Automatic Measuring System for Oil Stream Paraffin Deposits Parameters

A V Kopteva, V Yu Koptev
Saint-Petersburg Mining University, 21-th line, Saint-Petersburg, 199106, Russian Federation
E-mail: Alexandrakopteva@gmail.com

Abstract. This paper describes a new method for monitoring oil pipelines, as well as a highly efficient and automated paraffin deposit monitoring method. When operating oil pipelines, there is an issue of paraffin, resin and salt deposits on the pipeline walls that come with the oil stream. It ultimately results in frequent transportation suspension to clean or even replace pipes and other equipment, thus shortening operation periods between repairs, creating emergency situations and increasing production expenses, badly affecting environment, damaging ecology and spoil underground water, killing animals, birds etc. Oil spills contaminate rivers, lakes, and ground waters. Oil transportation monitoring issues are still subject for further studying. Thus, there is the need to invent a radically new automated process control and management system, together with measurement means intellectualization. The measurement principle is based on the Lambert-Beer law that describes the dependence between the gamma-radiation frequency and the density together with the linear attenuation coefficient for a substance. Using the measuring system with high accuracy (± 0.2%), one can measure the thickness of paraffin deposits with an absolute accuracy of ± 5 mm, which is sufficient to ensure reliable operation of the pipeline system. Safety is a key advantage, when using the proposed control system.

1. Introduction
In 2017, the direction of priority in development of the oil and gas complex is the implementation of promising project in constructing pipelines, and developing transport infrastructure, because, despite all pipelines advantages, there are still drawbacks and issues in connection with oil products transportation [1].

The analysis of risks of accidents in oil transportation facilities revealed the most common reason for discovery the paraffin deposits later on, and removal from the inner walls in a pipeline [2]. According to Greenpeace, in 2015, in Russia, the oil losses during production and transportation are around 1% per year. Another source, NP “TEK Ecology Center” cites 3.5-4.5%. Therefore, with the annual production of around 510 million tons, the amount lost is around 18÷23 million tons, well above the world standards.

Dense deposits reduce the pipe performance down to complete clogging, possible pipe damage, resulting in ecological disasters. Asphaltene-resin-paraffin deposits (ARPD) formation results in disposing around 1.5 million cubic meters of oil and oil products into water, killing many animal species. Besides, multiple pipelines are built close to cities and towns, and the local population would be at risk in case of an accident. In addition to affecting the environment, asphaltene-resin-paraffin deposits (ARPD) adversely affect system performance, reduce the efficiency of pumping devices,
resulting in reduction of main pipeline intervals between servicing. The oil flow then has to be suspended, resulting in severe financial losses and energy wasting.

It is further worth mentioning that at Russian oil enterprise checkpoints, the transported oil composition is controlled mostly via laboratory research, with the frequency, depending on a specific parameter checked, ranging between one hour and several weeks. The oil composition from a well is not constant in time, and this is the reason for a frequent mismatch between the recent measurement and the actual situation with the phases in the oil stream. Therefore, there is the demand for a device capable of ongoing oil products monitoring, including measuring oil stream density and rate, as well as detecting deposits on the pipeline inner walls. This would significantly improve the production level via implementing more efficient production methods in timely manner, improving transportation process and obtaining profit.

While oil being extracted from a mining well, it comes not as a pure oil and gas, but as an oil-gas emulsion. At present component division of oil is being done, for example, by keeping water-oil mixture in huge oil tanks, where water and oil taking the level according to its density. Then water being released through a vent on a correspondent level of the tank. However, this method is difficult and time consuming, which brings down the productivity and increases the running costs [3].

After the separation process has been completed, there is a high level of finely dispersed gas that still remains in the oil. This effect may take place due to the turbulence in the oil stream, reduction of pressure and increase of temperatures. The presence of excess gas may malfunction the volume and mass flow meters. The margin of error of volume flow meters is directly dependent on the level of the excess gas. It has not been properly researched how much excess gas influence the function of volume flow meters. Recent research with a use of volume meters CMF-1000 and ROTOMASS has shown, that with 1.3-3.5% of gas presence, the level of average cubic deviation comes to 24% (according to the data provided by NPC "SKPNeft", fig. 1).

There is always dissolved gas in the extracted oil. The higher the pressure and the lower the temperature in the reservoir, the more gas will remain in the oil after completion of the separation process. When commercial measuring stations encounter errors in their measurements and quality research of the oil, it causes huge financial losses of state and private capital, creates domestic or even international disputes between supplier and consumer, negatively effects the efficiency of the technological process and diminishes productivity. Therefore, one of the most important challenges for all modern oil producers, is availability of precise and reliable measurement technology for multicomponent oil flows [4-7].

2. Measurement methodology

In Saint-Petersburg Mining University and LLC “Complex-Resource”, a measurement system was developed to resolve all the abovementioned issues with good accuracy and without a contact with the medium measured. Figure 2 shows the structure diagram of the device. The measurement principle is based on the Lambert-Beer law that describes the dependence between the gamma-radiation frequency

![Figure 1. The data from the volume meter "Rotomass" RCCS(T)38 at different times](image-url)
and the density together with the linear attenuation coefficient for a substance:

\[ I_h = I_{h0} \cdot \exp(-\mu_{h0} \cdot d) = I_{h0} \cdot \exp(-\mu_h \cdot \rho \cdot d), \quad (1) \]

where \( I_{h0} \) and \( I_h \) are radiation intensities initially and upon passing through the controlled substance; \( \mu_{h0} \) and \( \mu_h \) are the linear and the mass coefficients of attenuation by the medium.

Specifically for the developed system, the intensity of the direct radiation shall be calculated according to the expression [5]:

\[ I_d = I_0 \cdot \exp\left(-\left(\mu_1 \rho_1 d_1 + \mu_2 \rho_2 d_2 + \mu_3 \rho_3 d_3 + \mu_4 \rho_4 d_4\right)\right), \quad (2) \]

where \( \mu_1, \mu_2, \mu_3, \mu_4 \) are the radiation attenuation mass coefficient for the materials of the pipeline, oil, paraffin deposits and free gas bubbles in the stream (which in fact are the main reason for obtaining wrong results if ultrasound measuring systems are used), correspondingly; \( \rho_1, \rho_2, \rho_3, \rho_4 \) are the density values for the materials of the pipeline, oil, paraffin deposits and free gas bubbles in the stream; \( d_1, d_2, d_3, d_4 \) are the thickness values for the materials of the pipeline, oil, paraffin deposits and free gas bubbles in the stream.

**Figure 2.** The structure of the non-contact method of measuring oil quantity and quality in a pipeline

By letting the radioisotope radiation pass through the controlled portion of the pipeline with the oil stream and the asphaltene-resin-paraffin deposits (ARPD), its attenuation values are obtained. The specific attenuation degree together with pulsations pattern typical for a particular source energy spectrum allows assessing the corresponding controlled parameter for the medium that behaves like the radiation sink [8, 9].

The figure 3 represents the diagram for gamma-radiation attenuation by oil, water and the saline, for Cs137, which is used in the radiation source, with specified probability for \( \mu \sigma \) - Compton scattering and \( \mu \tau \) - photoelectric absorption (with gamma-quantum beam components presented for oil; other substances shall show different values).

**Figure 3.** A diagram for gamma-radiation attenuation by oil, water and the saline
The control quality of oil product component composition, according to radioisotope measuring system, directly depends on the radiation nature. When measuring free gas, detecting only the direct radiation power is not sufficient, for it passes a single chord of a pipeline thus rendering the obtained information useless [10-14]. The scattered radiation should be registered for more precise assessment of the oil stream density.

3. Findings of the Research
Oil product component composition control quality, according to the radioisotope measuring system, directly depends on the radiation nature. When measuring free gas, detecting only the direct radiation power is not sufficient, for it passes a single chord of a pipeline thus rendering the obtained information useless. The scattered radiation should be registered for more precise assessment of the oil stream density.

For Compton scattering, the probability of interaction is approximately proportional to the absorbent density. Scattering is often considered as an unwanted effect in gamma-meters because it makes result interpretation more complicated. But this is a severe mistake when assessing multiphase multicomponent stream component content. Heterogeneous oil stream substance density measurement needs accounting for the scattered radiation because gas and liquid phase mutual redistribution is described via the random distribution law. Identifying the scattered radiation may to some extent be considered as geometrical measurements of the characteristics, as averaged by the pipe cross-section. The energy of a photon that underwent scattering may be determined out of the following expression [11]:

\[ E_t = E_i \frac{1 - \beta \cos \Theta_1}{1 - \beta \cos \Theta_2 + E_i (1 - \cos \Theta) / E_e}, \]

(3)

where \( E_t \) is the initial energy of photon; \( \beta \) is the electron velocity; \( \Theta_1 \) is the angle between the electron motion vector and the incident photon; \( \Theta_2 \) is the angle between the electron motion vector and the scattered photon; \( E_e \) is the energy of electron; \( \Theta \) is the angle between the motion vector of the incident and the scattered photon.

A laboratory device was developed and tested on the basis of the University of Mines, to determine the optimal location of the detection unit relatively the radiation unit. The value of the direct and scattered radiation was fixed by shifting the detection unit by 1 degree, and the distance between the source of gamma radiation and oil was increased. According to the obtained data, the authors concluded that the instrumental error of 30 cm from the detector device is minimal and satisfying, whereas the maximum value of the direct radiation valid signal is recorded in a coaxial alignment of the detection unit and the radiation unit, with location on the opposite sides of pipelines.

Using the measuring system with high accuracy (± 0.2%), one can measure the thickness of paraffin deposits with an absolute accuracy of ± 5 mm, which is sufficient to ensure reliable operation of the pipeline system.

4. Safety guarantee
Safety is a key advantage, when using the proposed control system. The measuring system has no contact with the medium measured, all components of the measuring system are mounted on the outer side of the reservoir, and measuring is implemented through its wall. This technique of "non-intrusive measurement" ensures high safety and reliability level, regardless the measured medium and its properties. Currently, it is the only device that allows, with good accuracy, using the non-contact method to control streams and deposits by measuring its quantity and composition.

The radiation source is installed in a container for a source, which protects it from mechanical impacts and chemical effects. The container’s design provides maximum shielding with minimum weight. The container is made of lead (which has high density and capable of attenuating the radiation) within a housing made of stainless steel. Since gamma rays are electromagnetic radiation,
the measured product, the reservoir and the source container itself are free of radioactive contamination.

Besides protecting the premises, making walls, floorings, and security doors adequately thick, the priority is radiation safety of the personnel. Loading sources into containers is carried out in a special chamber. An operator performs all operations, from outside of the chamber, via two manipulators. The operator monitors the process through a special window, made of lead glass 30 cm thick. A video camera, mounted inside the operating chamber, allows observing the operating area via monitor in an enlarged scale. The operating chamber provides complete radiation protection. Only one door of the chamber weighs two tons, and the chamber itself weighs 24 tons.

The only possibility to expose oneself to radiation with unsafe level, when using this equipment, is surface irradiation, when one stays close to the radiation source. Leaking the products that could get inside the body shall not be possible.

Furthermore, it is worth noticing that permanent radiation control is carried out via multiple counters. Trained personnel not only determine the level of radiation, but they are also prepared to proceed properly in case of radioactive materials leakage. Besides the control by employees, Sanitary and Epidemiological Station, Federal Inspectorate of Russia for Nuclear and Radiation Safety, Moscow Committee for Nature Protection and Internal Affairs Directorate also control the level of radiation.

And above all: irradiation during the nuclear study is usually even less than during X-ray examination. For example, TV sets and video-display terminals, with electron-ray tubes, with accelerating voltage of more than 10 kW, are also X-ray sources. According to US studies, the rate of radiation dose, even in the worst samples does not exceed 0.02 mSv/h, and in most cases is below natural background level [15].

From all the aforesaid, one can conclude that safety is the priority advantage when using the proposed control system, based on radioisotope radiation.

5. Results of the research
The developed device can be used both at the design stage and piping, and on existing pipelines. In addition, the radioisotope density measuring devices are successfully applied in metallurgy, mining, geology, chemical and other industries. As of today, it is the only device that allows controlling streams and deposits by measuring its quantity and composition, via a non-contact method.

The measuring system, based on the radioisotope radiation, provides an accurate and reliable pipeline diagnostic system, which significantly reduces energy wasting and increases the performance of pipelines, and therefore provides energy-efficient transportation of hydrocarbons, and detecting the deposits in the timely manner reduces the capital investments in pipes replacement and results in transport infrastructure development [16-19].

The main advantages of the proposed method:
• Reliability, easy maintenance, low cost, easily interchangeable;
• Ability to control the flow of liquids, gases and granular media-contact method;
• High frequency measurements (time interval between measurements of 0.2 sec);
• Measurement process continues throughout the lifetime of the measurement system with a frequency of 0.2 second strobes;
• Increased efficiency of information appliance;
• There is a great potential for the application of this method.

6. Conclusion
Huge amount of work during recent decade aims to develop automated intellectual monitoring systems for hydrocarbons transportation. There is a number of commercial proposals related hereto, yet all of them either break the flow integrity, or give too large errors ±5%. Developing new measuring systems based on radioisotope radiation for automated hydrocarbon quality monitoring, precisely (±0.2%) detecting various contaminations like water or free gas improves accuracy of results obtained, thus
improving oil plant productivity; it also contributes into reliability, durability, has advantage of non-contact dealing with flow monitored, being cheaper if compared to existing methods and instrumental tools available for measurement.

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