

EXPERIMENTAL STUDY ON THE ADSORPTION PERFORMANCE OF TVOC BY NEW RGO COMPOSITE FILTER MATERIAL

Tao YU^{1,2*}, Minhao MU², Wenjun LENG², Xin ZHANG^{3*}, Qing LIU⁴, Rui Tao³

(¹School of Energy and Power Engineering, Beihang University, Beijing, 100191, China; ²Wuhan Second Ship Design and Research Institute, Wuhan, 430205, China; ³College of Architecture and Energy Engineering, Wenzhou University of Technology, 325000, Wenzhou, China; ⁴School of Resources Engineering, Xi'an University of Architecture and Technology, 710055, Xi'an, China)

* Corresponding author: E-Mail: m17809248612@163.com; 2601084634@qq.com

It is of great significance to effectively control the impact of Total Volatile Organic Compounds (TVOC) on personnel's physical health in working and living environments. This paper conducts adsorption experiments on TVOC in commonly used paints using a new type of rGO composite filter material. The adsorption performance and desorption performance are studied under different conditions such as temperature, humidity, airflow velocity, and initial concentration. The results showed that the new filter material has good adsorption performance for TVOC in paint. With the increase of TVOC gas concentration, airflow velocity, temperature, and humidity, the penetration time of rGO composite filter material will continuously shorten. After five cycles, the desorption rates of displacement desorption and heating desorption reached 82.3% and 61.2%, respectively, and the displacement desorption efficiency was 25.6% higher than the heating desorption efficiency. It provides reference for effectively removing TVOC, which is helpful for ensuring air quality in special industries.

Keywords: rGO composite filter material; TVOC; adsorption characteristics; detachment method; experimental research

1. Introduction

Human health is closely related to the quality of the living environment, and the air environment contains various pollutants [1-2]. Related studies have shown that total volatile organic compounds (TVOC), being widespread pollutants in indoor and outdoor environments, pose a dual threat to environmental quality and human health [3-4]. TVOC mainly come from compounds such as formaldehyde and benzene released during the use of indoor decoration materials [5-7], volatilization of daily necessities [8], emissions from office supplies [9], as well as outdoor car exhaust, industrial waste gas, etc. [10]. These pollutants enter the air environment through volatilization, diffusion, and other means, forming complex mixture systems [11-13]. Short-term exposure to such an environment can cause symptoms such as headaches and dizziness, affecting the functioning of the nervous system and leading

to lack of concentration and memory decline. Long term exposure may cause damage to the liver, kidneys, and hematopoietic system, induce leukemia, and may also cause damage to the reproductive system, affecting normal fetal development [14-16]. According to relevant literature [17], about 90% of a person's life is spent indoors, and it is particularly important to reduce TVOC concentration and create a healthy living environment.

In order to effectively control pollutants in the atmosphere, air filter systems have been widely promoted and used [18]. Its mechanism of action is to effectively intercept TVOC, PM, and microorganisms in pollutants through filtering materials, achieving effective air purification [19]. Among them, TVOC is mostly removed by adsorption method [20], which often utilizes the characteristics of porous and high specific surface area of adsorbents to enrich TVOC gas on the surface of adsorbent pores. This method has the advantages of simple operation, low energy consumption, and good purification effect, but also has limitations in adsorption capacity, selectivity, stability, and regeneration performance [21]. Such as activated carbon [22].

The focus is on the research and development of adsorption materials [23], cost control of adsorption materials [24], and condition parameters that affect adsorption efficiency [25]. Existing research has mostly focused on activated carbon [26], metal oxide materials [27], carbon-based materials [28], metal organic frameworks (MOFs) [29], covalent organic framework materials (COFs) [30], and other. However, due to the continuous increase in people's demand, the concentration of harmful gases in the air is getting lower and lower. Therefore, the development of new adsorption materials in air filtration systems has always been the mainstream direction of research while meeting the demand. Not only can it filter and adsorb pollutants in the air, but it can also overcome the drawbacks of complex and bulky filtration systems composed of multiple single filter materials, achieving the multifunctionality and simplicity of filter materials.

Since its discovery, graphene has been applied in various fields due to its unique characteristics [31]. By utilizing graphene, each carbon atom can form a large π bond, providing $\pi - \pi$ conjugation forces [31]. It can be used as an adsorbent for adsorbing aromatic gaseous pollutants. By combining graphene with other materials, a new type of rGO composite filter material can be composed, which has advantages in terms of capacity, adsorption rate, and selectivity for adsorbing harmful gases. However, there is currently relatively little research on the adsorption performance of rGO composite filter materials for TVOC, and there is a lack of research on the adsorption performance under different parameter properties. There is also a lack of research on the adsorption of TVOC in commonly used paints by rGO composite filter materials.

Therefore, based on the above practical problems, this article conducts multi parameter adsorption experiments on TVOC in paint through a new type of rGO composite filter material, which has great engineering application value for enhancing indoor air quality.

2. Methods

2.1. Material preparation

Using non-woven fabric as the background material, graphene oxide filter material was obtained by direct impregnation method, and then reduced by ascorbic acid to obtain rGO composite air filter material. The preparation diagram is shown in Fig. 1.

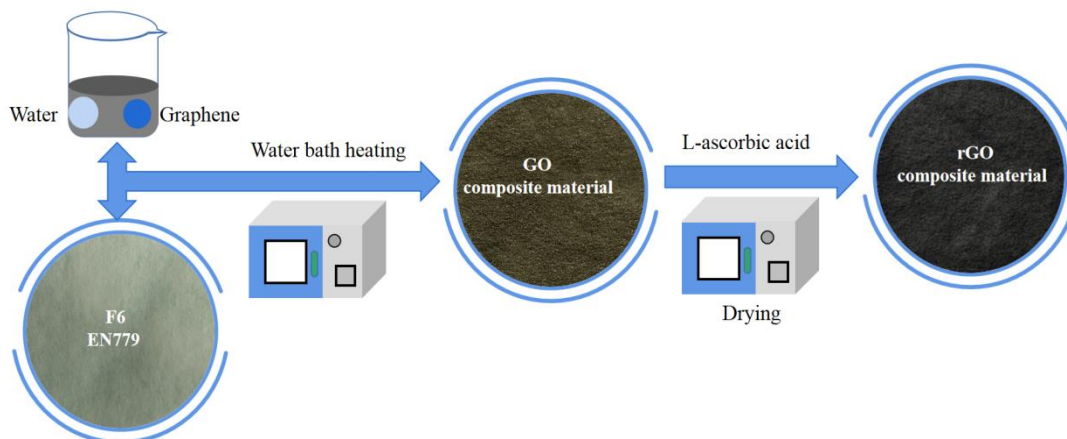


Fig. 1 Schematic diagram of preparation process

2.2. Adsorption / desorption experiment

Selecting commonly used paints as pollution sources, dynamic adsorption experiments were conducted to test the adsorption performance of rGO composite filter materials for TVOC in paints. After the rGO composite filter material reaches saturation during the adsorption process, desorption experiments were conducted using both heating and displacement methods. Heating desorption is the process of placing a new type of reduced graphene oxide air filter material that has reached adsorption saturation into a drying oven and heating it at 100 °C for 1 hour. Permutation desorption is the process of immersing a newly saturated reduced graphene oxide air filter material in deionized water and stirring for half an hour, followed by drying at 70 °C for 1 hour in a drying oven. TVOC adopts PGM-7320TVOC organic gas detector, with a range of 0.1-15000 ppm (0.12-18495 mg/m³) and a measurement accuracy of $\pm 3\%$ of 10-2000 ppm isobutene standard point. Temperature and humidity is specified for each test run. The TSI7525 indoor air quality measuring instrument is used to measure the test temperature and humidity, with a temperature range of 0-60 °C, an accuracy of ± 0.6 °C, and a resolution of 0.1 °C; The relative humidity is 5-95%, the accuracy is $\pm 3\%$, and the resolution is 0.1%. Conducted were 3 repeated tests for each group of tests under different parameters, with each test lasting 10 minutes. The average of the test results was taken for data analysis to make the results more representative.

2.3. Performance parameter representation

When the export concentration reaches 5% of the initial concentration, it is considered as adsorption breakthrough; when it reaches 95% of the initial concentration, it is considered saturated. The calculation of dynamic adsorption capacity is performed using the following expression [32]:

$$q_e = \frac{Q \int_0^t (C_{in} - C_{out}) dt}{22.4m} \quad (1)$$

where q_e is the adsorption capacity, mmol/g; Q is the gas flow rate, mL/min; C_{in} represents the inlet concentration of adsorbed TVOC, mg/m³; C_{out} represents the outlet concentration of adsorbed TVOC, mg/m³; m is the amount of adsorbent used, g; t is the adsorption time, min.

The calculation of desorption efficiency is done using the following equation [33]:

$$N = M_t / M_0 \quad (2)$$

where N is the desorption efficiency, %; M_t is the adsorption capacity after desorption, mg/m³; M_0 is the initial adsorption capacity, mg/m³.

3. Results and discussion

3.1. Adsorption performance of TVOC at different concentrations

The differences in adsorption performance of rGO composite filter materials for different TVOC gas concentrations are shown in Fig. 2.

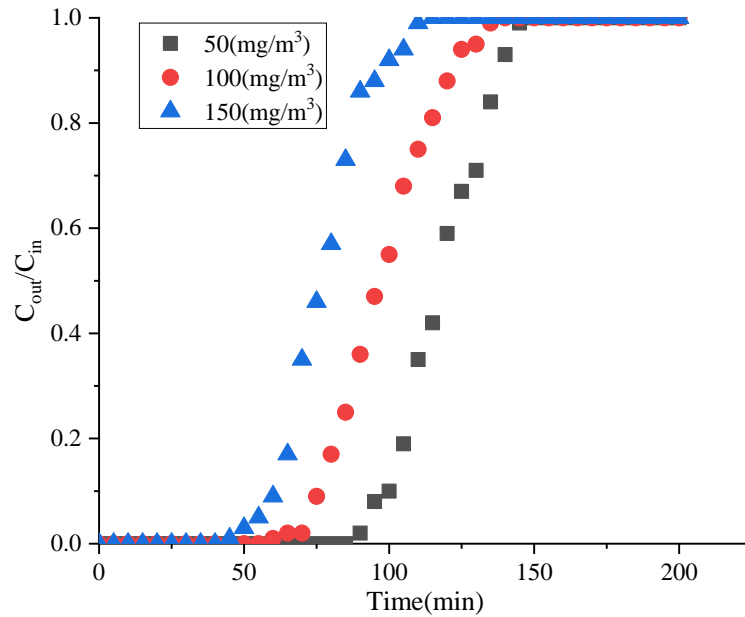


Fig. 2 Penetration curves of TVOC at different concentrations

From Fig. 2, it can be seen that as the TVOC gas concentration increases, the penetration time of rGO composite filter material continuously shortens. At a concentration of 50 mg/m³, the penetration time is about 93 min, at a concentration of 100 mg/m³, the penetration time is about 72 min, and at a concentration of 150 mg/m³, the penetration time is about 55 min. When the TVOC gas concentration increased from 50 mg/m³ to 150 mg/m³, the penetration time was shortened by 40.9%. This is because, while the adsorption sites remain unchanged, increasing the gas concentration provides more adsorbate molecules, increases the collision probability between gas molecules and adsorption sites [31], and the adsorption sites are quickly occupied, making the adsorption process easier to occur.

It can also be seen from the graph that as the TVOC gas concentration increases, the penetration curve becomes steeper, that is, the time of the penetration process is shortened. Like non-woven fabrics, rGO composite filter materials also rely on van der Waals forces [31], but have a relatively high specific surface area, slightly improving their adsorption capacity for TVOC. In addition, although rGO composite filter materials are reduced by reducing agents during the preparation process, functional groups such as carboxyl, hydroxyl, and epoxy groups in graphene oxide can be difficult to completely reduce [34]. During the adsorption process, there is also a small amount of chemical adsorption of TVOC by functional groups containing oxidation. As the concentration of TVOC increases, the internal adsorption sites gradually become occupied by TVOC molecules. The adsorption of TVOC by the new reduced graphene oxide air filter material shifts from single layer adsorption to multi-layer adsorption, reducing its attraction to TVOC molecules and slowing down the increase in adsorption capacity of the material. This is consistent with the results given in the literature [34], verifying the correctness of this paper. When the TVOC concentration is too high, it may cause the adsorption sites to be quickly occupied, and the adsorbent will quickly reach saturation. At this time, continuing to increase the concentration will no longer have a significant effect on improving the adsorption capacity. As a whole, it can be seen that the rGO composite filter material, due to its unique structure and synergistic composition, has a high specific surface area and abundant active sites, providing more adsorption space for TVOC molecules and further enhancing their adsorption performance. In addition, rGO composite filter material has good electronic conductivity, which accelerates the electron transfer during the adsorption process, allowing adsorbate molecules to interact with the adsorbent surface more quickly, thereby improving the adsorption rate.

3.2. Influence of different airflow velocities on adsorption performance

The initial concentration of TVOC is 100 mg/m^3 , and the experimental environment temperature is maintained at $25 \text{ }^\circ\text{C}$. The adsorption performance of rGO composite filter material for TVOC under different airflow velocities is shown in Fig. 3.

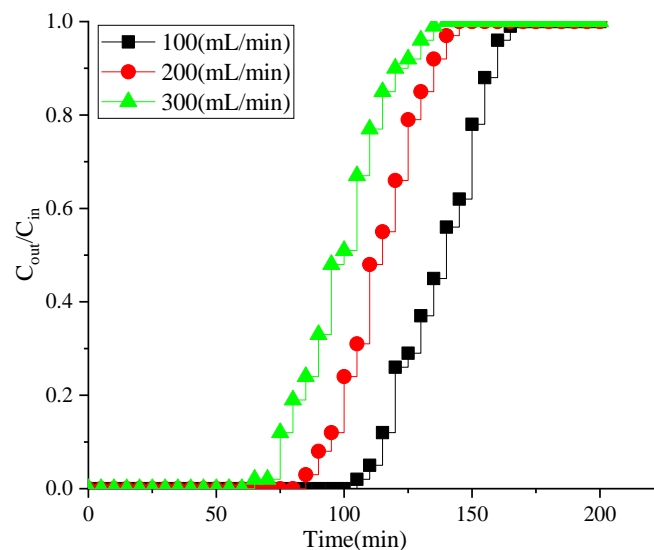


Fig. 3 TVOC penetration curves at different airflow velocities

From Fig. 3, it can be seen that as the airflow velocity increases, the penetration time of rGO composite filter material continuously shortens. At a airflow velocity of 100 mL/min, the penetration time is about 110 min, at a airflow velocity of 200 mL/min, the penetration time is about 87 min, and at a airflow velocity of 300 mL/min, the penetration time is about 73 min. When the TVOC gas flow rate increased from 100 mL/min to 300 mL/min, the penetration time was shortened by 33.6%. The main reason is that increasing the airflow velocity leads to an increase in TVOC molecules flowing through the rGO composite filter material per unit time. With the same total number of adsorption sites, the adsorption penetration time is shortened. And increasing the airflow velocity will also increase the tangential scouring force on the rGO composite filter material [35]. The interaction force between TVOC molecules and rGO composite filter material is weak [31], causing TVOC molecules that have been adsorbed by rGO composite filter material to be brought back into the gas flow, which will also shorten the penetration time and reduce the adsorption performance. Therefore, within a certain range, an increase in airflow velocity can improve mass transfer rate, allowing adsorbate molecules to reach the adsorbent surface faster, thereby accelerating adsorption rate. But when the airflow velocity is too high, the residence time of adsorbate molecules on the adsorbent surface is too short, and they are not fully adsorbed before being carried out of the adsorption column, resulting in a decrease in adsorption rate. It is necessary to control the airflow velocity range reasonably.

3.3. Influence of different temperatures on adsorption performance

The adsorption performance of the new rGO composite filter material for TVOC under different temperature conditions is shown in Fig. 4.

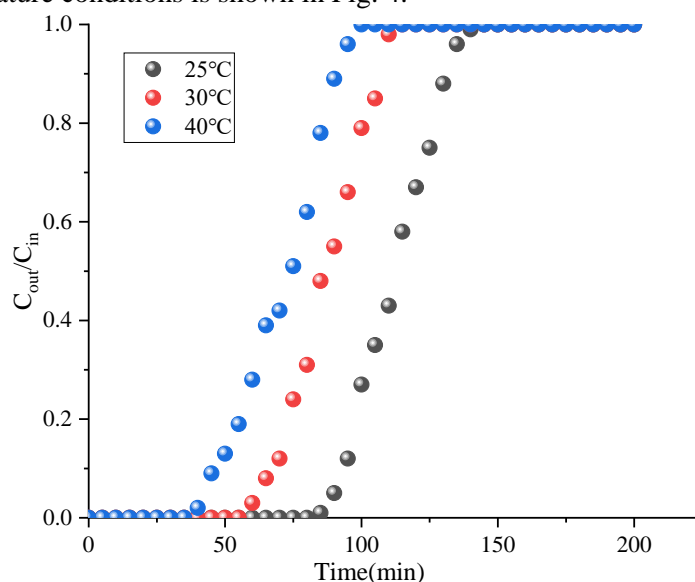


Fig. 4 TVOC penetration curves at different temperatures

From Fig. 4, it can be seen that as the temperature increases, the penetration time of rGO composite filter material decreases. At a temperature of 25 °C, the penetration time is about 90 min, at a temperature of 30 °C, the penetration time is about 62 min, and at a temperature of 40 °C, the penetration time is about 42 min. When the TVOC gas temperature increased from 25 °C to 40 °C, the penetration time was reduced by 53.3%. This indicates that

temperature has a significant impact on the adsorption process, and lower temperatures are beneficial for improving the adsorption performance of rGO composite filter materials for TVOC. This is because the adsorption process is usually exothermic, and an increase in temperature will intensify the thermal motion of the adsorbate molecules, thereby weakening the interaction force between the adsorbent and the adsorbate, resulting in a decrease in adsorption capacity. In actual life, the indoor temperature is generally between 16 °C and 28 °C [36]. Therefore, the release of gas pollutants from indoor pollution sources is a relatively long process, which may even take decades to several decades. For adsorption materials, whether they have reusable properties becomes even more important.

3.4. Influence of different humidity on adsorption performance

The adsorption performance of the new rGO composite filter material for TVOC under different humidity conditions is shown in Fig. 5.

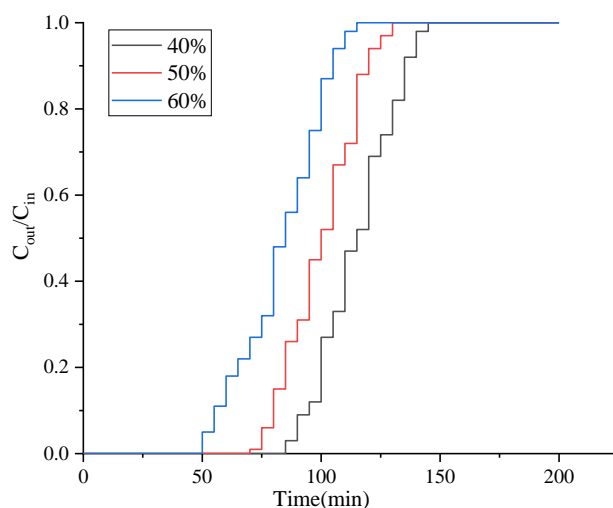


Fig. 5 TVOC penetration curves under different humidity conditions

From Fig. 5, it can be seen that as humidity increases, the penetration time of rGO composite filter material decreases. At a humidity of 40%, the penetration time is about 93 min, at a humidity of 50%, the penetration time is about 78 min, and at a humidity of 60%, the penetration time is about 55 min. When the humidity of TVOC gas increased from 40% to 60%, the penetration time was shortened by 40.9%. This is because when the humidity is low, micropores smaller than 0.3 nm will be blocked by capillary action. As the humidity gradually increases, some water molecules will condense in larger pores, and these water molecules will also absorb TVOC molecules [37]. This indicates that humidity has a significant inhibitory effect on the TVOC adsorption performance of rGO composite filter materials. In addition, in high humidity environments, water molecules compete with TVOC molecules for adsorption sites, and water molecules have strong polarity, making them more easily adsorbed on the material surface, occupying the active sites that could have been used to adsorb formaldehyde, thereby reducing the adsorption capacity for TVOC. The adsorption of water molecules on the surface of materials may alter their surface properties, affecting their interactions with TVOC molecules and further inhibiting the adsorption process. Therefore, the adsorption capacity of rGO composite filter material for TVOC will significantly decrease.

3.5. Influence of desorption methods on adsorption performance

Under the conditions of initial TVOC concentration of 100 mg/m³, airflow velocity of 200 mL/min, temperature of 25 °C, and humidity of 40%, the desorption efficiency of the new rGO composite filter material under different desorption methods is shown in Fig. 6.

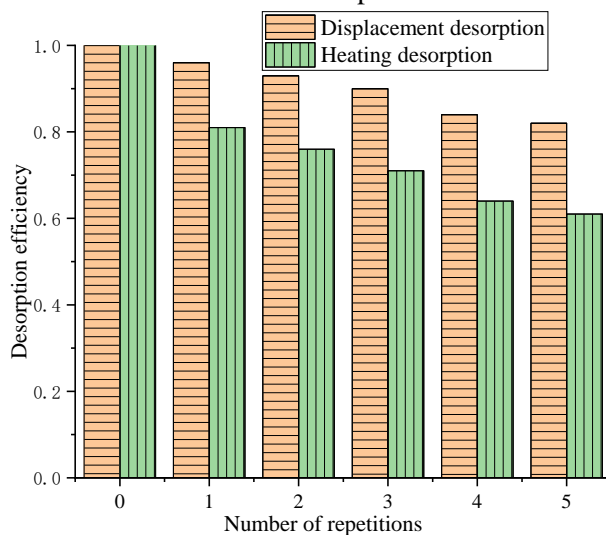


Fig. 6 Desorption efficiency under different desorption methods

As shown in Fig. 6, both displacement desorption and heating desorption cannot achieve initial efficiency level (100% desorption), but displacement desorption has a higher desorption rate and better desorption effect. The displacement desorption efficiency of the new rGO composite filter material can reach 82.3%, while after five heating desorption cycles, the desorption efficiency of the material is only 61.2%, which is 25.6% higher than the heating desorption efficiency. This is due to the complex internal structure and high porosity of the new rGO composite filter material. Even with an increase in temperature, the TVOC adsorbed by the micropores inside the material is difficult to desorb. When using displacement desorption, both the inner and outer surfaces of the material can fully contact deionized water, making it easier for TVOC molecules to be absorbed by water molecules. Additionally, there is a drying step after soaking, which is more conducive to TVOC desorption.

In addition, although chemical adsorption is irreversible, displacement desorption can still achieve good desorption effect, further proving that the adsorption of TVOC by the new rGO composite filter material mainly relies on its large specific surface area and high porosity for physical adsorption of TVOC [31]. The residual small amount of oxygen-containing functional groups on the material can improve the responsiveness of the material to TVOC, which is beneficial for the adsorption of TVOC by the new rGO composite filter material in high-temperature environments, but will not significantly reduce the desorption efficiency of the material. The reduction process greatly improves the stability of the material, and the structure of the material will not be damaged during displacement desorption, making it highly reusable. In terms of stability, the new rGO composite filter material still exhibits good cycling stability after 5 adsorption desorption cycles. This is because rGO forms stable chemical bonds and tight interface bonding with other materials, effectively suppressing structural changes and loss of active sites during cycling [38].

This study investigates the performance of a new rGO composite filter material for TVOC adsorption, providing a feasible technical path for the development of high-performance adsorption materials. It has broad application prospects in industrial waste gas treatment and indoor air purification, and has positive implications for environmental protection and sustainable development. However, there are still limitations in the research, and there is a gap between experimental conditions and actual complex working conditions. There is insufficient exploration of material service life and long-term stability, and research on cost control and large-scale production processes is relatively shallow. Future research needs to focus on the performance laws and influencing mechanisms under complex working conditions, optimize material composition and structure, improve specific TVOC adsorption selectivity, develop efficient regeneration technologies and extend their service life, while optimizing preparation processes and reducing costs to promote industrialization. The feasibility of materials also needs to be verified through practical engineering applications.

4. Conclusion

This paper conducts adsorption experiments on TVOC in commonly used paints using a new type of rGO composite filter material. The adsorption performance and desorption performance are studied under different conditions such as temperature, humidity, airflow velocity, and initial concentration. Preliminary conclusions have been drawn as follows:

1. With the increase of TVOC gas concentration, the penetration time of rGO composite filter material continues to shorten. When the TVOC gas concentration is from 50 mg/m³ to 150 mg/m³, the penetration time is shortened by 40.9%.

2. As the airflow velocity increases, the penetration time of rGO composite filter material continuously shortens. When the TVOC airflow velocity increases from 100 mL/min to 300 mL/min, the penetration time shortens by 33.6%.

3. As the temperature increases, the penetration time of rGO composite filter material decreases. When the TVOC gas temperature increased from 25 °C to 40 °C, the penetration time was reduced by 53.3%.

4. As humidity increases, the penetration time of rGO composite filter material decreases. When the humidity of TVOC gas increased from 40% to 60%, the penetration time was shortened by 40.9%.

5. Neither displacement desorption nor temperature induced desorption can achieve 100% desorption. The displacement desorption efficiency of the new rGO composite filter material can reach 82.3%, while after five heating desorption cycles, the desorption efficiency of the material is only 61.2%, which is 25.6% higher than the heating desorption efficiency.

Acknowledgment

This study was supported by the Shaanxi Provincial Department of Education Service Local Special Plan Project (No. 24JC050), the National Natural Science Foundation of China (Grant No.52578116), the Zhejiang Provincial Natural Science Foundation of China under Grant No. ZCLQN26E0801, and the Scientific Research Fund of Zhejiang Provincial Education Department under Grant No. Y202559062.

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Paper submitted: 22.11.2025

Paper revised: 01.02.2026

Paper accepted: 10.02.2026