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Effect Analysis of Floating Deck and Vents Positions on N-hexane Evaporation Loss of the Internal Floating-roof Tank

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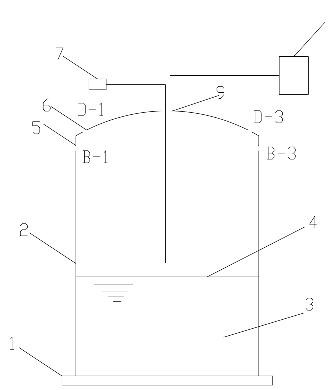
Abstract. As a relatively ideal oil storage container, there is still space for further research on the mechanism of evaporation loss and the law of emission and consumption reduction of internal floating-roof rank. A small internal floating-roof tank was made to investigate the influence of vents and floating-deck positions on the distribution of airflow, wind speed, mass concentration and evaporation loss rate in the tank. The results showed that the wind speed in wall window tank is higher than that in top window tanks, but mass concentration is lower in the latter one. The higher the position of the floating-roof is, the higher the evaporation loss rate is and the better the effect of the emission reduction. It is recommended that vents should be transferred from the tank shell to the tank wall, and the influence of vents and floating decks positions should be considered in API loss formula.

Introduction

IFRT (internal floating-roof tank), as a relatively ideal oil storage container with less oil loss and vapor pollution than other kinds of tanks, is often used to store high-quality oil and produced oil. But the rim seal between floating deck and tank wall gradually ages or even damages with service time, resulting in that liquid surface get contact with gas space thus speeding up the oil evaporation, which causes the waste of resources and deterioration of oil quality. Loss formula of two horizontal storage tanks on the ground and underground which about petroleum small-breathing evaporation loss was conducted by Sharma [1], which was found different with AP-42 formula [2]. Tamaddoni et al [3] studied the emission characteristics of VOCs (volatile organic compounds) when oil tankers were loaded with crude oil. Zhao et al [4] numerically simulated the 5000 m^3 IFRT, and found that the wall window tank and the top window tank have different airflow distributions, to be exact, the former is easier to make a wide range of oil vapor dispersion. In practical production, the IFRT is often affected by the surrounding wind, and when the outside wind goes in and out of the vent freely is bound to bring loss of oil vapor. The influence of the position change of vents and floating-deck on the loss and the airflow distribution in the tank were not considered yet, and the understanding of its loss mechanism was not yet thorough and comprehensive. In this paper, the influence of the position change of the vents and the floating decks on the airflow direction of the vent, the wind speed in the tank, the concentration of the vapor, and the loss rate of evaporation were studied through the small internal floating-roof tank.

Experimental Materials and Methods

An experimental system of evaporation loss of the small internal floating-roof tank (Figure.1) was designed. The tank diameter, the space distance between the floating deck and the internal tank wall, the tank wall height, the roof height was 344, 6, 395, and 41 mm respectively. The tank was placed in a cool, spacious and well-ventilated room, and a constant temperature environment (13℃) was approximately simulated. Liquid surface of the rim gap was exposed to the air. Two groups of vents numbered B1-B4 and D1-D4 were anticlockwise arranged on the top wall of the tank and the edge of the tank roof uniformly and respectively. These tanks were called top window tank and wall window tank respectively. The vent was 17 mm wide and 9 mm high. There was a test window in the center of the top, wind speed and vapor concentration at different heights in the tank were measured. The evaporation loss was measured in the end. IFRT is often used to store produced oil like petroleum. However, due to the complexity of gasoline components, the research is more difficult. N-hexane was a single component and has moderate volatility, so was selected as the experimental storage solution. A large fan was used to simulate the outside wind. The center of the blade is flush with the vent. The blade radius was about 0.5 times of the tank height. The wind speed is uniform and stable (4.0 $m \cdot s^{-1}$) at an appropriate section.



1. Electronic balance; 2. Tank wall; 3. N-hexane; 4. Floating deck; 5. Tank wall vent; 6. Tank top edge vent; 7. Anemometer; 8. Air bag; 9. Test window

Figure 1. Schematic diagram of experimental device.

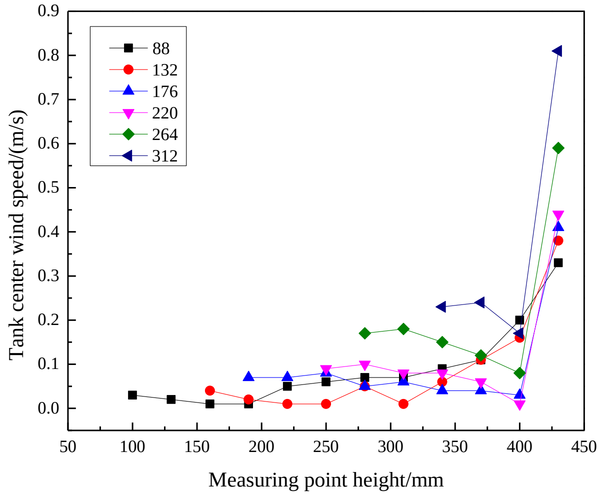
In order to observe the airflow direction, one end of the soft cotton thread was stuck to the inside of the vent. Turn on the fan and snapshot the swing conditions of the cotton thread. Repeat the observation process multiple times. Adjust the position of the floating deck and continue the observation process by the same method. Four floating deck positions were selected (the distance from the floating-deck to the tank bottom was 88, 132, 176, 220, 264, 312 mm respectively). The first row of measuring points is 100 mm from the bottom of the tank, and the subsequent measuring point interval was 30 mm. The last measuring point was close to the center of the tank top. Excluding the data of error or deviation, and average value was got from 4 set of stable data, and then the final result of the wind speed and concentration were measured.

Results and Analysis

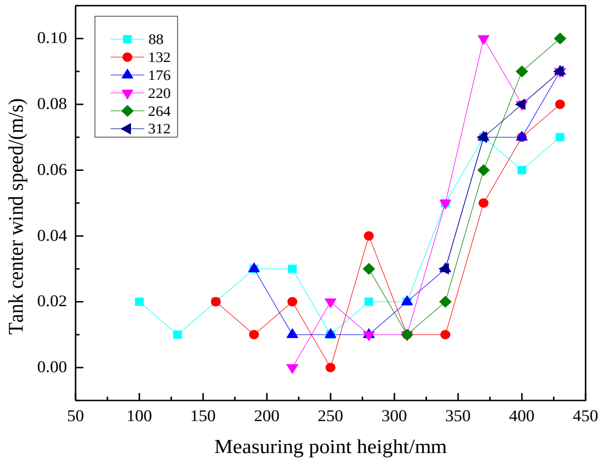
The Influence of Floating Deck and Vents Position on the Wind Speed in the Internal Gas Space of the Tank

According to Figure. 2(a), the wind speed below the vent is gentle; at the height of 400 mm, there is a ‘concave’, that is, the plane at the top of the tank wall as a boundary, down from the boundary, the wind speed increases gently; and up from that, the wind speed increases sharply. After raising the floating deck, the wind speed of each point increases according to such law.

The reason is that the wind speed at the tank wall of vent B1 is not zero, but there is a point where the velocity is zero at somewhere below that, in other words, the maximum static pressure point. Under the action of the pressure difference, the outside wind moves through the air window and moves along the top cover to B3. Then it collides with the inlet airflow at B3, and its momentum and B3 airflow momentum are reduced. After the two air currents converge, they continue to move towards the floating deck, and when they encounter the floating deck, they turn to the windward side and the flow momentum decreases again. On the inner side of the vent, there is a low pressure around it due to the influence of high velocity airflow, and the surrounding gas is "sucked" to B1. Finally, in the tank, the vortex is formed successively through the roof, leeward side, floating deck and windward side. The vortexes are developed on both sides of the tank, and the gas is "extruded" out of B2 and B4. Because of the existence of this vortex, the "concave" point appears at the height of 400 mm. After the raise of the floating deck, the gas space becomes smaller, and the remaining momentum of the airflow at B1 increases, then it will increase the disturbance of the gas space, and the wind speed of each point will increase accordingly.



(a) Wall window tank



(b) Top window tank

Figure 2. Influence of floating-roof height on airflow speed in tank.

As shown in Figure. 2(b), the wind speed decreases from the top to the bottom of the tank. After raising the floating deck, the wind speed curves overlap, and the wind speed is almost unchanged. The maximum wind speed in the top window can be about 0.1 $m \cdot s^{-1}$, while in the remaining space is mostly 0.01~0.07 $m \cdot s^{-1}$. Most of the wind speeds in the window can fluctuate in the vicinity of 0.1 $m \cdot s^{-1}$. Only the wind speed in the top space can increase to 0.3~0.8 $m \cdot s^{-1}$.

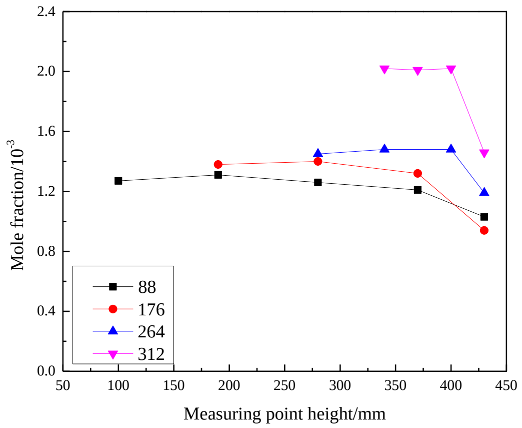
This is because the gas space in the top window tank has lost the strong impact of airflow at B1. After entering the tank from D3, the airflow rushed to the floating deck along the tank wall and couldn't form effective disturbance in tank gas space. Moreover, the collision with floating deck caused a substantial loss of momentum, so the turbulence intensity of the airflow in this tank was weaker than that in wall window tank. The gas which accumulated in the leeward side of the floating pan flowed at a low speed to the windward side. Both inside and outside of D1 were in low pressure, and some of the gas below D1 was pumped out of the tank, and the other part returned to the leeward side along the top cover. As the airflow to the windward side was blocked by the wall of the tank, it turned to the center of the cover, so the wind speed at the top center was higher than that of the measuring point below it. The gas space shrunk after raising the floating deck, but the momentum loss was too large after the collision between the D3 inlet airflow and the floating deck, so the wind speed didn't changed much.

The Influence of Floating Deck and Vents Position on the Tank Concentration

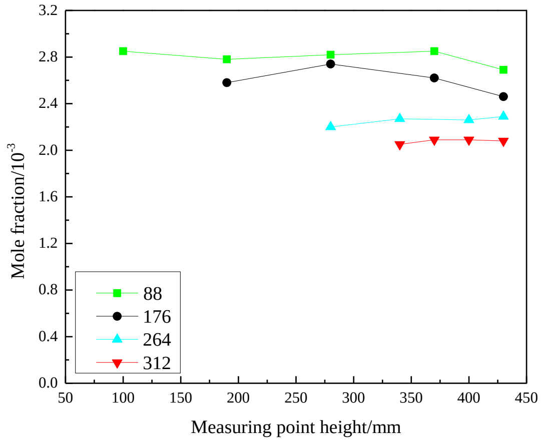
As shown in Figure. 3(a), the mole fraction in the middle part of the gas space is roughly equal, but it is significantly larger than that in the top center. The distribution trend of the mole fraction is unchanged after raising the float, but the average mole fraction increase.

The fresh air was injected into the tank through B1, and the mole fraction was reduced at the top center significantly. When the outside wind was moving along the roof to the downwind, a lot of small vortices were created by the rubbing friction between outside wind and surrounding gas. Varying sizes of vortex did random fluctuation relying on energy provided by the mainstream wind, which strengthened the mixing degree of air and reservoir steam. Therefore, the mole fraction in the middle of the gas space was evenly distributed. When the floating deck was raised, the inlet airflow was in a smaller gas space, and the thickness of the liquid boundary layer surface to be thinner [5] and the concentration gradient to increase; the shear stress causes the liquid surface to fluctuate as the air passes through the liquid surface, and the stock solution molecules will have more kinetic energy to escape from surface; the ventilation volume between gas space in and out of the tank increased, and all three factors accelerated the evaporation of the stock solution. Although evaporation rate will make average mole fraction of gas space increases and restrain reservoir fluid evaporation. The effect of these three factors on evaporation are more significant with the raising of the floating deck. As a result, the mole fraction increases.

According to Figure. 3(b), the distribution of mole fraction of gas space is relatively uniform. After raising the floating deck, the mole fraction decreases. The mole fraction in the top window tank is greater than that of the wall. This is because the airflow in the top window tank can be weaker than that of the wall window tank, and when the floating deck is raised, the ventilation volume increases, the new air volume takes away more liquid vapor, and the evaporation rate of storage fluid is quickened. But the rate of evaporation is less than the rate at which the new wind takes away the steam, therefore, the mole fraction goes down.



(a) Wall window tank

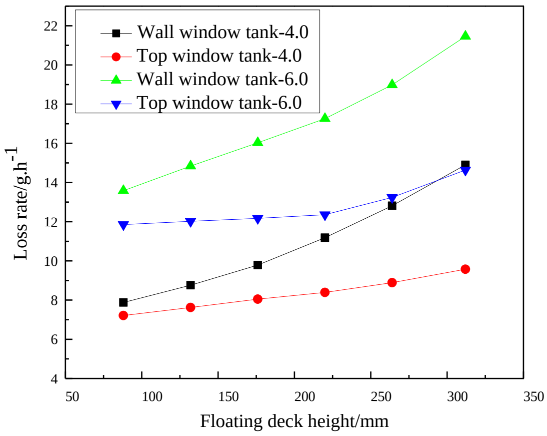


(b) Top window tank

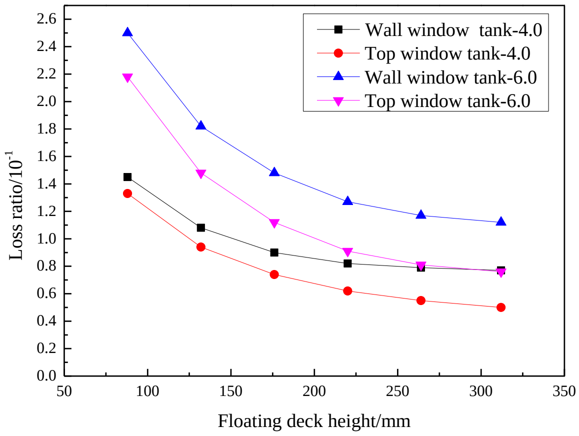
Figure 3. Influence of floating-roof height on n-hexane concentration in tank.

The Effect of Floating Deck and Vents on the Rate of Evaporation Loss

The Figure. 4(a) shows that when the floating deck raises, the evaporation rate of the wall window tank and the top window tank can both increase, as well as the curve slope. However, the evaporation rate and curve slope of the top window tank is less than that of the wall window tank. Besides, the higher the floating deck, more obvious the gap is; the same is true after changing the outside wind rate. The rise of the floating deck will promote the evaporation of the liquid, and more steam will exhaust into the atmosphere and increase the air pollution. But for liquid storage, the evaporation rate per unit weight of liquid storage decreases, and the higher the floating deck is, the higher the evaporation rate curve tends to be, as shown in Figure. 4(b). Therefore, filling the tank with liquid not only makes full use of the tank space, but also helps to reduce the evaporation rate.



(a) Evaporation rate



(b) Evaporation ratio

Figure 4. Comparison of evaporation loss rate in wall window tank with that in top window tank.

The reasons for this phenomenon are described in the preceding sections. In-situ where the tank transformation is needed like oil depots, refinery and chemical industry, if the wall window of the IFRT is transformed into a top window, the evaporation rate and evaporation ratio will be reduced when the outside wind disturbance is encountered, and the air pollution can be reduced. This kind of transformation is beneficial to improving the volume utilization ratio of the tank and the economic efficiency, which can save the cost compared with the nitrogen seal transformation.

Conclusion

- The direction of the airflow in and out of the tank is not related to the position of the floating deck, but was related to the position of the vent, which presents the characteristic that two in two out.
- The wind rate in the wall window tank can be higher than that of the top window tank, and the

average mole fraction was less than the latter. With the raising of the floating deck, the wind speed in the wall window tank increased, and the change of the top window tank wasn't obvious.

- The loss rate increases and the loss ratio decreases when the floating deck was raised. The top window tank can significantly reduce the storage loss. The higher the floating deck, the more obvious the reduction effect. The wall window had a stronger disturbance to the gas space in the tank, and it was suggested that the wall window tank should be transformed into a top window tank.
- It was recommended to consider effect of vents and floating deck positions in API IFRT loss formula correlations.

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