Conduction of a Laboratory Experiment with the Goal of Researching Submerged Flow Peculiarities

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Abstract. In connection with the decreasing hydrocarbon reserves on land, the interest of researchers in new alternative methods of hydrocarbon production is growing. One of the actively developing areas is the production of hydrocarbons from deep-water deposits, in connection with which the share of developed deposits in the water area of the World Ocean is growing every year. However, this production method is not completely safe, since any damage to the production structure can lead to leakage of hydrocarbons. In this case, hydrocarbons are distributed in the form of a submerged jet. Predicting the behavior of submerged jets, calculating their trajectories and thermophysical parameters is important in the elimination of leakage. The article discusses an experimental study of a submerged jet. The results of the experiment will make it possible to verify the mathematical model describing the propagation of a submerged jet. The experiment was carried out to study the trajectory of the jet and its temperature. This paper presents the results on the analysis of the jet trajectory. In the experiment, gasoline or diesel fuel was used as a liquid, air was used as a gas. The work shows a diagram of the experimental setup, describes the process of the experiment, and also shows a photograph of the experiment and a comparison with the results of calculations.

1. Introduction

The process of deep-sea hydrocarbon recovery in the shelf is promising: the bowels of the World Ocean contain most of the hydrocarbon reserves (oil, gas and hydrates) and are practically untouched. The negative aspect is the increased likelihood of a hydrocarbon spill that can occur during production. In this case, hydrocarbons are distributed in the form of a submerged flow. The relevance of the study of submerged jets is associated with the need to predict the features of the oil flow, which will make it possible to understand how the jet will behave and what measures can be taken to contain the spill. Thus, the study of the peculiarities of submerged jets is a necessary fundamental component to prevent man-made leaks when using of deep-water wells. One of the ways to eliminate leaks is considered in [1-2].

The experiment performed allows us to verify the mathematical model of the flow of submerged jets, which is generally written for the case of a multiphase submerged jet propagating at great depths under conditions of stable hydrate existence. This model is described in more detail in [3-5] and can be modified for the case of a jet flow at shallow depths. The study of hydrates is important from the point
of view of the study of alternative methods of hydrocarbon production [6-10]. For more information about the features of the spread of submerged jets in the works [11-21]. The calculation results obtained using this model will be compared with the experimental results.

2. Conducting an experiment

To study the trajectory of the submerged jet, the following setup was assembled: at the bottom of a water-filled aquarium, a nozzle with a flexible tube supplied to it is fixed, through which liquid (gasoline or diesel fuel) is supplied using a low-power electric pump (Figure 1). The nozzle is fixed in such a way that at the initial moment the jet velocity is directed vertically. The pump power is regulated by variac. The results of the experiment are recorded on a camera directed at the front surface of the aquarium. To assess the linear dimensions, a scale is used, which is attached to the back wall of the aquarium. The density of the liquid supplied through the nozzle (gasoline or diesel) is measured using a hydrometer.

To measure the volumetric flow rate of the liquid supplied from the nozzle, a 400 ml graduated beaker, fixed upside down, is used. The distance from the nozzle through which the jet is supplied to the lower edge of the beaker is 20 cm. The filling time of each subsequent 50 ml of the volume of the graduated beaker is measured. Knowing the filling time, the volumetric flow rate of the supplied liquid is determined.

![Figure 1. Experimental setup scheme: 1 — aquarium, 2 — tube, 3 — electric pump, 4 — diesel fuel container.](image)

During the experiment, the nozzle was fixed vertically. Gasoline is dispensed from the nozzle. Figure 2 shows the configuration of the jet at a certain moment in time. The volumetric consumption of gasoline is $Q_o^c=1.09 \cdot 10^{-5}$ m$^3$/s, the radius of the nozzle is $r = 0.2$ cm, gasoline density is $\rho_o=760$ kg/m$^3$, and the water density is $\rho_w=1000$ kg/m$^3$. 
Figure 2. Photo of the experiment.

Figure 3 shows a photograph of the experiment, combined with the results of calculations of the mathematical model [3] for the initial parameters. It can be determined from the figure that a qualitative match was obtained between the experimental and calculated results.

Let us compare the obtained and empirical data given in [11]. Let us determine the specific impulse flux at the mouth $M_0$ and the specific buoyancy flux $F_0$:

$$M_0 = Q_0 \cdot w_0, \quad F_0 = Q_0 \cdot (g \Delta \rho / \rho_w).$$

Figure 3. Jet’s trajectory (solid line) combined with the experiment photo. Starting parameters: $r=0.2 \text{ cm}$, $Q_0=1.09 \cdot 10^{-5} \text{ m}^3/\text{s}$, $\rho_o=760 \text{ kg/m}^3$, $\rho_w=1000 \text{ kg/m}^3$, $\varphi=90^\circ$, $\tan \gamma=0.154$. 
Then the distance at which the specific impulse of the buoyancy force exceeds the specific impulse acquired by the jet at the beginning:

\[ z_s = \frac{M_0^{3/4}}{F_0^{1/2}} \]  \hspace{1cm} (1)

The radius of the jet at height \( z \) is represented as:

\[ b = b_0 + \beta z, \]  \hspace{1cm} (2)

where \( \beta = 0.149 \) is an empirical parameter.

Jet lift velocity and volumetric flow rate in cross section \( z \):

\[ w = \left( \frac{M}{nb^2} \right)^{1/2}, \quad Q = \pi wb^2. \]  \hspace{1cm} (3)

The temperature in any cross section of the jet can be determined, assuming that it is the same in the cross section, and depends only on the coordinate \( z \):

\[ T_{jet} = T_w + (T^v - T_w) \frac{(Q_v^e + Q_g^e)}{Q}. \]  \hspace{1cm} (4)

For the case of the experiment, the distance at which the specific impulse of the buoyancy force exceeds the specific impulse acquired by the jet at the beginning is \( z_s = 3.4 \) cm.

3. Results

An experiment was carried out to study the flow of a submerged jet in laboratory conditions. The data obtained during the experiments were compared with the results calculated by the integral Lagrangian control volume method. Paper also shows estimates of empirical data which is consistent with the results of the experiment.

4. References

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