IOP Conference Series: Earth and Environmental Science

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To cite this article: L E Zemlerub *et al* 2021 *IOP Conf. Ser.: Earth Environ. Sci.* **808** 012042

IOP Conf. Series: Earth and Environmental Science **808** (2021) 012042 doi:10.1088/1755-1315/808/1/012042

Automatic mass meter, increasing the accuracy of calculating the gross weight of oil in vertical steel tanks

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Abstract. Improving the efficiency of operation of trunk pipelines. However, to assess the activities carried out, accurate and reliable information about the amount of the pumped and stored product is required. Existing methods for measuring the amount of liquid and methods of using capacity measures lead to large errors in calculations. Measurement and tampering with the turnover reporting process depends on the "human factor" and the prerequisites for introducing measurement and tampering into the turnover reporting process. In operation, an automatic system for measuring pressure and temperature by product layers based on the hydrostatic principle of operation, which allows calculating the gross mass of oil. Also, the paper analyzes methods for increasing the accuracy of calibration tables obtained in the process of tank calibration. The proposed system improves the measurement accuracy, productivity and operational efficiency of tank farms.

1. Introduction

Improving the accuracy of determining the mass of oil and oil products is a significant problem for enterprises involved in the transport and storage processes, including when establishing plans for receiving and supplying oil and oil products through pipelines, calculating cargo turnover and specific electricity consumption, monitoring the total availability of products and free containers, when carrying out repair work and making decisions about the possibility of changing the pumping mode.

The unjustified use by enterprises and organizations of the oil product supply system of overestimated norms of natural loss (losses) leads to the unreliability of accounting for oil products, which leads to writing off the shortage as costs instead of purposeful actions to develop appropriate resource-saving measures. Therefore, the development of new and improvement of existing methods for determining the mass of petroleum products in the process of transport and storage is currently an urgent task.

The regulatory framework governing the issues of metrological support for measuring and accounting for oil and oil products includes Federal laws "On energy conservation" and "On ensuring the uniformity of measuring instruments", a number of State standards, recommendations on metrology and departmental instructions.

The disadvantage of the existing measurement methods is the presence of an error due to the fact that the calculations of the final result are made according to algorithms that do not fully take into account the relationship of density, temperature, viscosity, the level of the bottom liquid (ballast) with the mass of the marketable product under changing external and internal conditions. After analyzing the sources [1-5], we can conclude that the calculation of the gross mass of oil products, based on the indirect hydrostatic method, is carried out with greater accuracy than any other measurement methods.

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2. Materials and methods

All methods for measuring the mass of oil and oil products are considered in GOST 8.587-2019 “State system for ensuring the uniformity of measurements. Mass of oil and oil products. Measurement techniques (methods)” [6]. According to this document, direct and indirect methods of dynamic and static measurements are used to determine the mass of the product in the pipeline transportation system of oil and oil products. The dynamic method for determining the mass is applicable only to the product in motion and the use of automated systems for accounting for the quantity and quality of oil and oil products on the flow made it possible to reduce the error in determining the mass by 50% (from +/- 0.50% for the static method for determining the gross weight of oil to +/- 0.25% with dynamic method). The mass of a product that is at rest in tank farms during inventory, operational and commercial accounting, as well as in case of failure of the accounting systems for the quantity and quality of oil and oil products, is determined by indirect static methods.

The gross mass of oil in the tank is measured as follows: the oil volume is determined by the measured level of oil and bottom water in the tank and by the calibration table obtained during the calibration of the tank. Then a sample is taken, which is sent to the metrological laboratory, where the value of the oil density is determined. The gross mass of oil in the tank is calculated by multiplying the density by the volume. When carrying out all these operations, the indicators are reduced either to the temperature of one indicator, or to normal conditions, where the application of the coefficient of volumetric expansion is required, which leads to the introduction of an additional error.

When it is taken into the reservoir, oil as a complex product begins to stratify, and in the process of settling, produced water necessarily appears. The Rules for the technical operation of tanks indicate that after receiving oil into the tank, it is settled for at least two hours, after which the produced water is drained, and only after that, samples are taken and the quality of oil is determined in the metrological laboratory. Sedimentation of mechanical impurities and drainage of produced water in tank farms reduces the mass of ballast, which leads to a change in oil quality indicators, an increase in the proportion of net weight, and an increase in the profitability of pipeline transportation of oil [7].

There are many ways to measure the filling level and other parameters of oil and oil products in vertical cylindrical steel tanks. In addition to measuring the level, a temperature measurement is necessary for a reliable assessment of the contents of the tank. Each liquid has a coefficient of thermal expansion, and it is necessary to leave an appropriate margin of capacity and perform appropriate calculations for changes in product temperature and ambient temperature during commercial transactions between suppliers and consumers.

3. Results

The paper proposes to use an automatic system for measuring the gross mass of oil products in vertical cylindrical steel tanks based on an indirect hydrostatic measurement method. In a device operating on the hydrostatic principle, the pressure and temperature are measured over the layers of the product. For example, the Multi-function Tank Gauge system.

The device is a pipe structure with equally spaced sensor modules, which makes it possible to measure the pressure and temperature of each sensor located under the layer of the product, with the subsequent calculation of the layer-by-layer and average density, as well as the filling level of the product, which is converted into volume through a calibration table and given to the temperature at which the tank was checked or the level and volume are brought to normal conditions. It can be noted that the transfer of indicators to other conditions is performed once, which reduces the error in calculating the gross mass.

According to [6], the limits of the permissible relative error in measuring the mass of the product with the indirect method based on the hydrostatic principle are calculated by the formula:

$$\delta m_2^c = \pm 1{,}1\sqrt{\delta P^2 + \delta \mathrm{K}^2 + (\mathrm{K}_\Phi - 1)^2 \delta H^2 + \delta N^2} \tag{1}$$

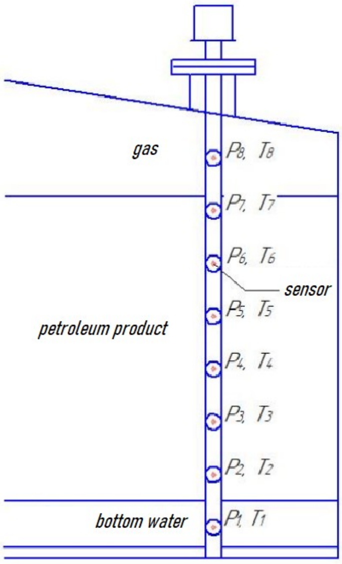

Figure 1. System design.

Where δP, δH - relative measurement errors of hydrostatic pressure and product level%;

δK - relative error in compiling the calibration table of the capacity measure%;

δN - the limit of the permissible relative error of the information processing device or measuring and computing complex (from the certificate of type approval or the certificate of verification)%;

K_ϕ - coefficient taking into account the geometric shape of the capacity measure.

The measurement error of the hydrostatic pressure is determined by the relative error of the pressure sensor $\delta P=0,25$ %. The error of the calibration table for tanks with a volume of 5000-50000 m^3 does not exceed δK=0,1%, δN=0,05 %. As a result of the calculation, the relative error of mass measurement based on the hydrostatic principle is equal to:

$$\delta m_2^c = \pm 1{,}1 \cdot \sqrt{0{,}25^2 + 0{,}1^2 + 0{,}05^2} = \pm\, 0{,}301\% \quad (2)$$

$$\delta m_2^c = \frac{0{,}301\%}{8} = \pm 0{,}038\% \quad (3)$$

According to [6], the relative error in measuring the mass of oil by the hydrostatic method should not exceed 0.50% for the mass of the product from 200 tons or more and 0.65% for the mass of the product up to 200 tons. the use of an indirect method based on the hydrostatic principle of measurements is much higher than the results obtained using the indirect method of static measurements.

To further improve the accuracy, you can increase the number of installed sensors, but this will increase the cost of the device. The most effective solution for increasing the accuracy in calculating the gross mass is the use of a mathematical model for approximating the obtained measurement results. It is currently accepted that the best approximating function will be the one for which the sum of the squares of the deviation at the experimental points is minimal (least squares method).

Based on the measurement results, a graph is built with which you can determine the density and temperature at any level of the tank, and not only at specific points where the sensors are installed. Thus, the error in the installation of sensors is eliminated, and the influence of the error in changing the shape of the tank during filling and emptying is reduced. This approach will significantly increase the measurement accuracy.

4. Discussion

As a result, it turns out that the proposed system is devoid of many of the disadvantages of the traditionally used indirect static system for measuring the gross mass of oil and oil products in vertical cylindrical steel tanks. Thus, with the hydrostatic method of measurement, the sensors are completely immersed in the product, which ensures complete identity of the temperatures of the product, diaphragm and other elements. However, all the proposed methods of increasing the accuracy are leveled by the low accuracy of the calibration table obtained in the process of checking the tanks. Improving the accuracy of the calibration table is achieved with modern methods of tank calibration, such as 3D laser scanning. Laser scanning makes it possible to perform measurements with high accuracy and detect deviations from the ideal shape of the tank, which shows the advantages of laser scanning technology compared to the traditional geometric method [9-10].

It is planned to conduct experiments on the existing model of the tank with the operator's workstation, which will make it possible to compare the errors in the results of the obtained measurements of the radar level gauge and the proposed multifunctional device.

5. Conclusion

Thus, this method will automatically measure the temperature and pressure across the layers of the product with one device, which will allow you to calculate the level, volume, density, percentage of water and gross weight of the product, and the use of mathematical modeling will lead to the elimination of most of the errors. Improving the accuracy of the calibration tables obtained during the calibration of tanks with modern 3D laser scanning systems will improve the accuracy of the overall result - calculating the gross weight of oil and oil products in vertical cylindrical steel tanks.

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