

Review

Dining Lampblack Treatment Processes in China

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Abstract: The PM_{2.5} and other small particles produced by cooking oil fumes have contributed up to 25% to the urban atmospheric PM_{2.5}, which has a bad impact on air quality and seriously threatens human health. Aiming at the pollution problem caused by catering oil fume, this article analyzes the threats of air pollution to human health based on the compositions and characteristics of catering oil fume, illustrates the development trend of China's food and beverage lampblack control policy, and summarizes and points out the current situation and development trend of catering oil fume treatment. In order to provide ideas for the design of more efficient and energy-saving treatment processes in the future, the advantages and disadvantages were reviewed, and the improvement direction of the treatment technology was discussed.

Keywords: dining lampblack; purification technology; air pollution; VOCs; PM_{2.5}; technological development



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1. Introduction

Aerosol state pollutants and gas state pollutants are the main air pollutants. Among which PM_{2.5} (particles with equivalent diameter less than 2.5 microns), PM₁₀ (particles with equivalent diameter less than 10), and VOCs (volatile organic compounds) are the important pollutants that affect air quality and reduce visibility [1]. The sources of PM_{2.5} and PM₁₀ are divided into natural sources such as forest fires or volcanic eruptions and man-made sources such as fuel combustion and industrial emissions; the sources of VOCs are divided into BVOCs (biogenic volatile organic compounds) and man-made VOCs. BVOCs refer to volatile organic compounds emitted by forests, microorganisms, and other plants [2], and anthropogenic sources refer to volatile organic compounds emitted by man-made pollution sources in human daily life. Hydrocarbon compounds and their derivatives are the main part of BVOCs and anthropogenic VOCs, which mainly include various hydrocarbons, aldehydes, fatty acids, alcohols, ketones, as well as polycyclic aromatic hydrocarbons. They have a large photochemical reaction activity. They can react with nitrogen oxides in the atmosphere after being irradiated by strong solar ultraviolet rays to form photochemical smog. Moreover, organic substances such as isoprene and monoterpenoids contained in BVOC and aromatic compounds contained in anthropogenic VOCs can also react deeply with ozone in the atmosphere to produce secondary organic gases [3]. Sols, chemical fumes, and aerosols can all cause damage to the human respiratory system. In addition, most VOCs and PM_{2.5} also have direct carcinogenic effects and mutagenic effects on cancer [4].

Since the beginning of the 21st century, the economies of all countries in the world have continued to grow, leading to a continuous increase in the rate of dining out and the rapid rise of the catering industry. At the same time, it has led to an increase in catering oil fume emissions, and the resulting air quality problems have also sharply increased. Catering fume refers to a gas–liquid–solid three-phase mixture, mainly including water vapor and oil mist, solid particulate matter, and volatile organic compounds (VOCs) [5]. The large solid particles with an equivalent diameter of more than 10 μm are subjected to gravity greater than buoyancy and can be deposited in the air, which has little effect on air quality; small particulate matter, such as $\text{PM}_{2.5}$ and PM_{10} , can only be suspended in the air, which seriously affects air quality. $\text{PM}_{2.5}$ has become one of the important sources of urban atmospheric environmental particulate matter pollution. According to statistics [6], the contribution rate of $\text{PM}_{2.5}$ generated by catering oil fume to urban atmospheric $\text{PM}_{2.5}$ is as high as 25% in Beijing, and that is about 15% in Shenzhen and in Wuhan. Additionally, dining lampblack is one of the main sources of anthropogenic VOCs, which will cause irreversible damage to human health. The threat of cooking fumes to human health has attracted close attention from all walks of life.

This article mainly analyzes the components and hazards of catering oil fumes, interprets the Chinese catering oil fume emission standards, and summarizes the advantages and disadvantages of domestic and international catering oil fume treatment technologies. From the perspective of improving purification efficiency, the treatment technology and its improvement direction are discussed in order to provide a theoretical basis for advancing the catering oil fume treatment policy and improving the oil fume treatment technology.

1.1. Features and Hazards of Dining Lampblack

Dining lampblack is formed during the use of edible oil, and its emission characteristics are greatly affected by the heating environment. The boiling point of the main components of cooking oil is about 300 $^{\circ}\text{C}$, but the composition of lampblack is complex and changeable due to different heating temperatures. When the temperature is raised to 270 $^{\circ}\text{C}$, the high boiling point components in the cooking oil vaporize, forming the pungent odor of smoke consisting of 0.03–10 μm oil droplets. At this time, the vaporized substances in food condense into fog, and the oil molecules—triglycerides—decompose at high temperature to form VOCs, at which point they combine with the oil vapor to form lampblack [7]. In addition, the soot and smoke formed by the incomplete combustion of the fuel and the gaseous substances produced in the above two temperature ranges mix and rise, and collide with air molecules during the rise process, and the temperature drops at the same time. When the temperature drops to 60–80 $^{\circ}\text{C}$, the mixed gas forms an aerosol, which is suspended in the atmosphere and causes atmospheric pollution. Chung et al. tested the composition of cooking oil lampblack by heating edible oil, and found 42 kinds of hydrocarbon organic compounds, 22 kinds of aldehydes organic compounds, 11 kinds of fatty acids, 8 kinds of ketones organic compounds, 8 kinds of alcohols, 4 kinds of furans, and 2 kinds of esters [8]. The composition of cooking fumes is affected by factors such as cooking time, cooking methods, edible oil types, dishes, and seasons; the main harmful components are $\text{PM}_{2.5}$ and VOCs.

Heating time is another main factor affecting the compositions of cooking lampblack. Through GC/MS analysis, Wang et al. [9] found that there were 39 compounds in unheated cooking oil, and 29 compounds after the isomers were removed. Respectively, there were 21 and 24 types compounds in the lampblack after being heated for 2 h and 4 h.

Cooking style, dishes, seasons, regions, and types of cooking oil will lead to changes in the compositions of cooking lampblack. Li et al. [10] studied the $\text{PM}_{2.5}$ in cooking fume of residents, hotpot restaurants, barbecue restaurants, workers' cantons, Chinese restaurants, and shopping malls in Chengdu, Wuhan, and Tianji. The measurement range of $\text{PM}_{2.5}$ density from the six types of catering sources is 330–15110 $\mu\text{g}/\text{m}^3$. Among them, the density of $\text{PM}_{2.5}$ emitted by barbecue is the highest, which is 158.2 times the background value of residential kitchens (96 $\mu\text{g}/\text{m}^3$), and the density of $\text{PM}_{2.5}$ emitted by hot pot

restaurants is the lowest, which is 3.5 times the background value of residential kitchens. Cui et al. [11] selected and analyzed the VOCs emission concentrations in the cooking fumes of five popular types of catering industry in Beijing—including barbecues, the popular fast food in both China and the West, and Sichuan and Zhejiang cuisines. The results showed that barbecue emits the highest VOCs concentration, reaching 12.22 mg/m³, while the values of the rest samples are around 4 mg/m³. These data exceed the 1.0 mg/m³ limit of the 'Emission Standard for Fume Pollutants from Catering Units' for catering units. Xu et al. [12] studied the organic comprehensive characteristics of PM_{2.5} generated in the cooking process of seven of the most popular kinds of restaurants in Northwest China and found that Chinese barbecue, Chinese fast food, and western fast food generated relatively higher PM_{2.5}, and organic fatty acids are the highest compounds in all oil fume. It can be seen that the catering industry is an important source of PM_{2.5} and VOCs emissions, and the PM_{2.5} and VOCs emission levels from barbecue are the highest.

Pei et al. [13] conducted PM_{2.5} emission concentration detection on Shanghai cuisine, Sichuan cuisine, and Italian restaurants. The results showed that the PM_{2.5} emission concentration of catering lampblack in the evening was higher than that in the afternoon, which might be because the catering lampblack emission was related to the attendance of restaurants at different times. After analyzing the sources of PM_{2.5} in each season in Xining City, Dou [14] found that the PM_{2.5} contribution of cooking oil fume in winter was higher than in the windy and sandy season, and in the non-heating season. In the same season, the attendance at different times also affects the PM_{2.5} emission concentration. The high attendance rate at lunch is mainly the catering source of working fast food, while the high attendance rate at dinner is mainly the catering industry in the form of potluck, barbecue [6]. Torkmahalleh [15] studied the PM_{2.5} and ultrafine particles (particle size 10–100 nm) produced by cooking seven kinds of edible oils at a cooking temperature of 197 °C, and found that—in the range of 131–197 °C—the number of ultra-fine particles emitted accounted for 76–99% of the total particles among soybean oil, safflower oil, rapeseed oil, peanut oil, corn oil, coconut oil, and olive oil (particle size 10–500 nm).

1.2. Hazards of Dining Lampblack

Catering lampblack causes irreversible harm to the human body. According to the statistics of VOCs in cooking lampblack [16], polycyclic aromatic phenanthrene (PHE), pyrene (PYR), and fluoranthene (FLT) are generally higher in mass fraction and account for 13.8–21.6%, 9.2–26.5%, and 6.9–22.0% of the total PAHs emitted from catering sources, respectively. All of the above substances are carcinogenic, teratogenic, and mutagenic. Lipophilic compounds, such as PAHs, can increase the level of free radicals (O²⁻) in the body, and increase the risk of atherosclerosis and coronary heart disease. Even short-term exposure in PAHs-containing surrounding can lead to thrombosis in patients with coronary heart disease [17]. Polycyclic aromatic hydrocarbons, such as dibenzopyrene and tetrahydrofuran, in catering lampblack are reproductive toxic substances, among which toluene and styrene are reproductive toxic to women. Long-term exposure to catering lampblack will lead to women's menstrual cycle disorders, gestational hypertension [18], abnormal fetal growth, and other adverse results. Moreover, PM_{2.5} and PM₁₀—also known as inhalable particles—have a small equivalent diameter; can remain in the respiratory tract, alveoli, and other organs; and can further cause diseases. The smaller the particles, the more and deeper in they will affect the respiratory system. Particles smaller than 10 µm usually remain in the upper respiratory tract, while the ones around 5 µm can run deeper, and those with a diameter of less than 2 µm can completely penetrate into the bronchioles and alveoli. Therefore, catering lampblack is an irritant and obstructive to the human nose, throat, trachea, bronchus, and other organs. If a person is working in a high-concentration lampblack environment for a long time, they will encounter issues such as cough, chest tightness, shortness of breath, and other symptoms, which can induce rhinitis, pharyngitis, tracheitis, bronchitis, and other respiratory diseases. Among many diseases induced by food lampblack, lung cancer is a common disease [4,19]. Epidemiological

studies have confirmed that the incidence of lung cancer in the population is associated with the exposure to cooking lampblack and which further significantly increases the risk of lung cancer in non-smoking women [20]. It has been reported that every $10 \mu\text{g}/\text{m}^3$ increase in $\text{PM}_{2.5}$ will lead to a 6% increase in the death rate of heart disease and lung disease, and an 8% increase in the death rate of lung cancer [21]. The use of range hoods can reduce the risk of lung cancer by approximately 50% [22].

In addition to the threat to human health, dining lampblack will also cause environmental problems [23]. $\text{PM}_{2.5}$ and other small particles will form atmospheric brown clouds in the high-altitude area [24], reflecting sunlight and lowering the surface temperature of the earth, reducing the solar energy reaching the planet. When they are in low altitude areas, haze will be formed [25]. VOCs will form photochemical smoke with nitrogen oxides in air under light conditions, whose aerosol particles are between 0.3 and $1.0 \mu\text{m}$, which can be floating in the air for a long period of time, reducing the visibility of the atmosphere and shortening the visual range. Chlorine atoms are produced when some VOCs undergo photochemical reactions, which can catalytically damage the ozone layer [26]. The depletion of the ozone layer leads to increased ultraviolet radiation [27], accelerated degradation and aging of building materials [28], and ultimately shortened their service life.

2. Control Policies and Treatment Status of Dining Lampblack

2.1. Control Policies

As early as 1995, the “Notice on Strengthening Environmental Management of Catering and Entertainment Service Enterprises” jointly issued by the State Environmental Protection Administration (SEPA) of China and the State Administration for Industry and Commerce stipulated that the location of catering companies must be equipped with pollution prevention facilities. However, before 2000, no detailed sampling methods, analysis methods, and emission standards for cooking fumes had been formulated in China [29]. In 2000, SEPA issued the “catering industry lampblack emission standard (trial)” (GWPB5-2000), which is the first time that China has made clear the emission standard of catering lampblack. In 2001, China issued the “Food and Beverage Industry Lampblack Emissions Standards” (GB18483-2001) and “Technical Requirements and Testing Specifications for Food and Beverage Industry Lampblack Purification Equipment”, which formulated in detail the emission standards for catering lampblack, the standards for the efficiency of catering lampblack purification equipment, and the standard requirements for catering lampblack detection technology. However, there are no strict requirements in the fine particulate matter PM_{10} and $\text{PM}_{2.5}$. With the increasingly serious problems of PM_{10} and $\text{PM}_{2.5}$ pollution, China’s environmental protection departments are paying more and more attention to the research work on the comprehensive treatment of catering oil fumes. In 2010, China made detailed provisions on the site selection of catering enterprises and catering lampblack purification emissions for the first time, even including the corresponding requirements for the height of the lampblack vent. Despite increasingly comprehensive standards on lampblack emissions, China’s domestic $\text{PM}_{2.5}$ pollution increased from 10 percent to 14 percent [30] between 2012 and 2017, an increase of four percent in just five years. This situation has prompted the government to introduce stricter intervention policies, laws, and regulations [31,32]. In 2019, China revised the “Emission Standard for Oil Fume Pollutants in the Catering Industry GB18483-2001”, and the limit on oil fume emission concentration was tightened from $2.0 \text{ mg}/\text{m}^3$ to $1.0 \text{ mg}/\text{m}^3$. At present, the emission standards of oil fume pollutants for catering units in China are implemented in accordance with the “Emission Standards for Fume Pollutants for the Catering Industry (Draft for Comment)”, as shown in Table 1.

Table 1. Limits of dining lampblack and total hydrocarbon emission for catering service unit.

Pollutant Item	Emission Limit (mg/m ³)	Pollutant Emission Monitoring Location
Dining lampblack	1.0	Lampblack exhaust funnel or purifying facility discharge outlet
Total hydrocarbon	10	

While the Chinese central government has formulated strict laws and regulations related to catering oil fume control, local governments have also issued relevant oil fume control policies, which clearly require catering companies to improve the purification efficiency or emission limit of oil fume purification equipment. In 2017, the Shenzhen local standard stipulates that the maximum emission concentration of oil fumes is 1 mg/m³, among which the purification rate of lampblack from small, medium, and large catering sources is required to reach more than 90%. In 2018, the Chongqing local standard stipulates that the purification rate of large-scale catering source fume must be more than 95%. In 2019, the maximum emission concentration of catering fumes in Shandong must be less than 1.5 mg/m³; and Beijing local standards stipulated that both the purification rate of oil fumes from large-scale catering sources must be more than 95% and the maximum emission concentration should not be greater than 1 mg/m³.

In addition, some local standards have also made corresponding requirements for the emission of particulate matter or total hydrocarbons. For example, Liaoning's "Fume Emission Standard for Catering Industry (Draft for Comment)" stipulates that the maximum emission concentration of total hydrocarbons is 7.5 mg/m³, Henan "Emission Standard for Catering Industry Air Pollutants" (DB41/1604-2018) stipulates that the emission concentration limit of particulate matter is 10 mg/m³, and Beijing "Emission Standard of Air Pollutants for Catering Industry" (DB11/1488-2018) requires that the particulate matter emission should not exceed 5.0 mg/m³.

In recent years, China has continued to strengthen the control of catering oil fume, and has continued to carry out the "control the edible oil fume pollution and win the blue sky defense" action in many places, which effectively promote the control of oil fume, and the relevant national laws and regulations also stipulate "prevent and control air pollution, and protect people's health" [33].

2.2. Treatment Status

At present, China adopts the methods of source reduction, process control, and terminal treatment to achieve the purpose of oil fume purification. The methods of source reduction reduce food fume, particulate matter, and VOCs emission concentration during food processing and cooking strengthen the control of the source, and reduce the difficulty of terminal management. Process control refers to the idea that the collection and treatment of oil fume must be in accordance with the principle of unified emission, the working surface of the gas hood should be larger than the cooking area, and the oil fume from floating and leaking must be avoided. Yang [34] improved the gas collecting device of the gas collecting hood through adding carburetor and substances to the water transport hood in order to reduce the pressure on the end treatment. Terminal treatment is the use of purification technology to prevent the emission of lampblack into the air. It is mainly through a series of methods to degrade the harmful substances in the oil fume. According to the purification principle, the research and development of catering oil fume purification processes and the improvement of purification efficiency have become the focus of catering oil fume treatment.

Although there are strict regulations on the emission standards of catering lampblack, administrative intervention to control the emission standards of catering lampblack can only reduce the emission of lampblack to a certain extent. For small particulate matter—PM_{2.5}, PM₁₀, and non-condensing gas VOCs—control means must be taken to transform or remove lampblack before being released. The domestic catering industry mostly uses electrostatic, compound, and other oil fume purification process to control oil fume emission.

However, these processes have the drawbacks of high maintenance and cleaning costs. At present, most domestic households often use range hoods to deal with kitchen catering oil fumes, and the indoor catering oil fumes are sucked into the inside of the range hood for oil fume separation. Under the action of centrifugal force, the oil mist condenses into oil droplets and is collected to the oil cup, while the uncondensed gas is directly discharged to the outdoors. The PM_{2.5} and VOCs in the oil smoke cannot be effectively treated.

3. Purification Processes and Prospects

3.1. Lampblack Purification Processes

Due to the differences in food culture between China and other countries, the purification techniques used are also different. The cooking method of international catering industry is simple, where the cooking temperature is low and the diets are mainly raw or semi-finished products, so the kitchen pollution degree and the lampblack concentration are both relatively lower. Therefore, oxidation incineration method and catalytic oxidation method are mainly used to oxidize the organic matter in the lampblack into CO₂ and H₂O to purify the lampblack. Their working principles and application characteristics are shown in Table 2. Some catering lampblack from oil-fried cooking food also needs to be treated by other purification technologies, such as the electrostatic equipment used in the process of meat cooking, which can reduce the emission of single aromatic hydrocarbon VOCs [35].

Table 2. Principle and characteristics of cooking fume purification technology.

Purifying Technology	Purifying Principle	Advantages	Disadvantages	Application Situation
Oxidative Incineration Technology	The particulate matter and VOCs in the cooking fume are oxidized with oxygen and converted into harmless substances after full combustion.	Purification efficiency is high; low emission of nitrogen oxides	A large amount of oxygen is required to be introduced; equipment cost is high; inconvenient maintenance	Large-scale fried food and beverage industry and the enterprise
Catalytic Oxidation Technology	The organic substances in the cooking fume are catalytically converted into carbon dioxide and water.	Purification effect is strong; can remove that peculiar smell of oil smoke	The equipment cost is high; purification effect is greatly influenced by the type and efficiency of catalyst	Small and medium-sized catering industry and family kitchen

The cooking methods of the Chinese catering industry are different from those of international, and most of them are fried at high temperature, which leads to the complicated composition of catering oil fume and high pollutant concentrations. Oxidation incineration equipment is huge and costly, suitable for large-scale frying enterprises, but not for small and medium-sized restaurants. Li [36] developed a metal wire catalyst for immersion and plating of Pt and Pd, which has a good purification effect on low concentration organic matter in a low temperature environment. The honeycomb ceramic supported precious metal catalyst proposed [37] by Zhengzhou University can also convert catering oil fume and VOCs into H₂O and CO₂. However, there is no industrial application cases of catalytic oxidation technology in China.

The catering oil fume purification technologies adopted in China mainly include mechanical separation, high-voltage static electricity, washing (wet) method, photolysis,

filtration/adsorption [38,39], and composite processes [40]. The working principle of the mechanical separation purification process is that the oil fume enters the purification equipment laterally and is thrown out by the centrifugal force generated by the rotating blades, and then accumulates and flows down to the bottom of the equipment to separate the oil fume. It has the advantages of low cost, convenient maintenance, and no secondary pollution, but it is less used because of its incomplete separation effect, and the inability to eliminate irritating odor substances. High voltage electrostatic purification process has been widely used in recent years due to its low cost and good purification effect [41]. Its working principle is to make the electrons in a high-voltage electric field collide with lampblack molecules and charge the oil smoke molecules. Under the electric field force generated by an external high-voltage electric field, the charged oil fume particles move to the positive dust collecting plate, and to be purified and separated. The disadvantage is that the quality requirements of the high voltage insulation materials in electrostatic equipment is quite strict. The working principle of the washing (wet) method is that the absorption liquid mist with good hydrophilicity is ejected from the nozzle, collides with the lampblack particles in the lampblack airflow, converts the gaseous pollutants into liquid state, and absorbs the particulate matter and VOCs in the catering lampblack. In addition, this method can also efficiently absorb nitrogen oxides and SO₂ in the cooking fume, but the absorption liquid that absorbs contaminants will cause secondary pollution whose regeneration or treatment will also increase the cost. The principle of photolysis treatment technology is to decompose the macromolecular organic matter into small molecular organic matter such as water and carbon dioxide by irradiating the catering oil fume with a specific wavelength of ultraviolet light, thereby avoiding the deposition of oil fume on the fan and pipeline. However, the photolysis purification process cannot remove the VOCs in the cooking fume, but increases its emissions. With the increasingly stringent emission standards, the number of photolysis products in the market has gradually faded. The principles of filtration and adsorption are similar. Use a certain number of metal grids to trap the large particles of contaminants, and then deal with the small particles. The difference between the filtration and adsorption method is that the former uses a filter layer, such as fiber, to remove small particles using its dynamic collection effect, while the latter usually uses activated carbon to remove small particles and VOCs in the lampblack. These two methods share the same disadvantage that the filter or adsorbent material needs to be replaced regularly due to its limited treating capacity, resulting in high operating costs. The composition of catering oil fumes is complex, and a single process is not effective enough to purify them, so the compound purification process [40] has gradually been increasing, which is to combine two or more different purification technologies with complementary advantages in order to improve the purification efficiency.

With the increasingly strict standards for catering lampblack emission, some single purification processes that can only remove small particles in the lampblack and ignore the pollution of VOCs cannot meet the requirements, so more and more compound purification processes gradually appear in the market. According to the statistical data of oil fume purification process in the "Environmental Protection Product Certification List" from 2016 to 2019, the common composite oil fume purification processes are wet electrostatic, mechanical electrostatic, electrostatic photolysis, mechanical photolysis, and mechanical photolysis electrostatic types. The application of the above five processes is shown in Figure 1.

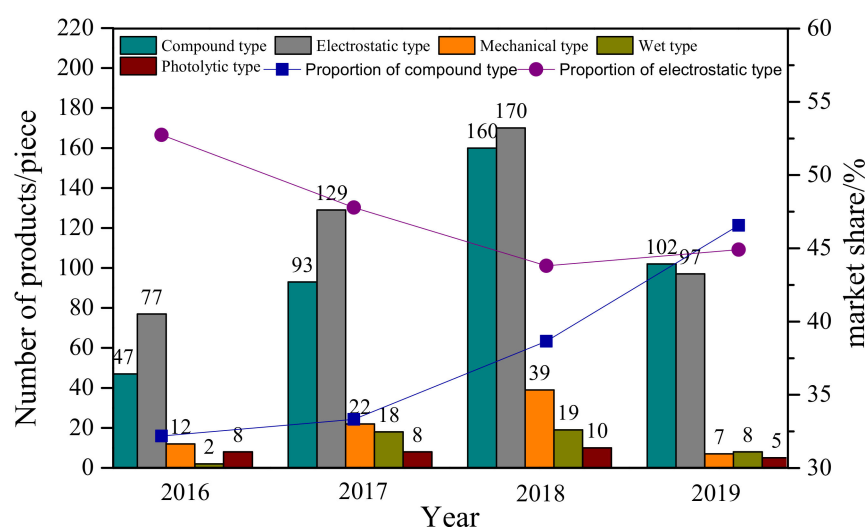


Figure 1. The application of oil fume purification processes from 2016 to 2019 in China.

The left axis in Figure 1 indicates the quantity of products, while the right one indicates the market shares of the proportion of the compound and electrostatic types, and the values on the bar graph represent the quantity of the specific type of purification processes on the market. The above data comes from the 2016–2019 “Environmental Protection Product Certification Directory”. Due to incomplete data, the information of 2020 is not shown in Figure 1.

As can be seen in Figure 1, in recent years, the electrostatic process has cornered the market, and the proportion of composite purification processes has gradually increased. In 2016, the electrostatic type processes accounted for 52.74%, whereas composite type processes accounted for 32.19%. By 2019, electrostatic type processes accounted for 44.29%, whereas composite type processes accounted for 46.58%. Cheng [42] et al. tested eight different types of cooking fume samples from Beijing’s catering industry and found that the concentration of aldehydes and ketones was in the range of 115.47–1035.99 $\mu\text{g}/\text{m}^3$. After treatment with high-voltage electrostatic fume purification process, not only were the aldehydes and ketones not effectively removed, but the concentration of some compounds increased instead. It may be that part of the large molecular substances were decomposed into small molecular organic substances, such as aldehydes and ketones, during the high-voltage discharge process. Similarly, it is difficult to effectively remove VOCs in oil fume with other single technical methods. Therefore, the market share of composite purification processes is gradually increasing. Figure 1 reflects people’s attention to the purification and treatment of cooking fumes. In addition, the gradual increase in the compound share shows that compound catering oil fume purification equipment will become the main trend of catering oil fume purification technology in the future.

Among composite purification processes, the electrostatic photolysis type oil fume purification process is the main one, which accounted for 51.4% in 2019. The lampblack removal efficiency of the compound purification processes is higher than that of the single ones, and the lampblack removal efficiencies of the compound processes are up to more than 90%. Among them, the lampblack removal efficiency of the electrostatic photolysis type is the highest at 97% [41]. However, its VOCs removal efficiency is low.

3.2. VOCs Treatment Processes

The purification of VOCs is also achieved by means of source reduction, process control, and terminal treatment. The source of lampblack cannot be changed, the closure control of the lampblack production process cannot be realized, and the way of source reduction and process control is limited; therefore, VOCs purification still needs to use the terminal treatment method. According to the treatment results, the terminal treatment processes can be divided into two categories: destruction and recovery processes. ‘Destruc-

tion processes' refers to the decomposition of organic matter into small molecules such as CO₂ and H₂O through chemical methods. The main methods of destruction process include high-temperature incineration, catalytic combustion, and low-temperature plasma. 'Recovery processes' refers to the separation of useful substances from the mixed gas for reuse, including adsorption, absorption, condensation and membrane separation. Among them—the most commonly used are adsorption method and absorption method. Adsorption method uses adsorbent to react with VOCs, enriches VOCs, and then desorbs and recovers them at high temperature and low pressure. The absorption is to use the difference in solubility of different gases in the same solvent to separate the mixed gas and recover the useful components. However, in the absorption process, there is a serious problem of secondary pollution, and it is difficult to find an ideal absorbent; therefore, its application was limited. The removal efficiency of VOCs by adsorption method, low-temperature plasma method, and catalytic combustion method are pretty close; all can reach 80–90% [43]. The low-temperature plasma method is only suitable for the treatment of medium and low concentration VOCs [44].

3.3. Technical Outlook

The compositions of cooking fumes are complex, and in practical application, the purification processes of cooking fume are usually combined with VOCs treatment processes to enhance the purification effect [45,46]. Based on the current Chinese and international processes for catering oil fume purification, a single use of a cooking fume purification process has drawbacks that cannot be ignored and results in the fact that the purification effect is not ideal, nor can meet the requirements for the energy environmental protection and economic benefits. Therefore, the compound cooking fume purification processes are supposed to have the capacity to treat VOCs.

4. Conclusions

To sum up, the air pollutants and toxic chemicals—such as VOCs and PM_{2.5}—in cooking oil fume cause threats to human health. Therefore, the treatment and purification of oil fume has important engineering and social significance.

In terms of catering oil fume treatment, although the purification efficiency of some catering oil fumes in China reaches 90%, the pollution situation has not yet been alleviated and resolved well. There still is room for improvement not only in terms of purification efficiency, but also of market promotion, equipment cost, energy consumption, etc. In order to strengthen the effective management of oil fumes and improve the treatment technology, different types of purification technologies can be coupled in the future design. Additionally, oil fume purification efficiency, environmental pollution, energy circulation, economic aspects, and noise reduction, have to be taken into consideration.

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