Pollution characteristics and source analysis of carbonaceous components in PM$_{2.5}$ in a typical industrial city

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ABSTRACT

Carbonaceous components are important components of fine atmospheric particulate matter (PM$_{2.5}$) and can affect the local environment, climate, and human health. In this study, online observation data from September 1, 2022, to August 31, 2023, were used to analyze the carbonaceous components, namely, organic carbon (OC) and elemental carbon (EC), in PM$_{2.5}$ in Jincheng, which is a typical industrial city. The OC and EC concentrations and annual average ratio of OC/EC in Jincheng were 5.54 μg m$^{-3}$, 0.98 μg m$^{-3}$, and 5.67, respectively. The concentration change in carbonaceous components shows strong seasonality and daily variation characteristics, and the influence of biomass combustion on carbonaceous components in winter cannot be ignored. OC was divided into primary organic carbon (POC) and secondary organic carbon (SOC) using the minimum R squared (MRS) method, and the highest and lowest amounts of SOC were generated in winter and summer, respectively. However, owing to the photochemical reaction that produces SOC in summer, the SOC/OC ratio was high. The high OC/EC ratio in summer was strongly dependent on the O$_3$ concentration, proving that more SOC was formed through photochemical oxidation in summer, and multi-phase inversion may be the main method of SOC generation in winter. Correlation analysis between the carbonaceous components and gaseous pollutants in Jincheng showed that the carbon components in Jincheng City in autumn and winter were significantly influenced by combustion sources, mainly coal combustion emissions.
and vehicle emissions. Vehicle emissions were the main source of carbon components in Jincheng during summer. The formation of SOC was related to other VOCs emission sources. Our results show that carbon aerosol pollution in typical industrial cities, such as Jincheng, can be further alleviated by strengthening the control of vehicle exhaust emissions, fuel combustion, and biomass combustion.

**Keywords:** Carbonaceous components, Pollution characteristics, SOC estimation, Source analysis, Industrial city.
1 INTRODUCTION

Carbonaceous components are an important part of atmospheric fine particulate matter (PM$_{2.5}$), accounting for approximately 10~70% of PM$_{2.5}$ (Liang et al., 2016), and mainly contain two subcomponents: organic carbon (OC) and elemental carbon (EC). Studies have shown that carbon-containing aerosols affect the radiation balance of the Earth through both direct and indirect radiation forcing (BondBergstrom, 2006). Notably, OC cools the atmosphere by scattering solar and Earth radiation, whereas EC and brown carbon (BrC) accelerate climate warming by absorbing solar radiation (Bond et al., 2013). OC and EC play important roles in the formation of cloud condensation nuclei (Huang et al., 2006), resulting in a higher cloud albedo and stronger monsoon circulation (Bond et al., 2013; Ji et al., 2018). Additionally, an increasing number of studies have shown that the OC and EC concentrations are positively correlated with the mortality of blood vessels and the respiratory system in urban environmental centers (Cao et al., 2012). Therefore, determining OC and EC concentrations is important for studying air pollution, climate change, and human health.

EC mainly originates from the incomplete combustion of fuel and vehicle exhaust emissions, whereas OC can originate from direct source emissions or the conversion of gas to particles containing primary organic carbon (POC) and secondary organic carbon (SOC). POC and EC have similar sources (Wang et al., 2015), and SOC is formed from volatile organic compounds (VOCs) (Chen et al., 2017; Yu, 2011; Zhang et al., 2017).

Owing to the rapid industrialization, significant consumption of fossil and biomass fuels, and
high population and motor vehicle density, China is one of the largest producers of carbonaceous aerosols (Cao et al., 2017). According to a previous study (Ji et al., 2019a), the OC and EC concentrations in the Beijing–Tianjin–Hebei region showed clear temporal and spatial evolution characteristics and their concentrations were higher in the cold season. The concentrations of atmospheric particulate matter, OC, and EC were found to be high in winter and low in summer (Bao, 2017). Simultaneously, SOC was high in autumn and winter owing to the strengthening of emission sources and unfavorable meteorological conditions. Although SOC was low in summer, the SOC/OC ratio was high owing to high temperatures, high humidity, and strong solar radiation. According to a previous study (Xue et al., 2020), carbon pollution was most severe in winter in Handan, and the OC and EC concentrations were significantly higher than those in other seasons. Notably, high concentrations of carbonaceous components in PM$_{2.5}$ were observed in North China Plain (Dao et al., 2022; Ji et al., 2019b; Zhang et al., 2021).

Jincheng is located in the southeast region of Shanxi Province at the intersection of the North China Plain and Loess Plateau. The entire area is surrounded by ridges to form the basin topography. It is a typical industrial city, and the main industries are coal, steel, coal chemicals, and cement. A common feature of these industries is that the emissions of particulate matter are large, and controlling unorganized emissions is difficult. Fine particulate matter pollution is frequent and affected by the topography, unfavorable meteorological conditions, and regional transmission, especially after the start of autumn and winter. Therefore, studying the carbonaceous components of PM$_{2.5}$ in Jincheng is of great significance for air pollution control in typical industrial cities. According to a previous study, the ionic components in TSP (total suspended
particulates) during the heating season in Jincheng mainly came from fixed pollution sources (coal-burning smoke and dust), and the OC/EC ratio was less than 2.0, which means that there was almost no secondary carbon aerosol in air particles in Jincheng (Cui, 2011). It was found that primary PM$_{2.5}$ concentrations in December were significantly higher than those in July. However, the concentrations of secondary sulfate ions (SO$_4^{2-}$) and nitrate ions (NO$_3^-$) in July were higher than those in December. And residential heating was the main contributor to the PM$_{2.5}$ concentration, accounting for 50%, and industrial processes and dust (Guo et al., 2020). However, there is still a lack of research on the composition of PM$_{2.5}$ in Jincheng in recent years.

As is mentioned above, it is necessary to discuss the changes of carbon components in PM$_{2.5}$ in Jincheng in the context of the seasonal variation. Based on the hourly data of OC, EC, and other pollutants in Jincheng City, China, from September 1, 2022, to August 31, 2023, we investigated the concentration characteristics of carbonaceous components during different time scales, separated POC from SOC by the EC tracer and minimum R squared (MRS) methods, and analyzed the source of carbonaceous components. We aimed to provide a reference for the formulation of air pollution control countermeasures and environmental management policies in typical industrial cities, such as Jincheng City.

2 MATERIALS AND METHODS

2.1 Description of the site

The observation point was at the National Automatic Monitoring Station of Environmental Air Quality in Jincheng, located at the former site of the Jincheng Environmental Protection
This location is approximately 15 m above the ground in commercial and residential areas surrounded by roads, office buildings, residential buildings, shops, and restaurants. It is a typical urban site in the downtown area of Jincheng. The distribution of major industrial enterprises is shown in Fig. 1. The observation point is approximately 3 km away from the Erguang Expressway, approximately 200 m east of Zezhou Road (north–south direction), and approximately 250 m south of Fengtai West Street (east-west direction).

Fig. 1. Location of the observation site.

### 2.2 Quality control and quality assurance

The observation period was from September 1, 2022 to August 31, 2023. Data on the carbonaceous components of PM$_{2.5}$ (OC and EC) were measured using a TR20N9 online atmospheric fine particle OC/EC analyzer developed by Zhongke Tianrong (Beijing) Technology Co., Ltd. The instrument was calibrated once per week using a standard solution, the membrane
was replaced once per week, and the cutter was cleaned once per month. Data on the K\(^+\) of PM\(_{2.5}\) were measured using an URG9000 online atmospheric fine particle anions and cation analyzer developed by URG company of America. The instrument was calibrated every two weeks.

Simultaneously, the concentration data of conventional pollutants (PM\(_{2.5}\), O\(_3\), SO\(_2\), NO\(_2\), and CO) were obtained from the National Automatic Monitoring Station for Ambient Air Quality in Jincheng. PM\(_{2.5}\) concentrations were measured using a continuous particulate matter monitor (TEOM1405F series). The NO\(_2\), SO\(_2\), CO, and O\(_3\) concentrations were measured using Thermo Scientific Models 42i NOx, 43i SO\(_2\), 48i CO, and 49i O\(_3\) analyzers, respectively. The instrument was calibrated daily and manually once a week.

Owing to the lack of information on the data quality, data quality assurance/quality control was conducted by referring to the methods described in a previous study (Zhang et al., 2021). First, hourly datasets with one or more missing components were removed. We identified data points with more than three median absolute deviations from the median as outliers and removed the datasets with outliers. Finally, 8346 data sets were extracted from a total of 8760 data sets.

### 2.3 SOC estimation by the MRS method

The EC tracer method (Pio et al., 2011; Turpin and Huntzicker, 1995; Wu et al., 2019) is widely used to divide OC into POC and SOC, and its basic principles are expressed in the following equations.

\[
m(POC) = (OC/EC)_{pri} \times m(EC)
\]

\[
m(SOC) = m(OC) - m(POC)
\]

(OC/EC)\(_{pri}\) is the characteristic value of the OC/EC ratio in the atmosphere owing to the primary combustion source. In this method, the POC and EC are assumed to originate from the
same combustion source; therefore, EC can be used as the primary combustion source to produce OC tracers. Based on the assumption that the chemical composition of a certain combustion source is constant, the OC/EC ratio in particulate matter emitted under the same or similar combustion conditions is considered to be constant; \( m(\text{POC}) \) is estimated by the observed EC, and \( m(\text{SOC}) \) is obtained by subtracting \( m(\text{OC}) \) from the observed EC.

As expressed in the above equations, \( (\text{OC}/\text{EC})_{\text{pri}} \) is an important parameter used to estimate SOC by the EC tracer method. In this study, we used the MRS method (Wu et al., 2018; Wu and Yu, 2016) to determine the seasonal \( (\text{OC}/\text{EC})_{\text{pri}} \) to calculate the POC and SOC content. The MRS method is based on the assumption that EC and SOC are not related; thus, \( (\text{OC}/\text{EC})_{\text{pri}} \) should be the ratio when the correlation \( (R^2) \) between \( m(\text{SOC}) \) and \( m(\text{EC}) \) is minimal. The correlation between EC and SOC was the worst and the secondary generation of OC was the weakest, and the cases where the OC/EC ratio exceeded this value were considered to be caused by SOC.

3 RESULTS AND DISCUSSION

3.1 Pollution characteristics of carbonaceous components

During the observation period, the daily concentration variation characteristics of PM\(_{2.5}\) and carbonaceous components in Jincheng City in different seasons are shown in Fig. 2, wherein September to November, December to February, March to May, and June to August are considered as autumn, winter, spring and summer, respectively. The change trend of the OC and EC concentrations of carbonaceous components in Jincheng was consistent with that of PM\(_{2.5}\), indicating that carbonaceous components were important components of PM\(_{2.5}\). The concentrations
of the carbonaceous components in autumn and winter were higher than those in spring and summer. Table 1 lists the m(TC), m(OC), m(EC), and OC/EC ratios during different seasons in Jincheng, China. By consulting and counting the concentration levels of carbonaceous components in some economically developed cities and industrial cities in China, and comparing them with those in Jincheng City as presented in Table 2, the concentration level of carbonaceous components in Jincheng City was found to be not significant, but the OC/EC ratio was relatively high. The number of motor vehicles in Jincheng was not very high compared with other cities, and a strict prohibition of heavy vehicles was implemented in main city proper, so the EC concentration level was relatively low. However, as a resource-based city, there were many phenomena of fuel combustion and biomass combustion. And this led to a relatively high OC/EC ratio (Dao et al., 2022; Ding et al., 2022).
Fig. 2. From September 2022 to August 2023, the concentrations of PM$_{2.5}$, OC and EC changed day by day in each season.

Table 1. Concentration of TC, OC, EC and OC/EC ratio in different seasons in Jincheng City.

<table>
<thead>
<tr>
<th>Season</th>
<th>TC (µg m$^{-3}$)</th>
<th>OC (µg m$^{-3}$)</th>
<th>EC (µg m$^{-3}$)</th>
<th>OC/EC</th>
</tr>
</thead>
<tbody>
<tr>
<td>Autumn</td>
<td>7.13</td>
<td>6.24</td>
<td>0.89</td>
<td>7.01</td>
</tr>
<tr>
<td>Winter</td>
<td>9.12</td>
<td>7.94</td>
<td>1.18</td>
<td>6.73</td>
</tr>
<tr>
<td>Spring</td>
<td>5.64</td>
<td>4.56</td>
<td>1.08</td>
<td>4.22</td>
</tr>
<tr>
<td>Summer</td>
<td>4.19</td>
<td>3.43</td>
<td>0.76</td>
<td>4.51</td>
</tr>
</tbody>
</table>
Table 2. Comparison of Carbonaceous Component Concentrations in Different Cities in China.

<table>
<thead>
<tr>
<th>City</th>
<th>Time (year-month)</th>
<th>OC (μg m⁻³)</th>
<th>EC (μg m⁻³)</th>
<th>OC/EC</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beijing</td>
<td>2017-12~2018-12</td>
<td>11.20</td>
<td>1.20</td>
<td>9.7</td>
<td>(Dong et al., 2020)</td>
</tr>
<tr>
<td>Zhengzhou</td>
<td>2019-4~2020-1</td>
<td>9.40</td>
<td>1.50</td>
<td>–</td>
<td>(Zhao et al., 2021)</td>
</tr>
<tr>
<td>Chongqing</td>
<td>2019-11~2020-10</td>
<td>9.03</td>
<td>2.45</td>
<td>3.80</td>
<td>(Ding et al., 2022)</td>
</tr>
<tr>
<td>Guiyang</td>
<td>2020-4~2020-12</td>
<td>7.60</td>
<td>2.00</td>
<td>3.90</td>
<td>(Gui et al., 2023)</td>
</tr>
<tr>
<td>Lanzhou</td>
<td>2020-1~2020-7</td>
<td>8.60</td>
<td>2.55</td>
<td>3.84</td>
<td>(Zhang et al., 2020)</td>
</tr>
<tr>
<td>Taiyuan</td>
<td>2018-12~2019-11</td>
<td>8.60</td>
<td>1.60</td>
<td>–</td>
<td>(Zhang, 2021)</td>
</tr>
<tr>
<td>Anqing</td>
<td>2020-3~2021-2</td>
<td>8.00</td>
<td>1.40</td>
<td>5.83</td>
<td>(Pan et al., 2023)</td>
</tr>
<tr>
<td>Yuncheng</td>
<td>2020-3~2021-2</td>
<td>8.27</td>
<td>1.66</td>
<td>–</td>
<td>(Wang, 2022)</td>
</tr>
<tr>
<td>Hohhot</td>
<td>2019-10~2020-10</td>
<td>10.27</td>
<td>1.34</td>
<td>7.60</td>
<td>(Bao, 2022)</td>
</tr>
<tr>
<td>Jincheng</td>
<td>2022-9~2023-8</td>
<td>5.54</td>
<td>0.98</td>
<td>5.67</td>
<td>This study</td>
</tr>
</tbody>
</table>

Fig. 3 shows the monthly variation characteristics of OC and EC concentrations, OC/EC ratios, and the correlation between EC and K⁺ in Jincheng during the observation period. Notably, the concentrations of OC and EC in Jincheng City were relatively low in warm months but significantly high in cold months, mainly owing to the change of emission intensity and unfavorable meteorological conditions, such as frequent inversion in cold seasons and low boundary layer height (Liu et al., 2019; Shang et al., 2018). After the start of a cold month, the combustion of coal and biomass for household heating increased, leading to a relatively high OC/EC ratio (Dao et al., 2022; Ding et al., 2022). Simultaneously, the correlation between EC and K⁺ increased and fluctuated after the start of the cold season, indicating that the contribution of biomass combustion to the EC concentration and OC/EC ratio cannot be ignored. Lower temperature and overall static atmospheric conditions promote the transformation of semi-volatile organic compounds/intermediate organic compounds (SVOCs/IVOCs) in the gas phase to the granular state (Wang et al., 2022). The SVOCs/IVOCs in the granular state continue to react or
condense, leading to further transfer of chemical equilibrium to the granular state (Kroll-Seinfeld, 2008), thus increasing the OC concentration and OC/EC ratio. Moreover, the OC/EC ratio tended to increase slightly during warm months with good diffusion conditions, indicating that active photochemical oxidation at higher temperatures is beneficial for the formation of OC in particulate matter (Liu et al., 2021; Ning et al., 2018).

Fig. 3. Monthly variation of OC and EC concentration, OC/EC ratio and correlation between EC and K⁺.

Fig. 4 shows the daily changes in OC, EC, and OC/EC ratio during different seasons in Jincheng during the observation period. The daily variation trend of OC in the four seasons was consistent, showing a “single peak,” wherein the concentration peaked in autumn, spring, and summer at 09:00–10:00 AM, and the peak time in winter was delayed to approximately 12:00 AM. The lowest OC concentration occurred in all four seasons from 16:00 to 17:00 PM. The peak value of EC concentration in autumn and spring appeared before 09:00 AM, and the peak time of EC in winter was delayed to approximately 12:00 AM, whereas the daily variation of EC concentration in summer did not fluctuate significantly. The lowest concentrations of EC occurred in autumn,
winter, and spring from 17:00 to 18:00. In winter, the overall atmospheric conditions were static and stable, and pollutants do not spread easily; however, secondary generation was promoted and the pollution was intensified. In the afternoon, the diffusion conditions gradually improve.

Previous studies have found that the combustion of biomass and coal is related to a high OC/EC ratio, whereas the OC/EC ratio of vehicle emissions is relatively low (Chen et al., 2006; Hildemann et al., 1991; Panicker et al., 2021; Watson et al., 2001; Zhi et al., 2008). The levels of the OC/EC ratio in autumn and winter were similar but increase from 07:00 AM to 12:00 AM in autumn, indicating that biomass combustion, such as straw combustion, was more frequent in autumn than in winter. However, the levels of the OC/EC ratio in spring and summer were similar; therefore, the OC/EC ratio from morning to noon in summer was higher than that in spring as the photochemical reaction in summer was relatively strong, resulting in significant SOC (Hallquist et al., 2009; Na et al., 2004), which makes the OC/EC ratio higher in summer than in spring. Low OC/EC ratios were observed around the evening in all four seasons; however, they were observed during the late peak of traffic. Thus, traffic source emissions also had a significant impact on the OC/EC ratio.
Fig. 4. Diurnal variation of OC and EC concentrations and OC/EC ratio in autumn (a), winter (b), spring (c) and summer (d).

3.2 Estimation of SOC

To ascertain the appropriate (OC/EC)\textsubscript{pri} value, we used datasets of different seasons to implement the MRS method, and the (OC/EC)\textsubscript{pri} values of autumn, winter, spring, and summer in Jincheng City were 3.45, 4.38, 3.23, and 2.57, respectively. Fig. 5 shows the specific MRS fitting data.
POC and SOC in different seasons were calculated using the EC tracer equation, and the seasonal variation characteristics of SOC and the SOC/OC ratio in Jincheng are shown in Fig. 6(a). The SOC concentrations in winter, autumn, summer, and spring in Jincheng were 3.84, 3.47, 1.67, and 1.47 μg m⁻³, respectively. Static atmospheric conditions and low temperatures in autumn and winter cause the SVOCs/IVOCs to condense/absorb into particulate matter (Wang et al., 2022), which is an important process of SOC formation in autumn and winter. However, owing to the higher humidity and lower average wind speed in autumn (September–November 2022) than in winter (December 2022–February 2023), the SOC/OC in autumn was slightly higher than that in winter. Higher temperatures, stronger radiation, and higher O₃ concentrations in summer promote the formation of significant amounts of SOC through photochemical oxidation (Liu et al., 2021;
Ning et al., 2018). Consequently, the SOC/OC ratio in summer was equivalent to those in autumn and winter.

Fig. 6(b) shows the concentration accumulation diagram of POC, SOC, EC in different seasons in Jincheng. From Fig. 6(b), the POC in winter was obviously higher than that in other seasons, namely, the contribution of primary emission was greater than that in other seasons. Notably, the SOC in autumn and winter was higher than that in spring and summer, which means that the secondary generation in autumn and winter was stronger than that in spring and summer.

3.3 Source analysis of carbonaceous components

The correlation between OC and EC is generally used to explain whether they originate from the same emission source (Ji et al., 2019b; Wang et al., 2022). A higher $R^2$ value between OC and EC concentrations implies that they originated from common emission sources (Ji et al., 2019a,b) or OC was mainly dominated by primary sources (Hu et al., 2012). Whereas a lower $R^2$ value implies that the emission sources of OC and EC are considerably different or that secondary generation is more significant (Bian et al., 2018; Huang et al., 2014; Ji et al., 2019a,b; Lee et al.,
To further study the sources of EC and OC in Jincheng during the observation period, the correlation between OC and EC during different seasons is shown in Fig. 7. In this study, the correlation between OC and EC in spring was good ($R^2 = 0.661$), indicating that OC and EC originate from similar emission sources in spring; namely, POC contributes more to OC. However, the pollution sources of OC and EC in autumn ($R^2 = 0.239$), winter ($R^2 = 0.470$), and summer ($R^2 = 0.333$) were more complicated, and significant secondary generation led to a relatively large contribution of SOC to OC. The slopes ranged from high to low: winter (4.622), autumn (3.445), spring (3.412), summer (2.560). This can be ascribed to the obviously seasonal variations of primary emission sources and SOC formation (Liu et al., 2019). The circles represent hourly observations in four seasons and are colored according to the observed O₃ concentrations. We found that the high OC/EC ratio in Jincheng in summer was strongly dependent on the O₃ concentration, which indicates that SOC was more significantly formed through photochemical oxidation in summer (Liu et al., 2021; Ning et al., 2018). And there was a certain correlation between high OC/EC ratio and O₃ concentration in spring, which indicates that SOC in spring was formed through photochemical oxidation to some extent, and the contribution of heterogeneous reaction cannot be ignored. However, no obvious relationship was observed between the OC/EC ratio in autumn and winter and O₃ concentration, indicating that in addition to the photochemical oxidation process, multi-phase reactions have a more important contribution to the formation of SOC.
Fig. 7. Correlation between OC and EC in autumn (a), winter (b), spring (c) and summer (d).

To further investigate the potential influences of sources on OC (including POC and SOC), correlations of OC components with gaseous pollutants were analyzed by using Spearman's rank correlation coefficient and plotted in Fig. 8. The correlation between carbon components and gaseous pollutants in autumn and winter in Jincheng City was stronger than that in summer. Clearly, EC, POC, and SOC had significant positive correlations with NO\textsubscript{2} and CO in winter, indicating may be obviously influenced by combustion sources, mainly coal combustion emissions and vehicle emissions (Liu et al., 2023; Moutinho et al., 2020). At the same time, the strong correlation between SO\textsubscript{2}, NO\textsubscript{2} and CO in winter also indicates that the influence of industrial emissions such as coal combustion cannot be ignored. The correlation between EC, POC, and NO\textsubscript{2} was stronger than other gaseous pollutants in summer, indicating that vehicle emissions were the
main source of carbon components in Jincheng in summer; alternatively, the weak correlation between SOC and gaseous pollutants indicates that the former was influenced by other VOCs emission sources.

**Fig. 8.** Correlation heatmaps between carbonaceous components and gaseous pollutants in autumn (a), winter (b), spring (c) and summer (d).

**4 CONCLUSIONS**

In this study, the pollution characteristics of carbonaceous components in Jincheng, a typical industrial city, at different timescales were analyzed through hourly real-time observations. POC and SOC were separated using the MRS method, and the sources of the carbonaceous components
were analyzed. The OC and EC concentrations in the cold months in Jincheng were significantly higher than those in the warm months. Except for those in summer, the daily concentrations of OC and EC in the other seasons showed a “single peak” change. Frequent biomass combustion and coal-fired combustion led to an obvious increase in the OC/EC ratio in the mornings of autumn. The photochemical reaction was more intense in summer, and the OC/EC ratio also increased owing to the relatively high SOC yield. After the start of the cold month, biomass combustion, such as straw combustion, significantly contributes to the EC concentration level; therefore, the control of biomass combustion, such as straw combustion, should be strengthened in autumn and winter.

The highest SOC concentrations in different seasons in Jincheng occurred in winter, followed by autumn, summer, and spring. Owing to the low wind speed and high humidity, the SOC/OC ratio was the highest in autumn, similar to that in winter and summer, and lowest in spring. Improving the control of VOCs in summer cannot only reduce the generation of O₃ but also reduce the formation of OC in particulate matter to some extent. The OC and EC in Jincheng City originated from similar emission sources in spring, and the pollution sources of OC and EC in autumn, winter, and summer were more complicated. In autumn and winter, multi-phase reactions contributed more to OC formation, whereas in summer, OC was formed through photochemical oxidation. The carbon components in Jincheng City in autumn and winter were significantly influenced by combustion sources, mainly coal combustion emissions and vehicle emissions. Vehicle emissions were the main source of carbon components in Jincheng during summer, and the formation of SOC was related to other VOCs emission sources.
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