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IMPROVING THE ACCURACY OF MEASURING THE VOLUME AND MASS OF LIQUID PRODUCT IN HORIZONTAL CYLINDRICAL TANKS

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Abstract: *The article is devoted to improving the accuracy of the system for measuring and controlling the level of liquid materials in horizontal cylindrical tanks. The task of ensuring continuous accurate control of the level, volume and mass of petroleum products, taking into account the shape of the bottom of the tank, is set. In order to improve the accuracy of the measuring device, a laser rangefinder is installed, which allows you to determine the distance from the tank lid to the point of the surface level of the liquid product and calculate the volume of the liquid material by determining the average temperature and correcting for temperature changes when calculating the density, volume and mass of petroleum products with different shapes of the bottoms of a horizontal cylindrical tank. The developed method provides high accuracy, low power consumption, implementation is simple and economical. The device has no mechanically moving parts, so the measuring equipment is protected from failures and has a long service life.*
Keywords: *level gauge, tank, bottoms, volume, non-contact measurement, laser rangefinder accuracy, temperature, microprocessor, ADC-DAC, sensor.*

Аннотация: *Мақола горизонтал цилиндрик резервуарларда суюқ материаллар сатҳини ўлчаш ва назорат қилиш тизимининг аниқлигини оширишга бағишланган. Вазифа қилиб, резервуар тубини шаклини ҳисобга олган ҳолда нефть маҳсулотлари сатҳи, ҳажми ва массасини узлуксиз аниқ назорат қилишни таъминлаш белгиланган. Ўлчаш қурилмасини аниқлигини ошириш учун оптик қурилмалар ёрдамида лазерли масофа ўлчагич ўрнатилган бўлиб, бу эса резервуарнинг қопқоғидан суюқ маҳсулот сиртидаги сатҳгача бўлган масофани аниқлаш орқали ҳажмни ҳисоблашга имкон беради. Ишлаб чиқилган усул юқори аниқликни, кам қувват истеъмолини, уни амалга ошириш иқтисодий жиҳатдан жуда оддийлиги, механик ҳаракатланувчи қисмларга эга эмаслиги билан ўлчаш ускунасини узилишлардан ҳимоялайди ва узоқ ишлаш даврини таъминлайди.*
Таянч сўзлар: *сатҳ ўлчагич, резервуар, туб, ҳажм, контактсиз ўлчаш, лазерли масофа ўлчагич, аниқлик, ҳарорат, микропроцессор, АРЎ-РАЎ, датчик.*

Аннотация: *Статья посвящена повышения точности системы измерения и контроля уровня жидких материалов в горизонтальных цилиндрических резервуарах. Поставлена задача обеспечения непрерывного точного контроля уровня, объема и массы нефтепродуктов с учетом формы днища резервуара. С целью повышения точности измерительного устройства установлен лазер-дальномер, что позволяет определять расстояние от крышки резервуара до точки уровня поверхности жидкого продукта и рассчитывать объем жидкого материала, путем определения средней температуры и введения поправки на изменение температуры при расчете плотности, объёма и массы нефтепродуктов при разных формах днищ горизонтального цилиндрического резервуара. Разработанный способ обеспечивает высокую точность, низкую мощность потребления, реализация осуществляется просто и экономично. Устройства не имеет механически движущихся частей, в связи с чем измерительное оборудование защищено от сбоев и обладает долгим сроком службы.*

Ключевые слова: *уровнемер, резервуар, днище, объем, бесконтактное измерение, лазер-дальномер, точность, температура, микропроцессор, АЦП-ЦАП, датчик.*

1. INTRODUCTION

Liquid level measurement in large tank systems, used in the oil and gas industry is necessary to accurately determine the product volume during storage. Tank gauging systems have to ensure accurate measurement of the filling level, temperature, pressure and flow as part of inventory management. To get accurate results, when measuring mass flow more variables need to be controlled [1-3].

Horizontal cylindrical tank is one of the types of tanks widely used in tank farms for storing oil and petroleum products. These tanks must be carefully calibrated [4, 5] to ensure accurate measurement of the volume of contained liquid for custody transfer purposes.

Today it is possible to monitor the level measurement of liquid products in many technological processes lies in the fact that in measuring the petroleum volume in tank, made in a cylinder form, the height measurement of the oil product in the tank produced with a measuring tape, in a cylindrical round horizontally located form, and for known the radius values and the tank length the oil product volume is determined by the dimensionless diagram, single for all horizontally located tanks. But, this method disadvantage of measuring the liquid products level is insufficient accuracy, which leads to large errors and applies only to cylindrical tanks of round horizontal sample.

However, when storing petroleum products in tank farms and gas stations there are other tank designs [6, 7].

2. RESEARCH METHODS AND THE RECEIVED RESULTS

Depending on technical requirements tanks can be completed with different bottoms types: elliptical, spherical and torispherical (Fig. 1). In such forms of tanks when calculating the volume or mass of liquid on the measuring accuracy the filling height influence two segments of the equal volume ball on both sides, which need to be considered.

Petroleum products are viscous liquids, which change their performance properties under certain storage conditions; for example, the viscosity depends on temperature, increasing with decreasing temperature. When calculating a product mass, its density value is used. Therefore, the volume and density when receiving, dispensing and accounting for oil and oil products must be corrected [8] according to the liquid temperature.

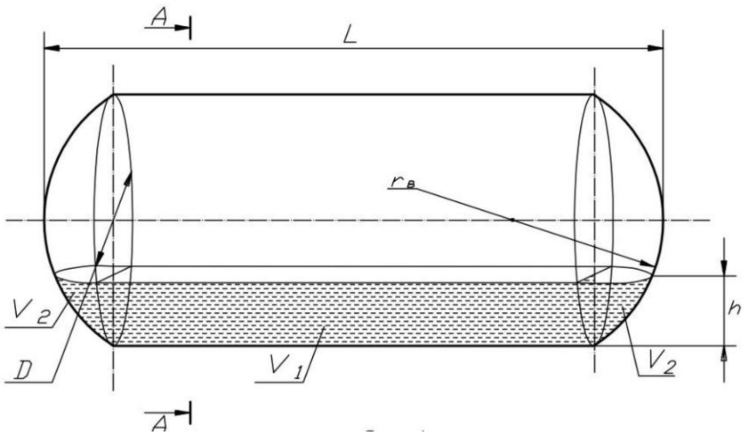

Fig. 1. ***Horizontal cylindrical tank with hemispherical bottoms.***

The problem: Ensuring continuous accurate level control, volume and mass of oil products, taking into account the tank bottoms shape, by determining the average temperature and the introduction of a correction for temperature changes when calculating density using formulas to determine the liquid material volume in tanks.

To solve the task developed a new way to solve the above problem, providing a kind of intelligent measuring system for storage and accounting of petroleum products, based on real data measurement, whereby data measurements are performed with correction-compensation so that more accurate continuous measurement of a liquid product volume is obtained for a horizontally located cylinder with any bottom type.

In the measuring process the level and volume of liquid material non-standard horizontal cylindrical tank with spherical, elliptical or torospherical bottoms is two geometric shapes combination (see. Fig. *2*.): horizontal cylinder in the central part of the tank (volume V_1) and two segments of an equal volumes ball (each volume V_2). Determination of V_{total} - the total liquid volume in the tank can be reduced to solving two problems - finding liquid volume of V_1, V_2 and their addition [9].

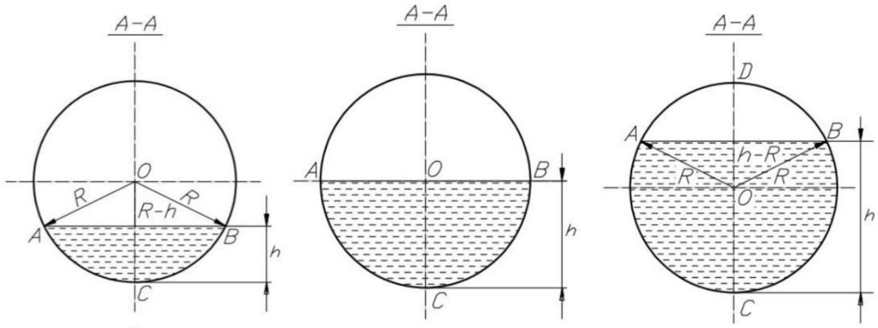

Fig. 2. ***Three cross-sectional views of a cylindrical tank when filling a liquid product.***

In all tanks a type in the measuring process the cylinder volume considered on the basis of the cross section of the cylinder, and has three positions of the liquid in the tank (Figure 2):

1. h>R the liquid level is less than half the cylinder volume. For this position of the cross-section cylinder when determining the area of the bulk liquid material from the AOBC sector area the AOB triangle area is subtracted and the ABC segment area is obtained, where *R*-*h* is the triangle height. The V_1 liquid product volume can be found by multiplying the $L_ц$ tank length by the $S_{сег}$ segment area: $V= L_ц\ S_{сег}$, i.e.

$$V_1 = L_ц\left[R^2cos^{-1}\left(\frac{R-h}{R}\right) - (R-h)\sqrt{2Rh-h^2}\right] \quad (1)$$

2. $h=R$ the liquid level is equal to half the cylinder volume. The segment area will be half the cross-sectional area and $V_1=1/2(\pi R^2)$

3. $h<R$ the liquid level is more than half the cylinder volume. For this position of the cross-section cylinder, when determining the bulk liquid material area, the AOB triangle area is subtracted from the AOBD sector area and the ABD segment area is obtained, where *h*-*R is* the triangle height. Next, the resulting area of the ABD segment is subtracted from the total area of the circle and the volume of the liquid product V_1 is calculated

$$V_1 = L_ц\left[R^2cos^{-1}\left(\frac{h-R}{R}\right) - (h-R)\sqrt{2Rh-h^2}\right] \quad (2)$$

Consider three types of tanks at all liquid product levels positions as measured by *H*. With knowledge of the basic tank parameters, the liquid material volume in the tank can be determined.

Consider three types of tanks at all liquid product levels positions as measured by *H*. With knowledge of the basic tank parameters, the liquid material volume in the tank can be determined.

To do this, we will use the following designations for all figures: *1* – tank with diameter *D*; L_p – total tank length, $L_ц$ – length of the cylindrical part of the tank; 2 – petroleum product, *3* – filling pipe, *4* – a drain pipe, *5* – laser rangefinder; *6* – optically transparent window *7* – tank support leg, *8*, *9*, *10* – thermometers for measuring the temperature of petroleum products, *H* – distance from the top of the tank to the surface of the oil product, determined by the laser rangefinder; *h* – height of oil in the tank; *R* – tank radius; *r* – radius of rounding of the side bottom of the tank.

The reservoir *1* is usually filled with oil *2*, which is supplied through the filling pipe *3* and drained through the drain pipe *4*. If a laser rangefinder *5* is placed in the upper part of the tank over a sealed optically transparent window *6*, then using the laser rangefinder, it is possible to determine the distance *H* from the upper part of the tank to the liquid material surface.

Calculation option 1. Horizontal cylindrical tank with hemispherical bottoms. V_2 - volume of a filled liquid material in the form of a hemispherical ball; *C* – according to the ASME standard is 1;$r_{в}$ - convex radius, $r_{в}=D/2$; h – liquid material height (Figure 3):

$$V_2 = D^3 C \frac{\pi}{12}\left[3\left(\frac{h}{D}\right)^2 - 2\left(\frac{h}{D}\right)^3\right] \quad (3)$$

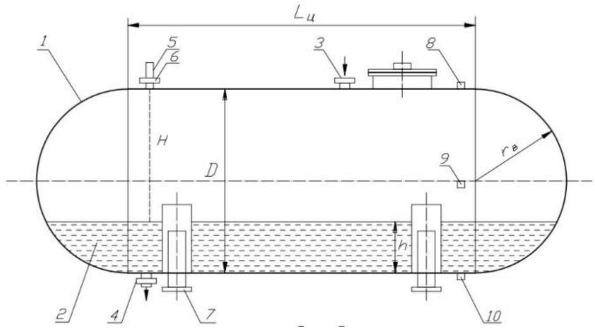

Fig. 3. ***Horizontal cylindrical tank with hemispherical bottoms.***

Calculation option 2. Horizontal cylindrical tank with elliptical bottoms. V_2 - the bottom volume of the filled liquid material in the ellipse form; *C* – according to ASME standard is 0.5; $r_{в}$ - convex radius, $r_{в}=0.8D$; r_{con} - fillet radius, $r_{con}=0.15D$; z – bottom depth, z=0.25D; h – liquid material height (Fig. 4).

$$V_2 = D^3 C \frac{\pi}{12}\left[3\left(\frac{h}{D}\right)^2 - 2\left(\frac{h}{D}\right)^3\right] \quad (4)$$

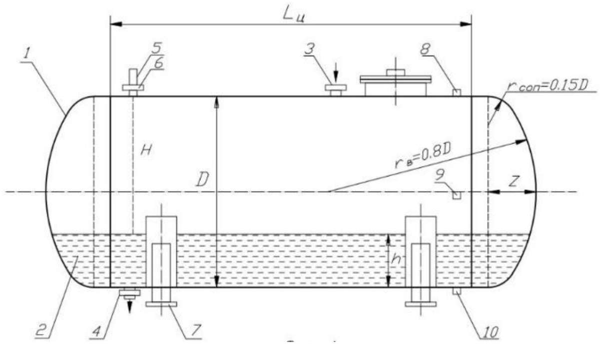

Fig 4. ***Horizontal cylindrical tank with elliptical bottoms.***

Calculation option 3. Horizontal cylindrical tank with torispherical bottoms. V_2 - the bottom volume of the filled liquid material in the torisphere form: t - wall thickness (in meters), *C* – according to ASME standard is 0.5; $r_{в}$ - convex radius, $r_{в}=D+t$; r_{con} - fillet radius, $r_{con}=3t$; z – bottom depth; h – height of liquid material (Figure 5).

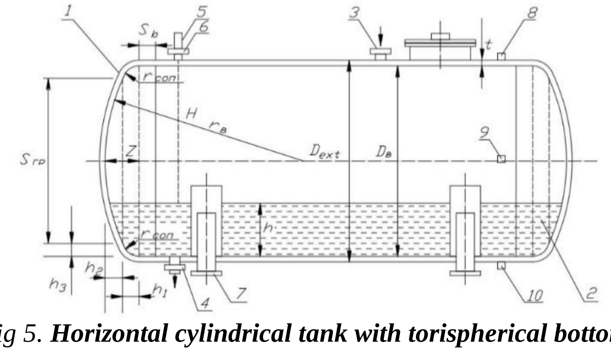

Fig 5. ***Horizontal cylindrical tank with torispherical bottoms.***

$$z = r_{в} - \sqrt{(r_{в} - r_{соп})^2 - (\frac{r_{в}}{2} - t - r_{соп})^2} \quad (5)$$

The total volume of the bottom is according to [3]:

$$V_{дн.} = 0.9(\frac{2\pi r_{в}^{2}}{3})z \quad (6)$$

V_2 - bottom volume of filled liquid material, $V_2 = V_{сфер.} + V_{эллипс.}$:

$$V_{сфер.} = \pi \int_0^{h_1} (2r_{в}h - h^2)dh = \pi(r_{в}h_1^2 - \frac{1}{3}h_1^3) \quad (7)$$

$$V_{эллипс.} = \frac{\pi}{4}\int_0^{h_2}(D - 2r_{соп} + 2\sqrt{r_{соп}^{2} - h^2})^2 dh = \frac{\pi}{4}\left[8r_{соп}^2 h_2 - \frac{4}{3}{h_2}^3 + 2Dh_2\sqrt{r_{соп}^2 - {h_2}^2} + 2Dr_{соп}^2\arctan(\frac{h_2}{\sqrt{r_{соп}^2 - {h_2}^2}} - 4r_{соп}h_2\sqrt{r_{соп}^2 - {h_2}^2} - 4r_{соп}^3\arctan\frac{h_2}{\sqrt{r_{соп}^2 - {h_2}^2}} + D^2{h_2}^2 - 4{h_2}^2 D r_{соп})\right] \quad (8)$$

According to the present developed method in the intelligent measuring system of the tank farm in Figure 6 shown a block-block diagram of continuous level measurement in the tank 1 of oil products, used for obtaining data in real time, consisting of a measuring part, including a laser rangefinder 2 and temperature sensors 3, 4, 5, as well as the control unit 6, which calculates the data, on the available reserves of petroleum products using real-time data.

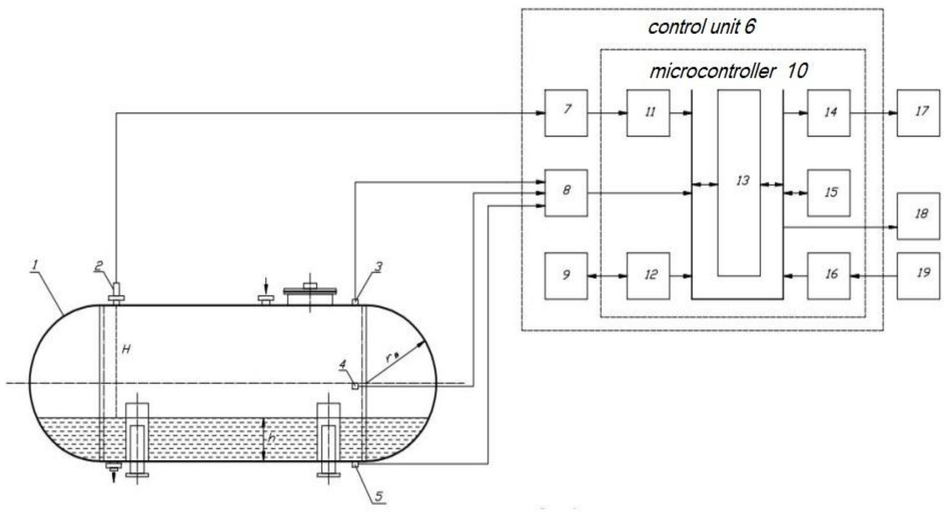

Fig. 6. ***Block-block diagram of an intelligent measuring system for measuring the level and mass of a liquid product.***

For monitoring the tank [10, 11] and made on the basis of a microcontroller 10 containing a microprocessor 13, with a program and data memory unit 15 connected to it, connected via a common bus with analog-to-digital converters (ADC) 11 and 12 with universal eight-bit bidirectional input-output ports 14, 16, which are connected to the display unit 17 and the data input unit 19. The control unit also includes operational amplifiers 7 and 8, and the unit itself is additionally connected to the Wi-Fi unit 9 for further remote control of the intelligent measuring system and display 18 for data output.

Laser rangefinder 2 of the measuring part is installed above sealed optically transparent quartz glass 10 mm thick and serves to determine the exact distance *H* from the tank top to the oil product surface. The signal from the laser rangefinder 2 is fed through the amplifier 7 and the analog-to-digital converter (ADC) 11 to the microprocessor 14 of the control unit 6, where the level of oil *h* in the tank is determined: *h =D – H*, where D – tank diameter. Since the liquid temperature in a large tank is not constant throughout the entire liquid volume, the change in temperature *Δt* is of interest for determining the change in volume under the influence of temperature changes. The oil product temperature or other similar liquid should be measured at different heights from the tank bottom [12-14]. For this reason, three temperature sensors 3, 4, 5 are installed in the present invention: in the upper, middle and lower parts of the tank. The signals from these sensors through the amplifier 8 enter the microprocessor 14, where the average temperature is calculated using the following formula (9):

$$t_{ср.} = (t_{в.} + t_{с.} + t_{н.})/3, \quad (9)$$

which is used to determine the thermal mixing degree. Microcontroller 14 can read temperature changes up to *0.01°C* with an accuracy of ± *1%.* Then the change in density *Δρ* caused by these changes is calculated according to the following formula (11):

$$Δρ = ρ_{20} – x(t_{cp.} – 20), \quad (10)$$

where x – correction for density change with temperature change by 1^0C; $ρ_{20}$ – density of oil or liquid at $t=+20^0C$.

3. Software

Figure 7 shows the control unit algorithm of an intelligent system for measuring the volume and mass of a liquid product in horizontal cylindrical tanks.

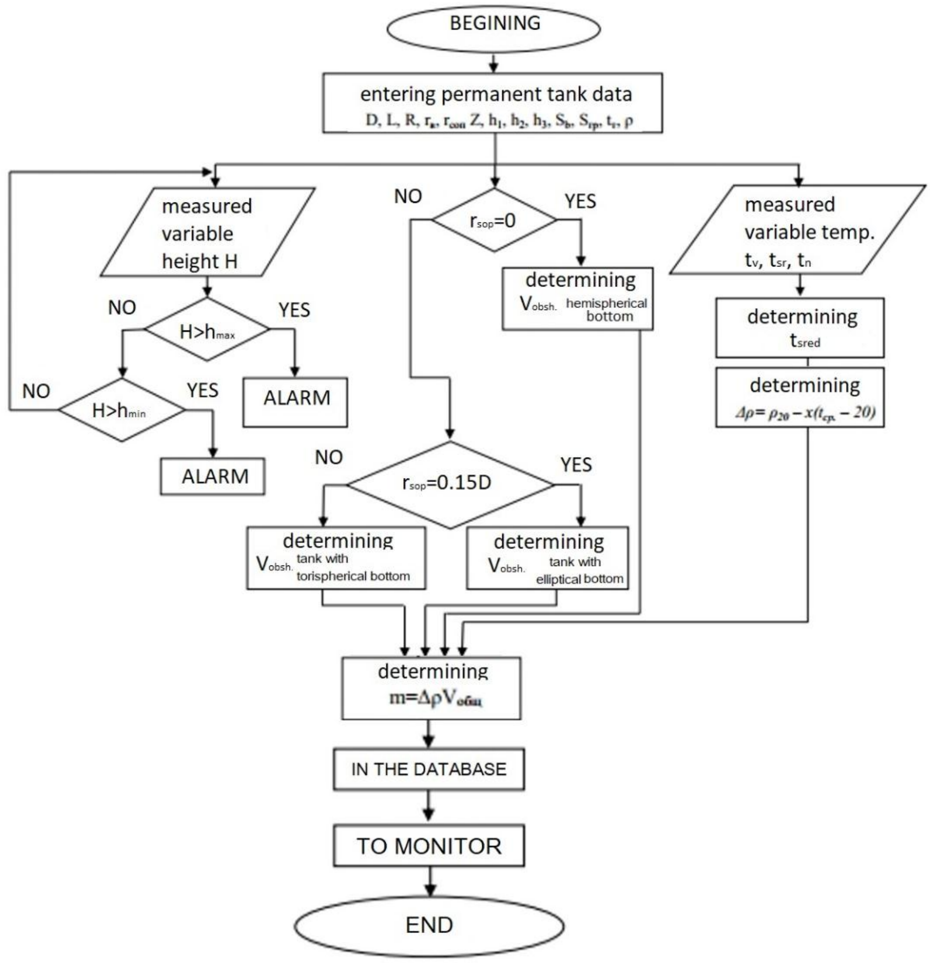

Fig. 7. ***The control unit algorithm of an intelligent system for measuring the volume and mass of a liquid product in horizontal cylindrical tanks.***

The actions sequence in the method implementation for measuring the volume and mass of the product in the tank is as follows:

- after the work start, the main tank parameters are entered, by which the measuring system determines its bottoms shape (if $r_{con}=0$ – spherical, if $r_{con}=0.15D$ – elliptical, if $r_{con}≠0.15D$ – torispherical) and the corresponding formula for determining the volume $V_{общ}$ is selected.

- laser rangefinder 2 measures the exact distance *H* from the tank top to the oil product surface. Knowing *H* value, the measuring system determines the level of the bulk oil product $h = D - H$.

- in parallel, variable temperatures of the oil product from three temperature sensors 3, 4 and 5 are determined ($t_в$, $t_{ср}$, $t_н$), installed at different tank levels and the average temperature is calculated ($t_{ср.}$). After that, the change in density under the temperature influence is calculated: $\Delta\rho = \rho_{20} - x(t_{ср.} - 20,)$ where *x* – correction for density change with temperature change by 1^0C.

- the mass of oil in storage mode is calculated by the formula: $m = \Delta\rho V_{общ}$, where $\Delta\rho$ - density, $V_{общ}$ – oil product volume.

- the obtained measurement results and calculation are recorded, for the safety of preventing oil spills, the system determines the oil product position at the minimum and maximum values and the oil level is signaled by the indicator 19. All data are entered into the database and displayed on the operator's monitor 18.

4. Conclusion

At the laboratory of the "Automation of production processes" department a laboratory model was made at Tashkent state technical university, consisting of a horizontal cylindrical tank with hemispherical bottoms with a measuring system and a control unit based on the Arduino platform. A computer display is used as a display device. The test results fully confirm the feasibility of using the proposed solution.

This increasing method the accuracy of measuring the liquid level in horizontal cylindrical tanks has many advantages over the prior art, consisting in the fact that the implementation is carried out quite simply and economically and has no mechanically moving parts, therefore the measuring equipment is protected from failures and has a long service life. What's more, the measuring system takes into account the temperature effect in highly accurate volume and mass measurements in various horizontal cylindrical tanks shapes with different bottoms types, which is relevant for enterprises in the oil production, oil refining, aviation, medical, food industries.

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