The algorithm of measuring parameters of separate oil streams components

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Abstract. This paper describes a development in the area of non-contact measurement of moving flows, including mass flow, the number of components and their mass ratios in a multi-component flow, as well as measurement of flows based on algorithms and functional developed for various industries and production processes. The paper demonstrates that at the core of the proposed systems, there is the physical information field created in the cross section of the moving flow by hard electromagnetic radiation. The substantiation and measurement of the information parameters are performed by the hardware and the software of the automatic measuring system. A new way of statistical pulsation measurements by the radioisotope technique is described, being alternative to the existing stream control methods and allowing improving accuracy of measurements. The basic formula fundamental for the method of calibration characteristics correction is shown.

1. Introduction
The subject on which we work refers to the general theory of streams. Streams can be divided into two types: homogeneous (uniform or Newtonian) streams and multiphase multiunit streams. They all are characterized by the fact that parameters and features of streams are changed by random stationary or non-stationary laws which are characterized in time by functions of ‘hite noise’ type. These high-frequency changes of random values trouble quantitative measurement of any stream parameter.

Talking about homogeneous streams, most often it is required to measure the discharge and the quantity of substances and materials. In liquid streams (oil, mineral pulps, etc.), this problem is solved easily – by integral discharge measurement, for example, measuring volumetric discharge by a turbine flowmeter that has high-quality accuracy and benefits industry.

Multiphase and multiunit streams are controlled worse or even poorly when it is essential to measure quantitatively, for example, one of the components of the stream (the amount of non-associated gas in oil, the amount of dead rock on a conveyor) [1]. Until now this problem used to be transcendental [2].

2. The need for instrument development
However, demands of our time, new technologies, new economic relations put a question point-blank – for example, what is the volume of non-associated gas in oil transported by a pipeline? [3] When the crude-oil production in Russia was about 600 million tons, even insignificant volume inclusions of gas created big ambiguity and contradiction between producers and consumers [4]. In the eighties of the
last century, this type of ambiguity between two big states resulted in the two million tons imbalance that forced scientists to search for explanation of that imbalance. In the first decade of the twenty first century, it was discovered and proved that the reason was in the presence of non-associated gas in the stream (about 2% of the volume), but oil producers did not admit that fact until the last minute [5, 6]. The scientists from the Central Research and Development Institute of Robotics and Engineering Cybernetics, and the scientists from Research and Production Company ‘Complex Resource’ proved that fact with the help of experimental facilities at the laboratories and under production conditions. Whereupon the fact was admitted by the oil producers with great difficulties, and the adequate government standards were adopted and the process of instrument development began. The instruments of Research and Production Company ‘Complex Resource’ have passed the metrological examination and are placed in the oil industry register. We should mention that postgraduates Moiseev, Bragin, Levashov, etc. of Saint-Petersburg Mining University took part in the development, examination and implementation.

3. Description of the measurement algorithm
The essence of the project (Figure 1) is the following: the statistical pulsation method of measurement of the separate components of the stream was invented on the basis of a highly reliable, simple and endurable radioisotope densimeter. Figure 1 presents: 1 – the pipe section with a multicomponent flow moving with speed \( V \); 2 – bubbles of free gas, 3 – the transducer, 4 – the light source (chemical element \( ^{137}\text{Cs} \)); 5 – direct radiation of detection block N1; 6 – an intelligent system (single-chip computer), 7,8 – scattered radiation of detection blocks N2 and N3, respectively, 9,10 – direct and scattered \( \gamma \)-rays, respectively. Oil flow and its amount in a pipeline are controlled by the turbine flowmeter or by the densimeter as follows: ‘speed — section’ (certainly, there should be marking in the stream to calculate the speed, for example, ionization marking). The individual components of oil stream are registered by transducers (to measure the flux density), previously calibrated for the gas content, due to the ‘knockout’ of its hard electromagnetic radiation (in this case, \( \gamma \)-radiation of isotopes of chemical elements \( ^{137}\text{Cs} \)). Processing a large amount of statistic material, one determines that the analytical form of the measured signal is random, provoked, for example, by accumulation of bubbles of non-associated gas. That is usually characterized by the correlation function or by the probability density function [7].

![Figure 1. The structure of measurement parameters of separate components of streams.](image-url)
pulsing is produced by the single-chip computer of a secondary instrument. Calibration factors are corrected in a definite period of production activity.

4. Automatic updating of calibrated characteristics

We have found the way of enhancing the measuring accuracy of calibrating instrument, i.e. self-correcting transfer characteristics of the measuring system. The main point of the algorithm is as follows: the system on a main stream (oil, coal, gas, etc.) is calibrated in a static mode; according to sampling theorem, \( \Delta t_i \) – the time interval between measurements, that is important for exact reproduction of characteristics (of a random signal) of the measured parameter. For conveyor scales, \( \Delta t_i = 0.02 \) s; for an oil-trunk pipeline, \( \Delta t_i = 0.2 \) s. According to the method of moving average during each measurement, the controller of a secondary instrument calculates the function value of the measured parameter according to the formula [10]:

\[
y(t) = \frac{1}{2l} \int_{t-\frac{l}{2}}^{t+\frac{l}{2}} x(t) dt,
\]

where \( y(t) \) – the value of the measured parameter; \( t \) – the time, s; \( l \) – the time period between measurements, s.

The value of measured parameter \( y(t) \) is saved in the memory of instrument (basic calibrated characteristics) and is calculated according to the given formula (1). The value is improved by averaging and is recorded by the instrument memory unit as a new (improved) value of calibrated characteristics. During the whole period of the instrument work, new characteristics are averaged with previously iteratively averaged calibrated characteristics by the Monte-Carlo method. Figure 2 explains the process of averaging the calibrated characteristics, where 1 – calibrated characteristics which are recorded by the processor of the secondary instrument; 2 – calibrated characteristics which are calculated by the processor according to the method of moving average; 3 - improved calibrated characteristics obtained according to the Monte-Carlo method.

5. Measurement methodology

With RAIS, we may obtain the information about:
– Pipeline integrity even for quite a long pipeline;
– The technical condition of the pipeline;
– The content of gas, water and other components in a large amount of oil;
– The type of the oil transported;
− The content of paraffin residing on the pipeline’s inner wall;
− The flow rate.

For example, lying in the basement of the liquid and gas flow rate measurement, there is the area-speed method, developed in the Mining University. This method accounts for the rate of each component in a multiphase and multicomponent flow, determining it by multiplying the average flow rate per component by the area of a part of the cross-section of the flow occupied by this component to be measured with the proposed measuring system. Therewith, the averaged mass flow of oil shall be defined by the following expression:

\[ Q_{\text{mdl,qty}} = Q_{\text{qty}} (1 - W_{\text{mdl}}), \] (1)

where \( Q_{\text{mdl,qty}} \) — the mass flow of oil averaged by time \( T_{\text{mdl}} \); \( W_{\text{mdl}} \) — the mass fraction of water in the crude oil averaged by time \( T_{\text{mdl}} \).

Oil weight \( m_o \) shall be defined by the following expression:

\[ m_o = T_{\text{mdl}} Q_{\text{mdl,qty}} \] (2)

The flow rate of the crude oil flow is measured via the mark method. Impurities, for example, free gas bubbles in liquid, are used as natural flow marks. The speed of gas in this case is assessed by the average flow speed of all bubbles (bubbles with various sizes). The speed of liquid is thus assessed by the average flow speed of the bubbles within, which is less than some threshold value, and which, therefore, behave as if they had been “frozen” into the liquid, i.e. with no sliding relatively the liquid. Figure 3 presents the portion of a pipeline with two radioactive isotope measuring converters (RMC).

![Pipeline Diagram](image)

**Figure 3.** The portion of a pipeline with two radioactive isotope measuring converters (RMC).

S1 is the cross section of the pipeline, controlled by the first RMC;
S2 is the cross section of the pipeline, controlled by the second RMC;
L is the distance between sections S1 and S2.

6. Results of the research

As the gas bubbles are missing in the flow (the flow is single-phase and uniform), the output signals from RMC1 and RMC2 are the same. If there is a free gas bubble in the uniform medium flow, the bubble with the flow will be passing section S1 first, and then section S2; therefore, the output signals from RMC1 and RMC2 will then be like those presented in Figures 4 a, b. The bubble speed in Figure 4 a is twice as fast as that in Figure 4 b.
Figures 4 a, b demonstrate that the RMC output signals comprise impulses n1 and n2 as the bubble is passing nearby. Impulse n2 comes with the delay after n1, and delay time $\tau$ is equal to $L/V_b$, where $V_b$ is the speed of the bubble. Therefore, by measuring delay time $\tau$ of impulse n2 relatively n1, one could calculate the gas bubbles motion speed.

Since a gas bubble moves together with the liquid flow, the bubble motion speed is an indicator of the local (i.e. at the point where the bubble is being at the moment) speed of the liquid flow. In the real oil and gas mixture, not a single bubble moves, but rather a cluster of bubbles with different sizes does [11]. Therefore, measuring the output signal from RMC would give a more complicated result. RMC1 output signal fluctuations would be repeated by the RMC2 output signal, delayed by time $\tau$. Time $\tau$ would depend on the speed values of all bubbles in the flow (i.e. located in various points of its cross section), i.e. on the average speed of gas $V_g$.

Inside the oil and gas mixed flow, large bubbles of free gas mainly move through the central area of the flow, where the local speed is higher than that near pipeline walls. Smaller bubbles are distributed more or less evenly throughout the flow cross section, with their speed characterizing the average speed of the liquid flow. If fluctuations caused by the smaller bubbles were extracted from the RMC output signal fluctuation, then the time delay between RMC2 and RMC1 output fluctuations would characterize the bubbles motion speed thus revealing the average speed of the liquid flow itself [12].

If signals have random nature, the delay time between one signal and the other one is usually measured with the cross-correlation method. Changing the delay time of RMC 2 relatively RMC1 also changes the timescale (width) of RMC1,2 signal impulses (Figure 4). Higher speed compresses the RMC signals along the time axis, whereas the lower speed stretches them. Therefore, provided certain restrictions are imposed on RMC output signal properties, the time delay between RMC2 and RMC1 signals may be substituted by measuring the timescale (width) of the RMC 1-τ. Usually, the timescale (width) of the output signal is measured using the autocorrelation method (ACM) [10].

The speed of liquid and gas is calculated in accordance with the following expressions:

$$V_{lq} = \frac{L_{lq}}{\tau_{lq}} + V_{lq0}, \quad (3)$$

$$V_{g} = \frac{L_{g}}{\tau_{g}} + V_{g0}, \quad (4)$$

where $L_{lq}$, $L_{g}$, $V_{lq0}$, $V_{g0}$ are calibration factors; $\tau_{lq}$ is the width of the autocorrelation function, fluctuations, caused by “frozen-in” bubbles; $\tau_{g}$ is the width of the autocorrelation function, fluctuations, caused by all bubbles within the flow.

7. Conclusion
So, the necessary multiplicity of measurements of the target value (0.2 s or 0.02 s), improvement of calibrated characteristics by any informative stream parameter that can be marked by registering the
change in stream density correlated with the measuring value are performed in statistical measurements with the help of the radioisotope y-method. Even if the distinction of the oil density value is insignificant compared to the total stream, the controller switches calibrated characteristics to the matching stream component.

Taking all the aforesaid into consideration, we draw the following conclusion: a random value in this instrument acts as a metrological device, viz. switching of the measuring instrument to the required mode and permanent automatic updating of calibrated characteristics throughout a dynamic range.

References
[1] Voytyuk I N and Kopteva A V 2015 Int. Conf. on Mech. Engineering, Automation and Control Syst. (Tomsk) vol 1 (Tomsk Polytechnic University: IEEE Xplore) p 1-4
[2] Gazin D I and Kratirov V A 2003 Microprocessor Measuring Instruments Ed. III (S.Petersburg: Nestor, SPGPU) pp 48-54
[3] Ibragimov G Z 2005 Technique and Technology of Oil and Gas Production (Moscow: MGOU)
[4] Luai M, Shaahid S M, Lukman O and Al-Sarkhi A 2014 The Sci. World J. 20-31
[5] Yaryshev G M, Yaryshev Yu G and Gorchakov V G 2009 Exposition Oil and Gas 20–21
[6] Lishchuk A N 2013 Oil Industry 3 1–3
[7] Kopteva A V and Voytyuk I N 2015 Int. Conf. on Mech. Engineering, Automation and Control Syst. (Tomsk) vol 1 (Tomsk Polytechnic University: IEEE Xplore) p 1-4
[8] Ochoa B, Kruspe T and Goodbread J 2014 IEEE Int. Conf. Sensors and Measuring Syst. pp 1-6
[9] Barak A M 2015 Oil and Gas 29–32
[10] Lur’e M V 2003 Mathematical modeling of oil pipeline transport processes of oil and gas (Moscow: Oil and gas) p 235
[11] Lishchuk A N 2013 Oil Industry 1–3
[12] Bujdosó E 1996 J. of Radioanalytical and Nuclear Chemistry 1 557-577