

Article

The Emission Characteristics of Pollutants from Thermal Desorption of Soil Contaminated by Transformer Oil

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Abstract: In order to reduce pollutant emission from substation fires into the soil environment, developing technology to remove pollutants in soil after substation fires is necessary. Among the soil remediation technologies, thermal desorption has been proven to be an effective soil remediation method. In this paper, the effects of thermal desorption temperature and atmosphere on the releasing characteristics of pollutants in the soil polluted by waste oil in the accident oil pool in the substation were examined. The results showed that when the thermal desorption temperature was 500 °C, a large number of macromolecular organics decompose from the solid phase and change into long-chain alkanes and macromolecular acids under pure N₂ atmosphere. When the thermal desorption temperature was higher than 500 °C the pollutants in the soil were further decomposed into small molecular organics. In addition, the organics were transformed to CO₂, SO₂, NO_x, and CO under 20% O₂/N₂ atmosphere when the temperature was above 500 °C.

Keywords: substation fire in electrical equipment; transformer oil; contaminated soil; thermal desorption; pollutants emission



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1. Introduction

With the rapid development of economy and society, electricity has become an indispensable part in the whole world. As an essential central link of power transmission system, substation plays a bridge role in power transmission. Due to the large number of substations, electrical equipment fire accidents occur occasionally [1,2]. After the fire of electrical equipment in the substation, besides the property losses, the residues after fire will pollute the water, air, and soil around the substation [1,3]. As for the fire of substation electrical equipment, it is mainly focusing on fire prevention and risk assessment recently. During the burning of substation electrical equipment, transformer oil leakage will cause soil pollution around the substation, but there is no relevant research reports on the treatment of this kind of soil residual pollutants. In other research fields, such as the remediation of chemical sites or petroleum hydrocarbon contaminated soil, thermal desorption technology is widely used and has been proved to be an effective way to remove organic pollutants in soil [4–6]. The main component of transformer oil is hydrocarbons, of which more than 80% is cycloalkanes [7]. Therefore, the introduction of thermal desorption technology into the treatment and remediation of waste mineral oil contaminated soil after substation electrical equipment fire is of great potential for application.

Since 1980, researches in developed countries, such as Europe and the United States, have carried out soil remediation research based on thermal desorption technology to remediate soil polluted by benzene series, petroleum hydrocarbons, and polychlorinated biphenyls [8–10]. In 1989, Lighty et al. [11] firstly studied the thermal desorption rate of pollutants from soil and established a large-scale model to predict the releasing characteristics of pollutants in the process of thermal desorption, which laid a foundation for the practical application of this technology. At present, the thermal desorption technology was more developed in engineering application [12]. Due to the increasing demand for

practical application, the researches on thermal desorption technology in China have entered a rapid development stage since 2010 [13–15]. In 2011, Wang et al. [16] reported the effects of pollutants content and soil particle size on the thermal desorption remediation of dichloro-diphenyl-trichloroethane (DDTs) contaminated soil. The results indicated that there was little difference in the thermal desorption efficiency between different pollution levels in soils. In 2013, Xia et al. [17] firstly applied the thermal desorption technology to the study of polycyclic aromatic hydrocarbons in coking soil (polyaromatic hydrocarbons, PAHs) desorption, and obtained the thermal desorption characteristics of different kinds of PAHs in coking soil. In 2018, Gou et al. [18] investigated the effects of system parameters of thermal desorption method on the remediation of polycyclic aromatic hydrocarbons and mercury contaminated soil, finding that increasing the temperature and holding time were benefit for the removal of polycyclic aromatic hydrocarbons and mercury, especially on the desorption efficiency of high polycyclic aromatic hydrocarbons. Gao et al. [19] carried out research on thermal desorption technology of organic contaminated soil and analyzed the characteristics of different types of thermal desorption technology. Zhao et al. [20] carried out the thermal desorption experiment of electric heating rotary kiln at 500 °C with the heating time of 10 min, discovering that the total PAHs removal rate was 98.94%, and the thermal desorption effect was particularly prominent. Lee et al. [21] studied the effects of melting heat desorption treatment temperature and heating time on pollutant removal efficiency of diesel contaminated soil and found it was available. Niu et al. [22] also used thermal desorption technology to repair oil contaminated soil, and analyzed the main influencing factors on thermal desorption, the removal effect of petroleum hydrocarbon components and pyrolysis oil components.

Above researches clarified that the thermal desorption method could better remove the hydrocarbon organic pollutants in soil, meaning that the method may also achieve better pollutant removal effects for the polluted soil caused by transformer oil leakage after the electrical equipment fire in the substation. However, there is still a lack of relevant reports. Based on the above, taking the transformer oil contaminated soil in the substation as a sample, this paper carried out the effects of thermal desorption temperature and different atmosphere on the releasing characteristics of pollutants in the soil, so as to provide a theoretical basis for the development of soil pollutant degradation technology after substation electrical equipment fire.

2. Experimental

2.1. Material Preparation

In order to explore the thermal desorption characteristics of soil contaminated transformer leakage oil after substation fire, the thermal desorption experiment of simulated soil contaminated by transformer oil was carried out under laboratory conditions. The soil was obtained from a substation in Quanzhou City at Fujian Province and the oil was taken from the waste oil in the accident oil pool of the same substation after a fire. The PH of the waste oil was tested by PH meter (PHSJ-3F, Yueming, China). In addition, the transformer oil used in the substation is Karamay 25 transformer oil [2]. The experimental material was prepared by the mix of soil and oil. Firstly, drying the original soil in a blast drying oven at 45 °C for 12 h, removing external water, and then grinding to 80 mesh. At this stage, to clarify the properties of original soil, the PH and particle size of the soil were also analyzed. The PH of the soil was tested by PH meter (PHSJ-3F, Yueming, China) and the particle size was detected by laser particle analyzer (Mastersizer 3000, Malvern Panalytical, England). Secondly, mixing the oil and soil with the ratio of 1 mL, 2 mL, and 3 mL waste oil and 25 g soil in a teflon tube, respectively, and then oscillating the mixture in centrifuge for 24 h. Thirdly, the mixed simulated polluted soil is dried in a blast drying oven at 105 °C for 4 h. At this temperature, the water in the soil will evaporate, but the oily organic matter in the soil will not decompose. After drying, 80 mesh sieve was used to obtain simulated polluted soil samples contaminated oil, which were recorded as A1, A2, and A3, respectively.

2.2. Experimental System

Figure 1 is the thermal desorption experimental system. The system is composed of gas distribution device, reacting device and tail gas collection device. The gas distribution device is composed of N₂ and O₂ gas cylinder and mass flowmeter, which can provide necessary N₂ and O₂ during the thermal desorption experiment. The reacting device consists of a vertical tubular furnace with a quartz tube reactor, and the reaction temperature in the furnace is accurately controlled through the temperature control system. A quartz tube reactor with the internal diameter of 50 mm is placed in the tubular furnace. The experimental sample placed on a quartz basket is located in the middle of the reactor. During the thermal desorption experiment, the tail gas is collected by an aluminum foil bag and sent to gas analyzer for detection.

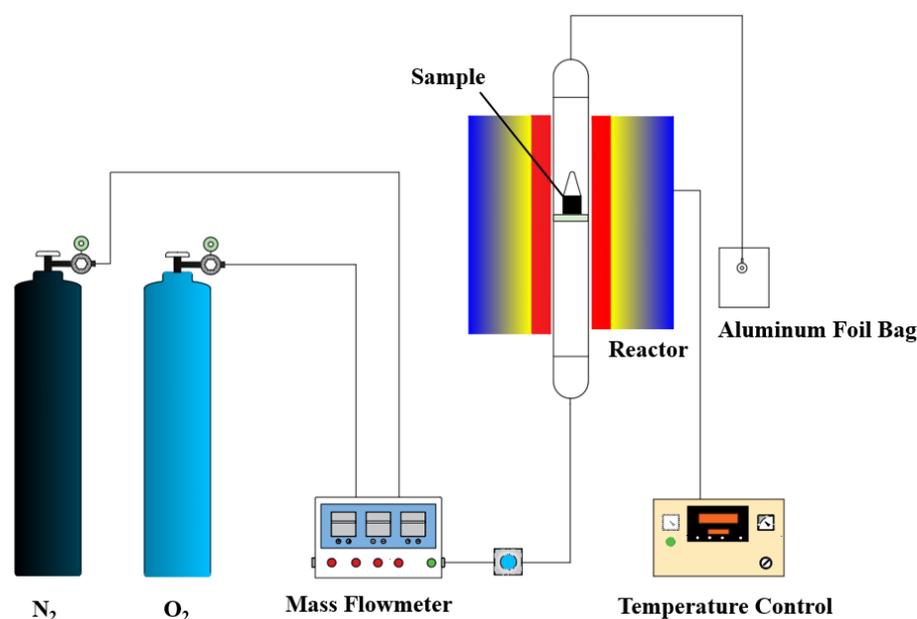


Figure 1. The thermal desorption experimental system.

In order to get the releasing characteristics of gaseous pollutants in the simulated polluted soil thermal desorption experiments under different temperatures, the organic and inorganic components in tail gas were both analyzed. Among them, gas chromatography-mass spectrometry (GC-MS, GCMS-QP2010 Plus, Shimadzu Company, Kyoto, Japan) is used to determine the organic gas components in the tail gas. The chromatographic column is SH-Rxi-5Sil MS, and the carrier gas used in the analysis is Ar. As for the inorganic gas components in the tail gas, a type of PG350 flue gas analyzer (Horiba, Kyoto, Japan) which can analyze SO₂, NO_x, and CO is adopted. Small molecular hydrocarbons (C_mH_n) in the tail gas is detected by a type of gas analyzer (Gasboard-3100P, Cubic Ruiyi, China).

2.3. Experimental Conditions

The thermal desorption temperatures were set as 300 °C, 400 °C, 500 °C, 600 °C, and 700 °C, respectively. The experimental atmosphere was pure N₂ and 21% O₂/N₂ and the gas flow rate was 0.5 L/min. The mass of simulated polluted soil used in each test was 1.0 g, and the thermal desorption time was 10 min. In each experiment, firstly raising the reacting device to the target temperature, then placing the sample in the middle of the quartz tube. After that, immediately collecting the tail flue gas with tail gas collection device. Each test is repeated three times to ensure the accuracy of the experiment. At the beginning of the experiment under each experimental condition, the thermal desorption of the soil without the waste was also studied. The results showed that no organic and inorganic gas components were found at different temperatures and atmospheres. Therefore, the organic

and inorganic components detected after the thermal desorption experiments on A1, A2, and A3 were caused by the thermal decomposition of organic components in the waste oil.

3. Results and Discussion

3.1. Composition Analysis of Waste Oil

Before the experiment, the composition of waste oil and original soil were clarified. The PH of waste oil and the waste oil and original soil were 7.2 and 4.1, respectively. Moreover, the particle size distribution of the original soil was shown in Figure 2. Since the original soil was dried and grinded to 80 mesh, over 90% of the soil was with the particle size of 5–200 μm , which was benefit for the simulated contaminated soil preparation.

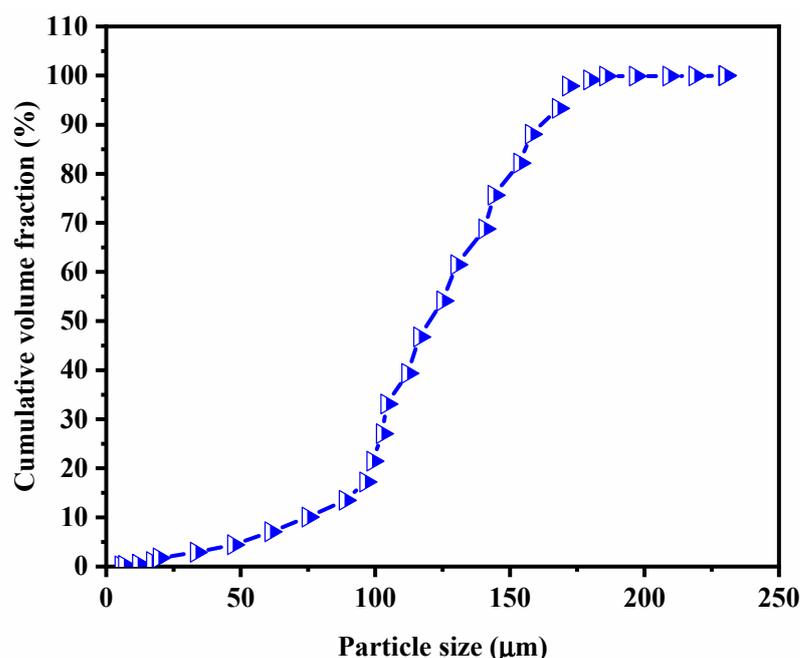


Figure 2. Particle size distribution of the original soil.

In addition, the composition of waste oil in the accident oil pool of the substation was analyzed by GC-MS. Since GCMS-QP2010 Plus can only conduct qualitative and quantitative analysis of gaseous organic matter, it is necessary to extract the liquid sample first [23]. In this test, the extraction diluent was dichloromethane, and the dilution ratio was 100 times. The composition of waste oil was listed in Table 1. It showed that the organic components in the waste oil were complex. Alkanes, olefins, aldehydes, ketones, and esters were all existed in the waste oil. More than 50 kinds of substances were detected, including pentadecane, 2,6,10,14-tetramethyl, hexadecane 2,6,10,14-tetramethyl, butylated hydroxy-toluene, 3,7,11,15-tetramethylhexadecyl-2-en-1-yl acetate, and 2-methyltetrahydrofurane, suggesting that the main component of waste oil was long-chain alkanes. After the fire, the unburned waste oil was easily to mix into the soil. Therefore, using the waste oil mixed soil to simulate the polluted soil after the substation fire was representative.

3.2. Releasing Characteristics of Macromolecular Organic Gas Components

The macromolecular organic gas components were analyzed by GC-MS. According to the detected results, only the peak of carrier gas Ar was observed in both 21% O_2/N_2 and pure N_2 atmosphere at 300 $^\circ\text{C}$ and 400 $^\circ\text{C}$. Only this phenomenon was observed in repeated experiments. No organic macromolecular pollutants were released in various simulated polluted soils. The possible reason was that the temperature of 300 $^\circ\text{C}$ and 400 $^\circ\text{C}$ was not reaching the decomposition temperature of organic pollutants in the soil, indicating that higher temperature was needed to desorb the organic pollutants in the simulated polluted soil.

Table 1. The composition of waste oil in the accident oil pool of substation.

Retention Time/s	Peak Area Ratio/%	Substance	Retention Time/s	Peak Area Ratio/%	Substance
20.620	1.31	Phytol	27.315	1.92	3,7,11,15-Tetramethyl-2-hexadecen-1-ol
21.570	0.64	Pentadecane	27.470	1.84	9-Octadecen-1-ol
21.870	5.07	Butylated Hydroxytoluene	27.635	0.89	1,1'-Bicyclooctyl
22.465	0.65	1H-Indene, 5-butyl-6-hexyloctahydro-	27.740	0.60	Cholestan-3-one, (5.alpha.)
22.740	1.08	1H-Indene, 5-decyloctahydro-	27.980	1.06	1,1':3',1''-Tercyclopentane, 2'-dodecyl
23.015	1.34	(+)-(Z)-Longipinane	28.110	1.47	1H-Indene, 5-decyloctahydro-
23.960	1.16	Hexadecane	28.365	1.95	Octadecane
24.140	0.66	2,10-Dodecadien-1-ol, 3,7,11-trimethyl-, (Z)-	28.555	6.44	Hexadecane, 2,6,10,14-tetramethyl-
24.940	0.75	[1,1'-Bicyclohexyl]-4-carboxylic acid, 4'-pentyl-, 4-pentylphenyl ester	29.030	0.82	1H-Naphthalen-2-one, 3,4,5,6,7,8-hexahydro-4a,8a-dimethyl-
25.095	2.36	Pentadecane, 2,6,10-trimethyl-	29.255	0.63	Undec-10-ynoic acid, pentadecyl ester
25.390	1.49	Cyclohexane, 1,3-didecyl-	29.895	1.92	18-Norabietane
25.520	4.23	1-Hexadecanol, 3,7,11,15-tetramethyl-	30.240	4.72	3,7,11,15-Tetramethylhexadec-2-en-1-yl acetate
25.660	1.60	Undec-10-ynoic acid, tetradecyl ester 1,2,5,5,6,7-	30.380	4.35	2-Methyltetracosane
25.925	1.40	Hexamethylbicyclo[4.1.0]hept-2-en-4-one	30.605	0.62	Neophytadiene
25.995	0.94	Oleyl alcohol, trifluoroacetate	30.805	1.86	Bicyclo[2.2.2]octane, 1,2,3,6-tetramethyl-
26.235	3.49	Heptadecane	30.915	1.96	1-Pentacosanol
26.370	7.60	Pentadecane, 2,6,10,14-tetramethyl-	31.080	3.73	3-Eicosyne
26.505	2.37	Oxalic acid, cyclohexylmethyl tridecyl ester	31.165	1.63	1,3-Benzodioxin-4-one,4a,5-dimethylperhydro-2-(1,1-dimethylethyl)
26.635	1.98	Cyclopentane, 1,1'-[3-(2-cyclopentylethylidene)-1,5-pentanediy]bis-	31.240	1.04	Androstane
26.760	1.20	Cyclohexane, 1-(cyclohexylmethyl)-2-ethyl-, trans-	31.670	0.85	Cyclohexene, 1-pentyl-4-(4-propylcyclohexyl)-
26.865	3.27	Acetic acid, 3,7,11,15-tetramethyl-hexadecyl ester	32.300	2.69	2-Methylhexacosane
26.940	1.46	3-Methyl-5-(1,4,4-trimethylcyclohex-2-enyl)pentan-1-ol	32.570	1.04	Cyclohexane, [2-[(2-ethylhexyl)oxy]ethyl]-
26.990	1.19	Acetic acid, 3,7,11,15-tetramethyl-hexadecyl ester	32.670	3.79	15-Isobutyl-(13.alpha.H)-isocopalane
27.090	1.69	Bicyclo[10.4.0]hexadecane, 14,15-diethyl-	32.900	1.01	1H-Indene, 2-butyl-5-hexyloctahydro-
27.180	0.97	Tetradecane, 2,6,10-trimethyl-	34.095	1.29	2-Methyltetracosane

When the thermal desorption temperature was 500 °C, a small amount of organic components are detected by GC-MS analyzer in pure N₂ atmosphere. However, macromolecular organic pollutants were still not detected under 21% O₂/N₂ atmosphere. It suggested that the organic pollutants in various simulated polluted soils were beginning to decompose at 500 °C [24], but in 21% O₂/N₂ atmosphere, due to the existence of O₂, the decomposed gaseous organic components were burned into inorganic components.

Figure 3 listed the macromolecular organic gas components emission from simulated polluted soil during thermal decomposition under N₂ atmosphere at 500 °C. It suggested that the waste oil in the simulated polluted soils began to release in the form of macromolec-

ular gaseous organic pollutants when the thermal desorption temperature was 500 °C. Among the macromolecular organic gas components, the content of octadecanoic acid ($C_{18}H_{36}O_2$) and palmitic acid ($C_{16}H_{32}O_2$) were relatively higher, especially for $C_{18}H_{36}O_2$, the content accounted for 45.44%, 45.33%, and 46.09% during the thermal desorption of A1, A2, and A3 at 500 °C, respectively. As for $C_{16}H_{32}O_2$, the content was accounted for 41.1%, 37.12%, and 37.12% during the thermal desorption of A1, A2, and A3 at 500 °C. However, the major composition of the released gaseous organic pollutants was quite different from that in the original waste oil, indicating that these substances were decomposed from the macromolecular organic matter in waste oil.

When the thermal desorption temperature reached 600 °C, the kinds of macromolecular gaseous organic components released from the simulated polluted soil were less than that at 500 °C in pure N_2 atmosphere, indicating that the macromolecular organic matter in the simulated polluted soil was further decomposed into small molecular substances as the decomposition temperature increasing. Xia, et. al. [17] also discovered that more than 98.4% organic compounds were decomposed from coking plant soil when the temperature was above 450 °C, indicating that 500 °C was a critical temperature for thermal desorption of soil contaminated by transformer oil in this study.

Figure 4 was the macromolecular organic gas components of different simulated polluted soils thermal decomposed at 600 °C. Compared with the components during thermal desorption at 500 °C, it can be seen that the substances produced by simulated polluted soil decomposed at 600 °C were quite different. The main substances were tricyclic [4.3.1.1 (3,8)] undecane-1-carboxylic acid, 1,2-diphenylcyclopropane, 9-octadecanoic acid, and propylene during the thermal decomposition of A1, A2, and A3 under pure N_2 atmosphere at 600 °C. Moreover, a small amount of methylphenylsulfoxide was detected in the tail gas after the thermal decomposition of A3, indicating that more complex organic compounds were also desorbed from the soil with the increase of desorption temperature and the waste oil contained sulfur components. In addition, the siloxane detected by GC-MS in Figure 4 was provided for the detection system, not for the thermal desorption of organic components in simulated polluted soil. As for the condition of 21% O_2/N_2 at °C, macromolecular gaseous organics were not detected in the tail gas after thermal desorption of various simulated polluted soils, indicating that the gaseous macromolecular organics were completely burned and transformed into gaseous inorganic components as for the existence of O_2 in the experimental condition.

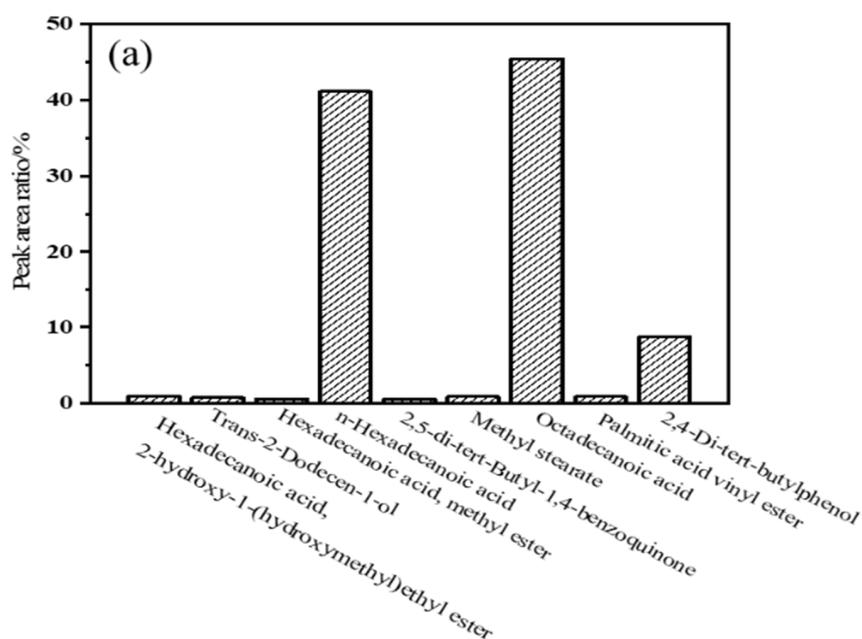


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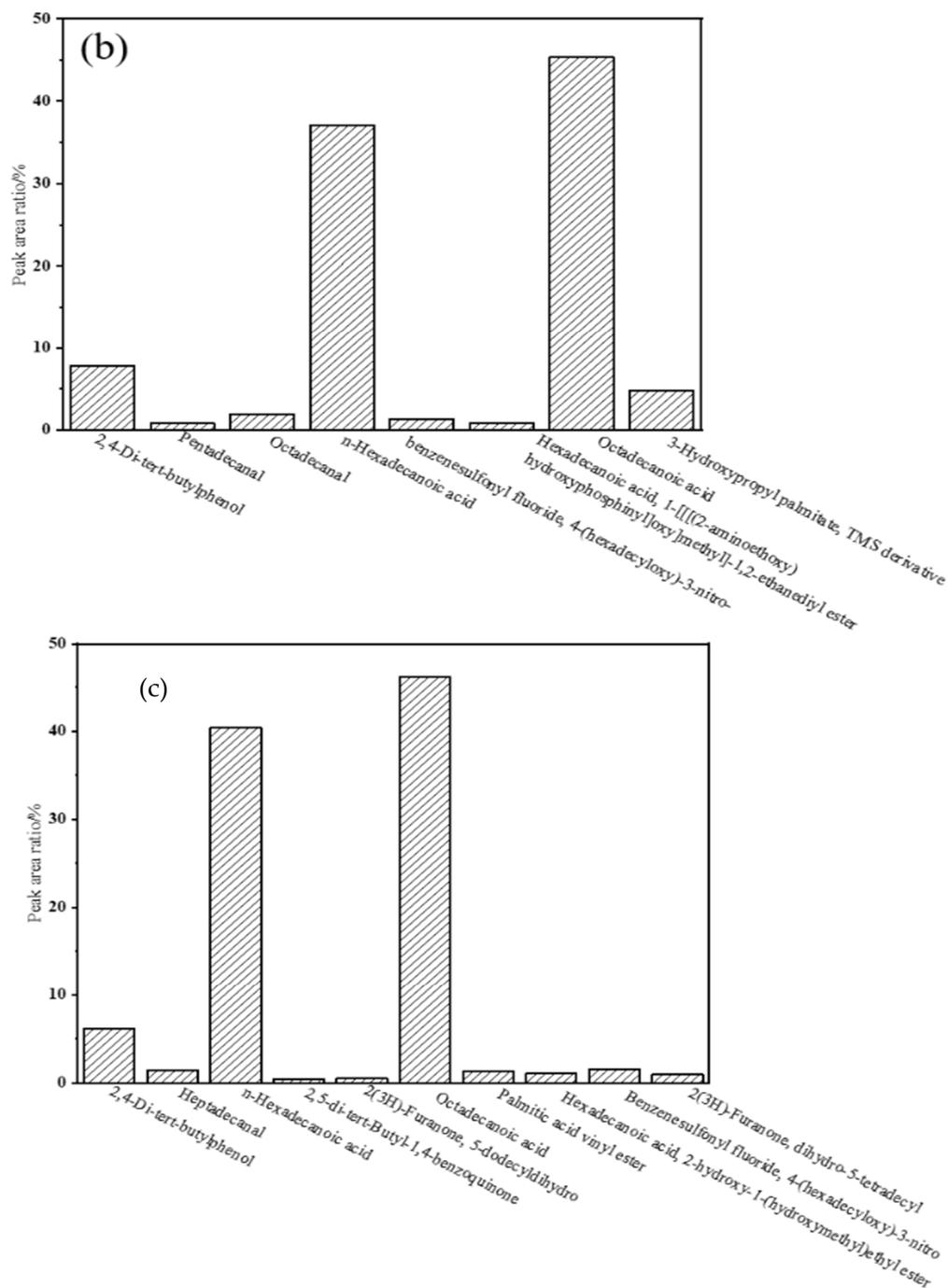


Figure 3. Composition of macromolecular organic gas pollutants during thermal desorption of simulated polluted soils under pure N₂ atmosphere at 500 °C. (a) A1, sample of 1 mL waste oil mixed with 25 g soil; (b) A2, sample of 2 mL waste oil mixed with 25 g soil; (c) A3, sample of 3 mL waste oil mixed with 25 g soil.

When the thermal desorption temperature was 700 °C, no macromolecular organic components were detected in the tail gas of various kinds of simulated polluted soil after thermal desorption whether in pure N₂ or 21% O₂/N₂ atmosphere, suggesting that at 700 °C, the long-chain alkanes in simulated polluted soil was completely decomposed, which was transformed into small molecular organics. Moreover, in the presence of O₂, completely combustion was transformed into inorganic components.

Comparing the results of other researches, it could be found that the main pollutants emission from heavy fuel oil fire were mainly PHAs [2,25], such as naphthalene, aenaphthylene, phenanthrene, etc. while in this study the main pollutants were macromolecular organic matter during the thermal desorption in pure N₂ atmosphere. It may be because that the basis component in transfer oil was long chain polymer organic matter, a large amount of organic matter is released in a short time when a fire occurs, but there is enough time for the oil in contaminated soil decomposing due to the high dispersion of oil in soil.

3.3. Releasing Characteristics of Small Molecule Organic Gas Components

In order to verify that the gaseous macromolecular organic matter was whether further decomposed into small molecular organic pollutants in the process of higher temperature thermal desorption of simulated polluted soils or not, the small molecular alkanes thermally decomposed by simulated polluted soil in pure N₂ atmosphere at 600 °C and 700 °C were analyzed by gas analyzer. As shown in Figure 5, with the thermal desorption temperature increasing, the content of small molecular alkanes (C_mH_n) in tail gas increased, and the maximum content was as high as 1.5%, which was the product of A3 thermal desorption at 700 °C. Moreover, with the increasing of mixed waste oil, the content of C_mH_n gradually increased, proving that with the increase of thermal desorption temperature, the released macromolecular gaseous organic pollutants were further decomposed into small molecular alkanes.

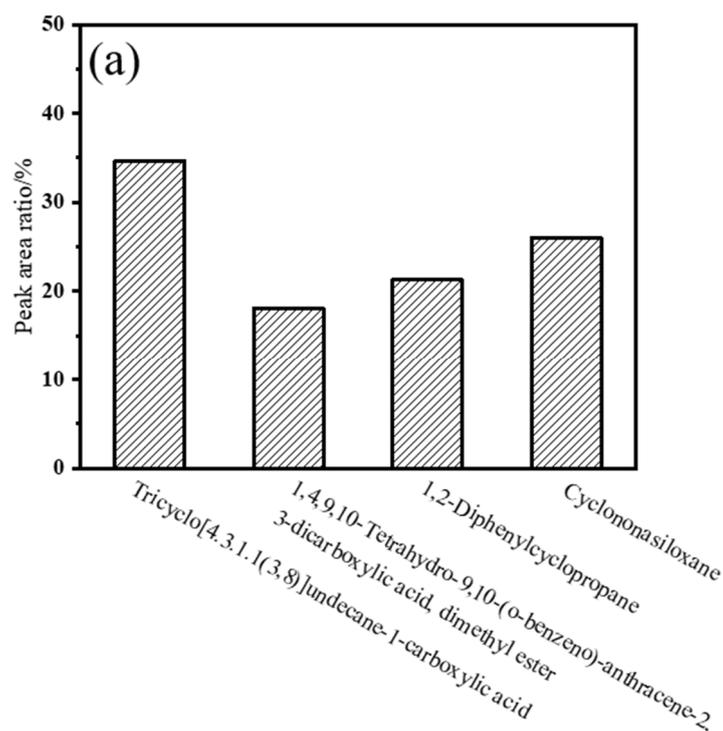


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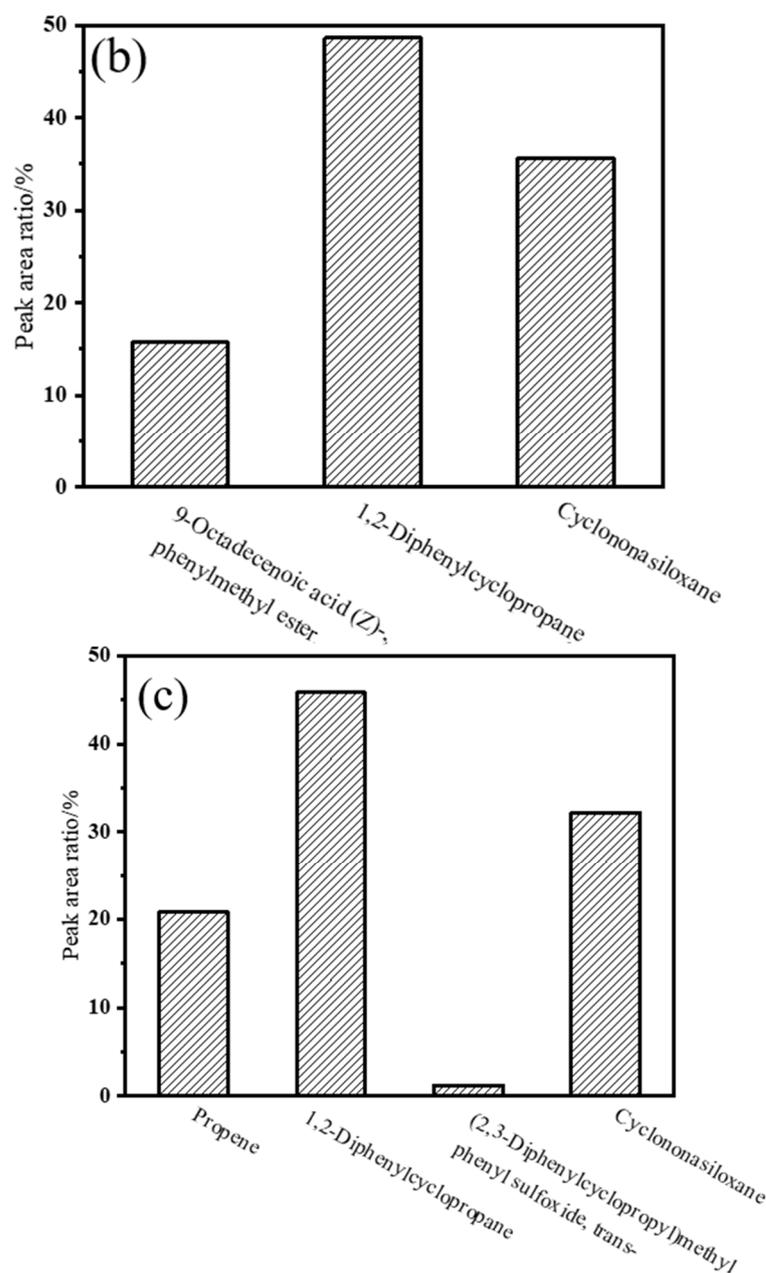


Figure 4. Composition of macromolecular organic gas pollutants during thermal desorption of simulated polluted soils under pure N_2 atmosphere at $600\text{ }^\circ\text{C}$. (a) A1, sample of 1 mL waste oil mixed with 25 g soil; (b) A2, sample of 2 mL waste oil mixed with 25 g soil; (c) A3, sample of 3 mL waste oil mixed with 25 g soil.

3.4. Releasing Characteristics of Inorganic Gas Components

Since macromolecular gaseous organic pollutants were not detected in all tests under 21% O_2/N_2 atmosphere, the contents of NO , SO_2 , CO , and CO_2 in tail gas of various polluted soils thermal decomposed at different temperatures under this atmosphere were analyzed by flue gas analyser [26]. The results were shown in Figures 6–9. As shown in Figure 6, when the temperature was $300\text{ }^\circ\text{C}$ and $400\text{ }^\circ\text{C}$, only a small amount of NO was produced. With the increase of thermal decomposition temperature, the concentration of NO increased and reached the peak at $500\text{ }^\circ\text{C}$. When the temperature was further increasing, the NO content was constant. With the content of waste oil in soil increasing, the concentration of NO in the tail gas gradually increased. Among the all test conditions, the maximum concentration of NO was 95 ppm at $500\text{ }^\circ\text{C}$, indicating that nitrogen-contained or-

ganic pollutants in the simulated polluted soil was completely released at this temperature. Chen et al. [7] also found that NO was produced after different types of transformer oil burning, it was due to the combustion of nitrogen containing substances in the transformer oil, which was consistent with the results of this study.

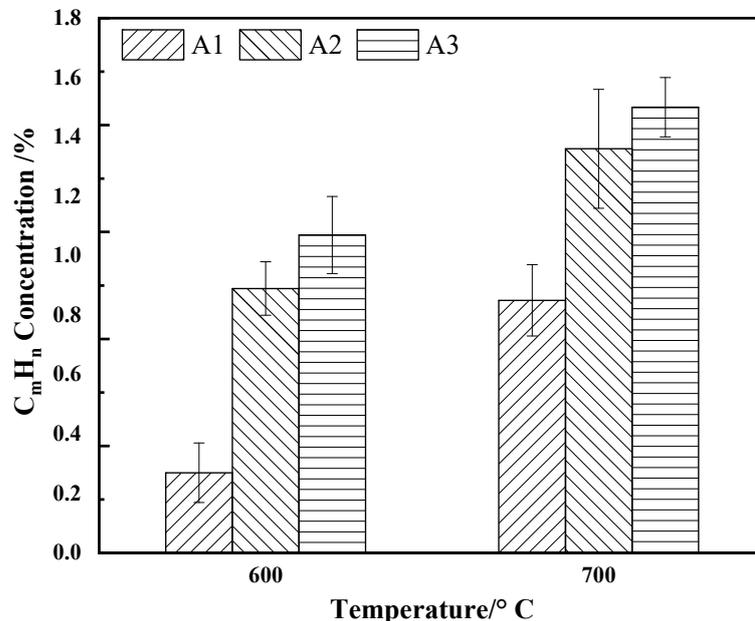


Figure 5. The concentration of small organic gas pollutants (C_mH_n) during thermal desorption of simulated polluted soils under pure N_2 atmosphere at 600 °C and 700 °C. (A1, sample of 1 mL waste oil mixed with 25 g soil; A2, sample of 2 mL waste oil mixed with 25 g soil; A3, sample of 3 mL waste oil mixed with 25 g soil).

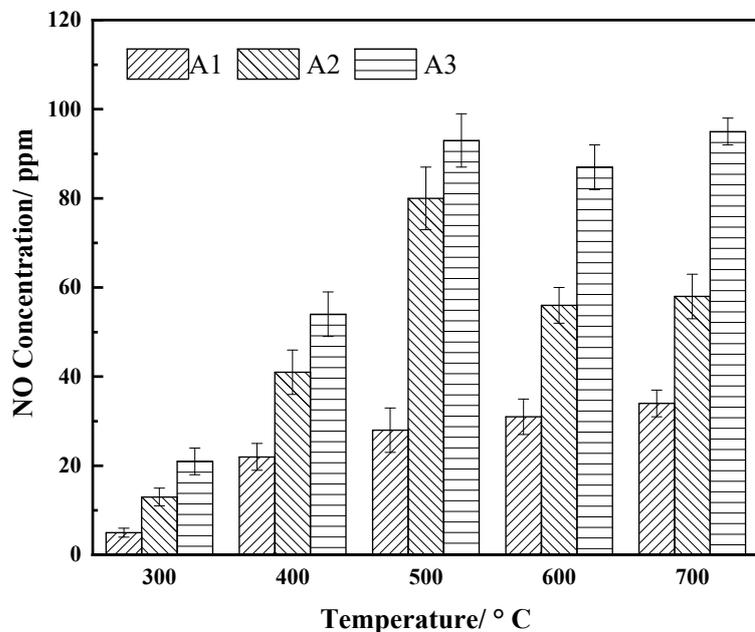


Figure 6. The concentration of NO during thermal desorption of simulated polluted soils under 20% O_2/N_2 atmosphere at different temperatures. (A1, sample of 1 mL waste oil mixed with 25 g soil; A2, sample of 2 mL waste oil mixed with 25 g soil; A3, sample of 3 mL waste oil mixed with 25 g soil).

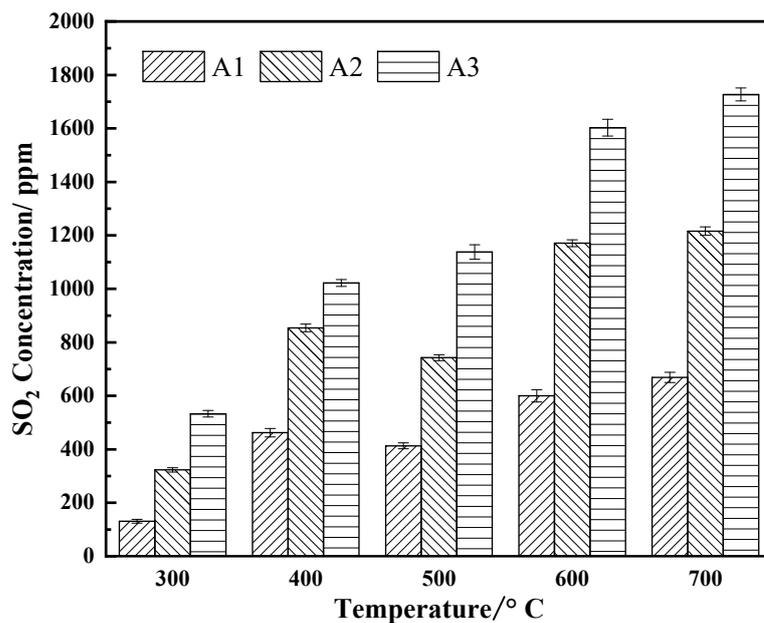


Figure 7. The concentration of SO₂ during thermal desorption of simulated polluted soils under 20% O₂/N₂ atmosphere at different temperatures. (A1, sample of 1 mL waste oil mixed with 25 g soil; A2, sample of 2 mL waste oil mixed with 25 g soil; A3, sample of 3 mL waste oil mixed with 25 g soil).

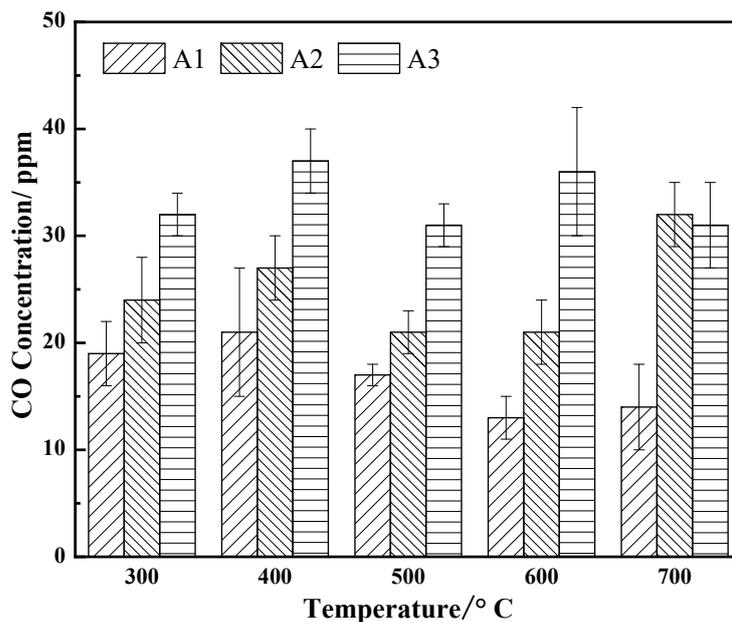


Figure 8. The concentration of CO during thermal desorption of simulated polluted soils under 20% O₂/N₂ atmosphere at different temperatures. (A1, sample of 1 mL waste oil mixed with 25 g soil; A2, sample of 2 mL waste oil mixed with 25 g soil; A3, sample of 3 mL waste oil mixed with 25 g soil).

Figure 7 was the releasing characteristics of SO₂ during different kinds of simulated polluted soils thermal desorption at different temperatures under 21% O₂/N₂. With the increasing of waste oil addition, the content of SO₂ in tail gas was gradually increased. When the temperature was 300 °C, SO₂ started to release, and the concentration of SO₂ in tail gas reached 533 ppm after the sample of A3 thermal decomposed. With the increase of thermal decomposition temperature, the concentration of SO₂ was gradually increased, reaching 1603 ppm at 600 °C and 1727 ppm at 700 °C, indicating that sulfur-contained organic compounds in simulated polluted soil were continuing to decompose after the temperature was above 500 °C, which was unlike the nitrogen-contained organic compounds

in simulated polluted soil. The main reason was that the sulfur-contained components in the waste oil, such as the decomposition and combustion of methylphenyl sulfoxide, begin to burn to generate SO_2 when the thermal decomposition temperature was $300\text{ }^\circ\text{C}$. As the thermal decomposition temperature increased to higher temperature, the decomposition speed of sulfur-contained components was accelerating and more SO_2 was generated in the existence of O_2 . However, the concentration of SO_2 generated at $600\text{ }^\circ\text{C}$ and $700\text{ }^\circ\text{C}$ was the similar, indicating that the decomposition of sulfur-contained components was complete and the best reaction temperature for sulfur releasing was between $600\text{ }^\circ\text{C}$ and $700\text{ }^\circ\text{C}$.

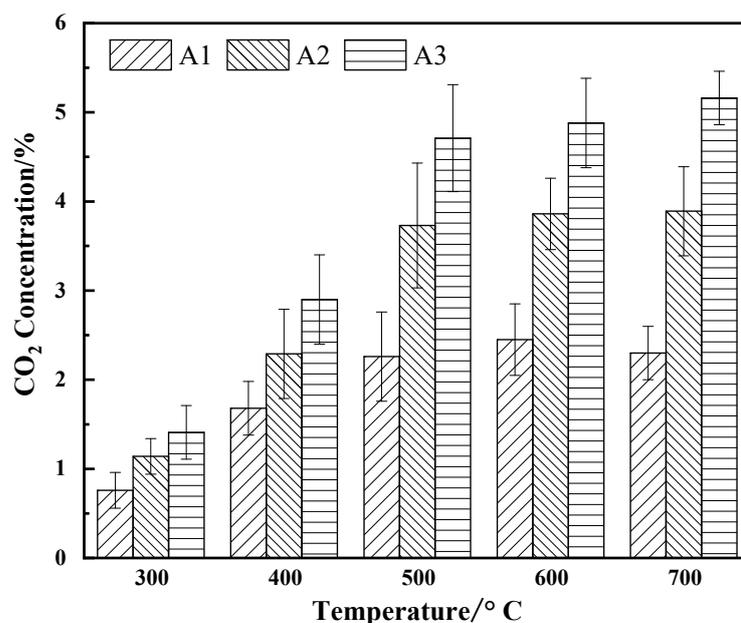


Figure 9. The concentration of CO_2 during thermal desorption of simulated polluted soils under 20% O_2/N_2 atmosphere at different temperatures. (A1, sample of 1 mL waste oil mixed with 25 g soil; A2, sample of 2 mL waste oil mixed with 25 g soil; A3, sample of 3 mL waste oil mixed with 25 g soil).

Figure 8 showed the releasing characteristics of CO after thermal desorption of different kinds of simulated polluted soil at different temperatures under 21% O_2/N_2 . The results suggested that the concentration of CO was relatively low in all experimental conditions, which was lower than 40 ppm, and the regularity was poor, indicating that the organic pollutants released from the soil have been completely burned out in the presence of O_2 at different temperatures. Figure 9 was the releasing characteristics of CO_2 after thermal desorption of different kinds of simulated polluted soils at different temperatures under 21% O_2/N_2 . It suggested that the concentration of CO_2 in tail gas was gradually increased with the increasing of thermal temperature, and the increasing range of CO_2 concentration was decreased after the thermal temperature reached $500\text{ }^\circ\text{C}$, indicating that $500\text{ }^\circ\text{C}$ was the best temperature for thermal desorption of these type of simulated polluted soils. Both Chen et al. [7] and Zhang et al. [27] confirmed that peak CO_2 production rate was much higher than the peak CO production rate during the combustion of transfer oil, suggesting that the carbon in organic tended to transform into CO_2 when enough oxygen was supplied.

4. Conclusions

Through the study of thermal desorption of simulated polluted soil after substation electrical equipment fire, it was found that the decomposition of macromolecular pollutants in soil was less when the thermal desorption temperature was lower than $500\text{ }^\circ\text{C}$. When the thermal desorption temperature was $500\text{ }^\circ\text{C}$, a large number of macromolecular organics decomposed from the solid phase and changed into long-chain alkanes, macromolecular acids, and other substances. Among them, $\text{C}_{18}\text{H}_{36}\text{O}_2$ accounted for 45.44%, 45.33%, and

46.09% of the organic components, thermally desorbed by A1, A2, and A3, respectively. $C_{16}H_{32}O_2$ accounted for 41.1%, 37.12%, and 37.12% of the organic components thermally desorbed by A1, A2, and A3, respectively. When the thermal desorption temperature was 600 °C, the organic macromolecular components in the simulated polluted soil continued to desorb, but the components were less than those at 500 °C, indicating that most organic components in the simulated polluted soil were desorbed at 500 °C. Moreover, when the thermal desorption temperature was higher than 500 °C, the pollutants in the soil were further decomposed into small molecular alkanes (C_mH_n). In addition to gaseous organic pollutants, sulfur-containing and nitrogen-containing substances in the simulated polluted soil generate SO_2 and NO during the thermal desorption process, respectively. Therefore, tail gas adsorption technology needed to be further adopted in the harmless process of gaseous pollutants after the thermal desorption of simulated polluted soil after substation electrical equipment fire.

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