Analysis of Air Pollutant Emission Differences and Emission Reductions of Coal-fired Stoves of Different Residents

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Abstract. In order to explore the differences in air pollutant emissions of different types of stoves, this study selected five common new types of residential coal-fired stoves (square coal stoves, baffle heat exchange stoves, kang heating and cooking integrated stoves, Gasification forward burning and gasification reverse burning stoves) Simulated combustion and atmospheric pollutant emission level monitoring in the laboratory to quantitatively evaluate the environmental effects of different stoves, identify the influencing factors and causes of differences in pollution emission levels, and propose furnaces Suggestions for improvement of pollution reduction such as R & D and design. The results show that:
① The emission of air pollutants differs greatly among different stoves, and the intensity of pollution emitted by the stoves with kang heating and cooking is the largest. The emission intensity of the three types of atmospheric pollutants (SO2, NOx and particulate matter) is 2.9 kg t-1 It is 1.6 times the average value; stoves using square coal technology have the lowest air pollutant emission intensity, which is 65% of the average value. ② The emission of gaseous pollutants in different furnaces at different combustion stages also showed obvious differences and characteristics. During the fire stage, the NOx emission concentration of the square coal stove is 0.49mg · m-3, which is 45% ~ 72% lower than that of other types of stoves; the SO2 emission concentration of the gasification anti-burning stove is 1.38mg · m-3. Compared with other types of stoves, the maximum reduction is 28%. ③ The factors that affect the emission of atmospheric pollutants of the stove include the application technology and the type of combustion. The stoves with square coal and gasification anti-burning technology have better environmental benefits, but the economic costs of the two types of stoves are 20,000 yuan and 18,000 Yuan, significantly higher than other types of stoves. ④ Considering the differences in pollution emissions from different stoves, it is recommended to adopt differentiated economic policies and strict emission and product standards, promote the use of energy-saving and environmentally friendly stoves, and reduce the emission of atmospheric pollutants from coal-fired stoves.

1. Introduction
The coal combustion process will release a large amount of pollutants, including particulate matter, sulfur dioxide (SO2), nitrogen oxides (NOx), volatile organic compounds (VOCs), carbon monoxide (CO), polycyclic aromatic hydrocarbons (PAHs), and polychlorinated biphenyls (PCBs) and dioxins (PCDD / Fs) and other harmful substances have a serious impact on the surrounding environment and...
human health [1]. Coal-fired power sources such as coal-fired power generation, coal-fired industrial boilers and residential coal-fired pollution sources are the main contributors to urban air pollutant emissions in China. During the heating season, air pollutants emitted from residential coal-fired sources are due to quiet weather. It is difficult to diffuse and accumulate in large quantities, and contribute to 15% to 27% of atmospheric PM2.5 pollution [2]. Therefore, controlling residents' coal-fired air pollution emissions plays an important role in improving China's atmospheric environmental quality [3].

Scholars at home and abroad have carried out a lot of research on the impact of residential coal combustion on atmospheric environmental quality and quantitative characterization of emissions. Previous studies focused more on old-fashioned coal-fired stoves. With the continuous advancement of air pollution control measures, the coal-fired stoves used in northern areas have been improved. New-type residential coal-fired stoves are located in Shandong, Liaoning, Inner Mongolia and Hebei. It has been promoted and applied to a certain extent, but there have been few studies on the differences and influencing factors of air pollutants emission from different new-type residential coal-fired stoves [4].

Therefore, in order to explore the differences in the emission of atmospheric pollutants from coal-fired stoves of different residents, this study selected 5 common and new types of residential coal-fired stoves to conduct simulated combustion experiments in the laboratory, to actually monitor their pollution emission levels and the resulting environmental benefits are evaluated. By analyzing the differences in pollution emissions of different stoves, identifying their influencing factors and causes, and combining the economic costs of different stoves, suggestions for pollution reduction such as stove design improvements are proposed to provide reference and support for reducing coal-fired air pollution emissions from residents.

2. Materials and Methods

2.1. Research object

| Stove | Technology type | Type of combustion | Features |
|-------|-----------------|--------------------|----------|
| A     | Square coal technology | Back burn | Horizontal push feed method |
| B     | Baffle heat transfer technology | Burning | Secondary air design, baffle plate structure |
| C     | Integrated technology of cooking and heating | Burning | Secondary air design |
| D     | Gasification combustion technology | Burning | Gasification combustion, secondary air design |
| E     | Gasification combustion technology | Back burn | Gasification combustion, secondary air design |

There are many types of coal-fired stoves for residents. At present, there are hundreds of stove models in the market, which use different combustion and technology types. According to the type of combustion, it can be divided into forward burning stove and reverse burning stove. In order to explore the differences in air pollutant emissions between different technology types and combustion types of stoves, this study selected five common and new types of residential coal-fired stoves (square coal) based on the results of field research and questionnaire surveys conducted by the research team in rural areas. Stoves, baffle heat exchange stoves, Kang heating cooking integrated stoves and gasification combustion stoves were tested in the laboratory simulation combustion. The specific technical information is shown in Table 1. The emission types of the five types of coal-fired stoves are the same. Except for the square coal stoves, the particulates of the other four types of stoves will be discharged into the atmosphere through the agitation of the furnace when feeding. The stove with secondary air supply design can make the combustion more full and reduce the emission of atmospheric pollutants.
2.2. Laboratory simulation combustion platform
In this study, the smoke hood method recommended by the US Environmental Protection Agency (EPA) was used for the experiment. The laboratory simulation combustion platform was set up in the laboratory room of the Beijing Academy of Environmental Protection Sciences, including gas collection hood and dilution Pipes, valves, filters, fans, exhaust pipes, etc. Carry out simulated combustion experiments on the selected 5 kinds of stoves in turn, and each stove performs 2 ~ 3 sets of experiments and monitoring of air pollutant emissions. The specific operation process is: after putting an appropriate amount of coal in the furnace, it is ignited with liquefied petroleum gas, the ignition time is 5 ~ 15min, after the ignition is completed, the fire is burned for 40 ~ 80min, then the furnace door is closed, and the fire is closed, 12h is a cycle. During the combustion process, the air is drawn into the flue gas hood together with the high-concentration flue gas by the fan's draught effect, so that it is evenly mixed in the flue, and the particulate matter and gaseous pollutants are sampled in the monitoring section. According to the requirements of literature, five types of stoves uniformly use briquette with sulfur content of 0.3%, ash content of 25%, volatile content of 11% and calorific value of 24 MJ kg⁻¹.

2.3. Atmospheric pollutant monitoring and analysis methods
This study uses the dilution sampling method, that is, the method of measuring the atmospheric pollutants after mixing the flue gas with the air after dilution and cooling, to avoid the unstable flow rate, high temperature and high pollution concentration when sampling directly from the flue gas Situation interference. The specific atmospheric pollutant monitoring and analysis methods are shown in Table 2. For the particulate matter, this study uses the "IV501 dual-stage virtual impact particulate sampler" developed by Tsinghua University for continuous sampling, using a 37mm filter to collect the particulate matter, and classifying the particulate matter based on the difference in inertia size of the particulate matter with different particle sizes. Calibrate the instrument before sampling, and place the quartz film used for sampling in a muffle furnace at 600 ° C for 4 hours, cool it and place it in a desiccator for 24 hours. After weighing, place it in aluminum foil for use. After the sampling is completed, the filter membrane is placed in a membrane box, sealed and refrigerated and stored until analysis. For gaseous pollutants, NO-NO₂-NOₓ analyzer (42i), SO₂ analyzer (43i) and CO analyzer (48i) developed by ThermoFisher of the United States were used for continuous monitoring.

| atmospheric pollutant | equipment name | Instrument method                          |
|-----------------------|----------------|-------------------------------------------|
| NOₓ                   | NO-NO₂-NOₓ Analyzer | Chemiluminescence method                  |
| SO₂                   | SO₂ analyzer     | Pulsed fluorescence                       |
| CO                    | CO Analyzer      | Infrared absorption method                |
| particulates          | IV501 dual-stage virtual impact particle sampler | Principle of Virtual Impact               |
3. Materials and Methods

3.1. Differences in air pollutant emissions from different stoves

According to the monitoring results, there are obvious differences in the emission intensity of air pollutants between different stoves, as shown in Figure 1(a). The sum of the emission intensity of 3 kinds of atmospheric pollutants (SO2, NOx and TSP) of 5 kinds of stoves is 1.20, 1.80, 2.88, 1.82 and 1.47kg t-1, and the average value is 1.83kg ꞏ t-1. The pollution emission of the old coal stoves has decreased significantly, because the five new stoves have been updated in terms of combustion method, air distribution design and furnace structure. Among the five new types of stoves, the K-heating integrated stove is the biggest in terms of pollution emission intensity, which can reach 2.88kg ꞏ t-1, which is 1.6 times the average value, which is related to its low combustion efficiency. The horizontal coal-burning technology A's horizontal reverse burning stove A has the smallest pollution emission intensity of 1.20kg ꞏ t-1, which is 65% of the average value. The application of square coal technology and horizontal back-burning technology makes the coal combustion fully burn and improve it. It improves the combustion efficiency and reduces the combustion temperature, thereby reducing the emission intensity of atmospheric pollutants.

As shown in Fig. 1 (b), stove C has a low combustion efficiency, not only exhibits a high CO emission factor (65.3g kg-1), but also has the highest SO2 and NOx emission factors among the five stoves. Stove E adopts gasification technology and anti-burning technology, which effectively improves the combustion efficiency and produces a low-emission effect. Therefore, its CO and SO2 emission factors are small, 34.0g ꞏ kg-1 and 0.40g ꞏ kg-, respectively. 1. The square coal stove A adopts the horizontal back-burning combustion method to effectively improve the combustion efficiency, reduce the
combustion temperature, and effectively reduce the emissions of NOx and CO. The emission factors are 0.36g · kg⁻¹ and 36.4g · kg⁻¹ respectively. The particle emission intensity of square coal stove A is significantly lower than that of other stoves. The reason for the significant difference is that the square honeycomb type coal honeycomb coal type and flat push feed method adopted by the stove are helpful to reduce the combustion temperature. The disturbance to the furnace during the feeding process is low, which makes the emission intensity of the particulate matter the smallest. The emission factor of the total particulate matter (TSP) of other types of stoves is between 0.47 ~ 0.68g · kg⁻¹. The square coal stoves have only 0.19g · kg⁻¹, and the emission reduction effect can reach more than 60%. The effect is obvious; the average emission intensity of PM10 and PM2.5 of the five stoves are 0.41g · kg⁻¹ and 0.18g · kg⁻¹, respectively, the proportion of TSP is 91% and 79%, and the particle size is mainly concentrated in 2.5μm. In the following, the fine particles are mainly used, and the differences between the PM10 and PM2.5 emissions of the five stoves show a high consistency with TSP.

3.2. Changes of SO2 and NOx emissions in different combustion stages

The gaseous pollutant emissions of stoves at different combustion stages also show obvious differences and characteristics. The SO2 and NOx emissions of different types of stoves during the ignition, vigorous and sealing stages are shown in Figure 2(a) and Figure 2(c). It can be seen that the SO2 and NOx pollutant emission levels during the vigorous stage are relatively high, fully related to the combustion at this stage, also shows that the type of combustion is the most important factor affecting pollutant emissions. Gasification anti-burning stoves and square coal stoves all show lower emission levels of gaseous pollutants during the ignition, vigorous and flame sealing stages.

![Fig 2. Differences of gaseous pollutant emission in different combustion stages of stoves](image-url)
During the vigorous fire stage, the NOx and SO2 pollutant emission concentrations are relatively high. As shown in Figure 2 (b), the average SO2 emissions of the five types of stoves during the vigorous fire stage are between 0.49 and 1.62 mg · m⁻³, and the square coal stove A has the lowest SO2 emission levels during the vigorous fire stage. It is 0.49 mg · m⁻³, and the SO2 emission level of Kang heating cooker C is the highest, the average emission concentration is 1.62 mg · m⁻³, and the highest real-time concentration can reach 2.50 mg · m⁻³. As shown in Figure 2 (d), the average NOx emissions of the five types of stoves during the vigorous fire period are between 1.38 and 1.88 mg · m⁻³, of which the NOx pollutant emission level of the gasification anti-burning stove E is low. The average emission concentration of NOx is 1.38 mg · m⁻³, the NOx emission level of the baffle heat exchange furnace is relatively high, and the highest real-time concentration can reach 4.12 mg · m⁻³. The sulfur content in coal is the most important factor affecting the generation of SO2 [25]. The fuel consumption in the Wanghuo combustion stage is the largest. In addition, the sulfur in the fuel is more easily oxidized at high temperatures, resulting in SO2 emissions during the Wanghuo combustion stage. Significantly improved; some studies have shown that [26,27], hot nitrogen is difficult to form under low temperature conditions. After the furnace temperature reaches above 1000 °C, the release rate of hot nitrogen rises rapidly, while the burning stage of civil coal burning stoves The internal temperature is within the temperature range formed by hot nitrogen, thus causing a large amount of NOx pollutant emissions.

It can be seen from the distribution of gaseous pollutant emission concentration in different combustion stages that the five types of stoves show differences in environmental benefits at different stages. The gasification anti-burning stove E has NOx emissions during the ignition, vigorous fire and seal fire combustion processes The intensity is at a relatively low level, and the SO2 emission intensity at the stage of sealing fire is at the lowest level; the SO2 emission intensity of the square coal horizontal reverse burning stove A during the ignition and vigorous combustion process is at a relatively low level. The emission difference has a great relationship with the furnace design, combustion technology and temperature control and optimization of the stove.

On the whole, in order to achieve the ultimate goal of pollutant emission reduction, stove manufacturers should produce square coal technology and gasification anti-burning technology stoves as far as possible while ensuring economic costs, and install additional coal-fired stove installations for residents Research on the direction of dust and smoke removal devices; at the same time, the government should vigorously promote furnaces with good environmental benefits such as square coal furnaces and gasification anti-burning furnaces while ensuring subsidies.

4. Conclusion
In this paper, we obtained the emission intensity of the main air pollutants of five kinds of stoves and the difference in emissions at different combustion stages. Kang heating and cooking stoves have the highest emission level of air pollutants, the emission intensity of main air pollutants reaches 2.88 kg · t⁻¹, and the overall emission level of all three pollutants using square coal stoves is low, 1.20 kg · t⁻¹. The particle emission reduction effect can reach more than 60%.

In addition, this paper studies the SO2 and NOx emissions of the five stoves at different combustion stages. The pollutant emissions of the stove during the ignition phase rise rapidly, reaching the peak of the pollutant emissions during the vigorous fire phase, and finally the discharge continues to decline until the end of the combustion process during the flame sealing stage, in which the gasification anti-burning stove is in the whole process of combustion The NOx emission intensity is lower; the SO2 emission intensity during the entire combustion process of the square coal horizontal burner A is relatively low.

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