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ABOUT THE POSSIBILITY OF PERSPECTIVE APPLICATION OF HYDROPHOBIC AND SUPERHYDROPHOBIC MODIFIED INTERNAL COATINGS OF PIPELINES IN PIPELINE TRANSPORT

D. SARELA, A. VARONIN
Polotsk State University, Belarus

The article considers the possibility of using hydrophobic coatings on the internal surfaces of main transport equipment to reduce the wettability zone and hydraulic roughness. This coating can be used on pipelines, pump impellers to reduce energy consumption. It was concluded that it is necessary to study further the theoretical and practical aspects of hydrophobization and the introduction of this method in large-scale production.

One of the main technological processes of the energy systems of the oil complex is the transport of hydrocarbon raw materials through pipeline systems, the functioning of which consumes a large amount of electricity. Energy saving issues are widely considered in various regulatory documents, including STB 1771-2010 Energy-consuming equipment. In the operation of pipeline systems, it is important to minimize hydraulic losses.

The main reasons that increase wear and reduce the degree of reliability of various pipeline systems are the formation of deposits on the in-pipe surfaces and corrosion processes caused by the aggressiveness of the transported fluids. Corrosion processes increase the surface roughness of pipelines and affect the increase in the coefficient of hydraulic friction, accelerating the accumulation of a layer of deposits on the inner surface. The formation of heavy oil deposits leads to a narrowing of the diameter of the passage section and, as a result, an increase in hydraulic resistance with the consumption of electricity for the transportation of liquid hydrocarbon raw materials.

In oil pipelines, to reduce hydraulic losses, depressants are mainly used, which are inhibitors of the formation of heavy oil deposits, anti-turbulent additives that change the coefficient of hydraulic efficiency, and heating of the transported fluid. In the result of applying this method, the physicochemical properties of the transported raw materials are affected.

Simultaneously for an additional effective reduction of hydraulic resistance, it is necessary to take into account the initial state of the pipeline surface. Thus, you can use a different method, affecting the inner surface of the pipeline. In the course of this method, protective smooth-walled epoxide and silicate-enamel coatings with a reduced absolute roughness coefficient are used, as well as hydrophobic coatings with a reduced surface wettability area. The use of modified internal coatings with hydrophobic properties is a promising and still insufficiently studied direction. It is possible to use internal hydrophobic coatings in the pipeline transport of oil and petroleum products, which requires additional research and refinement in the calculation of hydraulic parameters, taking into account the hydrophobicity of the surfaces and changes in the flow characteristics of the transported fluids.

The main approaches to reducing the hydraulic resistance due to the hydrophobicity of surfaces were proposed by R. N. Wenzel (1936), B. D. Cassier and S. Baxter (1944). These approaches are based on the use of such natural phenomena, in particular, on the imitation of the properties of the lotus leaf [1]. The mechanics of the lotus effect process is that due to the high surface tension, water droplets tend to shrink the surface, turning into a spherical shape. When the liquid comes into contact with the surface, the adhesion forces cause the surface to be wetted. The degree of wetting depends on the structure of the surface and on the tension of the liquid drop. The degree of wetting depends on the surface structure and the liquid tension of the drop [2].

The essence of hydrophobization for prospective use in the internal surfaces of pipelines is to achieve the lotus effect in technical systems by modifying the surface relief with its subsequent hydrophobization, in particular, by means of surfactants in the transported liquid or using hydrophobic compounds in the inner coating. The contact area of a liquid drop in a conventional pipeline is much larger than the contact area of a liquid drop in a pipeline with a hydrophobic coating. Presumably, the free area under the liquid is supposedly filled with gas. All this helps to reduce hydraulic resistance.

It is well known that the hydraulic resistance of the pipeline is determined by the Darcy-Weisbach formula:

$$\Delta P = \lambda \cdot \frac{\upsilon^2}{2g} \cdot \frac{L}{d} \quad (1)$$

where ΔP –pressure drop, Pa;

λ - dimensionless coefficient of hydraulic friction, which generally depends on the Reynolds number and the relative roughness of the inner surface of the pipeline;

L - pipeline length, m;

d –pipeline diameter, m;

ρ - density of the pumped liquid, kg/m^3;

v – pumped medium speed, m/s.

From this formula it follows that the main influence on the hydraulic resistance is exerted by the density and speed of the pumped medium, the diameter of the pipeline, its length and the roughness of the in-pipe surface.

The resistance of pipelines with a modified hydrophobic surface cannot be correctly calculated using formula (1) due to changes in the surface wetting conditions and flow structure in the near-wall zone. The generally accepted characteristic of surface wettability is the contact angle θ between the droplet and the surface plane. However, for the surface of pipelines, the roll angle α and the equivalent roughness k_e, which characterize the hydraulic properties of the surface, play a more important role. Based on formula (1), it can be concluded that with constant parameters d, l, ρ, the hydraulic resistance is determined by the value of the coefficient λ, which is a function of the wetting characteristics, i.e. λ = f (θ, α, k_e) [1]. In this regard, it is of great interest to establish the dependence of the decrease in hydraulic resistance on the state of surface wetting, in particular, on the basis of the results of experimental physical research or computer simulation.

The advantages of using hydrophobic coatings have been experimentally confirmed in a number of scientific studies. Thus, a study conducted on pumping equipment [2, 3] showed that the modified coating had a positive effect on the hydrodynamic effect of the elements of the flow part of rotary pumps and certain types of losses in centrifugal pumps. Due to the hydrophobization of the elements of the flow part of rotary pumps, there was a decrease in vibration by 25-30%, acoustic noise by 10-15%, wear of mechanisms by 2-5 times, as well as a decrease in power consumption by an average of 7-10 W per 1 $m^3$of pumped liquid. It is also advisable to apply this approach to the pumping equipment of the main pipeline transport.

The possibility of using hydrophobic coatings in water supply networks was proposed in [4, 5, 6]. Modification of the inner surface of the pipeline was carried out by introducing surfactants with the formation of molecular layers. As a result of experiments on a laboratory bench, optimal values of hydraulic resistance reduction were obtained for the Dn50 pipeline with a length of l=4 m at a wetting angle of θ=141° and a rolling angle of α=32°. With an increase in the internal diameter of the pipeline, the maximum reduction in hydraulic resistance decreases, for the DN50 it was approximately 30%, depending on the flow rate. It was noted that there are optimal characteristics of the hydrophobizing layer (the thickness of the molecular layers of surfactants, the angle of wetting and rolling), leading to the maximum reduction in resistance for each pipeline diameter.

The use of hydrophobic coatings has also found a place in the oil production industry [2]. In oil production, one of the most common causes of failure of oil-submersible equipment is salt deposition on the submersible electric motor, working bodies of electric rotary pumps, in filter systems. The share of failures of electric rotary pump installations reaches up to 30% of the total number of failures. Effective methods in combating salt deposition in electro-rotary pumps are the use of low-adhesion working bodies of electro-rotary pumps made of polymer materials with increased resistance to salt deposition. Impellers of electric rotary pumps with a hydrophobic coating based on polyphenylene sulfide successfully cope with salt deposition. The filters of the input modules of electric centrifugal pumps coated with a hydrophobic coating have a number of advantages over other filters: low hydraulic resistance, high throughput, regenerability, elastic properties of the material that ensure long-term and efficient operation of the equipment, reducing salt deposition on the filter elements of the grid, increasing the operating time. In addition, filter elements with a hybrid hydrophobic coating can theoretically be used for the separation of petroleum products from the watered reservoir fluid.

An important feature is the choice of a specific hydrophobic material for each specific task. The materials for the hydrophobic coating are fluorotelomers such as tetrafluoroethylene, sulfonate fluorotelomer, acrylate fluorotelomer, and methylacrylate. They have properties such as heat resistance, low surface tension, chemical resistance, repels water and grease. These materials have properties that correspond to those required to give hydrophobicity to the internal surfaces of pipelines, nodes and parts of pumping units, as well as for equipment used in oil production [7]. The task of choosing the material for the internal surfaces of the main pipeline may depend on the physicochemical characteristics of the pumped liquid and needs further research.

In the future, as a surface imparting hydrophobicity, it may be possible to use a special laser technology to impart superhydrophobic properties to the metal, first carried out at the University of Rochester [8]. The essence of this technology lies in the fact that micro- and nanoscale structures are applied to the metal surface using a femtosecond laser, which are capable of capturing and retaining air. Products made of such materials do not sink in water, even after damage and punctures, which may indicate their durability and resistance to mechanical stress. When a metal plate is immersed in water, an air bubble forms around it, which pushes it to the surface. The process of applying the structure is very time consuming and costly. It takes an hour to process a surface of 2.5 cm^2. This method of hydrophobization is very promising and has a very huge potential in pipeline transport in order to reduce hydraulic resistance, but for treating a surface with a large area, very powerful and expensive lasers are required, and the refinement of the very technique of applying the structure, which does not make it possible to use this method on large-scale goals to date.

When analyzing the works concerning the application of the method of surface modification using the application of hydrophobic coatings and the creation of micro- and nanoscale structures, it can be concluded that this method is effective in the pipeline transport and oil production industry. To introduce hydrophobization into large-scale use, it is necessary to carry out additional research using computer modeling and make additional calculations to clarify the coefficient of hydraulic resistance, which affects the hydraulic resistance of the pipeline.

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