Application of ANSYS/FLUENT software package for analysis of thermohydraulic processes in the low-temperature main pipeline for liquified hydrocarbon

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Abstract. The article discusses examination automation of thermohydraulic processes in the low-temperature main pipeline for liquified hydrocarbon. The computerized simulation of the nonisothermal flow of liquified hydrocarbon in the low-temperature main pipeline is performed by means of ANSYS/FLUENT software package. The authors have performed the analysis of the nature how the temperature and the pressure is distributed in the flow of liquified hydrocarbon mixture along the pipeline length. The computational model of the low-temperature pipeline for examination of hydraulic and thermal loss of the pumped mixture of liquified hydrocarbon is designed. The possibility of application of ANSYS/FLUENT computational fluid dynamics software package is proved for automation of thermohydraulic calculation of the low-temperature pipeline for liquified hydrocarbon mixture taking its thermophysical properties into account.

1. Introduction

The simulation experiment during scientific examinations carrying out is one of the key directions during studying of heat and mass exchange tasks. However for better understanding of physical effects, high cost or impossibility of the physical or natural experiment performance it is preferable to use different software applications and software packages for scientific and technical tasks solution [1-3].

At the present time a large number of researchers are busy with designing of the calculation methods and developing of the software applications and packages for scientific and technical tasks solution. Such software packages as ANSYS/FLUENT, Star-CD, Comsol Multiphysics, CFdesign, ADINA, FLOWVISION, etc. are known for solution of the tasks to calculate liquid and gas flow. In this article the application of computational fluid dynamics tasks is described relating to the pipeline transportation of oil and gas and their calculation by means of ANSYS/FLUENT software environment.

2. Computerized simulation

ANSYS/FLUENT is the part of the generalized program system of the ANSYS finite element analysis. In the software package the simulation of hydrocarbon flow with the wide range of
thermophysical properties changes by means of providing various parameters of simulation and application of multiple grid methods with improving convergence is performed [4].

In this project the virtual simulator of the low-temperature pipeline was built by means of ANSYS/FLUENT software environment. ANSYS/FLUENT software package is intergrated into ANSYS Workbench platfo rm. Such intergartion allows performing data exchange with other software packages, for example ANSYS (Mechanical, Maxwell, etc.), as well as with the external CAD-systems. This environment provides high productivity and application simplicity. The structure of the project is consistent and includes the following stages: geometrical arrangement designing by means of ANSYS DesignModeler, grid model designing by means of ANSYS Meshing, preliminary processing by means of CFX-Pre, solver ANSYS CFX-Solver Manager and post processing by means of ANSYS CFD-Post [5].

For calculation by means of software package ANSYS/FLUENT the following RANS turbulence models are available: the system of k-ε models (standard; Renormalized Group Model – RNG – on the basis of technology borrowed from the theory of renormalized groups), k-ω-model, SST (shear-stress transport model).

The standard k-ε turbulence model satisfies the tasks of pipeline transportation of multicomponent hydrocarbon which are oil and gas.

During transportation in the low-temperature pipelines the main problem is the nature of temperature and pressure distribution in the flow of transported product.

3. Temperature and pressure change in the flow of liquefied hydrocarbon mixture by means of ANSYS/FLUENT software package

In the published articles about the methods of hydraulic and thermal calculations of the pipelines for liquified gases analytical dependences were obtained for temperature and pressure distribution along the length of the pipeline during steady conditions of its flow, different allowances were adopted for some physical and chemical and thermodynamic properties of liquified hydrocarbon mixture [6].

In standard calculations thermophysical properties change along the length of the pipeline is not taken into account for oil. For the pipeline of liquified gases such accountantse is necessary. We suggest taking into account dependences of the change of pumped product thermophysical properties (density, heat capacity, viscosity, heat conductivity, compressability, etc.) on main parameters of the system (pressure and temperature).

The characteristic property of the given below hydraulic and thermal calculations of the low-temperature main pipeline is:

1. Low temperature of the pumped mixture to exclude two-phase flows formation of the pumped medium.
2. Pipeline laying by underground method as well as if it is necessary by ground surface, underwater methods, etc.
3. Comparatively small allowable level of temperature rise (adopted more than enough for temperature nearly 10 °C) between the intermediate pumping station and the intermediate cooling station.
4. Turbulent flow (self-similar mode) of the pumped product.

For nature analysis of temperature and pressure distribution in the pipeline by means of ANSYS/FLUENT software package a virtual model of the pipe for the underground low-temperature pipeline was designed having set all necessary reference geometrical data and boundary conditions. The pipeline model was consisted of four parts: the part of hydrocarbon mixture, the pipeline part, the insulation part and the ground part. As well as the hydraulic and thermal analysis of the pipeline model operation was carried out. This project includes the following stages: designing of the pipeline geometrical model, generation of the computational grid on the basis of the geometrical model, setting of the model boundary conditions and the model starting-up for calculation.

By means of ANSYS/FLUENT software package computerized simulation of the nonisothermal
flow of liquified hydrocarbon in the low-temperature pipeline was performed using the software package, the nature analysis of temperature and pressure distribution in the flow of liquified hydrocarbon mixture during thermophysical parameters change (density, heat conductivity and heat capacity) was carried out. During transportation of liquified hydrocarbon mixture it is recommended to take the change of thermophysical parameters along the length of the pipeline into account.

For the purpose of the nature analysis of temperature and pressure distribution in the pipeline by means of ANSYS/FLUENT software package a virtual model of the pipe for the underground low-temperature pipeline was designed having set all necessary reference geometrical data and boundary conditions (the pipeline with the nominal diameter 720mm, with the length 100m, with foam polyurethane heat insulation). The pipeline model was consisted of four parts: the part of hydrocarbon mixture, the pipeline part, the insulation part and the ground part. As well as the hydraulic and thermal analysis of the pipeline model operation was carried out. This project includes the following stages: designing of the pipeline geometrical model, generation of the computational grid on the basis of the geometrical model, setting of the model boundary conditions and the model starting-up for calculation. The designing final result of the computational grid of the pipeline virtual model is shown in Figure 1.

For the purpose of time reducing it is reasonable to cut twice fully-symmetrical parts of the virtual model because all processes flowing in the cut part will be absolutely identical to those which flow in the designed part. Simulation of the quarter of the model volume greatly reduce the calculation time without any influence on the final result. In our case the symmetry planes (section) are situated in planes XZ and YZ.

![Figure 1. Design grid](image)

The calculation results are listed below. In figure 2 the example of the temperature field for the cross section of the flow, the pipeline, thermal insulation and ground is shown.

To be noted that during transportation of liquified hydrocarbon on long distances the change of thermophysical parameters is great.
Figure 2. Temperature distribution in the cross section of the flow

Figures 3 and 4 shows the diagrams of temperature and pressure drop along the pipeline with the length of 100 meters.

Figure 3. Hydraulic gradient line.
Figure 4. Diagram of temperature change of the pumped product along the pipeline length

The calculations for one part of the low-temperature pipeline between two transfer intermediate pumping stations (IPS) and intermediate cooling stations (ICS) were performed. The authors analyze the thermohydraulic calculation of the low-temperature pipeline with producing capacity 5 mln tons per year (the pipeline diameter $D=0.72$ m) by means of ANSYS/FLUENT software package. At that the following basic data were used: initial pressure $P_i = 12$ MPa, allowable final pressure $P_f = 10$ MPa, initial temperature of liquified gas mixture $T_i = -50$ °C, allowable temperature of liquified gas mixture $T_n = -40$ °C, the part length $L = 10$ km, heat insulation – foam polyurethane, heat insulation thermal conductivity $\lambda_{ins} = 0.03$ W/m·K. It is required to determine the change of the flow parameter (pressure, temperature) along the length of the pipeline.

The results of pressure and temperature distribution along the the length of the pipeline part of liquified gases between IPS and ICS are shown in Figures 5 and 6. On the basis of the performed calculation it is allowed using the ANSYS/FLUENT software package to calculate pressure and temperature differences (taking thermophysical parameters change into account). It is proved the necessity of application of ANSYS/FLUENT computational fluid dynamics software package for thermohydraulic calculation of the low-temperature pipelines of liquified hydrocarbon mixture if the calculation high accuracy is required.

Figure 5. Pressure distribution along the length of pipeline part.
Figure 6. Temperature distribution along the length of pipeline part.

4. Conclusion
Consequently, for automation of thermohydraulic calculations the computerized simulation of the nonisothermal flow of liquified hydrocarbon in the low-temperature main pipeline is performed by means of ANSYS/FLUENT software package, as well as the nature analysis of temperature and pressure distribution in the flow of liquified hydrocarbon mixture during thermophysical parameters change (density, heat conductivity and heat capacity) was carried out. During transportation of liquified hydrocarbon mixture it is recommended to take the change of thermophysical parameters along the length of the pipeline into account.

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