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Analysis and Calculation of Two-Phase Flow in Industrial Pipelines Using Regime Classification

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ABSTRACT

The analysis shows that using regime classification for individual phases, it is possible to obtain a more reliable design scheme for two phase flows. In contrast to the flow structure, the concept of mode is more accessible for calculating an industrial pipeline. In this case, transient processes can be determined and calculated. The analysis shows that in field conditions it is very difficult to determine transition boundaries for flow structures. However, taking into account the structural approach, it is very difficult to determine the boundaries of the flow, and based on the laws of hydrodynamics of a homogeneous liquid and gas, it is possible to determine the transition of one regime to another using the Reynolds number. This technique is based on the theory of the great Russian scientist Academician A.P. Krylov. Let us note that this theory has not yet lost its specialty in the fishing industry. Based on numerous data, a method for calculating the gas-liquid mixture in horizontal pipes is proposed. Based on the laws of homogeneous liquid and gas, an equation for the distribution of speed, flow and pressure loss in a pipeline is obtained. The analysis shows that, based on the laws of homogeneous liquid and gas, it is possible to propose a method for calculating the hydrodynamic parameters of a two-phase flow, such as liquid and gas in a round pipe. This technique is based on the theory of Academician A.P. Krylov, which characterizes the reliability of this technique.

KEYWORDS

Multiphase flow, two-phase mixtures, pressure loss, liquid and gas, Reynolds steam gauge.

1. INTRODUCTION

Practice shows that in order to solve numerous technical problems it is necessary to know the basics of mechanics, fluid mechanics, aeromechanics, etc.

One of the sections of hydromechanics is continuum mechanics, that is, a summary of the laws of multiphase media that continuously fill a certain area of large-scale technology and industry. This area serves as a link between the real and the technical link, between real objects, natural and technical processes, and their mathematical models. This question fully applies to modeling objects in the oil and gas industry.

This work makes it possible, based on the work of the great Russian scientist, academician A.P. Krylov, to propose a new model and general laws of flow of two-phase systems, such as liquid and gas in pipelines.

The proposed work is focused on the needs of industry, including the needs of the oil and gas industry. The conducted research makes it possible, based on the laws of fluid mechanics, to construct a mathematical model that completely describes the process and gives minimal error in calculations. It was noted that scientific research in the oil and gas industry begins with an analysis of actual field material and a carefully organized study of the phenomena and processes occurring in the pipeline. It should be noted that the factual material was not analyzed and used in any depth and not in a purposeful manner.

2. PROBLEM STATEMENT

The analysis shows that in order to solve numerous problems of field practice, it is necessary to use the formulation of the planned model, processing and interpretation of factual material to design important indicators of transport and the oil and gas environment.

The purpose of this work is to propose a metal model and sculpt this model based on experiments. Note that the complexity and uncertainty of modern technological processes is becoming a problem of the current century.

3. THE MAIN PART

From the course of technologies and engineering of oil and gas production [1], friction losses can be defined as

$$i_{TP} = 0.0294\frac{Q_r^2}{D^{\frac{16}{3}}} + 17.2\frac{Q_l^{1.75}}{D^{4.75}}\sqrt[4]{\mu} + m(Q_rQ_l)^k \quad (1)$$

i_{TP}-pressure loss to overcome friction per 1 m of pipe length;

μ-dynamic viscosity of liquid (oil);

D -internal diameter of the pipe;

Q_r-volumetric flow rate of the gas phase;

Q_l-volumetric flow rate of the liquid phase;

m ,k-coefficients depending on the diameter, viscosity and fluid flow.

As can be seen, Academician A.P. Krydov took into account the influence of each phase and the interaction between phases in the friction process. So, on the right, the first term shows the losses of only gas, the second term only of liquid, and the third term - the interaction between phases during the movement of the gas-liquid mixture.

Taking into account the above, we will solve this problem based on the laws of hydromechanics [2]. Analyzing numerous experimental data 3, 4, 5, an equation of the form was obtained

$$\tau_{CM} = \tau_l + \tau_r + k\sqrt{\tau_r\tau_l} \quad (2)$$

τ_{CM} -shear stress for gas-liquid mixture;

τ_l- shear stress for a homogeneous fluid;

τ_r - shear stress for homogeneous gas;

к -experimental coefficient.

Now we have the values of the tangential stress and determine the distribution of velocities across the cross section of the isometric flow in a round pipe. In this case, the velocities and pressures at any point in the flow remain constant. In this case, the speed at the point of flow of the gas-liquid mixture will depend only on the distance from the pipe axis, i.e. on the coordinates of the point.

In a uniform flow, we select a liquid cylinder of radius (r) and length (L), the axis of which in this case coincides with the axis of the pipe, and write the equilibrium equations for a given cylindrical volume of the mixture. On this cylindrical volume, forces $F_1 = p_1 \pi r^2, -F_2 = -p_2 \pi r^2$ act on the end surface on the left and right. Note that these forces are completely projected onto the axis of the pipe.

In addition to the above forces, the friction force (-T) acts, directed in the direction opposite to the movement. The magnitude of this friction force is determined by the shear stress at the distance of the cylinder radius from the central axis of the pipe.

According to the law of friction, the friction force, varying along the cross section of the pipe according to a linear law, is equal to

$$-\mathrm{T} = -\tau_{\mathrm{CM}} 2\pi \mathrm{rL} = \tau_{\mathrm{l}} + \tau_{\mathrm{r}} + \mathrm{k}\sqrt{\tau_{\mathrm{r}}\tau_{\mathrm{l}}} \quad (3)$$

In this formula, the direction of the normal coincides with the direction of the radius. The minus sign shows that the friction force is directed in the direction opposite to the resultant pressure forces. In this case, the friction force is completely projected onto the pipe axis.

As is known, the lateral surface of this adopted cylinder is subject to normal pressure forces acting on the surrounding fluid. However, this does not provide forces on the axis of the projection pipe.

Taking into account the above, we can write that for the equilibrium of the proposed cylinder with uniform motion, the sum of the projections of all acting forces, according to the law of theoretical mechanics, is equal to

$$F_1 - F_2 - T = 0 \quad (4)$$

Or

$$p_1 \pi r^2 - p_2 \pi r^2 + \tau_{CM} 2\pi r l = 0 \quad (5)$$

Let us determine separately the shear stress along the fluid and along

$$\tau_l = \mu_l \frac{du_l}{dr}, \tau_r = \mu_r \frac{du_r}{dr} \quad (6)$$

It is known that there is a concept of volumetric gas content

$$\beta = \frac{\mathrm{u_r}}{\mathrm{u_r} + \mathrm{u_l}} \quad (7)$$

among

$$u_r = \frac{\beta}{1-\beta} u_l \quad (8)$$

Then the tangential stress across the gas can be written as

$$\tau_r = \mu_r \frac{\beta}{1-\beta}\frac{du_l}{dr} \tag{9}$$

Substituting this expression into the previous formula we have

$$-T = \tau_{CM} 2\pi r L = \left[\mu_l \frac{du_l}{dr} + \mu_r \frac{\beta}{1-\beta}\frac{du_l}{dr} + k\sqrt{\frac{du_l}{dr}\frac{\beta}{1-\beta}\frac{du_l}{dr}\mu_l}\right] 2\pi r L \tag{10}$$

Taking into account what was obtained, after reduction we have

$$P_1 - P_2 = \Delta P = -\frac{du_l}{dr}\left[\mu_l + \mu_r \frac{\beta}{1-\beta} + k\sqrt{\mu_r \frac{\beta}{1-\beta}\mu_l}\right]\frac{2}{r}L \tag{11}$$

$$\text{Or } du_l = \left[\frac{\Delta p}{\left(\mu_l + \mu_r \frac{\beta}{1-\beta} + k\sqrt{\mu_r \frac{\beta}{1-\beta}\mu_l}\right)2L} - r dr\right] \tag{12}$$

Integrating this equation makes it possible to determine the velocity distribution over the cross section of a round pipe with a uniform flow.

$$U_l = -\frac{\Delta p}{4L}\frac{r^2}{\left[\mu_l + \mu_r \frac{\beta}{1-\beta} + k\sqrt{\left[\mu_l \mu_r \frac{\beta}{1-\beta}\right]}\right]} + C \tag{13}$$

This equation is the equation of a parabola. The integration constant (C) is determined taking into account the boundary conditions. It is believed that on the pipe wall the particle velocity is zero, i.e. atr $= r_0$: $U_l = 0$.

Then we have: .

$$U_l = \frac{\Delta p}{4L}\frac{(r_0^2 - r^2)}{\left[\mu_l + \mu_r \frac{\beta}{1-\beta} + k\sqrt{\left[\mu_l \mu_r \frac{\beta}{1-\beta}\right]}\right]} \tag{14}$$

If a homogeneous system moves, i.e. only liquid, then we have$\beta = 0$. From the final formula we have Stokes' parabolic law, which was first obtained by Stokes in 1867.

The above equation expresses the law of velocity distribution over the cross section of the pipe.

As can be seen, the speed at any point in the flow in laminar mode changes in direct proportion to the absolute viscosity of the phases that make up the system.

The phases on the pipe axis have the minimum speed. The magnitude of the instantaneous speed is determined at r = 0.

$$U_{max\, l} = \frac{\Delta p}{4L}\frac{r_0^2}{\left[\mu_l + \mu_r \frac{\beta}{1-\beta} + k\sqrt{\left[\mu_l \mu_r \frac{\beta}{1-\beta}\right]}\right]} \tag{15}$$

Using the formula for phase velocities at any point in the cross section of a uniform isometric flow, it is possible to derive equations for determining the volumetric flow rate of the mixture. To solve this problem, we select a mixture ring, the axis of which coincides with the axis of the pipe, having an internal radius (r) and a width in the radial direction (dr). The area of this ring is dF = 2πrdr. Then the elementary flow rate through this annular area is equal to $dQ_l = u_l 2\pi r dr$. Taking into account the liquid phase, we find

$$dQ = \frac{\pi\Delta p}{2L}\frac{(r_0^2 rdr - r^3 dr)}{\left[\mu_l + \mu_r\frac{\beta}{1-\beta} + k\sqrt{\left[\mu_l\mu_r\frac{\beta}{1-\beta}\right]}\right]}$$

Integrating this expression over the entire section of the pipe

$$Q = \frac{\pi}{2\left[\mu_l+\mu_r\frac{\beta}{1-\beta}+k\sqrt{\left[\mu_l\mu_r\frac{\beta}{1-\beta}\right]}\right]}\frac{\Delta p}{L}\left[\int_0^{r_0} r_0^2 rdr - \int_0^{r_0} r^3 dr\right] \quad (16)$$

Then in the end

$$Q = \frac{\pi}{8\left[\mu_l+\mu_r\frac{\beta}{1-\beta}+k\sqrt{\left[\mu_l\mu_r\frac{\beta}{1-\beta}\right]}\right]}\frac{\Delta p}{L}r_0^4 \quad (17)$$

If $\beta = 0$, then from the final form we have the formula for second flow rate, which was first obtained experimentally in 1840 by the French physician Poiseuille, who studied the movement of a homogeneous liquid in capillary pipes in relation to issues of blood movement in the circulatory system.

From this formula for the average speed of the mixture, we can derive the law of hydraulic resistance, which determines the pressure loss during laminar movement of both phases in the pipe

$$\Delta p = \frac{32LU_l\left(\mu_l+\mu_r\frac{\beta}{1-\beta}+k\sqrt{\left[\mu_l\mu_r\frac{\beta}{1-\beta}\right]}\right)}{D^2} \quad (18)$$

Multiplying the numerator and denominator, respectively, by the speed and density of the phases, we have the value of the hydraulic resistance of the mixture in round pipes

$$\Delta p = \frac{32L}{D^2}U_l\mu_L\frac{2U_lS_l}{2U_lS_l} + \frac{32L}{D^2}U_r\mu_r\frac{2U_rS_r}{2U_rS_r} + k\sqrt{\frac{32L}{D^2}U_l\mu_L\frac{2U_lS_l}{2U_lS_l}\times\frac{32L}{D^2}U_r\mu_r\frac{2U_rS_r}{2U_rS_r}} \quad (19)$$

In this formula, in particular, we introduce the concept of the Reynolds number for the corresponding phases

$$\Delta p = \frac{64}{Re_l}\frac{U_l^2L}{2D}S_l + \frac{64}{Re_r}\frac{U_r^2L}{2D}S_r + k\sqrt{\frac{64}{Re_l}\frac{U_l^2L}{2D}S_l\times\frac{64}{Re_r}\frac{U_r^2L}{2D}S_r} \quad (20)$$

Then for the laminar mode of phase motion we have

$$\Delta p = \lambda_l\frac{U_l^2L}{2D}S_l + \lambda_r\frac{U_r^2L}{2D}S_r + k\sqrt{\lambda_l\frac{U_l^2L}{2D}S_l\times\lambda_r\frac{U_r^2L}{2D}S_r} \quad (21)$$

λ_l , λ_r-coefficient of hydraulic resistance of liquid and gas;

S_l, S_r -respectively, the density of liquid and gas.

Note that many authors believe that gas-liquid flow is characterized by turbulent flow. Then it is enough to replace the coefficient of hydraulic resistance in this equation with one of the equations, respectively, for the phases, for example, the Blasius equation

$$\lambda_l = \frac{0.3165}{\sqrt[4]{Re_l}}, \lambda_r = \frac{0.3165}{\sqrt[4]{Re_r}}$$

This formulation is valid for gas-liquid mixtures such as oil and natural gas. If there is a need, then other experimental data of A.A. Armand and Chisholm can be used for the gas phase. As shown, a comparison between actual and calculated experiments, the average error is (3+5)%, which is acceptable under field conditions.

4. CONCLUSIONS

1) Based on mathematical analysis, a method for calculating the horizontal flow of a horizontal mixture is proposed.

2) A calculation formula is proposed for determining the pressure loss during the movement of a gas-liquid mixture in pipelines. This technique makes it possible to determine the main parameters

3) pipelines based on phase classification, which is more accessible in field conditions.

REFERENCES

[1] Muravyov I.M., Bazlov M.N., Zhukov A.I., Cherkov B.S. “Technology and equipment of oil and gas production” Publishing house “Nedra”, Moscow, 1971, 495 pp.

[2] Wallis G. “One-dimensional two-phase flows” Publishing house “Mir”, Moscow, 1972, 440 pp

[3] Armand A.A. Nevstrueva E.I. “Study of the mechanism of movement of a two-phase mixture in a vertical pipe” Izvestia VTI. 1950. No. 2. 27-38 p.

[4] Basniev K.S., Kogima I.N., Maksimov V.M. “Underground hydromechanics” Publishing house “Nedra”, Moscow, 1993, 495 pp.

[5] Natanson I.P. “Short course of higher mathematics” St. Petersburg, Moscow-Krasnodar, Publishing House “Lan”, 2007, 593 pp.

[6] Nigmatulin R.I. “Dynamics of multiphase media” Moscow, Publishing House “Science” 1987, 824 pp

[7] James P. "Brill and Hemanta Mukberjee Multiphase How is well", Texas, 2009, 285 p

[8] Design of development and operation of oil fields. Reference manual in 2 volumes / Ed. Sh.K.Gimatudinova 3rd ed. Moscow. “Nedra” 1983, T. 1 Oil production / R.S. Andriasov, I.T. Mishenko, A.I. Petrov 453 p.