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Methods for an assessment of emergency leaks taking into account hydraulic characteristics of oil 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. Considering, that rate of the expiration of oil in a place of damage of the underwater pipeline is not to constants and depends on a direction of streams of oil in a pipe at movement to a defective aperture, a line profile, diameter of the pipeline and pressure in it, damage size, have been estimated the values of the flowed out oil depending on time of the expiration taking into account the various pressures created in a standpipe of the underwater pipeline. Estimated formulas for definition of time of the expiration of a liquid through an aperture in a damage place are given at constant and headless modes at small leaks of oil.
Keywords: *technological and main pipes, oil leakages, hydrocarbon losses, centrifugal pumps, pressure, cinematic viscosity, the relative change of discharge, leakage area, degree of the leak.*

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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. 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.

Process of calculation of leak of oil of the pipeline is generally rather labor-consuming. When scoping the oil which has flowed out from the pipeline depending on time which has passed since the beginning of process it is necessary to consider an oil pipeline profile, opening parameters, and also physical properties of liquid and the modes of her expiration. For so-called "small" openings in the pipeline, the movement of oil towards an opening can be neglected, and for big openings, it is necessary to consider losses of a pressure at her movement towards an opening [1].

MATERIALS AND METHODS

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 [2, 3], respectively: before leakage, i.e. for a normal operation regime

$$H_0^{pump} = a - bQ_0^{2-m} \qquad (1)$$

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

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

$$H_1^{pump} = a - bQ_1^{2-m}$$

$$H_1^{b.k.} = kQ_1^{2-m}x + kQ_2^{2-m}(l-x) + \Delta z, \qquad (2)$$

$$k = \beta\frac{\mu^m}{D^{5-m}}$$

Here, $Q0$, $Q1$, $Q2$ – are discharges before and after leakage in pump station, and after the leakage area, respectively ($Q2 = Q1 - q$ 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; $\Delta ç$ –height differences in the initial and final points of pipe; 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 pipe. 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:

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

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

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 oil and volume of leaked oil. $\neq 0$, values show slope of characteristics for relief pipelines and pump stations, respectively(regardless of motion regime and the leakage = 1.1 ÷1.8.

If we consider the motion regime as laminar (m = 1) and Q_2=Q_1-q, the expression (3) for horizontal (ΔZ=0) pipeline will be as following:

$$-\frac{a}{H_0} + \frac{\left(1-\frac{Q_2}{Q_0}\right)\frac{a}{H_0}}{\frac{q}{Q_0}} \qquad (5)$$

or

$$-\frac{\left(\frac{Q_1}{Q_0}-1\right)\frac{a}{H_0}}{\frac{q}{Q_0}} \qquad (6)$$

If we take into account that, $1 - \frac{Q_2}{Q_0} = \delta_{Q_2}$ and $\frac{Q_1}{Q_0} - 1 = \delta_{Q_1}$- uin 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 area $\left(\frac{x}{l}\right)$ and degree $\left(\frac{q}{Q_0}\right)$ of leakage:

$$: \frac{\frac{q}{Q_0}\left(\frac{x}{l} + \frac{a}{H_0} - 1\right)}{\frac{a}{H_0}} \qquad (7)$$

$$:\frac{\frac{q}{Q_0}\left(1-\frac{x}{l}\right)}{\frac{a}{H_0}} \qquad (8)$$

It is possible to use the following formula to determine the relative change ($\delta\grave{U}$) of pressure in the initial point of pipeline (pump station) taking into account formula (8), expressions (1) and (2):

$$\delta_{Q_1} \cdot \left(\frac{a}{H_0} - 1\right) \qquad (9)$$

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 to the ΔOMQ_0 and ΔqNQ_1 triangles:

$$\frac{Q_1}{Q_0} = \frac{q}{Q_0} + \frac{H_1}{H_0} \qquad (10)$$

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):

$$\frac{\left(1-\frac{H_1}{H_0}\right)\frac{a}{H_0}}{\frac{a}{H_0}-1+\frac{x}{l}} \qquad (11)$$

The analysis of expressions (7) and (8) shows that the parameters and can be more or less than each other depending on a location of the leakage. There is such a point where= δ_{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:

$$_{k_*} = 1 - \frac{a}{2H_0} \qquad (12)$$

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:

$\frac{\delta_{Q_1}}{\frac{q}{Q_0}} = f\left(\frac{x}{l}\right)$, $\frac{\delta_H}{\frac{q}{Q_0}} = f\left(\frac{x}{l}\right)$ (see Figure 3).

The grapho-analytic method drafted for the determination of the leakage degree in the initial point of a pipeline is shown on the figure 5.

Generally the liquid expiration which happens in a strut junction to a linear part of the underwater pipeline at a constant pressure created by the estuarial pressure of wells (or a pressure – He.w.). Also cases of the expiration of oil in case of a variable pressure when the amount of the liquid inflowing from slits to the underwater pipeline reaches zero are possible and there is a depletion of the pipeline. Some of these tasks were considered below. The scheme of leak of oil in underwater pipelines at various pressures is submitted in Figure 1.

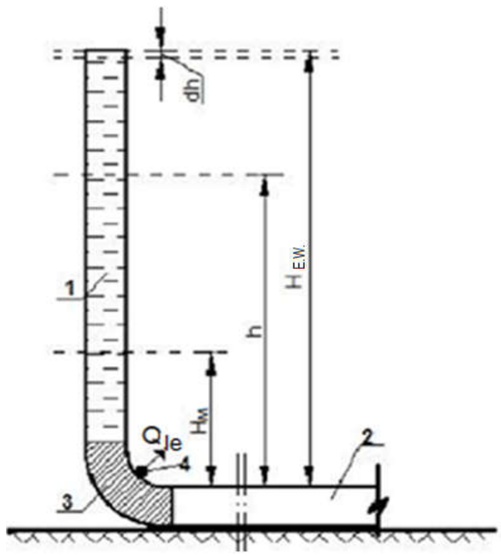

Figure 1. The scheme of leak of oil in underwater the pipeline at various pressures 1. Strut 2. Linear part of the pipeline 3. A strut junction with a linear part of the pipeline 4. Place of leak of oil

RESULTS AND DISCUSSION

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 on oil pipelines (entrance and exit) in Absheron peninsula in different times have been used for this purpose (Tables 1, 2). 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 figure 4. According to the table 1, the relative changes of discharge and pressure during the small leakagecases constituted:

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

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

In accordance with δ_{Q_1} and δ_H-δ on the figure 2, we obtained the following:

$$\frac{\delta_{Q_1}}{\frac{q}{Q_0}} = 0.625 \text{ and } \frac{\delta_H}{\frac{q}{Q_0}} = 0.352.$$

In this condition, we get for the area of leakage as $\frac{x}{l} = 0.15$; from the figure 2, *a*; and as $\frac{x}{l} = 0.08$ from the figure 2, *b*. As we can see, the area of leakage determined by the relevant change of discharge and the area of leakage determined by the change of pressure is slightly different (~ 8%) from the factual leakage area

$$\left(\frac{x}{l}\right)_{fak.} = 0.137$$

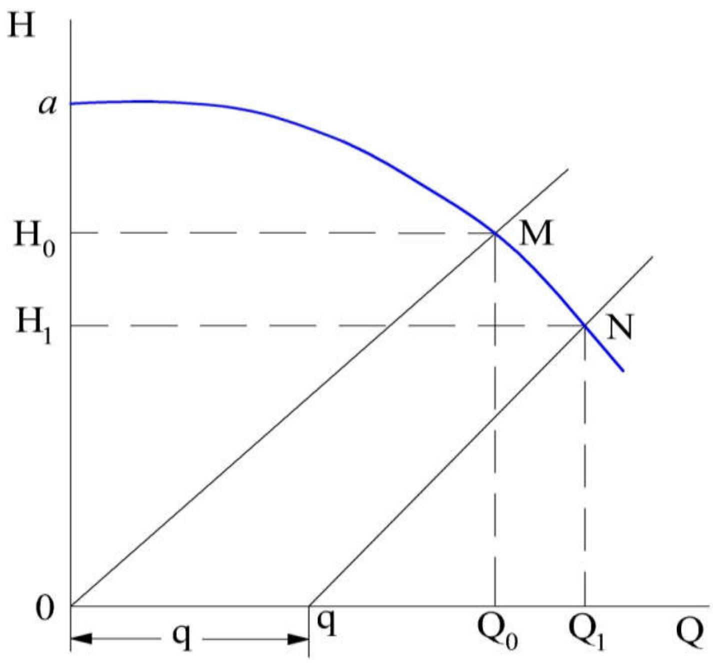

Figure 2. Common characteristics of pump station and pipeline considering the oil leakage.

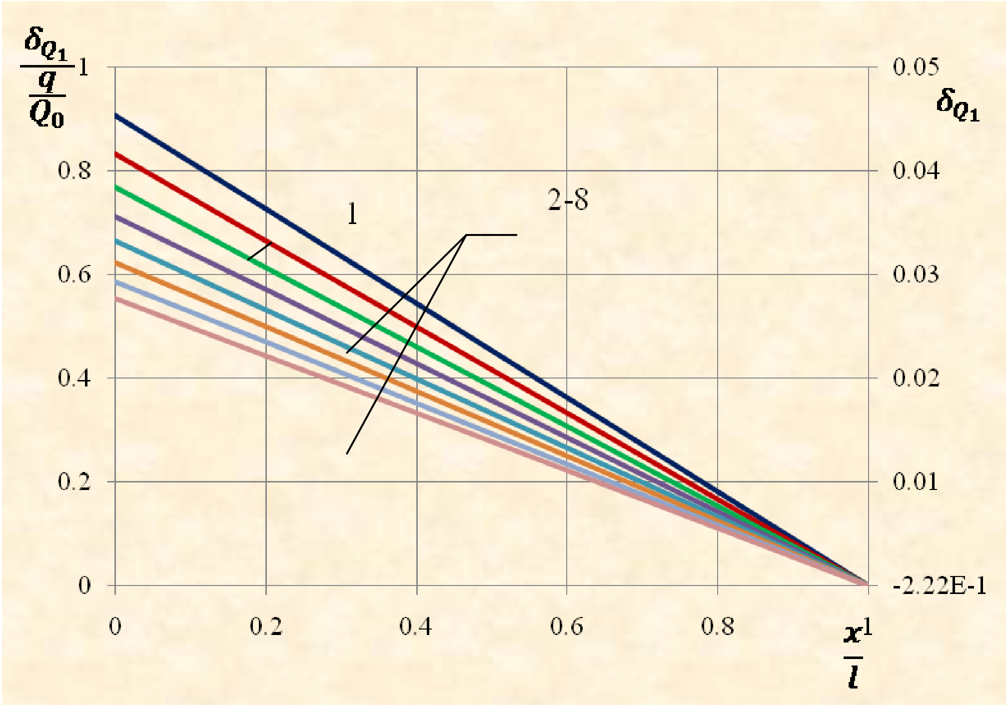

Figure 3 (a). Detection of the leakage area and degree by the relevant change of discharge (a) and pressure (b):1–8-constitutes $\frac{a}{H_0}$ = 1,1; 1,2; 1,3; 1,4; 1,5; 1,6; 1,7; and 1,8 respectively.

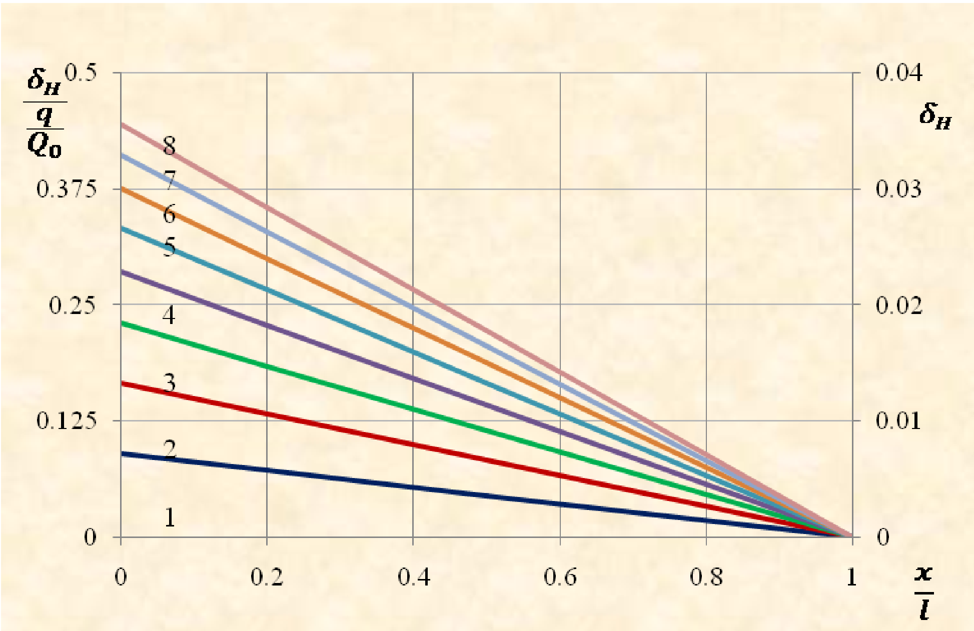

Figure 3 (b). Detection of the leakage degrees in the initial point of pipe:1–8-is the $\frac{a}{H_0}$ = 1,1; 1,2; 1,3; 1,4; 1,5; 1,6; 1,7 and 1,8 respectively.

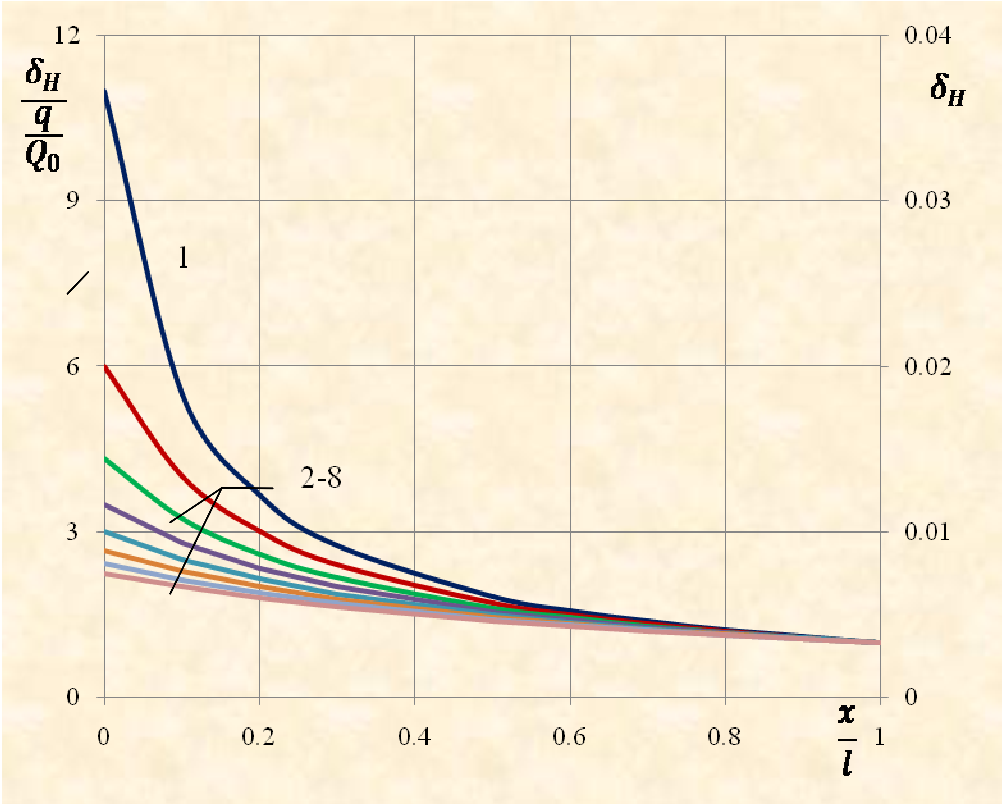

Figure 4. Detection of the leakage degrees in the initial point of pipe: *1-8* is the same as in the Figure 2 (a, b).

Table 1

26.05.2006						26.05.2006			
Hour	Discharge, m³/hour	Pressure, atm		Note	Hour	Discharge, m³/hour	Pressure, atm		Note
		Ent.	Exit				Ent.	Exit	
01:00	-	-	-	Oil transpo-rtation started at 09:00	01:00	-	-	-	Oil transpo-rtation started 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 occur-red at 11:40 and elimina-ted at 13:20	08:00	-	-	-	Leakage occurred at 11:18 and elimina-ted at 16:00
09:00	-	-	-		09:00	-	-	-	
10:00	93	9.6	8.5		10:00	-	-	-	
11:00	156	10.7	8.6		11:00	62	9.5	8.6	
12:00	151	10.4	8.5		12:00	149	10.6	8.6	
13:00	-	-	-		13:00	157	10.7	8.5	
14:00	150	10.3	8.5		14:00	157	10.7	8.5	
15:00	155	10.7	8.6		15:00	47	6.8	6.2	
16:00	157	10.6	8.6	Oil transpo-rtation stopped at 21:35	16:00	-	-	-	Oil transpo-rtation stopped at 22:55
17:00	157	10.7	8.6		17:00	112	10.6	8.5	
18:00	157	10.7	8.6		18:00	155	10.8	8.6	
19:00	158	10.6	8.6		19:00	157	10.8	8.6	
20:00	157	10.6	8.6		20:00	157	10.8	8.6	
21:00	157	10.6	8.6		21:00	158	10.7	8.6	
22:00	84	10.6	8.6		22:00	157	10.7	8.6	
23:00	-	-	-		23:00	141	10.6	8.6	
24:00	-	-	-		24:00	-	-	-	

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

0.051 and 0.079

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

$$\delta_{Q_1} = \frac{752 - 740}{752} = 0.0159$$

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

We can obtain the following results from the values of and reflected on the

figure 2: $= 0.30$ and 0.188. In this condition, we get for the area of lea- kage as $.50$; from

the figure 2, *a;* and as $.52$ from the figure 2, *b*.

Table 2

21.04.2006				22.04.2006				23.04.2006			
Time, hour	Discharge, m³/ho.	Pressure, atm Entr-ance	Pressure, atm exit	Time, hour	Disch-arge, m³/ho.	Pressure, atm Entr-ance	Pressure, atm exit	Time, hour	Disch-arge, m³/ho.	Pressure, atm Entr-ance	Pressure, atm exit
01:00	750	14.1	3.8	01:00	752	14.2	3.8	01:00	353	12.4	3.1
02:00	750	14.1	3.8	02:00	751	14.1	3.8	02:00	352	12.4	3.1
03:00	750	14.1	3.8	03:00	740	14.0	3.8	03:00	351	12.4	3.1
04:00	752	14.2	3.8	04:00	320	11.3	2.1	04:00	354	12.4	3.1
05:00	751	14.1	3.8	05:00	Leakage occurred at 02:53, discharge at 03:43	8.2	1.3	05:00	353	12.4	3.1
06:00	752	14.2	3.8	06:00		6.1	0.9	06:00	355	12.4	3.1
07:00	750	14.1	3.8	07:00		5.8	0.7	07:00	352	12.4	3.1
08:00	752	14.2	3.8	08:00		5.7	0.6	08:00	550	13.1	3.1
09:00	751	14.1	3.8	09:00		5.5	0.6	09:00	611	13.4	3.2
10:00	752	14.2	3.8	10:00		5.5	0.6	10:00	643	13.5	3.3
11:00	751	14.1	3.8	11:00		5.4	0.5	11:00	661	13.6	3.4
12:00	752	14.2	3.8	12:00		5.5	0.6	12:00	720	13.8	3.5
13:00	750	14.1	3.8	13:00		5.5	0.6	13:00	742	14.1	3.7
14:00	752	14.1	3.8	14:00		5.4	0.5	14:00	749	14.1	3.7
15:00	751	14.2	3.8	15:00	238	10.9	2.9	15:00	748	14.1	3.7
16:00	751	14.1	3.8	16:00	291	11.1	3.1	16:00	752	14.2	3.8
17:00	752	14.2	3.8	17:00	342	12.4	3.1	17:00	751	14.1	3.8
18:00	751	14.1	3.8	18:00	346	12.4	3.1	18:00	752	14.2	3.8
19:00	752	14.2	3.8	19:00	353	12.4	3.1	19:00	750	14.1	3.8
20:00	750	14.1	3.8	20:00	352	12.4	3.1	20:00	752	14.2	3.8
21:00	752	14.2	3.8	21:00	351	12.4	3.1	21:00	751	14.1	3.8
22:00	751	14.1	3.8	22:00	355	12.4	3.1	22:00	752	14.2	3.8
23:00	752	14.2	3.8	23:00	354	12.4	3.1	23:00	752	14.2	3.8
24:00	752	14.2	3.8	24:00	355	12.4	3.1	24:00	752	14.2	3.8

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 area

$\left(\frac{x}{l}\right)_{fak.} = 0.47$ 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:

0.053 və 0.075

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

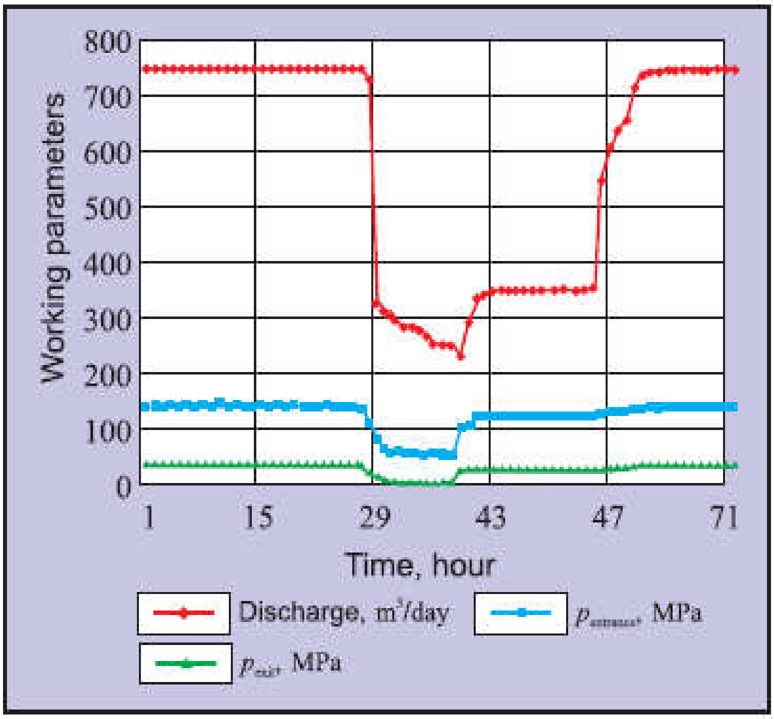

Figure 5. Change of working parameters in the pipeline before and after the oil leakage case.

Let's say that in a point of connection of a strut with a linear part of the underwater pipeline there was a leak to an expense of Q_{le} and (inflow) of oil from wells to the pipeline is absent, there are depletions of a strut (1) from the level of He.w. to a mark to a pressure – H_M. In the case under consideration the pressure in a strut all the time changes from the size of He.w. up to the size H_M. For an infinitesimal period of dt it can be considered constant and equal h, then

$$Q_{le} \cdot dt = \mu F \sqrt{2gh}\ \ dt \qquad (13)$$

During dt liquid level in a strut will fall by the size dh, very small in comparison with h. Owing to what we will receive:

$$Q\ dt = -\pi d^2 / 4 \cdot dh \qquad (14)$$

The minus sign means that size h decreases. Therefore,

$$\mu \cdot F\sqrt{2gh}\ \ \cdot dt = -\frac{\pi d^2}{4} \cdot dh \qquad (15)$$

From (15) it will turn out

$$dt = -\frac{\pi d^2 \cdot h^{\frac{1}{2}} \cdot dh}{4\mu F \cdot \sqrt{2g}} \qquad (16)$$

After integration of expression (16) we will receive

$$t = -\frac{\pi d^2 (\sqrt{H_{E..W..}} - \sqrt{H_{M}}}{2\mu F \cdot \sqrt{2g}} \qquad (17)$$

The analysis (17) shows that full depletion of a strut happens at decrease in level of liquid from H_{sl}. to Nanometer.

We will present what the expirations of liquid through an opening in the place of damage of the pipeline occurs at a constant pressure $H_{E.W.}$ = const. The sea underwater pipeline functions in the presence of small leak (with Q_{le} expense) in a strut bottom. We will compare time of depletion of a strut of t to time for which the same volume V will flow out from a strut at a constant pressure of $H_{E.W.}$. At a constant pressure of $H_{E.W.}$.

$$Q_{le} = \mu F \sqrt{2gH_{E.W.}} \qquad (18)$$

At the same time volume $V = \frac{\pi d^2}{4} \cdot (H_{E.W.} - H_M)$. Therefore, time of the expiration of volume of V at constant level will be:

$$t_1 = \frac{V}{Q} = \frac{\pi d^2 (H_{E.W.} - H_M)}{4\mu F \sqrt{2gH_{E.W.}}} \qquad (19)$$

From comparison of formulas (17) and (19) it is visible that time of depletion of a strut $\frac{1-\sqrt{\frac{H_M}{H_{E.W.}}}}{2}$ time there is more time of the expiration of the same volume of liquid at a constant pressure.

$$t_1 = \frac{1-\sqrt{\frac{H_M}{H_{E.W.}}}}{2} \cdot t \qquad (20)$$

On the basis of expressions (17) and (19) have been defined expiration time at the free-flow and pressure head modes of a current of oil from a small opening (d_{le} = 10 mm) in a strut junction with a linear part of the underwater pipeline with a diameter of 300 mm. Values for depth of the sea (H_M) and a pressure on the mouth of wells ($H_{E.W.}$) were accepted equal respectively 100 and 300 m. As a result of the carried-out calculations respectively for time of t and t1 the following values have been received:

t = 1,3 hour and t_1 = 0,27 hour.

CONCLUSION

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

Settlement formulas for determination of quantity and time of the expiration of liquid through an opening are given in the place of damage at the constant and free-flow modes of functioning of pipelines. Results of calculations have shown that time of self-flowing depletion of a strut 4-5 times is more than time of the expiration of the same volume of liquid at a constant pressure.

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