maximum rating) not more than
Sulfides: C	1.0 (1.5)
Oxides: OT, OC	2.0 (2.5)
Brittle silicates	2.0 (2.5)
Non-deformable silicates	2.0 (2.5)

CONCLUSION

Based on the results of a comprehensive study aimed at examining recommendations for the selection of pipes and fittings for transporting hydrogen sulfide-containing gas, special attention should be paid to the following indicators:

1. Nominal yield strength of the steel should not exceed 360 MPa (3640 kgf/cm²).
2. Carbon equivalent should not exceed 0.38%.
3. Contamination of steel by non-metallic inclusions should comply with GOST 1778.

Steels meeting these indicators:

1. For seamless pipes made of steel grades 20 and 12GF according to TU 14-3R-77-2004, API 5L PSL2 Annex H: BNS, X42NS, X42QS, X46NS, X46QS, X52QS;
2. For seam pipes made by submerged arc welding with one longitudinal weld — strength classes K48, K50, K52, X42SS (MS), X46SS (MS), X52SS (MS) according to TU 1381-046-05757848-2009, API 5L PSL2 Annex H: X42MS, X46MS, X52MS possess relatively low strength and sufficiently high viscoplastic properties and have demonstrated good resistance to sulfide stress cracking and hydrogen-induced delamination cracking over past operating periods at fields in Central Asia, including Uzbekistan. The relatively low strength properties of such steels result in a comparatively small loss of structural strength per mm of general corrosion depth, which becomes significant over the long service life of pipelines.

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