DIAGNOSIS OF OIL SPILLS FROM SUBSEA PIPELINES

Mansur Shahlarli[1], Hajar Ismayilova[2], Gulnara Zeynalova[2]

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[1]Oil and Gas Research and Design Institute, SOCAR, AZERBAIJAN
[2]Azerbaijan State Oil and Industry University
mansursahlarli1994@gmail.com
İsmayilova.hecer@bk.ru
gulnara.zeynalova93@mail.ru

Abstract

Taking into account the importance of quick detection of oil leaks from submarine pipelines in sea conditions, and the importance of eliminating their consequences, the issues of diagnostics for the determination of leaks and oil losses are discussed in the article. The possibility of determining the location of the leak depending on the degree of leakage is shown. Since the diameter of the pipeline and the physico-chemical properties of oil are assumed in the calculations, the development and application of the mentioned method for the purpose of detecting leaks in specific subsea oil pipelines operated in practice does not require additional costs, as it is based on a known software set and field data.

Keywords: Caspian Sea, subsea pipelines, leak, flow rate, pressure

I. Introduction

One of the factors affecting the ecological environment of the Caspian Sea is the occurrence of oil leaks into the sea as a result of accidents during the operation of offshore pipelines.

Since the products are mainly supplied under wellhead pressure to the subsea pipelines used for the collection and transportation of well products from offshore fields, it is inevitable that new wells start up, stop working, and change their operating modes due to operational challenges. On the other hand, since these pipelines are laid along the bottom of the sea, they are under different hydrostatic pressure depending on the water depth. In deep water basins, it is also possible that this pressure exceeds the working pressure of the pipelines. In such cases, if the subsea pipeline is damaged or punctured, oil will not leak into the sea, but seawater will be absorbed into the pipeline. Once leaks are confirmed, an important issue that arises is the location of leaks and the assessment of oil losses. Detection of small oil spills in marine conditions is associated with many challenges. For the accurate detection and identification of a leak, it is necessary to know the behavior of the fluids inside the pipeline, which allows to determine the pressure drop along the pipeline and the total amount of fluid released, to stop the pumps and control valves to prevent or minimize the damage to the environment [1-4].

II. Methods

Methodology. If we assume that the pipeline is laid along the bottom of the sea with a depth Hd and the internal pressure Px at the point of leakage, the amount of oil flowing into the environment (q) and the condition of oil flowing into the sea can be determined according to the following expressions:

$$q = c_0 \cdot a\sqrt{\frac{2(P_x - P_e}{\rho_n}} \qquad (1)$$

$$X_{l.l} < \frac{\left(\frac{P_1}{P_e}-1\right)H_d}{\frac{\rho_o}{\rho_w}\cdot K\cdot Q_1^{2-m}} \quad (2)$$

where: $P_e = \rho_w g H_d$ - hydrostatic pressure exerted by seawater; c0-flowrate factor for the stream (for calculation c0=0.61 can be accepted); a-area of the leakage location (m2); ϱo - oil density (kq/m3); Xl.l - distance to the location of the oil spill; P1 - pressure at the beginning of the pipeline; Q1 - flowrate of oil in the pipeline after the occurrence of a leak; m və k - are indicators that characterize the oil flow regimes in the pipeline.

As can be seen from statement 1, in order to determine the amount of leaking oil, the pressure inside the pipe at the location of the leak must be known.

The pressure inside the pipe at the point of leakage can be determined as follows, depending on the inlet pressure of the pipeline:

$$P_{\tilde{o}} = P_1 - K\cdot \rho_o g Q_1^{2-m}\cdot X_{l.l} \quad (3)$$

If we consider expression 3 in 1, we get:

$$q = c_0\cdot a\sqrt{\frac{2}{\rho_o}\left(P_1 - K\cdot\rho_o\cdot gQ_1^{2-m}\cdot X - P_e\right)} \quad (4)$$

Since the difference between the oil flow rate at the inlet and the outlet of pipeline is taken equal to the oil loss due to leakage, it can be assumed that the leakage amount (q) is known. Then from expression 4 we obtain the following expression to determine the location of the oil leak:

$$X_{l.l} = \frac{\left(\frac{P_1}{P_e}-1\right)H_d}{\frac{\rho_o}{\rho_w}\cdot K\cdot Q_1^{2-m}} - \frac{q^2}{2c_0 a^2 K\cdot gQ_1^{2-m}} \quad (5)$$

Thus, as it can be seen from the statement (5), if a leak has occurred in the subsea oil pipeline, the location of the leak can be determined based on the parameters q, P1/Pe and Q1, taking into account the flow regime and the depth of the sea.

In order to diagnose various cases of oil leakage in submarine oil pipelines, calculations were made for oil with density kg/m3 and viscosity ν = 5*10-6 m2/s in different flow regimes based on expression (5). In order to correspond to real situations, the calculations are based on the depths of the sea Hd = 10, 30, 50, 100, 150, 200, 250 m, the initial pressure in the pipelines P1=1.0-6.0 MPa, and the flow rate Q=0.1-0.8 m3/s. performed for pipelines. The location of leakage (Xl.l) was determined for values of q=1,2,3,4,5,6,7% of different leakage cases. Based on the results of the calculations, the dependences between the Xl.l, Q1 and P1/Pe parameters in 3-dimensional space were graphically depicted in the Delphi environment using a special program for Windows. Those images are shown in Fig. 1 and 2, respectively, for values of q=1 and 7% of leakage cases in Xl.l - Q - P1/Pe coordinate system.

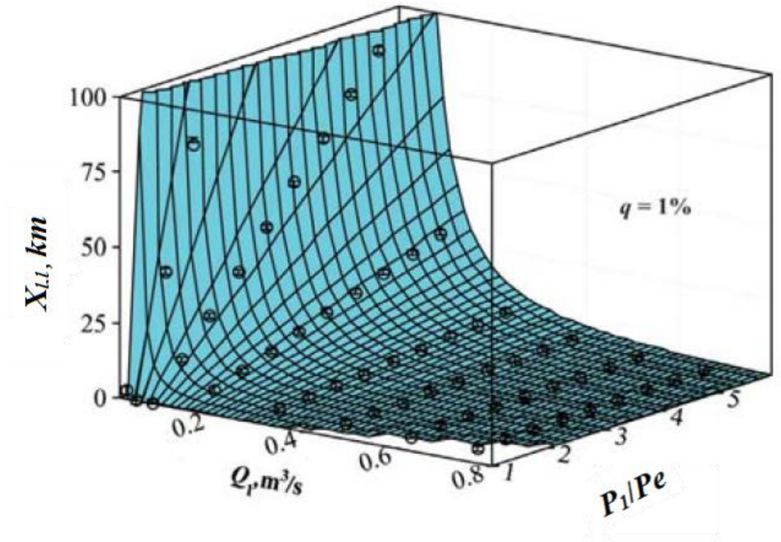

Figure 1: *Dependence of the distance to the leak point in subsea pipelines on the flowrate and pressure ratio (q=1%)*

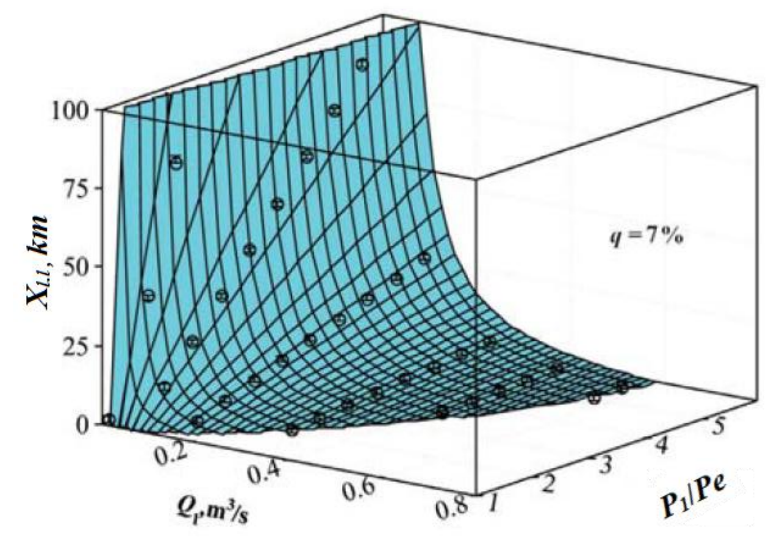

Figure 2: *Dependence of the distance to the leak point in subsea pipelines on the flowrate and pressure ratio (q=7%)*

It was determined that the location of the leak can be indirectly determined with an accuracy of up to 1%, depending on the Q1 and P1/Pe parameters, based on the following regression equation-empirical expression with a very high correlation coefficient (R2=0.999):

$$X_{1.1} = a + \frac{b}{Q_1} + c\frac{P_1}{P_e} + \frac{d}{Q_1^2} + e\left(\frac{P_1}{P_e}\right)^2 + f\frac{P_1}{Q_1 P_e} + \frac{g}{Q_1^3} + h\left(\frac{P_1}{P_e}\right)^3 + \frac{i}{Q_1}\left(\frac{P_1}{P_e}\right)^2 + \frac{j}{Q_1^2}\left(\frac{P_1}{P_e}\right) \quad (6)$$

Here, a, b, c, d, e, f, g, h, i, j are coefficients and are determined by the depth of the sea, the amount of leaks and the flow regimes of oil (Table 1).

III. Results

Table 1: *The values of the coefficients included in the empirical expression*

For various leakage conditions								
	Hd = 150 m				Hd = 200 m			
q, %	1	3	5	7	1	3	5	7
a	-0,204	-1,006	-2,185	-4,821	-0,060	-0,927	-1,781	-4,0362
b	-0,302	-0,191	0,232	0,198	-0,438	-0,312	0,174	0,170
c	-0,396	-0,210	-0,994	0,733	-0,650	-0,398	-1,964	-0,797
d	-0,1399	-0,1434	-0,1574	-0,1623	-0,1836	-0,1874	-0,2030	-0,2007
e	0,1166	0,1124	0,6537	-0,1068	0,2833	0,2828	1,3870	0,8646
f	0,4274	0,3838	0,2034	0,3302	0,5300	0,4672	0,2100	0,2932
g	0,0001	0,0001	0,0002	0,0003	0,0001	0,0001	0,0002	0,0002
h	-0,0427	-0,0467	-0,1259	-0,0223	-0,1011	-0,1107	-0,2980	-0,2291
i	0,0441	0,0490	0,0679	0,0432	0,0785	0,0872	0,1210	0,1130
j	0,1311	0,1318	0,1355	0,1357	0,1748	0,1758	0,1810	0,1773
	Hd = 250 m				Hd = 300 m			
a	0,096	-0,813	-1,203	-3,789	0.311	-0.655	-0.423	-3.399
b	-0,563	-0,421	0,132	0,106	-0.679	-0.519	0.1064	0.0543
c	-0,981	-0,698	-3,393	-1,158	-1.463	-1.139	-5.367	-2.754
d	-0,2274	-0,2314	-0,2478	-0,2451	-0.2711	-0.2754	-0.2930	-0.2898
e	0,5465	0,5717	2,5189	1,6199	0.9543	10.101	41.335	27.221
f	0,6116	0,5283	0,1847	0,2941	0.6736	0.5667	0.1287	0.2675
g	0,0001	0,0001	0,0002	0,0002	0.0001	0.0001	0.0002	0.0002
h	-0,1952	-0,2163	-0,5830	-0,4475	-0.3371	-0.3737	-10.076	-0.7732
i	0,1230	0,1364	0,1891	0,1768	0.1772	0.1966	0.2725	0.2546
j	0,2185	0,2198	0,2258	0,2217	0.2622	0.2638	0.2710	0.2660

IV. Discussion

According to expression 6, in order to determine the locations of oil leaks from subsea pipelines based on the values of Q1 and parameters as soon as the fact of leakage is confirmed, the coefficients included in that expression should be selected according to the known depth of the sea and the accepted leakage rate, and then appropriate calculations should be made. It should be noted that the proposed diagnostic method is not universal and should not be applied to all pipelines. Since the diameter of the pipeline and the physico-chemical properties of oil are assumed in the calculations, the development and application of the mentioned method for the purpose of detecting leaks in specific subsea oil pipelines operated in practice does not require additional costs, as it is based on a known software set and field data.

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