Modeling flows of heterogeneous media in pipelines when substantiating operating conditions of hydrocarbon field transportation systems

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Abstract. The works of researchers at VNIIgaz, Giprovostokneft, Kuibyshev NIINP, Grozny Petroleum Institute, etc., are devoted to modeling heterogeneous medium flows in pipelines under laboratory conditions. In objective consideration, the empirical relationships obtained and the calculation procedures for pipelines transporting multiphase products are a bank of experimental data on the problem of pipeline transportation of multiphase systems. Based on the analysis of the published works, the main design requirements for experimental installations designed to study the flow regimes of gas-liquid flows in pipelines were formulated, which were taken into account by the authors when creating the experimental stand. The article describes the results of experimental studies of the flow regimes of a gas-liquid mixture in a pipeline, and also gives a methodological description of the experimental installation. Also the article describes the software of the experimental scientific and educational stand developed with the participation of the authors.

1. Introduction

At various times, many researchers have been engaged in modeling the flow of hydrocarbon raw materials in pipelines, among them are N.A. Slezkin, S.G. Teletov, S.S. Kutateladze, M.A. Styricovich, H.A. Rakhmatullin, A.N. Kraiko, L.E. Sternin, A.K. Dyunin, Yu.T. Borshchevsky, A.I. Guzhov, V.F. Medvedev, R.I. Nigmatulin, N.A. Yakovlev, M.A. Huseynzadeh, A.B. Shabarov, Yu.S. Danielyan, V.A. Yufin, V.N. Antipiev, V.A. Zysin, E.L. Kitanin, A.K. Gallyamov, SE Kutukov, G. Wallis, and others.

By now, many authors have developed a number of models of the flow of hydrocarbon liquids in pipelines using the classical provisions of the theory of continuum mechanics. Differences are in the quantity and quality of the conditions and features of pipeline transportation of hydrocarbons that are taken into account.

2. Materials and methods

Common preconditions for modeling heterogeneous media flows through pipelines are the following [1, 2, 3, 4, 5 et al].

1. When hydrocarbon media move through pipelines, homogeneous media, homogeneous mixtures and multiphase (heterogeneous) media are distinguished. A model of a homogeneous medium is used when

the proportion of impurities is negligible, compared with the proportion of the main carrier liquid or gas. In homogeneous mixtures, the constituents are mixed at the molecular level. In heterogeneous mixtures there are isolated heterogeneities: drops, gas bubbles, solid particles, etc. The most studied are homogeneous media, homogeneous mixtures and two-phase (dispersed) mixtures. Two-phase flows are a special case of a heterogeneous medium, the mathematical description of which can be produced on the basis of multi-rate continua. In this case, each phase, filling part of the total volume of the mixture, is characterized at a given point by the true phase density, velocity, temperature and enthalpy.

2. In the mathematical modeling of heterogeneous mixtures, there are usually three main assumptions. The first assumption is that dimensions of inhomogeneities (diameters of particles, droplets or their conglomerates, etc.) are much larger than the characteristic distances between molecules. This assumption makes it possible to use the approaches adopted in the mechanics of continuous media in describing processes near the surface of inhomogeneous inclusions. The second assumption is that the dimensions of the inhomogeneities are many times smaller than the diameter and linear dimension of the pipeline. This assumption allows correctly averaging the parameters and using the equations of continuous medium mechanics for averaged quantities. When the problem is formalized, the third assumption about the continuity of the medium is adopted, which makes it possible to simplify considerably the problem and to represent the flow in the form of a continuous liquid and gas phase. Due to this, it is possible to use the apparatus of continuous functions and differential calculus for studies.

3. The presence of phase transformations in the flow and the use of a two-velocity model leads to the need to take into account the change in mass and momentum of each phase by using the equations of conservation of mass and momentum for each of the phases separately, and also take into account the kinetics of the formation of a two-phase flow, i.e., two-phase transformations.

In Tyumen region, a generalized model of the quasi-one-dimensional flow of multiphase hydrocarbons in pipelines, developed by Professor A.B. Shabarov, serves as the basis for the development of questions of the physico-mathematical modeling of technological processes in the oil and gas industry - a physical and mathematical model of the flow of multiphase hydrocarbon media in pipeline systems, the essence of which is the following [6, 7].

The basis of the model is the principle of constructing a quasi-one-dimensional model, i.e. a one-dimensional model of the flow of the medium, in which, in one way or another, the properties of the real three-dimensional flow are approximately taken into account. With this approach to the description of fluid motion, the main flow parameters, the cross-sectional variables of the channel, are replaced by some constants throughout the section at a fixed time. When averaging, an irregular flow in an arbitrary section is replaced by a canonical flow, some of whose parameters may differ from the actual flow. The canonical flow is characterized by a certain set of constant averaged parameters, under which all properties of a real non-uniform flow are preserved [10, 11].

Most publications on the pipeline transport of multiphase hydrocarbons reveal the issues of transport of two-phase hydrocarbon systems, where special attention is paid to the flow regimes of gas-saturated and gas-liquid mixtures with the separation of gas and liquid phases in the flow structure.

It is known that under given specific operating conditions of pipelines, hydrocarbon media can be in a liquid, gaseous or two-phase gas-liquid state. For hydrocarbons taken in their pure form, the boundary pressure between the gaseous and liquid states at a given temperature is their vapor pressure. At the vapor pressure, the complete transition of the hydrocarbon in question from one phase to another occurs [2].

In the pipeline transport of hydrocarbon media, the transition from one state to another occurs when the pressure and temperature change, which causes evaporation or condensation. In practice, the movement of hydrocarbon media through pipelines is usually accompanied by evaporation of hydrocarbons, which occurs under the influence of pressure reduction at a relatively constant temperature.
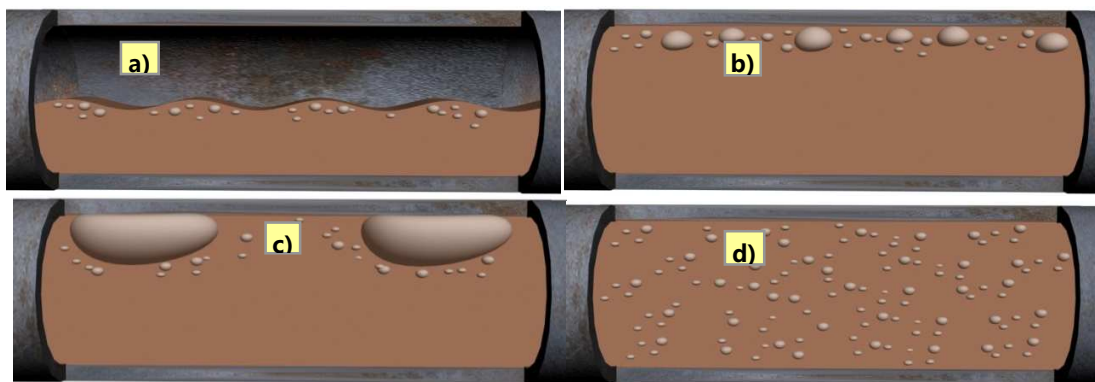
Figure 1. Structural forms of the gas-liquid flow:
a – separated; *b* – bubbly; *c* – slug; *d* - emulsion

In commercial pipelines the most common structural forms of the flow are slug and emulsion.

In contrast to the analytical method of studying regularities and describing the flow regimes of gas-liquid mixtures through pipelines, few works have been devoted to experimental studies. First of all, this is due to the fact that the movement of two-phase gas-liquid systems in pipes, complicated by mass-exchange processes and other factors, is quite difficult to model in the laboratory [1, 2]. However, the research of VNIIgaz, Giprovostokneft, Kuibyshev NIINP, Grozny Petroleum Institute, etc. is known, which, based on the data obtained, has developed methods for calculating pipelines transporting multiphase products. The developed methods distinguish the number of fixed and varying values, and in objective consideration they represent a bank of experimental data on the problem of pipeline transport of multiphase systems [8, 9].

At the department of "Transport of Hydrocarbon Resources", IUT, the research and experimental stand has been developed, the general layout of which is shown in Fig. 2. This stand allows simulating the movement of a gas-liquid flow in the pipeline and is a closed hydraulic circuit consisting of three series-connected sections with a glass tube-insert for visualization of structural flow forms.

Experimental studies were carried out in accordance with the technique of preliminary planning and carrying out the experiment, according to which the experiments simulated conditions characterized by different regimes, the magnitude of the hydraulic resistance, and the physico-chemical properties of the pumped product.

At the first stage of the study, parameters of a single-phase flow were measured, and at the second stage - of a gas-saturated liquid. As a working fluid, water and a water-glycerine mixture saturated with carbon dioxide were used. In accordance with the experimental procedure, a total of 51 series of measurements were performed, an average of about 40 measurements in each, in which four gas-liquid systems with a liquid component viscosity of 1.13 cSt to 3.38 cSt and a density of 998 kg/m^3 to 1098 kg/m^3. The experiments were carried out in the range of gas saturation from 0.54 to 0.97.

3. Results

Based on the results of the research, experimental graphs of the change in the basic hydrodynamic parameters of gas-liquid mixtures are constructed and empirical relationships are obtained. Fig. 3 shows experimental data on the investigation of flow regimes of a two-phase two-component system. Fig. 4 presents experimental data on the structural forms of a gas-liquid flow.

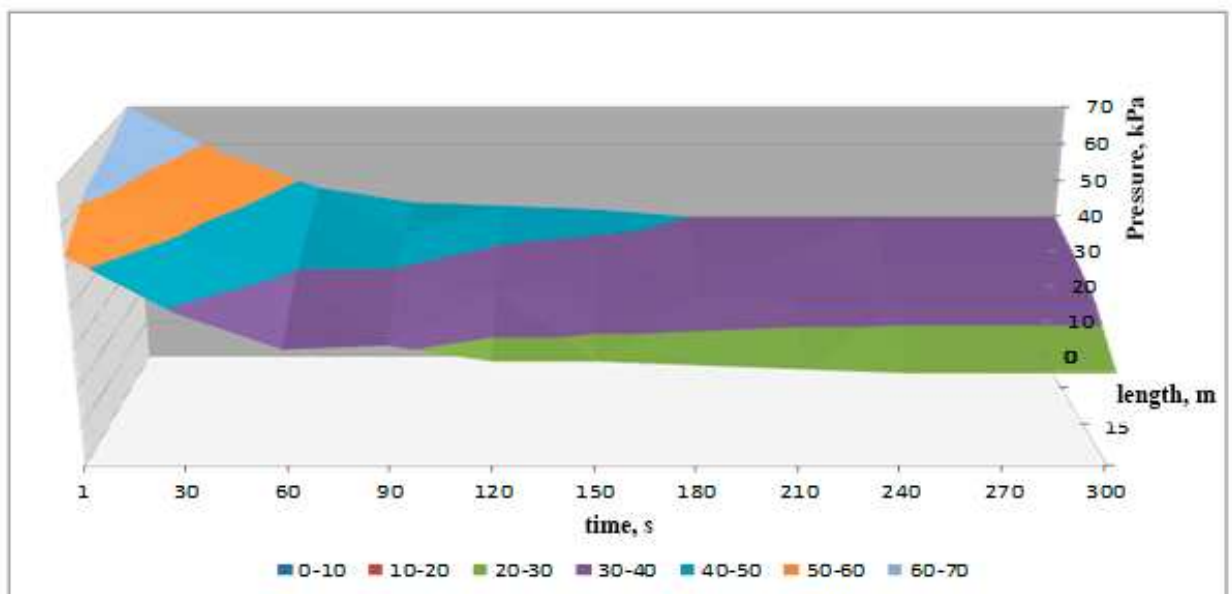**Figure 2.** A general layout of the experimental installation

Figure 3. Changes in the pressure of the gas-saturated flow in the slug flow regime
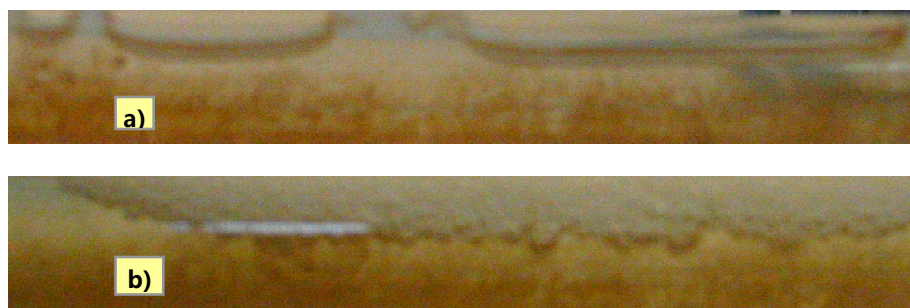
Figure 4. Structural forms of the flow of gas-liquid media, marked in the experimental study of a two-phase flow in a pipeline:
a – slug; *b* – emulsion (foamed)

4. Conclusions

1. A research and development stand has been designed that allows simulating and studying the flow regimes of heterogeneous media in horizontal pipelines.

2. The results of the experimental studies and the obtained empirical dependencies of the hydrodynamic characteristics of two-phase flows can be used in the analysis of heterogeneous medium flows in pipelines, in particular, in the study of slug and emulsion flow regimes.

3. The created research laboratory stand and the experimental data obtained with its use make it possible to predict and carry out the selection of rational operating modes of hydrocarbon transportation systems.

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