MODELING OF EMERGENCY OIL SPILL IN FREE MODE OF FLOW

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Abstract

In the paper, based on the analysis of accidental oil spills from pipelines, a grapho-analytical method was proposed for the correct determination of the amount of hydrocarbons spilled into the environment in different modes. During the accident, it was proved that the opinion about the free flow of oil into the environment is not correct due to the fact that the atmospheric pressure was not created at the maximum point of the track profile, but at the accident site (hole).
Currently, there are almost no correct methods for multiphase flows, unlike single-phase flows, in normative documents and literature sources.
Taking into account that the determination of which part of the oil flows from the pipeline during real accidents is very important for risk analysis, studies were carried out on the basis of the compressed profile of the oil pipeline.
In the paper, accident-oil spills, as well as the conditions under which it is possible to make 3-5% of the volume of the pipeline in the free flow mode, and the complete emptying of the pipeline are defined.

Keywords: oil spill, free flow, hydrostatic pressure, vapor elasticity, condensed profile, grapho-analytical method

I. Introduction

Although oil spills during the operation of oil and gas pipelines that do not result in explosions, fires and pollution of water sources are not considered very serious accidents, it is important to determine the amount of oil spilled in order to assess the losses and environmental impact. Explosion and fire monitoring and assessment of such accidents must be done. In this regard, the development and application of methods for correct determination of the volume of oil or gas spilled into the environment due to any impact from pipelines in different regimes deserves special attention.

If we are talking about short pipelines, then the simplest method for determining the volume of liquid and gas is the method based on the average flow rates of the phases, taking into account the speed of movement of the mixture. The results of such a calculation result in a significant reduction of the volume of the liquid phase in the pipeline, and an increase of the volume of the gas, on the contrary. However, experience shows that during multiphase flows in relief pipelines, there is always a ballast volume that is not displaced by gas. This ballast volume can be small at high speed of movement of multiphase mixture, and much more at low speed values.

According to the current methodology [1, 2], the volume of oil spilled into the environment during accidents in oil pipelines is determined according to the following expression:

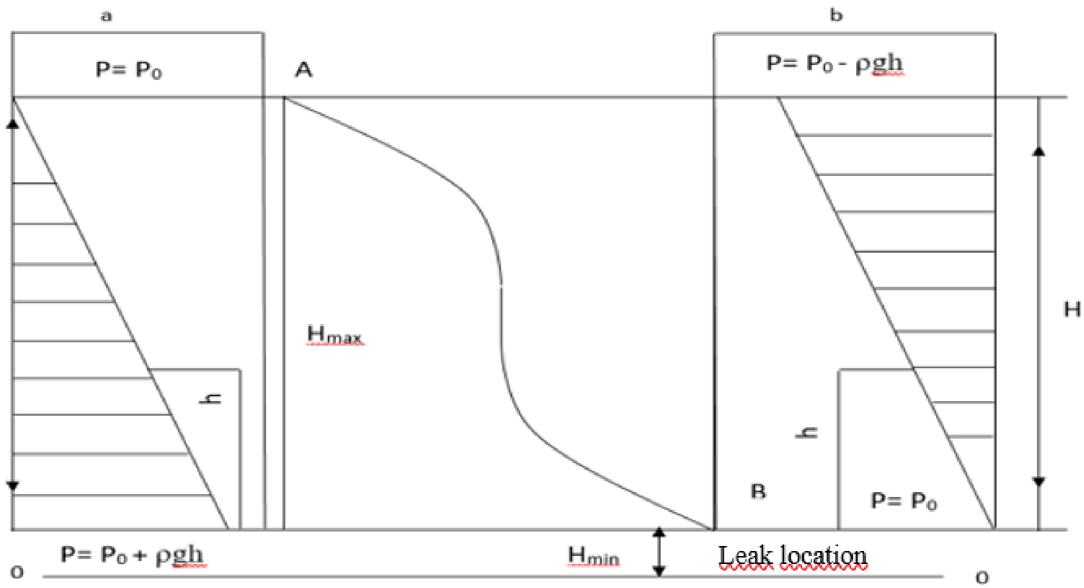
V= V_1+V_2+V_3

Here: V_1- the volume of oil discharged (dispersed) in pressurized mode. This volume is the volume of oil flowing during an accident until the pumps stop working (within 2 minutes); V_2- is the volume created due to unpressurized (free) flow, it is the volume of oil spilled during the time between stopping the pumps and closing the valve in the pipeline; V_3-is the volume of oil flowing through the emergency hole in free flow mode.

It should be noted that the main oil or oil product pipelines are equipped with an automatic system, so the flow time in the pressurized mode does not exceed 2 minutes (the pump and outlet drawer are closed at the same time and within 2 minutes). After the pumps are stopped, the oil flow time in the free-flow mode is assumed to be almost zero, since the valve is closed at the same time. The most interesting problems are observed during the determination of the volume of oil flowing in the free-flow mode after the valve is closed. This volume depends very much on the detection and localization of the place of damage and collapse of the pipeline.

II. Methods

In order to solve the mentioned problem, 2 points (A and B) are marked as the maximum and minimum on the profile of the pipeline. Then the graph of pressure distribution in the intended part is constructed. At this time, the crash site (hole) is considered as the minimum point of the profile. The pressure distribution graph constructed in this way is shown in figure 1.



a and b – on the false and true model, respectively

Figure 1: *Distribution of hydrostatic pressure in the leaking part of the oil pipeline*

Then it is assumed that the pressure varies along the profile of the AB part of the oil pipeline according to the graph (a) in figure 1. At this time, it is considered that the atmospheric pressure in the pipeline corresponds to its maximum point (A). Then, accepting the distribution of pressure along the height according to the law P = $P_0 + \rho g h$, the oil flow rate from the emergency hole is determined by the following formula known from hydraulics:

$$v = \sqrt{\frac{2P}{\rho}} = \sqrt{\frac{2(P_0 + \rho g h)}{\rho}} \quad (1)$$

Here: ρ- density of oil, kq /m^3 ;P_0 –atmospheric pressure, Pa; g- free acceleration, m/s^2; h- current height, m.

From Fig. 1, it can be seen that, the atmospheric pressure in the accident oil pipeline is not created at the maximum point of the profile as in option (a), but at the minimum point of the profile, i.e. at the accident hole (B). The pressure of the liquid column below the crash hole increases because the pressure of the liquid column is added to the atmospheric pressure. On the other hand, going up from the hole, the pressure in the pipeline decreases to the pressure of the liquid column at the height h (Fig. 1, b). Thus, it is found that in non-pressurized flow, since the intra-pipe pressure is equal to the atmospheric pressure in the cross-section of the crash hole, it will not be possible for the oil to flow freely to the environment. The free flow of oil from the accident hole will be possible when the hole is not located under water. When this hole is dry, only a part of the pipeline between the near crossing point and the emergency hole will slowly and gradually loosen. The rest of the oil in the pipeline will not be able to flow freely (without pressure). In this case, the relief is usually provided by compression with a piston or by opening holes in the pipeline at all crossing points (to allow air to freely enter the pipeline).

In general, the currently existing mathematical models for calculating the amount of oil and gas spilled as a result of accidents are adopted according to the hydraulics of single-phase flow of liquids and gases through holes and pipes [2÷4]. Appropriate assessment and calculation methods for multiphase flows are almost non-existent in normative documents and literature sources.

Let's examine the possibility of complete discharge of the pipeline section when the valves are closed at the beginning and end. Using the principle of continuity of flow, it can be confirmed that, in principle, it is impossible to completely empty the pipeline. This also goes against the laws of physics. So, the place of the oil removed from the pipeline must be filled with another cold medium (for example, atmospheric air or oil vapors).

It should be noted that oil evaporation is possible due to the difference between the atmospheric pressure and the pressure inside the pipeline when the heights are different along the pipeline route. That is, the pressure drop in any section of the pipeline leads to the following equation:

$$P_0 - \rho g h = P_{v.e} \tag{2}$$

Here, $P_{v.e}$- oil vapor elasticity pressure, Pa; h - is the height of the oil column from the accident hole, m.

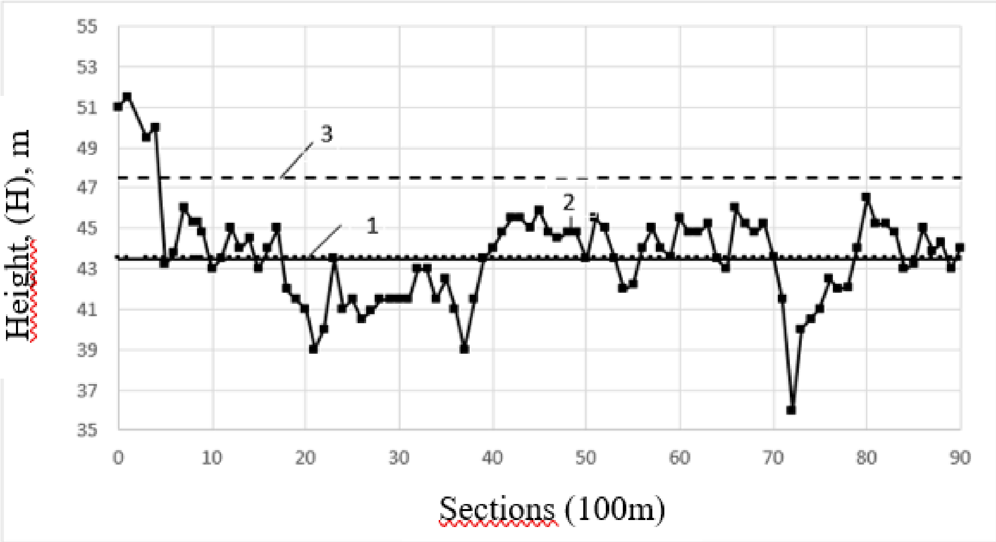
Where condition (1) is met, the oil begins to "boil" and the vapor phase separates from it, which replaces the liquid phase flowing through the pipeline.

Taking into account that determining which part of the oil flows from the pipeline during real accidents in practice is also very important for risk analysis, let's examine the issue based on the condensed profile of the oil pipeline (Figure 2). The parameters of the considered oil pipeline are as follows:

- pipeline length L=8.5 km;
-pipeline diameter D=0.7 m;
- pipeline volume V_P=3103 m^3;
- the minimum point of the profile - 36 m;
- the maximum point of the profile - 51.2 m;
- the middle point of the profile - 43.6 m;
- temperature of transported oil - 40°C;
- temperature at the depth where the ipeline is buried - 5°C.

The investigation of the flow of oil through the pipeline was considered according to 2 options:

- It is assumed that the accident hole is at the level of the average height of the pipeline route. For the considered pipeline, this value is H_{ave}= 43.6 m as mentioned.
- In order to estimate the maximum spillage of oil, it is assumed that the accident hole occurs at the minimum point of the pipeline. As can be seen from picture 2, the 72nd section of the pipeline corresponds to the mentioned condition. In this case, the length of the pipeline between two crossing points is considered as the part under accident. That section is 1.1 km long and is located between section- 69 and 80.



1÷3- is the average height of profile (H_{ave}), pipeline (H_{pipe}) and oil discharge (H_{empty}) respectively

Figure 2: *Compressed profile of the pipeline route*

Considering that there are 17 intersection points at the average height (H_{ave}= 43.6) for the studied oil pipeline profile, and if the leakage point is located at the minimum point of the profile H_{min}= 39 m, then oil will flow into the accident hole from both sides. Since the intersection point divides the profile section into two parts, the oil flow area is located above the intersection point. At this time, the 2nd part will not be free of oil. The average length of the pipe section free of oil can be determined according to the following expression:

$$l_{ave} = 0{,}427 \cdot \frac{L}{n}, m \tag{3}$$

Here: L- the length of the pipeline, m; n- is the number of intersection points of the profile with the average height of the pipeline. If we consider the values of L and n in (3), we get:

$$l_{ave} = 0{,}427 \cdot \frac{8500}{17} = 213{,}5\ m$$

Fig. 3 shows the distribution of pressure during oil discharge in the oil pipeline section from the accident hole formed at the middle height of the profile in a non-pressurized mode. The discharge level corresponds to the vapor elasticity pressure of the oil.

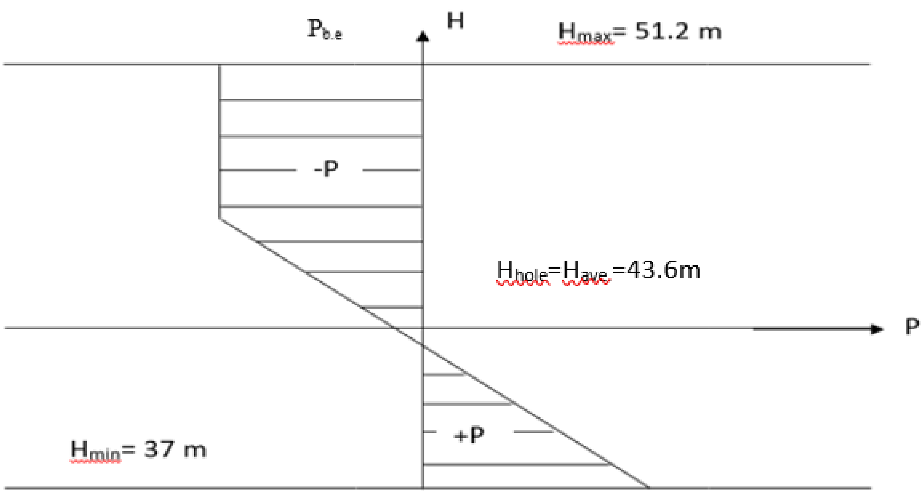


Figure 3: *Pressure distribution diagram in the damaged part of the oil pipeline*

According to the currently existing and above-mentioned methodical guidance, the volume of oil spilled during pipeline accidents is always assumed to be equal to the volume of the pipeline, regardless of the location of the damage. But as it turns out, even in the worst case, it is almost impossible to completely empty the pipeline. These are listed in table 1 in a comparative manner. As can be seen from Table 1, according to the existing methodical guidelines, the volume of accidental oil spills is increased by 39.8 and 7.6 times according to the mentioned scenarios (options).

It was also confirmed by analyzing the data of the Internet HSE AgensyLtd, Labor Protection, Industrial and Fire Safety, Warning of Emergency Events - Chronicle of Events and Accidents (2007-2008 years) [5] that the opinion about free flow of oil during the accident is not valid.

Table 1: *Assessment of accidental oil spills in pipelines under different scenarios*

Scenarios	The volume of oil pipeline, m^3	Pipeline discharge volume, m^3	Reconciliation of part share
According to methodological guidance [2].			
Probable Hypothetically	3103 3103	3103 3103	1 1
According to the proposed grapho-analytical method			
Probable Hypothetically	3103 3103	78 408	0,025 0,13

In those data, accidents related to oil spills from 8 different pipelines were investigated and systematized. Preliminary data characterizing oil spills occurring in oil pipelines of different diameters and systematized results are given in table 2.

Table 2: *Calculated results of the part of oil spilled from pipelines in free flow mode (based on accident statistics)*

D, m	V_o^s, m^3	L_p^v, km	V_p^v, m^3	$Q_o^{b.a}$, m^3/hour	v, m/s	V_o^p, m^3 (within 2 min)	V_o^f, m^3	$\frac{V_o^s}{V_p^v}$	$\frac{V_o^f}{V_p^v}$	$\frac{V_o^f}{V_p^v}$, %
0,15	9,1	10	176,6	64	1,0	2,1	7,0	0,0012	0,0396	3,96
1	12,8	10	7850	367	0,13	12,2	0,6	0,001	0,0001	0,01
1,2	26,0	10	11304	732	0,18	24,4	1,6	0,002	0,0001	0,01
0,7	43,0	10	3846,5	1246	0,90	41,5	1,5	0,004	0,0004	0,04
0,8	49,0	10	5024,0	1429	0,80	47,5	1,4	0,009	0,0003	0,03
0,6	51,5	10	1962,5	707	1,0	23,5	28,0	0,012	0,0143	1,43
1,2	126,0	10	11304	3744	0,91	124,7	1,3	0,011	0,0001	0,01
0,7	272,0	10	3846,5	2769	2,0	92,2	179,8	0,024	0,0467	4,67

Here,

D – Diameter of the oil pipeline, m;

V_o^s – the volume of oil spilled from the pipeline, m^3;

L_p^v – length of pipeline between valves ($L_p^v = 10km$) ;

V_p^v – volume of pipeline between valves, m^3 ;

$Q_o^{b.a}$- volumetric flow rate of oil before accident, m^3/hour;

v – flow velocity, m/s ;

V_o^p - volume of oil spilled under pressure (within 2 min)., m^3;

V_o^f – volume of oil spilled in free flow mode, m^3.

The volume of oil discharged in pressurized mode is determined based on the flow rate of oil flowing through the pipeline in 2 minutes, and the volume of oil flowing in free flow mode is determined based on the expression $V_o^f = V_o^s - V_o^p$.

As can be seen from the calculation results shown in Table 2, the volume of oil spilled in free flow mode does not exceed 3-5% of the volume of oil in the pipeline. The experience of long-term operation of main oil pipelines confirms the above.

III. Results

A grapho-analytical method was proposed for the evaluation of oil spills with free flow in pipelines. It was determined that even in the worst case, it is not possible to completely empty the oil pipeline. In the case of accidental spills, complete emptying of the pipeline in the free-flow mode is possible when holes are formed at all extreme points of the pipeline (at the maximum and minimum points of the profile) during the accident.

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