Experimental study on the collection efficiency of gas collection hoods in the plastic products industry under the effect of flue gas temperature

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Abstract: The gas collection hood is a crucial component of the waste gas treatment system, and its collection efficiency directly impacts the treatment effectiveness. To clarify the relationship between flue gas temperature and the collection efficiency of the gas collection hood, this study took seven plastic product enterprises in Cang County as the research subjects. The point source correction method was employed to deduce the unorganized emission source strength, and the collection efficiency at different temperatures was analyzed. The results showed that within the temperature range of 120~210 ℃ , the collection efficiency decreased from 95% to 68%, exhibiting a strong negative correlation (r=-0.977). The regression equation is collection efficiency = -0.00341 × temperature + 1.366. The study suggests that enterprises should pay attention to the impact of flue gas temperature and optimize the design of the gas collection hood.

Key words: gas collection hood; flue gas temperature; collection efficiency; regression equation

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0 Introduction

As the initial stage of the exhaust gas collection system, the performance of the gas collection hood has a decisive impact on the subsequent treatment effect. In practical operation, flue gas temperature is one of the important variables affecting collection efficiency. Existing specifications mostly evaluate the efficiency of gas collection hoods from the perspective of structural form, and research on the impact of operational parameters, especially temperature, is still insufficient. Taking the plastic products industry as an example, this study analyzes the quantitative relationship between flue gas temperature and the collection efficiency of the gas collection hood through on-site monitoring data, aiming to provide a basis for optimizing the design and operation of the gas collection hood.

1 Factors affecting the collection efficiency of gas collection hood

The gas collection hood is a local suction device used to capture pollutants emitted from pollution sources. It is mainly applicable to two types of working conditions: one is when the process conditions inside the enclosed equipment do not allow the formation of micro-negative pressure; the other is when pollutants are directly generated on the surface of open or semi-open pollution sources. Its collection efficiency is affected by various factors, mainly including the design parameters of the gas collection hood and the characteristics of the flue gas. The design parameters include the area, geometric dimensions, and relative distance of the gas collection hood to the pollution source; the flue gas characteristics include key parameters such as the type of pollutants and flue gas temperature. Peng Taiyao et al. conducted experiments on the capture

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efficiency of local exhaust hoods to study the relationship between different wind speeds and the capture efficiency of the gas collection hood; Zhang Xiaobing stated that the gas collection hood is an important component of the local gas purification system, serving as a device for collecting and capturing gaseous pollutants.

China has established relevant standards and specifications in the design and evaluation of gas collection hoods. The "Classification and Technical Conditions of Exhaust Hoods" (GB/T 16758-2008), issued by the General Administration of Quality Supervision, Inspection and Quarantine of the People's Republic of China and the Standardization Administration of the People's Republic of China in 2008, sets out clear requirements for the classification and technical conditions of gas collection hoods. Furthermore, in the "Accounting Method for Volatile Organic Compound Emission Reductions from Industrial Sources in Guangdong Province (Trial)" issued by the Guangdong Provincial Department of Ecology and Environment in 2021, reference values for exhaust gas collection efficiency are provided from the perspective of gas collection hood structure.

Existing standards primarily assess gas collection efficiency based on structural forms, with relatively insufficient attention paid to the impact of flue gas operating parameters. Therefore, this study focuses on the key parameter of flue gas temperature, exploring its specific influence on the collection efficiency of gas collection hoods through empirical data analysis. The aim is to provide a more refined basis for the optimal design and operation of gas collection hoods.

2 Research methods and data sources

2.1 Research subjects

This study focuses on seven plastic product enterprises in Cang County, collecting relevant monitoring data during the project acceptance period for case investigation and analysis. During the design process of the gas collection hood, the enterprises adhered to the standards set out in "Classification and Technical Conditions for Exhaust Hoods" (GB/T 16758-2008), ensuring that the gas collection hood meets the requirement of a wind speed of not less than 0.3 m/s at the location of unorganized VOCs emissions farthest from the opening surface of the exhaust hood, as stipulated in the "Control Standard for Unorganized Emissions of Volatile Organic Compounds" (GB 37822-2019).

These seven enterprises were selected as case studies for two reasons. Firstly, they share the same governance technology, making them comparable and helping to eliminate interference caused by differences in technical routes. Secondly, they are all in the acceptance monitoring phase, with relatively standardized operating conditions and monitoring conditions, ensuring that the data obtained can accurately reflect the actual operational effectiveness of this governance technology in similar industries and under similar operating conditions. By comprehensively comparing and analyzing the monitoring data from these cases, we can provide a realistic basis for further evaluating the stability, applicability, and optimization direction of this governance technology. Additionally, it can serve as a reference for similar enterprises in selecting and managing their waste gas treatment processes.

2.2 Data collection and processing

According to the acceptance monitoring report, the collection volume of organized waste gas for non-methane hydrocarbons can be directly observed. However, for unorganized waste gas of non-methane hydrocarbons, the monitoring report does not provide the direct generation volume. In this study, the midpoint source correction method (for small area sources S≤1km2) in the unorganized source intensity back-extrapolation method was adopted for back-extrapolation.

Formula for point source correction method:

$$Q=C\times U\times \pi\times \sigma_y\times \sigma_z$$

Where: Q—fugitive emission rate of waste gas, unit: mg/s;

C—Downwind concentration, unit: mg/m³;

U—wind speed, unit: m/s;

σ_y—diffusion parameter in the horizontal direction, unit: m;

σ_z—diffusion parameter in the vertical direction, unit: m;

2.3 Summary of monitoring data

Table 1 is obtained through the statistics and analysis of acceptance monitoring data from 7 plastic product enterprises.

Table 1 Summary of acceptance monitoring data survey results

Serial number	Flue gas temperature / ℃	Organized production rate / (kg·h^{-1})	Fugitive emission rate /(kg·h^{-1})	Collection efficiency	Data source
1	120	0.024 3	0.001 3	95%	Technical transformation project of plastic product production line of a packaging product company in Cangzhou
2	130	0.027 3	0.002 1	93%	New project with an annual output of 50 tons of plastic caps at Cangxian Chengchen Plastic Products Factory
3	145	0.020 8	0.002 3	90%	A new project with an annual output of 5 million sets of metal and plastic farming equipment accessories has been established by a farming equipment factory in Cang County
4	150	0.031 5	0.005 6	85%	A plastic product factory in Cang County has a project to produce 600 tons of PP plastic boards annually
5	175	0.084 1	0.028 0	75%	Technical transformation project of plastic product production line in a plastic factory in Cang County
6	185	0.036 5	0.015 6	70%	Plastic slicing project of a plastic product factory in Cang County
7	210	0.029 9	0.014 1	68%	A new project with an annual output of 3 million plastic bottles has been established in a plastic product factory in Cang County

3 Gas collection hood for the collection and analysis of non-methane hydrocarbons at different temperatures

By summarizing and statistically analyzing the monitoring data of the aforementioned seven enterprises, the main results are presented in the figure. The figure visually illustrates the collection efficiency of gas collection hoods and flue gas temperature for each enterprise, facilitating horizontal comparison.

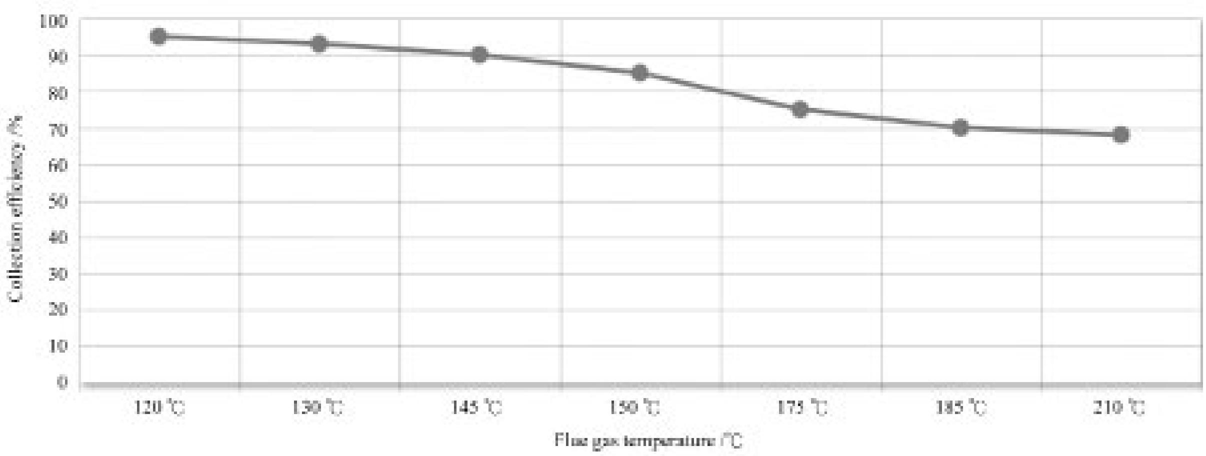

Figure 1 Collection efficiency diagram of gas collection hood under different flue gas temperatures

Through statistical analysis of the monitoring data in the figure, the dataset comprises seven observation samples, recording the collection efficiency of the gas collection hood under different flue gas temperatures. The temperature range is from 120 ℃~210℃, and the collection efficiency range is from 68% to 95%. From 120℃~150℃, the efficiency decreases from 95% ~85%, with a relatively gentle decline (about 10 percentage points). From 150℃ ~185℃, the efficiency drops sharply from 85%~

70%, with an accelerated decline (15 percentage points). Above 185 ℃, the efficiency decline slows down (reaching 68% at 210 ℃).

3.1 Analysis of the strength and direction of the relationship between flue gas temperature and collection efficiency of the gas collection hood

Strong negative correlation: There is a significant negative correlation between flue gas temperature and collection efficiency of the gas collection hood (correlation coefficient: -0.9768), indicating that as the flue gas temperature increases, the collection efficiency significantly decreases.

3.2 Relationship between flue gas temperature and collection efficiency of gas collection hood

(1) Collection efficiency=−0.003409× Temperature (℃) +1.365793.

(2) For every 1℃ increase in temperature, the collection efficiency of the gas collection hood decreases by an average of approximately 0.0034.

3.3 Key statistical parameters

The correlation coefficient (r) is−0.976834, indicating a strong negative correlation between flue gas temperature and collection efficiency.

Coefficient of determination (R^2): 0.954204, the model explains 95.42% of the data variation, and the fitting effect is excellent.

3.4 Reasons for the decrease in collection efficiency of the gas collection hood due to the increase in flue gas temperature

(1) An increase in temperature causes the volume of exhaust gas to expand, leading to an increase in volumetric flow rate under the same mass flow rate. This results in an increased volume of exhaust gas that needs to be processed by the gas collection hood per unit time, and a decrease in capture efficiency under a fixed exhaust capacity.

(2) As the density of high-temperature exhaust gas decreases, the inertia of the gas weakens, making it more prone to bypass and escape in the suction airflow of the gas collection hood.

(3) The temperature gradient induces a difference in gas density, intensifies local turbulence, complicates the diffusion path of pollutants, and reduces the time for effective capture by the gas collection hood.

(4) High-temperature exhaust gas generates significant thermal buoyancy, enhancing its upward movement trend. This competes with the side or top suction airflow direction typically set by the gas collection hood, resulting in interference with the trapped airflow.

4 Suggestions

Effectively controlling the collection efficiency of gas collection hoods is a crucial step in reducing fugitive emissions and enhancing the effectiveness of corporate waste gas treatment. This study confirms that an increase in flue gas temperature will directly lead to a significant decrease in collection efficiency. Therefore, in the design and operation of gas collection hoods, enterprises must consider flue gas temperature as a core factor.

For high-temperature operating conditions, the following optimization measures are recommended:

(1) Optimize the structure of the gas collection hood. For points where high-temperature exhaust gas is generated, priority should be given to using semi-enclosed or fully enclosed hoods to reduce the mixing of exhaust gas with the surrounding air, thereby enhancing capture efficiency at the source. For open pollution sources, gas collection hoods with enclosures or side suction functions can be selected to strengthen the confinement of high-temperature flue gas.

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hoods with enclosures or side suction functions can be selected to enhance the restraint effect on high-temperature flue gas.

(3) Strengthen system matching and process control. Installing a cooling section or air mixing device after the gas collection hood can reduce the temperature of the flue gas entering the collection system, effectively improving the operating conditions of subsequent pipelines and equipment. At the same time, it is recommended to install temperature monitoring and interlock control devices in high-temperature sections to achieve dynamic matching between the operating state of the gas collection hood and the flue gas temperature.

Through the aforementioned targeted measures, the collection efficiency under high-temperature flue gas conditions can be significantly improved, maximally reducing fugitive emissions and providing technical support for enterprises to achieve stable and compliant emissions as well as refined environmental management. In the future, it is recommended to further conduct research on the optimization of gas collection hood structures and standardization of operating parameters across different temperature ranges, promoting the formation of industry technical specifications.