Safety risks in VOCs treatment process of oil storage tank farms

WANG Peng¹², DANG Wenyin¹², YU Anfeng¹²* (corresponding author)

¹ Qingdao safety Engineering Institute, SINOPEC, Qingdao, Shandong 266071, China
² State Key Laboratory of Safety and Control for Chemicals, Qingdao, Shandong 266071, China

Abstract. The safety risks of VOCs treatment process of tank farms were studied by using the compound risk assessment method of “HAZOP+LOPA+ Risk Matrix”. The results shown that when the gas spaces of several tanks were interconnected with pines and lead to VOCs treating facilities, all the tank group or several tank groups were connected to be an integrated whole. When fire or explosion accident occurred in one tank, flame can spread to other tanks, and would lead to serious tanks group fire. The key to safety risk prevention and control measures were to prevent major tank group fires. Recommended measures were provided to reduce the safety risk of gas spaces interconnected tanks.

1. Introduction
The breath of oil storage tanks have become one of the major sources of air pollution in refineries. As people pay more attention to environmental protection, relevant regulations and standards are becoming increasingly strict. In order to meet the requirements of national laws and regulations, more and more refineries begin to implement VOCs collection and treatment projects of oil storage tank farms, involving intermediate raw materials and products, naphtha, refined oil products, three benzene, dirty oil, oily sewage and other tank groups¹³. The trend of oil storage tank’s VOCs treatment is to connect several tank’s gas spaces, according to the characteristics of the storage medium, and collect VOCs centrally. The collected VOCs are sent to the follow-up VOCs processing device by fan⁴. When tanks are connected together, if explosion or fire accident occurs in one oil storage tank, the flame spread to other tanks along the connected pipeline, causing significant group fire. At present, there are no relevant standards and research materials for the safety design for the gas spaces connection of combustible oil storage tanks. Therefore, it is of great significance to carry out safety risk research for gas phase spaces connection of storage tanks.

2. Gas phase spaces connection of storage tanks
When conducting VOCs governance in tank farm, in order to collect VOCs centrally, the gas phase spaces of multiple tanks are usually connected together. As shown below, a gas connected branch line is added to the top of each storage tank, and the openings of the storage tanks were closed. The gas phase connected branch lines of each storage tank are gathered into the gas connected main pipe, and then the exhaust gas discharged from the storage tank is sent to the VOCs processing device through a boosting device. The main transformations involved include close the openings of the storage tanks, add the exhaust gas collection line, and the improvement of the pressure measuring instrument and the
shut-off valve. A flame arrestor is installed on the gas phase branch of each tank. Many storage tanks also involve the transformation of the nitrogen seal system.

Figure 1. Schematic illustration of vapor spaces interconnected tanks.

3. Risk analysis method
In order to assess the safety risk of gas spaces connected tanks reasonably, the HAZOP+LOPA+ risk matrix composite risk assessment method is used to evaluate the risk of the VOCs collecting and processing systems [5]. The process of evaluation is shown in Figure 2.
4. Safety risk analysis of gas connected storage tank

For a typical VOCs collecting and treating process of tank area, the system risk analysis is carried out by using the "HAZOP+LOPA+ risk matrix" method. The main safety risks of gas phase connection system of storage tanks are obtained.

4.1. Risk of fire accident

4.1.1. Probabilities of tank fire accidents. The probability and statistics of the fire and explosion of the common storage tanks are shown in Table 1. It can be seen from the table that according to the industrial standard design and operation and maintenance, the frequency of the internal explosion of the single vaulted roof tank or the inner floating roof tank with the full area fire is about $9.0 \times 10^{-5}$/years; the frequency of the internal explosion without fire is about $2.5 \times 10^{-5}$/years; the frequency of the vent fire is $9.0 \times 10^{-5}$/years; the frequency of the small bund fire is about $9.0 \times 10^{-5}$/years; the frequency of the full bund area is $6.0 \times 10^{-5}$/years.
Table 1. Probabilities of fire and explosion accidents

| Type of fire                          | Fixed roof Tank (per tank year) | Fixed plus internal floating Roof Tank (per tank year) |
|--------------------------------------|----------------------------------|-------------------------------------------------------|
| Rim seal fire                        | -                                | 1.6×10⁻³                                               |
| Internal explosion & full surface fire| 9.0×10⁻⁵                         | 9.0×10⁻⁵                                              |
| Internal explosion without fire       | 2.5×10⁻⁵                         | 2.5×10⁻⁵                                              |
| Vent fire                            | 9.0×10⁻⁵                         |                                                       |
| Small bund fire                      | 9.0×10⁻⁵                         | 9.0×10⁻⁵                                              |
| Large bund fire (full bund area)      | 6.0×10⁻⁵                         | 6.0×10⁻⁵                                              |

4.1.2. Risk of large tanks group fire accident. When tanks are connected together, if explosion or fire accident occurs in one oil storage tank, the flame can be transmitted to other tanks along the connected pipeline, causing significant group fire. For example, serious tank group fires and explosion accident happened in a petrochemical enterprise in Nanjing in 2014. After the explosion accident happened in 6# tank, the flame transmitted to other tanks throw the gas spaces connection pipes system, and the 7# and 8# tanks exploded in succession.

![Figure 3. Fire and explosion accidents of gas spaces interconnected tanks.](image)

In addition, flame transportation in the long pipeline systems may promote deflagration to detonation. However, at present, the design of gas phase connected pipeline network in China does not consider the explosion protection of pipelines. Detonation may lead to the destruction of connected network and cause the leakage of fire.

4.2. Safety risk of tank top gas spaces connection process

4.2.1. Risk of the connection of sewage lagoons and tanks. There is a problem of sharing a VOCs collection pipe network and processing system between storage tank and sewage pool system in the VOCs governance process of refining and chemical enterprises. Because the sewage pond is not well sealed, the exhaust gas collected is rich in air, and the concentration of hydrocarbons in the sewage sump is so volatile, and it is easy to form the explosive gas. Effective monitoring of non-methane total hydrocarbons in volatile organic waste gas from 9 oil separation ponds had been achieved, and 5 ponds’ VOCs concentration were over 5000mg/m³. In recent years, many sewage pool flash exploding accidents confirm the danger of sewage sump. Although some enterprises has set up a separate gas collection pipe network for the sewage pools, but share the same VOCs treatment facility, and there’s
no measurement of total hydrocarbon concentration and interlock cut off measures. There is no emergency shutoff valve and pipe resistance facility in the oil and gas processing unit of the tank area, and there is also a high safety risk.

4.2.2. Mode of tank connection and VOCs collection. There are problems in the mode of tank connection and VOCs collection, such as the direct connection between storage tanks with different fire hazards, high sulfur and low sulfur storage tanks, high temperature materials and storage tanks at normal temperature, internal floating roof tanks and vault tanks, and nitrogen sealed tanks and no nitrogen sealed tanks. The difference of fire hazard risk, sulfur content, oil and gas concentration and space oxygen content of gas tanks will increase the risk of each other.

4.2.3. Gas connectivity of tanks can’t be remotely cut off in a fire accident. After the tank top gas spaces are connected, the manual valves in the gas phase branch of each tank can be cut off during a tank fire accident. Once an accident occurs, the gas phase of the other storage tanks connected can’t be cut off. Although a flame arrester is installed, the in-line detonation flame arrester is usually not resistant to long time burning. If the pipe is burning continuously, the flame arrester can invalid, and flame may be transmitted to other storage tanks and cause a large group of tank fires.

4.3. Risk of VOCs incinerator and flare system

Some enterprises send tank’s VOCs to open fire equipment such as heating furnace and incinerator. Flare, incinerator, heat storage oxidation (RTO) and thermal oxidation (TO) are fire sources. Fire accidents will occur if the control is improper. Flame transportation in the long pipeline systems may promote deflagration to detonation. If fire accident occurs in one place, flame may spread quickly to other devices through the VOCs collecting pipe system.

In addition, when the gas is sent to flare system, there are some problems, such as: the heat value is too low to maintain continuous combustion, no oxygen concentration on-line monitoring and control system, for and safety interlocking in some process; oxygen content measurement is 1001, reliability does not meet the safety requirements. Most processes do not consider the risk of reverse channeling when flare gas is discharged in large quantities.

4.4 Risk of VOCs incinerator system

The flame arrester is a very critical safety device in refining and chemical enterprises. Flame arresters are fitted to the opening of an enclosure, or to the connecting pipe work of a system of enclosures, and whose intended function is to allow flow but prevent the transmission of flame.

4.4.1. The serious lack of in-line flame arrester. The gas phase branch line of some storage tanks did not install the detonation fire arrester according to the requirements. In the projects that have been put into operation, there are 399 tanks lack in-line flame arresters in the gas branch pipe lines, accounting for 36%.

4.4.2. The serious quality problems of the in-line detonation flame arrester. In the existing VOCs management project, 759 detonating flame arresters were installed, of which 595 were not tested and only 126 were certified. Whether the flame arrester can be effectively impeding the fire is doubtful.

4.4.3. The lack of technical guidance or standards for installation and maintenance of flame arresters. There is no unified standard for the installation of pipe fire arresters. For the installation of pipeline detonation type arresters, we should avoid the unsteady detonation area to prevent the failure of pipeline fire arresters in the pipeline explosion. Usually, the flame arrester on gas branch pipe line of the storage tank should be installed close to the tank top. For some old tanks, the strength of the tank can not meet the requirements, and can be installed under the tank. The unsteady detonation position should be taken into account if the flame arresters are installed under the tanks. Due to the absence of
technical standard, the location of the flame arrester installed under the existing tank may not meet the safety requirement of "avoiding the critical point of unsteady detonation".

5. Conclusions and suggestions
After increasing the gas connected pipeline and VOCs control device, the whole tank group are connected together by the gas connected pipeline system. The key point of safety risk prevention and control is to prevent large group tank fires. Its safety prevention and control level needs to be improved.

(1) The VOCs source control of the tank farms should be strengthen. It’s recommended to adopt pressure tanks, cryogenic tanks and highly efficient sealed floating roof tanks under the premise of safety and other related specifications. When the source control measures can meet the national and local VOCs emission standards, it’s not recommended to connect the tanks.

(2) It is suggested that the share of VOCs collection system between high oxygen, high risk facilities and tank areas should be strictly prohibited. If the incinerator or flare system is used to process VOCs, the system risk analysis should be carry out.

(3) The design of safety measures should consider the perspective of system safety control, combined with the characteristics of subsequent VOCs processing facilities.

(4) The test and sec of flame arrest should implement the international technology standard ISO16852 to control the quality of flame arrester strictly.

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