Development of Protective Gas Pipes Sleeves for Operation in Permafrost Soils

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Abstract. Experimental studies were carried out and causes of emergencies with gas pipes in protective sleeves used in construction of gas pipelines were identified. Protective sleeve design has been developed that excludes deformation or destruction of gas pipeline during groundwater freezing in the annulus. Model tests of polyethylene gas pipeline in steel casing, using polyethylene foam as an element that compensates expansion of water during freezing, showed complete exclusion of deformation of gas pipes during freezing. Test results of developed designs of protective casings showed the possibility of widespread use to improve reliability and safety of gas supply.

1. Introduction

Many years of experience in operating underground gas pipelines in the Republic of Sakha (Yakutia) showed that one of the most common causes of premature failure of pipeline is collapse of pipes in protective sleeves. Sleeves are provided at intersections with roads, rail- and tramways and other utilities to protect gas pipes from mechanical damage, according to current regulatory and technical documents[1-4]. Steel, polyethylene, sand asbestos-cement pipes are recommended as material of casings. It is possible to use other materials, the list of which is regulated by regulatory documents.

Analysis of the causes of the observed pipe deformations in casings shows that the only cause of their occurrence can be only the depressurization of mechanical seals of casing, entry of groundwater into the annular space and the collapse of the gas pipe in the winter during their freezing. It should be noted that the soil surrounding the gas pipeline freezes earlier and the sheath of the case is placed in the medium with high enough strength. Therefore, no deformation of the shell is usually observed, but the internal gas pipe is crushed in the process of freezing water.

Volume expansion of water during freezing is about 9% [5], however, since the process of ice formation is uneven, and begins at ends of casing, pressure in unfrozen part of water increases significantly and leads to local collapse of the pipe. Location of maximum collapse is determined by heat transfer conditions but is most often observed in the middle part of the sleeve. Depending on filling degree of sleeve with water and intensity of ice formation, pressure in unfrozen part of the water, as shown by theoretical calculations, can reach very large values, significantly exceeding the strength of steel pipes under external compression. For example, when water is frozen in cylindrical steel pipe at temperature of minus 30°C, freezing temperature of water drops to minus 28.5 ° C, and pressure in centrally located liquid medium can increase to 350 MPa [6, 7]. This explains the fact that in practice
there have been cases of almost complete flattening of gas pipes in protective cases, which is shown in Figure 1.

![Figure 1](image1)

**Figure 1.** Photos of the accident caused by collapse of gas pipeline in sleeve: a) crumpled section of gas pipeline; b) cavity of crumpled gas pipeline.

2. **Objects and research methods**

Objects of testing were model designs of protective sleeves of gas pipelines. Casing shell was made of steel pipe with 219 mm diameter, which housed polyethylene gas pipe with 110 mm diameter and 1.5 m length.

Studies of gas pipe deformation during waterfreezing in the cavity of protective sleeve were carried out in freezer at temperature of minus 35°C.

3. **Results and discussion**

As indicated above, cause of groundwater ingress into casing is depressurization of rubber or rubber-fabric seals. Unfortunately, detailed review of current regulatory and technical documents showed that they completely lack instructions for any routine and preventive work to monitor the performance of seals. The durability of rubber products, including seals, usually does not exceed 10-12 years, but this fact is not considered in current regulatory documents. In permafrost soils due to frost heaving and frost cracks, quite significant displacements of casing sheath relative to gas pipe are possible. Applied seal designs cannot always withstand indicated movements, guarantee the preservation of tightness, and exclude the possibility of groundwater ingress into the casing.

It should be noted that the study of scientific and technical information practically did not reveal results of the study of the problem described above. The patent literature also contains information on technical and technological solutions that are practically absent except for the patent [8].

In this patent, the annulus is filled with polyurethane foam during construction work, foamed in the cavity of the casing to exclude possibility of groundwater ingress under protective sheath. Disadvantage of this approach is impossibility of obtaining high-quality closed-cell polymer at low ambient temperatures. Meanwhile, due to climatic and soil conditions in Yakutia, the construction of gas pipelines is carried out mainly in the winter.
To assess and study the nature of accidents, model tests were carried out. The gas pipeline model in sleeve was made of piece of plastic SDR11 pipe with 110 mm diameter, 10 mm thickness and 1.5 m long in steel casing with 219 mm diameter and 6 mm thickness. Ends of sleeve were sealed with rubber gaskets and filled with water. Sample of gas pipeline in the casing was placed eccentrically to tighten test conditions, which is shown in Figure 2a. Model tests were carried out in freezing mode at temperature of -35 °C for 24 hours and until completely thawed at room temperature.

Almost complete collapse of polyethylene gas pipeline occurred after freezing. Sectional area after deformation decreased by 85 ÷ 90% (Fig. 2b).

![Figure 2. Placing the pipe in casing (a) and its crushing after freezing the water (b).](image)

Thus, possibility of destruction of gas pipes in protective cases by crushing them during freezing of groundwater entering them due to depressurization of seals was experimentally confirmed.

Protective case design, that excludes deformation or destruction of pipeline during groundwater freezing in the annulus, was developed to solve this problem, (Fig. 3).

![Figure 3. Design of protective casing with compensator: 1 - gas pipe; 2 – casing shell; 3 - end seals; 4 - coupling; 5 - centralizer (spacer); 6 - ring-shaped segments of foamed closed-porous polymers.](image)

Distinctive feature of proposed design is placement of closed-cell polymer, for example, polystyrene foam, polyethylene foam or polyurethane foam, manufactured in the factory, in the annular space of...
annular segments [9]. The gas pipe 1 is placed in the shell of the casing 2, sealed at ends by seals 3. At one end of the casing, sleeve 4 is installed to secure the gas control pipe. The position of the pipe 1 in the shell 2 is fixed by the centralizers 5. Annular segments of foamed polymers 6 are placed in annulus between centralizers.

The use of annular segments of foam is technologically much easier to perform polymer foaming in the process of construction and installation work and can be carried out at almost any ambient temperature.

The proposed technical solution, however, has a certain drawback, which consists in inconvenience of transporting annular segments of foam, especially in the construction of large diameter gas pipelines, and possibility of damage. It is much more convenient instead of annular segments to use tapes of rolled polyethylene foam, winding them on gas pipe between centralizers. Roll polyethylene foam is usually available in 1 m width with 2 ÷ 10 mm thickness and is very easily wound even on relatively thin pipes with diameters of 50 mm or more. Fixing of foam layer wound on the pipe is ensured by adhesive tapes.

Tests of casing models (Fig. 4) using rolled polyethylene foam were carried out under the following conditions: diameter of polyethylene pipe – 110 mm, diameter of steel casing – 219 mm, length of the model – 1.5 m. Thicknesses of winding polyethylene foam 44, 35 and 12.5 mm, which amounted to 66, 52 and 20% of the annulus, respectively.

![Figure 4. Model sample of gas pipeline in protective sleeve with external drafts.](image)

Pipe freezing was carried out at ambient temperatures from minus 30 to 38 °C for one day. End seals were removed from the models and state of the gas pipe was studied after specified time elapsed. In this case, no deformation of polyethylene pipes was observed (Fig. 5), in contrast to experiments conducted without the use of polyethylene foam coating (Fig. 2a).

The results of model tests of polyethylene gas pipeline in steel casing, using polyethylene foam as an element that compensates the expansion of water during freezing in the annulus, showed complete exclusion of deformation of gas pipes when freezing (Fig. 5).
Figure 5. Photos of polyethylene gas pipeline model sample in protective casing with compensator made of foamed polyethylene after testing: a) 66% filling - compensator thickness is 44 mm; b) 52% filling - compensator thickness is 35 mm; c) 20% filling - compensator thickness is 12.5 mm.

4. Conclusion
Polyethylene foam placed in the annulus completely compensates the expansion of water during freezing and eliminates possibility of deformation of the gas pipe. As indicated above, the expansion of water during freezing is about 9% and the main condition for using the foam as compensating element is its use in amount exceeding this value. In addition, filling the annular space with foam in appropriate amount reduces amount of possible water flow into the case and further reduces the impact on the gas pipe.

The proposed design of protective sleeve fully meets the requirements of current regulatory and technical documents and can be used without restrictions in practice of building underground gas pipelines in permafrost soils.
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