Fuel Temperature Fluctuations During Storage

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Abstract. When oil and petroleum products are stored, their temperature significantly impacts how their properties change. The paper covers the problem of determining temperature fluctuations of hydrocarbons during storage. It provides results of the authors’ investigations of the stored product temperature variations relative to the ambient temperature. Closeness and correlation coefficients between these values are given. Temperature variations equations for oil and petroleum products stored in tanks are deduced.

1. Introduction
Significant losses of liquid hydrocarbons happen due to their temperature fluctuations during storage. According to some estimates, minimum 5% of oil produced in Russia is lost on its way to consumers, which is approximately 25 million ton per year. About a quarter of these losses are caused by their temperature fluctuations during storage. [1]

Fuel temperature, due to a relatively slight thermal fluid expansion, does not affect the volume increase and for one degree temperature gradients amounts to a relative value of about 1 volume %. This refers to the gas-vapor mixture in a tank where the coefficient of volume expansion is an order of magnitude greater and temperature fluctuations cause significant pressure fluctuations.

2. Research object
2.1 Seasonal fuel temperature fluctuations
Measurements of seasonal fluctuations of temperature and pressure were taken at the tank battery. Together with the temperature were measured wind velocity, wind direction, cloudiness and humidity. According to experts the most important is the ambient temperature and wind velocity. Empirical data were processed and curves were developed (figures 1-4).

Pressure fluctuations in the vicinity of the tank battery are insignificant, which is noted in other works [1]. The greatest pressure fluctuations – about 40-50 mm of mercury over 2-3 days – are observed in November and April.

This leads to a change in the pressure vent valves operation conditions. As a consequence, the pressure drop leads to the gas-vapor mixture emission from the tank. Such major blast emissions occur no more than 5 times a year. Pressure drop does not exceed 5% under these conditions. Moreover, the pressure drop is leveled by daily fluctuations (small breathings). Due to low impact and simplified correlation dependences, pressure fluctuations, humidity and wind direction were not further taken into account. What was considered is temperature. Data on internal petroleum product state in the tank were recorded together with data on ambient environment changes over the autumn-winter and spring-summer periods.

As seen in figure 2, the curve repeats a change in ambient temperature with some delay compared to figure 1. This inertia is due to the high heat capacity of oil products. The curve has a flattened shape and smaller highs and lows. This is explained by a complex model of heat return in the tank. Changing the temperature in the vessel leads to a change in the density and innage level (see figures 3-4). The curves repeat the temperature variations precisely which indicates a good convergence and high precision of measuring equipment.
Based on literature analysis and expert evaluation it was discovered that the primary cause of oil product temperature changes in the tank is ambient temperature. In this regard we will first find the dependence in which changing one value changes another, a static one. In particular, the static dependence is shown in the fact that the average value changes with one of the other values. In this case, the static dependence is called correlation.

**Figure 1.** Ambient temperature variation in the vicinity of the tank battery.

**Figure 2.** Average product temperature variations in the tank №0 of strategic storage.
2.2. Daily fuel temperature fluctuations

The rate of temperature change of the gas phase depends on the ability to absorb and emit radiant energy incident on the tank wall, on the outside temperature drop and velocity.

In this regard, there was a practical interest in determining the effect of daily temperature fluctuations on thermal oil product fluctuations [2]. To do this, at different levels of the tank were installed temperature sensors, with temperature measurement results shown in Table 1.

7 belts of the tank were filled with a petroleum product, belts 8 and 9 were left empty to measure the gas space temperature. Moreover, the radiant energy incident on the tank results in a non-uniform heating of the outer wall. For example, Table 2 shows the outer surface temperature depending on its orientation in space.
Table 1. Results of measuring temperature of gasoline A 92 at various tank belts.

| Time  | Innage height, mm | Capacity, liter | Weight, kg | 1<sup>st</sup> belt | 2<sup>nd</sup> belt | 3<sup>rd</sup> belt | 4<sup>th</sup> belt | 5<sup>th</sup> belt | 6<sup>th</sup> belt | 7<sup>th</sup> belt | 8<sup>th</sup> belt | 9<sup>th</sup> belt |
|-------|-------------------|----------------|-----------|---------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
| 08:00 | 9101              | 2605888        | 1938702   | 5.82                | 6.01              | 6.17              | 6.29              | 6.35              | 6.51              | 6.62              | 6.63              | 7.80              |
| 12:00 | 9103              | 2606452        | 1938756   | 6.01                | 6.16              | 6.29              | 6.44              | 6.57              | 6.64              | 6.74              | 7.91              | 14.65             |
| 16:00 | 9106              | 2607297        | 1937768   | 6.21                | 6.39              | 6.58              | 6.66              | 6.77              | 6.9               | 6.99              | 8.67              | 11.6              |
| 20:00 | 9106              | 2607297        | 1936022   | 6.16                | 6.33              | 6.49              | 6.64              | 6.68              | 6.78              | 6.94              | 7.57              | 3.49              |
| 23:00 | 9104              | 2606734        | 1936072   | 6.06                | 6.23              | 6.37              | 6.49              | 6.63              | 6.71              | 6.86              | 6.46              | 1.72              |
| 08:00 | 9097              | 2604760        | 1935679   | 6                   | 6.12              | 6.16              | 6.21              | 6.25              | 6.21              | 6.35              | 5.89              | 0.86              |
| 12:00 | 9097              | 2604760        | 1935259   | 6.02                | 6.22              | 6.23              | 6.3              | 6.38              | 6.39              | 6.52              | 7.59              | 14.9              |
| 16:00 | 9101              | 2605888        | 1932292   | 6.23                | 6.4               | 6.48              | 6.56              | 6.62              | 6.73              | 6.83              | 8.89              | 17.15             |
| 20:00 | 9104              | 2606734        | 1932463   | 5.85                | 6.03              | 6.08              | 6.13              | 6.16              | 6.27              | 6.32              | 7.38              | 13.97             |
| 23:00 | 8740              | 2504122        | 1857783   | 7                   | 7.15              | 7.29              | 7.42              | 7.55              | 7.66              | 7.86              | 11.91             | 10.79             |

Table 2. Temperature of the first tank wall belt depending on its location in space

| Time  | Temperature of the tank wall outside around the perimeter in different points |
|-------|-------------------------------|-------------------|-------------------|-------------------|-------------------|-------------------|-------------------|
|       | 1    | 2    | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   | 11   | 12   | 13   | 14   |
| 08:00 | 5.2  | 6.5  | 7    | 7.5  | 9    | 10.5 | 11.2 | 12   | 13   | 12   | 9    | 7    | 6    | 5    |
| 12:00 | 6    | 8    | 8.5  | 9    | 10   | 11   | 11   | 10.5 | 10   | 9.5  | 8    | 7    | 6.5  | 6    |
| 16:00 | 6.3  | 6.5  | 6.7  | 7.5  | 9    | 8.1  | 9.3  | 8.5  | 8.7  | 8.5  | 7    | 8.6  | 9.3  | 8.6  |
| 20:00 | 1.4  | 2    | 3.5  | 5.1  | 6.3  | 6.9  | 6.8  | 1.8  | 3.1  | 4.5  | 5.6  | 6.1  | 6    | 7.1  |
| 23:00 | 5.4  | 6    | 6.5  | 6.6  | 4.2  | 5.5  | 5.9  | 5.3  | 5.8  | 5.9  | 3.7  | 4.9  | 5.2  | 5.75 |
| 08:00 | 2    | 1.0  | 0.7  | 1.0  | 2.1  | 2.6  | 2.4  | 2.7  | 2.9  | 3.0  | 1.9  | 2.5  | 2.6  | 2.9  |
| 12:00 | 9.6  | 8.5  | 7.3  | 6.3  | 4.5  | 1    | 3.4  | 3.9  | 4.6  | 5.1  | 5.7  | 7    | 7.6  | 8.5  |
| 16:00 | 7.8  | 8.1  | 8.4  | 7.8  | 7.8  | 5.2  | 5.6  | 6    | 6.1  | 5.7  | 5.8  | 6.1  | 6    | 7.1  |
| 20:00 | 7.8  | 8.2  | 8.4  | 7.8  | 5.5  | 5.2  | 5.2  | 1.2  | 1.8  | 4.5  | 5.6  | 6.1  | 6    | 7.1  |
| 23:00 | 3.9  | 1.9  | 1.4  | 1.9  | 4.1  | 5.1  | 4.8  | 5.3  | 5.8  | 5.9  | 3.7  | 4.9  | 5.2  | 5.75 |

As a result of the correlation analysis of statistical data on the tank ambient temperature and innage level were prepared graphical and numerical dependences of daily temperature changes in the tank of strategic storage (figures 5, 6, 7).
As seen from graphs 5 and 6 they have three clearly pronounced maximums and three minimums. These are maximum and minimum temperatures and tank innage levels corresponding to the three days of “still” storage. According to the formula and physical meaning, these curves repeat the ambient temperature changes (see figure 7). However, product temperature fluctuations in figure 5 have smaller amplitude than ambient temperature fluctuations in figure 6. This is explained by a high fill-up level and large capacity of a tank. We can also state that the curve will be even more smoothed if tank capacity is increased.
Polynomial (joint probability distribution of random variables) curves of average temperature (dash lines) were built.

\[ y = 4 \cdot 10^{-06}x^2 - 0.0028x + 21 \text{ (average temperature in a tank)} \quad (1) \]
\[ y = 2 \cdot 10^{-05}x^2 - 0.0169x + 7096 \text{ (product level in a tank)} \quad (2) \]
\[ y = 3.6 \cdot 10^{-02}x^2 - 0.9867x + 20 \text{ (ambient temperature)} \quad (3) \]

As the figures show, for the last equation the approximation error is much greater, which is connected with the fact that it is difficult to forecast ambient temperature variations. It can also be noticed that for the test data the average ambient temperature axis is 1 degree Celsius below due to a higher average temperature prior to the period of investigation (operation range). On the other hand, the curves demonstrate a good correlation of input and output data. Moreover, a change in the level of the product in figure 6 proves high precision of temperature measurements and low error of raw data and statistical processing.

3. Summary
A close correlation between the temperature in the VST and the ambient temperature was identified, with the correlation coefficient and the sample correlation ratio being greater than 0.9 From the presented data of temperature variation we can make a conclusion on the degree of temperature change inertia at different tank belt levels. This allows efficient predicting hydrocarbon emissions in tanks.

References
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