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# MODELLING OF MULTIPHASE MULTI-VELOCITY UNSTEADY FLOWS IN PIPES WITH ELEVATION DIFFERENCE

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## Abstract

The article importance lies in the interest among scientists in describing such complex streams as multiphase flows, which physical models have now been developed and corrected. This research aims at studying the behaviour of flows of multiphase mixtures in pipes, when there is a difference in elevations. The study method is based on computer modelling using a simulator of multiphase flows created by the authors. The simulator is appropriate for describing the flow of multiphase mixtures in complex systems, with implementation of two-velocity motion model of various phases. In liquid-gas mixture, it results in different velocities of phases motion. The analysis results demonstrate that velocities differ substantially. The presence of gravitational component greatly affects the nature of flow, and, in some cases, leads to a change in flow regimes. The work shows that regimes can also be implemented without reaching steady-state conditions. The article materials are of practical value to design long-distance pipelines, placed across the terrains of certain topography.

**Key words:** hydrodynamics of multiphase media, modelling of technical systems, flow regimes, software codes, phase equilibria

## Introduction

Describing the behaviour of multiphase flows is a complex scientific and technical problem, many scientists all over the world have dealt with. Actually, it is a non-conventional gas-hydrodynamics, where heterogenous substances, present in the mixture composition, require non-standard approaches to adequately describe the physical phenomena, occurring in the processes. First, different phases move with various velocities (as opposed to classic gas dynamics, where the mixture moves at each point with one velocity). In some problems the velocity of gas phase differs by ten folds. It gives rise to such specific exchange components as interfacial friction. Phase transitions are the next essential factor, along with the necessity to develop a special library of equations and parameters, using which the mixture state is computed, considering nonequilibrium in some cases. The flow of multiphase mixtures in pipes and channels is an important process in many production systems, with extraction process in gas and gas-condensate fields as an example, although there have existed many problems for such other sectors of economy as energy industry, ecology, medicine, where multiphase streams play a significant role.

Numerous works are devoted to examining multiphase flows both experimentally and using software codes (V. De Henaut and G.D. Raithby1994; Danielson, 2011;Shippen 2012;Godunov, 1999, Jolgam 2017,Karni, 2004).

Specifically, such software codes as Olga make it possible to examine particular flow processes in pipes and channels (Danielson, 2011). The authors have developed a special software code that enables simulation of such processes. Of importance is to study the effect of different factors on flow regimes of multiphase media, taking into account variable velocities of phases flow. Here, gravitational component constitutes an essential factor. Its influence is known, when there are big differences in elevations within several kilometres in boreholes. This article explores the effects in transport pipelines, where elevation differences per kilometre do not exceed 1%.

## Research methods

The authors have developed a special software code to describe multiphase flows with phase transitions in pipes and channels (Zhigalov, Kibkalo, 2022), hereinafter designated as TFS.

Two-phase thermal-hydraulic code is intended for modelling unsteady regimes in long-distance systems, which can incorporate control and regulation systems. Computation of two-phase media flow involves determination of heat transfer, including heat exchange with walls, and other physical processes, related to friction on the walls and interfacial friction. A complete computational model of complex pipeline systems can therefore be used.

The mixture can remain in two states: liquid and gaseous state with phase transitions while moving. According to conditions, such various flow regimes are modelled in the software code as bubbly, stratified, annular-mist, slug, and interfacial interactions (heat-mass transfer, friction) therewith depend on the flow regime.

The main properties of the mixture flow:

- Presence of numerous components in two phases. The mixture can be in two states: liquid and gaseous. Each phase can incorporate several components: liquid – water and solutions, gaseous – steam and non-condensable gas.
- Heterogeneity, velocity and temperature non-equilibrium. Each phase has its: volume, velocity and temperature.
- Interfacial interactions, that depend on the flow regime. Interfacial interactions (heat-mass transfer, friction) depend on the flow regime (bubbly, annular-mist, stratified, etc.).
- Wall heat transfer, depending on heat transfer regime (convection, nucleate boiling, boiling crisis, transition boiling, film boiling, condensation). Both one-dimensional, and two-dimensional modelling of heat transfer in structural elements of systems can be performed as selected by a user.

State equations taking into account phase transitions are developed in terms of software codes (Zhigalov, Kibkalo, 2020;Kibkalo, Zhigalov, 2020;Bashurin, Zhigalov, 2019), which are used along with pipe simulator.

Computation of multi-velocity two-phase flows must involve correct description of interfacial friction. Since interfacial friction is described by correlation relationships, it is necessary to verify the implemented friction model, what was made through comparison with the experimental data published in (Wallis et-al1970;Ottens, Hoefsloot,et-al 2001;Hart et-al 1989;Badie, Haleet-al 2000).

To verify the possibility of modelling slug flow regimes, a problem with four connected W-shaped pipes was solved. The problem is described in article (De Henaut and Raithby1994), where the experimental results, obtained on a special test facility, are also given.

Article (Ottens, Hoefsloot,et-al 2001) presents the data on two series of experiments on a straight horizontal pipe:

for two-phase water-air mixture flow (42 points),

for mixture of air and water, containing water and glycerine (26 points).

experimental results for various inclination angles are given: 1 degree, 2 degrees and -1 degree.

The data from article (Ottens, Hoefsloot,et-al 2001)are used to estimate the accuracy of interfacial friction model for water-air mixture in horizontal pipe (see figure 1).

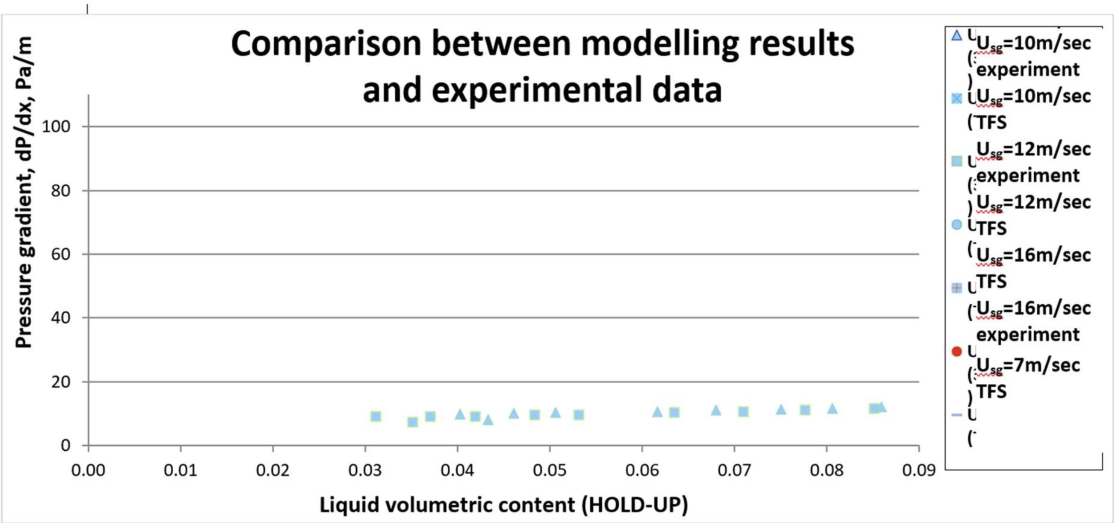


**Figure 1 – Comparison between experimental data (Ottens, Hoefsloot, Hamersma, 2001).and TFS modelling results**

Proximity of calculation results to experimental data indicates how adequate the model is for the studied class of two-phase flows. Mean relative deviations of predicted values are utilised as a criterion of proximity of computed values to the experiment data.

This work examines, through the presented code, the unsteady flow of two-phase compound mixtures in pipes with elevation difference. Physical models of the flows of such kind are based on approaches mentioned in a number of works(Nigmatulin, 1987; Okava, 1999;Kataoka,1987; Bestion, 1990; Delaie, 1984). These regimes are typical of gas pipelines, by which different mixtures or natural gas with admixtures are transported.

Gas phase continuity equation

$$\frac{\partial}{\partial t}(\alpha_g\rho_g) + \frac{1}{A}\frac{\partial}{\partial z}(A\alpha_g\rho_g V_g) = \Gamma_{iv} + \sum_{n=1}^{Nn} S_n + S_v.$$

Liquid phase continuity equation

$$\frac{\partial}{\partial t}(\alpha_f\rho_f) + \frac{1}{A}\frac{\partial}{\partial z}(A\alpha_f\rho_f V_f) = -\Gamma_{iv}.$$

Gas phase motion equation

$$\alpha_g\rho_g\frac{\partial V_g}{\partial t} + \alpha_g\rho_g V_g\frac{\partial}{\partial z} V_g + \alpha_g\frac{\partial}{\partial z} P = \Gamma_{iv}(V_{ig} - V_g) + \tau_{ig} + \tau_{wg} + \tau_{lg} - \alpha_g\rho_g g \sin\theta.$$

Liquid phase motion equation

$$\alpha_f\rho_f\frac{\partial V_f}{\partial t} + \alpha_f\rho_f V_f\frac{\partial}{\partial z} V_f + \alpha_f\frac{\partial}{\partial z} P + \frac{\partial}{\partial z} P_h = -\Gamma_{iv}(V_{if} - V_f) + \tau_{if} + \tau_{wf} + \tau_{lf} - \alpha_f\rho_f g \sin\theta.$$

Gas phase energy equation

$$\alpha_g\rho_g\frac{\partial h_g}{\partial t}+\frac{1}{A}\frac{\partial}{\partial z}(A\alpha_g\rho_g h_g V_g) - \frac{h_g}{A}\frac{\partial}{\partial z}\alpha_g\rho_g V_g) - \alpha_g\frac{\partial P}{\partial t} =$$
$$\Gamma_{iv}(h_{iv}-h_g) + (\tau_{wg}+\tau_{lg})V_g + Q_{iv} + Q_{gf} + Q_{wg} + Q_g + \sum_{n=1}^{Nn} S_n(h_{*n}-h_g) + S_v(h_{*v}-h_g).$$

Liquid phase energy equation

$$\alpha_f\rho_f\frac{\partial h_f}{\partial t}+\frac{1}{A}\frac{\partial}{\partial z}(A\alpha_f\rho_f h_f V_f) - \frac{h_f}{A}\frac{\partial}{\partial z}\alpha_f\rho_f V_f) - \alpha_f\frac{\partial P}{\partial t} =$$
$$-\ \Gamma_{iv}(h_{if}-h_f) + (\tau_{wf}+\tau_{lf})V_f + Q_{if} - Q_{gf} + Q_{wf} + Q_f.$$

Non-condensable gas continuity equation

$$\frac{\partial}{\partial t}(\alpha_g\rho_g X_n) + \frac{1}{A}\frac{\partial}{\partial z}(A\alpha_g\rho_g X_n V_g) = S_n.$$

List of symbols and parameters, used in the analysis

$A$ – channel passage cross-section, $m^2$

$A_i$ – specific interface area, interfacial area in a volume unit, $m^{-1}$

$a$ – sound velocity, m/sec

$c_к$ – specific heat at constant pressure, J $kg^{-1} \cdot K^{-1}$

$D = 4A/\Pi$ – hydraulic diameter of channel, m

$F$ – surface area, $m^2$

$G = G_f + G_g$ – specific mass flowrate of mixture, mass velocity, kg $\cdot$ $m^{-2} \cdot sec^{-1}$

$G_k = \alpha_k\rho_k v_k$ – specific mass flowrate of phase, mass phase velocity, kg $\cdot$ $m^{-2} \cdot sec^{-1}$

$g$ –acceleration of gravity, m/$sec^{-2}$

$h_{fg}$ –specific enthalpy of phase transition, J/kg

$h_k$ – specific enthalpy of phase, J/kg

$h_{ik}$ – specific enthalpy of phase k at interfacial boundary, J/ kg

$h_{sk}$ – specific enthalpy of phase k at saturation, J/ kg

$h_{*k}$ – specific enthalpy of “source-sink” phase k, J/ kg

$j$ – mass velocity, $kg \cdot m^{-2} \cdot sec^{-1}$

$K_k$ – heat conductivity factor, $W \cdot m^{-1} \cdot K^{-1}$

$L$ – section length, m

$M' = \frac{M}{M_{nom}}$ – nondimensional hydraulic resistance moment

$M$ – hydraulic resistance moment

$M_{fr}$ – frictional resistance moment

$P$ – pressure, Pa

$P_h$ – hydrostatic pressure in horizontal channel, Pa

$Pr_k = \frac{C_k\mu_k}{K_k}$ – Prandtl number

$P_{cr}$ – critical pressure (22064000 Pa for water)

$Q$ – volumetric flowrate of heat carrier, $m^3 sec^{-1}$

$Q' = \frac{Q}{Q_{nom}}$ – nondimensional pump flowrate

$Q_{nom}$ – nominal volumetric pump flowrate, $m^3 \cdot sec^{-1}$

$Q_{ik}$ – volumetric capacity of heat transfer between phase and interfacial boundary, W $\cdot$ $m^{-3}$

$Q_{wk}$ – volumetric capacity of heat transfer between phase and channel wall, W $\cdot$ $m^{-3}$

$Q_{wi}$ – volumetric capacity of heat transfer between wall and interfacial boundary, W $\cdot$ $m^{-3}$

$Q_v$ – volumetric capacity of heat release per unit volume, W $\cdot$ $m^{-3}$

$q = q_{wg} + q_{wf} + q_{wi}$ – density of total heat flow from wall to heat carrier, W $\cdot$ $m^{-2}$

$q_{wi}$ – density of heat flow from wall to interfacial boundary, W $\cdot$ $m^{-2}$

$q_{wk}$ – density of heat flow from wall to phase, W $\cdot$ $m^{-2}$

$q_{rad,j}$ - flow density of $j^{th}$ thermal element resulting radiation
(difference between radiation flows: received and given), W/$m^2$

$r$ – radial coordinate in thermal element, m

$R_j$ – flow density of element j effective radiation (total flows of intrinsic and reflected radiation), $W/m^2$
$R = 461.526$ J/kgK – universal gas constant
$Re_k = \frac{G_k D}{\mu_k}$ – Reynolds number
S – specific intensity of “source-sink” phase, non-condensable gases or liquid admixture, $kg \cdot m^{-3} \cdot sec^{-1}$
$St_{ki} = \frac{\alpha_{ki}}{\rho_k c_{pk} v_{ki}}$ – Stanton number
$T_{cr}$ – critical temperature (647.096 К for water)
$T_k$ – phase temperature, К
$T_{ik}$ – temperature of phase at interfacial boundary, К
$T_s$ – saturation temperature, К
$T_w$ – wall temperature, К
t – time, sec
$V_k$ - velocity of phase k, $m \cdot sec^{-1}$
$V_{ik}$ – velocity of phase at interfacial boundary, $m \cdot sec^{-1}$
$X_n$ – mass concentration of non-condensable gas in gaseous phase
$X = \alpha_g \rho_g / \rho$ – mass steam content
$X_{is}$ – mass concentration of soluble admixture in water
z – coordinate along channel, m
$\alpha_k$ – volume concentration of phase
$\alpha_{ik}$ – coefficient of heat transfer from phase to interfacial surface, $W \cdot m^{-2} \cdot К^{-1}$
$\beta_{is}$ – precipitation/dissolution rate of soluble admixture
$\delta P_p$ – pump-generated pressure drop, Pa
$\Delta$ - absolute roughness of channel walls, m
$\Delta T_{wk} = T_w - T_k$ – difference between wall and heat carrier temperatures, К
$\Delta T_{ws} = T_w - T_{sv}$ – wall overheating, К
$\varepsilon$ – emissivityfactor
$\Gamma_{ik}$ – specific intensity of mass transfer between phase and interfacial boundary, $kg \cdot m^{-3} \cdot sec^{-1}$
$\varphi_{ij}$ – visibility factor (portion of energy, radiated by element j, incident on element i)
$\lambda_{ik} = \frac{\alpha_{ik} A_i}{c_k}$ – volumetric coefficient of heat transfer from phase to interfacial surface, $kg \cdot sec^{-1} \cdot m^{-3}$
$\mu_k$ – dynamic viscosity, $N \cdot sec \cdot m^{-2}$
$\vartheta_{sf}$ – solution residual mass per channel volume unit, $kg \cdot m^{-3}$
$\rho = \alpha_g \rho_g + \alpha_f \rho_f$ – heat carrier density, $kg \cdot m^{-3}$
$\rho_k$ – phase density, $kg \cdot m^{-3}$
$\rho'_n = \rho_g X_n$ – partial density of non-condensable gas n in gaseous phase, $kg \cdot m^{-3}$
$\rho_{sk}$ – density of phase k at saturation, $kg \cdot m^{-3}$
$\xi$ – hydraulic friction coefficient
$\xi_{loc}$ – coefficient of local hydraulic resistance
$\sigma_r = 5.67 \cdot 10^{-8}$ $W/m^2K^4$ – Stefan-Boltzmann constant
$\sigma_{fg}$ – surface tension coefficient at the liquid-steam boundary, $N \cdot m^{-1}$
$\tau_{ik}$ – friction force between phase and interfacial boundary per unit volume, $N \cdot m^{-3}$
$\tau_{wk}$ - friction force per unit volume between phase and channel wall, $N \cdot m^{-3}$
$\Pi$ – wetted perimeter of channel, m
$\theta$ – angle of channel inclination to horizontal
$\tau$ – time-step, sec

**Lower indices**

f – liquid phase parameters
g – gaseous phase parameters

i – interfacial boundary parameters
k – phase identifier (f, g)
n – parameters of non-condensable gases
s – saturation parameters
w – wall parameters
v – steam parameters
0 – parameter of donor (upstream) volume
1 – parameter of acceptor (downstream) volume
* – critical cross-section parameters

The work presents an analysis of computation of multiphase flow in the pipe with elevation differences in disabling and then enabling pipeline to demonstrate major effects that occur under such regimes.

Gas-dynamic and thermodynamic parameters of two-phase flow (natural gas and gas condensate) have been computed at the pipeline section with 1km long difference in elevations. The profile contains both descending, and ascending sections, what makes it possible to analyse, in particular, flows in valleys. Computation specifies the multiphase mixture, which is presented as both gaseous phase and liquid while calculating.

The main initial data are given in Table 1.

**Table 1 Main initial data**

| Parameter | Measurement unit | Value |
|---|---|---|
| Internal pipeline diameter | m | 0.8436 |
| Steel pipeline wall thickness | mm | 28.2 |
| Polypropylene coating thickness | mm | 4 |
| External concrete coating thickness | mm | 50 |
| Absolute roughness of pipeline inner surface | mm | 0.01 |
| Mass rate of gas | kg/sec | 240 |
| Pipeline output pressure | bar | 100 |
| Water temperature | degree C | 1 |
| Natural gas input temperature | degree C | 60 |

Distribution is analysed of the following parameters along the pipeline prior to, after shutdown, and after restart:

Pressure;
Gas temperature;
Liquid and gas velocity
HOLDUP function (section gas-liquid phase ratio).

It has also been determined how these parameters are distributed throughout time domain at characteristic pipeline points.

The mixture of hydrocarbons from Table 2 was used as a compound mixture. Heat exchange was taken into consideration with environment through the wall with polypropylene and concrete coating.

**Table 2 Composition of natural gas**

| Formula | Component name | Molar % |
|---|---|---|
| 1 | 2 | 3 |
| $CH_4$ | METHANE | 93.79 |
| $C_2H_6$ | ETHANE | 2.02 |
| $C_3H_8$ | PROPANE | 0.78 |

| | | |
|---|---|---|
| **$iC_4H_{10}$** | i-BUTANE | 0.14 |
| **$nC_4H_{10}$** | n-BUTANE | 0.23 |
| **$iC_5H_{12}$** | i-PENTANE | 0.08 |
| **$nC_5H_{12}$** | n-PENTANE | 0.07 |
| **$C_6H_{14}$** | HEXANE | 0.101 |
| **$C_7H_{16}$** | HEPTANE | 0.081 |
| **$C_8H_{18}$** | OCTANE | 0.069 |
| **$C_9H_{20}$** | NONANE | 0.028 |
| **$C_{10}H_{22}$** | DECANE | 0.018 |
| **$C_{11}H_{24}$** | UNDECANE | 0.013 |
| **$C_{12}H_{26}$** | DODECANE | 0.010 |
| **$C_{13}H_{28}$** | TRIDECAN | 0.006 |
| **$C_{14}H_{30}$** | TETDECAN | 0.005 |
| **$C_{15}H_{32}$** | PENTADECAN | 0.005 |
| **$C_{16}H_{34}$** | HXDECANE | 0.004 |
| **$C_{17}H_{36}$** | HDECAN | 0.003 |
| **$C_{18}H_{38}$** | OCTADECAN | 0.004 |
| **$C_{19}H_{40}$** | NONADECAN | 0.003 |
| **$C_{20}H_{42}$** | EICOSANE | 0.002 |
| **$C_{21}H_{44}$** | HENEICOSANE | 0.002 |
| **$C_{22}H_{46}$** | - | 0.001 |
| **$C_{23}H_{48}$** | - | 0.001 |
| **$C_{24}H_{50}$** | - | 0.0007 |
| **$C_{25}H_{52}$** | - | 0.0006 |
| **$C_{26}H_{54}$** | - | 0.0004 |
| **$C_{27}H_{56}$** | - | 0.0003 |
| **$C_{28}H_{58}$** | - | 0.0008 |
| **$N_2$** | NITROGEN | 2.14 |
| **$CO_2$** | CARBON DIOXIDE | 0.42 |
| **He** | HELIUM | 0.015 |
| **Ar** | ARGON | 0.001 |
| **$H_2$** | HYDROGEN | 0.001 |
| **Total** | - | 100 |

240 kg/sec mass flowrate of mixture is specified as a boundary condition at the input, constant pressure 100 Bar at the output.

The following pipeline operation mode is predetermined: gate valves are open during first 10000 sec, a steady-state regime emerges in the pipeline (first stage), then gate valves are closed and remain closed during 5000 sec (second stage), then they are opened again (third stage). Totalcomputingtimeamountedto 20000 sec. Such a method of problem statement is appropriate for considering the questions of the flow's reaching the steady regime at the first stage before closing gate valves and analysing the effect of gravitational component on the main liquid-gaseous phase relationships. The second stage involves flow deceleration, and the third phase involves its acceleration again. Identification of the flow regime type is an important element of the analysis (bubbly, annular, etc.).

To analyse time characteristics, the results of computing gas-dynamic parameters have been analysed examined at characteristic pipeline points (downhill, at the “well” bottom, uphill), positioned in the mid-section of pipeline at about 500m distance. There have also been given distributions of parameters along the pipeline length at time marks 10000, 14800, 20000sec (before shutdown, before start, in the end of computation).

## Results and discussion

The results of studies conducted using software code are given in figures. Figures 2-6, in addition to parameters of pressure, temperature, relationships between phases and velocities, provide the data on regimes, occurring within various sections (sections along the abscissa are stained a colour, corresponding to a specific flow regime). The software code accomplishes the following flow regimes: bubbly, annular, stratified, bubbly-annular, bubbly-stratified, annular-stratified, and transient. Any particular regime is defined depending on the ratios taking place in the flow process. HOLDUP function characterises the ratio between liquid and gaseous phase velocities. All figures present the profile of differences in elevations along the pipe length.

Figures 2 and 3 provide the data along the pipe length at the moment before shutdown. Maximum gradients appear in motion velocities of liquid and gaseous phases and ratios between them. Mostly, the velocity of liquid phase changes. It is vital to note that the system becomes steady, and the parameters presented in figures 2,3 remain unchanged long time before shutdown.

Figure 4 presents the results of pressure, temperature, and HOLDUP function distribution over the pipe after shutdown at 14800 sec in the state when end pipeline gate valves are closed.

Figures 5, 6 show the results of pressure, temperature, HOLDUP function distribution, as well as the distribution of velocities of gaseous and liquid phase after start for 20000 sec. Gaseous phase velocity therewith raises to about 6m/sec, and liquid phase velocity is within 1.5-0.1m/sec range and strongly depends on the pipe profile height.

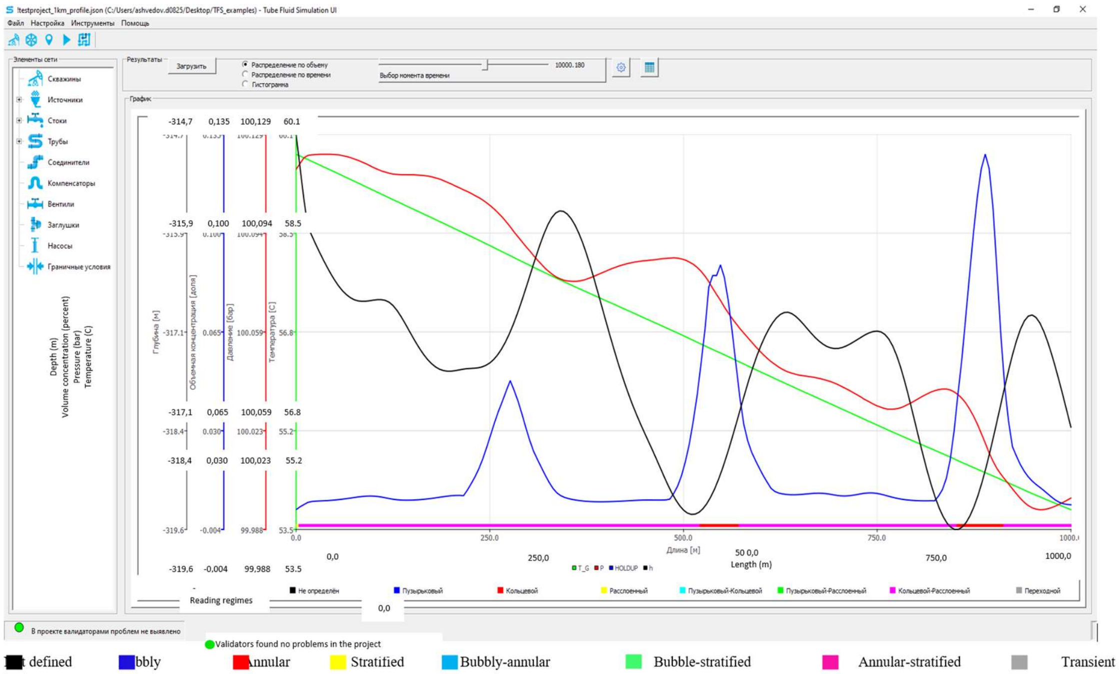


Figure 2. Distribution of pressure, temperature, and HOLDUP function before shutdown

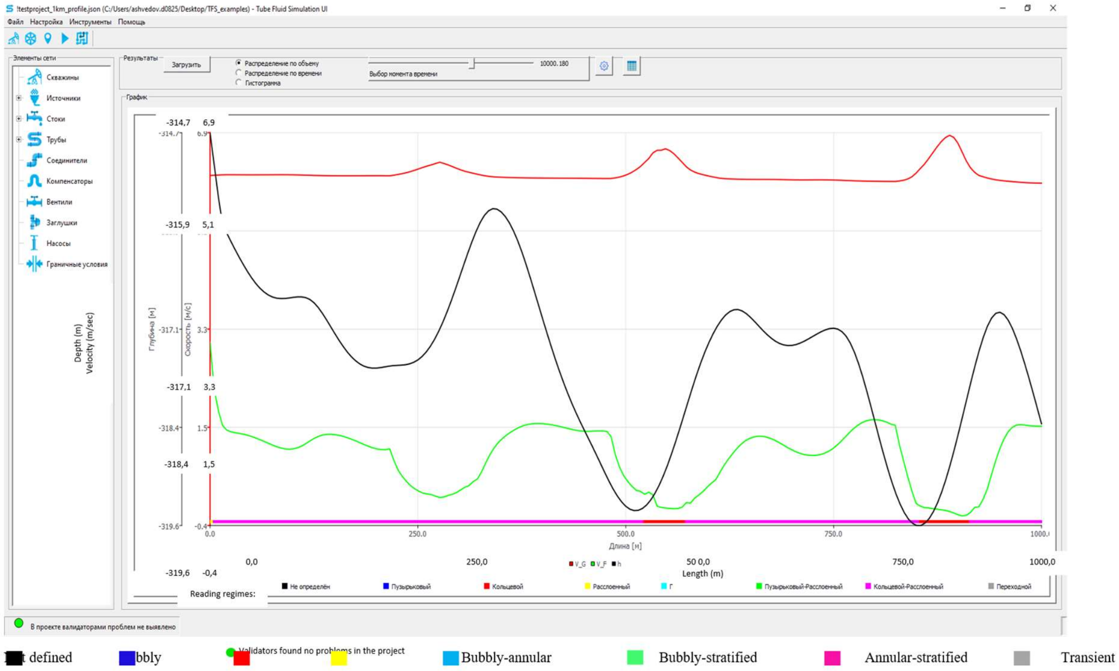
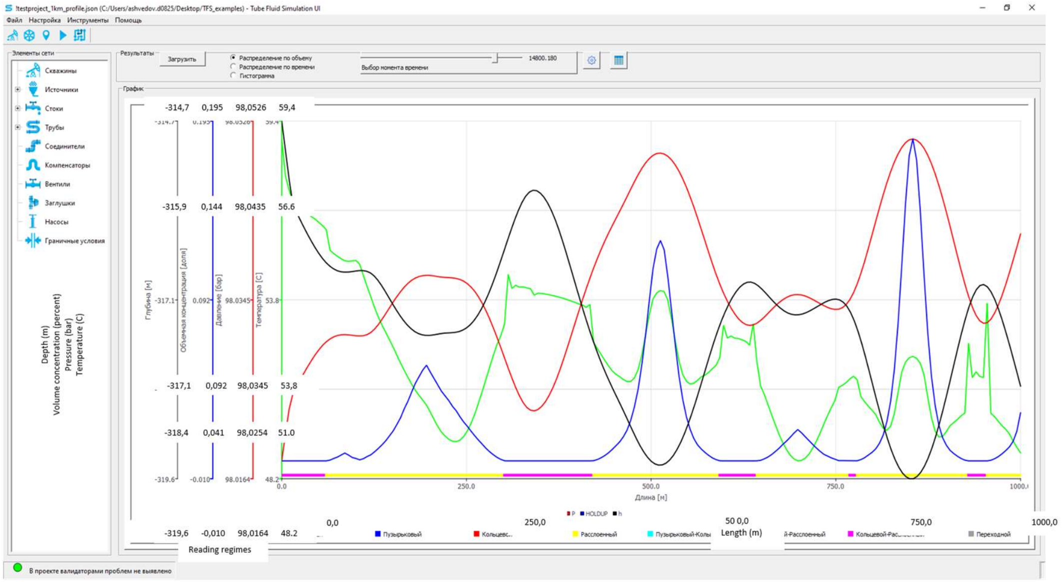


Figure 3. Distribution of gaseous and liquid phase velocities before shutdown



В проекте валидаторами проблем не выявлено

Validators found no problems in the project

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Figure 4. Distribution of pressure, temperature, and HOLDUP function after shutdown at 14800sec.

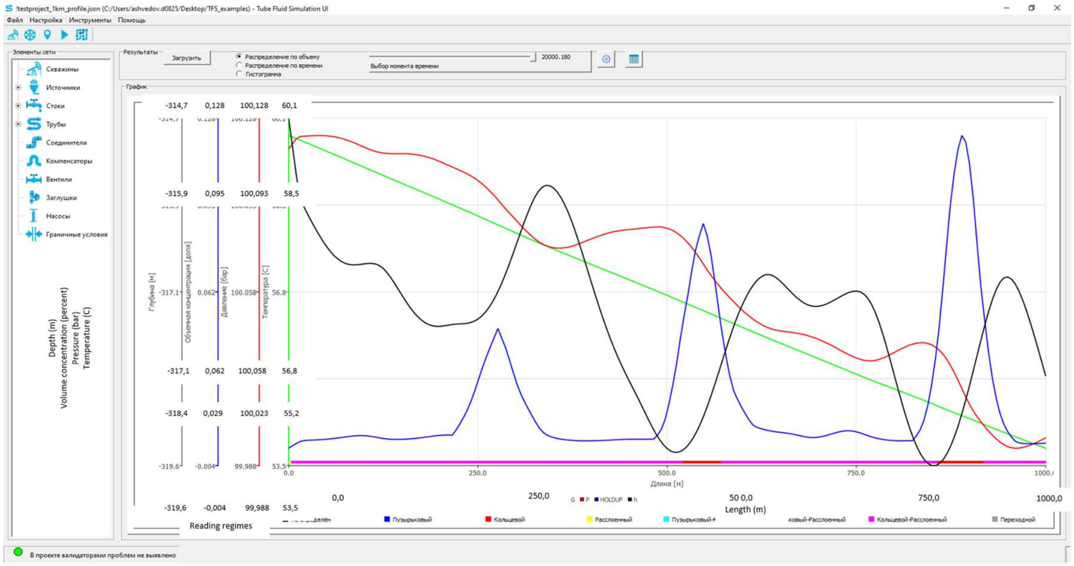

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Figure 5. Distribution of pressure, temperature, and HOLDUP function after start for 20000sec.

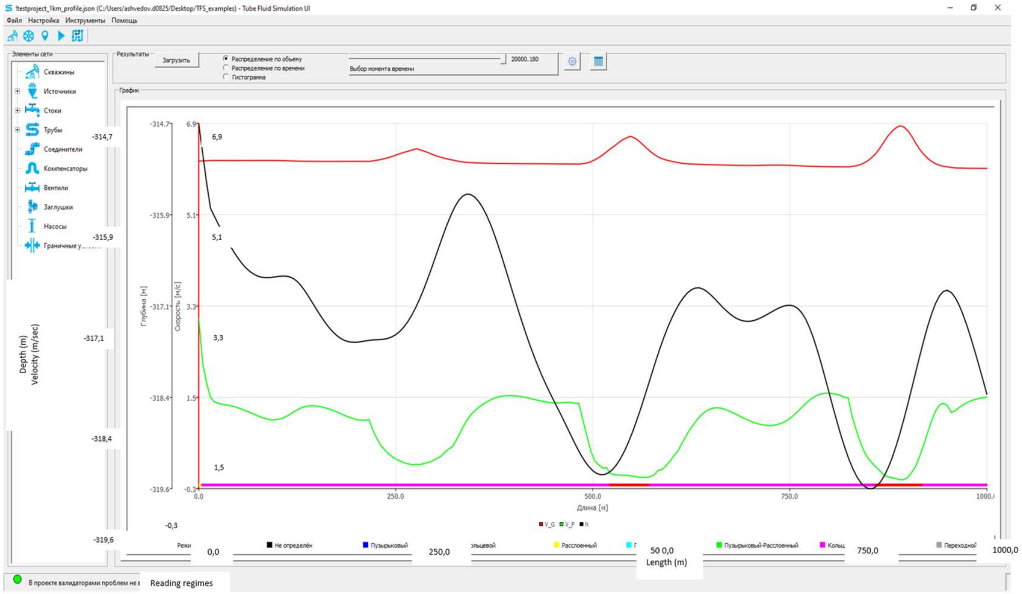

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Figure 6. Distribution of gaseous and liqu● Validators found no problems in the project .

Below the distribution of gas-dynamic parameters in time domain is considered. Threecharacteristicpointshavebeentakentodothis. The first point at the 422m distance is located in the middle of descending section of the pipeline. The second point at the 513m distance corresponds to the maximum pipeline location depth at this section. The third point at the 568m distance is placed in the middle of the pipeline uphill. The figures present distributions of pressure, temperature, and HOLDUP function, and indicators of flow regimes. In figure 8, of note are periodic fluctuations and changes in flow regimes.

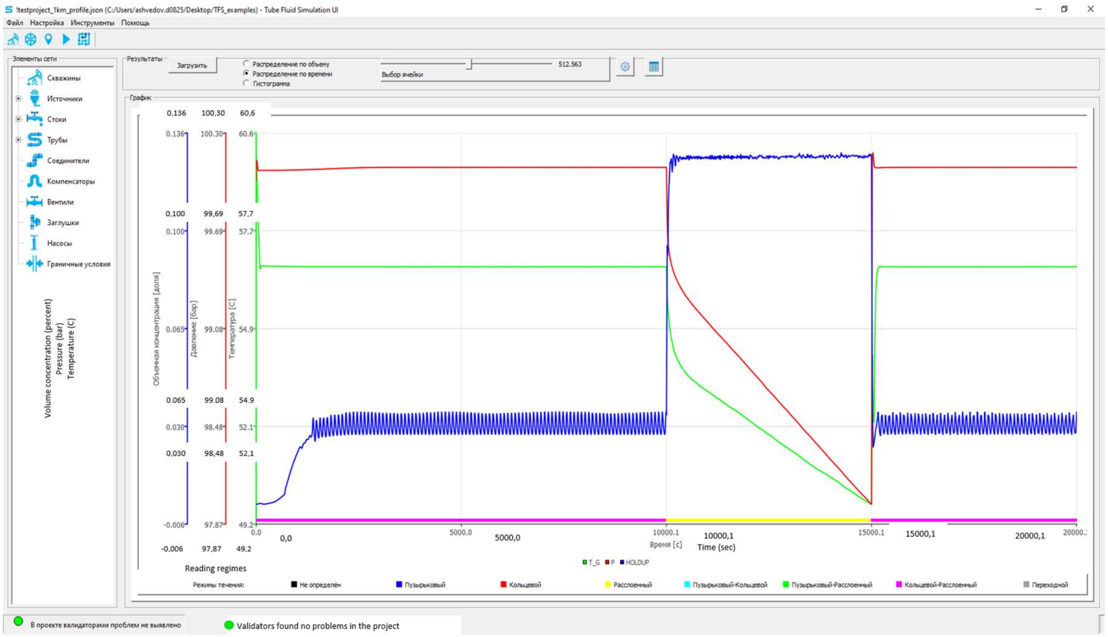

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Figure 7. Distribution of pressure, temperature, and HOLDUP function over time domain at the 513m distance.

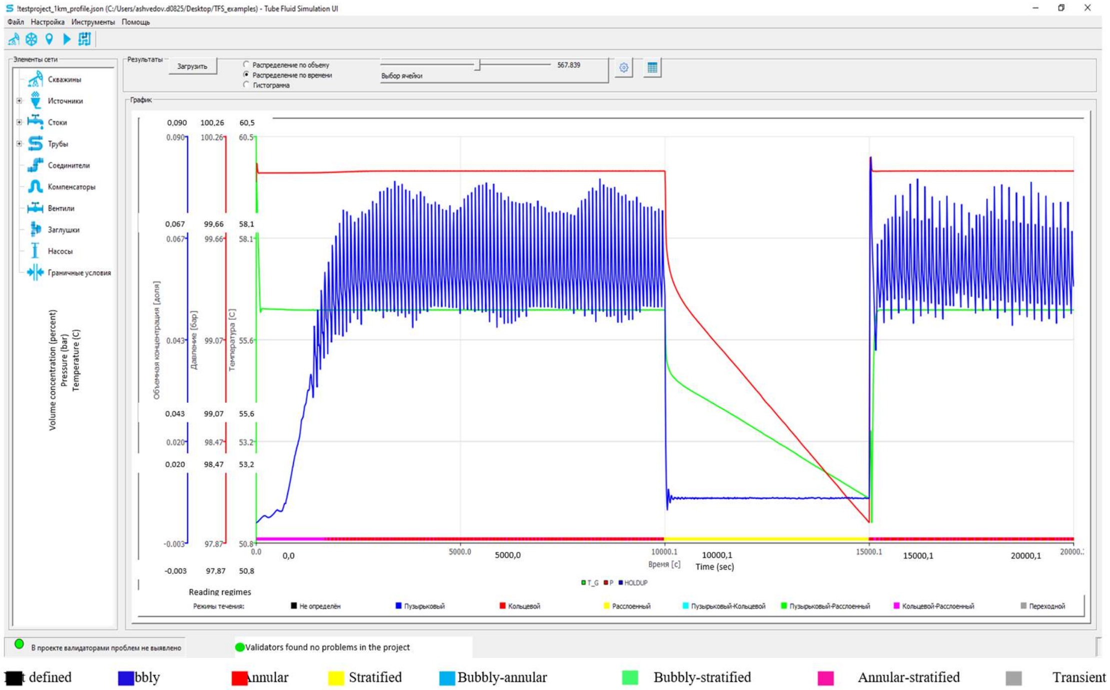

Figure 8. Distribution of pressure, temperature, and HOLDUP function over time domain at the 568m distance

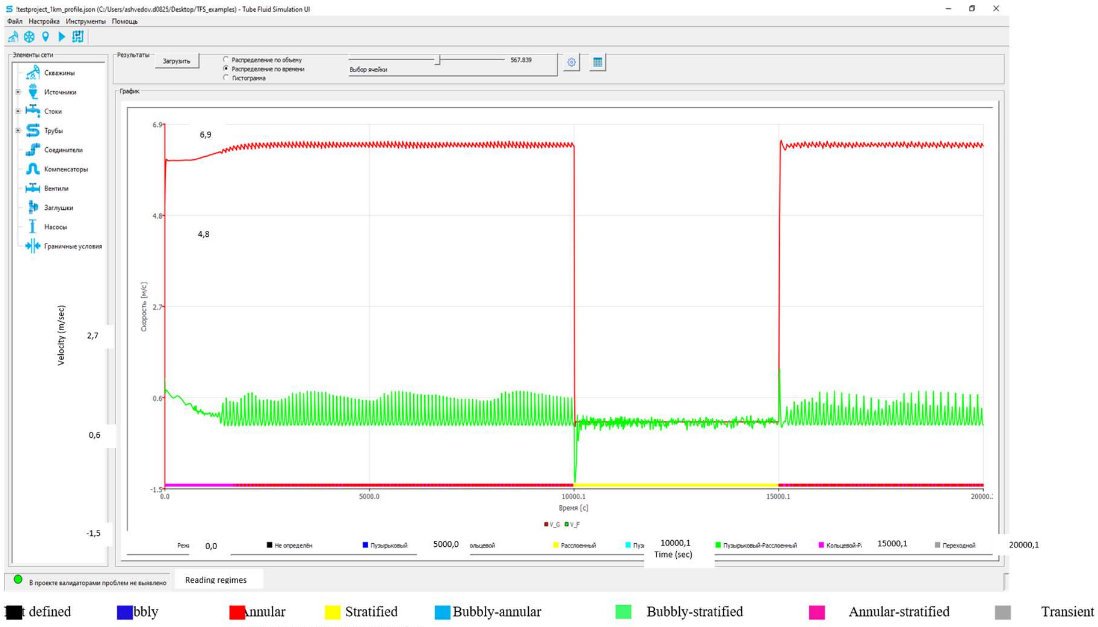

Figure 9. Distribution of gaseous and liquid phase velocities over time domain at the 568m distance

Calculations have shown that steady flow regime in the pipeline is set up by the moment of shutdown and after start by the end of computing time. The analysis of computation results given in figures 2 and 3 reveals substantially different velocities of gaseous and liquid phase distribution even when equal velocity at the pipeline input is specified, and the ratio between gaseous and liquid phase velocities therewith changes a lot within the range of 3-30. In valleys this ratio is maximum, what demonstrates a considerable influence of gravitational component, and with that a relatively small elevation difference of 5m is predetermined at the kilometre pipeline section. Of note also is a change in the flow regime from transient to annular at the places, where liquid is accumulated. The results, shown in fig. 2,5 indicate that, under steady regime, liquid is accumulated in the pipeline “uphills”, and it is seen from the results in fig.4 of HOLDUP function distribution that all liquid is concentrated in the pipeline “valleys”, due to the effect of gravitational component and interfacial friction force, and friction on the walls as well.

Time domain provides the most interesting results. Analysing gas-dynamic parameters in time domain makes it possible to register, when taking gravitation into account, all unsteady-state processes occurring in the pipeline with complex shape. The results of computing gas-dynamic parameters at characteristic pipeline points are shown in figures 7-9. In descending section, gas-dynamic flow parameters are stable with no deviations detected. Within time interval, when valve gates are closed, there are small fluctuations in liquid velocity. At the maximum depth point (potential well bottom) periodic fluctuations are superimposed on the steady-state flow, which are clearly seen on the graphs of liquid velocity and HOLDUP function, what is suggestive of pulsating (slug) flow of liquid phase. However, the HOLDUP function value indicates that no liquid plug, fully shutting the pipeline off, is formed, as in the case of W-shaped pipe. It occurs when the liquid flow is stratified wave-like. Liquid is accumulated within the next uphill section (Fig.8,9), as HOLDUP function indicates, and rather large fluctuations in HOLDUP function are also seen, what implies that liquid moves in portions (slug regime). Transient (annular-stratified) to annular periodic changes in the flow regime take place here. Perhaps, such changes in the flow regime result in fluctuating liquid motion.

After shutdown, a change in the direction of liquid flow velocity to the opposite is seen (figure 9), liquid runs down from the ascending pipeline section with ongoing fluctuations. After liquid’s having dripped down the walls, some fluctuations in liquid phase velocity around zero value are observed (fig.9), mean velocity of liquid phase therewith is zero. Considerablefluctuationsarealsoseeninfigures 8, 9. Their oscillation period is comparable with the time of liquid flowing along the entire pipeline length due to potential reflection from the pipeline limit. These fluctuations must decay, what can be seen when the time specified for computations is very long.

Heat exchange with environment through double-layer heat-insulating coating were accounted for in the calculation. Pipeline warming and cooling processes are plainly seen in figures 7,8 on pressure and temperature graphs.

The computations have shown that under standard operation conditions in long-distance pipelines with complex elevation profile, highly unsteady regimes of fluid flow may emerge, which must be accounted for when designing pipeline systems of natural gas collection and transportation. In conditions of typical gas velocities of about 10 m/sec, transient flow regimes emerge, what is demonstrated by the performed calculations and is in compliance with the data given in articles (Nigmatulin, 1987, Okava 1999).

Modelling of multi-phase unsteady flows, when there are multi-velocity flows of gaseous and liquid phase in pipelines with elevation difference, shows that even with minor differences in elevations, velocities of phases change significantly. Specifically, within plain sections, the velocity of gaseous phase is about three times higher than the velocity of liquid phase, at the same time, in valleys this ratio increases by ten times and achieves thirty.

## Conclusion

Currently, empirical models employed in the TFS simulator, have been adapted to calculate the flows of multiphase mixtures of hydrocarbons within a wide range of thermobaric conditions. Such adaptation is performed based on the published results of laboratory studies on examining the flow of multiphase mixtures in channels. Development of adequate mathematical models and software codes describing the behaviour of multiphase flow in various systems and conditions constitutes a complex scientific and technical problem, many scientists throughout the world have dealt with. Actually, it is the development of non-conventional gas-hydrodynamics, based on some empirical relationships. Heterogenous substances, present in the mixture composition, require non-standard approaches to adequately describe physical phenomena, occurring in the processes.Different phases usually move with various velocities, what gives rise to such a physical process as interfacial friction. In this case, the processes associated with phase transitions, friction on the walls, and heat conductivity under various flow regimes need to be taken into account. Gravitation is a factor, which presence greatly affects the type of flows in pipes with elevation difference, because liquid phase is more inertial than gaseous. The considered calculations of computer-based simulation indicate that even with relatively small about 5m changes in elevations within 1km, more than 10 times change in the ratio between gaseous and liquid phase velocities takes place. The velocity of gaseous phase reaches 30 times higher values than the liquid phase velocity. We shall also mention that allowance for gravitational component may cause changes in flow regimes and even lead to such type of flow as slug. Most production systems have control systems, connected with such various elements as valves and gate valves, with unsteady flows therewith produced and flow regimes changed, what needs to be taken into consideration when designing and operating such facilities. Computations have shown that it is possible to implement intermittent regimes accounting for the effect of gravitation force in pipeline systems with elevation difference. Since the flow of multiphase mixtures in pipes and channels is an important process in many production systems, various scenarios need to be modelled that can unfold in the process of operation. The extraction process in gas and gas-condensate fields is such an example, although the research results may be of help in other sectors of economy, specifically, in the systems with multi-phase heat carrier for power installations. Flow management system implies its potential temporary cutting-off with subsequent actuation. Transient effects that occur in such cases, may lead to fluctuations, what needs to be taken into account in the design of pipeline systems.

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