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Study of Charging Nitrogen to External Floating Roof Tank to Prevent Rim-seal Fires from Lightning

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Abstract

It is estimated that 95% of rim seal fires are caused by lightning strikes. To avoid rim-seal fires caused by lightning, the existing methods mainly focus on the use of secondary sealing to reduce volatilization of oil and the electrical connections measures such as air terminals, deflectors, grounding device, discharge shunts and scalable grounding device to avoid sparks caused by lightning current. But these devices can't eliminate the spark generation thoroughly. A new method charging nitrogen to external floating roof tank seal ring is proposed to prevent rim-seal fires from lightning. In this paper, the safe oxygen content is set as the goal to charge nitrogen. An annular nitrogen charging pipe network is designed and its reliability is verified by experiment. The time of filling nitrogen to the seal ring of an external floating roof tank with the capacity of 10×10^4 m^3 at the rate of 63.38 m^3/h to reach the nitrogen charging goal is proved within the time of lightning warning through experiment. And this experiment can provide some reference to the application of nitrogen charging.

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Keywords: external floating roof tank, seal ring, nitrogen charging, safe oxygen content

Nomenclature

n	the amount of carbon atoms
m	the amount of hydrogen atoms
λ	the amount of oxygen atoms
f	the amount of halogen atoms
L	the lower explosion limit

1. The introduction

There is a large number of oil and gas easily gathered in the space in the seal ring of external floating roof tank. It's easy for the external floating roof tank to catch rim-seal fires. And it is estimated that 95% of rim seal fires are caused by lightning strikes [1]. Mainly because when the lightning-related currents flow across the roof-shell interface, if there were gaps in the interface, sparks would have been generated. The sparks can ignite the mixture of oil and gas.

To avoid rim-seal fires caused by lightning, the existing methods mainly focus on the use of secondary sealing to reduce volatilization of oil and the electrical connections measures such as air terminals, deflectors, grounding device, discharge shunts [2] and scalable grounding device [3] to avoid sparks caused by lightning current. But these devices can't eliminate the spark generation thoroughly.

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Some foreign oil companies set aluminum dome on the external floating roof tank top [4, 5], making external floating roof into internal floating roof tank and forming a Faraday cage. This method can avoid lightning effectively. However, once there is rim-seal fires caught by other reasons, it is hard to extinguish. What's more, due to the design of engineering force and the economic costs, it is not suitable for promotion in China.

Some scholars propose filling the external floating roof tank seal ring with inert gases to make the oil gases outside the range of explosion limits, which can effectively prevent rim-seal fires.

The external floating roof crude storage tank is the most common storage tank. In this article, the safe oxygen content of crude-volatilizing gas will be determined and the pipe network to charge nitrogen gas to the external floating roof crude storage tank seals will be designed. A simulation experiment is carried out to prove the effectiveness of the design at last.

2. The principle of charging nitrogen to prevent rim seal fires

As we all know that filling inert gas into the mixture gas of combustible gas and air can reduce the volume fraction of oxygen. If the oxygen concentration is decreased to the point that a combustible gas can never explode or be fired, the critical oxygen concentration is the safe oxygen content of the combustible gas [6].

The theory of charging inert gas to prevent rim seal fires is filling inert gas into the external floating roof tank seals to decrease the oxygen concentration to the safe oxygen content within the time from lightning warning to real lightning. A complete process of inert charging design can be seen from figure 1.

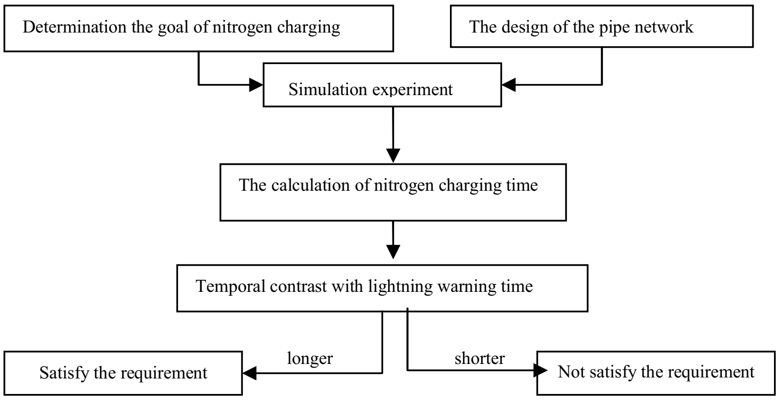

Fig.1. The principle block diagram of charging nitrogen to prevent rim seal fires.

The mechanism charging inert gas to prevent combustible gas fires is inert gas not only dilute the oxygen concentration but also increase the destruction of free radicals and cool the temperature. So for a kind of combustible gas, different inert gases have different safe oxygen content correspondingly [7].

In this paper, nitrogen gas is chosen as the inert gas. So in the following part of this paper, the safe oxygen content just corresponds with nitrogen gas and the safe oxygen content needs to be determined.

3. Determination of the crude-volatilizing gas's safe oxygen content

There is no definitive data of the crude-volatilizing gas's safe oxygen content. To calculate the safe oxygen content of crude-volatilizing gas must refer to the formula to calculate the minimum oxygen concentration. Minimum oxygen concentration is the minimum concentration of oxygen required by flammable gas (vapor) to sustain combustion or explosion, which exists in the explosive range. Safe oxygen content is a special point of minimum oxygen concentration. It is not only minimum oxygen concentration correspond to lower explosion limit and upper explosion limit but also the minimum oxygen concentration of the explosive range.

The chemical reaction of flammable gas (vapor) and oxygen in complete combustion is as follows:

$$C_nH_mO_\lambda F_f + \left(n + \frac{m-f-2\lambda}{4}\right)O_2 \Leftrightarrow mCO_2 + \left(\frac{m-f}{2}\right)H_2O + fHF \tag{1}$$

In the chemical reaction, n, λ, m, f represent the amount of carbon, hydrogen, oxygen and halogen atoms respectively.

When the flammable gas (vapor) volume fraction is equal to lower explosion limit, the theoretical minimum oxygen volume fraction can be calculated with following formula [8]:

$$\phi_L(O_2) = L(n + \frac{m - f - 2\lambda}{4}) = LN \tag{2}$$

In the formula *n, m,* λ*, f, L* represent the amount of carbon, hydrogen, oxygen, halogen atoms, lower explosion limit respectively.

According to Amag's law of partial volume, crude-volatilizing gas can be approximated as single gas containing carbon and hydrogen and the simplified molecular formula of crude-volatilizing gas can be calculated.

To calculate the simplified molecular formula of crude-volatilizing gas, the composition of crude-volatilizing gas should be determined at first. Wang Yu-de [9] and his colleagues have statistical analysis on gas volatilized from crude oil produced from Da Qing and other seven places. The proportion of different components is averaged (shown in Table 1). Then the simplified molecular formula of crude-volatilizing gas can be calculated and the result is $C_{4.035}H_{10.067}$.

The explosion limit of crude-volatilizing gas is 1.1% ~ 6.4% [10]. According to formula above, the theoretical value of safe oxygen content is determined as 9.226%.

Fu Zhi-yuan [11] has a study on the safe oxygen content of common alkanes gas. From his study, we can see that the safe oxygen content of the main components of crude-volatilizing gas is greater than 11% and the value proved by experiment is more than calculated theoretically to 0.5% ~ 2.9%.

A foreign literature [12] points out that for most petroleum products the safe limit of the oxygen content is 10% to 11%.

Taking all the data above into account, the safe oxygen content of crude-volatilizing gas can be determined as 10%.

Table 1. The averaged proportion of different components

Name of component	C1	C2	C3	C4	C5	>C6
Averaged proportion	3.577	4.119	18.346	32.409	41.406	0.163

4. Design of nitrogen charging pipe network

Most studies on applying nitrogen charging to prevent floating roof tank fires focus on internal floating roof tank. And the technology to charge nitrogen to the space between floating roof and fixed roof of internal floating roof tank is maturity. However, study on applying nitrogen charging to prevent external floating roof tank fires especially the rim seal fires is rarely and most studies just give overall ideas. Until now, Zeng Ming-hui graduated from Chinese people's armed police force school had designed a specific nitrogen charging pipe network and done some simulation experiments [13].

There are three drawbacks in his design. Firstly, the pipeline network is branch-shaped and the reliability is poor. Secondly, the amount of setting the nozzle is limited. Thirdly, the use of pipe network is large.

In this article, nitrogen charging pipe network is redesigned (shown in figure 2).

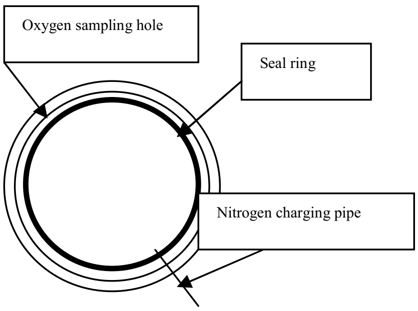

Fig.2. Design of nitrogen charging pipe network.

- The nitrogen charging pipe network is designed circle-shaped to ensure the effectiveness of charging;
- The number of nozzles can be set freely according to demand without increasing the length of pipeline network;
- The amount of the pipe needed is less.

5. Experiment verification

The validity of the nitrogen charging pipe network design need be verified by experiment. The mainly aim is to test whether the pipe network design can achieve nitrogen charging goal and whether can achieve goals on time. Li En-tian [14], a scholar of Jiangsu Key Laboratory of Oil and Gas Storage and Transportation Technology in Chang Zhou University and Zeng Ming-hui [13] have conducted some floating roof tank nitrogen protection tests. And they all put the data got from the experiment to estimate the actual time to charge nitrogen into the real seal ring of external floating roof tanks. So the data got from the experiment also put to estimate the actual time to charge nitrogen into the real seal ring of external floating roof tanks to serve some reference for the actual nitrogen charging pipe network design.

5.1. *Selection of experimental models*

In the experiment of En-tian Li [14], a glass tube with the length of 500 cm, width of 1 cm, height of 4cm is used as the model of the seal ring of external floating roof tanks. However this model is overly simplistic and glass surface is smooth , for the actual surface of the inner ring is rough, and the resistance is large.

In the experiment of Ming-hui Zeng [13], the seal model is a steel ring whose outer diameter is 90 cm and inner diameter is 88 cm and height is 4 cm. This model is highly similar to the seal ring of external floating roof tanks with a capacity of 10 $\times 10^4$ m^3 and the outer diameter of seal ring outer diameter is 40 m and inner diameter is 39.75 m and height is 1 m. This model is similar to the actual seal, and can achieve the requirement of the experiment. So the seal model in this experiment is the same to Ming-hui Zeng's.

There are 8 quick connectors whose diameter is 4 mm mounted on the upper and bottom ring cross-section symmetrically. And the quick connectors on upper and bottom is stagger respectively. The upper quick connectors-are used to charge nitrogen and bottom connectors are used to discharge air in seal ring space.

5.2. Equations and formulae

The equipments of this experiment including an AreaRAE detector, a seal ring model, a nitrogen gas tank, an air pump, a glass rotameter, pipelines and other auxiliary components. All the experimental equipment is shown in Figure 4. A brief introduction of AreaRAE detector is given in the following.

AreaRAE detector extracts air sample through sampling probe. The volume percentage of the oxygen is measured by the oxygen sensor internal and the measurement value is read and stored per second automatically. The measurement accuracy and the range of AreaRAE for O^2 can meet experimental requirements. AreaRAE detector is shown in Figure 4.

Fig.3. The experiment equipments.

Fig.4. AreaRAE detector.

5.3. *Experimental scheme*

In this experiment, change of the oxygen concentration under the condition that nitrogen is charged into seal ring model at different flow rate and the time oxygen concentration reach safe oxygen content is measured through AreaRAE detector. The flow rate of nitrogen charging is 0.5 m^3/h, 0.75 m^3/h, 1.0 m^3/h, 1.25 m^3/h, 1.5 m^3/h respectively. The crude-volatilizing gas concentration in actual seal ring is generally around only 2%, so the concentration of crude-volatilizing gas can be ignored. And since the concentration of oxygen in the experiment is greater than in actual seal ring, the time oxygen concentration reach safe oxygen content in experiment is shorter than in actual use. The result of this experiment is more conservative.

In the process of charging nitrogen gas, the nitrogen flow into the pipe network by the air intake and the original gas in real ring discharge from the recovery pipe. The position to extract air sample is at the real ring where is under the end of the nitrogen charging pipe network (shown in Figure 2), for it is the most negative point to fill nitrogen into the seal ring model.

5.4. Experimental data and its processing

5.4.1 The analysis of the experiment

The change of the oxygen concentration under the condition that nitrogen is charged into seal ring model at different flow rate is as shown in figure 5. From figure 5 we can read:

- In initial stage of charging nitrogen, the rates of oxygen concentration decreasing is slow;
- The greater the nitrogen charging rate the shorter the time to reach safe oxygen content.

The time reaching safe oxygen content under different nitrogen charging rates is shown in Table 2.

5.4.2 The application of experiment

The experiment is used to verify the validity of the nitrogen charging pipe network design. So the result of the experiment is applied to the seal ring of a external floating roof tank whose capacity is 10×10^4 m^3 to get the real time reaching safe oxygen content. The volume of experimental seal ring model is 0.00447136 m^3 and the real seal ring's is 62.60375 m^3, so volume ratio parameter is 14000. The inner diameter of experimental pipe is 10 mm and the real pipe's is 65 mm, so the inner diameter ratio parameter is 6.5. In this calculation, the flow rate of nitrogen in both experiment and real is the same. Then the traffic ratio parameter of the experimental and the actual is 42.25, and the time ratio parameter reaching safe oxygen content is 331.36. Through the ratio parameters, we can get the actual time reaching safe oxygen content (shown in Table 3).

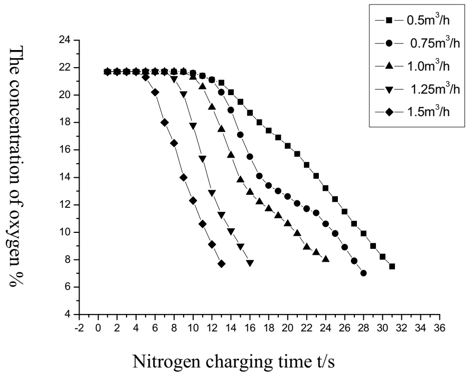

Fig.5. The change of the oxygen concentration under different nitrogen flow rate.

Table 2. The time reaching safe oxygen content under different nitrogen charging traffic

nitrogen charging traffic m^3/h	0.5	0.75	1	1.25	1.5
Time s	28	24	20	15	11

Table 3. The actual time reaching safe oxygen content under different nitrogen charging traffic

Nitrogen charging traffic m^3/h	21.13	31.69	42.25	52.81	63.38
Time min	154.63	132.54	110.45	82.84	60.75

The early lightning warning technology can make the warning time from 90 min to 120 min before the lightning. It can be seen from the table that, for a external floating roof tank with the capacity of 10×10^4 m^3, when the flow reaches 63.38

m^3/h ,the time reaching safe oxygen content is 60.75 min. The 60.75 min is within the early lightning warning time. So the nitrogen pipe network can prevent seal ring fire from lighting.

In the experiment of Zeng ming-hui, the time reaching the goal to prevent seal ring fire from lighting is 69 min at the flow rate of 70 m^3/h when the crude-volatilizing gas's concentration is increased to 2% [13].

Obviously, the design of nitrogen charging pipe network in this article is better than Zeng Ming-hui's.

6. Conclusion

All the work did in this paper can be concluded as following:

- The feasibility of charging nitrogen to the seal ring of external floating roof tank to decrease the oxygen concentration to safe oxygen content to reach the inert goal is theoretically analyzed and the safe oxygen content of the crude-volatilizing gas is determined as 10%.
- A new design of nitrogen charging pipe network is given. The design using annular pipe network to instead branch pipe network can improve the reliability of pipe network.
- The effect of the nitrogen charging pipe network design and the time achieving nitrogen charging goal is studied through experiment. And the experiment results prove that the pipe network design can achieve the actual nitrogen requirements and can be applied to prevent external floating roof tank from rim-seal fires. This nitrogen charging pipe network design can work with the lightning warning system to prevent rim-seal fires of external floating roof tank from lightning.

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