Monitoring and Forecasting of the Consequences of the Oil Products Discharge and Pumping Out During Real-Time Processes of Operation of a Horizontal Oil Pipeline

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Abstract. The authors proposed a method for predicting the consequences of oil product release to the surface of the earth when the horizontal pipeline is discharged based on an estimate of the volume of the pipeline discharge. While ensuring the safety of main oil pipelines, it is important to monitor leaks and emissions when pipeline integrity is violated. Before removing the defective area, oil products are discharged from the pipeline to ensure the safety of repair and recovery works. When modern repair and recovery technologies are implemented, one of the most important tasks is to determine the volume of the oil pipeline discharge and the time of repair work. The proposed method has been tested and can be used when estimating the volumes of leaks and discharge of pipelines.

1. Introduction

In the Industrial University of Tyumen, researchers at the Department of Hydrocarbon Transportation develop a comprehensive system for monitoring the reliability of oil and gas pipelines using the probabilistic-statistical approach and methods of system analysis [2-7, 17]. An assessment of the probability of pipeline failure and the amount of leakage allows foreseeing the most effective measures to reduce damage to nature in the event of oil product leakage. Complex monitoring requires assessing the parameters of deterministic technological processes.

The flow of oil through the damage in the body of the pipeline is a complex process determined by several factors: the size of the damage, the diameter and productivity of the pipeline, the properties of oil, the terrain, and so on.

Most often, the processes that occur in the pipeline after a breach of its tightness are divided into three parts in time: pressure drop at the initial moment; pumping under new hydraulic conditions; stopping the pipeline [1,4]. Discharge begins at the moment of crack formation and lasts from several fractions of a second to 1 ÷ 2 hours. During this time, it is usually possible to detect damage; line valves are closed.

A conditional division of the oil discharge process through the damage into 5 stages should be considered more appropriate [5,6,7]. The first stage is characterized by the discharge of oil from the moment of the damage formation to the moment when the pumping station is shut down. The second stage is the oil discharge period under the inertial operating conditions of the pumping units. The third
stage is characterized by a reduction in the pipeline pressure to the pressure of the oil vapor elasticity and the release of lighter fractions. The fourth stage is the stage of gravity flow discharge due to a hydrostatic column of liquid. The stage continues after the preparation of the oil collection tank and the discharge trench, when the damaged section of the oil pipeline is emptied from the oil by gravity through the defective site and further along the trench to the tank or emergency pit (sump).

The fifth stage takes place during the compulsory discharge of the pipeline section to ensure the safety of repair and restoration works. Forced discharge is carried out by means of mobile pumps, while the volume of pumped oil can reach 20 thousand m³ (for pipes with a diameter of 1200 mm) [7,8].

In addition, discharge of the pipeline is the longest operation - up to 35% (percentage of the total time for the accident elimination).

An important task is to calculate the discharge parameters. The duration of the discharge of the damaged section shut off by line valves varies widely and can amount to more than 50% of the total duration of the restoration work and requires the most accurate assessment.

![Figure 1. TDW hot tapping repair technology [12,13].](image)

2. Materials and methods

It is established that the methods of leakage calculation described in the literature are based on the theory of unsteady fluid flow with concentrated selections and have many difficulties in various solutions. It is noted that at present it is not possible to determine the duration of fluid discharge through the damaged place and consider the dynamics of changes in its shape and size and the effective head, the unsteady discharge process, etc.

The calculation of leakage and discharge by classical discharge formulas is associated with many difficulties. First, it is not always possible to determine the duration of discharge through the damaged place, and the process of discharge is characterized by unsteadiness. Secondly, the question of the growth rate of the dimensions and shape of the hole remains open to this day. Serious problems arise when determining the head.

For example, in [8-13], issues of gravity drainage of pipelines based on the profile of the route and gas saturation were considered. It is noted that the time for the free discharge of gas-saturated oils depends on the rate of change in pressure on the free surface, the back pressure of the soil, and on the coefficient of hole discharge, which in turn is determined by the geometric dimensions and shape of the hole, and also by its spatial arrangement on the pipe.

The authors developed a set of mathematical techniques for estimating leakage parameters for various design schemes. Let us perform modeling for the case of a horizontal pipeline since for most of the oil pipelines in Western Siberia, small values of the angle α in the design scheme are characteristic.
Figure 2. Design scheme of pipeline with the angle of inclination $\alpha$ with respect to the horizon $\alpha$ - angle of inclination of pipeline with respect to the horizon, deg; $h$ - height of the section, m; $L_h$ - length of the horizon, m; $L$ - length of the pipeline section, m.

Let us find the solution of the problem for the special case when $\alpha=0$, if the point $A$ is the location of damage (Fig. 2.3).

Using the dependence suggested by the authors, it is possible to estimate the volume of the product to be pumped out:

$$V = \frac{2L}{b} \left\{ \frac{(b-R)}{2} \left[ (b-R)\sqrt{R^2-(b-R)^2} + R^2 \arcsin \left( \frac{b-R}{R} \right) \right] + \frac{\pi \cdot R^2}{2} \right\} + \frac{1}{3} \left[ R^2 - (b-R)^2 \right] \frac{\pi}{2}. \quad (1)$$

In the case of a horizontal pipeline, the formula for calculating the volume of the pumped product is found for two variants:

1) $h>R$, 2) $h<R$,

where $h$ - height of the section, m.

Let us consider the first variant (Fig. 3a).

From the triangle $AOD$ we find the angle $\beta$ necessary to calculate the $AKCD$ segment area:
\[ OD = h - R; \quad AD = \sqrt{R^2 - (h - R)^2}; \]
\[ \tan \left( \frac{360 - \beta}{2} \right) = \frac{AD}{OD} = \frac{\sqrt{R^2 - (h - R)^2}}{h - R}. \]  
(2)

Then
\[ \tan \left( \frac{360 - \beta}{2} \right) = \tan \left( 180 - \frac{\beta}{2} \right) = -\frac{\beta}{2} = \frac{\sqrt{R^2 - (h - R)^2}}{h - R}; \]
\[ \tan \left( \frac{\beta}{2} \right) = -\frac{\sqrt{R^2 - (h - R)^2}}{h - R}. \]  
(3)

Hence the angle \( \beta \) equals:
\[ \beta = 2\arctan \left( -\frac{\sqrt{R^2 - (h - R)^2}}{h - R} \right). \]

The AKCD segment area
\[ S = \frac{R^2}{2} \left( \beta - \sin \beta \right); \]
\[ S = \frac{R^2}{2} \left[ 2\arctan \left( -\frac{\sqrt{R^2 - (h - R)^2}}{h - R} \right) - \sin \left( 2\arctan \left( -\frac{\sqrt{R^2 - (h - R)^2}}{h - R} \right) \right) \right]. \]  
(4)

Then the formula for calculating the volume of the pumped product is:
\[ V = S \cdot L. \]  
(5)

For the second variant, we similarly obtain (Fig.3b) the AKCD segment area
\[ S = \frac{R^2}{2} \left[ 2\arctan \left( \frac{\sqrt{R^2 - (R - h)^2}}{R - h} \right) - \sin \left( 2\arctan \left( \frac{\sqrt{R^2 - (R - h)^2}}{R - h} \right) \right) \right]. \]  
(6)

and the volume of the pumped product is also determined by the formula (5).

Based on the above methodology, using the formulas (1) ÷ (6), a program was developed to calculate the volume of the pumped product, with the help of which a series of calculations for various pipeline diameters was carried out, depending on the length of the section and the angle of inclination of the pipeline with respect to the horizon. The amount of product to be pumped out before carrying out repair and restoration works can be determined according to the developed nomograms as shown in Fig. 4-6.

If there is a leak in the pipeline, to improve the effectiveness of measures to eliminate its consequences, it is important to predict the consequences of the product's release to the surface of the earth, the formation of contaminated sites not only considering the terrain and the natural and climatic conditions of the terrain. The basis for the relevant calculations should include information on the amount of leakage, conditions for the entry of petroleum products into water bodies, emissions into the atmosphere, etc. This estimate can be made using computers and used in the organization of repair and restoration work.
Figure 4. Change in volumes of pumped product for pipelines D=1200x10 mm depending on the angle of inclination $\alpha = 0.0014 \div 0.0340$.

Figure 5. Change in volumes of pumped product for pipelines D=1200x10 mm depending on the angle of inclination $\alpha = 0.011 \div 0.115$.

Figure 6. Change in volumes of pumped product for pipelines D=1200x10 mm depending on the angle of inclination $\alpha = 0.017 \div 0.570$.

A mathematical apparatus for describing curvilinear surfaces -spline functions- can be used for modeling. To implement the method, coordinates of the nodal points of the isohypses of the oil pipeline, streams, ravines and rivers are entered into the initial data of the algorithm. A step along the pipeline, for example 100 m, is specified. Each isohypse is described numerically by spline functions.
After this, the shortest distance between two neighboring isohypses (i.e., the section with the greatest slope) is calculated. The process is repeated, and as a result, the program gives the coordinates of the trajectory of emergency spreading of oil or oil products.

3. Conclusion

The method is tested on the main condensate pipeline using a special program and profile of the route. This method can be used to select the means of protection, to determine the volumes and locations of construction of earthen pit and various tanks for collecting the discharge.

4. References

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