The study of the stress-strain state of the tank with bottom water drainage during operation

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Abstract. Bottom drainage from tank is a current problem in modern tank usage. This article proposes the use of the bottom drainage system from the tank with the shape of the sloped cone to the centre of it. Changing the bottom design alters the stress-strain state to be analyzed in the Ansys. The analysis concluded that the proposed drainage system should be applied.

1. Introduction

The tank for the storage of crude oil and oil products is a complex engineering and technical facility for the reception, storage and issuance of oil and oil products.

When oil and oil products are stored in tanks, the liquid densities stratification occurs. Due to this so-called bottom water, containing dissolved salts, is accumulated in the lower part of the tank. In addition, oil stored in the tank contains sulphur, i.e. the bottom water is a weak solution of sulphuric acid.

The prolonged contact of the bottom water with the inner surface of the tank, in the hold-up spots (when the gradual settlement takes place), causes the bottom and lower ring of the tank to be subjected to accelerated corrosion [1]. The need to protect the inner surface of the lower ring and the bottom from the corrosion occurs.

According to [1], it was proposed to equip tanks with a water header collector: a special water header collector with a diameter of about 1 m and a depth of 70-80 is cut into the bottom of the tank. Thus, the authors' intention is to localize the area where the bottom water is accumulated, and it is also possible to equip water header with level sensors and a phase switch. The disadvantage of such a system is the complexity of the bottom structure, the introduction of stress concentrator on the tank bottom - the water collector, as well as the creation of differential aeration corrosion in the section of phases in the water collector. This also reduces the corrosion reliability of the tank bottom.

Figure 1 shows a schematic version of the use of the water collector in the automated system for bottom water drainage from the tank [2], which includes: electrodes 1, globe valve 2, blocking relay 3, automatic control unit 4, display unit 5, valve 6, drainage pipe 7, pit-water controller 8.

Similar schemes can be found in the work [3-4].

Thus, the disadvantage of all existing schemes is the formation of hold-up spots of bottom water in the most loaded parts of the tank bottom.
According to [5] a gauging nipple 1 placement under the conic tank bottom 2 (figure 2) cannot be considered to be effective, since, despite the useful tank volume increase, its state monitoring deteriorates. Also, this increases leaks through the sealing surfaces and corrosive defects because of its ground placement.

Figure 1. The tank equipped with the system for the automatic drainage of bottom water

2. Problem statement

In analyzing the disadvantages of existing bottom water drainage systems, a perfect end result can be formulated to improve the bottom of the water drainage scheme:

- the bottom water evenly flows to one of the tank points;
- at the point of the selection of the bottom water there should be a swing pit for the efficient operation of the siphon drain;
- water drainage is done automatically.

This technical result can be achieved by changing the structure of the tank bottom: the bottom must be conical and have a slope to the center.

Figure 3. The device for bottom water drainage from the tank

The paper [6] proposes the oil and oil products tank bottom in the form of cone, with the cone vertex being the centre of the tank bottom and ensuring bottom water accumulation.

This assembly works as follows: in the lower part of the tank there are the hold-up spots of bottom water "H1", resulting from the storage of oil and oil products in the most loaded tank areas. These allow the bottom water to accumulate in its maximum in the lower part of the tank bottom, as oil
gravity is less than water one. When bottom water appears in zone (H1), the sensor (D) is activated and sends a signal to the control unit (CU), which, in its turn, switches on the pumping unit (PU) draining bottom water out of the tank through the pipeline. One pipe end is located at the distance H from the center of the bottom, to ensure the suction of the bottom water from the zone H1. Another end is sealed in the tank sidewall and with analyzer (A) is connected with the pumping unit (PU), linked by pipeline with bottom flow regulator (FR). The bottom flow regulator (FR), the pumping unit (PU), the analyzer (A), and the interphase oil-water sensor (D) are electrically linked between themselves and with automatic control unit (CU). The form of piping 4 can be different, the main requirement is: to provide bottom dewatering from the accumulating area "H1". The drained bottom water flows through analyzer "A" 5 to determine its treatment quality and sends a signal to the control unit "CU" 8 in order to stop the pumping unit "PU" 6 and analyzes the presence of bottom water in pipe line 4.

The significant distinguishing features of the given tank for oil and oil products are:

- the bottom of the tank is conical with the slope from the periphery;
- the tank is equipped with a pipeline for the drainage of bottom water;
- the pipeline is equipped with: quality analyzer, pump, flow regulator;
- automatic control unit;
- sensor regulating the position of the interphase oil-water level.

Changing the direction of the bottom cone gives the opportunity to accumulate the bottom water directly in the swing pit, reducing the chance of commercial oil being pumped together with the bottom water. In its turn the interest in such bottom design has been increasing, and the experience with slope-bottom tanks has not been accumulated.

As a result, the study of the stress and strain state by numerical experiment is relevant.

3. Theory
The papers [7-8] contain an extensive experimental and numerical study of the stress-strain state of the vertical steel tank with floating roof. The shell and bottom stresses are measured by special sensors. To study the impact of key factors influencing on stress and strain state a finite element model is used. The selection and justification of finite elements is confirmed by computational and experimental data.

To analyze the stress and strain state, in this work we use the finite element method (FEM) allowing us to solve a wide range of physical tasks that are mathematically formulated by systems of differential equations. The system of equations obtained by FEM for the static linear-elastic model in question can be considered as a system of linear algebraic equations.

Study subject was a number of tanks from 5000 m$^3$ to 50000 m$^3$ with nominal sizes in accordance with [9].

As different variations, it was decided to use the slope angles of the tank bottom from 2 to 20 degrees.

The creation of VST mathematical model and design calculations are carried out by ANSYS Workbench 15.0.

The model geometry is very simplified, some elements are omitted because of their small influence on the main structure behavior (figure 4).

The model consists of the following elements:

- the wall of the tank;
- the bottom of the tank;
- soil bedding;
- clay bed.

The geometry of the tank bottom with 0 degree slope angle is shown in figure 4 a; 8 degrees -Figure 4 b.
Figure 4. Tank bottom model geometry: a) with 0 degree angle; b) with 8 degree angle

We use steel 09Г2С as the most common in the industry and with sufficient strength and plasticity. Medium-grained sand is used for bedding. Clay is a soil base. The tank walls and bottom are simulated by shell elements. The sand bedding and the soil base are modeled as solids. Then the geometry is broken into finite elements.

The applied loads on the main structure and the boundary conditions consist of:

- fixed movement restriction, displacement is prohibited in all directions for soil base on the depth of 10 m;
- limiting the movement of the top tank ring of under the roof impact;
- force putting pressure on the upper ring of the tank and equal to total load from the weight of the spherical roof and the snow load;
- hydrostatic pressure of the product;
- gravity pull shall be indicated for the self-weight of the structure.

4. Experimental results

The analysis of the data obtained at the end of the main task calculation, in particular the tank, resulted in stresses and deformations appearing in the tank. The resulted calculations in the form of a graphical interpretation in the light gradation are shown in figures 5 (a) and 6 (a) for tanks with 0 degree slope angle, and 5 (b) and 6 (b), with 8 degree slope angle.

Figure 5. Von Mises stress in the tank: a) with 0 degree angle; b) with 8 degree angle

Figure 6. General deformations in the tank: a) with 0 degree angle; b) with 8 degree angle
In analyzing the stress and strain state of the flat bottom tanks, a slight stress change at the tank bottom has been detected during postprocessing stage. The main stresses are concentrated in the rim weld. In the case of gradual settlement, all the points of the tank structure have the same displacement.

The situation is quite different when calculating conical-bottom tank with slope to the center due to the bottom water drainage system. During the analysis of the stress and strain state, no concentrations of stress were found. However, the picture of the displacements will change dramatically. However, the maximum displacements are in the middle of the radius.

5. Results and discussion
Practical tests of the tank with 2-3 degrees bottom slope were carried out at oil pump station Ukhta-2, Transneft North, JSC.

The following features have been found during testing process:

- the selection of bottom water has been effectively carried out by the proposed system for 10 years;
- upon tank opening there were no paraffin deposits in practice;
- for effective selection of bottom water from TVS 5000 m³, it is sufficient to use one PDP located at the tank bottom.

The rim weld was diagnosed after the TVS test and cleaning. The results of the diagnosis showed that the rim weld had been deformed within the limits.

As the test of 2-3 degrees slope and 5000 m³ TVS was successful, this design could be proposed for tanks with larger volumes.

6. Conclusion
During the study of the stress-strain state of the tank wall and bottom by ANSYS Workbench package there were created the geometric model and the model of loading the tank structure and calculated the stress-strain state of the tank, taking into account the elements of the bottom water drainage system.

During the analysis of the calculation results, it was found that the main load in the operation of such tank was in the central part of the bottom. However, the practical study of such design showed its run capability.

During the graduate qualification work, a new promising system for bottom water drainage was developed and proposed, based on the use of the conical bottom structure with slope to the center and the installation additional design in the problem area that provides greater bottom strength and more complete bottom water drainage, as well as the possibility of work automating.

During the tank operation it has been found that when draining bottom water, oil sludge discharge from VST also happens, thus reducing by half the cleaning time.

Consequently, the proposed structure of VST bottom is efficient, workable and can be implemented into tanks with 5000-50000 m³ volume.

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