Composite gas pipelines: prospects of energy conservation

O V Smorodova, S V Kitaev and I R Baikov
Ufa State Petroleum Technological University, 1 Cosmonauts str., Ufa, 450062 Russian Federation
E-mail: olga_smorodova@mail.ru

Abstract. This article is devoted to the issue of assessing the feasibility of using alternative materials for the construction of gas mains. In this perspective, one of the most promising areas of the industry development is now the use of composite PE-RT polymer-based metal-plastic pipes. Such materials come with high durability, low unit weight and comparable cost to the traditional ones. The main operational advantage of composite pipelines is absolute stability in relation to corrosion. This makes it possible to exclude from a project of a gas transportation system the main facilities and auxiliary equipment of the electrochemical protection of pipelines. That substantially reduces the costs of CAPEX (for construction) and OPEX (electricity costs for the operation of the linear part of the main gas pipelines in terms of providing protection against corrosion). As a result, the guaranteed lifetime of composite gas pipeline systems reaches 80-100 years. In addition, composite pipes have minimum internal roughness. This beneficial characteristic allows gas to be pumped at a lower pressure and consequently reduce the consumption of fuel gas for gas-compressor units. The rationale for the work was the results of multiple joint meetings between the management of gas industry and the country's power-generation system. During these meetings, long-term plans for the development of nanotechnologies and the introduction of composite pipes into the structure of the gas transportation system were adopted. A comparison of energy efficiency of steel pipes, steel pipes with an internal smooth coating and composite pipes was performed for a gas transportation system. The economic advantage of composite gas pipelines is established at the level of 7 times over the steel analogies.

1. Introduction

In recent years reliability of pipeline systems of engineering and technological designation almost everywhere is experiencing a crisis. The main cause of frequent accidents on steel communications was corrosion [1]. Numerous theoretical studies and practical tests have shown that polymers and their compositions are a promising alternative to metal pipelines. The composite pipelines effectiveness is confirmed by the engineer composite communications growing [2]. The main advantages of nanocomposite pipes are a long service life (up to 80-100 years), low hydraulic resistance and no need for cathodic and anodic protection systems due to external corrosion resistance.

In accordance to the PJSC "GAZPROM" annual report - 2017, the length of the gas transportation system (GTS) of the country currently stands at 172100 km. All main gas pipelines are constructed of steel pipes from DN500 to DN1400. Natural gas superchargers with motor drive, gas engine, and gas turbine drive are used to supply gas from the fields to the western border and to Russian consumers eventually (Figure 1).
Figure 1. Structure of the gas compressors fleet by drive type, Russia

(a) by quantity
(b) by power

The main share of gas transportation equipment is gas turbine compressors - 86% in total power. Hydraulic resistance of the main gas pipelines and site piping at gas-compressor stations (CS) determines consumption of fuel gas for GTC drive. In accordance with the target indicators of PJSC GAZPROM for 2018, the own needs of GTC are about 11% (60 billion m³ per year) of gas production volume [3].

2. Hydraulic efficiency of modern gas pipeline systems

Multiple joint management meetings of PJSC «GAZPROM» and LLC «MC RUSNANO» confirm high interest in the application of nanoindustry modern developments. Along with DC systems with lithium-ion batteries, fiber optic devices for monitoring the technical condition of gas pipelines, membrane technologies, thermoelectric generators powered by natural gas, a great interest is noted for nanocomposite pipes for the construction of main gas pipelines (MGP) and gas pipeline branches (GPB) [4]. Two control plots for the construction of gas pipelines from composite pipes (one ground (90 km), one underwater (14 km) stream crossing) and a contractor for the production of composite gas pipelines to DN1400 have been agreed upon with company's management.

The justification of the energy and economic effect from the possible reconstruction of GTS is made by comparing four versions of gas pipes:

- basic version: steel with an electrochemical protection system (ECP) from external corrosion;
- alternative A1: steel with an internal smooth enamel coating and ECP system;
- alternative A2: composite pipes without ECP system;
- alternative A3: steel with Scotchkote internal smooth coating and ECP system.

According to [5], the roughness of gas pipes with an internal smooth coating (alternative 1) should not exceed 15 μm. According to the requirements [6], this figure is recommended to be equal to 0.01 mm. The main purpose of internal antifriction coatings is to reduce the roughness of the inner surface of pipes.

The internal two-component smooth coating of Scotchkote [7] (alternative 3) has special antifriction properties. The material does not contain solvents, benzyl alcohol, and other volatile substances, that makes it possible to obtain an inner coating with a roughness of 1 ... 10 μm.

Nanocomposite (alternative 2) is a large number of special nanolayers [8] with a thickness no more than $2 \times 10^{-9}$ m. It is made from clay minerals of montmorillonite [9]. Montmorillonite particles are artificially added into the PE-RT polymer [10] and form a unique super-strong material.

The result of creating a multi-layered structure [11] is an increase in the mechanical strength of the pipe, heat resistance, and durability due to the elimination of the corrosion of gas-conducting pipes.

The inner layer of the nanocomposite pipe in contact with the flow is made of PE-RT polyethylene. From the point of view of ensuring optimal hydraulic conditions of gas pipelines, this material has the following advantages:
extremely low roughness value - 0.0015 mm;
almost zero adhesiveness.

Evaluation of the energy efficiency of hydraulic regimes for the base and three alternative variants is performed by calculating the pressure at the end of a section with a length of 100 km in accordance with the methods [6]:

\[ P_2 = \sqrt{P_1^2 - \frac{10^{12} q \Delta \lambda T_m Z_m L}{3.32^2 d^2}}. \]

The hydraulic characteristics of gas pipelines for pipes from DN 500 to DN 1400 are constructed. Figure 2 shows the dependence of hydraulic efficiency for the largest and smallest diameters on the gas system loading in the range of 60% ... 100%.

![Figure 2](image.png)

**Figure 2.** Hydraulic efficiency of gas pipelines

Calculations have shown the value of the necessary head pressure for gas pumping varies significantly, depending on the roughness of the pipelines. Figure 3 shows the relative values of the pressure loss on a 100 km long division between CS with the notations:

- B/A1 - the ratio of pressure losses in the steel pipeline (the basic version of the system design) to the pressure losses in the steel pipeline with a smooth internal enamel coating (alternative A1);
- B/A2 - the ratio of the pressure losses in the steel pipeline (the basic version of the system design) to the pressure losses in the composite pipeline (alternative A2);
- B/A3 - the ratio of the pressure losses in the steel pipeline (the basic version of the system design) to the pressure losses in the steel pipeline with a Scotchkote internal coating (alternative A3).

![Figure 3](image.png)

**Figure 3.** Comparison of hydraulic efficiency of pipes with different roughness under design load

To provide increased pressure gas flow in the head section of the system, it requires an additional fuel gas consumption of GCU (gas-compressor unit) for supercharger driving. Taking into account the
initial data (Table 1), a decrease in fuel gas costs was calculated in the implementation of the GTS reconstruction for variants A1 ... A3 (Table 2) using the example of the DN1400 gas pipeline.

**Table 1.** Initial data for assessing the effectiveness of the use of composite and alternative gas pipelines

| №  | Parameter name           | Unit of measure | Parameter value |
|----|--------------------------|-----------------|-----------------|
| 1  | Initial gas pressure     | MPa             | 7,5             |
| 2  | Distance between CS      | km              | 100             |
| 3  | Diameter of the gas pipeline | mm             | DN1400         |
| 4  | Gas pipeline capacity    | million m³/day  | 70...95         |

3. **Results of reasonability assessment of reconstruction of GTS**

For a comprehensive reasonability assessment of using composite pipelines for a gas pipeline system, another component of the effectiveness of the proposed solution is determined - the operational costs for the ECP system of the main gas pipelines. The consideration takes into account the Minerva-3000 cathodic protection units, designed according to the task and technical specifications of PJSC "Gazprom". The rated power of the unit is 3 kW. The length of the coverage area of the gas pipeline is 10 ... 30 km, depending on the state of gas pipeline insulation and soil properties.

The normative power requirements for the ECP stations of DN1400 gas pipelines were estimated according to [12] (Table 2).

**Table 2.** Economic reasonability assessment of using gas pipelines from composite and alternative materials

| №  | Parameter name                          | Unit of measure | Parameter value |
|----|-----------------------------------------|-----------------|-----------------|
| 1  | Saving fuel gas                         | million m³/year | 0,9...7,5       |
|    |                                         |                 | 1,2...10,8      |
|    |                                         |                 | 1,1...9,4       |
| 2  | Reducing the cost of fuel gas           | million rubles/year | 3,4...29,9   |
|    |                                         |                 | 4,9...43,0      |
|    |                                         |                 | 4,3...37,6      |
| 3  | Electricity saving at ECP               | million kWh/year | absence         |
|    |                                         |                 | 0,295           |
|    |                                         |                 | absence         |
| 4  | Reducing the cost of electricity of ECP | million rubles/year | absence       |
|    |                                         |                 | 1,329           |
|    |                                         |                 | absence         |
| 5  | The costs of maintaining gas pipelines in working condition | million rubles/year | 14,42     |
|    |                                         |                 | 5,87            |
|    |                                         |                 | 14,42           |
| 6  | Totale economic impact                  | million rubles/year | 2,7...29,2   |
|    |                                         |                 | 6,2...44,3      |
|    |                                         |                 | 3,6...36,9      |
| 7  | Additional costs for gas pipelines      | million rubles                           | 1690,0         |
|    | normalized to a maximum service life    |                 | 335,8          |
|    |                                         |                 | 1013,7         |
| 8  | Payback period                          | years           | more than 40 years |
|    |                                         |                 | from 8 years    |
|    |                                         |                 | more than 25 years |

4. **Conclusions**

1. Saving fuel gas with the use of composite gas pipelines, depending on the load, reaches almost 450 thousand rubles per one kilometer of a single-pipe DN1400 gas pipeline per year.

2. The resulted annual capital costs for the construction of the composite gas main DN1400 pipeline are more than 4.5 times lower than the similar index of steel gas pipelines with enamel smooth-coating.

3. The account of the annual total costs of the operation of the gas trunk-line systems provides almost the 7-fold economic advantage to nanocomposite pipelines over the steel analogies.
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