HEAT AND GAS SUPPLY, SEWERAGE, BUILDING CONSTRUCTION OF WATER RESOURCES PROTECTION

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ON THE DEFINITION OF OPERATIONAL PARAMETERS OF TANK INSTALLATIONS IN COMBINED REGASIFICATION OF LIQUEFIED PETROLEUM GAS

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Statement of the problem. Combined regasification of liquefied petroleum gas is characterized by different operating conditions of the reservoir system. Varied selection of the vapor and liquid phases of the reservoir causes a significant trend component composition of the liquefied gas in the tank, which may adversely affect the efficiency of gas-powered equipment. This led to the need for additional research to determine the operating parameters of the reservoir installation with natural and artificial re-gasification of liquefied natural gas.

Results. A mathematical model allowing one to determine the content of propane at the beginning of the cycle and regasification before the next refueling, the amount of gas produced in the combined mode selection, the amount of gas produced in the natural mode regasification liquefied petroleum gas.

Conclusions. The efficiency of the combined cycle liquefied petroleum gas regasification providing significant savings of energy consumed in the evaporation plant. The contribution of natural evaporative capacity feed tank to the overall steam production plant is 33—58 %.

Keywords: liquefied petroleum gas, tank installation, combined regasification, natural evaporative capacity.

Introduction

Gas is commonly supplied to users residing remotely from natural gas pipelines based on liquefied hydrocarbon gas.

The use of gas in household applications (heating, cooking and hot water supply) is possible if tank setups of liquefied hydrocarbon gas. Gas supply systems using underground gas tank setups with artificial regasification are most common. Tank sets are thus fitted with special heat exchangers using hot water or water vapor, gas fuel combustion products, electrical energy for regasification [1, 2].

Studies of heat exchange in underground tank setups showed that natural evaporative capacity of tank setups has a large influence on the overall steam capacity.

Therefore the authors put forward a scheme of a combined regasification of liquefied hydrocarbon gas allowing one to fully account for natural evaporative capacity of tanks [3, 4].

An underground tank setup is thus fitted with a switch-on valve which while maintaining the pressure of a steam blanket P_0 provides alternate selection of vapor and liquid phases of liquefied hydrocarbon gas. The vapor phase of liquefied hydrocarbon gas is regenerated in the suction tank due to heat coming in from the subbase and the liquid phase undergoes regasification in the evaporator.

The operation of an underground tank setup means there are the following modes:

— mode of cooling of liquid down to a calculation state that corresponds with the pressure of adjusting the switch-on valve $P_0 = 0{,}15$ MPa (absolute) (natural regasification of liquefied hydrocarbon gas);

— a combination of selection of liquid and gaseous phases (combined regasification of liquefied hydrocarbon gas).

1. Developing a mathematical model describing a combined regasification of liquefied hydrocarbon gas. Combined selection of liquid and gas phases in the suction tank due to heat and mass exchange there is intensive dynamics of physical processes, quantitative evaluation of which is necessary to predict operational parameters of tank setups.

Let us express a rate of change of operational parameters of tank setups of liquefied hydrocarbon gas through a rate of change of its filling levels σ:

$$\frac{\partial F}{\partial \sigma}\cdot\frac{\partial \sigma}{\partial \tau}; \quad \frac{\partial M_{\Gamma}}{\partial \sigma}\cdot\frac{\partial \sigma}{\partial \tau}; \quad \frac{\partial M_{M}}{\partial \sigma}\cdot\frac{\partial \sigma}{\partial \tau}; \quad \frac{\partial t}{\partial \sigma}\cdot\frac{\partial \sigma}{\partial \tau}, \tag{1}$$

where F is a moistened surface of the tank setup; M_{Γ} is the mass of liquefied gas in the tank setup; M_M is the mass of a metal body contacting the liquid; σ is a level of filling of the tank setup; t is the temperature of the liquefied gas; τ is the time.

According to [5, 6], a rate of change of the parameters $\partial F / \partial \sigma$, $\partial M_{\Gamma} / \partial \sigma$, $\partial M_{M} / \partial \sigma$ in a range of change in filling of the tank setup from 15 to 85 % with no significant effect on the accuracy of calculations can be assumed to be constant with the maximum error of 4—5 %.

This equally applies to a rate of change in the temperature of liquefied gas $\partial t/\partial\tau$ and level of its filling $\partial\sigma/\partial\tau$.

Considering the accepted admissions let us write the equation of a heat balance of the tank setup with a cooling mode of the liquid:

$$k\left(\frac{F_H+F_K}{2}\right)\left(t_{гр}-t\right)d\tau+\left[C_г\left(\frac{M_Г^H+M_Г^K}{2}\right)+C_M\left(\frac{M_M^H+M_M^K}{2}\right)\right]d\tau=rgd\tau, \qquad (2)$$

where k is the coefficient of heat transfer of the tank setup (according to [5] depending on the volume of a tank setup and heat conductivity of the base); dependences on the volume of the tank setup and heat conductivity of the base course); $C_Г$, C_M are heat conductivity of liquefied gas and metal body of the tank setup; r is latent hear of vapor of liquefied gas; $t_{гр}$ is a natural temperature of the base course on the axes of laying of the tank setup; g is the consumption of liquefied gas. Letter indices «*b*» and «*e*» stand for the beginning and ending of cooling of the liquid in the underground tank setup.

Dividing the variables and integrating we get

$$\tau_{охл}=\frac{C_г\left[\left[\left(\frac{M_Г^H+M_Г^K}{2}\right)\right]\right]+C_M\left[\left[\left(\frac{M_M^H+M_M^K}{2}\right)\right]\right]}{k\left[(F_H+F_K)/2\right]}\times\ln\frac{rg-k[(F_H+F_K)/2](t_{гр}-t_H)}{rg-k[(F_H+F_K)/2](t_{гр}-t_K)}. \qquad (3)$$

As the initial temperature of liquefied gas following the filling of the tank setup is assumed to be the temperature of the air outside, i.e. $t_н = t_в$.

Calculation parameters $M_Г^H$, M_M^H, F_H correspond to the initial level of filling of the tank setup $\sigma_н = 85$ %. The parameters $M_Г^K$, M_M^K, F_K are assumed depending on filling of the tank setup at the end of cooling $\tau_{охл}$.

The temperature of the liquefied gas at the end of cooling t_K is determined according to the diagrams: the composition temperature [7] for corresponding parameters of liquefied gas P_K and Ψ_K:

— $P_K = P_0$ is the pressure of gas in the tank setup corresponding to the beginning of combined regasification;

— Ψ_K is the amount of propane in the liquid phase at the end of cooling.

The amount of propane in the liquid phase of gas Ψ_K in the tank setup at the end of cooling depends on the initial amount of propane Ψ_H and relative percentage of vaporized gas φ according to the formula [7]

$$\frac{\psi_K}{(1-\psi_K)^m}=\frac{\psi_H\left(1-\frac{M_Г^H-M_Г^K}{M_Г^H}\right)^{m-1}}{(1-\psi_H)^m}, \qquad (4)$$

where m is the ratio of the elasticity of propane vapors and n-butane. It is accepted according to thermodynamic tables depending on the average temperature of liquid in the tank setup. Equation (3) is solved using the iteration method by choosing the corresponding values $\tau_{охл}$, at which the left and right part of the equation are linked with a specified accuracy. As the tank setup switches off a combined regasification, the latter provides the user with only that part of vapor that is due to natural heat coming in from the base course. The rest is generated by the evaporator.

The amount of vapor obtained in the tank setup during a combined regasification:

$$G_o = \frac{k\left(F_К + F_o\right)\left(t_{гр} - \frac{t_К + t_o}{2}\right)\tau_o}{2r}, \tag{5}$$

where t_o is the temperature of the liquefied gas prior to another filling; F_o is a moisturized surface of the tank setup prior to another filling; τ_o is the length of a combined regasification.

The length of the regasification mode is as follows

$$\tau_o = \frac{M_Г^Н - M_Г^О}{g} - \tau_{охл}, \tag{6}$$

where $M_Г^О$ is the mass of gas in the tank setup prior to another filling.

The total amount of vapours obtained in the tank setup in between fillings:

$$G = g\tau_{охл} + G_o. \tag{7}$$

The relative percentage of liquefied gas obtained due to natural evaporative capacity of the tank setup:

$$\phi = \frac{G}{M_Г^Н - M_Г^О}. \tag{8}$$

Equation (5) is solved by the iteration method by linking the left and the right parts with a necessary accuracy. Specifying a range of values of t_o we get the amount of vapor G_o. Hence using the values of G_o according to the formulas (7) and (8) we get the relative percentage of evaporated gas obtained due to natural evaporative capacity of the tank setup φ and using the formula (4) the residual amount of propane in liquid prior to another filling $\Psi_К = \Psi_0$. Then according to the diagrams [7], knowing the composition of the liquid phase in the tank setup Ψ_0 and the pressure in a combined regasification P_o, we determine the temperature of liquefied gas t_o prior to another filling of the tank setup.

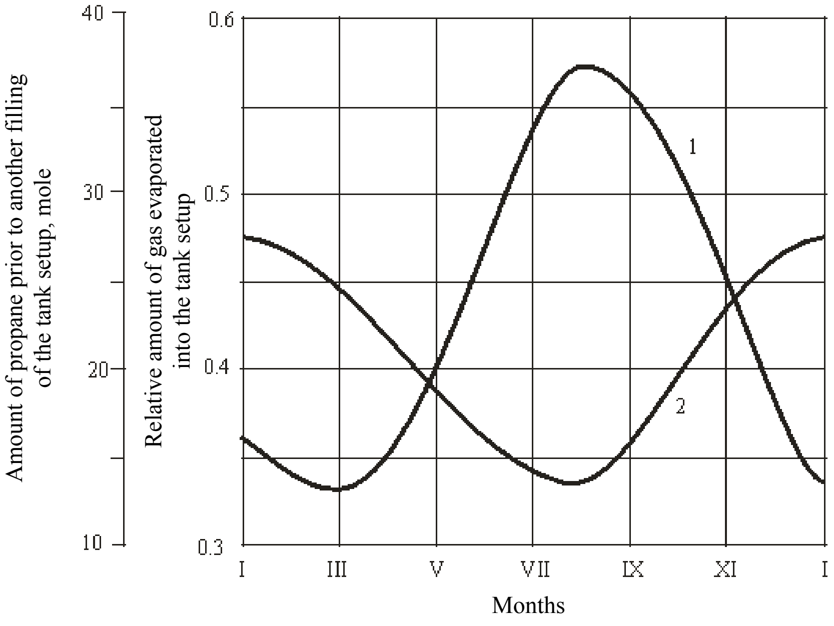

Fig. Calculation characteristics of combined regasification of liquefied gas (the amount of propane in the supplied gas is 50 %):
1 is a relative amount of gas evaporated in the tank setup;
2 is the amount of propane in the tank setup prior to another filling

2. Implementing a mathematical model of a combined regasification of liquefied hydrocarbon gas. For numerical implementation of the suggested mathematical model (1)—(8) the corresponding calculations were performed. The following initial data was used:
— climatic areas of the operation of an underground tank setup — Orenburg;
— geometric volume of an underground tank setup is 5,0 m^3;
— calculation gas pressure in a tank setup P_o = 0,15 MPa (absolute);
— amount of propane in the supplied $\Psi_н$ = 50 moles %;
— residual gas level in a tank setup σ = 25 %;
— average consumption of liquefied gas per hour g = 10 kg/h.

For a specified consumption of gas in a tank setup, the supply of gas in a tank setup keeps it running for a week. During calculations the annual range of the operation of a setup is broken down into ranges per month where natural temperatures of the base course and the air outside were assumed as specified according to the climate data of the area in [8]. The results are shown in Fig.

As the graph suggests, selection of vapors in an underground tank setup causes significant fluctuations of the composition of the liquefied hydrocarbon gas. The amount of propane in the liquid phase ranged from 50 moles % (following another filling) to 14—28 % (prior to another filling). However due to almost identical physical and chemical properties of propane and butane these fluctuations do not largely impact gas setups. Changes in the Wobbe index describing a heat load of devices is not over ±5 %, which meets the requirements of interchangeability of combustible gases.

Conclusions

1. A mathematical model has been first developed to describe a combined regasification of liquefied hydrocarbon gas and to determine operational parameters of a tank setup in natural and artificial regasification of liquefied gas.
2. The results of numerical implementation of the mathematical model show that the contribution of natural evaporative capacity of a suction tank into the overall performance of a setup changes from 33 in the winter season and to 58 % in the summer season.
3. A combined regasification significantly saves energy for evaporative setups. A switch from artificial to combined regasification of liquefied hydrocarbon gas saves of up to 45—46 % of energy for regasification per year.

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