Abstract. The basic constructive and methodical limitations of using well log tool are revealed. This problem requires fair quantities of experimental researches by using special-purpose hydrodynamic stand. The stand description is given. The stand models of well conditions for slope and horizontal borehole. The results of special log tool testing in multi-phase flow conditions are given. The necessity of physical modeling of interaction well log tool and multi-phase flow with using the hydrodynamic stand is shown.

Keywords: horizontal wells, log tool, multi-phase flows, phase flow rate, control of oil-field development

The process of obtaining quantitative characteristics of well and bed operation from the results of a geophysical survey is always important and complex, being especially difficult under the conditions of a multiphase composition of the extracted product. One of the ways to solve this problem is to develop specific well tools with distributed sensors which provide the scanning of the physical fields in the fluid flow along the cross-section of the borehole. At present several groups of specialists are working over development and manufacturing application of the multi-sensor equipment which assesses the fluid composition by the cross-section and measures the temperature field and the flow velocity. The transfer to the quantitative parameters of a fluid (phase velocities, inflow profile) is carried out with the help of specialized algorithms of processing the initial signal. In this case, a fluid composition is identified according to the criteria defined in the laboratory on the basis of standard fluids, and a fluid velocity is identified according to the results of tool calibration on the vertical stand in pure water [1, 2].

Manufacturing application of specialized well tools together with the survey of operating horizontal wells showed great difference between the claimed parameters and the actual ones, observed under real conditions. As a result, quantitative parameters measured in the borehole are significantly different from those obtained with wellhead tools. Thus, the question of reliability of the results of well survey and the correct work of algorithms of processing the initial information is especially crucial at the early stage of development of specialized equipment.

The analysis of global experience shows that obtaining quantitative parameters of a flow requires a considerable volume of experimental research on a specialized hydrodynamic stand which simulates well conditions when well equipment is tested, to obtain interpretation criteria and improve processing algorithms. For example, Schlum-
berger well equipment FSI developed to survey operating horizontal wells was tested in
detail on the hydrostand [3].

A similar stand is developed and functions in Bashkir State University [4]. The
stand is constantly being modernized and at present it provides the opportunity to work
with three-phase flows (water, mineral oil, gas) in a wide range of rates and at various
angles of borehole inclination. To test the equipment in an inclined well a simulator was
developed and made. It has a changeable angle of inclination of 0 - 90 degrees and is
able to simulate one-, two-, and three-phase flows – Fig. 1. Metrological performance of
the stand is certified by State Unitary Enterprise Metrological Center “Ural-Geo”.

![Module of multiphase hydrostand with alternate angle of borehole inclination.](image)

Fig. 1. Module of multiphase hydrostand with alternate angle of borehole inclination.

By the present time practically all home developments of flow-metric well equ-
ipment for the survey of operating horizontal wells have been tested on the stand. The
results of testing showed that carrying out the equipment survey in the multiphase flow
on the stand allows to improve considerably the operating characteristics of the tool
before its manufacturing application, or to correct development mistakes which were
made and not found out during the traditional testing of the equipment in the metrolo-
gical center. For example, complex testing was carried out on the hydrostand for devel-
oping the operational module of mechanical flow survey of the complex borehole tool
XXX to work under the conditions of low production rate with multi-phase flows. The
results of industrial survey in horizontal and controlled directional wells with two-phase
flows showed that the tool is not adaptable for highlighting functioning intervals with
the production rate less than 50 m³/24 h. The main obstacle is a high level of fluctuation
for readings of the mechanical flowmeter, reaching ± 25 m³/24 h in a string with a dia-
meter of 114 mm. As a working version of such a high level of noise there was a hypo-
thesis put forward of the influence of free gas on the operation of the turbine. However,
the results of testing the tool on the stand, under the conditions of one- and two-phase flows proved that the mode of a stratified flow characterizing horizontal and directional wells does not affect the work of the flowmeter sensor. A deeper survey of the tool work showed the necessity to change the algorithm of processing the initial signal, which is taken from the turbine of the flowmeter. Due to the modernization carried out on the programming level, the noise was reduced significantly and the resolution capacity of the module of hydrodynamic flowmeter reached more than 2 m³/24 h in the string with the inner diameter of 150 mm, without any changes in the design of the tool. The initial testing results and the results obtained after modernization are given in Fig. 2.

![Fig. 2. Results of assessing the level of noise produced by the mechanic flowmeter on the stand before and after modernization](image)

In the process of testing the tool XXX one more characteristic in the module of hydrodynamic flowmeter was found out, leading to great differences of the hydrodynamic well survey results with the field data. Fig. 3 shows the results of mechanic flowmeter calibration completed in water and oil at different angles of borehole inclination. As it is seen, the change of properties of the operating fluid, with the geometric tool and stand parameters unchanged, results in the change of the coefficient value of transforming the working turbine in the module of hydrodynamic flowmeter. Thus, it should be admitted that the metrological parameters of the flowmeter module stated in

the registration certificate are referred to calibration conditions only and cannot be applied to actual operating conditions.

A more complicated situation takes place under the conditions of a mixed flow, water + oil or oil + gas. The results of testing the tool YYY, with a diameter of 42 mm in the tubing of 63 mm of the inner diameter (Fig. 4, 5), have proved that the possibility to obtain quantitative parameters of the mixed flow with the use of the traditional non-packer flowmeter is doubtful. Regardless of the high flow velocity and the turbulent flow character, the flowmeter reaction depends to a great extend on the relation of phase flow rate to the angle of borehole inclination. In this case, the final readings of the sensor can both increase and decline.

Fig. 6 gives the results of testing the STI sensor (thermo-conductive inflow indicator) mounted on the industrial well equipment in one-phase flow at different flow rates. The survey is completed on a separate sensor and on a sensor in the complex well equipment, which was located in the flow on the pipe axe of 150 mm in diameter, the supply current and the fluid composition remaining unchanged. It was traditionally believed that the STI sensor (thermo-conductive inflow indicator) in the borehole equipment gives information at low flow rates, up to 60 m³/24 h, and registration velocities do not exceed 5 - 7 cm/sec (up to 200 m/h). In connection with that, there was a severe limitation in the registration velocity of STI (thermo-conductive inflow indicator) diagrams. Besides, the function of transforming the STI sensor (thermo-conductive inflow indicator) was considered nonlinear, and it was impossible to use it for the quantitative interpretation (making inflow profile/absorption), even in one-phase medium.

As we can see, the function of transforming the STI module (thermo-conductive inflow indicator) in the complex equipment turned to be practically linear within the range of velocities from 1 to 10 cm/sec (0 - 150 m³/24 h). In contrast, the same graph shows the results of STI sensor (thermo-conductive inflow indicator) calibration without the tool, which are characterized by obvious nonlinear effect. The results obtained are explained by the fact that the flow structure changes due to the tool box and local whirls appearing in the zone of the sensor, which change considerably the process of heat exchange between the sensor and the borehole medium.

The fact of distortion of the flow mode by the borehole equipment is clearly seen in Fig. 7. The survey is completed in a stratified flow of oil and water, which is characteristic of operating horizontal wells. Putting the borehole equipment into a stabilized stratified flow with a clear borderline of the phases leads to considerable redistribution of water and oil flows and shifts the borderline between the phases in relation to the initial position in the free pipe. A similar result is obtained in mathematical simulation of the interaction between the tool and a two-phase stratified flow. The simulation is completed in cooperation with the Institute of Mechanics, Ufa Scientific Center of Russian Academy of Sciences (scientific adviser S.F. Urmancheyev).
Fig. 3. Dependence of the results of the hydrodynamic flow survey on the fluid composition at different angles of borehole inclination. The survey is done in the tubing of 2.5”, the curve code is the angle relative to the horizon.

Fig. 4. Results of testing mechanic flowmeter in the mixed flow oil + gas. The curve code is the angle of borehole inclination. The flow rate of oil is fixed, the flow rate of gas is variable.

Fig. 5. Results of testing mechanic flowmeter in the mixed flow water + oil at different angles of inclination. The curve code is different ratio of flow rates.
Fig. 6. Results of surveying the reaction of a separate STI sensor (thermo-conductive inflow indicator) and in complex borehole equipment to the linear one-phase flow

Fig. 7. Distortion of the borderline between the phases in the flow due to the installation of the tool at different ratios of water and oil production rate:
   a – experiment; b – mathematical simulation

A strict dependence of the flow distortion character is not fixed at present. However, it is obvious that the effect is determined by the construction of the tool, the well path and fluid parameters. Contemporary processing programs contain the module of calculating the water and oil content in the flow section by the data of the distributed composition sensors, or water hold up. Further on, this indicator is used for calculating phase flow rates. The appropriate application of this algorithm is possible under the condition that the distributed composition sensors interact with the undistorted flow, and there is no influence of the tool box [5]. However, the results of the survey on the stand prove the opposite. To obtain trustworthy results it is of importance to study the reaction of the borehole equipment to a mixed flow experimentally, under various conditions. It will help to determine correcting factors empirically to be used in calculations.
Fig. 8 shows the results of testing the borehole tool AGAT KG-42 STB-6, which is widely used in production, with 6 distributed sensors of bottom-hole sludge and water monitor in a mixed flow water+oil. The survey is carried out in a vertical inclined well at various ratios of phase flow rates, the total rate being $Q_{\text{Oil-water}} = 2 \text{ m}^3/\text{h}$.

Fig. 8. Results of processing the data obtained while testing the complex tool AGAT KG-42 STB-6 in a mixed flow in a vertical and inclined pipe
According to the results of visual examinations, the structure of the flow at the given rates and characteristics of the oil used on the stand is mainly dropping. If the water share is more than 30\%, one can observe oil drops chaotically emerging in the water phase, with less water share – the drops of water in the oil flow. The data have been processed using a special algorithm in the system *Prime*, without taking into account the influence of the tool on the flow structure, with standard data on the calibration of composition sensors. As it can be seen, the result of the used algorithm confirms the tendency in the change of phase rates, but the quantitative parameters of the flow differ from the real ones. Thus, direct use of the results of the tool calibration in water and diesel fuel, which was completed at the wellhead, or the results of calibration in a metrological center in tanks with immobile fluid, does not provide the accuracy of real water share in the flow.

**Conclusions**

The results of a wide range of experiments completed on the thermal hydrodynamic stand in Bashkir State University have shown the necessity of physical simulation of the interaction between the operating borehole equipment and the tools being developed and the multi-phase flow. The results of testing the tools under the conditions similar to the well are necessary to optimize the construction of the tools and to find factors transforming the sensors which are used to process the initial information and give the quantitative parameters of the flow.

**References**


