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INCREASING THE SENSITIVITY OF MEASUREMENT OF A MOISTURE CONTENT IN CRUDE OIL

Purpose. Investigation of a moisture frequency transducer based on a moisture-sensitive capacitive element of a cylindrical structure with mesh electrodes for a system for measuring the amount and parameters of crude oil.

Methodology. When constructing a moisture-sensitive element, an oscillatory method for measuring humidity was applied to achieve high sensitivity and accuracy while maintaining a low cost of the device. A moisture sensitive capacitive sensor based on a cylindrical structure with mesh electrodes was introduced into the measuring generator system based on a transistor structure with a negative differential resistance.

Findings. Analytical expressions are obtained to describe the dielectric constant of an inhomogeneous mixture of water and oil. Using these equations, the capacitance of a moisture-sensitive sensor with mesh electrodes is calculated as a dependence of the moisture content of crude oil. It was determined that the capacitance of the moisture sensitive sensor increased from 20 to 44 pF when the mass moisture of crude oil changed from 0 to 30 %. The sensitivity of the developed capacitive sensor is 0.8 pF/% when using a measuring device in the form of a crude oil pipeline with a diameter of 50 millimeters.

Originality. A mathematical model has been developed for the primary transducer of the moisture content of crude oil based on a cylindrical capacitor structure with net-like electrodes, which allows determining the value of the capacitance of the primary transducer of the moisture content of crude oil. A self-oscillator device for controlling the moisture content of crude oil has been developed on the basis of the structure of bipolar and field-effect transistors with a cylindrical capacitor structure with mesh electrodes.

Practical value. Circuitry solutions for a moisture transducer for crude oil have been developed. The results of experimental studies showed that for the selected version of the moisture converter circuit, the output signal frequency decreased in the range from 1.617 to 1.27 MHz with a change in the mass moisture content of the Turkmen mixture from 0 to 30 %, respectively, and is close to a linear dependence. The wide frequency range of the output signal of the secondary converter with the frequency output of the measured information increases the accuracy of moisture measurement in crude oil by an order of magnitude.

Keywords: *crude oil, moisture content, capacitive sensor, frequency converter, negative differential resistance, moisture sensitivity*

Introduction. The development of the oil industry provokes a range of important issues that need to be taken into account to provide a stable process of hydrocarbon resource production technology [1], development of modern tools and devices to improve the production of the oil fluid [2] as well as forecasting of geothermal fluid production [3]. At the same time determination of the moisture content of oil has always been a relevant topic and object of scientific research. Water, as an integral component of various oils and greases, comes into contact with the surface of metals, contributing to their corrosion and physical demolition [4]. Therefore, it is necessary to develop devices for controlling oil moisture directly in the flow for the prompt making decision on the regulation of this parameter.

The presence of moisture in oil can affect the operation of flow meters, wear of mechanisms and the appearance of possible emergency situations [5].

Water molecules in oil products can chemically interact with other impurities, while the resulting compounds can adversely affect some metals, and also increase the likelihood of cavitation (the appearance of bubbles and cavities in a liquid filled with steam) [6, 7].

Excessive moisture in the insulating (for example, transformer) oil leads to premature aging and an increase in the likelihood of electrical breakdown [8]. Therefore, highly sensitive control of this physical quantity is necessary to improve the reliability of structures and mechanisms, as well as to increase production efficiency.

Literature review. In the oil industry, moisture meters are used during individual measurements in wells [9], group production measurements [10], as well as in the process of dehydration in tanks of oil depots [11].

At this time, systems for measuring the quantity and quality parameters of crude oil are used, designed for automatic accounting and delivery of commercial oil from the manufacturer to the consumer, to determine the quality indicators of oil at oil refining facilities, as well as during accounting and settlement operations in the transportation of oil and oil products [12].

The system for measuring the quantity and quality indicators of oil and oil products automatically measures the mass (volume) of oil, quality indicators of oil (density, viscosity, moisture, pressure, temperature) and transfers the information to the central computer and then displays this information at the operator's automated workstation.

The oil quantity and quality measurement system is based on volumetric [10], mass [11] and ultrasonic [12] oil flow meters. The way of constructing such systems is regulated by technical conditions and other regulatory documents, and depends on the technological regime of oil pumping, as well as the physical and chemical properties of oil [9–12].

The complete set of such measurement and control systems is to a greater extent determined by the requirements of the consumer, but functionally it consists of the following components: a technological component, an information processing system and management of life support systems (lighting, heating, fire alarm, ventilation, gas control system).

A structural block diagram of a system for measuring the quantity and quality of crude oil parameters is shown in Fig. 1 [13]. The technological part consists of the following blocks: the block of measurement and regulation, block of filters and the block of pipe piston installation [13].

The unit of measurement and regulation in turn includes the unit of quality indicators, the block of measuring lines, the block of reference means, the block of test installation, knots of regulation of expenses of oil product and pressure, the sampling device, technological and drainage pipelines.

The information processing system includes an operator and an information processing unit, which consists of an automatic protection and signaling board and a board of the information and computer complex [13, 14].

Fig. 2 shows the structure of the control and monitoring system. Measuring and control reserve line equipped with filters, flow meters, temperature and pressure meters. In this case, valves and other locks can be manually or automatically driven.

In the quality measurement unit, all measuring devices are mounted in series on a quality line with a diameter of 50 mm which ensures drainage of gas and moisture, alternating switching on of measuring instruments.

Consider in more detail the block of measuring lines and the block of measuring quality indicators, which are shown in Figs. 3 and 4 respectively.

The system for measuring the quantity and parameters of crude oil provides automatic measurements and calculations

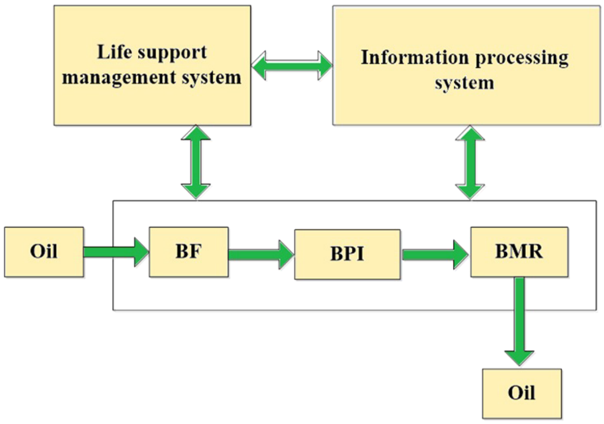

Fig. 1. Block diagram of the system for measuring the quantity and quality parameters of oil: BF is the block of filters, BPI is the block of pipe-piston installation, BMR is the block of measurement and regulation

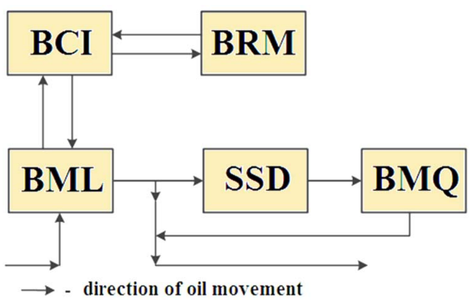

Fig. 2. Block diagram of the measurement and control unit: BCI is the block of check installation, BRM is the block of reference means, BML is the block of measuring lines, BMQ is the block of measuring quality indicators, SSD is the sample-sampling device

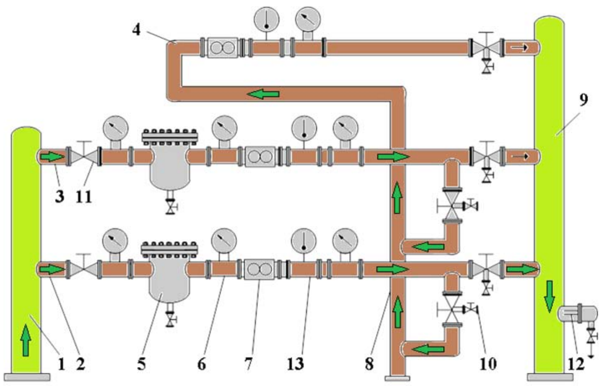

Fig. 3. The block of measuring lines:

1 – entrance collector; 2 – working line; 3 – backup line; 4 – control line; 5 – strainer; 6 – laboratory manometer; 7 – flow meter; 8 – control collector; 9 – output collector; 10 – visual inspection of leaks; 11 – hut-off valves; 12 – sampling device; 13 – temperature meter

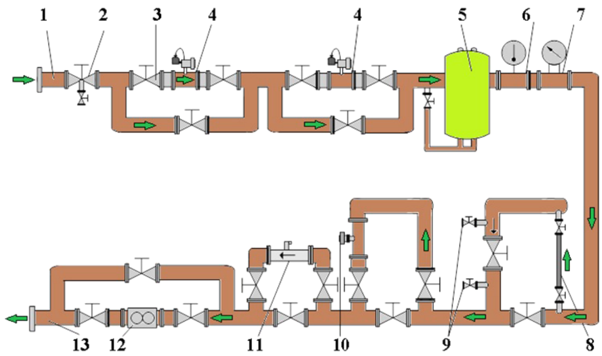

Fig. 4. The unit for measuring quality indicators:

1 – oil from the sampling device; 2 – manual sampler; 3 – shut-off valves; 4 – automatic sampler; 5 – thermostatic cylinder for the hydrometer; 6 – temperature meter; 7 – laboratory manometer; 8 – flow density sensor; 9 – connection point of the pycnometer or the device for determining the content of free gas; 10 – viscometer; 11 – moisture meter; 12 – flow meter; 13 – oil output to the outlet manifold of the unit of measuring lines

in real time of instantaneous and average values of the measured physical quantities. Including measurement of volumetric and mass consumption of oil, temperature, pressure and humidity on each of the measuring lines.

The quality of the moisture measurement in crude oil depends on a type and parameters of the used sensors [15]. Currently, there are a large number of various sensors for measuring the moisture content of oil [16]. Some of the known sensors are of a high cost and at the same time of a low reliability, while others utilize outdated measurement technologies [17].

Purpose. The purpose of the study is to develop a new design of the capacitive sensor for measuring the moisture content of crude oil in a pipeline for a crude oil quality control unit. The main task of the study is development of a new moisture-sensitive structure to increase the sensitivity and accuracy of measuring the moisture content of crude oil. The application of this moisture-sensitive structure is also possible for laboratory measurements in order to increase the measurement accuracy, and, as a consequence, to enhance the efficiency of consumption of oil. Theoretical analysis and experimental study on the processes of converting the humidity of Turkmen Blend oil into the frequency of an electrical signal.

Theoretical and experimental research. Currently, there is a wide range of primary oil moisture sensors which, however, have a number of disadvantages, such as low accuracy, outdated measurement technology, low reliability. The solution to this problem is possible by using a cylindrical moisture sensitive cylindrical structure.

Increasing the accuracy of measuring the moisture content of oil is also associated with the use of highly efficient secondary converters of information [17, 18].

An oscillating structure can serve as such an effective secondary converter of a parametric capacitive humidity sensor [19]. In this case, a change in the capacitance of the primary sensor causes an unambiguous change in the frequency of the output signal of the oscillator [19, 20]. At the same time, modern methods for calculating the signal frequency allow performing calculations within the information control and measuring system without the use of an ADC, which significantly reduces the signal processing speed, leads to an increase in the cost price and the appearance of a quantization error [19]. The proposed humidity sensitive capacitive sensor (Fig. 5) consists of mesh-shaped electrodes, which are placed opposite each other so that the location of the holes in the first electrode coincides with the holes in the second electrode [20]. The electrodes *1* and *2* are firmly attached to the dielectric tube *3*, and they are covered with a layer of polymer *4* and contain holes *5* for the movement of the fluid flow having dielectric properties. The outer diameter of the dielectric tube is 50 mm, and the distance between the electrodes is 1.5 mm.

The capacitive humidity sensitive sensor works in this way. During the flow of fluid through the dielectric tube, which contains a moisture-sensitive capacitive sensor for measuring humidity, the fluid through the holes *5* fills the space between the electrodes *1* and *2*, which are covered with a polymer layer *4* and are rigidly fixed in the dielectric tube *3*.

This causes a change in dielectric constant. Depending on the change in humidity of the measuring fluid, its dielectric constant changes, therefore, the capacity of the humidity sensor also changes.

If the material consists of a mixture of components with different dielectric constants, the total polarization of the material can be found as the sum of the polarizations of the components. In our case, to find the total dielectric constant ε_Σ, it is necessary to take into account the dielectric constant of a heterogeneous mixture of water and oil product ε_c in which the particles are placed chaotically and the dielectric constant of the polymer ε_p.

Let us first determine the dielectric constant of a heterogeneous mixture of water and oil ε_c. Water molecules act as a dispersed phase, and the dispersed medium, respectively, is a petroleum product. An empirical Bruggeman equation is proposed for the evaluation ε_c

$$\frac{\varepsilon_1-\varepsilon_c}{\varepsilon_1-\varepsilon_2}=\left(1-\alpha\right)\cdot\sqrt[3]{\frac{\varepsilon_c}{\varepsilon_2}}, \tag{1}$$

where ε_1 is the dielectric constant of water; ε_2 is the dielectric constant of oil; α is the volumetric water concentration.

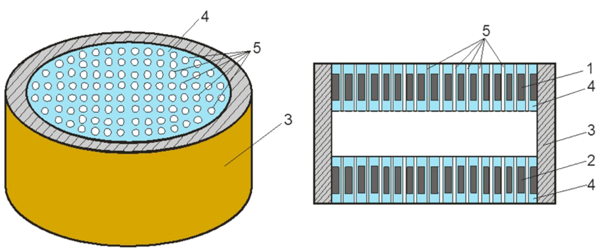

Fig. 5. Moisture-sensitive capacitive sensor for measuring the humidity of petroleum products General view (a), cross section (b):

1, 2 are the electrodes; 3 is the dielectric tube; 4 is the polymer layer; 5 are the holes

Water is a substance that can be polarized, so to determine the value of the dielectric constant of water, we use the complex dielectric constant of water

$$\varepsilon_1^*=\varepsilon_1'-j\left(\varepsilon_1'\cdot\mathrm{tg}\,\delta_1\right), \tag{2}$$

where ε_1^* is the complex dielectric constant of water; ε_1' is the real component of the complex dielectric constant of water; $\mathrm{tg}\,\delta_1$ is the tangent of the angle of dielectric loss of water.

The real component of the complex dielectric constant of water ε_1' and the tangent of the angle of dielectric loss $\mathrm{tg}\,\delta_1$ in turn are calculated from equations

$$\varepsilon_1'=\varepsilon_{O1}+\frac{\varepsilon_{C1}-\varepsilon_{O1}}{1+(\omega\tau_1)^2}; \tag{3}$$

$$\mathrm{tg}\,\delta_1=\frac{(\varepsilon_{C1}-\varepsilon_{O1})\cdot\omega\tau_1}{\varepsilon_{C1}+\varepsilon_{O1}\cdot(\omega\tau_1)^2}, \tag{4}$$

where ε_{O1} is the optical dielectric constant of water; ε_{C1} is the static dielectric constant of water; ω is the frequency of the electric field [Hz]; τ_1 is the relaxation time of water molecules (s).

The real component of the complex dielectric constant of oil ε_2' and the tangent of the angle of dielectric loss of oil $\mathrm{tg}\,\delta_2$ in turn are calculated from the equations

$$\varepsilon_2'=\varepsilon_{O2}+\frac{\varepsilon_{C2}-\varepsilon_{O2}}{1+(\omega\tau_2)^2}; \tag{5}$$

$$\mathrm{tg}\,\delta_2=\frac{(\varepsilon_{C2}-\varepsilon_{O2})\cdot\omega\tau_2}{\varepsilon_{C2}+\varepsilon_{O2}\cdot(\omega\tau_2)^2}, \tag{6}$$

where ε_{O2} is the optical dielectric constant of oil; ε_{C2} is the static dielectric constant of oil; τ_2 is the relaxation time of the oil (s).

Find the modulus of complex dielectric constant of oil

$$\varepsilon_2=\sqrt{(\varepsilon_2')^2+(\varepsilon_2'\cdot\mathrm{tg}\,\delta_2)^2}. \tag{7}$$

Use the expression to determine the volume concentration of water

$$\alpha=V_{\mathrm{H_2O}}/V_{mix}; \tag{8}$$

$$V_{mix}=V_{\mathrm{H_2O}}+V, \tag{9}$$

where $V_{\mathrm{H_2O}}$, V, V_{mix} are the volumes of moisture, oil and mixture respectively (m^3).

Determine the volume of water $V_{\mathrm{H_2O}}$

$$V_{\mathrm{H_2O}}=m_{\mathrm{H_2O}}/\rho_{\mathrm{H_2O}}, \tag{10}$$

where $m_{\mathrm{H_2O}}$ is the water mass (kg).

Substituting expressions (9, 10) in (8) we obtain

$$\alpha=\frac{m_{\mathrm{H_2O}}}{\rho_{\mathrm{H_2O}}\cdot\left(m_{\mathrm{H_2O}}/\rho_{\mathrm{H_2O}}+V\right)}. \tag{11}$$

Write down the expression for mass humidity W

$$W=\frac{m_{\mathrm{H_2O}}}{m_{mix}}\cdot100\,\%=\frac{m_{\mathrm{H_2O}}}{m+m_{\mathrm{H_2O}}}\cdot100\,\%; \tag{12}$$

$$m_{\mathrm{H_2O}}=\frac{W\cdot m}{100-W}, \tag{13}$$

where m, m_{mix} are the mass of oil and mixture, respectively (kg).

Substituting the value $m_{\mathrm{H_2O}}$ from expression (13) into (11) we obtain

$$\alpha=\frac{W\cdot\rho}{(100-W)\cdot\rho_{\mathrm{H_2O}}+W\cdot\rho}. \tag{14}$$

To calculate the capacity of the humidity-sensitive sensor with mesh electrodes, taking into account the active area of the electrodes S, as well as all the following expressions, the equation will look like

$$C_w = \frac{\varepsilon_{\bar{i}}\varepsilon_c\varepsilon_0(\pi R^2 - p\pi R_0^2)}{d(\beta_1\varepsilon_c + \beta_2\varepsilon_n)}, \qquad (15)$$

where ε_0 is the dielectric constant of vacuum (F/m); R_0 is the hole radius (m); p is the number of holes in the electrode.

According to expression (15), the capacity of the moisture-sensitive sensor with mesh electrodes in the environment "Maple 18" was calculated. Fig. 6 presents the theoretical and experimental dependences of the capacity of the humidity-sensitive sensor on the humidity of oil in the range from 0 to 30 % of the mass humidity.

As can be seen from the graph, the theoretical and experimental dependences have a good match. Thus, when the mass humidity content of Turkmen Blend oil changes from 0 to 30 %, the capacity increases from 20 to 44 pF. The adequacy of the mathematical model can be estimated using a relative error of 3 %. The sensitivity of the humidity-sensitive capacitive sensor can be increased by changing its geometric dimensions. So you can increase the number of mesh electrodes in the dielectric tube, which will increase the capacity of the capacitor cylindrical structure, and thus increase the sensitivity of the sensor. Also, the increase in the sensitivity of the capacitive sensor can be achieved by increasing the diameter of the mesh electrodes, which is necessary when used in the unit for measuring the quality of crude oil pipelines with a diameter greater than 50 millimeters.

At the given geometrical sizes of the humidity-sensitive capacitive sensor sensitivity at change in mass humidity of Turkmen Blend oil from 0 to 30 % makes 0.8 pF/%. To increase the accuracy of measuring the humidity content in crude oil, a humidity-sensitive capacitive sensor was connected to a secondary means of processing, namely an oscillator on a transistor structure with negative differential resistance (Fig. 7) [19, 20]. To carry out the experimental studies we used bipolar transistor BC847 and silicon p-channel MOSFET BSS84, resistors: R_1 = 8.2 kΩ, R_2 = 5.6 kΩ, R_3 = 1 kΩ and inductance 150 μH, to create the circuit, shown in Fig. 7. The voltage of the power sources is equal to 5.0 V.

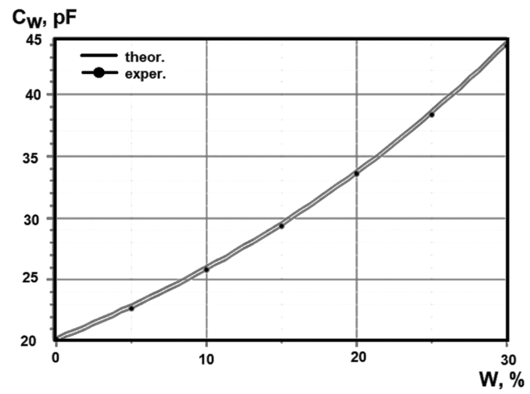

Fig. 6. Theoretical and experimental dependences of tank change on Turkmen Blend oil humidity

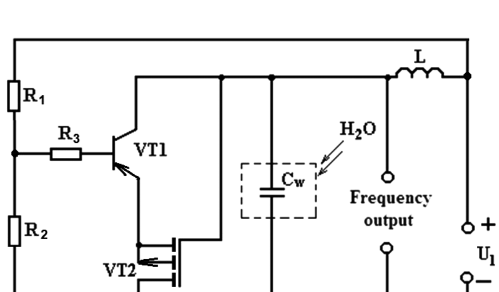

Fig. 7. Oscillator based on a transistor structure with negative differential resistance

In Fig. 8 shows the theoretical and experimental dependences of the change in the frequency of the output signal of the oscillator on the negative differential resistance from the humidity of the Turkmen Blend oil.

Discussion. The paper proposes a new capacitive sensor for measuring the moisture content of crude oil. This sensor is based on a cylindrical capacitor structure with mesh electrodes. The sensor is located in the crude oil quality measurement unit. It measures the moisture content of the oil flowing through a pipeline with a diameter of 50 mm. The dielectric constant of a heterogeneous mixture of water and oil was determined. This provided determining the total dielectric constant of the cylindrical capacitor structure with mesh electrodes. The capacitance of the cylindrical capacitor structure with mesh electrodes was calculated when the moisture content of Turkmen Blend crude oil varied in the range from 0 to 30 % of the mass moisture.

When the mass moisture content of Turkmen Blend crude oil changes from 0 to 30 %, the sensor capacitance increases from 20 to 44 pF. In the study, it was determined that the sensitivity and accuracy of measuring the moisture content in crude oil significantly increased when the capacitive sensor was connected to the oscillatory circuit of the autogenerator based on transistor structure with negative differential resistance. The sensitivity is 4600 Hz/% when the mass humidity of oil changes from 0 to 30 %. As can be seen from Fig. 8, theoretical and experimental dependences have a good match.

Conclusions. A mathematical model of the capacitive humidity sensor has been developed, which describes the dependence of the electric capacity on the humidity content of crude oil. The primary humidity sensor is a capacitor cylindrical structure with mesh-shaped electrodes, which are fixed in a dielectric tube. The sensitivity of the developed sensor for Turkmen Blend oil is about 0.8 pF/%. The discrepancy between theoretical and experimental results does not exceed 3 %. When the geometric dimensions of the humidity-sensitive capacitive sensor change, its electrical capacity increases, which leads to an increase in the sensitivity of humidity measurement in oil. Further increase in accuracy and sensitivity of humidity measurement in crude oil is possible due to use of the humidity-sensitive capacitive sensor in combination with secondary means of processing.

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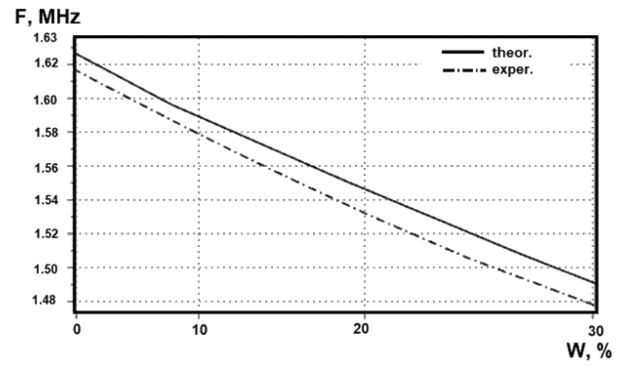

Fig. 8. Theoretical and experimental dependences of changes in the frequency of output signal of the oscillator on the humidity of the Turkmen Blend oil

References.

1. Bazaluk, O., Slabyi, O., Vekeryk, V., Velychkovych, A., Ropyak, L., & Lozynskyi, V. (2021). A Technology of Hydrocarbon Fluid Production Intensification by Productive Stratum Drainage Zone Reaming. *Energies, 14*(12), 3514. https://doi.org/10.3390/en14123514.

2. Vynnykov, Yu., Manhura, A., Zimin, O., & Matviienko, A. (2019). Use of thermal and magnetic devices for prevention of asphaltene, resin, and wax deposits on oil equipment surfaces. *Mining of Mineral Deposits, 13*(2), 34-40. https://doi.org/10.33271/mining13.02.034.

3. Fyk, M., Biletskyi, V., Abbood, M., Al-Sultan, M., Abbood, M., Abdullatif, H., & Shapchenko, Y. (2020). Modeling of the lifting of a heat transfer agent in a geothermal well of a gas condensate deposit. *Mining of Mineral Deposits, 14*(2), 66-74. https://doi.org/10.33271/mining14.02.066.

4. Bravo-Méndeza, J., González-Velázqueza, J.L., Domínguez-Aguilarb, M.A., & Rivas-Lópeza, D.I. (2018). High-temperature corrosion of a UNS K03006 steel pipe in a crude oil vacuum residue distillation unit. *Engineering Failure Analysis*, *92*, 149-162. https://doi.org/10.1016/j.engfailanal.2018.05.016.

5. Bharatiya, U., Gal, P., Agrawal, A., Shah, M., & Sircar, A. (2019). Effect of Corrosion on Crude Oil and Natural Gas Pipeline with Emphasis on Prevention by Ecofriendly Corrosion Inhibitors: A Comprehensive Review. *Journal of Bio- and Tribo-Corrosion 5*(35), 1-35. https://doi.org/10.1007/s40735-019-0225-9.

6. Trnka, P., Mentlík, V., & Svoboda, M. (2014). The effect of moisture content on electrical insulating liquids. *2014 IEEE 18th International Conference on Dielectric Liquids (ICDL)*, 1-4. https://doi.org/10.1109/ICDL.2014.6893120.

7. Liu, H., Tang, X., Lu, H., Xie, W., Hu, Y., & Xue, Q. (2020). An interdigitated impedance microsensor for detection of moisture content in engine oil. *Nanotechnology and Precision Engineering*, *3*(2), 75-80. https://doi.org/10.1016/j.npe.2020.04.001.

8. Ab Ghani, S., Abu Bakar, N., Chairul, I.S., Ahmad Khiar, M.S., & Ab Aziz, N.H. (2020). Effects of Moisture Content and Temperature on the Dielectric Strength of Transformer Insulating Oil. *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences*, *63*(1), 107-116.

9. Tan, C., Zhang, Z., Feng, G., Li, B., Wu, H., & Tan, T. (2019). Research on Measurement Model of Water Content of Oil Well Based on Data Fusion. *2019 International Conference on Intelligent Computing, Automation and Systems (ICICAS)*, 44-47. https://doi.org/10.1109/ICICAS48597.2019.00018.

10. Yi, L., Ding, J., & Liu, C. (2019). NMR principle analysis based object detection for intelligent measurement of crude oil moisture content. *12th Asian Control Conference (ASCC)*, 456-461.

11. Ren, G., Ge, D., Sun, K., Chen, X., Mi, L., & Yao, X. (2020). A Novel Method of Crude Oil Water-Cut Detection Based on Multi-Sensor Fusion. *International Petroleum Technology Conference*. https://doi.org/10.2523/IPTC-20216-Abstract.

12. Dong, P., Zeng, X., Duan, C., Wang, T., Luo, S., Wang, P., ..., & Zhao, H. (2020). Error Correction Method of Crude Oil Moisture Content Detection Based on BP Neural Network, *IOP Conference Series: Earth and Environmental Science*, *558*, 022005, 1-12. https://doi.org/10.1088/1755-1315/558/2/022005.

13. Osadchuk, A.V., Semenov, A.A., Zviahin, O.S., Savytskyi, A.Y., Komada, P., & Nurseitova, K. (2019). Numerical method for processing frequency measuring signals from microelectronic sensors based on transistor structures with negative differential resistance. *Proceedings of SPIE*, *11176*, 111765Y. https://doi.org/10.1117/12.2536942.

14. Varavallo, R., Moreira, V.M., Paes, V., Brito, P., Olivas, J., & Pinto, H.C. (2014). Microstructure and residual stress analysis of explosion cladded inconel 625 and ASME SA516-70 carbon steel bimetal plates. *Advanced Materials Research*, (996), 494-499. https://doi.org/10.4028/www.scientific.net/AMR.996.494.

15. Xiong, C.Y. (2012). Design and Application of Time-Domain Transmission Moisture Content of Crude Oil Sensor. *Advanced Materials Research*, (542-543), 928-932. https://doi.org/10.4028/www.scientific.net/amr.542-543.928.

16. Bian, X.N., He W., & Han, H.Y. (2010). Design of Capacitance Sensor's Circuit. *2010 Symposium on Photonics and Optoelectronics*, 1-4. https://doi.org/10.1109/SOPO.2010.5504236.

17. Korkua, S.K., & Sakphrom, S. (2020). Low-cost capacitive sensor for detecting palm-wood moisture content in real-time. *Heliyon*, *6*(8), e04555, 1-7. https://doi.org/10.1016/j.heliyon.2020.e04555.

18. Makeev, Y.V., Lifanov, A.P., & Sovlukov, A.S. (2014). Microwave measurement of water content in flowing crude oil with improved accuracy. *24th International Crimean Conference Microwave & Telecommunication Technology*, 956-957. https://doi.org/10.1109/CRMICO.2014.6959712.

19. Semenov, A.O., Baraban, S.V., Osadchuk, O.V., Semenova, O.O., Koval, K.O., & Savytskyi, A.Y. (2019). Microelectronic Pyroelectric Measuring Transducers. *4th International Conference on Nanotechnologies and Biomedical Engineering*, 393-397. https://doi.org/10.1007/978-3-030-31866-6_72.

20. Osadchuk, A.V., Semenov, A.A., Baraban, S.V., Semenova, E.A., & Koval, K.O. (2013). Noncontact infrared thermometer based on a self-oscillating lambda type system for measuring the human body's temperature, *Microwave and Telecommunication Technology*, 1069-1070.

Підвищення чутливості вимірювання вмісту вологи в сирій нафті

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Мета. Дослідження частотного перетворювача вологи на основі вологочутливого ємнісного елемента циліндричної конструкції із сітчастими електродами для системи вимірювання кількості й параметрів сирої нафти.

Методика. При побудові вологочутливого елемента застосовано осциляторний метод вимірювання вологості для досягнення високої чутливості й точності при збереженні низької вартості приладу. Вологочутливий ємнісний сенсор на основі циліндричної структури з сітчастими електродами був уведений до системи вимірювального генератора на основі транзисторної структури з від'ємним диференційним опором.

Результати. Отримані аналітичні вирази для опису діелектричної проникності неоднорідної суміші води й нафти. Застосовуючи ці рівняння, розрахована ємність чутливого до вологості сенсора з сітчастими електродами як залежність вологості сирої нафти. Було визначено, що ємність чутливого до вологості сенсора зросла з 20 до 44 пФ у випадку, коли масова вологість сирої нафти змінилася від 0 до 30 %. Чутливість розробленого ємнісного сенсора становить 0,8 пФ/% при використанні вимірювальної установки у вигляді трубопроводу сирої нафти діаметром 50 міліметрів.

Наукова новизна. Розроблена математична модель первинного перетворювача вологості сирої нафти на основі конденсаторної циліндричної структури з сіткоподібними електродами, що дозволяє визначити значення електричної ємності первинного перетворювача вологості сирої нафти. Розроблено автогенераторний засіб контролю вологості сирої нафти на основі структури біполярного й польового транзисторів із конденсаторною циліндричною структурою з сіткоподібними електродами.

Практична значимість. Розроблено схемотехнічне рішення перетворювача вологості сирої нафти. Результати експериментальних досліджень показали, що для обраного варіанту схеми перетворювача вологості частота вихідного сигналу зменшувалася в діапазоні від 1,617 до 1,27 МГц зі зміною масової вологості нафти туркменської суміші від 0 до 30 % відповідно, і є близькою до лінійної залежності. Широкий діапазон частот вихідного сигналу вторинного перетворювача з частотним виходом вимірюваної інформації на порядок підвищує точність вимірювання вологості в сирій нафті.

Ключові слова: *сира нафта, вміст вологи, ємнісний сенсор, частотний перетворювач, від'ємний диференційний опір, чутливість до вологи*

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