Effect of temperature fields and bottom sediments of oil products on the stress-strain state of the design of a vertical steel tank

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Abstract. Tanks for storing oil and oil products during operation are exposed to a combination of external, static, low-cycle, temperature, snow and wind loads, bottom sediments, etc., which leads to a decrease in operational reliability and a decrease in the durability of tank structures. Numerical modeling methods, in contrast to standard methods for calculating strength and stability, allow us to create an adequate finite element model at the stage of development of a geometric model. This article describes the analysis of the stress-strain state of the tank taking into account bottom sediments of oil products and the influence of the temperature of the oil product and the environment using the Ansys software package. Based on the analysis of the stress-strain state using finite element modeling on the example of a vertical steel tank, it was shown that the stresses in the zone of the miter weld, as well as in the places of installation of the receiving-distributing branch pipe and the manhole, are maximum. It is in these zones that the influence of bottom sediment and temperature is significant, since they form local elevated stress zones, which increase significantly when the walls are thinned.

1. Introduction

Tanks for oil and oil product storage are one of the main technological objects of oil depots and trunk oil pipelines [1]. The ecology of the area where tank farms and human safety are located depends on their reliability. Ensuring the required level of reliability of the steel vertical cylindrical tank is carried out at the operation stage. In case of tank accidents, oil products pollute adjacent territories and water basins. The economic damage from accidents involving leakage of petroleum products includes not only direct losses, but also the costs of environmental measures to restore the environment, as well as the costs of replenishing the stock of petroleum products.

Modern regulatory documents, (GOST R 52910 - 2008) do not establish the maximum service life of tanks. Tank dismantling is done only according to the results of a diagnostic examination - instrumental and calculated. The tank is a vertical shell with a bottom; however, the presence of geometric features significantly changes the symmetry of the structure, the distribution of stresses and strains in local zones, which is difficult to take into account when performing analytical calculations [2].

Thanks to the use of software systems for finite element calculations, such as Ansys, it becomes possible to determine the most dangerous zones and predict the stress-stain state (SSS) during operation, taking into account additional factors [3]. One of such is bottom sediment, which is formed during storage and mixing of oil products. Especially active sedimentation is observed when different types of residual oil products are mixed due to their incompatibility [4, 5, 6]. Sedimentation occurs due to imbalance and instability of fuels, when the amount of aromatic hydrocarbons decreases, so the
proportion of paraffin and asphaltenes in the mixture increases [7, 8]. Cases of “incompatibility” during the mixing of petroleum products are associated with the emergence of strong intermolecular interactions caused by changes in the structural group composition and the mutual ratio of the concentrations of high molecular weight compounds of petroleum products, which leads to the formation of molecular associates, bulk colloidal particles of various shapes and structures [9]. The problem of “incompatibility” of oil products is extremely urgent, since due to the precipitation of sediment on the tanks during operation, the useful volume decreases and the need to clean the tanks arises, and when mixing fuels because of the “incompatibility”, the quality of the whole product deteriorates in the first place, the subsequent use of which increases the risk of equipment wear.

2. Theory and Method
To determine the effect of bottom sediment, mainly consisting of asphaltene-tar paraffin deposits, on SSS diagram, we consider vertical steel tank PBC-20000, which stores a mixture of residual fuels of the RMK-700 grade with a density of 958 kg/m$^3$ at 15 °C and has a viscosity of 550 sSt at 50 °C [10]. Liquid surface height is 12 meters, the material of the tank is Steel 3. There is a fixed roof, the weight with the equipment installed on it is 10,000 N. Laboratory tests of viscosity were performed using a Stabinger SVM 3000 laboratory instrument, and Anton Paar DMA 4100 M equipment used to measure density. The results are shown in table 1.

Table 1. Density of the residual fuel and total sediment depending on the measurement temperature

| Temperature, °C | total sediment, kg/m$^3$ | Residual fuels RMK-700, kg/m$^3$ |
|-----------------|--------------------------|---------------------------------|
| 15              | 1090.0                   | 958.0                           |
| 20              | 1087.2                   | 954.8                           |
| 25              | 1084.4                   | 951.6                           |
| 30              | 1081.5                   | 948.4                           |
| 35              | 1078.7                   | 945.1                           |
| 40              | 1075.9                   | 941.9                           |
| 45              | 1073.0                   | 938.7                           |
| 50              | 1070.2                   | 935.4                           |
| 55              | 1067.4                   | 932.2                           |
| 60              | 1064.5                   | 928.9                           |
| 65              | 1061.6                   | 925.7                           |
| 70              | 1058.8                   | 922.4                           |

The reservoir model was created and the tank SSS calculations were performed in the Ansys software package, taking into account the stored residual fuel and total sediments at a temperature of 20 °C (Figure 1).
In the absence of sediments, the maximum stresses of 126 MPa are observed in the zone of the masonry weld, as well as in the places of installation of the dispensing nozzle and manhole.

Another calculation is made with bottom sediment with a height of 1.3 meters. The density of sediments is 1090 kg/m$^3$ at 15 °C. (Figure 2).

Attention should be paid to an increase in the maximum stresses created by the liquid column by more than 2%. This value does not exceed the engineering calculation error; however, unaccounted stress in the metal can lead to negative consequences, especially under bad circumstances. Especially when you consider that the tank is loaded cyclically, and metal failure may occur earlier than anticipated.

When the ambient temperature changes, the magnitude of the stresses in the wall of the reservoir changes significantly. This is due to the thermal expansion of the metal. Bottom sediments also affect the stress experienced on the tank wall. So, with a large temperature difference, the maximum stress in the metal can exceed the yield strength, which leads to the destruction of the tank. The fluid in the tank is heated, its density and temperature are constant (935.4 kg/m$^3$ and 1070 kg/m$^3$ at 50 °C for fuel oil and sediments, respectively). Calculations at various temperatures ($–40 °C$; $–20 °C$; $0 °C$; $+20 °C$; $+40 °C$) are presented in Figures 3–7.
Figures 3-7. SSS of a reservoir, 1.3 meter of bottom sediment, different ambient temperatures

As expected, maximum stress values are obtained with greater temperature difference, and are located in the zones of nozzle and manhole. As the temperature gets higher, stress is lowered at first and gets bigger then, but its distribution is almost the same. Points of max and min values in these cases differ because of low mesh resolution due to free license limitations. Results of calculations are in the table 2.

**Table 2. Stress depending on the temperature**

| Temperature, °C | Maximum stress, MPa |
|-----------------|----------------------|
| -40             | 336                  |
| -20             | 228                  |
| 0               | 159                  |
| 20              | 129                  |
| 40              | 178                  |
In the previous case, it was believed that the products in the tank are heated, therefore their temperature does not change, which means that their density is also constant. Now imagine that the products are not heat up, and their temperature directly depends on the ambient temperature. With increasing temperature, the density of liquids in the tank decreases, which somewhat reduces the total load on the wall, bottom and edge of the tank. Calculations at various temperatures (+15; +20; +25; +30; +35; +40; +45; +50; +55; +60; +65; +70 °C) are presented in figures 8–13.
Figures 8-19. SSS of a reservoir, 1.3 meter of bottom sediment, different temperatures, no heating

Table 3. Stress depending on the temperature, no heating

| Temperature, °C | Maximum stress, MPa |
|-----------------|---------------------|
| 15              | 134                 |
| 20              | 129                 |
| 25              | 132                 |
| 30              | 141                 |
| 35              | 154                 |
| 40              | 174                 |
| 45              | 195                 |
| 50              | 215                 |
| 55              | 235                 |
| 60              | 257                 |
| 65              | 278                 |
| 70              | 293                 |
As expected, thermal stresses in the metal are the most dangerous, especially in the places where the nozzle and manhole are installed. Again, as the temperature gets higher, stress gets bigger, but its distribution is almost the same. Some part of stress is damped because of density decline. Calculation results with no heating are shown in table 3.

3 Conclusions

As a result of the analysis of the stress-strain state of the tank, taking into account the operational loads of the reservoir models, it was established that the stress in the casing increases during the operation of the reservoir.

Analysis of SSS using finite element methods showed that with active sedimentation and an increase in the temperature of the stored product, an increase and redistribution of stresses occurs in the lower zone. Also, calculations of the influence of ambient temperature and bottom sediment on VAT showed the highest stresses in the lower zone at the most negative values, namely -40°C. As a result, stress concentration zones arise that are located directly in the zone of the weld seam and in the places of installation of the receiving-distributing branch pipe and manhole, which are not taken into account when calculating by standard methods.

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