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# Measures to ensure the necessary accuracy of accounting petroleum products in the tanks

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**Abstract**

This paper considers the measures to ensure the necessary accuracy of accounting petroleum products in the vertical and horizontal cylindrical tanks at tank farms, gas stations and other facilities, which are subject to the sphere of legislatively regulated metrology. The maximum permissible error of the set of calibrated tank, level gauge and density meter during the measurement of difference of the masses of petroleum products at the start and at the end of the accounting operation in the vertical tanks, as well as the maximum permissible error of the set of calibrated tank, level gauge and density meter during the measurement of difference of the masses in the horizontal tanks at a level approximately equal to half of the height of the tank, have been analyzed. It is shown that the same calibration table is used both for the level of petroleum products at the beginning of the accounting operation and at the end of such operation. The component of the error caused only by the maximum permissible error of the used level gauge is analyzed. On a number of examples with the most common capacity of vertical tanks for tank farms, the relative maximum permissible error of the set of calibrated tank, level gauge and density meter during the measuring the mass of dispensed petroleum products due to the error of level gauges ranges from ±2% to ±9% with the level gauge error from ±1 mm to ±4 mm. This error is significantly larger than ±0.75% given in DSTU 7094. It is concluded that, in accordance with OIML R 85, it is not feasible to consider the maximum permissible error of the level gauge installed on the tank equal to ±4 mm. When installing the level gauge on a rigid crossbar, fixed at the ends of the tank walls, the maximum permissible error of the level gauge during the measuring the level of petroleum products under operating conditions of ±2 mm can be achieved, as specified in the Instruction for accounting of petroleum products.

To improve the measurement accuracy, it is necessary to reduce the effect of deformation of the bottom of vertical tanks, which can be achieved by keeping the level of petroleum products in the tank at least two meters.

**Keywords:** petroleum product; volume; error; tank; level.

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## Introduction

Improving the accuracy of petroleum products accounting requires, first of all, an increase in accuracy of volume and mass measurements of petroleum products in tanks, as the main places of storage of petroleum products.

## The results of research

This article has been prepared as a follow-up to [1].

Accounting for petroleum products in the tanks is an important task for the economy of each country. The tanks are sufficiently accurate measuring instruments, the maximum permissible error of their calibration tables (volume dependence on level) is mainly from ±0.1 to ±0.2% [2, 3]. The calibrated tanks do not perform measurements by their own and are measuring instruments only in combination with level gauges.

As a rule, in the tasks of petroleum products accounting the output value is the mass or volume of petroleum products reduced to a temperature of 15 °C. To obtain these values, in addition to volume measurement, it is necessary to measure the density of petroleum products [1].

In accordance with the Law of Ukraine "On metrology and metrological activity" [4], tanks for petroleum products fall into the sphere of legally regulated metrology if they are used in trade and commercial operations, the calculation of taxes and duties, in tax control. In addition, according to the Resolution of the Cabinet of Ministers of Ukraine "On approval of the list of categories of legally regulated measuring instruments subject to periodic verification" [5], stationary tanks for commercial accounting of petroleum products are subject to periodic verification if they are used when carrying out the above operations. It should be noted that the expression "commercial accounting" must, apparently, be understood as "commercial operations or accounting", since these two directions, according to [4], are completely different.

Moreover, as a rule, tanks are not used for commercial operations with petroleum products. For this, mainly oil product meters, road and rail tank cars are used [6]. At the same time, with rare exceptions, tanks are widely used for accounting the petroleum products. These exceptions include tanks in industrial and agricultural applications.

In contrast to vertical cylindrical tanks (Fig. 1), in which the volume and level are related through an almost constant value – the area of the horizontal section of the tank, for horizontal cylindrical tanks (Fig. 2) this relation is much more complicated and the maximum permissible error of a set of a calibrated tank, a level gauge and a density meter when measuring the mass of petroleum products depends on the level. For this reason, for practical estimates of the maximum permissible error of a set of a calibrated tank, a level gauge and a density meter for measuring the mass of a petroleum product, in this article, for the case of horizontal tanks, the largest value of the maximum permissible error is analyzed, corresponding to a level approximately equal to half the height of the tank. The conventional area of the horizontal section of such a "quasi-vertical" tank is equal to the product of the length of the tank by its diameter. With this approach, the calculated expressions for the maximum permissible error of a set of a calibrated tank, a level meter and a density meter for measuring the volume and mass of petroleum products in vertical and horizontal cylindrical tanks are identical. In this case, the maximum permissible relative error of a calibrated tank is the maximum permissible relative error of its calibration table $\delta_K$.

For a vertical cylindrical tank, the confidence limits of the non-excluded systematic error (NSE) for measuring the mass of petroleum in the tank for a confidence level of 0.95 $\delta_m$ were obtained from formula (26) of the standard [7] with the substitution of expressions (23) and (28) of this standard and have the form:

$$\delta_m = \pm 1.1 \sqrt{\begin{array}{l}\delta_K^2 + \delta_H^2 + \dfrac{1+2\cdot\beta\cdot T_V}{1+2\cdot\beta\cdot T_\rho}\times \\ \times\left(\delta_\rho^2 + \beta^2\cdot 10^4\cdot\Delta_{T\rho}^2\right) + \beta^2\cdot 10^4\cdot\Delta_{T_V}^2\end{array}}, \quad (1)$$

where $\delta_K$, $\delta_H$, $\delta_\rho$ are maximum permissible relative errors of a calibrated tank, a level gauge and a density meter, respectively, %; $T_V$, $T_\rho$ are the temperatures of the petroleum product when measuring its volume and density, respectively, °C; $\beta$ is the coefficient of volumetric expansion of the petroleum product, °C$^{-1}$; $\Delta_{T_V}$, $\Delta_{T\rho}$ are the maximum permissible absolute errors of thermometers used to measure the temperature of the petroleum product when measuring its volume and density, respectively, °C.

In order to simplify the estimation of the NSE according to formula (1), we will take into account that the following conditions are most often satisfied: $\beta \approx 0.001$ °C$^{-1}$, $\Delta_{T\rho} = \Delta_{Tv} = 0.1$ °C, $\delta_\rho \approx 0.001$, the value $\delta_\rho^2 + \beta^2\cdot 10^4\cdot\Delta_{T\rho}^2 \approx \delta_\rho^2$, $\delta_\rho^2 + \beta^2\cdot 10^4\cdot\Delta_{Tv}^2 \approx \delta_\rho^2$.

These simplifications, which are suitable in most cases, allow to analyze the calculated expressions.

Then, from expression (1) we get:

$$\delta_m = \pm 1.1\sqrt{\delta_K^2 + \delta_H^2 + \delta_\rho^2}. \quad (2)$$

When moving from the maximum permissible error of a set from a calibrated tank, a level gauge and a density meter for measuring the mass of petroleum in the tank to the maximum permissible error of a set from a calibrated tank, a level meter and a density meter for measuring the mass difference $\delta_{m_0}$ at the beginning ($m_1$) and at the end ($m_2$) of the accounting

Fig. 1. Vertical steel cylindrical tanks for petroleum products

Fig. 2. Horizontal steel cylindrical tanks for petroleum products

operation, where $m_0=|m_2-m_1|$, the maximum permissible relative error of the calibration table for the mass difference $\delta_{K_0}$ in [1, 7] does not exceed the value of the normalized maximum permissible error of the calibration table $\delta_K$:

$$\delta_{K_0} = \sqrt{\delta_{K_1}^2 + \delta_{K_2}^2}, \quad (3)$$

where $\delta_{K_1}$ and $\delta_{K_2}$ are the maximum permissible errors of the calibration table at the level $H_1$ and $H_2$, respectively.

This is indeed the most general expression for the case when two separate calibrations are made – to the initial level and to the final one, at different times, by different means, and, at the same time, it is important that the difference is calculated exactly from the initial level $H_1$, determined with an error $\delta_{K_1}$. If it is taken into account, that the same calibration table is used for both the initial and final levels, and the determination of the initial volume from the calibration table is not needed, only the difference in volumes ($V_1 - V_2$) according to one calibration table is needed.

From (2) and (3) in this case, taking into account that $\delta_{m_0} = \frac{\delta_m \cdot m}{m_0}$, we get:

$$\delta_{m_0} = \pm 1.1\sqrt{\delta_K^2 + \delta_\rho^2 + \frac{m_1^2}{m_0^2}\cdot\delta_{m_1}^2 + \frac{m_2^2}{m_0^2}\cdot\delta_{m_2}^2}. \quad (4)$$

Here it is taken into account that $\delta_K$ and $\delta_\rho$ are the same for the levels $H_1$ and $H_2$.

For vertical and "quasi-vertical" tanks

$$\frac{m_1}{m_0} = \frac{m_1}{m_2 - m_1} = \frac{H_1}{H_2 - H_1}, \quad \frac{m_2}{m_2 - m_1} = \frac{H_2}{H_2 - H_1}.$$

Moving from the relative maximum permissible error $\delta_H$ to the absolute one $\Delta_H$, we obtain

$$\frac{m_1}{m_0}\delta_{H_1} = \frac{H_1}{H_2 - H_1}\cdot\delta_{H_1} = \frac{H_1}{H_2 - H_1}\cdot\frac{\Delta_{H_1}}{H_1} = \frac{\Delta_{H_1}}{H_2 - H_1}.$$

Similarly $\frac{m_2}{m_0}\delta_{H_2} = \frac{\Delta_{H_2}}{H_2 - H_1}$, and from (4) we get:

$$\delta_{m_0} = \sqrt{\delta_K^2 + \delta_\rho^2 + \frac{\Delta_{H_1}^2}{(H_2 - H_1)^2}\cdot(100\%)^2 + \frac{\Delta_{H_2}^2}{(H_2 - H_1)^2}\cdot(100\%)^2}. \quad (5)$$

Since the maximum permissible absolute error of the level gauge $\Delta_H$ does not depend on the level $H$, then $\Delta_{H_1} = \Delta_{H_2} = \Delta_H$ and the confidence limits of the non-excluded systematic error (NSE) for measuring the difference in the mass of the petroleum in the tank for a confidence level of 0.95 $\delta_{m_0}$ are:

$$\delta_{m_0} = \sqrt{\delta_K^2 + \delta_\rho^2 + 2\frac{\Delta_H^2}{(H_2 - H_1)^2}\cdot(100\%)^2}, \quad (6)$$

where $\Delta_H$ is the maximum permissible absolute error of the level gauge, mm; $H_1$ and $H_2$ is the level of petroleum products at the beginning and end of the accounting operation, respectively, mm.

Due to the fact that the random error in measurements using a stable tank and a level gauge is much less than NSE, for estimation calculations the maximum permissible relative error of a set of a calibrated tank, a level gauge and a density meter when measuring the mass difference at the beginning and at the end of a trade (accounting) operation is taken equal to NSE.

It is taken into account that the density is measured once, before the start of the accounting operation.

Here are some examples of calculating the maximum permissible relative error of a set of a calibrated tank, a level gauge and a density meter for measuring the difference in mass of petroleum products in a vertical tank during accounting operations.

*Example 1.*

Vertical cylindrical tank with a nominal capacity of 2000 m³. The maximum permissible relative error of its calibration table according to [2] is $\delta_K \pm 0.2\%$. The petroleum product is dispensed from this tank into a tank car with a capacity of 10 m³. The tank has a height of 12 m, a diameter of 4.6 m and a cross-sectional area of 167 m², which corresponds to a volume of 10 mm with a height of 1.67 m³.

$H_1 = 5.94$ m, $H_2 = 6$ m, $H_2 - H_1 = 60$ mm.

Maximum permissible error of the level meter $\Delta_H = \pm 1$ mm, the maximum permissible relative error of the density meter $\delta_\rho \pm 0.1\%$.

$$\delta_{m_0} \pm 1.1\sqrt{(0.2\%)^2 + (0.1\%)^2 + 2\cdot\frac{(1\,\text{mm})^2}{(60\,\text{mm})^2}\cdot(100\%)^2} = \pm 2{,}61\%.$$

*Example 2.*

The same tank, the same maximum permissible error of the level gauge, but the petroleum product is dispensed into the tank from a railway tank with a nominal capacity of 60 m³.

$H_2 = 6$ m, $H_1 = 5.64$ m, $H_2 - H_1 = 360$ mm, $\delta_{m_0} \pm 0.5\%$.

In addition to the maximum permissible error of the level gauge and the calibration table, there is another important source of the maximum permissible error of a set from a calibrated tank, a level gauge and a density meter when measuring the mass of petroleum products in tanks – the instability of vertical cylindrical tanks due to deformation of their bottoms when loading and unloading of petroleum products, as well as deformation of the roof. To reduce this rarely considered component of the maximum permissible error of a set of a calibrated tank, a level gauge and a density meter, the next rules should be followed.

1) The level gauge in a vertical tank should be installed not in a hatch on the roof, but on a rigid

crossbar under the hatch, fixed at the edges of the extending upper part of the tank walls. In addition, it is necessary to periodically check the change in the distance from these edges to the surface of the earth near the tank during loading and unloading of petroleum products for subsequent introduction of corrections to the level measurement data, if necessary.

2) During accounting operations in vertical tanks, the level of petroleum products, according to the experience of tank farm workers, should be at least two meters. In this case, almost all the deformed parts of the bottom are in their lower stable position.

3) Measurements of the base height (the vertical distance from the measuring hatch to the bottom) of vertical cylindrical tanks should also be carried out at a level of petroleum products of at least two meters to ensure the stability of the position of bottoms.

It is necessary to evaluate the influence of the maximum permissible error of the level gauge on the maximum permissible error of a set of a calibrated tank, a level gauge and a density meter for measuring the difference in the mass petroleum products during the accounting operation. In accordance with (6), even without taking into account the maximum permissible error of the calibration table $\delta_K$, the maximum permissible error of the density meter $\delta_\rho$, but only due to the maximum permissible error of the level meter $\delta_H$, for the above Example 1:

$$\delta_m = \sqrt{2 \cdot \frac{(1\text{ mm})^2}{(60\text{ mm})^2} \cdot (100\%)^2} = \pm\, 2.36\%.$$

If at the place of operation the maximum permissible error of the level gauge becomes equal to ±4 mm, then the maximum allowable error of the set of a calibrated tank, a level gauge and a density meter when measuring the mass difference in this Example is:

$$\delta_m = \sqrt{2 \cdot \frac{(4\text{ mm})^2}{(60\text{ mm})^2} \cdot (100\%)^2} = \pm\, 9.44\%.$$

At the same time, the Instruction on accounting of petroleum products [9] states that the maximum permissible error of a level gauge for measuring the level of petroleum products in real conditions should be ±2 mm, and the maximum permissible relative error of a set of a calibrated tank, a level meter and a density meter for measuring the mass of petroleum products by the method of indirect static measurements with a mass of up to 120 tons should be ±0.75%.

With some contradiction of the given figures, it is obvious that in order to achieve the maximum permissible error of a set of a calibrated tank, a level gauge and a density meter for measuring the mass of the unloaded (loaded) petroleum product of no more than ±2%, the maximum permissible error of the level gauge under operating conditions should be no more than ±2 mm. And in order to achieve such a maximum permissible error of the level gauge under operating conditions, and not in accordance with the recommendation in [8] about the maximum permissible error of ±4 mm, it is necessary to install the level gauge not on the swinging roof of the tank, but on a rigid crossbar fixed at the ends of the tank walls. The requirement of the Instruction [9] on the necessity to measure the level of petroleum products in the tank with a maximum permissible error of ±2 mm seems to be correct, but the requirement for the maximum permissible error of the level gauge when installed on a tank of ± 4 mm in [8] seems completely unjustified and leads to a large maximum permissible errors of a set from a calibrated tank, a level gauge and a density meter for measuring the mass of petroleum products in the tank. Moreover, this is the maximum permissible error not of the level gauge, but of the tank if the level gauge is incorrectly installed on the tank. The recommendation in this standard [8] to perform calibration of the level gauge during operation at only one level value is even more inconsistent.

It is necessary to dwell in more detail on the features of horizontal tanks. Unlike vertical tanks, they do not have a roof with an unstable position, and there is no bottom with unstable irregularities – clearance gaps. Both the upper part and the lower part of the horizontal tanks are quite rigid, being the lateral surfaces of the cylinder. However, horizontal tanks have their drawbacks too:

1) The bottoms of horizontal tanks should be made, according to [3], spherical, conical, rectangular or in the form of a truncated cone. However, in practice, already during manufacture, they represent a conditionally certain convex shape, and during repairs, their shape changes even more in comparison to the given shape. This leads to a significant increase in the maximum permissible error of the calibrated tank. It is necessary not to change the shape of the bottoms during the manufacture and repair of tanks.

2) Horizontal tanks are very sensitive to changes in their slope. This is especially important for underground tanks of filling stations, the slope of which often changes during operation. Sufficiently small changes in the slope of horizontal tanks (in tenths of a degree) can change significantly the calibration table of the tank and cause an additional error in the calibration table from several tens of fractions of a percent to a few percent [10]. It is necessary to place underground horizontal tanks on a rigid (concrete) foundation.

## Conclusion

An increase in the accuracy of accounting the petroleum products should be based on an increase in the accuracy of the used level gauges, the optimal placement of level gauges on tanks and measurement modes. The approaches proposed in the article make it possible to correctly evaluate and significantly increase the accuracy of accounting the petroleum products.

# Заходи із забезпечення необхідної точності обліку нафтопродуктів у резервуарах

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**Анотація**

Розглянуто заходи із забезпечення необхідної точності обліку нафтопродуктів у вертикальних та горизонтальних циліндричних резервуарах нафтобаз, автозаправних станцій та інших, які потрапляють у сферу законодавчо регульованої метрології. Проаналізовано максимально допустиму похибку комплекту з градуйованого резервуара, рівнеміра та густиноміра під час вимірювання різності мас нафтопродуктів на початку та в кінці облікової операції у вертикальних резервуарах та максимально допустиму похибку комплекту з градуйованого резервуара, рівнеміра та густиноміра під час вимірювання різності мас у горизонтальних резервуарах на рівні, який приблизно дорівнює половині висоти резервуара. Показано, що як для рівня нафтопродуктів на початку облікової операції, так і в кінці такої операції використовується одна й та ж градуювальна таблиця. Проаналізовано складову максимально допустимої похибки, обумовленої тільки похибкою рівнеміра, який застосовується. На ряді прикладів із найбільш розповсюдженою для нафтобаз місткістю вертикальних резервуарів відносна максимально допустима похибка комплекту з градуйованого резервуара, рівнеміра та густиноміра під час вимірювання маси відпущених нафтопродуктів, яка обумовлена похибкою рівнемірів, становить від ±2 до ± 9% при похибці рівнеміра від ±1 до ±4 мм. Ця похибка значно більша від наведеної в ДСТУ 7094 ±0.75%. Зроблено висновок щодо недоцільності, відповідно до OIML R 85, вважати максимально допустиму похибку рівнеміра, який встановлений на резервуарі, рівною ±4 мм. При встановленні рівнеміра на жорсткій поперечині, яка закріплена на торцях стінок резервуару, може бути досягнуто максимально допустимої похибки рівнеміра під час вимірювання рівня нафтопродукту в умовах експлуатації ±2 мм, як це встановлено в Інструкції з обліку нафтопродуктів.

Для підвищення точності вимірювань необхідно зменшувати вплив деформації днища вертикальних резервуарів, що може бути досягнуто дотриманням рівня нафтопродуктів у резервуарі не менше двох метрів.

**Ключові слова:** нафтопродукт; об'єм; похибка; резервуар; рівень.

# Меры по обеспечению необходимой точности учета нефтепродуктов в резервуарах

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**Аннотация**

Рассмотрены меры по обеспечению необходимой точности учета нефтепродуктов в вертикальных и горизонтальных цилиндрических резервуарах нефтебаз, автозаправочных станций и других, попадающих в сферу законодательно регулируемой метрологии. Проанализирована максимально допускаемая погрешность комплекта из градуированного резервуара, уровнемера и плотномера при измерении разности масс нефтепродуктов в начале и в конце учётной операции в вертикальных резервуарах и максимально допускаемая погрешность комплекта из градуированного резервуара, уровнемера и плотномера при измерении разности масс в горизонтальных резервуарах на уровне, приближенно равном половине высоты резервуара. Показано, что как для уровня нефтепродуктов в начале учетной операции, так и в конце такой операции используется одна и та же градуировочная таблица.

Для повышения точности измерений необходимо уменьшать влияние деформации днища вертикальных резервуаров, что может быть достигнуто соблюдением уровня нефтепродуктов в резервуаре не менее двух метров.

**Ключевые слова:** нефтепродукт; объём; погрешность; резервуар; уровень.

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