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Vertical and Horizontal Tanks: Mathematical and Statistical Analysis of Petroleum Products Distribution Over Time

Shavazov Kadirjon Achilovoch[1]*, Parpiyeva Almakhan Zholdasovna[2], Rakhimov Bakhtiyor Ne'matovich[3] and Makhmudov Nimadulla Akhmatovich[4]

[1]PhD., Professor, National Research University, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Uzbekistan

[2]PhD., Associate Professor, Chirchik Higher Tank Command Engineering School, Uzbekistan

[3]PhD in Physics and Mathematics, Department Professor, Military Institute of Information and Communication Technologies and Communications, Uzbekistan

[4]PhD., Professor, Academy of the Armed Forces of the Republic of Uzbekistan

***Corresponding Author:** Shavazov Kadirjon Achilovoch, PhD., Professor, National Research University, Tashkent Institute of Irrigation and Agricultural Mechanization Engineers, Uzbekistan.

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Abstract

The article discusses the existence of many problems in the distribution of oil (fuel) products in any situation, including extreme conditions. For example, it is recognized that fuel products are stored in tanks, the vertical and horizontal location of the tank, the size of the slot (jumrak) through which the liquid flows, and its geometric shape (circle, cone, etc.).

Keywords: reservoir; fuel; Bernoulli's law; differential equation; extremum; oil product; volume; time; slot; fist

Introduction

In every process involving the distribution of objects, various problems (shortcomings) arise. As a result of scientific research, these problems (shortcomings) have been confirmed in cases where the mass per unit volume changes over time with slight temperature variations, as well as with a significant increase in the accuracy of measurement methods for substances (elements) that form new modifications.

Oil is a complex liquid that is an organic product, meaning a gas formed in a living organism and composed mainly of hydrogen (H) and carbon (C). Oil is a natural combustible substance that includes both liquid and solid components, has a multicomponent composition, varies in color from black to brown, has a specific (or swampy) odor, and follows the general formula C_nH_{2n+2} (where n is a corresponding natural number). Petroleum products are mainly obtained by physical methods. If the number of carbon atoms in the oil is 4–5 and its color is brown, it is used to produce light aromatic gasoline. If the number of carbon atoms approaches 10, such a petroleum product can only be obtained through a chemical process (via cracking). Colored compounds in oil, in turn, are components of diesel fuel. Diesel fuel also has a complex composition: the average molecular weight of hydrocarbons in it ranges from 110 to 230, and its boiling temperature varies from 170 to 380 °C. Additionally, lubricants are derived from diesel fuel, which are several times heavier by mass, and at the final stage of processing, residual products such as fuel oil and asphalt remain [1].

Currently, petroleum products are the main energy resource, making the demand for them extremely high. However, despite being studied for centuries, their distribution still has significant shortcomings. Worldwide, petroleum products are primarily distributed in two ways: by mass and by volume. Both of these modern distribution methods have their specific drawbacks.

There is a difficulty in installing tanks on scales when distributing by mass because petroleum products are liquids and cannot maintain their shape [2]. Secondly, although the mass of petroleum products remains unchanged in international sales, the acceleration due to gravity (g) varies depending on geographical latitude. For example, in Tashkent, a petroleum product with a mass of $m = 1\ kg$ results in a weight of $p = mg = 1 \cdot 9.8\ kg$, whereas at the pole, this value would be $p = mg = 1 \cdot 10\ kg$. The difference in values, $\Delta p = 10$ kg - 9.80 kg = 0.2 kg, indicates the presence of discrepancies. This, in turn, creates serious problems in transportation and aviation. Due to these issues, there is a difference in airline ticket prices between the U.S. and Tashkent depending on the flight direction.

It has been established that the dependence of petroleum product volume distribution on temperature affects not only their distribution (increase in volume when heated or decrease when cooled) but can also influence modification quality and cost. More problems arise during the distribution (sale and use) of petroleum products than during storage. For example, temperature changes can lead to a sharp increase in volume (foaming) or a decrease (settling). Since petroleum products are primarily sold by volume (liters), a correction factor is applied for each temperature to account for the mass-to-volume ratio of the petroleum product at t = 20°C, as changes are minimal at this temperature. In other words, there is no difference between selling petroleum products by volume or mass. If the temperature $t_1 > 20°C$, the volume increases, causing the product to foam (V > m). Conversely, if $t_2 < 20°C$, the product settles, meaning that for the same amount of petroleum products, V < m. A petroleum densimeter (hydrometer) is used to measure changes in petroleum product density. Modern hydrometers are equipped with built-in thermometers. When distributing petroleum products, temperature correction factors for density, as listed in D. Mendeleev's table [3], are taken into account.

Given the sharp temperature fluctuations in the conditions of the Republic of Uzbekistan, with variations in the oil densimeter (hydrometer) and a temperature difference of t = 20°C, the density correction formula is:

$$\rho^{20} = \rho^{t} + \alpha \cdot (t-20) \quad (1)$$

where

ρ^t - is the reading of the oil densimeter (areometer);
t - is the temperature of the tested fuel, °C;
α·- is the temperature correction coefficient for a 1°C change [4].

If the temperature *t* is below 20°C, the correction factor is subtracted; otherwise, it is added.

For example, if the density of diesel fuel at t = 27°C is ρ27 = 820 kg/m^3, then its density at t = 20°C is calculated as follows:

$$\rho 20 = 820 + 0{,}738 \cdot (27-20) = 825{,}2\ кг/м^3.$$

The given temperature correction factor is 0.738, taking into account that the temperature correction factor for the density of petroleum products falls within the range of (820.0...829.9) [5]. If the mass of diesel fuel in the tank is m = 103 kg and the temperature changes to 20°C, the volume distribution will be as follows:

$$\Delta V = m\left(\frac{1}{\rho_{20}} - \frac{1}{\rho_{27}}\right) = 10^3 \cdot \left(\frac{1}{820} - \frac{1}{825{,}2}\right) = 7{,}685\ (liter).$$

If measured by volume, the difference is approximately 8 liters.

Purpose of the Scientific Research

Sharp temperature fluctuations in the Republic of Uzbekistan and Central Asian countries necessitate the development of new modern scientific distribution devices. When receiving petroleum products under extreme conditions from rail tank cars, it is essential to find the most optimal distribution method based on the existing conditions. As a result of our scientific research, it will be proven that the most effective method is exclusively temporary distribution.

Methodology

Since it is known that time distribution is related to fluid dynamics, our task is to equalize the volumes of liquid flowing out of a reservoir with a volume of V(m^3) through a faucet of a certain size ρ(m), based on the continuity laws of B. Pascal and D. Bernoulli. In doing so, we formulate a differential equation describing the motion of the fluid in vertical and horizontal reservoirs.

When deriving these differential equations for a vertical tank, they were similarly formulated for the horizontal position to study the outflow time of liquids. Our objective is to conduct the following research work. It is proven that the distribution times t_v and t_g differ. As an example, let us consider a cylindrical tank with a height of $h = 6$ *m* and a diameter of $D = 2r = 4m$, with a faucet installed at the bottom having an opening radius of 1/12 *m*. We investigate the duration for which petroleum products can be received through this faucet.

When solving this problem, Bernoulli's law is used. If a liquid flows out of a vessel or reservoir through an opening (faucet) at a velocity (m/s), and the distance from the liquid surface in the vessel to the opening (faucet) is h(m), then the outflow velocity of the liquid is determined by the following formula [6].

$$v = \sigma\sqrt{2gh} \qquad (2)$$

Here, $\boldsymbol{g}$ is the acceleration due to gravity, which depends on geographic latitude (m/s^2). For example, at the equator, it is 9.81 m/s^2, while on the territory of the Republic of Uzbekistan, the acceleration due to gravity is approximately 9.73 m/s^2. $\boldsymbol{\sigma_o}$ is a dimensionless coefficient that depends on the properties of the liquid and is approximately 0.62 (Figure 1).

$$-\pi r^2 dh = \pi\sigma_o r_c^2\sqrt{2gh}dt \qquad (3)$$

The variables are substituted; in formula (3), $\boldsymbol{r}$, $\boldsymbol{h}$ and $\boldsymbol{\sigma}$ are constants, while $\boldsymbol{h}$ and $\boldsymbol{t}$ are considered variables.

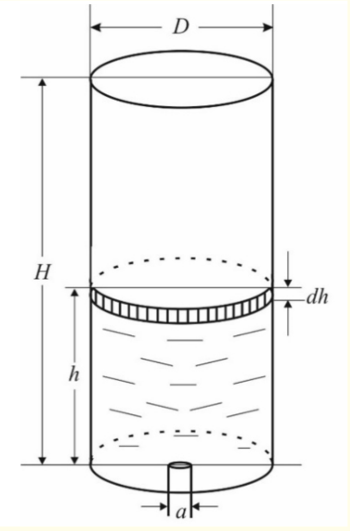

Figure 1: Placement of the tank in a vertical position.

$$t = \frac{2r^2\sqrt{h}}{\sigma_o r_c^2\sqrt{2g}} \quad (4)$$

Although the calculations for the drainage time of petroleum products from the valve of vertical tanks are presented in many literary sources, accurate calculations for the drainage time from the valve of a horizontal tank have not yet been performed. Mainly, only experimental results obtained for water with approximate accuracy are available. The outflow coefficient of the liquid has been determined only for water, whereas for various modifications of petroleum products, the corresponding coefficients have not been specified. In some sources, a constant outflow coefficient for petroleum products is assumed to be σ = 0.62. In this regard, one of our main tasks is to derive a theoretical formula for the distribution of liquid drainage time from the most commonly used horizontal tanks, taking as a basis a real tank with a volume of 75 m^3, without altering the conditions of the aforementioned problem.

On one hand, this $d\omega$ volume is equal to the product of the fuel level area and ***dh***.

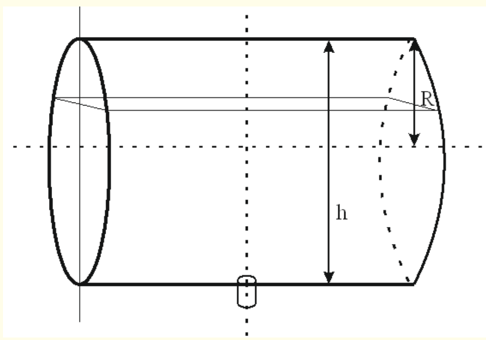

Figure 2: Placement of the tank in a horizontal position.

Research Results

As seen in the above image (Fig. 2), the volume of a cylindrical tank positioned horizontally varies depending on the liquid diameter and is calculated using the following differential equation.

A horizontally positioned railway or tanker truck, when distributing fuel under extreme conditions, has time as the main parameter. Under such conditions, the change in fuel level in the tank occurs along the diameter of the cylindrical vessel. At the same time, the height of the tank remains unchanged, forming a constant level. In this case...

$$\frac{\pi h}{4}\int_0^{2r} DdD = \frac{\pi}{4}h\int_0^{D} 2rd(2r) = \frac{\pi h}{4}\int_0^{D} 4rdr = \rho^2\pi\sigma_o\sqrt{2gD}\int_0^{T} dt \quad (5)$$

$$h\int_0^{2r} rdr = \rho^2\,\pi\sigma_o\sqrt{2g2r}\int_0^{T} dt \quad (6)$$

$$h\int_0^{2r} \sqrt{r}dr = 2\sigma_o\rho^2\sqrt{g}\int_0^{T} dt \quad (7)$$

We integrate both sides of the equation, taking into account that the reservoir parameters are constant values, while their variability is considered in the case of horizontal fluid flow.

$$\frac{2h}{3} 2^{\frac{3}{2}} \Big|_{0}^{2r} = \sigma_o \sqrt{g} \int_0^T dt \quad (8)$$

$$\frac{2}{3} h r^{\frac{3}{2}} \Big|_{0}^{2r} = \sigma_o r_c^2 2\sqrt{g} \Big|_{0}^{T} \quad (9)$$

Using the $F(x)|_a^b = F(b) - F(a)$ Newton-Leibniz formula, we obtain the following resulting experimental formula.

$$\frac{hr\sqrt{2r}}{3} = \sigma_o r_c^2 \sqrt{gT} \quad (10)$$

Here, T denotes time, and its value is determined by the following resulting formula:

$$T = \frac{2rh\sqrt{2r}}{3\sigma_o \rho^2 \sqrt{g}} = \frac{2 \cdot 2 \cdot 2 \cdot 6 \cdot 144}{3 \cdot 0{,}62 \cdot 3{,}1} = 1198{,}75\ s = 20\, min\ \ 37\ s.$$

Conclusion

Mathematical statistical analyses show that in vertical tanks, the liquid pressure changes perpendicularly to the base surface, resulting in $S_a = \pi R^2$, whereas in the horizontal position of the same cylinder, $S_{yon} = \pi rh$. Thus, the lateral surface of the cylinder is larger than its base surface, and if ***rh***, the lateral surface will be twice as large. According to the mechanical properties of liquids, in regions with a larger surface area, the velocity is lower. For this reason, the time for complete drainage of liquid from a horizontal tank turned out to be significantly longer compared to vertical tanks, which has been confirmed in practice.

The calculations show that, under the same volume and identical conditions, changes in the state of the tanks result in a difference in the fuel product release time of 1.15. In the conducted scientific study, the phenomenon of evaporation was not considered when distributing petroleum products. In reality, the mass of petroleum products that could be accounted for is lost due to evaporation into a gaseous state, leading to a deterioration of the environmental situation in the atmosphere. Moreover, if a leak occurs in unventilated spaces, it may result in an explosion or fire, which is a scientifically proven fact.

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