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Hydrodynamic Calculations of the Movement of Two Phase Systems in Complex Pipelines

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Abstract

Based on hydromechanics of homogenous fluid and gas, a new model of two- phase systems movement of fluid-gas type in horizontal tubes is suggested and the major calculation formula for the complicated development. This method enables us to define the main parameters of the complicated pipelines considering the physical properties of two- phase systems. The equation of two-phase systems movement in simple and complicated pipelines, allowing recommending using this approach in field experience is also obtained.

Keywords: complicated pipeline, diameter, shear stress, volumetric fluid gas discharge, multiple connection.

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Mürəkkəb boru kəmərlərində ikifazalı sistemlərin hərəkətinin hidrodinamik hesablamaları

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Xülasə

Bircins maye və qazın hidrodinamik qanunları əsasında horizontal borularda ikifazalı sistemlərin hərəkətinin yeni modeli təklif olunmuşdur. Bu üsul ikifazalı sistemlərin fiziki xassələrini nəzərə almaqla mürəkkəb boru kəmərlərinin əsas parametrlərini müəyyənləşdirməyə imkan verir. Məqalədə bircins maye və qaz hidravlik qanunlarına əsasən ikifazalı sistemlərin kəmərdə hərəkəti və mürəkkəb kəmərlərin hesablanması düsturları alınmışdır. Eyni zamanda, ikifazalı sistemlərin sadə və mürəkkəb kəmərlərdə hərəkət tənliyi verilmişdir ki, bu da göstərilən üsulun mədən praktikasında istifadəsinə imkan verir.

Açar sözlər: mürəkkəb boru kəməri, diametr, toxunma gərginliyi, maye və qazın həcm sərfiyyatı.

Гидродинамический расчет движения двухфазных систем в сложных трубопроводах

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Аннотация

На основе законов гидромеханики однородной жидкости и газа предложена новая модель движения двухфазной системы типа «жидкость-газ» в горизонтальных трубах и получены основные расчетные формулы для сложных трубопроводов, дающие возможность определить основные параметры сложных трубопроводов с учетом физических свойств двухфазных систем. Получено уравнение движения двухфазной системы в простом и сложном трубопроводах, что позволяет рекомендовать использование данной методики в промысловой практике.

Ключевые слова: касательное напряжение сдвига, сложный трубопровод, параллельное соединение, диаметр, объемный расход жидкости и газа.

Introduction

Oil fields in the world are located in different climatic zones, wells have different depths and physical and chemical properties of oil, gas and water, which is the basis for an individual approach when developing projects for their development. Practice shows that the system for collecting and transporting oil, gas and water is a separate branched network of pipelines located throughout the territories of the fields. These are underground, aboveground, underwater and overwater pipelines. Taking into account the conditions of oil field development, pipeline networks are different for different layers. Thus, for Russian fields, the total length of all underground pipelines exceeds more than 30 thousand km. The geometric dimensions of such pipelines vary widely from 0.1 to 1.02 m.

Basically, small-diameter pipelines (flow lines) are laid from the wellhead to group metering installations. Fresh water is transported through large-diameter pipelines to flood the oil reservoir to maintain reservoir pressure in them, increasing the oil recovery factor. The results of the analysis show that all pipelines transporting single-phase (oil, gas, fresh or produced water), two-phase (oil and gas) or multiphase (oil, gas and water) systems are tested for capacity, i.e. on hydraulic resistance, as well as on mechanical strength.

Setting the issue

Practice shows that for all work on the collection, transportation and preparation of oil, gas and water, a complex field development project provides for the placement of main oil field facilities and communications, the construction of which consumes about 50% of the capital investments allocated to the oil industry [1-6]. It is known that pipelines transporting well products in the territory of oil fields are divided into the following categories: by purpose - oil and gas pipelines, oil and gas pipelines; by the nature of the movement - with the combined movement of watered and non-watered oil; by the nature of the pressure - pressure and non-pressure; by installation method - underground, aboveground, under-water and suspended; by function - flow lines, prefabricated and commodity manifolds; according to the hydraulic scheme, the work is simple without branches, complex - with branches, which include parallel, ring and closed pipelines.

For these pipelines provided for in a complex project, hydrodynamic calculations are required. Basically, prefabricated reservoirs transporting gas-liquid mixtures such as oil and gas must be designed and calculated taking into account the rate of drilling of production wells, as well as the climatic conditions of a given field. Numerous hydraulic calculations show that the pace of putting a well into operation influences the choice of rational diameters of prefabricated reservoirs. Thus, at low rates of commissioning of wells with a small flow rate in offshore conditions, they should be designed as two prefabricated collectors, equal in cross-sectional area to one large one, designed for the maximum productivity of all operating wells.

Solution methods

At high rates of well operation, it is possible to design and build one common system, i.e. one prefabricated manifold designed for maximum productivity of all connected wells. When constructing a complex pipeline system transporting both single-phase and two-phase systems, first of all, it is necessary to take into account the location of wells in the field, their initial and final flow rates, as well as the physicochemical properties of hydrocarbons produced from various productive horizons. Taking into account the location of wells in an oil field, sea depth, seabed topography and climate makes it possible to select rational routes for all pipelines.

Basically, hydraulic calculations are performed for simple and complex pipelines transporting both single-phase and multiphase systems. Hydraulic calculation of a simple pipeline comes down to determining its throughput, the required initial pressure and diameter of the pipeline. Complex pipelines can have different diameters along the line and branch.

In the hydraulic calculation of complex pipelines, four cases that are often encountered in field conditions are of practical interest.

1. Dispensing manifold with a constant diameter for uniform and uneven selection of hydrocarbons.

2. A collection reservoir having a constant or different diameter for uniformly or unevenly flowing fluids.

3. A common collecting manifold forming parallel pipelines (lupings).

4. General collecting manifold, shaped like a ring.

In this work, based on the hydraulic laws of homogeneous liquid and gas, a model of the movement of a two-phase mixture in a pipeline is proposed and basic calculation formulas for complex pipelines are obtained. It is known that the joint transport of two-phase hydrocarbon systems through pipelines is common in the oil and gas industry. The complexity of the hydrodynamic processes occurring during the movement of the oil and gas system, which differ from calculations for a single-phase flow, is the reason that this problem has not yet found a satisfactory solution.

Processing the results of numerous theoretical and laboratory-experimental works of classics on hydraulics of multiphase systems A.I. Guzhov, A.A. Armand, S.I. Kosterin, S.S. Kutateladze, V.A. Mamaev, K.J. Hogendoorn, G. Wallisy et al. within the following parameters: Gas frud $Fr_г$ =0.15-3246; Froud liquid Fr_l = 0.0005-134.12; Reynolds gas Re_t =211-67500; Reynolds liquid Re_l =404-18886 and with pipe diameter D=0.02-0.05 m for various liquids the dependence was obtained

$$\tau_c = \tau_{\text{j}} + \tau_g + k\sqrt{\tau_j}\tau_g \qquad (1)$$

where τ_c - shear stress during movement of a two-phase system; τ_{r}, τ_g - tangential stresses of liquid and gas, respectively; k - experimental parameter.

Laboratory analysis shows that this experimental parameter depends on the ratio of liquid and gas densities.

For a water-air system $k = \sqrt{\frac{p_l}{\rho_g}} = 26$,, for other liquids $k = \sqrt{\frac{\rho_l}{p_g}} = 26 \div 33$ depending on the physico-chemical properties of the liquid and gas. A complete study of this model is given in [4].

$$\Delta p_c = \Delta p_l + k\sqrt{\Delta p_l}\sqrt{\Delta p_g} \qquad (2)$$

where Δp_c - loss of pressure due to friction when moving a two-phase system; Δp_l ; Δp_g- accordingly, friction loss during the movement of homogeneous liquid and gas.

Taking into account individual parameters for liquid and gas, respectively, we obtain:

$$\frac{\Delta p_c}{L} = \lambda_l \frac{v_l^2}{2D}\rho_l + \lambda_г \frac{v_g^2}{2D}\text{p}_g + k\sqrt{\lambda_l \frac{v_l^2}{2D}\rho_l \lambda_g \frac{v_g^2}{2D}\rho_g} \quad (3)$$

where $\lambda_l; \lambda_g$ - respectively, coefficients of hydraulic resistance for homogeneous liquid and gas; $v_l; v_g$ - respectively, the reduced speed of liquid and gas; ρ_l; ρ_g - density of liquid and gas, respectively; D is the internal diameter of the pipe; L is the length of the pipeline.

When calculating the hydrodynamics of pipelines, the Chezy formula is often used. Let us accept this equation for homogeneous liquid and gas

$$\lambda_l = \frac{8g}{c_l^2}; \lambda_g = \frac{8g}{c_g^2}; \quad (4)$$

Let us introduce the volume-flow gas content into this equation:

$$\beta = \frac{v_g}{v_g + v_l}; \quad (5)$$

It is known that the reduced speed of liquid and gas, respectively, can be determined by the formula:

$$v_l = \text{c}_l\sqrt{R\text{Il}} \text{ and } v_l = \text{c}_l\sqrt{RIg} \quad (6)$$

where Il and Ig are the hydraulic slope for liquid and gas; R is the hydraulic radius.

Then

$$\frac{\Delta p_c}{\rho_l} \cdot \frac{D}{4L} = \frac{v_l^2}{c_l^2} \cdot \left(1 + \frac{I_g}{I_l} \cdot \frac{\rho_x}{\rho_x} + k\sqrt{\frac{I_g}{I_l} \cdot \frac{\rho_x}{\rho_x}}\right) \quad (7)$$

Let us denote the expression enclosed in parentheses by the parameter

$$A = 1 + \frac{I_g}{I_l} \cdot \frac{\rho_g}{\rho_l} + k\sqrt{\frac{I_g}{I_l}\frac{\rho_g}{\rho_l}} \quad (8)$$

This expression makes it possible to determine the volumetric flow rates of individual phases. So, for liquid it is

$$Q_l = v_l s = k_l\sqrt{\frac{I_l}{A}} \quad (9)$$

where k_l- is the liquid flow characteristic.

Then

$$Q_l = k_l\sqrt{\frac{h_l}{L}} \cdot \frac{1}{\sqrt{A}} \quad (10)$$

where h_l is the hydraulic pressure of the liquid.

Often in difficult offshore conditions it is recommended to build parallel pipelines, for which

$$Q_l = Q_{l_1} + Q_{l_2} \quad (11)$$

Then, taking into account (10) and (11) we obtain

$$Q_l = k_l \sqrt{\frac{h_{l_1}}{L_1}} \cdot \frac{1}{\sqrt{\text{A}_1}} + \sqrt{\frac{h_{l_2}}{L_2}} \cdot \frac{1}{\sqrt{\text{A}_2}} \quad (12)$$

Conclusion

As you can see, using this method it is possible to determine the main parameters for complex pipelines, taking into account the physical properties of two-phase systems. This technique can be applied to other complex pipelines. Considering the simplicity and validity of this technique by the laws of hydromechanics of homogeneous liquid and gas, it can be recommended for wide use in field conditions.

Conflict of interests

The authors declare no conflict of interest.

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