Stabilization of fluid flow rate upstream the verifiable instrument

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Abstract. Results of experimental study of free fluid surface in a fixed long tank (pressure tank) in conditions of mass transfer through the tank are presented. The research has been conducted on an experimental setup that included a model pressure tank to improve the State Primary Standard of volume flow rate GET 64–74 and a simplified system of fluid motion. The effect of free surface wave amplitude in the tank on stability of flow rate maintenance through the metering line of the Standard has been estimated.

1. Introduction

The current system of metrological support for measuring the liquid flow provides a unit of volumetric flow to a high-precision metering instrument (SI) in the range of 36-500 m³/h at a pressure of up to 1 MPa. In 2013, it was decided to improve the State Primary Standard of volume flow rate GET 64-74 in order to expand the flow rate range up to 2000 m³/h. Changes were made to the hydraulic schematic of the Standard aiming to improve the characteristics of the latter, including the stability of the flow rate through the metering line. For damping the pump-generated oscillations of the free fluid surface (level), the fluid supply circuit between the pump group and metering line is broken in the new scheme. There is a pressure tank with a fluid at the point of gap, and an air ullage with an automatically regulated level of overpressure is generated above the free fluid surface. The fluid flow through the metering line is associated with the pressure drop between the pressure tank and outlet atmospheric pressure. If preset pressure and average fluid level in the air ullage of the pressure tank is maintained automatically, the stability of the flow rate depends on the amplitude of fluid’s level oscillations relative to the mean value and free surface wave amplitude.

The research results of free fluid surface in fixed or moving vessels, in particular with different internal baffles, are presented in [1-9]. Despite the variety of problems on the free fluid surface in a vessel, there is practically no variants of formulation of such a problem under conditions of inflow and outflow of fluid. In these cases, not only the gravitational forces, but also the dynamics of the fluid flow effected on the shape and nature of the oscillations of free fluid surface.

The goal of this work is the experimental research of ripple fluid level in pressure tank. The studies were carried out in an experimental setup included a 6:1 pressure tank model and simplified fluid flow system.
2. Problem statement and experimental setup

A setup simulating fluid motion in the Standard line was designed for experimental studies of free fluid surface in a model pressure tank. The experimental setup is shown in figure 1. When the centrifugal pump 1 is switched on, the fluid through line 2 enters the model pressure tank 4 of the experimental setup, then it returns to the suction pipe of the pump through line 10. The main lines of the setup are filled through the vertical pipe 8, and its drainage adjusts through the valve 9. To ensure stable operation of the pump at low flow rates, a by-pass 15 with a valve 14 and an output device 13 is used, through which part of the fluid returns to the suction line of the pump. The fluid flow rate is controlled by the valve 3. For the convenience of observation and video recording of the free fluid surface in the upper part of the pressure tank, a window 6 margined by a box 7 with transparent walls is cut out. The total pressure above this surface corresponds to atmospheric pressure. The actual flow rate through the model pressure tank was measured by the difference of fluid levels in the total head 12 and static pressure 11 pipes. The dimensions of the model pressure tank and the diameter of the supply line 2 are six times smaller than the dimensions of the same elements in the Standard.

The pressure tank consists of two interconnected cavities. The first cavity 17 with a smaller volume serves to suppress the dynamic head of the liquid stream coming from the pipeline 2, for this purpose, a conic diverging channel 16 is installed in the outlet section of the supply line. With the same purpose of reducing the dynamic head, the supply of liquid to the main cavity of the pressure tank is arranged through two inlet sections:
- the supply of liquid to the far wall (figure 1, right) of the main cavity is carried out through a pipe with a conic diverging channel 21 at the end;
- the liquid to the near wall (figure 1, left) is supplied through the annular divergent channel 18.

Inside the latter the above-mentioned liquid supply pipe to the far wall is located.

The main task of the experiments is to study the shape and processes of oscillation of the free fluid surface in a pressure tank when supplying fluid flow. Therefore, the key issue was to ensure the similarity of the processes in the full-size and model tanks. If the gravitational forces predominate in

![Figure 1. Experimental setup: 1 – centrifugal pump; 2, 10 – lines; 3, 9, 14 – valves; 4 – pressure tank; 5 – free fluid surface; 6 – window; 7 – box; 8, 11, 12 – vertical pipe, static pressure pipe, total head pipe, respectively; 13 – output device; 15 – by-pass; 16, 21 – conic diverging channel; 17 – cavity of pressure tank; 18 – annular divergent channel; 19, 20 – air taps.](image-url)
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the process of the present case, then the Froude number serves as the main similarity criterion \( Fr = \frac{V}{(gh)^{0.5}} \), where \( V \) is the average flow velocity, \( h \) is the depth of the liquid in the pressure tank, \( g \) is the acceleration of gravity. The equality of the Froude numbers of the actual and model flows provides a geometric similarity of waves on the free fluid surface. When simulating jet streams excluding the buoyancy forces, the Reynolds number \( Re \) is the main similarity criterion. Thus, for total hydrodynamic similarity of the free fluid surface in vessels under conditions of inflow and outflow, it is necessary to observe similarity according to both two criteria - the numbers \( Fr \) and \( Re \). The total hydrodynamic similarity of flows according to both Froude and Reynolds criteria is impossible, therefore the Froude criterion was chosen as the main determining criterion. In accordance with this, the ratio of the linear dimensions of the experimental and full-size setups is identically equal to the square of the ratio of flow rates in the full-size and model tanks and is identically equal to the ratio of corresponding flow rates to the power of 0.4.

The internal diameter of a 6:1 model pressure tank was 200 mm, the length of the tank was 1400 mm. The maximum fluid flow through the supply line of the experimental setup was \( Q = 22.7 \text{ m}^3/\text{h} \) (corresponding to a flow rate of 2000 m\(^3\)/h in the supply line of the full-size setup). This value was accepted as the main one in the preparation and conduct of experiments. Additionally, studies were carried out at \( Q/2, Q/3 \). These rates were monitored under the difference of fluid levels in the pipes. During the experiment, a video of the free fluid surface in a tank with a frequency of 50 Hz was recorded. The maximum height of waves and the amplitude of their oscillations on the fluid surface was measured by a ruler graduated in 1 mm.

3. Results

As a result, it was found experimentally that a local decrease in the average fluid level is observed upstream from the edge of the conical divergent channel, the maximum fluid level is of the order of 10 mm, figure 2. Near the opposite edge of the tank, due to the turn of the fluid flowing from the pipe, an increase in the average fluid level in the tank by approximately 20 mm followed by a decrease at a distance from this region is obtained. Oscillations of the fluid surface are irregular, the amplitude of the oscillations is less than 8-10 mm. Near the free surface, the surface masses drift in the direction from the inlet section of the tank (annular divergent channel). Video fragment of the free fluid surface in the pressure tank of the experimental setup at a flow rate \( Q = 22.7 \text{ m}^3/\text{h} \) is shown in figure 2.

Figure 2. (Left) Free surface in experimental tank \( Q = 22.7 \text{ m}^3/\text{h} \); (Right) Video snapshot of free fluid surface in pressure tank of experimental setup at \( Q = 22.7 \text{ m}^3/\text{h} \).

4. Conclusions

Experimental studies of the free fluid surface in a fixed long tank under conditions of mass transfer of fluid between the tank and external air are performed. The obtained results can be used in the design and construction of a pressure tank for the improvement of the GET 64-74. It is shown that in modeling such flows, the Froude number can be chosen as the main determining criterion for similarity. This criterion allows determination of the fluid rate flowing to the model tank of the experimental setup. The flow rate provides an adequate simulation of the shape of the free fluid surface: the deviation of the fluid level from its average value referred to the diameter of the corresponding tank is approximately the same.
The proposed method of supplying fluid to the pressure tank makes it possible to reduce approximately twice the Froude number of the flow and hence the irregularity and amplitude of oscillations of the free fluid surface. It is shown that the shape of the free fluid surface remains stable and does not change with time and the small amplitude of the free-surface oscillations does not exceed 15 mm with the fluid supply system selected. This amplitude causes a change in the flow fluid rate through the metering line of the Standard not more than 0.0125%, which does not affect the stability of the flow rate.

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