Study of hydraulic resistance in collapsible pipelines

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Abstract. The features of conducting research on hydraulic resistances of collapsible pipelines with a bell and spigot joint are shown. The importance of taking into account the influence of pipe joints on the flow of the pumped liquid, as well as deviations from straightness due to angular mobility, is noted. Data on the determination of pressure losses in collapsible pipelines PMTP-100 and TSR-MK-100 based on the results of tests carried out on sections of 1200 m long when pumping water are presented. The values of Darcy friction factor are also set. As a result of processing experimental data using mathematical statistics, the values of the coefficient of equivalent roughness of the inner surface of pipes of prefabricated pipelines PMTP-100 and TSR-MK-100 were determined. Using the methodological apparatus of hydraulic modeling, calculations were made to simulate the pumping of various groups and brands fuels through collapsible pipelines. In the analysis of the data revealed that by reducing the coefficient of equivalent roughness of the inner surface of pipes, supply pipeline TSR-MK-100 can be higher than by pipeline PMTP-100 on average, 5-13%.

Introduction

Actuality due to the need for public testing of pipeline TSR-MK-100 for the integrated assessment of conformity with the technical and performance requirements of the Ministry of Defence of the Russian Federation. The aim of the study is to assess the actual performance of the system is collapsible pipeline TSR-MK-100.

The main objectives of the study:
- to analyze the methods of determining pressure losses and performance pressure in pipelines;
- to develop a method of determining pressure losses and performance pressure in collapsible pipelines;
- on the basis of data processing of experimental researches to determine the values of the Darcy friction factor and the coefficient of equivalent roughness of the inner surface of the pipe;
- to evaluate the efficiency of the pipeline TSR-MK-100 for pumping fuels from various groups and grades.

One of the main objectives when performing hydraulic calculations collapsible pipelines is the determination of the magnitude of the head losses due to friction [1]. They are usually expressed depending on the square of the average speed of the pumping according to Darcy-Weisbach equation:
where: $h_t$ – friction head loss; $\lambda$ – Darcy friction factor; $l$ – estimated pipeline length; $d$ – pipeline inner diameter; $w$ – average fluid velocity; $g$ – acceleration of gravity.

The Darcy friction factor depends on flow regime [2]. In the existing guidance documents manual for collapsible pipelines [1] applied Altshul equation [3]:

$$
\lambda = 0.11 \left( \frac{68}{Re} + e \right)^{1/4},
$$

where: $Re$ – Reynolds number; $e$ – coefficient of relative roughness of the inner surface of the pipe.

In the equation (2), the coefficient that takes into account the roughness of the inner surface of the pipe $e$ accepted for pipes with enameled coating equals 0.0001 for pipes with zinc coating – 0.00011 for all types of collapsible pipelines increased capacity [1]. It should be noted that the value of this ratio was obtained when testing on the plot of the collapsible pipelines, a length of less than 100 m, while the study was conducted only with collapsible pipeline PMTP-150, collapsible pipeline PMTP-100 was not investigated.

The coefficient of relative roughness as a dimensionless criterion of hydrodynamic similarity, defined as the ratio of the coefficient of equivalent roughness to the internal diameter of the pipeline:

$$
e = \frac{k_e}{d},
$$

where: $k_e$ – the coefficient of equivalent roughness of the inner surface of the pipe.

Obviously, for pipes with different diameter and type of the inner surface of this coefficient will change. This statement formed the basis of a new method for determining head losses and collapsible pipelines capacity.

Results

When assessing the hydraulic resistance of collapsible pipelines, it is also necessary to consider the influence on fluid flow the joints connections as well as deviations from straightness due to the angular movement of the pipes. This requires that the length of the experimental section of the pipeline must not be less than 1000 m, and the length of the entire collapsible pipelines deployed on the ground should not be less than 5000 m.

Experimental research, according to the method of determining the pressure loss in the collapsible pipelines was conducted at the test site. With this purpose was developed the technological scheme of the pipeline, which included two experimental parts:

– the first consisted of a pipeline PMTP-100 for checking and confirmation or refutation of the existing value of the coefficient of equivalent roughness;

– the second pipeline TSR-MK-100 for the determination of the equivalent roughness of the pipeline of a new generation.

Each experimental plot consisted of 200 pipes with a total length 1200 m. Both the pipeline section lying parallel to each other for eliminating the difference in elevations of the initial and final areas, and other terrain features. As a means of transfer of used fuel transfer pump station PSG-240 and a mobile pumping unit PNU-100/200K.

If you set the mode of transfer using flow meters liquid at the same time the following quantities were measured: the flow of the pipeline, the pressure at the beginning and end of test parts. The measurements were carried out by pumping water. Figure 1 presents a graph of pressure loss from the flow for two types of pipeline. It is obvious that the pressure loss when pumping through a new pipeline TSR-MK-100 less than that PMTP-100.
Figure 1. Dependence of the pressure loss in each experimental parts from the capacity of collapsible pipelines PMTP-100 and TSR-MK-100

According to the known value of the pressure loss and pipeline capacity was determined by Darcy friction factor by the equation:

$$\lambda = \frac{\Delta P \pi d^5}{Q^3 \rho},$$  

(4)

where: $\Delta P$ – pressure loss; $Q$ – pipeline capacity; $\rho$ – fluid density.

The equivalent coefficient of roughness of pipe inner surface was determined by the equation:

$$k_e = \left(6860 \lambda^4 - \frac{68}{Re}\right) d.$$  

(5)

Assuming that the distribution law of the measured values closes to the normal law, for the assessment of errors you can define the boundaries of the confidence intervals, for a given value of confidence [4].

The average value of the equivalent coefficient of roughness is determined by the equation:

$$\bar{k}_e = \frac{1}{n} \sum_{i=1}^{n} k_{ei},$$  

(6)

where: $n$ – number of experiments.

The standard deviation is determined by the equation:

$$\sigma_{k_e} = k_n \left[\frac{1}{n-1} \sum_{i=1}^{n} (k_{ei} - \bar{k}_e)^2\right]^{1/2},$$  

(7)

where: $k_n$ – coefficient value which is selected in accordance with the number of experiments [5].

The value of the confidence interval is determined from the equation [6]:
\( \alpha = F \left( \frac{\theta r^{-\frac{1}{2}}}{2 \sigma s} \right) \),

(8)

where: \( \alpha \) – a confidence probability to the mathematical expectation in the case of known standard deviation; \( \theta \) – confidence interval; \( F(z) \) – is the Laplace function.

The value of the confidence interval at Student's distribution is determined from the equation [6]:

\[ \theta = \frac{t_\alpha \sigma s}{\sqrt{n}} \],

(9)

where: \( t_\alpha \) – the amount determined by the table of Student's distribution.

Processing of results of measurements methods of mathematical statistics have shown that the value confidence probability, the values of the coefficients of the equivalent roughness of the inner surface of the pipe amount to 0.005 mm and 0.035 mm, respectively for pipelines TSR-MK-100 and PMTP-100.

Also the values of the standard deviations by the formula (7), when the number of experiments \( n = 22 \); ratio \( k_n = 1.0134 \), confidence probability to the mathematical expectation in the case of known standard deviation \( \alpha = 0.95 \); the amount determined by the table of student's distribution \( t_\alpha = 2.103 \); the value of the standard deviation of 0.0036 and 0.0086 for pipelines TSR-MK-100 and PMTP-100, respectively.

The magnitude of the confidence intervals is determined by the formula (8) and amounted to 0.0016 inch 0.0043 and for pipelines TSR-MK-100 and PMTP-100, respectively.

The dependence of Darcy friction factor from Reynolds number for TSR-MK-100 and PMTP-100 subject to the equivalent roughness coefficients for each type of pipeline are shown on figures 2, 3.

**Figure 2.** The dependence of the Darcy friction factor from the Reynolds number for composite pipeline TSR-MK-100

**Figure 3.** The dependence of the Darcy friction factor from the Reynolds number for steel pipeline PMTP-100
Using the methodological apparatus of the hydraulic calculations were plots of differential pressure performance pump through pipelines TSR-MK-100 and PMTP-100 of the following types of fuels: motor gasoline Regular 92, jet fuel TS-1, diesel fuel Z-minus 35 and diesel fuel EURO class 4 (figure 4).

In the analysis of the data revealed that by reducing the coefficient of equivalent roughness of the inner surface of pipes, supply pipeline TSR-MK-100 can be higher than by pipeline PMTP-100 when pumping:
- diesel fuel for 3-7% (average 5%);
- jet fuel 6-9% (average 8%);
- motor gasoline at 11-15% (average 13%).

![Figure 4. The dependence of pressure loss $\Delta P$ from capacity $Q$ at composite pipeline TSR-MK-100 and PMTP-100 for pumping of various groups and brands fuels](image)

Specific value increase flow through the pipeline depends on the physico-chemical properties of the product transfer (density and kinematic viscosity), as well as the number and type of means of pumping.

The study evaluated the effectiveness of the pipeline TSR-MK-100. Estimated cost daily fuel consumption mobile pumping unit (PNU-100/200K) was determined by the equation:

$$ S_{mpu} = Q_{mpu} t q_f, $$

where: $S_{mpu}$ – estimated cost daily fuel consumption mobile pumping unit; $Q_{mpu}$ – the rate of fuel consumption, l/hour; $t$ – working time will mobile pumping unit in the day, h; $q_f$ – the price for 1 liter of fuel, RUB/l.

Was calculated the estimated cost of daily fuel consumption engine performance mobile pumping unit PNU-100/200K. The study established that under the existing organization the application of the set of pipeline length 150 km, the economic effect from reduction of operating costs to conduct pumping can be up to 160 thousand rubles per day.
Conclusion
The study was carried out to estimate actual productivity pressure in the collapsible pipelines TSR-MK-100. When it was obtained the following research results:

– the analysis of the current methodology for determining the head losses and capacity for collapsible pipelines, the results showed that the existing method of determining the pressure losses in collapsible pipelines has a significant drawback, since it does not take into account the impact of the inner surface and the pipe diameter on the Darcy friction factor;

– the technique of determining pressure losses and capacity in collapsible pipelines with regard to the influence of pipes joints as well as deviations from straightness due to the angular movement of the pipes;

– using experimentally obtained data were used to determine the coefficients of the equivalent roughness of the inner surface of the pipe for pipelines PMTP-100 and TSR-MK-100, the value of which is made up of 0.035 and 0.005, respectively;

– the evaluation of the effectiveness of pipeline TSR-MK-100 showed that by reducing the coefficient of equivalent roughness of the inner surface of pipes, supply pipeline TSR-MK-100 can be higher than by pipeline PMTP-100 by pumping in an average of 5-13%.

An evaluation of the effectiveness of the implementation of the results of the study showed that the economic effect could be up to 160 thousand rubles per day.

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