Alternatives to Steel Pipes in the Oil and Gas Industry

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Abstract. One of the reasons why polyethylene pipes were not widely used in the oil field was their low (compared to steel equivalents) bearing capacity and, as a result, low working pressure of the transported medium (no more than 2.5 MPa). But thanks to the research of oil and gas companies, a technology has been developed to manufacture polyethylene pipes for oil and gas fields that will be able to withstand the operating pressure of the transported product up to 4.0 MPa inclusive.

1. Introduction
The industrial development of the Arctic in Russia began after 1883, when, by decision of the International Meteorological Congress, 12 countries (which included the Russian Empire) held the First International Polar Year (a comprehensive international research program on the Arctic and Antarctic). However, the first wave of industrialization of the Russian Arctic North began only in the 1930s. It is characterized by the development and production of coal deposits in Vorkuta, the construction of the Norilsk Mining and Metallurgical Combine, the laying of a trans-polar railway, etc.¹[1].

The second industrial wave started in the 1960s. and ended in the 1990s²[2]. It is primarily characterized by large-scale geological exploration work in the region, the creation of a center for oil and gas production in the Yamalo-Nenets Autonomous District, and the massive formation of zones of environmental disasters. To date, in the places of the former location of infrastructure facilities, it is still possible to observe tens of thousands of tons of scrap metal, fuel and oil spills, dilapidated buildings and structures. The soil in some places contains particles of radioisotopes (for example, Franz Josef Land Island)³[3].

The beginning of the third wave of industrialization (or neoindustrialization) of the Arctic region can be called 2013, when the Russian government approved the Strategy for the development of the Arctic zone of the Russian Federation, adopted a federal program for the socio-economic development of this macroregion until 2020 and established the State Commission for the Development of the Arctic⁴[4]. The main initiators of the third wave are large industrial (primarily, oil and gas producing) companies and the heads of the Arctic regions of the Russian Federation⁵[5].

According to the federal program “Socio-economic development of the Arctic zone of the Russian Federation”, extended by a resolution of the Government of the Russian Federation No. 1064 of August 20, 2017 to 2025, the main goal of the state program is to increase the level of socio-economic development of the Arctic zone of the Russian Federation.
Today, the most significant achievements in the implementation of this program include the formation of three new oil and gas production centers in the Yamalo-Nenetsky Autonomous District (Bovanenkovskoye field, Novoportovskoye field and Messoyakha field), launching the first stage of the natural gas liquefaction plant «Yamal LNG», the launch of the Tambey gas center and the beginning of work on the development of reference zones (Kola, Arkhangelsk, Nenets, Vorkuta, Yamalo-Nenets, Taimyro-Turukhansk, North-Yakutsk and Chukotka). The socio-economic effect of the third wave of the Russian sector of the Arctic is directly related to the level of technology used here.

However, after analyzing the development of the Arctic, it is possible to identify problems associated with the pollution of the territory due to oil and petroleum product spills, which primarily arise from the breakdown of obsolete pipelines.

2. Arctic pollution problem
According to data for 2017, the total length of existing oil and gas pipelines on the territory of the Russian Federation (including those oil and gas pipelines, some of which also cover foreign countries) is more than 257,000 km. The diameter of these pipelines also varies from 114 to 1420 mm. Most of these pipelines were installed in the 70-80s of the 20th century. Provided that the life of even modern steel pipes in accordance with regulatory documents should not exceed 30 years, the use of oil pipelines and gas pipelines built in those years is extremely dangerous[6].

Analysis of the annual reports on the activities of the Federal Service for Environmental, Technological and Nuclear Supervision from 2004 to 2017 showed that the main cause of emergencies in the oil fields is still depressurization and destruction of technical devices as a result of physical wear, corrosion of pipe metal or stress cracking. Every year, up to 70,000 pipeline failures occur in the oil fields. According to Rosneft, in 2017 alone, in the whole of Russia, the company recorded 5,312 cases of pipeline failures with oil spills and a total of 684.3 tons of oil and oil products were spilled. But besides this company, there are also LUKOIL, Gazprom Neft, Surgutneftegaz, British Petroleum, Shell and many others, who also have problems with pipeline failures during their operation. Oil companies spend significant funds on repairing dilapidated pipelines and reclaiming contaminated land. In 2017, Rosneft, LUKOIL and Surgutneftegaz companies spent a total of 16.5 billion rubles on the reconstruction of pipelines. (approximately $ 253 million), and in 2018 this amount increased to 22.13 billion rubles. (approximately $ 342 million).

Today, a critical level of pollution has been recorded in the Russian Arctic (at least 15% of the region’s area)[7]. Under the conditions of ultralow temperatures and the shielding effect of permafrost, pollutants for a long time retain the possibility of a negative impact on human health, the state of northern flora and fauna. The objects of Accumulated Environmental Damage are a constant source of environmental threat in the northern territories. The most dangerous of them are oil-polluted territories, formed due to the wear of existing pipelines and gas pipelines[8].

3. Objectives of the scientific work
The purpose of the authors:
- comparison of existing pipes used in oil fields;
- development of alternative pipe variants for their use in oil and gas fields;
- justification of the use of alternative pipes.

4. Alternative pipe overview
In the second half of the 20th century, the use of pipes from thermoplastics for the construction of low-pressure pipeline systems began[9]. For the first time, thermoplastic pipes for underground gravity pipelines were used in Germany and Holland. In Scandinavia, thermoplastic pipes have been used since the late 1960s for the construction of underground pipelines. In Russia, domestic thermoplastic pipelines were used only as process pipelines. But since 1957, thermoplastic pipelines have been used for water mains and pressure sewers, and later for the construction of underground gas
pipelines[10]. The reasons for the use of such pipes was their corrosion resistance, a high degree of
tightness at the welded joint, low cost. However, widespread in the USSR, and later in Russia, pipes
from polyethylene in the oil and gas field did not receive. This is primarily due to the fact that
previously pipes made from thermoplastics had a relatively low bearing capacity and, as a result, low
working pressure of the transported medium (not more than 1.0 MPa). Over time, the characteristics of
domestic pipe products were improved. For example, polyethylene pipes «PE 100» began to withstand
the working pressure of the transported medium up to 2.5 MPa. But compared to steel pipe
counterparts, this was not enough.

The situation was completely different with fiberglass pipes. The appearance and production of
fiberglass pipes became possible in the mid-1950s, when industrial production of thermo-plastic
binder and glass fibers was mastered.

Even then, the advantages of these pipes such as low mass, high corrosion resistance, and high
specific strength became apparent.

But during the specified period they could not win any share of the market of pipeline products due
to the low price of “traditional” pipe materials: steel, stainless steel, copper and aluminum. In the mid-
1960s, the situation began to change. Firstly, alloy steel and aluminum rose in price sharply, and
secondly, with the start of oil production on offshore shelves and in hard-to-reach land areas, the use
of lightweight and corrosion-resistant pipes was required. Thirdly, the production technology of
fiberglass pipes has been improved, and the product characteristics have been improved. During these
years, Ameron (USA) has mastered the large-scale production of high pressure fiberglass pipes (up to
30 MPa) for oil fields[11]. Pipes had a commercial success and many fiberglass manufacturers
appeared in the USA. In the 1970s, in the oil fields of North America and the Middle East, US-made
fiberglass pipes were widely used. In the late 1980s, interest in fiberglass pipes appeared in all
industrialized countries. Their production and use mastered in Europe, Japan, Taiwan. In the USSR,
experiments on the use of fiberglass pipes also began, but in connection with the secrecy regime, new
technologies were spreading to civilian industries very slowly[12]. Due to the rapid growth of
fiberglass production in foreign countries, the USSR also launched work in this direction - scientists
from the Academy of Sciences were attracted, and a laboratory of anisotropic structures was created to
study glass-fiber anisotropic materials. But the materials were used only in the military and defense
industries[13]. As a result, the fact that now in the USA, Japan and a number of European countries
has become a standard solution for the installation of pipeline systems, has not found popularity in
Russia due to the conservatism of design and construction organizations, as well as the unresolved
standardization problem until recently[14].

5. Offered pipe designs
Today, however, fiberglass pipes are manufactured by such Russian companies as, for example,
RenoTEK LLC, BioPlast LLC, Fiberglass Pipeline Technologies LLC, etc. Assortment of
manufactured their pipes are very wide both in terms of diameters (from 50 to 1420 mm) and in the
area of their use. Also, most pipes are designed for a working pressure of at least 25 MPa and a service
life of at least 50 years[15]. But among the advantages of such pipes there are flaws. The connection of such pipes is detachable (or sockets with sealing sleeves and fixation along the
axes, or threaded connection with a sealing solution), which does not fully meet the safety
requirements in the oil and gas industry. Also, the connecting nodes of these pipes are a weak point,
especially when laying in soils having a precipitation modulus with a load of 0.25 MPa more than 50
mm / m (deformation modulus less than 0.5 MPa) i.e. in conditions of possible bending of the
pipeline. Typically, fiberglass pipes have a special barrier layer to ensure tightness, and this layer in
the junctions does not close between them, which makes such pipeline connections vulnerable[16].

The solution to the problem of low bearing capacity of polyethylene pipes and the characteristics of
sealing fiberglass pipelines was the development of new pipe manufacturing technology. The essence
of the technology lies in the fact that a fiberglass shell is wound on the outer surface of a polyethylene
or polypropylene pipe, ensuring adhesion between the surfaces. Such pipes are called fiberglass composite (Figure 1).

![Fiberglass combined pipe](image)

**Figure 1. Fiberglass combined pipe.**

The advantage of this type of pipes is their equal strength with each other (the polyethylene parts of the pipes being joined are butt-welded during installation, and the fiberglass casings are connected using couplings) and the tightness of the pipelines. Also, pipes of this type are designed for high working pressure (up to 20.0 MPa in the case of using them for transporting water-gas-oil emulsions/wastewater from oil fields or up to 4.0 MPa for associated petroleum gas) depending on the thickness of the fiberglass layer, since the damage threshold fiberglass composite pipes, is the destruction of fiberglass shells from extreme stresses, because they have almost absolute tightness. In addition, according to test results, it was established that the predicted service life of fiberglass composite pipes is at least 50 years[17]. According to the results of these tests, the dependence of the magnitude of the operating pressure for a given period of operation of the pipeline on the wall thickness of the fiberglass shell of the pipes was obtained. In the future, this will allow the manufacture of target pipes.

Another alternative to steel pipes is flexible polymer-metal pipes. The design of flexible polymer-metal pipes consists of layers of high-strength steel, interleaved by polymeric shells[18].

This makes this type of pipe resistant to extremes of temperature and pressure, the dynamics of the flow of the transported fluid, the movement of trench soils, transport, installation and technological loads. Large construction length of individual sections, their flexibility and small bending radius of flexible polymer-metal pipes reduce the volume of construction and installation works[19]. The advantages of flexible polymer-metal pipes include:

- high chemical resistance to oil, reservoir wastewater containing hydrogen sulphide, carbon dioxide, mechanical impurities, free oxygen, active chlorine ions, as well as to petroleum products, etc.;
- increased throughput;
- high durability (over 40 years)[20].

During the operation of the pipelines of their flexible polymer-metal pipes, some design features were identified:

- hydraulic shocks in the pipeline of flexible polymer-metal pipes 1.5 - 2 times less than in steel pipes due to the lower elastic modulus of polymeric materials included in the design;
- the pipeline assembled from flexible polymer-metal pipes does not collapse when water freezes in it due to the high elastic-deformation capacity of the structure;
- polymeric materials included in the design of flexible polymer-metal pipes, have a low coefficient of thermal conductivity, which minimizes the formation of condensate on the outer surface and frost on the inner surface of pipes;
- low electrical conductivity of polymeric materials included in the design of flexible polymer-metal pipes, eliminates the possibility of the occurrence of stray currents in them and the associated corrosion damage to the pipeline;
flexibility and high deforming ability of flexible polymer-metal pipes ensures their adaptation to any terrain and to any soil composition.

Given all of the above, flexible polymer-metal pipes are a worthy alternative to steel pipes. But there are some drawbacks to these pipes. During the operation of pipelines of flexible polymer-metal pipes, it was revealed that they are subject to changes in the depth of occurrence, up to the exit to the trench surface. This is especially noticeable on high-pressure pipelines with a pulsating pressure, which leads not only to the possibility of their deformation from mechanical effects, but also causes the pipes to collapse due to their large bending, where the cross-spiral winding of the steel cord is sliding, forming weakened zones in the inner shell. In addition, an analysis of the Russian market for 2019 showed that prices for flexible polymer-metal pipes are on average about 5 times higher than prices for steel pipes. The use of such pipes becomes extremely expensive (even despite the fact that their use reduces the cost of construction and installation work).

6. Findings

Summing up, today an acceptable alternative to steel pipes in the oil and gas field is still only fiberglass pipes combined and flexible polymer-metal pipes. Fiberglass composite pipes still need to be improved and modified the inner surface of the pipes in order to reduce the negative impact of hydrocarbons on polyethylene and eliminate paraffin deposits, as well as increase their bearing capacity to overcome the operating pressure threshold of 4.0 MPa. As for flexible polymer-metal pipes, their main problem is the high cost of manufacture, which prevents their widespread use in the oil and gas industry.

7. Reference

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