DIAGNOSIS OF THE RISK OF OIL LEAKS FROM PIPELINES

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Abstract

The research paper studies the issue of detecting the location and amount of hydrocarbon losses in cases of accident-damage (spill), which occur during the transportation of oil and oil products via the technological and main pipes. The grapho-analytical method has been introduced and tested in order to determine a location and degree of the leakage following the change in working parameters.

Keywords: technological and main pipes, oil leakages, hydrocarbon losses, the relative change of discharge, leakage area, degree of the leak

I. Introduction

Occurrence of the hydrocarbon losses during the transportation of oil and oil products through the technological and main pipelines is mainly related with the accident-damage (spill) cases on pipelines. Reasons of losses caused by accidents are quite different, but they are mainly related to the violation of pipelines' operating procedures, non-compliance with construction norms and rules during their construction and the manufacturing defects of pipes.

Operational practice of pipelines shows that application of traditional methods for detection of leakages is not always efficient, while small leakages sometimes remain unrevealed for a long period of time. Currently, there are various methods in order to reveal the areas of accidents-caused oil leakages from pipelines and environmental pollution, as well as to determine the amount of spilled hydrocarbons.

II. Methods

It is known that during the emergency leak on the pipelines, the change of pipe and pump station's normal working regime heavily depends qualitatively and quantitatively on type of pump in use. Thus, characteristics of a pump station equipped with the centrifugal pumps differ essentially from the use of piston-type pump. As the latter is rarely used in practice, it has been studied below the impact of emergency oil leakage on change of pump station equipped with centrifugal pumps, pipeline with diameter expressed in D and length expressed in *l* and on their joint characteristics. To this effect, characteristics of a pump station and relief pipeline (dependence of pressure on discharge) have been determined via the following analytic expressions, respectively [1, 2]:

Before leakage, i.e. for a normal operation regime

$$H_0^{pump} = a - bQ_0^{2-m}$$

$$H_0^{b.k} = kQ_0^{2-m}l + \Delta z \tag{1}$$

After the oil leakage, the expression (1) can be written in the following form for pump station and pipeline:

$$H_1^{pump} = a - bQ_1^{2-m}$$
$$H_1^{b.k} = kQ_1^{2-m}x + kQ_2^{2-m}(l-x) + \Delta z \tag{2}$$
$$k = \beta \frac{\mu^m}{D^{5-m}}$$

Here. Q_0, Q_1, Q_2-are discharges before and after leakage in pump station, and after the leakage area respectively ($Q_2 = Q_1 - q$ and here q – is the amount of leaked oil; x – is a distance till the leakage area; μ– is a kinetic viscosity of leaked oil; Δz –height differences in the initial and final points of pipeline; a, b – maximum pressure of pump station equipped with centrifugal pump and approximation coefficient of its characteristics, respectively; m, β – indicators describing the oil flow regimes in the pipeline.

Taking into account the similarity in the relative change of pressures in pump station and pipeline when leakage occurs, it is possible to get the following formula to detect the leakage area based on change in discharge:

$$\frac{x}{l} = \frac{1 - \left(\frac{Q_2}{Q_0}\right)^{2-m} - A\left[\left(\frac{Q_1}{Q_0}\right)^{2-m} - 1\right]}{\left(\frac{Q_1}{Q_2}\right)^{2-m} - \left(\frac{Q_2}{Q_0}\right)^{2-m}} \tag{3}$$

$$A = \frac{\left(\frac{a}{H_0} - 1\right)}{\left(1 - \frac{\Delta z}{H_0}\right)} \tag{4}$$

Thus, expression (3) shows that it is possible to detect the leakage area based on change of discharge in oil pipeline and characteristics of pump station without taking into account the geometric values of pipe, features of transported and volume of leaked oil. Here, $\left(\frac{\Delta z}{H_0}\right) \neq 0$ and $\frac{a}{H_0}$ values show slope of characteristics for relief pipelines and pump stations, respectively (regardless of motion regime and the leakage $\frac{a}{H_0}$=1.1-1.8).

If we consider the motion regime as laminar (m = 1) and Q = Q_1 – q, the expression (3) for horizontal (Δz = 0) pipeline will be as following:

$$\frac{x}{l} = 1 - \frac{a}{H_0} + \frac{\left(1 - \frac{Q_2}{Q_0}\right)\frac{a}{H_0}}{\frac{q}{Q_0}} \tag{5}$$

or

$$\frac{x}{l} = 1 - \frac{\left(\frac{Q_1}{Q_0} - 1\right)\frac{a}{H_0}}{\frac{q}{Q_0}} \tag{6}$$

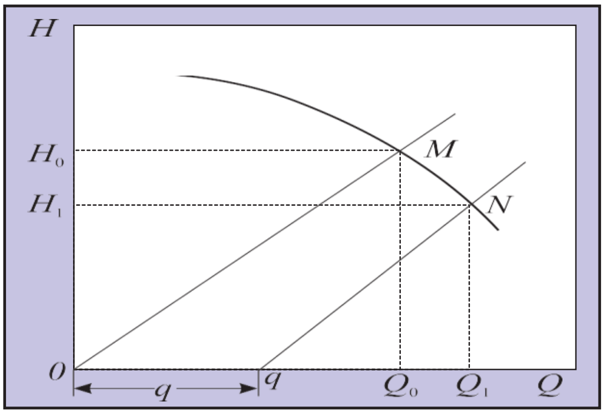

Fig. 1: *Common characteristics of pump station and pipeline considering the oil leakage*

If we take into account that, $1-\frac{Q_2}{Q_0}=\delta_{Q_2}$ and $\frac{Q_1}{Q_0}-1=\delta_{Q_1}$ in formulas (5) and (6) are describing the relative change in discharge in the initial and final points of pipeline, respectively, then in cases of accident-leakage, these changes can be determined depending on the distance $(\frac{x}{l})$ and degree $(\frac{q}{Q_0})$ of leakage:

$$\delta_{Q_2}=\frac{\frac{q}{Q_0}(\frac{x}{l}+\frac{a}{H_0}-1)}{\frac{a}{H_0}} \tag{7}$$

$$\delta_{Q_1}=\frac{\frac{q}{Q_0}(1-\frac{x}{l})}{\frac{a}{H_0}} \tag{8}$$

It is possible to use the following formula to determine the relative change (δ_H) of pressure in the initial point of pipeline (pump station) taking into account formula (8), expressions (1) and (2):

$$\delta_H=\delta_{Q_1}\left(\frac{a}{H_0}-1\right) \tag{9}$$

If we accept the occurrence of the leakage in the initial part of pipe, in compliance with the common characteristics of the pipeline, it would be possible to get the similar $\Delta 0MQ_0$ and ΔqNQ_1 triangles: (Fig.1)

$$\frac{Q_1}{Q_0}=\frac{q}{Q_0}+\frac{H_1}{H_0} \tag{10}$$

It is possible to obtain the following dependence between the known leakage degree and its place, as well as relative change of pressure by taking into account the expression (10) in (6):

$$\frac{q}{Q_0}=\frac{\left(1-\frac{H_1}{H_0}\right)\frac{a}{H_0}}{\frac{a}{H_0}-1+\frac{x}{l}} \tag{11}$$

The analysis of expressions (7) and (8) shows that the parameters δ_{Q_1} and δ_{Q_2} can be more or less than each other depending on a location of the leakage. There is such a point where $\delta_{Q_1}=\delta_{Q_2}$. This point identifies the length of the part that is being determined by change of discharge in the initial (or final) point of pipe and found as following:

$$\left(\frac{x}{l}\right)=1-\frac{a}{2H_0} \tag{12}$$

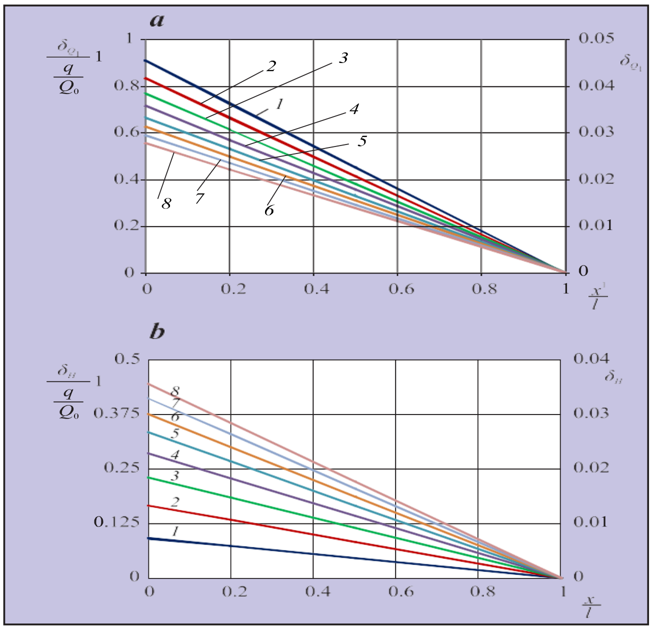

Fig. 2: *Detection of the leakage area and degree by the relevant change of discharge (a) and pressure (b): 1–8 – $\frac{a}{H_0}$ constitutes 1.1; 1.2; 1.3; 1.4; 1.5; 1.6; 1.7; and 1.8, respectively*

In accordance with expressions (8), (9) and (11), the leakage cases have been assessed by the relative changes of discharge and pressure and their dependences have been formed as following:

$$\frac{\delta_{Q_1}}{\frac{q}{Q_0}}=f\left(\frac{x}{l}\right),\text{ and }\frac{\delta_H}{\frac{q}{Q_0}}=f\left(\frac{x}{l}\right)\text{ (Figure 2)}$$

The grapho-analytic method drafted for the determination of the leakage degree in the initial point of a pipeline is shown on the Fig.3.

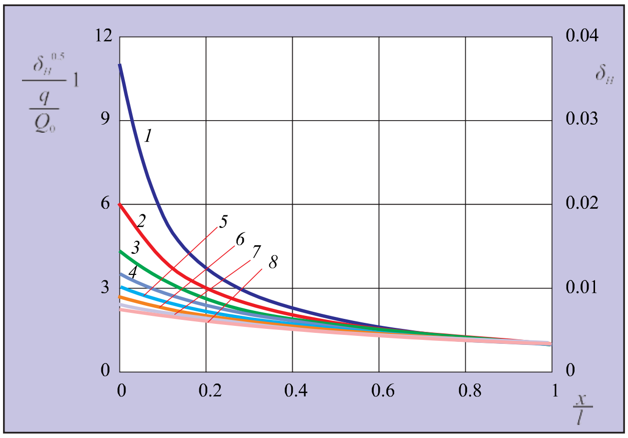

Fig. 3. *Detection of the leakage degrees in the initial point of pipe: 1-8 is the same as in the Figure 2*

III. Results

As it is obvious from the figures 2 and 3, it is possible to determine the location of leakage and its degree by the relevant dependences on the basis of the relative changes in discharge and pressure. Taking into consideration the above-mentioned findings, it has been studied the issue of determining the leakage location and degrees on the basis of changing working parameters of oil pipelines. Data of leakages that happened in oil pipelines (entrance and exit) in Absheron peninsula in different times have been used for this purpose (Tables 1, 2).

Table 1: *Data of leakages that happened in oil pipelines (entrance and exit) in Absheron peninsula*

Hour	26.05.2006			Note	Hour	26.05.2006			Note
	Discharge m³/hour	Pressure, MPa				Discharge m³/hour	Pressure, MPa		
		Entrance	Exit				Entrance	Exit	
01:00	-	-	-	Oil transportationstarted at 09:00	01:00	-	-	-	Oil transportationstarted at 10:30
02:00	-	-	-		02:00	-	-	-	
03:00	-	-	-		03:00	-	-	-	
04:00	-	-	-		04:00	-	-	-	
05:00	-	-	-		05:00	-	-	-	
06:00	-	-	-		06:00	-	-	-	
07:00	-	-	-		07:00	-	-	-	
08:00	-	-	-	Leakage occurred at 11:40 and eliminated at 13:20	08:00	-	-	-	Leakage occurred at 11:18 and eliminated at 16:00
09:00	-	-	-		09:00	-	-	-	
10:00	93	0.96	0.85		10:00	-	-	-	
11:00	156	1.07	0.86		11:00	62	0.95	0.86	
12:00	151	1.04	0.85		12:00	149	1.06	0.86	
13:00	-	-	-		13:00	157	1.07	0.85	

14:00	150	1.03	0.85		14:00	157	1.07	0.85	
15:00	155	1.07	0.86		15:00	47	0.68	0.62	
16:00	157	1.06	0.86	Oil transportationstopped at 21:35	16:00	-	-	-	Oil transportationstopped at 22:55
17:00	157	1.07	0.86		17:00	112	1.06	0.85	
18:00	157	1.07	0.86		18:00	155	1.08	0.86	
19:00	158	1.06	0.86		19:00	157	1.08	0.86	
20:00	157	1.06	0.86		20:00	157	1.08	0.86	
21:00	157	1.06	0.86		21:00	158	1.07	0.86	
22:00	84	1.06	0.86		22:00	157	1.07	0.86	
23:00	-	-	-		23:00	141	1.06	0.86	
24:00	-	-	-		24:00	-	-	-	

As we can see from the Table 1, the first leakage has occurred on 26 May 2006. Unlike to the first case of leakage, the second case has been followed by a significant spill and caused the spill of more than 50 % of oil.

Change of working parameters before and after the oil leakages, according to the Table 2, from the main pipe is shown on the Fig.4.

Table 2: *Change of working parameters before and after the oil leakages*

21.04.2006				22.04.2006				23.04.2006			
Time, hour	Discharge m³/hour	Pressure, MPa		Time, hour	Dischargem³/hour	Pressure, MPa		Time, hour	Dischargem³/hour	Pressure, MPa	
		entrance	exit			entrance	exit			entrance	exit
01:00	750	1.41	0.38	01:00	752	1.42	0.38	01:00	353	1.24	1.31
02:00	750	1.41	0.38	02:00	751	1.41	0.38	02:00	352	1.24	1.31
03:00	750	1.41	0.38	03:00	740	1.40	0.38	03:00	351	1.24	1.31
04:00	752	1.42	0.38	04:00	320	1.13	0.21	04:00	354	1.24	1.31
05:00	751	1.41	0.38	05:00	Leakage occurred at 02:53, discharge at 03:43	0.82	0.13	05:00	353	1.24	1.31
06:00	752	1.42	0.38	06:00		0.61	0.09	06:00	355	1.24	1.31
07:00	750	1.41	0.38	07:00		0.58	0.07	07:00	352	1.24	1.31
08:00	752	1.42	0.38	08:00		0.57	0.06	08:00	550	1.31	0.31
09:00	751	1.41	0.38	09:00		0.55	0.06	09:00	611	1.34	0.32
10:00	752	1.42	0.38	10:00		0.55	0.06	10:00	643	1.35	0.33
11:00	751	1.41	0.38	11:00		0.54	0.05	11:00	661	1.36	0.34
12:00	752	1.42	0.38	12:00		0.55	0.06	12:00	720	1.38	0.35
13:00	750	1.41	0.38	13:00		0.55	0.06	13:00	742	1.41	0.37
14:00	752	1.41	0.38	14:00		0.54	0.05	14:00	749	1.41	0.37
15:00	751	1.42	0.38	15:00	238	1.09	0.29	15:00	748	1.41	0.37
16:00	751	1.41	0.38	16:00	291	1.11	0.31	16:00	752	1.42	0.38
17:00	752	1.42	0.38	17:00	342	1.24	0.31	17:00	751	1.41	0.38
18:00	751	1.41	0.38	18:00	346	1.24	0.31	18:00	752	1.42	0.38
19:00	752	1.42	0.38	19:00	353	1.24	0.31	19:00	750	1.41	0.38

20:00	750	1.41	0.38	20:00	352	1.24	0.31	20:00	752	1.42	0.38
21:00	752	1.42	0.38	21:00	351	1.24	0.31	21:00	751	1.41	0.38
22:00	751	1.41	0.38	22:00	355	1.24	0.31	22:00	752	1.42	0.38
23:00	752	1.42	0.38	23:00	354	1.24	0.31	23:00	752	1.42	0.38
24:00	752	1.42	0.38	24:00	355	1.24	0.31	24:00	752	1.42	0.38

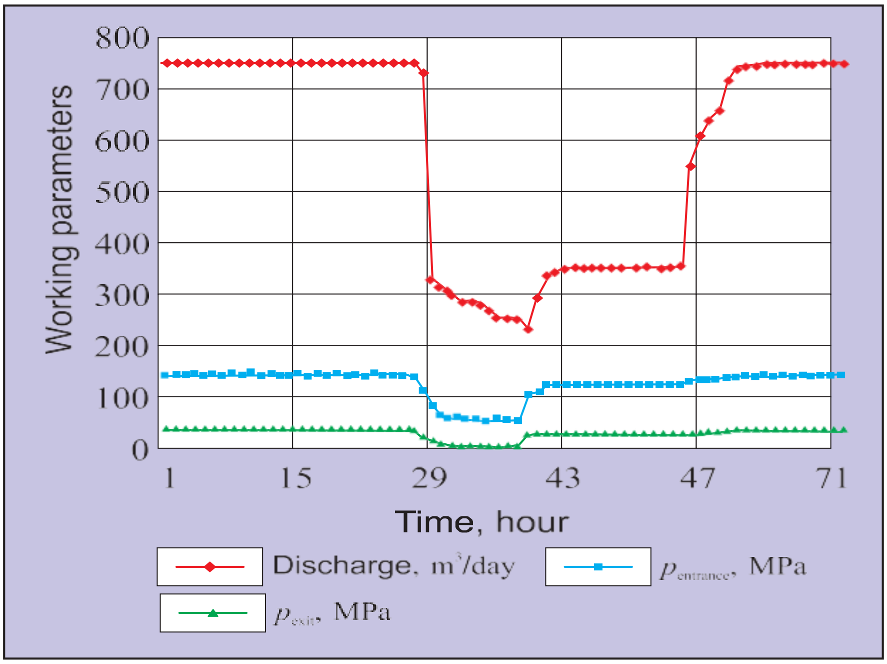

Fig. 4: *Change of working parameters in the pipeline before and after the oil leakage case*

IV. Discussion

According to the Table 1, the relative changes of discharge and pressure during the small leakage cases constituted:

$$\delta Q_1 = \frac{156 - 151}{156} = 0.0321$$

and

$$\delta_H = \frac{10.7 - 10.4}{10.7} = 0.028$$

In accordance with δQ_1 and δ_H on the Figure 2, we obtained the following:

$$\frac{\sigma_{Q1}}{\frac{q}{Q_0}} = 0.625 \text{ and } \frac{\sigma_H}{\frac{q}{Q_0}} = 0.352$$

In this condition, we get the coordinate of leakage from Figure 2 (a) and (b):

$$\frac{x}{l} = 0.15 \text{ and } \frac{x}{l} = 0.08$$

As we can see, the area of leakage determined by the relevant change of discharge and the distance of leakage determined by the change of pressure is slightly different (~ 8%) from the factual leakage distance: $\left(\left(\frac{x}{l}\right)_{fact} = 0.137\right)$

Thus, we obtain the following results for the degree of leakage by the relevant change of discharge and pressure, respectively:

$$\frac{q}{Q_0} = 0.051 \text{ and } \frac{q}{Q_0} = 0.079$$

According to the Table 2, the relevant change of discharge and pressure in case of a small leakage would be as following:

$$\delta_{Q1} = \frac{752-740}{752} = 0.0159$$

$$\delta_H = \frac{14.2-14.0}{14.2} = 0.0141$$

We can obtain the following results from the values of δ_{Q1} and δ_H reflected on the Figure 2:

$$\frac{\delta_{Q1}}{\frac{q}{Q_0}} = 0.30 \text{ and } \frac{\delta_H}{\frac{q}{Q_0}} = 0.188$$

In this condition, we get for the area of leakage as $\frac{x}{l} = 0.50$ from the Figure 2(a), and as $\frac{x}{l} = 0.52$ from the Figure 2, (b). In this case as well, the area of leakage determined by the relevant change of discharge in comparison the area of leakage determined by the change of pressure is closer to the factual leakage zone $\left(\left(\frac{x}{l}\right)_{fact} = 0.47\right)$ and differs by 6%. In addition, we get the following results for the degree of leakage by the relative change of discharge and pressure, respectively:

$$\frac{q}{Q_0} = 0.053 \text{ and } \frac{q}{Q_0} = 0.075$$

Thus, the suggested grapho-analytical method allows detection of small oil leakages by the relative change of discharge with accuracy to 8 %.

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