Assessing the efficiency of using carbon nanocomposite materials for corrosion protection of gas pipelines

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Abstract. The use of innovative technologies in the transportation and production of hydrocarbons is one of priority tasks. In the context of competition for energy, this issue is brought to the fore in the development of areas for the modernization of the industry. In addition, it is a matter of strengthening the country's competitive advantage in the world market of fuel and energy carriers. The study is dedicated to finding ways to improve the composition of anticorrosive coatings used in the gas industry. The paper studies the physical and mechanical characteristics of the main anticorrosive coatings. Carbon nanotubes were found to be the most profitable and economically viable. The composite material with new nanotubes was studied by comparing the physical and mechanical properties of various anticorrosive coatings in the framework of the experiment. The results of the experiment confirmed the feasibility of using nanotechnological materials and coatings. So, the use of carbon nanocomposites in the composition of anticorrosive coatings will increase the efficiency of transportation of gas, oil, and other raw materials.

1. Introduction

Today, the gas production, transportation and processing industries, along with the oil refining sector, play a decisive role in the development of the country's economy. In turn, the growth in the rate of development of the industry itself largely depends on the technologies used for the extraction, transportation and processing of hydrocarbons. In this regard, the development of environmentally friendly materials and compositions that ensure the reliability, profitability and durability of the structures used is becoming increasingly important [1]. The relevance of the study lies in the fact that in the modern oil and gas industry there is an acute problem of equipment wear and pipe damage caused by internal corrosion. So there is a need to improve anticorrosive compositions and methods for the synthesis of their components.

The aim of this work is to study the anticorrosive properties of polymer coatings based on nanocomposites and the effectiveness of their application in the oil and gas sector.

A leading trend in this area is the use of breakthroughs in nanotechnology [2]. This is the reason why we chose hydrocarbon nanotubes (CNTs) as a material for our research and included them in the composition of polymer anticorrosive coatings.

2. Experimental Part
The task we set in this work was to evaluate the physical and mechanical properties of a multilayer composite coating based on polymer fiber and embedded CNPs when used in the gas transportation and gas processing industries [3].

The material was chosen based on the results of a comparative analysis of various materials used for corrosion protection of metal structures, and a review of [4-6]. The physical and chemical properties of the following anticorrosive coatings were experimentally studied:

1. Ultra-high-molecular-weight polyethylene (UHMWPE).
2. UHMWPE composite using oxide ceramics (zirconium dioxide - ZrO₂).
3. UHMWPE composite with the addition of carbon nanotubes.

The main characteristics that were studied were electrical conductivity and thermal conductivity of the material, heat resistance of the coating, antistatic properties, mechanical characteristics, adhesive strength, and resistance to aggressive working environments.

The mechanical resistance of coatings to abrasion was studied on an IKI-M device in accordance with State Standard 8975-75, Russia, at a speed of 1000. For processing, a grinding cloth (State Standard 5009-82, Russia) and a weight of 0.5 kg were used. The setup for the synthesis was provided by the laboratory of the Novosibirsk-based company OCSiAI ("Oksial"). To study the physical and mechanical properties of materials, steel plates of rectangular shape with a section of 10 by 10 cm were used, made of duralumin alloy steel grade D16T, on which different types of coatings were applied using the gas-plasma spraying technology developed at the Gubkin Russian State University of Oil and Gas, using a device for rotating samples.

We experimentally synthesized carbon nanotubes with subsequent annealing of the material [7]. Currently, chemical vapor deposition is the main method for the production of nanotubes. It allows for the most accurate control of the location and nature of the growth of carbon nanotubes on various substrates. The CNT synthesis apparatus is an assembly of chambers, preheating and pyrolysis furnaces, a quartz tube and rods immersed in a tank with water, connected in series (Figure 1).

![Figure 1. A flow diagram of aerosol synthesis of carbon nanotubes.](image)

We chose this apparatus for use in our experiment as it is the most common one and provides the possibility of replacing various organic carbon sources in the creation of CNTs.

A carrier gas (argon) and a carbon-containing component (ethanol with ferrocene) are fed into the reactor. To create an aerosol, an ultrasonic nebulizer was used that produces aerosol particles with a diameter of up to 3 microns. A mixture of ethyl alcohol with a catalyst was used as a carbon source.

The argon flow, passing over the nebulizer bowl filled with the reaction mixture, picks up aerosol particles and enters a quartz tube with a diameter of 20 mm. After that, argon is fed through a branch pipe to the high-temperature zone. At an argon flow rate of 500 cm³/min through the nebulizer, the alcohol flow rate was 0.2 cm³/min. The stream of particles at the outlet is mixed with an additional stream of argon flowing around the nozzle.
The product was collected by passing a gas flow containing single-walled carbon nanotubes (SWCNTs) through a filter with a pore size of 0.40 μm at the outlet of the reactor.

In [8-9], facts are given that the morphology and structure of CNTs vary significantly, depending on external conditions. For example, annealing of amorphous nanotubes 10–50 nm in diameter in an inert medium at 1800–2000 °C leads to their crystallization with the further formation of numerous graphene layers [8-9].

We proposed to carry out the pyrolysis of synthesized CNTs at a temperature of 1000 °C using a nickel-cobalt catalyst. In the course of the study, it was found that the Ni₂O₃ - Co₂O₃ - Al₂O₃ catalyst is the best in terms of the yield-quality ratio of carbon nanotubes.

In addition, in the experiment, we chose methane as a carbon source, since it does not decompose at temperatures up to 800 °C, which makes it possible to obtain CNTs with a smaller amount of amorphous carbon impurities.

3. Results and Discussion
The study showed that the presence of a nickel-cobalt catalyst during the synthesis has a significant effect on the acceleration of the decomposition of hydrocarbon in the reactor and on the formation of carbon nanostructures at a lower temperature. The catalytic pyrolysis of methane led to the formation of multi-walled CNTs (MWCNTs) 30 nm in diameter with thin branches and a double structure in the low-temperature region of the reactor. Such particles are more suitable for creating nanocomposites than conventional MWCNTs. The analysis of the classical method for the production of CNTs from ethanol and the proposed one, taking into account the decrease in temperature, showed differences in production rate and energy consumption (Figure 2).

![Figure 2. Comparison of production rate (a) and energy consumption (b) in the production of CNTs from ethanol and methane.](a) (b)

Based on these indicators, the coefficient for assessing the economic efficiency of the method η was determined according to the production rate-energy consumption ratio using (1):

\[ \eta = \frac{Q}{E} \text{, kg/s/m} \]  

where \( Q \) – production rate of the technological process, and \( E \) – energy intensity of the process.

Let us substitute the numerical values in (1) to determine the coefficient of economic efficiency for the case of the nanotubes production from ethanol (2) and methane (3):
\[ \eta_1 = \frac{Q}{E} = \frac{15}{1400} = 0.011 \]  
\[ \eta_2 = \frac{Q}{E} = \frac{25}{1000} = 0.025 \]  

So, in terms of the energy intensity and production rate ratio, catalytic pyrolysis of methane at a temperature of 1000 °C is more promising. 

Table 1 shows the results of the study of the physical properties of coatings:

| Material         | Ultimate strength, MPa | Elongation at break, % | Breakdown strength, kV/mm | Tensile modulus | Substrate adhesion, MPa | Wear resistance, g |
|------------------|------------------------|------------------------|---------------------------|-----------------|-------------------------|--------------------|
| UHMWPE           | 26                     | 520                    | 44                        | 700             | 3.0                     | 0.020              |
| UHMWPE + ZrO₂    | 33                     | 280                    | 48                        | 800             | 3.6                     | 0.015              |
| UHMWPE + CNTs    | 36                     | 320                    | 63                        | 1200            | 4.0                     | 0.006              |

**Figure 3.** Comparison of production rate and energy consumption in the production of CNTs from ethanol and methane.

A comparative analysis of the effectiveness of these coatings showed the following (Figure 3):
- the ultimate strength of a coating with CNTs is 28% higher than that of UHMWPE without additives and 8% higher than the strength of coatings with the addition of a ceramic component (ZrO₂);
- the elongation at break is almost half that of UHMWPE and slightly less than that of UHMWPE + ZrO₂;
- the breakdown strength is 30-31% higher than that of the two other materials;
- the tensile modulus of the polymer coating with CNTs is 42-43% higher than that of UHMWPE and UHMWPE + ZrO₂;
- the introduction of CNTs increases the adhesion ability of the coating by 10% compared to UHMWPE + ZrO₂ and by 25% compared to UHMWPE;
- wear resistance of the new coating is 67% higher than that of UHMWPE and 58% higher than that of UHMWPE + ZrO₂.

As we can see from the results of the study, the use of CNTs as an additive to UHMWPE significantly increases the ultimate strength of the material, its resistance to breakdown, breaking and tensile strength, and also the degree of adhesion of the coating to the base material and its wear resistance.

The anticorrosive nanocoating under study fully complies with international environmental standards, which ensures the competitiveness of this product of Russian pipe manufacturers on the domestic market and in the countries of the European Economic Community (EEC).

4. Conclusion

According to the results of the study, we found that the addition of carbon nanofiber to the polymer composition can significantly improve the characteristics of the coating, namely: increase the electrical conductivity; increase thermal conductivity and heat resistance; impart antistatic properties; improve mechanical characteristics (tensile and breaking strength; increase the modulus of elasticity and ultimate elongation; increase wear resistance).

However, for a more objective assessment, the resulting composition must be tested in industrial conditions over a long period of time and under the influence of a wider range of factors. In this regard, the idea of modifying nanocomposite-based coatings and their use in the gas industry requires more thorough scientific and experimental research [9-10].

Having conducted these studies, we can recommend the introduction of this method for producing CNTs and the use of synthesized tubes as a component of an anticorrosive polymer coating to protect pipelines and components of gas processing apparatus. In addition, synthesized CNTs can be used not only as a component of coatings but also as sorbents in the purification of hydrocarbon feedstock during processing. This factor can significantly improve the environmental friendliness of production and the quality of the resulting product.

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