RT&A, Special Issue No 5 (75)
Volume 18, November 2023

DIAGNOSTICS OF RISKY MULTIPHASE FLOW ZONES IN OIL PIPELINES

Gulnara Zeynalova, Gafar Ismayilov

•

Azerbaijan State Oil and Industry University
gulnara.zeynalova93@mail.ru
asi_zum@mail.ru

Abstract

This article examines the properties and formation of free-flow areas in the compressed profile of indicative oil pipelines. The risks of the formation of multiphase flow zones in oil pipelines were investigated and a method for diagnosis was developed. Additionally, this article studies the issues related to the presence of free-flow zones formed within the stationary regimes of oil pipelines, as well as the identification of their coordinates. Case studies are drawn based on the hydraulic slope and the pressure balance and contingent upon the lay, which aim to account for the identification of the location and sizes of such zones.

Keywords: hydraulic slope, pass-point, geodesic height, free-flow zone, stationary operational regime

I. Introduction

The formation of gaps (free-flow areas) is frequently observed in the stationary operational regimes of the pipeline. The identification and research of such zones are of special significance for secure and efficient exploitation of oil pipelines. Since these free-flow zones are mainly linked to the pass-point (and/or points) the presence of such zones are by no means necessary, which depend upon the operational regime of the pipeline. As such, the identical zones are not formed in cases when the hydraulic slope lines do not cut through the profile of the pipeline, which prevents the existence of the pass-point. Accordingly, the stationary operation regime of the pipeline, as this may be the case in varied pressures, becomes inevitable. The formation of a pass-point, or free-flow zones is feasible in case of the alteration of the operational regime of a pipeline, termination of the operation of any pump stations, and the changing of rheological and physical-chemical properties of the transported oil. Such zones are noticed when the operation of a pipeline is terminated and during oil- spills resulted from accidents. The presence of free- flow zones, as a rule, raise the pressure and transportation costs at the initial installation stage of a pipeline [1-6].

II. Methods

In order to determine the presence of hydraulic point, a hydraulic slope value should be calculated and this value should be reflected in the profile of the pipeline. The identification of a free-flow zone in the compressed profile of an indicative pipeline based on a hydraulic line is described in Figure 1.

A hydraulic slope line (i) cuts through the profile, which begins from the last point (K) of the pipe. The touching point, which is close to the identical line and, which never cut through the profile, will be a pass-point.

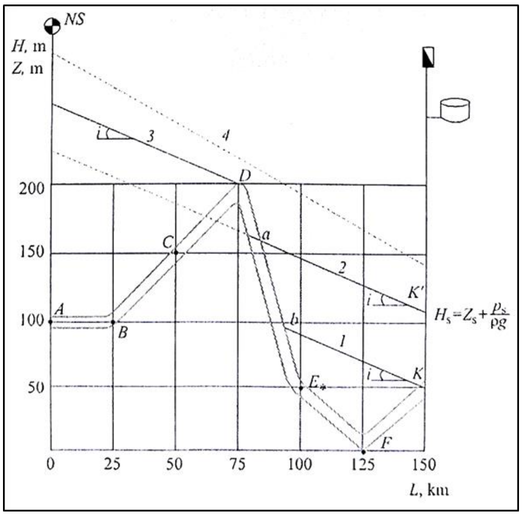

Fig. 1: *Identification of a free-flow zone in the compressed profile of an indicative pipeline on the basis of hydraulic slope line*

When there is supplementary pressure (p_s) at the end of the pipeline, a hydraulic slope line $H_s = Z_s + \frac{p_s}{\rho g}$ is drawn from K[1] point that corresponds to the pressure height until it cuts through the pipeline profile (2). In this case, the line (3) that does not cut through but touches the profile identifies D line as a pass-point. For the absence of a pass-point (non-formation of free-flow zones), the hydraulic slope line should not cut through the profile at any point, and nor should it touch the profile (4). In all cases of the presence of pass-points, free-flow zones (no-pressure) generate from that point (or from the points). The beginning of such areas is corresponding pass-points, and the ending of such areas is the intersection of a hydraulic slope line with the profile. E.g., in Fig.1.b and a points in line with 1 and 2 hydraulic slope lines represent the last points of the free-flow areas.

In order to prevent the formation of gaps, at any point of the pipline the peso-metric pressure (height *H*), in view of the vacuum-metric height (h_v), must not be lower than a geodesic height (Z):

$$H > Z + h_v;\ h_v = \frac{p_{b.s}}{\rho g} \tag{1}$$

Here, ρ indicates oil density kq/m^3 and $p_{b.s}$ is an indicator of steam elasticity pressure, Pa.

It should be noted that here in the speed-pressure will not be considered due to its significantly low velocity (ϑ^2/2g=0). In order to establish the coordinates of free-flow zones, a perpendicular linear line is drawn from the hydraulic slope line and intersection point of the profile up to the absis arrow (L). This time, point *x* drawn from the intersection identifies the coordinate of the last point of a free- flow zone (Figure 2).

In order to identify the length of a free-flow zone, the following transportation parameters are assigned [1, 2]:

Flow movement speed

$$\vartheta = \frac{4Q}{\pi d^2}, \tag{2}$$

Reynolds value

$$Re = \frac{\vartheta d}{\nu}, \tag{3}$$

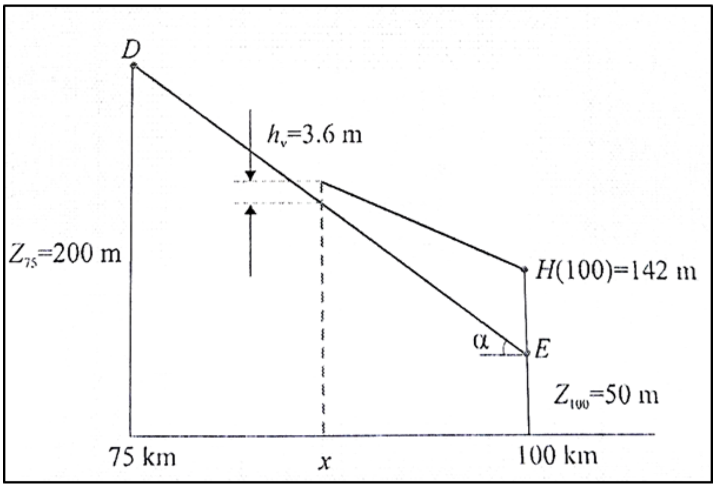

Fig. 2: *İdentification of a free-flow zone*

The hydraulic will indicate a coefficient of resistance:

$$\left.\begin{aligned} \lambda &= \frac{64}{Re} - \text{ for laminar regime } (\mathrm{Re} < 2300), \\ \lambda &= \frac{0.3164}{\sqrt[4]{Re}} - \text{ for a flat notch zone } (\mathrm{Re} > 2300), \\ \lambda &= 0.11\left(\frac{k}{d} + \frac{68}{Re}\right)^{0.25} - \text{ for a mixed friction zone } \left(10 < \mathrm{Re}\frac{k}{d} < 500\right) \\ \lambda &= 0.11\left(\frac{k}{d}\right)^{0.25} - \text{for a square movement zone } \left(Re\ \frac{k}{d} > 500\right) \end{aligned}\right\} \quad (4)$$

Here, ν, Q accordingly indicates the kinematic viscosity of the transported oil (m^2/s) and its waste (m^3/s); d indicates internal diameter of the pipeline, m; k represent s a coefficient of ruggedness. K= 0.1 mm can be taken for larger-diameter pipelines.

Hereby, hydraulic slope will be:

$$i = \lambda \frac{\vartheta^2}{2gd} \quad (5)$$

According to Fig.2 (*DE*), a hydraulic slope in a free-flow zone will produce the following result due to the known will produce the following result due to the known status of α angle (the hydraulic slope line passes through h_v distance while standing parallel to an identical area):

$$i^* = tg\alpha = \frac{Z_a - Z_E}{L_E - L_a} \quad (6)$$

Here, $Z_{p.s}$, $L_{p.s}$, Z_E, L_E accordingly represent a geodesic height in view of the vacuum height for the pass-point and the pipeline with a free-flow zone (segment), m.

We can write down the following equation:

$$Z_E + i^*(L_E - x) = H_E + i(L_E - x) \quad (7)$$

We come up with the following equations drawn from expression (7) for identifying the coordinates of the last point of a free-flow zone (x) and its length ($l_{s.a}$):

$$\begin{cases} x = L_E - \frac{H_E - Z_E}{i^* - i} \\ l_{s.a} = x - L_a \end{cases} \quad (8)$$

Hereby, i^2, i represent the hydraulic slope of the free-flow and full areas of the pipeline; H_E is pressure at the end of the pipeline area (segment) with e free-flow zone (H_S) and it is calculated as follows:

$$H_E = H_s - i(L_{b.k} - L_E). \quad (9)$$

If there is not any given pressure in the beginning, then it can be calculated. The beginning pressure is calculated as follows and it could be done by drawing upon the data on pressured hydraulic slope, the information concerning the pass-point ($Z_{p.s}$, $L_{p.s}$), and by using the data on vacuum-metric height:

$$H_b = Z_{p.s} + h_v + i \cdot L_{p.s} \quad (10)$$

Here, $i \cdot L_{p.s}$ represent the pressure loss formed in the pipeline up to the pass-point, m. Thus, the pressure p_b relevant to the pressure in the beginning is as follows:

$$p_b = \rho g H_b \quad (11)$$

Under a static operational regime, while the utilization of oil in the pipeline and in the free-flow areas is identical, the stream speeds vary. According to the law on the stability of utilization, due to the lower speed in the pressured movement zone compared to the free speed zone, in the latter zones, the movement of liquid will not occur in the precise wide-cut of the pipe. This time, in each free stream area, the wide-cut area of the pipe filled with liquid will be lower than the full wide-cut of the pipe.

III. Discussion

Let us consider the example on the identification of a pressure-free stream area formed in a given profile of an indicative pipeline (see: Figure 1). Let's assume that oil is transported through a pipeline of L=150 km length and of D=530x7 mm diameter under a pressure of c =850 kg/m³, with a kinematic viscosity of ν =15 mm²/s and a steam elasticity pressure of $p_{b.e.}$= 0.03 MPa. If the pressure level at the end of the pipeline is p = 0.3 MPa, the beginning pressure level should be such that the oil use equals to Q=500 m³/s. In calculations, it can be taken as k=0.1 mm.

As it could be obvious from the profile, D point is the pass-point of the pipeline and a free-flow zone is present beginning from this point. Therefore, transportation parameters are established at the outset according to formulas (2) and (5):

$$\vartheta = \frac{4Q}{\pi d^2} = \frac{4 \cdot 500}{3.14(0.516)^2 \cdot 3600} = 0.67 \text{ m/s},$$

$$Re = \frac{\vartheta d}{\nu} = \frac{0.67 \cdot 0.516}{15 \cdot 10^{-6}} = 23048,$$

$$\lambda = \frac{0.3164}{\sqrt[4]{23048}} = 0.0257,$$

$$i = \lambda \frac{\vartheta^2}{2gd} = 0.0257 \frac{1}{0.516} \frac{(0.67)^2}{2 \cdot 9.81} = 0.001139 \frac{m}{m}\, 1.139 \text{ m/km}$$

In the case considered, a vacuum-metric height will be:

$$h_v = \frac{p_{b.e}}{\rho g} = \frac{0.03 \cdot 10^6}{850 \cdot 9.81} = 3.6 \text{ m}$$

(K) at the en of pipeline will establish the pressure level:

$$H_k(150) = Z_{150} + \frac{p_s}{\rho g} = 50 + \frac{0.03 \cdot 10^6}{850 \cdot 9.81} \approx 86 \text{ m}$$

In this case, the following pressure values will be drawn for other points of the pipeline (F, E, D):

$$H_F(125) = H_K(150) + i \cdot 25 = 86 + 1.139 \cdot 25 = 114.0 \text{ m} > 0 + 3.6 = 3.6 \text{ m},$$

$$H_E(100) = H_F(125) + i \cdot 25 = 114 + 1.139 \cdot 25 = 142 \text{ m} > 50 + 3.6 = 53.6 \text{ m},$$

$$H_D(75) = H_E(100) + i \cdot 25 = 142 + 1.139 \cdot 25 = 170 \text{ m} < 200 + 3.6 = 203.6 \text{ m}.$$

As it is seen from the latter, $H_D(75)$<203.6 m. Obviously, the pressure level shall not be lower than the geodesic height. Thus, there exists a free-flow zone between 75th km and 100th km (between D and E points). This time, x=75 km will represent the beginning of the free-flow zone (see: Figure 2).

In the free-flow area, the value calculated based upon the hydraulic slope expression will constitute $i^*=6 \cdot 10^{-3}$ m/m.

In this case, the coordinate of the last point of the free-flow area in accordance with expression (8) will constitute x=81.074 km, and the length will be $l_{s.a}$= 6074 m.

We can come with the following if we verify the full pressure levels for the remaining edges of the pipeline (*C, B, A points*):

$$H_c(50) = H_D(75) + i \cdot 25 = 203.6 + 1.139 \cdot 25 = 232.1 \text{ m} > 150 + 3.6 = 153.6 \text{ m},$$

$$H_B(25) = H_C(50) + i \cdot 25 = 232.1 + 1.139 \cdot 25 = 260.6 \text{ m} > 100 + 3.6 = 103.6 \text{ m},$$

$$H_A(0) = H_B(25) + i \cdot 25 = 260.6 + 1.139 \cdot 25 = 289.1 \text{ m} > 100 + 3.6 = 103.6 \text{ m}.$$

As is it seen from the calculations, there is no other free-flow zones in the pipeline considered. Therefore, if we consider that the geodesic height at the beginning of the pipeline is Z_b=100 m, the pressure level for the case considered will be calculated as follows:

$$p_b(A) = \rho g[H(A) - Z_b] = 850 \cdot 9.81[289{,}1 - 100] = 1.58 \cdot 10^6 \text{Pa} = 1.58 \text{ MPa}$$

IV. Results

Taking into account the risks of formation of multiphase zones in oil pipelines, a method of their diagnosis has been developed. Thus, the existence of free-flow zones in a pipeline and the feasibility of identifying its location and coordinates are indicated based upon a hydraulic slope line and the pressure balance under a static operational regime in an indicative pipeline.

References

[1] Aliev R.A., Belousov V.D., Nemudrov A.G. Pipeline transportation of oil and gas. M.: Nedra, 1988, 368 s.

[2] R50.2.040-2004 Recommendations on metrology. GSI. Metrological support of oil accounting during its transportation through the system of main oil pipelines. – M.:, VNIIR, 2004. 47 s.

[3] Novoselov V.F., etc. 1995. Operation of oil pipelines at partial load. – M.:, VNIIOENG, 68 s.

[4] Lurie M.V. 2003. Mathematical modeling of pipeline transportation processes for oil, oil products and gas. M.: Nedra, 336 s.

[5] Ismayilov G., Ismayilova H., Babirov H., Jabrayilova R. Assesment of environmental oil spills and economic-environmental risks. RT&A, Special Issue № 4 (70) Volume 17, November 2022, pp 212-217. DOI: https://doi.org/10.24412/1932-2321-2022-470-212-217

[6] Ismayilov G.G., Fataliyev V.M. Iskenderov E.Kh. [6] A pipe configuration for smoothening pressure pulsation in a pipeline exporting multiphase hydrocarbon fluid. SLYWAN., 167(5), ISI Indexed, may 2023, Printed Poland.