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Study of Fire Fighting System to Extinguish Full Surface Fire of Large Scale Floating Roof Tanks

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Abstract

The basic characteristics of full surface fires of large scale floating roof tanks are briefed. It is pointed out that the present fire fighting systems of large scale crude oil storage depots cannot meet the need to extinguish full surface fires of large scale floating roof tanks. Adequate data of successful extinguishment of large scale tanks full surface fires and full scale tank fire experiments in the world are badly needed to design fire fighting system to extinguish full surface fires of large scale tanks in large scale crude oil storage depots. According to “*Code of design for low expansion foam extinguishing system*” and relative study results abroad, the fire fighting systems are calculated and designed to deal with full surface fires of large scale floating roof tanks. It is shown that designing parameters provided by API are more credible and large foam monitors act as the main fire extinguish facilities. The fire water supplying system is designed according to “*Fire prevention code of petrochemical enterprise design*”. The results show that the capability of the present fire fighting system should be raised up to at least 6-10 times to meet the need to extinguish full surface fires of large scale floating roof tanks. The reconstructing programs of fire fighting system are provided to deal with full surface fires of large scale floating roof tanks in the end.

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1. Foreword

With continual quick economic development in China and increasing need for crude oil, due to turbulence of international crude oil market, strategic storages of crude oil in China have been increasing evidently in recent years. Large scale floating roof tanks have been the main type tanks to store crude oil in China presently. The largest capability of single floating roof tank in China has reached $15 \times 10^4 \text{m}^3$, and floating roof tanks of capability of $10 \times 10^4 \text{m}^3$ are the main type for storage crude oil. The total capability of a large oil depot is more than several million cubic meters. Large scale crude oil depots are of high risk and explosion and fire accidents are one of the main reasons for high risk of large scale crude oil depots because crude oil is flammable and combustible. Full surface fires of large floating roof tanks are one of the most severe ones of all kinds of accidents in crude oil

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tanks. The statistic data of tank fire accidents in domestic oil and chemical industry shows that the crude oil tank fire accidents account for 40%^[1]. There were 22 full surface fire accidents among the 81 large scale floating roof tank fire accidents which API collected from 1951 to 1995, which accounted for 27% , and the diameter of those collected tanks were among 30.5m to 100 m^[2]. Therefore, the high risk of full surface fires of large floating roof tanks cannot be neglected and it is important work for fire research department in large scale crude oil depots to study how to deal with full surface fires of large floating roof tanks.

The design of fire fighting system in large oil depots to extinguish full surface fires of large floating roof tanks is elaborated.

2. Characters of Full Surface Fire of Large Floating Roof Tanks

Although the properties and developing rules of full surface fire of large floating roof tanks need to be researched further, the following points are evident at present^[3].

- Since crude oil is of low flash point, high volatility and fluidity, the flame travels quickly on the oil surface and the hot air stream in the flame is turbulent.
- The flame is of high temperature, strong heat radiation, thick smoke layer. What is more, the temperature in the flame center reaches 1050~1400°C.
- The oil surface is easy to reburn.
- The heat transmitting velocity in oil layer is quick and the long time burning in oil tanks may cause spillage and boilover.

3. Calculation of Fire Fighting System

The fixed foam system has been equipped for large floating roof tanks at present which is based on extinguishment of rim seal fires. For an example of a floating roof tank of $10 \times 10^4 \text{m}^3$, burning surface of full surface fire is as large as 75 times of the largest burning surface of rim seal fire. It is obvious that the present fire fighting system in oil depots cannot meet the need to extinguish full surface fires absolutely.

There are few cases of successful extinguishment of full surface fires of large floating roof tanks in the world by far, what is more, experimental researches of full surface fire of large scale tanks are seriously limited by high cost of experiments, poor repetition of experimental results and etc. Therefore, few researches go further and deeply except for LASTFIRE group in this field^[4]. The design of such a fire fighting system is short of enough accidents information and experiment data, what can be done now is to design basing on full surface fire accidents of medium and small pans and a few of experiments of floating roof tank fire extinguishment. The exploration to design fire fighting system for large scale crude oil depots is detailed with the example of extinguishing full surface fire of large floating roof tank of $10 \times 10^4 \text{m}^3$.

3.1. Design of Foam System

The burning surface of full surface fires of large floating roof tanks is so large that the distance from the center to the circumference of flame is several tens meters. However, the maximum spread distance of foam on oil surface is no more than 30m^[5], which of most foams are only 24~26 m. The foam running down the tank shell from foam pourers settled on top of tank shell has difficulties in reaching the center of flame causing the foam blanket unable to cover the whole burning surface, in addition, the complicated turbulent air stream surrounding the flame may largely affect the track of running foam stream across the flame, which causes some foam escaping to outside of the burning tank. A mass of foam have evaporated before reaching the burning oil surface due to high temperature of flame, which leads to great loss of foam. The experiments of large tank fire extinguishment performed in Japan showed that the amount of foam reaching burning oil surface accounted for only 30% of the total foam, the missing foam 61%, the evaporating foam 9%^[6].

What needed to point out is that the temperature of flame surface is higher than one thousand Degree Celsius and the burning oil surface temperature is about 350°C , so foam break into droplets quickly due to evaporation before reaching burning oil surface. The foam blanket can spread on oil surface continually only when oil surface temperature drops below 147°C^[7]. Therefore, compared to rim seal fire extinguishment, larger foam application rate for extinguishing full surface fire is essential to increase foam momentum, extend the time of foam blanket on

burning oil surface, stretch foam blanket spreading distance.

3.1.1 Design according to Chinese Designing Standard

The complete protection area of full surface fires of floating roof tanks is the cross-section of the tank. According to *Code of design for low expansion foam extinguishing system* (GB50151-92)^[8], the minimum foam application rate is 5.0L/min.m² and minimum discharge time is 45min for fixed foam system. The cross-section of 10×10⁴m³ floating roof tank with diameter of 80 m is 5024 m², therefore, the foam- water solution consumption for it is :

$$5.0 \times 45 \times 5024 = 1130.4m^3$$

The flow rate of foam-water solution is $5.0 \times 5024 = 25120L / \text{min}$.

Besides fixed foam system, three supplemental foam hose handlines are required according to *Code of design for low expansion foam extinguishing system* (GB50151-92), the minimum application rate of foam-water solution of which is 240L/min and the minimum discharge time of which is 30min, then the foam-water solution for the three supplemental foam hose handlines streams is $3 \times 240 \times 30 = 21.6m^3$.

The total foam-water solution flow rate of movable and fixed foam system is

$$25120L / \text{min} + 240L / \text{min} \times 3 = 25840L / \text{min}$$

In fact, the foam hose handlines cannot be applied to full surface fire due to fierce heat radiation of tank flame. Therefore, the total foam-water solution for the tank is

$$21.6 + 1130.4 = 1152m^3$$

3.1.2 Design Based on Overseas Research Results

The main fire fighting facilities for full surface fires of large floating roof tanks are foam monitors which flow rate is more than 40,000L/min.

Several large scale tests for full surface fires of floating roof tanks in Japan were conducted in 2004 and 2005 to accumulate data to design fire fighting system for full surface fires. It is stipulated that the foam should be applied to the burning oil surface efficiently and the tank which diameter is more than 30 m should be equipped with large flow foam monitors which flow rate is not below 10,000L/min and minimum continual discharge time is more than 2 hours^[9]. The referring standard to equip foam monitor for large scale tanks can be seen Figure 1. As shown in Figure 1, supposing the fire fighting time is 4 hours, the foam solution consumption for 10×10⁴ m³ tank is $45216L/\text{min} \times 240\text{min} = 10852m^3$.

API put forward a relation between tank diameter and foam application rate of large scale floating roof tank to extinguish full surface fire of large floating roof tanks^[10], such as shown in Figure 1. For tanks of 80 m in diameter,

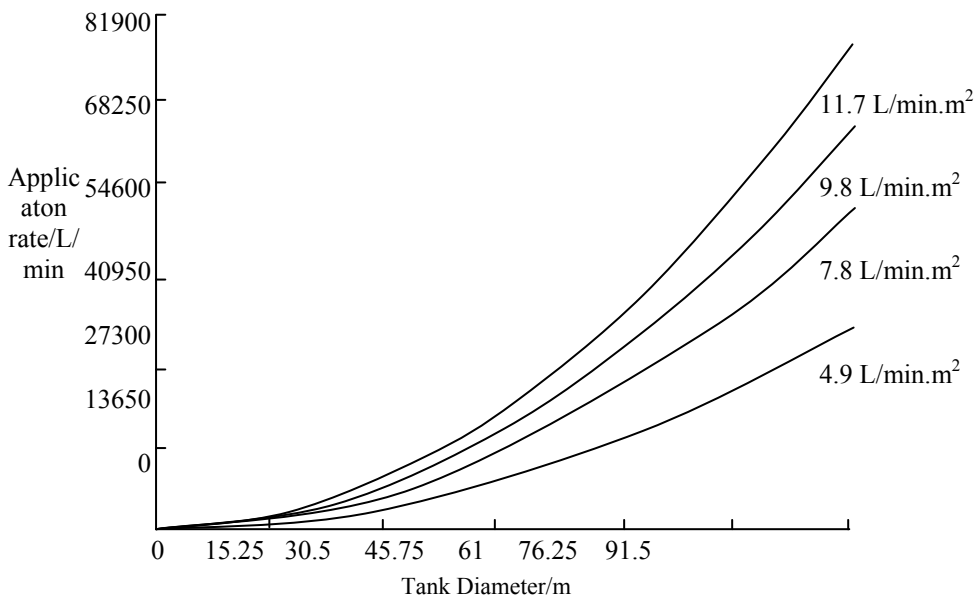


Figure 1 Relation Between Tank Diameter and Application Rate

flow rate of foam solution is 63,700L/min if foam application rate is 11.7L/min.m². The largest tank ever extinguished with large capacity foam monitors by Williams Fire & Hazard Control Inc is 82.4 m (270 ft) in diameter and the flow rate of foam solution is 54,600L/min and the foam application rate is 9.8L/min.m², which

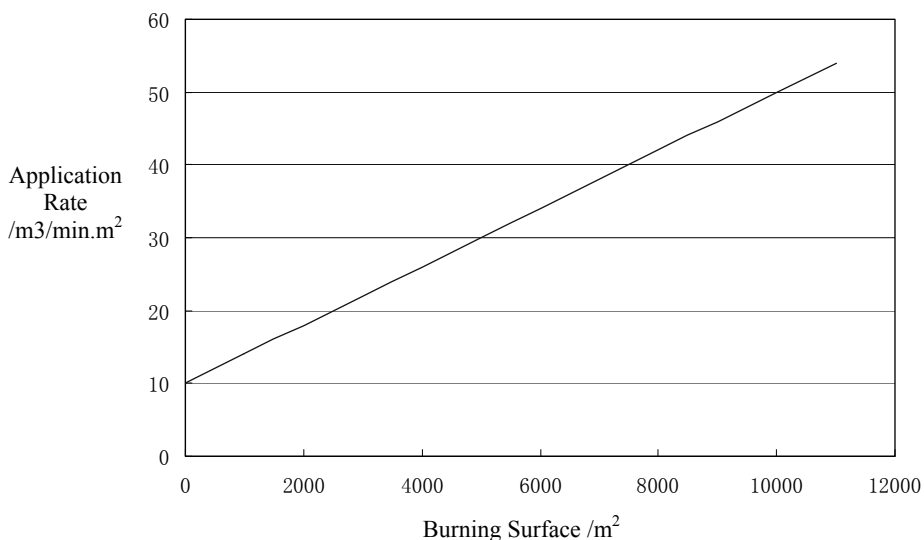


Figure 2 Relation of Burning Surface and Application Rate

shows parameters from API equals the factual foam application rate in fire extinguishment on the whole and proves the data supported by API is credible [11].

TFEX Engineering Ltd conducted fire extinguishment of full surface fire with a ring-formed continuous linear nozzle and drew a relation between foam application rate and burning oil surface as shown in Figure 2 [12]. The experiments results indicated that the large scale fires on tanks of diameter more than 80 m cannot be extinguished only by increasing foam amount through increasing the amount of foam outlets or foam monitors and the successful extinguishment is affected by the distance of foam blanket spreading on oil surface, oil property, wind velocity, the damage by flame and heat updraft and etc.

According to the designing parameters provided by API, the foam flow rate is 63,700L/min for tank of 10×10⁴m³ and the consumption of foam solution is :

$$63,700\text{L}/\text{min} \times 240\text{min} = 15288\text{m}^3$$

The foam concentrate consumption is 458.6m³ if proportion of foam in solution is 3%.

As can be seen from above, the foam system designed according to API is more instructive in dealing with real fires. The foam application rate and total consumption of foam solution calculated according to *Code of design for low expansion foam extinguishing system* (2000) are far small because the parameters of this code were concluded from medium and small tanks fire accidents and experiments, in addition, the largely increasing burning oil surface of tanks also attributes to the increasing loss of foam.

Table 1 Application Rate and Flow Rate of Foam-Water Solution for Tanks of Different Diameters

Tank Diameter (m)	Application Rate (L/min.m ²)	Flow Rate (L/min)
34	6.5	5902
45	6.5	10,335
50	8.0	15,704
60	8.0	22,608
70	9.0	34,623
80	9.0	45,216
90	10	63,590
100	10	78,500
110	10	94,990

It will take long time to extinguish full surface fire of large floating roof tank, such as several hours or several days. Therefore, the part of tank shell above burning oil surface are engulfed by flame and foam pipelines equipped

on top of tank shell will deform or rupture inevitably due to high temperature of flame, for which fixed foam system is caused to paralysis in most cases. So large flow foam monitor is the main facility to extinguish full surface fire of large scale floating roof tanks.

3.2. Fire Water System

Fire water system supply water to mix with foam concentrate, cool tank shell and feed movable fire equipments such as foam monitors. According to *Fire prevention code of petrochemical enterprise design* (GB50160• 2008)^[13], tanks within the distance of 1.5 D to burning tank should be cooled (D is diameter of the burning tank) when full surface fire occurs. Nowadays, the space of $10 \times 10^4 \text{ m}^3$ tanks is 0.4 D (32m) and there are four tanks in each tank group generally. Thus, there are eight tanks at most to be cooled at the same time when full surface fire occurs, as shown in Figure 3.

Floating roof tank of $10 \times 10^4 \text{ m}^3$ is diameter of 80 m and height of 21.8 m, the surface area of which shell is

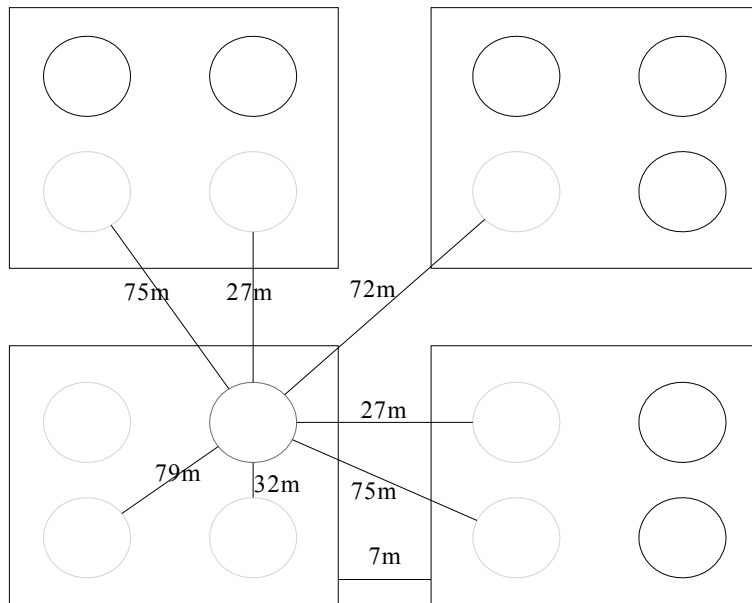


Figure 3 Distribution Diagram of Tank Groups

$$\pi Dh = 3.14 \times 80 \times 21.8 = 5476.2 \text{ m}^2$$

The water flow rate of spraying water is

$$2.0 \text{ L/min} \cdot \text{m}^2 \times 5476.2 \text{ m}^2 = 182.5 \text{ L/s}$$

The total water flow rate for cooling tank shell is $182.5 \text{ L/s} \times 9 = 1642.5 \text{ L/s}$

The minimum total water consumption for one extinguishment is

$$182.5 \text{ L/s} \times 4 \text{ h} \times 9 = 23652 \text{ m}^3$$

According to parameters supplied by API, the water flow for mixing foam concentrate is 61,789L/min if the foam solution flow rate is 63,700L/min and the proportion is 3%, thus, the total water flow rate to extinguish single tank fire is $1642.5 \text{ L/s} + 61789 \text{ L/min} = 160339 \text{ L/min}$

If the fire extinguishment lasts four hours, the total water consumption for extinguishment is

$$160339 \text{ L/min} \times 240 \text{ min} = 38481.36 \text{ m}^3$$

4. Analysis of Fire Fighting System Reconstruction

For extinguishing full surface fires of $10 \times 10^4 \text{ m}^3$ floating roof tanks, the basic designing parameters of fire

fighting system for large scale crude oil depots based on the above calculation are shown in Table 2.

Table 2 Parameters of Fire Fighting System Designing

Designing items	Parameters
Foam-Water solution Total Application Rate (L/min)	63,700
Application Rate of Water for Mixing Foam (L/min)	61,789
Minimum Discharge Time (min)	240
Mixing Proportion of Foam	3%
Water Consumption for Foam Mixing (m ³)	14,829.36
Foam Concentrate Storage (m ³)	458.6
Application Rate of Water Spray (L/min)	98,550
Spraying Time (min)	240
Water Consumption for Cooling (m ³)	23,652
Total Water Application Rate (L/min)	160,339
Minimum Water Storage (m ³)	38,481.36

Nowdays, the largest fire water flow of main pipeline in oil depots is 26,400L/min based on the present fire fighting equipment. Fire water storage in oil depot is generally limited to about 5000m³ and fire water is usually stored in several water tanks or sinks. Therefore, the present fire fighting system cannot meet the need to extinguish full surface fire because fire water storage and water application rate are all far below the minimum requirement unless the capability of the present fire system in the oil depot is raised to 6 to 10 times at least.

In order to satisfy the above need, the present fire fighting system should be reconstructed as follows.

- (1) The fire water storage should meet the minimum capability to extinguish fire for one extinguishment and the fire water can be stored in large scale tanks.
- (2) The fire pumps should be increased to satisfy the flow of the main fire pipeline. According to *Fire prevention code of petrochemical enterprise design* (GB50160• 2008), for the max flow velocity in the fire water pipeline is not above 3.5m/s• the diameter of the main fire water pipe is at least 1000mm to meet 160,339L/min.
- (3) The minimum three large flow foam monitors should be equipped at every large scale crude oil depot, which capability is not below 40,000L/min, additionally, 150% foam concentrate storage is required.
- (4) The large flow remote water supply system should be equipped to gather enough water nearby in order to meet the high water flow rate, such as the one manufactured by Kuiken in Holand which has been put to use in extinguishment of Buncefield oil depot fire.

5. Conclusion

Although full surface fire of large floating roof tank is of high risk and low probability, it will cause great loss for national properties and harmful effect on environment once it occurs.

The fire fighting ability for full surface fire extinguishment in Chinese oil depots should be enhanced as soon as possible with the increasing large floating roof tanks. For oil depot, they should know the risk of full surface fire of large tanks well and improve the fire infrastructure and equipment in order to strengthen the ability of dealing with large scale fire. For the fire fighting research departments, the researches for full surface fires of large floating roof tanks should be more furtherer and deeper, the full scale fire fighting experiments are needed to optimize the equipments of fire fighting system, study the fire fighting strategy further, develop efficient fire equipments in order to enhance the fire fighting ability of large oil depots.

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