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NONDESTRUCTIVE TECHNIQUES TO CONTROL THE QUALITY AND QUANTITY OF OIL FLOWS

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The article considers the issue of improving the efficiency of exploiting the acting oil fields and transportation system on the basis of modern hi-tech technologies to control the extracted and transported material. Factors are studied that lower the reliability of oil flow measurements, both qualitatively and quantitatively, the main ambiguities are described of using current systems for metrological account of oil transported through the pipelines. The effect is studied of inclusions in the transported oil flow on measurement efficiency.

A technique is suggested for selective measurements of separate phases in the complex multi-phase flows with isotropic radio emission, the principal relationships are presented to describe the intensity of direct and scattered gamma-radiation on flow parameters. Criteria are given for developing a measurement system that would control the actual component composition of the flow with time, hence the amount of oil transported; that would enable organizing a centralized open department to control the quality of oil and transportation conditions, upgrade the level of production and provide high measurement accuracy.

Results are presented of testing the technique on an operating oil field; the relative error margin of measuring free gas content was 0.2 %. The range is reviewed of possible applications for the measurement system of multiphase multi-component flows, developed in the Saint Petersburg Mining University.

Key words**:** flow, oil, free gas, backbone pipeline, radioisotopic radiation, Compton scattering, photoelectron absorption, quantum, discharge.

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Introduction. All the industries handling large masses of raw materials or products have to deal with large scale spatially distributed complex topologies and geographies of flow transportation systems. Generally, flows may be split into two types: homogenic (Newtonian) and heterogenic (multiphase and multi-component). One of the extremely important common characteristics of heterogenic flows is their inhomogeneity, corresponding, in particular, to specific features of hydrocarbon flows in oil industry.

Under the conditions of low global oil prices it will be extremely difficult to maintain the achieved level of oil production even in the mid-range prospect: developing new deposits would demand extra support, including that from the state. In such a situation the proper way forward lies with upgrading the efficiency of exploiting operational fields on the basis of high tech extraction technologies and control of raw materials produced and transported. This fact proves close attention of the state to that issue as manifested by the adoption of numerous regulatory documents. Flow metrology in mining industry to provide measurements on sites of oil and gas complex numbers more than 120 such regulatory documents [4, 5, 11]. Consider, for example, GOST R8.615-2005 "State System for Ensuring the Uniformity of Measurements. Measuring the Amount of oil and associated gas Extracted from Earth Entrails. General Metrological and Technical Requirements". It requires measuring the composition, properties and amount of produced oil, periodicity of studies, permissible error margins and sets other specifications. Practically it turns out as the need to measure and record in real time (the account being recorded and TID protected) the discharge and amount of gas, water and oil, produced at each well; measure the microconcentration of free gas and water in the backbone oil pipeline. Providing accurate component-by-component measurement of the discharge of hydrocarbon flows will make it possible to upgrade production level via implementing the respective production complexes and lower the level of harpy wastes of the national oil reserves [3].

Task setting. The analysis of measurement systems for oil flows used in the course of its production and transportation has demonstrated that the requirements of state standard are often violated (the main causes for that are presented in Fig. 1). In particular, the problem arises because of the complexity of the task of determining concentration of inclusions (free gas, water) in the flows of transported substance. This is an outrageous violation of technology regulations, which entails an avalanche of deteriorations in the techniques, technologies and instruments involved in the production of hydrocarbons [6, 9, 10, 13].

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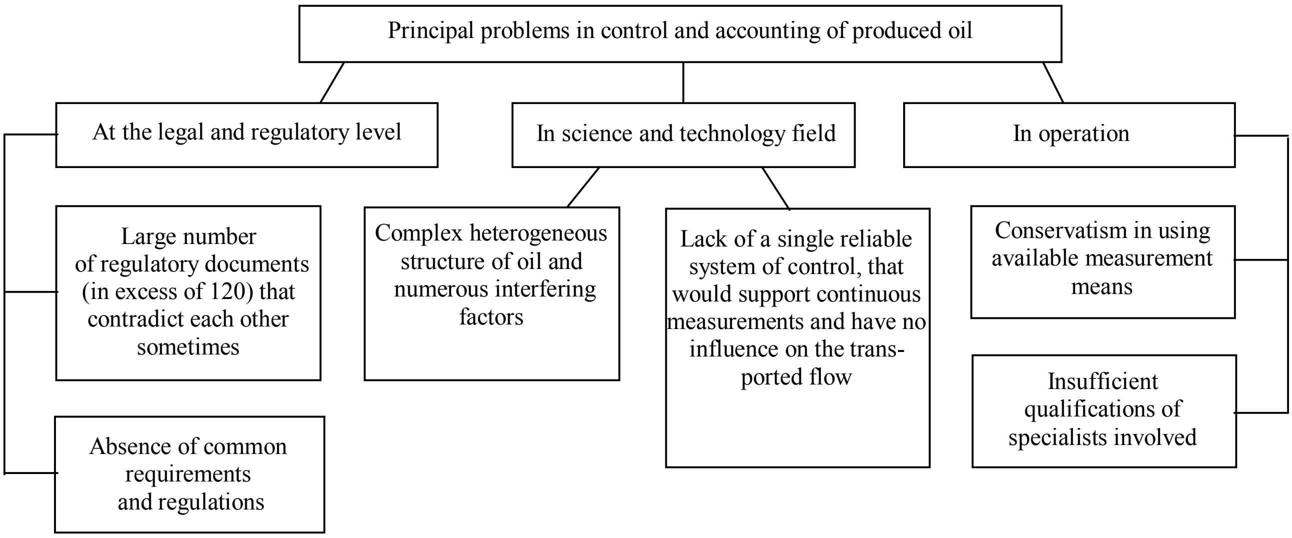

Fig. 1. Factors affecting the qualitative and quantitative results of measuring oil flows

Currently oil discharge is controlled mostly by flow discharge meters that are highly effective for homogeneous single component flows. When measuring oil flows additional errors emerge due to differences in the density of various phases, hence, of their velocities. Note that the accounting units of the Russian oil facilities mainly control the composition of transported oil using laboratory tests, their frequency varying from one hour to several weeks, in dependence of tested parameter. The composition of oil coming from production well is not constant with time, and that causes frequent discrepancies between the data of measurements taken earlier and the actual phase composition of oil flow [1, 2, 10]. Developing a measurement system that would control the actual component composition of the flow with time, hence the amount of oil transported; that would enable organizing a centralized open department to control the quality of oil and transportation conditions, upgrade the level of production and provide high measurement accuracy. Providing accurate control of the composition of oil flows would help to reduce significantly energy consumption and increase pipeline productivity, provide energy efficient transportation of hydrocarbons and development of transportation infrastructure in general.

Proposed solution. The principal criteria in choosing a system for measurements of a heterogenic oil flow through a pipeline: separation-free; contact-free; reliability; density measurement range for the controlled medium: 100-1,100 kg/m^3; free gas content measurement range: 5-75 % (larger values to be measurable at oil field producing wells); water content variations: 0-100 %. Oil pipelines need measurement capability of very low component contents (e.g., the dynamic range for free gas is 0-2 % abs.), and free water in the flow has a similar dynamic range.

Lately measurement systems meeting such requirements were designed by the collaborators of Saint Petersburg Mining University together with the "Complex-Resource" LLC. Contact-free measurement techniques using radio isotopic radiation is based on Compton scattering and photoelectric absorption of gamma-quanta; an important feature of the technique is that one needs to detect both direct and scattered radiation to provide high measurement accuracy and possibility to control the flow across the full cross-section of the pipe [3, 12, 14].

The measurement system consists of two principal components: the primary transducer interacting with the controlled flow and feeding the informative parameter to the secondary instrument in which the obtained value is processed and calibrated. The composition of the primary transducer includes the block of gamma-radiation which is a protective collimating device that forms a narrow beam of radiation by the Cs-137 radionuclide emitting in the energy range of 0.2-1.0 MeV and a detection block built around a scintillation crystal of NaJ(Tl), a photomultiplier tube and a pulse forming unit. The sought parameters of the flow (e.g., free gas content in oil) are estimated from the intensity of output gamma radiation signal in the secondary instrument [8]. The intensity of a narrow beam of direct gamma-radiation propagating through a layer of density ρ and depth *d* with temporally permanent properties follows the Lambert-Beer exponential law:

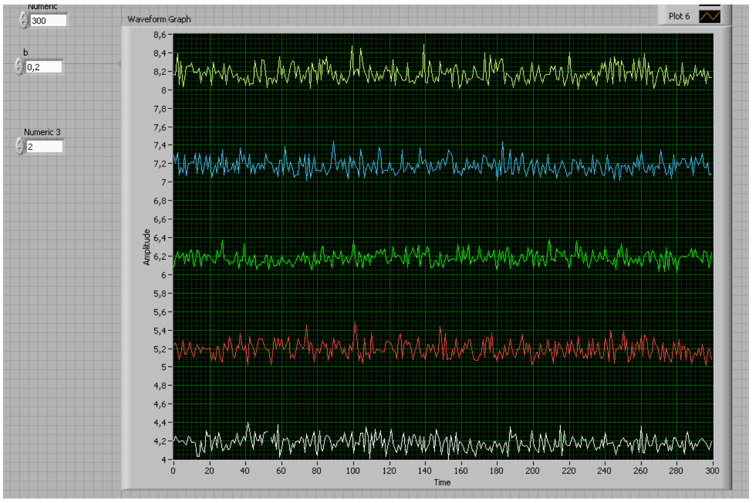

Fig. 2. The front panel of imitational model for the system to control several wells is

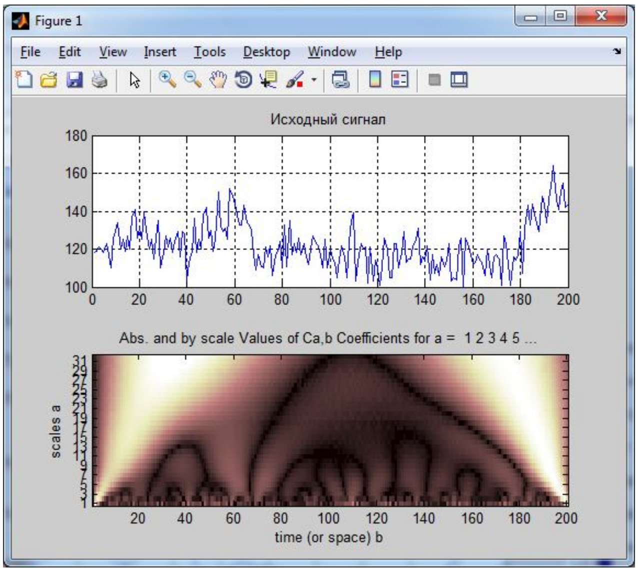

Fig. 3. The signal (for the 1-200 fragment) and wavelet spectrum of radiation intensity curve

$$N_h = N_{h0}\exp(-\mu_{h0}d) = N_{h0}\exp(-\mu_h\rho d), \quad (1)$$

where N_{h0}, N_h are the intensities of direct radiation in the absence and presence of the controlled medium, respectively; μ_{h0}, μ_h are the linear and mass attenuation coefficients for the direct radiation propagating through the medium.

The intensity of scattered radiation propagating through the controlled medium of density ρ, may, for certain conditions, be described by a linear relationship

$$N = N_0(1 - \mu_0 d) = N_0(1 - \mu\rho d), \quad (2)$$

where N_0, N are the intensities of scattered radiation in the absence and presence of the controlled medium, respectively; d is the parameter indicating the thickness of the medium for direct radiation that becomes ambiguous for scattered radiation (since radiation is also generated within the layer of the medium itself). Therefore, when measuring substance density by the attenuation of intensity of scattered radiation it is convenient to use the product μd as such parameter.

Discussion. Using the data from measurements in several lines control may be organized to cover a single site. The data for each oil backbone line are fed to the operator in the form presented in Fig. 2.

Field tests of the measurement system run on the basis of "Lukoil-Komi" LLC have made it possible to assess reliability of the proposed technique. The spatial diagram of the intensity distribution of gamma-radiation yielded by the control of gas constituent is presented in Fig. 3. To analyze measurement errors the flow of a composition known in advance was controlled. Light parts of the spectrogram correspond to density pulsations in the flow, i.e. these are splashes. For more exact analysis one needs to strike the signal from noises, for which purpose it is processed using a filter, then wavelet analysis is performed including the plotting of autocorrelation function and retrieval of RMS deviation and the average value.

The conducted studies have demonstrated that the results obtained are in complete mutual correlation with the actual values. The relative error margin for free gas measurements is 0.2 %, which meets in full the requirements of state standard for oil producers. Therefore, the developed measurement system on the basis of radioactive isotope radiation is recommended for use in control of the parameters and characteristics of the transported multi-phase flows by metrological services of Russian enterprises.

Conclusion. The proposed technique based on using radioactive isotope radiation features high penetration capability, high sensitivity to density changes, full or partial interchangeability of its principal units, simple methodology, and is capable to register various inclusions in oil flows with high accuracy, including gas component, which is its main advantage. The instrumentation designed may be applied to scientific studies in the interest of oil, gas and coal industries [7], geology, nuclear power industry, chemical and mining industries. Such a wide application range proves once again valuability of the technique we propose.

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