Study on NO\textsubscript{x} emission from an improved wood stove

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Abstract. Aiming at the problem that the NO\textsubscript{x} emission of civilian biomass wood stoves is difficult to meet the ultra-low emission requirements and the widespread use of biomass fuels, on the basis of traditional wood stoves, the stove structure is improved and a biomass pyrolysis device is added to make the stove have a reducing atmosphere. The final NO\textsubscript{x} emission mass concentration is reduced to below 150 mg/m\textsuperscript{3}, which meets the emission standards for civilian wood stoves.

1. Introduction
Energy is vital to the survival of human beings and the development of society. At present, energy distribution is uneven among regions in the world, and the difference in per capita energy consumption between developed and developing countries is becoming increasingly significant [1, 2]. The per capita primary energy consumption of developed countries and regions in North America, represented by the United States, is 200-300 times that of Africa [3]. Under the great changes in the world energy transition, the energy needs of more than 3 billion people in the world are still met by burning traditional biomass fuels such as agricultural and forestry wastes and animal wastes [4, 5].

Figure 1 shows the development process of human civil stoves [6]. The earliest stove used by humans was the three stone stove that appeared 200000 years ago. It is a stove surrounded by stones or soil as a wind shield and supported by cooking containers [7, 8]. Its emergence enables humans to use simple cooking containers to process food; but the heat utilization rate of three stone stove is very low and a large number of pollutants will be generated. With the maturity of technology, stoves with chimneys begin to appear. The performance of this way is better than that of three stone stoves. However, it still obtains heat through the direct combustion of biomass fuel [9].

Direct combustion of biomass is an extensive way of energy utilization (the energy utilization rate is only 5-10% [10-12]). The NO\textsubscript{x}, SO\textsubscript{2}, dioxins, soot and other toxic and harmful substances released by combustion not only pollute the atmosphere, but also cause respiratory diseases and eye diseases such as asthma and lung infection [3, 13-15], and damage human health. This will limit the further development of biomass energy as a fuel. Therefore, it is of great significance to improve the
traditional wood stoves and solve the problems of low efficiency, unsustainable and excessive pollutant emission in the direct combustion of biomass through advanced combustion technology to alleviate the energy crisis and promote the energy transformation.

![Figure 1](image)

**Figure 1.** Development of civil stoves.

In this paper, a new type of wood stove is proposed. Under the condition of high temperature (800-900 °C) and low oxygen, the biomass in the pyrolysis cylinder is pyrolyzed and gasified to produce coke, CO$_2$, CH$_4$, water vapor and reductive gas products (CO, H$_2$, and H$_2$S, etc.) [16, 17], and the reductive biomass pyrolysis gas is passed into the combustion zone of the stove. Make its internal formation of reducing atmosphere, so as to reduce the generation and emissions of NO\textsubscript{x} and other pollutants, to solve the problem of pollutant emission; The solid product coke after pyrolysis can be further used or sold as fuel to increase the income of rural women and children, which has important practical significance.

2. Generation mechanism of NO\textsubscript{x}

Many researchers have done a lot of research on the formation mechanism of NO\textsubscript{x}. According to the source of NO\textsubscript{x}, it can be divided into three types: thermal NO\textsubscript{x} (accounting for 25% ~ 30%), fuel NO\textsubscript{x} (accounting for 70% ~ 80%) and fast NO\textsubscript{x} (about 5%).

Thermal NO\textsubscript{x} refers to the nitrogen oxide formed by the oxidation of N\textsubscript{2} in the air at high temperature during combustion [18]. This mechanism was first proposed by Zeldovich, a scientist of the former Soviet Union. The specific reaction process of thermal NO\textsubscript{x} is as follows [19]:

$$ \begin{align*}
O + N_2 & \rightarrow NO + N \\
N + O_2 & \rightarrow NO + O \\
N + OH & \rightarrow NO + H 
\end{align*} $$

Among them, reaction (1) is the rate control step of the reaction, and the required activation energy is the highest. From this formula, the generation rate of thermal NO\textsubscript{x} can be obtained:

$$ \frac{d[NO]}{dt} = 3 \times 10^{14} [N_2][O_2]^{0.5} \exp \left( -\frac{54000}{RT} \right) $$

Where, r = 8.314 J/(mol·K) - gas constant; T-thermodynamic temperature, K.

According to Formula (4), the main factors related to the generation of thermal NO\textsubscript{x} are [20]: reaction temperature, concentration during N\textsubscript{2} and O\textsubscript{2} reaction, residence time, etc., among which the reaction temperature has the greatest impact. When the reaction temperature increases, the generation rate of NO\textsubscript{x} increases exponentially. Due to the uneven temperature in the furnace during combustion, it is easy to produce a large amount of thermal NO\textsubscript{x} in the high temperature area. In addition, the concentration of O\textsubscript{2} and N\textsubscript{2} in the reaction and their residence time in the high temperature zone will also affect the generation of NO\textsubscript{x}. The higher the concentration of O\textsubscript{2} and N\textsubscript{2} involved in the reaction, the more NO\textsubscript{x} will be generated; The longer the residence time, the more NO\textsubscript{x} will be generated. In conclusion, the key to reducing thermal NO\textsubscript{x} emission is to reduce the average combustion
temperature in the furnace, especially to avoid local high temperature, reduce the reaction concentration of O$_2$ and N$_2$ and their residence time in the high temperature zone.

The generation of fuel type NO$_x$ depends on the nature of the fuel itself, mainly including the nitrogen content of the fuel, the specific surface area of the fuel, and the mixing degree of fuel and air. These factors jointly affect the generation of fuel type NO$_x$ [21]. There are two forms of N in fuel: volatile N and coke N. Volatile n refers to the intermediate products HCN, NH$_3$, etc. generated by the pyrolysis of nitrogen organic matter in the fuel, which can be precipitated together with the volatile in the fuel. Coke N is the nitrogen compound remaining in coke after the escape of command hair N.

In order to reduce fuel type NO$_x$, not only the generation of NO$_x$ should be suppressed as much as possible, but also the generated NO$_x$ should be reduced as much as possible. The research shows that when the excess air coefficient $\alpha > 1$, 60% of fuel type NO$_x$ comes from volatile. And in $\alpha < 1$, the NO$_x$ generated from volatile matter will be greatly reduced. Therefore, using the characteristic that N in volatile matter is very sensitive to the ratio of air to fuel when it is converted to no, we try to establish the excess air coefficient in the process of fuel combustion $\alpha < 1$ to convert fuel nitrogen into N$_2$ in a reducing atmosphere. In this unit, the reductive pyrolysis gas generated in the biomass pyrolysis cylinder is used to reduce NO$_x$.

Because the proportion of fast NO$_x$ is very small, and only in the excess air coefficient $\alpha < 1$, which is basically negligible, so it will not be considered in this paper.

3. Experiments

The experiment device used as shown in Figure 2, the wood stove is mainly composed of wood pyrolysis and combustion, compared with traditional stove, can convert wood into pyrolysis gas (CO, H$_2$, CH$_4$ and CO$_2$ and water vapor, etc.), tar and coke products, such as reducing the pyrolysis gas injection in combustion chamber of a stove, after pyrolysis of solid product coke can be used as fuel. On the one hand, the pyrolysis area can absorb the heat released by the combustion process to reduce the heat loss of the whole system. On the other hand, the reducing pyrolysis gas is sprayed into the stove at a specific angle to increase the turbulence of the air flow in the stove, avoid the formation of local high temperature zone, and form a reducing atmosphere in the combustion zone. While improving the overall calorific value of the fuel, the generation and emission of NO$_x$ are effectively reduced.

![Figure 2. Structure diagram of wood stove.](image)

3.1. The main body of the stove

This wood stove is conducted on the basis of traditional stove improved optimization, joined the biomass pyrolysis section, when the fuel burning in the stove, the heat makes the pyrolysis cylinder of biomass pyrolysis, pyrolysis gas is generated and pyrolytic carbon, with reducing pyrolysis gas through pyrolysis of holes on one side of the cylinder into the stove, the content of NO$_x$ and SO$_2$ in the stove is reduced.
3.2. **Smoke test section**

The flue gas analysis and test part mainly include the flue gas analyzer, flue gas duct, filter, drying tower, etc., the flue gas discharged from the chimney is filtered and dried and then introduced into the flue gas analyzer to analyze its composition.

4. **Physical and chemical properties of raw materials**

The pyrolysis and stove fuel used in this experiment is chestnut wood, which is analyzed by ultimate analysis, proximate analysis, calorific value, thermogravimetric analysis. The results are as follows.

4.1. **Ultimate analysis and Proximate analysis**

The ultimate analysis of experimental raw materials is carried out with the element analyzer (Element Vario MACRO Cube) produced by Elementar Company in Germany, and the caloric value is carried out with the oxygen bomb calorimeter (ZDHW-8, Huatai Instrument Company in Hebi City, Henan Province, China). The results are shown in Table 1.

| The raw material | Ultimate analysis (%) | Proximate analysis (%) | Heating value (MJ/kg) |
|------------------|-----------------------|------------------------|-----------------------|
|                  | C[%]                  | H[%]                   | O[%]                  | N[%] | S[%] | A_ad | M_ad | V_daf | FC_ad | LHV_a | HHV_b |
| chestnut         | 46.43                 | 6.03                   | 44.25                 | 0.33 | 0.10 | 3.13 | 8.22 | 73.35 | 15.30 | 15.33 | 18.15 |

a Lower heating value.

b Higher heating value.

5. **Experimental contents and results**

5.1. **Experimental content**

The experiment was carried out in the environment shown in Table 2.

| The raw material | Ultimate analysis (%) | Proximate analysis (%) | Heating value (MJ/kg) |
|------------------|-----------------------|------------------------|-----------------------|
|                  | C[%]                  | H[%]                   | O[%]                  | N[%] | S[%] | A_ad | M_ad | V_daf | FC_ad | LHV_a | HHV_b |
| chestnut         | 46.43                 | 6.03                   | 44.25                 | 0.33 | 0.10 | 3.13 | 8.22 | 73.35 | 15.30 | 15.33 | 18.15 |

a Lower heating value.

b Higher heating value.

5.1. **Experimental content**

The experiment was carried out in the environment shown in Table 2.

| ambient temperature | relative humidity | Experimental site |
|---------------------|-------------------|-------------------|
| 21.7~27.6 °C        | < 85%             | Outdoor, altitude is 564m |

German testo 350 flue gas analyzer is used for the determination of the concentration of NOx, SO2, CO and other flue gas components. rayger 3I and rayger 3I high temperature infrared thermometer are used to measure the flue gas temperature at the outlet of stove and chimney.

In this experiment, the raw materials used for pyrolysis and combustion are chestnut wood. The difference is that the chestnut wood used for combustion in the stove is branches or irregular block firewood, and the chestnut wood in the pyrolysis cylinder are thicker branches and trunk firewood section (as shown in Figure 3), so as to obtain regular pyrolytic carbon.

![Figure 3. Experimental fuels.](image-url)
5.2. Experimental result

Use the flue gas analyzer to measure the flue gas composition and concentration at the outlet of the stove chimney, and detect the pollutant concentration within 100 minutes after the normal exhaust of the chimney. 5 ~ 8 data are detected at each time point, and a total of 9 groups of data are measured.

According to GB 5468-1991 test method for boiler smoke and dust and GB/T 16157-1996 sampling method for particulate and gaseous pollutants in exhaust from fixed pollution sources, the measured emission concentration of air pollutants is converted into the emission concentration of reference oxygen content of air pollutants, as shown in Formula (5) [22, 23]:

\[ \rho = \rho' \times \frac{(21 - \phi(O_2))}{(21 - \phi'(O_2))} \]  

(5)

The meanings of each symbol are as follows:
- \( \rho \) —— Emission concentration of reference oxygen content of air pollutants, mg/m\(^3\);
- \( \rho' \) —— Measured emission concentration of air pollutant, mg/m\(^3\);
- \( \phi(O_2) \) —— Measured oxygen content;
- \( \phi'(O_2) \) —— Reference oxygen content.

Table 3 lists the emission standards of flue gas pollutants from household biomass cooking or heating stoves.

| Table 3. Current emission index of flue gas pollutants from household wood stoves [24]. |
|---------------------------------|------|------|-----|----------------|
| Flue gas pollutants | SO\(_2\) | NO\(_x\) | CO | Ringelman emittance |
| unit | mg/m\(^3\) | mg/m\(^3\) | % | - |
| Emission index | \( \leq 30 \) | \( \leq 150 \) | \( \leq 0.2 \) | 1 |

The \( NO_x \) limit and oxygen reference content of biomass boilers in non-urban construction areas in some provinces and cities in China are listed in Table 4.

| Table 4. \( NO_x \) emission indicators and reference oxygen content of biomass boilers in different regions [25-28]. |
|---------------------------------|----------------|----------------|
| region | \( NO_x \) emission index, mg/m\(^3\) | Reference oxygen content of biomass boiler, % |
| Guangdong Province | 240 | 9 |
| Jiangsu Province | 200 | - |
| Shaanxi Province | 100 | 9 |
| Shandong Province | 200 | 9 |

According to the above standards, the reference oxygen content corresponding to the emission index of flue gas pollutants of biomass boiler is 9%. Convert the measured pollutant concentration to the reference oxygen content of 9% and calculate its mean value. The variation relationship of the converted concentration with time is shown in Figure 4.

![Figure 4](image-url)  

Figure 4. Variation of \( NO_x \) concentration with time (reference oxygen content is 9%).
Convert the measured NO\textsubscript{x} to the reference oxygen content of 9%, as shown in Figure 4. In the obtained data, when the flue gas is stably discharged for 10 minutes, the NO\textsubscript{x} concentration reaches the maximum value of 271.04 mg/m\textsuperscript{3}; When the flue gas is discharged stably for 78 minutes, the NO\textsubscript{x} concentration reaches the minimum value of 20.76 mg/m\textsuperscript{3}; The mean values of NO\textsubscript{x} concentrations in the nine groups of data are 224.57 mg/m\textsuperscript{3}, 215.76 mg/m\textsuperscript{3}, 271.04 mg/m\textsuperscript{3}, 120.13 mg/m\textsuperscript{3}, 67.87 mg/m\textsuperscript{3}, 107.29 mg/m\textsuperscript{3}, 89.77 mg/m\textsuperscript{3}, 27.08 mg/m\textsuperscript{3} and 153.07 mg/m\textsuperscript{3} respectively.

About 10 minutes after the start of combustion, the NO\textsubscript{x} concentration in the flue gas was significantly reduced. During the entire combustion process, the NO\textsubscript{x} concentration was always lower than when the combustion started. At the 27th and 82nd minutes, the NO\textsubscript{x} concentration began to have a small range The rise of the fuel is due to the addition of fuel to the furnace at these two moments (adding 3.5kg and 4.8kg of chestnut to the furnace respectively, the fuel-type NO\textsubscript{x} increases, so the total NO\textsubscript{x} concentration increases).

It can be seen from the experimental results that when the combustion starts, although the NO\textsubscript{x} concentration in the furnace fluctuates after the fuel is added, its concentration begins to fall after a period of time and is always lower than the initial NO\textsubscript{x} concentration, which indicates that the biomass in the pyrolysis cylinder begins Decomposition produces reducing gas, which effectively suppresses the production of NO\textsubscript{x}.

Figure 5 shows a part of the pyrolysis chestnut in the pyrolysis pipe. The chestnut has been completely carbonized and can burn well after ignition. It can be sold as fuel to increase the economic benefits of users.

Figure 5. Pyrolytic carbon remaining in pyrolysis cylinder.

6. Conclusions
This study starts with the mechanism of NO\textsubscript{x} generation to reduce the generation of NO\textsubscript{x}. Compared with the traditional wood stove, this wood stove has a pyrolysis cylinder that can produce reducing gas products. The reduced gas after pyrolysis is injected above the combustion area in the furnace at a certain angle, which will increase the turbulence in the furnace and reduce the formation of local high-temperature area as much as possible, so as to reduce the generation of thermal NO\textsubscript{x}; At the same time, the reducing atmosphere will inhibit the formation of NO\textsubscript{x} and reduce part of NO\textsubscript{x} to N\textsubscript{2}; The biomass carbon after pyrolysis can be recycled as fuel, which has objective economy.

Influence of uncertain factors on NO\textsubscript{x} concentration and combustion stability.
1. The impact of the fuel used on NO\textsubscript{x} emission. During the combustion process, the nature of the fuel itself (such as nitrogen content, water content, etc.) will have a certain impact on the final NO\textsubscript{x} emission. In this experiment, only chestnut wood which is easily available at the experimental site is used as the fuel for testing. If the fuel with high nitrogen content is used, the corresponding final NO\textsubscript{x} emission will also be higher.
2. Influence of surrounding environment on combustion and NO\textsubscript{x} formation. Due to the different climatic environment and living habits of different users, the combustion and NO\textsubscript{x} generation of stoves will also be affected to a certain extent. For example, when used in outdoor windy / cold weather, the air entering the furnace increases, the excess air coefficient increases, the turbulence in the furnace increases, reduces the output of thermal NO\textsubscript{x}, and makes the combustion unstable;
3. Effect of fuel addition on NO\textsubscript{x} content and combustion stability. In daily use of civil stoves, the addition of fuel is often irregular. The content of NO\textsubscript{x}, SO\textsubscript{2} and CO in the furnace will change with the amount of fuel added, which increases the instability of NO\textsubscript{x} content to a certain extent. However, from the whole combustion process, the change of NO\textsubscript{x} concentration is in a specific range.

Existing deficiencies and research to be carried out in the next step:
1. During the experiment, local materials were used, chestnut wood easily available in the experimental site was selected as the raw material to detect the NO\textsubscript{x} emission and combustion performance of the stove, instead of widely selecting biomass fuels in different regions as the control, which will be supplemented in the follow-up research;
2. In this study, no catalyst is added to the catalytic combustion zone to verify whether the NO\textsubscript{x} concentration in the furnace can be reduced only by pyrolysis gas and reduce the overall cost of the furnace. This part will be considered to be removed in the future.
3. In this experiment, the orientation of the pyrolysis gas outlet holes on the outside of the pyrolysis tube is fixed, and the orientation of these holes will be changed in subsequent studies to explore the influence of the injection angle of pyrolysis gas on NO\textsubscript{x} and combustion stability.

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References
[1] S Danlami Musa, Tang Zhonghua, Abdullah Al O Ibrahim and Mukhtar Habib 2018 China's energy status: A critical look at fossils and renewable options Renewable & Sustainable Energy Reviews 81(2) 2281-2290
[2] BP 2021 BP Statistical Review of World Energy June 2021 https://www.bp.com/content/dam/bp/business-sites/en/global/corporate/pdfs/energy-economics/statistical-review/bp-stats-review-2021-full-report.pdf
[3] Sonam A Mehetre, N L Panwar, Deepak Sharma and Himanshu Kumar 2017 Improved biomass cookstoves for sustainable development: A review Renewable and Sustainable Energy Reviews 73 672-687
[4] Gallagher M, Beard M, Clifford M J and Craig M 2016 An evaluation of a wood stove safety protocol used for testing household cookstoves Energy for sustainable development 33 14-25
[5] Thacker K S, Barger M and Mattson C 2016 Balancing technical and user objectives in the redesign of a peruvian cookstove Development Engineering 2 12-19
[6] Qi J 2017 Research on the Mechanism of Exhaust Pollutants Reduction and Energy Saving for Residential Biomass/Coal Combustion Beijing, China University of Mining and Technology
[7] Albalak R, Bruce N, McCracken J P, Smith K R and De Gallardo T 2001 Indoor respirable particulate matter concentrations from an open fire, improved cookstove, and LPG/open fire combination in a rural Guatemalan community Environ. Sci. Technol 35(13) 2650-2655
[8] Balakrishnan K, Sankar S, Parikh J, Padmavathi R, Srividya K, Venugopal V, et al. 2002. Daily average exposures to respirable particulate matter concentrations from an open fire, improved cookstove, and LPG/open fire combination in rural households of southern India Environ Health Perspect 110(11) 1069-1075
[9] Ezzati M and Kammen D M 2002 The health impacts of exposure to indoor air pollution from solid fuels in developing countries: knowledge, gaps, and data needs Environ. Health Perspect 110(11) 1057-1068
[10] Ram S, Nagar P S, Kaushik S C and Jain S K 1984 Transient heat transfer for liquid boiling with a cookstove: a start of art Chang Village 6(6) 11-21
[11] Clark M L, Peel J L, Burch J B, Nelson T L, Robinson M M, Conway S, Bachand A M and Reynolds S J 2009 Impact of improved cookstoves on indoor air pollution and adverse health effects among Honduran women Int J Environ Health Res 19(5) 357-368
[12] Clark M L, Reynolds S J, Burch J B, Conway S, Bachand A M and Peel J L 2010 Indoor air pollution, cookstove quality, and housing characteristics in two Honduran communities Environmental Research 110 12-18

[13] Miriam Zuk, Leonora Rojas, Salvador Blanco, et al. 2007 The impact of improved wood-burning stoves on fine particulate matter concentrations in rural Mexican homes Journal of Exposure Science and Environmental Epidemiology 17(3) 224-232

[14] Smith K R 2002 Indoor air pollution in developing countries: recommendations for research Indoor Air 12(3) 198-207

[15] Horacio Riojas-Rodriguez, Patricia Romano-Riquer, Carlos Santos-Burgoa and Kirk R Smith 2001 Household firewood use and the health of children and women of Indian communities in Chiapas, Mexico International Journal of Occupational and Environmental Health 7(1) 44-53

[16] Molino A, Larocca V, Chianese S and Musmarra D 2018 Biofuels Production by Biomass Gasification: A Review Energies 11(4) 811

[17] Blander M 1999 Biomass gasification as a means for avoiding fouling and corrosion during combustion Journal of Molecular Liquids 83(1-3) 323-328

[18] Cen K F, Yao Q and Luo Z Y 2000 Advanced Combustion Zhejiang: Zhejiang University Press

[19] Miller J A and Bowman C T 1989 Mechanism and modelling of nitrogen chemistry in combustion Progress in Energy and Combustion Science 15(4) 287-338

[20] Permchart W and Kouprianov V I 2004 Emission performance and combustion efficiency of a conical fluidized-bed combustor firing various biomass fuels Bioresource Technology 92(1) 83-91

[21] Su Y X and Mao Y R 2005 NO\textsubscript{x} emission control technology from coal combustion Beijing, Chemical Industry Press

[22] Ministry of Ecology and Enviroment of the People’s Republic of China 1991 Measurement method of smoke and dust emission from boilers: GB5468-91[EB/OL] Beijing: Ministry of Ecology and Enviroment of the People’s Republic of China http://www.mee.gov.cn/image20010518/2435.pdf

[23] Ministry of Ecology and Enviroment of the People’s Republic of China 1996 The determination of particulates and sampling methods of gaseous pollutants emitted from exhaust gas of stationary source: GB/T16157-1996[EB/OL] Beijing:Ministry of Ecology and Enviroment of the People’s Republic of China http://www.mee.gov.cn/image20010518/2436.pdf

[24] Ministry of Agriculture and Rural Affairs of the People’s Republic of China 2013 General technical specification of domestic biofuel cooking stove: NY/T 2369-2013 Beijing: Standards Press of China

[25] Department of Ecology Environment of Guangdong Province 2001 Emission limits of air pollutants:DB44/27-2001[EB/OL] Guangdong Province: Department of Ecology Environment of Guangdong Province http://gdee.gd.gov.cn/attachment/0/382/382560/24724359. pdf

[26] Department of Ecology Environment of Jiangsu Province 2021 Integrated emission standard of air pollutants: DB32/4041-2021[EB/OL] Jiangsu Province: Department of Ecology Environment of Jiangsu Province http://hbt.jiangsu.gov.cn/module/download/downfile.jsp?classid=0&filename=8e6bf9e992354a07a227b6ae7bdbd953 .pdf

[27] Department of Ecology Environment of Shaanxi Province 2018 Emission standard of air pollutants for boilers: DB61/1266-2018[EB/OL] Shaanxi Province: Department of Ecology Environment of Shaanxi Province http://113.140.66.226:8111/d/file/standard/dbbz/20190116/1547630042550376.-pdf

[28] Department of Ecology Environment of Shandong Province 2019 Regional and Integrated Emission Standard of Air Pollutants: DB37/2376-2019[EB/OL] Shandong Province: Department of Ecology Environment of Shandong Province http://sthj.shandong.gov.cn/zwgk/gsgg/201906/P0201907 02356943750080.pdf.