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WD-XRA technique in multiphase flow measuring

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ABSTRACT

A new technique to perform the analysis of multiphase fluid flow based on wave dispersive X-ray absorptiometry is suggested. The numerical simulation and comparison of this technique with currently used approaches are provided and a way to increase the luminosity intensity is found that includes the usage the X-ray focusing optics by a bent crystal and a polycapillary semilens. Based on numerical simulation of radiation spectrum the influence of the bent crystal on the luminosity is evaluated and experimentally shown the advantages of using the multicapillary optics.

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1. Introduction

During the past decades the real-time measurement of the amount and others parameters of the well production without the phase separation, moving parts and manual control has been challenging many research groups in gas and oil industry and yet still the question is opened. The detailed review of different problems and approaches to solve them can be found elsewhere [1]. Meanwhile the technical demands to accuracy of measurements are constantly growing. On the other hand new analytical methods and devices combined with computational techniques provide additional possibilities to satisfy those demands.

The analysis of X-ray, gamma or neutron radiation passed through the studied object is one of the several methods allowing the non-invasive fluids' components control. Based on this technique the promising Vx non-separation technology of flow metering has been implemented [2]. The idea of this technology consists of the combined usage of Venturi tube and a gamma-based density measurement device exploiting the radioactive ^{133}Ba source of emission with decay rate 10 mCi. The attenuation of the emission intensity during the passing through the multiphase fluid depends on the energy of the emission (in the discussed case it is 32 and 81 keV) and the composition of the fluid. The following analysis of the passed emission with two energies allows defining the composition of the three-component fluid. Those particular devices have a number of drawbacks due to usage of a danger radioactive gamma-ray sources, high prices, etc. The above mentioned radioactive sources also have a low level of the radiation intensity. Since the number of photons directly influences on the statistical error it leads either to low accuracy of measurements or to increase the duration measurement. The last one requires about an hour per one measurement with using the device based on radioactive isotopes in order to achieve the satisfactory statistical uncertainty [3]. The direct averaging over the time interval dramatically increases the systematic error with interval of integration growth due to the many nonlinear factors.

The use of X-ray tube as a source of radiation provides a higher intensity of radiation in the particular range of energy (for example, the multiplication factor is about three-four orders by magnitude on FWHM equal to 10 eV compared to radioactive isotopes). It is important to note that X-ray tube considered as the generating source of the radiation can be switch off at any moment of time becoming absolutely safe in the radioactive pollution sense. However the application of such sources of radiation leads to difficulties on the stage of radiation detection and data processing due to the continuous character of the radiation spectrum unlike the radioactive isotopes having the discrete number of monochromatic lines in the spectrum.

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The question of how to combine advantages of both approaches (easiness to register and process data in the case of radioactive sources and safety and high intensity of X-ray sources) is of a big practical interest. Development of that research field has led to creation the new device «X-ray based densitometer for multiphase flow measurement» [4] based on FluorX [5] as the source of radiation to produce the X-ray beam with quasiline spectra of the secondary fluorescence. The device in fact is the X-ray tube with secondary target and still possesses some of the drawbacks such as the lower characteristic lines intensity due to the reradiation that leads to the loss about three order of intensity by magnitude compared to the fluorescence [6]. The last phenomenon decreases the intensity of radiation down to the level of radioactive isotopes. Among others disadvantages one can mention the background radiation presence which consists of the scattered bremsstrahlung with continuous spectrum and characteristic K_β lines. The intensity of the background radiation is comparable with the intensity of the useful characteristic K_β radiation that leads to the undesired loading the detector. Such intensive background radiation increases errors after all. Thereby this device although provide some improvements in radiation safety however does not increase dramatically the accuracy and expressness of measurements is comparable with Vx technology based devices.

In this paper new alternative ways of wave dispersive X-ray absorptiometry (WD-XRA) as well as the prototype of the device implementing this idea are suggested. The method is based on the adaptation of wave dispersive technique [7] to the component analysis of a multiphase fluid. The detailed numerical simulation of the spectra and intensity of X-ray radiation on different regimes is performed. Since as it is mentioned above the main factor determining the accuracy and duration of measurement is the intensity of radiation there are considered different possibilities of how to increase the intensity using the focusing X-ray optics: a bent crystal and a polycapillary semilens.

2. General considerations

The Fig. 1 shows the main idea of the technology: the generation of radiation using the X-ray tube as a source of radiation, passing the combined spectrum radiation through the fluid flow (or other medium), segregation of narrow monochromatic lines of radiation using the block of crystal-analyzers, detection of segregated lines using one or two scintillators and analysis of the absorbed radiation level for those narrow lines. In order to achieve the individual registration of different energetic lines in the case of having one scintillator the hardware (electronic) methods of separation is used.

As a rule the multicomponent analysis of well production is based on three-component approach (oil–gas–water) and for that analysis of absorbed radiation two lines with different energy (low and high energy) is enough. The system of equations (1) is composed the solution of which gives data about the fraction of each component. Such approach, in particular, is used in devices

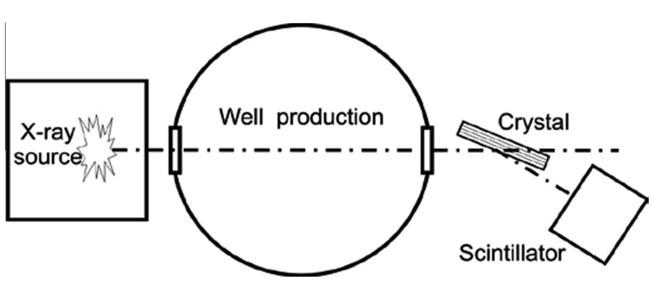

Fig. 1. The principal schema WD-XRA.

based on Vx-technology. In the system (1) the μ is the linear coefficient absorption, k is a fraction of component, I_0, I are intensities of radiation before and after passing the studied medium, h is the thickness of the studied medium, indices w, o, g denote water, oil and gas fractions, indices H and L denote high and low energy

$$\begin{aligned}
&\mu_{\mathrm{wL}}k_{\mathrm{w}} + \mu_{\mathrm{oL}}k_{\mathrm{o}} + \mu_{\mathrm{gL}}k_{\mathrm{g}} = -\frac{\ln(I_{\mathrm{L}}/I_{\mathrm{L0}})}{h},\\
&\mu_{\mathrm{wH}}k_{\mathrm{w}} + \mu_{\mathrm{oH}}k_{\mathrm{o}} + \mu_{\mathrm{gH}}k_{\mathrm{g}} = -\frac{\ln(I_{\mathrm{H}}/I_{\mathrm{H0}})}{h},\\
&k_{\mathrm{w}} + k_{\mathrm{o}} + k_{\mathrm{g}} = 1.
\end{aligned} \tag{1}$$

The suggested way of monochromatisation is implemented using the crystal monochromator herewith the module of monochromatisation can be realized by several techniques, in particular for more than two lines analysis that allows to determine the concentration of as much as needed fraction components of medium. It might be used, for example, the single crystal and the very first and second (or higher) order of the radiation diffraction on the crystal for the role of two lines for analysis. The other possibility is to use the number of crystal monochromators tuned to segregate different energetic lines and each diffracted from the monochromator radiation is detected by separate detector. In that case the possibility to distinguish several orders of diffraction from individual crystal and usage each of them as the particular level of energy is still conserved. Therefore there is a possibility to choose any schema satisfying to particular problem. Besides, the parameters of X-ray source (anode material, voltage and current of X-ray tube) might be easy optimized to specific problem.

To approach to the solution of the above discussed challenge – determining the composition of the fluid flow in three-approach approximation we propose as we believe the most prospective options, namely, the X-ray tube with a silver anode and 60 kV voltage on it as a radiation source and specially composed crystal monochromator–analyzer to separate two energetic lines. Such a monochromator presents a pair of glued between each other crystal membranes differ in size and with different orientation of the crystal plane. One of the lines should correspond to the characteristic K_α radiation, the second one is the bremsstrahlung with energy of 40–50 keV order. To separate the working lines two silicon crystals were chosen (111) and (100). Such technique allows reflecting two energetic lines in the first allowed order of the diffraction and the radiation corresponding to higher orders for both crystals absent in the X-ray tube spectrum.

3. Simulation of X-ray spectra

In order to evaluate the intensity of passed and scattered X-ray radiation the GEANT4 package is used for the simulation of spectral angular characteristics of X-ray tube radiation [8]. On the Fig. 2 results of such simulations are presented (spectrum of X-ray radiation). On the Fig. 2a two spectra are shown: the spectrum registered by detector without fluid flow and in the case when the fluid flow is the water. This panel shows the difference in absorption of radiation with different energies which in fact is the source of information about the composition of medium. As can be seen from presented spectra the suggested technology is capable to provide the flow radiation about 10^5 photons per second at the 1 mA current without even usage of special focusing X-ray optics and this flow can be increased by more than one order only by means of X-ray tube power increase. For comparison, the flow of radiation from radioactive isotopes with decay per second 10 mCi consists of 10^3 photons radiated in the same solid angle. On the Fig. 2b the spectrum of radiation reflected from composed monochromator is shown.

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