

Safety Analysis of Process of Regenerative Thermal Oxidizer for Treatment of Industrial Organic Waste Gas

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Abstract: Focusing on Regenerative Thermal Oxidizer (RTO), the main hazardous and harmful factors were identified in the whole process of industrial organic waste gas, including collection and transmission, RTO disposal and tail gas emission, and corresponding safety countermeasures were proposed. Aiming at the automatic control system, detection and monitoring system, alarm system and interlock system of RTO, a design scheme with certain intrinsic safety degree was proposed.

Introduction

Industrial organic waste gas refers to the waste gas containing volatile organic compounds discharged in the process of industrial production^[1-2]. The abbreviation for volatile organic compounds is VOCs. As is defined in *The Technical Specification for Industrial Organic Waste Gas Treatment by Regenerative Combustion Method* (HJ 1903-2020), volatile organic compounds refer to organic compounds involved in atmospheric photochemical reactions, or organic compounds determined in accordance with relevant regulations.

Petrochemical, chemical, coating, packaging and printing industries have attracted much attention as key VOCs emission industries^[3-5]. During recent years, due to the prominent environmental protection problems, all localities and enterprises are constantly increasing investment in environmental management, and most enterprises achieve emission standards through installation of terminal treatment facilities. Currently, common treatments for VOCs terminal processes include regenerative thermal oxidizer (RTO), regenerative combustion oxidizer (RCO), thermal oxidizer (TO), activated carbon adsorption and desorption, low temperature plasma, etc. Among them, regenerative combustion can control the reaction chamber temperature by timely controlling the valve switching period and adjusting the burner, so as to make thermal combustion more sufficient and more effective for the decomposition of pollutants, which has the dual advantages of high thermal efficiency and high degradation efficiency^[6].

However, the complex composition of VOCs waste gas is usually a variety of combustible and explosive mixed organic gases. The lack of technical process selection in the early stage or the lack of professional management and control in the application of equipment often brings new safety risks [7].

1. Hazard factors and safety countermeasures of the process of collection and transmission

1.1 Hazard factors of the collection and transmission

The main potential hazardous and harmful factors in the collection and transmission process are closely related to properties, gas concentration, static electricity, pipe material, etc of VOCs. The specific circumstances that may lead to an accident include the following aspects:

(1) When VOCs are mixed with contraindicated gases during collection, fire, explosion and poisoning accidents may occur after chemical reactions.

(2) When VOCs in the pipeline reach the explosion limit (usually the lower limit of explosion limit), it is likely to cause fire and explosion accidents in case of static electricity. The explosion limit (Pm) algorithm of mixed gas is:

$$p_m = \left(\frac{P_1 + P_2 + \dots + P_n}{V_1/P_1 + V_2/P_2 + \dots + V_n/P_n} \right)$$

Where, Pm -- the lower limit of explosion limit of mixed gas, %;

P1, P2..., Pn -- the lower explosive limit of each component in the mixed organic waste gas, %;

V1, V2..., Vn -- the volume percentage of each component in the mixed organic waste gas, %;

N -- types of organic compounds contained in mixed organic waste gas.

(3) When the actual wind speed is different in pipeline branch pipe transportation, it may cause local gas turbulence and electrostatic accumulation at the convergence point, thus causing fire and explosion accidents.

(4) As pipe connects flange, valve and so on, waste gas leakage may occur with welding defects or installation quality not meeting the requirements of the code, which may cause fire accident.

(5) The industrial organic waste gas contains corrosive gas, and the pipe material is not anticorrosive or has not been treated anticorrosive as required. In long-term operation, leakage occurs, which may lead to fire, leakage

and poisoning accidents.

1.2 Security countermeasures for collection and transmission

Aiming at the main potential dangerous and harmful factors in the collection and transmission, the following security countermeasures are proposed:

(1) Make analysis on whether the chemicals involve contraindications and whether chemical reactions will occur. In case of prohibition, a separate waste gas disposal system should be set up. *The Notice on Further Strengthening The Safety Management of Chemical Tank Areas* (No. 68 [2014] of Safety Supervisor 3) also puts forward similar provisions, requiring the immediate suspension of the use of multiple chemical tank exhaust connection recovery system, which can only be put into use after the safety verification is qualified.

(2) The exhaust gas collection system should be coordinated with the production process. With the assurance of the collection effect, it should strive for simple structure, easy installation and maintenance management. The exhaust gas collection system shall be designed in accordance with GB 50019, HJ 2000 and relevant industry regulations. When the exhaust gas production points are numerous, and the distance between each other is relatively far, several sets of collection system should set up appropriately.

(3) In the link of organic waste gas transmission, the air volume of the system should be calculated according to the 25% of the concentration of organic matter in the air duct not greater than the lower limit of explosion under normal operation and accident. Set up the gas concentration detection, automatic alarm and automatic interlock device with the fan. After the alarm occurs, corresponding measures can be taken timely within the specified time. The exhaust system of the whole device should also be equipped with a monitoring and alarm system for operating state and exhaust system failure.

(4) All the equipment which may produce electrostatic pipes should be reliable grounding; set up special electrostatic grounding system, with the grounding resistance value no more than $100\ \Omega$; the total leak resistance between electrostatic conductor and earth should be less than $1 \times 10^6\ \Omega$. When corrosive gases are present, the pipeline shall be treated and accepted with anticorrosive materials or according to HGJ 229.

2 Hazard factors and safety countermeasures in the disposal of regenerative thermal oxidizer (RTO)

2.1 Material selection of regenerative thermal oxidizer (RTO)

The industrial waste gas produced by the fine chemical industry often contains chlorine ion, sulfur ion and other elements; thus, chloride, sulfide and other corrosive substances will be produced during the combustion process. If the material selection of all structural parts of RTO equipment is improper, it is easy to be corroded and damaged, and there are safety risks such as equipment deformation, collapse and exhaust gas leakage. Therefore, in the design and purchase of equipment, the enterprise should require its material selection in consideration of the nature of waste gas.

2.2 Furnace internal cleaning setting of regenerative thermal oxidizer (RTO)

Investigations have found^[8] that, after RTO devices are used by several pharmaceutical and chemical enterprises for a period, a large number of secondary pollutants accumulate and stick to the bottom of the regenerator bed. This kind of situation is easy to cause the bottom of the heat storage bed to block, thus causing fire and other safety accidents. Therefore, it is suggested to add a cleaning device at the bottom of the thermal storage bed, and clean the thermal storage ceramics at the bottom regularly, so as to avoid the phenomenon of organic substance adhesion.

2.3 Design of furnace pressure relief of regenerative thermal oxidizer (RTO)

There is a risk of overpressure in the combustion chamber if the regenerator bed is blocked or the concentration of organic waste gas rises sharply during a certain period. For such situation, the combustion chamber should be set on the pressure relief valve, and pressure differential detection device should be set at the import and export pipelines of the regenerative thermal oxidizer (RTO); the differential pressure parameters are set according to the actual situation, and the system control program (PLC, DCS) interlock with pressure relief valve; therefore, when the import and export of pipeline pressure difference value is greater than the set value, the pressure relief valve can easily be opened.

2.4 Interlock design of regenerative thermal oxidizer (RTO)

Regenerative thermal oxidizer should set safe and reliable flame control system, temperature monitoring system and pressure control system. Multi-point temperature and pressure detection devices with automatic alarm function should be installed in the regenerator and combustion chamber. The combustion chamber should be equipped with detection and alarm devices of temperature and ultimate temperature; the upper and lower layers of the regenerator should be equipped with temperature and pressure difference detection devices respectively. Hot and cold double bypass design can be adopted. The hot bypass is interlocked with the fresh air valve, temperature meter and pressure gauge. When the temperature and pressure in the regenerative thermal oxidizer (RTO) are abnormal, the fresh air valve is opened, the concentration is diluted to reduce the temperature and pressure, and the hot bypass valve is opened. Part of the high-temperature waste gas is directly discharged from the combustion chamber to the chimney after being cooled. The cold bypass is interlocked with the concentration detector, exhaust gas inlet valve and emergency vent valve. When the organic exhaust gas concentration exceeds 25%LEL, the exhaust inlet valve will be closed and the emergency vent valve will be opened. The exhaust gas will be

discharged after the cold bypass treatment reaches the standard.

2.5 Auxiliary facilities of regenerative thermal oxidizer (RTO)

2.5.1 Fuel supply system

The reliability of fuel supply system is closely related to the normal operation of regenerative thermal oxidizer (RTO). Abnormal fuel supply is easy to cause combustion flameout, or even secondary ignition, which will cause explosion accidents. Therefore, the fuel supply system should be equipped with high and low pressure protection, leakage alarm device and pressure detection equipment. The fuel delivery pipe of the burner shall be equipped with an emergency shut-off valve close to the burner, and the emergency shut-off valve shall not be equipped with a bypass.

2.5.2 Power supply and compressed air

If the RTO system suddenly loses gas or power, the control program completely loses power and gas, and the parameters of key nodes in the control interface cannot be fed back in real time. The valve switch is not in place, and there are safety hazards such as exhaust gas combustion and explosion. Therefore, the RTO system should be equipped with a UPS backup power supply and compressed air storage tank.

2.6 RTO device and other safety countermeasures

2.6.1 Design stage

(1) Safety risk assessment demonstration shall be carried out in the design stage of heat storage combustion device (RTO). If the exhaust gas composition is complex, it should take HAZOP analysis and adopt the corresponding safety measures.

(2) Regenerative thermal oxidizer (RTO) should adopt PLC or DCS control system. According to HAZOP analysis, safety instrument system (SIS) can be set up if necessary to realize real-time monitoring and interlock of key parameters of equipment and facilities such as fan, valve, burner, furnace and exhaust pipe.

(3) The regenerative thermal oxidizer is an open flame device and should be far away from the inflammable and explosive dangerous area. The safe distance should be in accordance with the relevant provisions of GB 50016, GB 50160 and GB 51283.

(4) When the general layout is designed, the explosion danger area shall be accurately divided according to GB 50058. For devices and equipment installed in the environment of explosive gas, appropriate electrical equipment and electronic control devices shall be selected according to the requirements of explosion grade, and the equipment wiring shall conform to the relevant provisions in GB 3836.15.

(5) Flame arrester or fire valve should be installed in the pipeline system between regenerative thermal oxidizer (RTO) and main production process equipment. According to the nature of organic waste gas, detonation or deflagration flame arrester should be selected reasonably. Deflagration retardation flame arrester is used to prevent flame propagation of subsonic propagation, while detonation retardation flame arrester is used to prevent flame propagation of sonic and supersonic propagation. When installing the pipe detonation arrester, it should be noted that the detonation wave absorber should be oriented in the direction that is likely to produce detonation, otherwise it will lose the function of detonation retardation. According to the nature of materials and specific process requirements, a reasonable choice of fire valve installation location.

2.6.2 Operation and maintenance

(1) The concentration of particulate matter in organic waste gas should be lower than $5\text{mg}/\text{m}^3$, and it should be strictly controlled if it contains tar, paint mist and other viscous substances;

(2) Similar to conventional chemical plants, trial production, start-up and shutdown are often the links with high incidence of accidents in regenerative combustion units (RTO). Therefore, safety operation should also be emphasized in the debugging and use of the device. When the regenerative thermal oxidizer (RTO) is started, a small amount of fresh air is brought into the furnace for pre-purge mode. After the gas in the furnace is completely replaced for several times, it is switched to the heating and heat exchange process. After the oxidation chamber rises to the set temperature and operates stably for a period of time, organic waste gas is connected. Firstly, low concentration organic waste gas, such as waste gas from enterprise sewage pool and solid waste storage, is connected to the high concentration waste gas in the workshop step by step. At the same time, the concentration of the exhaust gas to be connected is continuously detected for 24 hours. If the concentration of a certain exhaust gas exceeds the limit, the cause must be found and solved timely to ensure that the mixed gas is within 25% of the lower limit of explosion. After all organic exhaust gases have been connected, on-site debugging personnel should closely observe the operation condition in the early stage of regenerative thermal oxidizer (RTO) operation, so as to solve sudden accidents timely.

3. Hazard factors of tail gas emission and safety countermeasures

Exhaust gas treated by regenerative thermal oxidizer (RTO) may still be dangerous. Exhaust gas is usually vented by exhaust cylinder. In some special cases, the device activates emergency emptying, which objectively increases the risk of exhaust emission. Therefore, the horizontal distance between the exhaust outlet and the air inlet of the mechanical air supply system should not be less than 20m to prevent the use of tail gas circulation. If the VOCs collection process involves chlorine, hydrogen cyanide and waste gas containing other extremely toxic substances, the exhaust cylinder should not be lower than 25m. In some areas, if the height of the exhaust cylinder

may not reach the above requirements, then the area near the base of the exhaust cylinder may involve an explosion risk, the explosion risk area shall be adjusted according to the relevant provisions of GB 50058, and the equipment in the area shall meet the explosion protection requirements.

4 Conclusion

The industrial organic waste gas disposed by the regenerative thermal oxidizer (RTO) has the characteristics of ignition and explosion, so the unit itself has a certain danger. In all safety factors to consider, the device inlet concentration explosive limit always lower than the lower limit of 25% organic matter is one of the keys to reduce safety accidents, especially in conjunction with wheel adsorption parsing, setting up reasonable gas concentration detecting system, automatic alarm system and interlocking system become the core link of lifting intrinsically safe device.

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