Biomass stove for solid waste processing in remote areas

Abstract

This article introduces China's current production of biomass solid waste, emphatically introduces the processing method of biomass stoves in remote areas of the biomass solid waste. Briefly review the development of biomass stoves in China, studies the application status and technical level of biomass stoves, discuss the improved stove method.

1.Characteristics of remote areas solid waste

Basically, 90% of the land area is rural area in China and the rural population has accounted for 70 % of the total population. Due to such a large rural population and area, the daily garbage generated either in sizeor in the composition, or even in the coverage is extremely large, which to some extent, has increased the difficulty of the pollution control department and has also intensified the rural environmental degradation. Nowthe main pollutants in rural areas are some wastes which are difficult to degrade such as bags, diapers and sanitary napkins. Besides,suchwastes asbatteries, glass and the plastics thrown away by peopleare also the major factor leading to the deterioration of the rural environment. The solid wastes in city can be classified and disposed in time because the urban population is more concentrated, while the wastes in rural area cannot be centrally managed in that way because of the dispersed population. Therefore, therural solid waste disposal meets a bigger difficulty.

2.Classification and harm of rural solid wastes

2.1 Rural household waste

With the continuous development of the rural economy, there have appeared more items in farmer’s life, followed with which is more garbage. Especially the plastics and disposable itemssuch as plastic bags, baby supplies, hygiene items and other solid waste like headwear and footwear. These kind of household wastes are difficult to get corroded and decomposed, which will not only lead to a waste of resources, but also will cause serious environmental problems.

2.2 Agricultural solid waste

Due to the flourish of China's agricultural industry, especially the continuous development and changes in planting patterns and breeding ways, there has resulted in a variety of agricultural plastic film, plastic greenhouses, crop residues and animal dung. These agricultural wastes, if not treated properly, will cause a serious pollution to the land, air and water sources.

2.3 Industrial solid waste of township enterprises

In recent years, the rapid development of township enterprises in rural areas has played an important role in promoting rural economic development. However, the industrial solid waste pollution problems arisen this are also very serious, which has caused a great damage to natural resources and the environment in rural areas.

2.4 Other Solid Wastes

In addition to the above solid wastes, there are many other rural solid waste pollution problemssuch as the transfer of municipal solid waste to the countryside, the improperly discarded medical waste, electronic waste in rural area, etc.The number is very large, and these wastes are easy to produce varieties of heavy metal pollution.

China is a great agricultural country and also one of the most resourceful countries of straw. There are more than 640 million of straw produced every year.With the improvement of crop yield, the straw will also increase a lot. China has an excellent tradition to use strawin the history. Straw is used by famers to build houses to protect themselves from rain and sun, to cook meals and stay warm. It is also usedto feel animals and thenlivestock manureis in return for fertilization.Rational use of straw is one of the essences of Chinese traditional agriculture. In the stage of traditional agriculture, straw resources are mainly used for fertilization,fuel and fodderwithout any treatment. With the transformation of traditional agriculture to modern agriculture and the development of economy and society, Therural energy and feed structure has undergone profound changes. The traditional straw utilization has experienced a historic change.On the one hand, the scientific and technological progress has opened up new ways and new methods for the use of straw. On the other hand, the main agricultural areas have an increasingly large surplus of straw resources. The burning of straw on site by farmers has brought waste of resources and environmental pollution problems,which has causedthe attention of the whole society.

3.Outlook of rural solid waste treatment planning and method during the urbanization process

Duringthe building of new rural cities and towns, the construction of solid waste collection facilities is relatively lagging behind. The solid wastes tend to be thrown away, but the piled solid waste will cause a pollution to the surrounding environmentsuch as air, water and soil, and ultimately willdo harm to human health. In order to avoid taking the old path of pollution first, the construction of the supporting garbage collection system is particularly important in the process of urbanization in China. It will be a common problem faced by China and the worldto conduct an effective solid waste classification and resource utilization in rural areato prevent and control the rural environmental pollution from the sourcedue to the increasingly scarce resources.

During the construction of the new rural area andurbanization, we first should set up household garbage collection points based on the population size and population density. There should be a collection container, for example, a brick-concrete structure whose construction and maintenance costs are relatively low; the collection points should be seton both sides of the road accessible to the residents and near the road where the garbage truck is easy topass by in a residential area. Around the collection points should set up a drainage channel to avoid leachate of the solid waste polluting the soil. In addition, since thetransportation cost of a single group of villagers' waste quantity is very high, it is better to build a garbage transfer station. . From the operational cost analysis, transfer stations should take the distance between groups of villagers into account and regard the lowest cost as the principle to choose the constructionsites. With the exhaustionof various resources, resource utilization of solid waste will be its final destination, but the premise of efficient resource utilization isvalid classification of solid waste. Comparing to city, there is a relatively small amount of waste in rural areas. Thus, artificial and auxiliary mechanical classification of garbage is better to be adopted. Different disposal methods can be applied for different kind of garbage. For example, the high calorific value of garbage can be composted and used for organic fertilizer production. In addition, it can be burned to produce steam for electricity and gas production and pyrolyzed for gas production. The low calorific value of garbage can be directly buried or used as raw material to produce building materials. Through the effective classification and resource utilization of solid waste, we can not only dispose the solid waste thoroughly and effectively, but also achieve recycling use of solid waste. Therefore,it can be said that the effective collection and classification of the rural solid waste in the process of urbanization is the fundamental guarantee to achieve recycling and reduction target of rural solid waste. Aimed at the agricultural solid wastes such as straw etc, the effective ways to utilize the rural solid waste have been proposed based on the actual situation in China.

4.Stove Usage Status

Now there are approximately 2.8 billion people still rely on solid fuels (such as biomass and coal) for cooking and heating. These families are using the originalfire or low-quality stove. Due to the incomplete combustion of solid fuels, there will be toxic pollutants released inside or outside the room. According to the 2010 Global Burden of Disease study report, it is estimated that there are about 4 million people suffering premature death because of household air pollution generated byusing the solid fuels for cooking and heating[1].

China has recognized the seriousness of this problem since long ago and has implemented a number of promotional items and energy policies for home stoves in order to improve conditions for household cooking and heating. During the 1980s and 1990s, the National Improvement of Stove Project (NISP) which promoted 180 million’s improved stoves and became the world's largest and most successful national stove improvement program. Today, China already has the world's largest biomass stove industry. However, China is also facing a great challenge. More than half of the population (mainly in rural areas) isstill relying on solid fuels for cooking and heating, and most of them are using the traditional stoves. Therefore, it is a difficult task to let them cook and stay warm in a cleaner and more efficient way.

More than half of the population (mainly in rural areas) isstill relying on solid fuels for cooking and heating, and most of them are using the traditional stoves.This situation will remain unchanged in the near future. An efficient way to achieve clean cooking and heating is to covert to modernized energy which should be promoted. However, the modern energy price ishigher than solid fuel, and it has a higher requirement for the supporting stove and transport infrastructure. Poor rural users who cannot afford the modern energy and improved stoves may continue to rely on solid fuels as the primary energy for cooking and heating. The IEA estimates that there will be still 280 million people dependingon solid fuels for cooking and heating.

Since 2005, both the production quantity and registeredquantity of clean biomass stoves have been growing rapidly. Despite the late development, the production quantity of biomass stove went up by 8 times within five years and reached 500 thousand in the end of 2010. The registered quantity of national clean biomass stoves was us up to 85 million in 2010 and it was11 times as that in 2005.

The production of clean biomass stoves begins to achieve industrialization and commercialization, especially in poor rural areas with rich biomass resources (such as Sichuan, Guizhou and Chongqing). China had more than 300 biomass stove manufacturer in 2011, and the production capacity reached 1.6 million.

The solid fuels burning in old stoves have a lot of hazards, which makes it imperative to change the stove and replace the fuels. Data from the World Health Organization show that premature deaths caused by pollution can be avoided by using new clean stoves and fuels. Large-scale promotion of clean biomass stoves can bring a wide range of benefits in health, environment, economic and other aspects. Theapplication of cleaner stoves and fuel has reduced emissions of greenhouse gas generated by burning carbons and biomass, which slows down the change of global climate. 2010 USAID report on the mitigation measures of Asian black carbon emissions shows that the best way to reduce black carbon emission is to promote clean stoves and fuels. At the same time, it is also a cost-effective way to relieve greenhouse effect [7]. The use of clean and efficient stoves can also reduce the indoor air pollution, thus creating a more comfortable lifestyle and a cleaner home environment for residents.

5.Different types of stoves

Biomass stoves havemany different kinds. According to the using situations, the stovescan be divided into cooking stoves, heaters, bake furnaces, water heaters and so on; if the air goes into the stoves by free convection, it is known as natural air furnace. If the air is supplied by a fan, it is called forced air oven; according to feed types, the stoves can be divided into batch feed types and continuous feed type. The thesis classifiesthe stoves based on the stove structuresin order to make a better improvement of the biomass stoves.

5.1 Rocket stove

The most primitive rocket stove was invented by American Dr. Larry Winiarski in 1982 [2], and the main fuel is wood. When using, ignite one end of the wood and put it on the rocket stove grate through the side. Under the grate, there is also some space connected to the outside to let the primary air in. The wood is heated and gets burned inside the combustor and mixed with secondary air to produce a flame. During the using process, we need to push the wood slowly inside. The construction of the rocket stove is simple and easy to use. It has been widely promoted in Africa, North America and other places (see Figure 5-1).

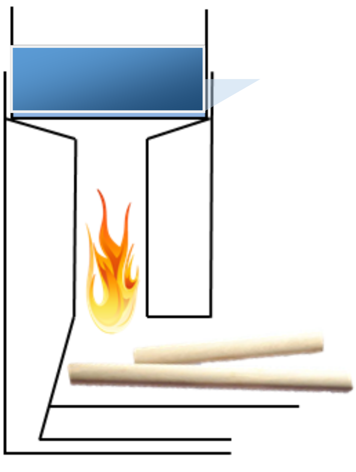

Fig.5-1 construction of rocket stove

5.2 Semi-gasified stove

In last century, the batch feeding and top ignition type semi-gasified stove (see Figure 1-5) began to appear in China. This stove's feature is to apply trans-combustion technology and achieve a clean and efficient combustion effect by controlling the air inside the combustor. The main fuels used are biomass briquette,wood or the like. When using the stove, you should fill up the furnace with biomass fuels in one time, ignite the wood from the top and let the fuels burning slowly from top to bottom. The air going into the furnace can be classified into the primary air and secondary air. The primary air goes into the combustor from the bottom to top to make the fuel heated and partially burned under hypoxic conditions. After thecombustible gas has been produced, it will get burned by mixing with the secondary air. The air can be fully mixed to achieve clean combustion and the CO, particulate matter, tar and other matters will burn out. At the same time, the stove fire intensity can also be controlled by regulating the volume of primary air and secondary air.

Now, there have been lots of semi-gasified stoves in production and application at home and abroad, and a variety of new semi-gasified clean stoves are widely popular with the majority of users.

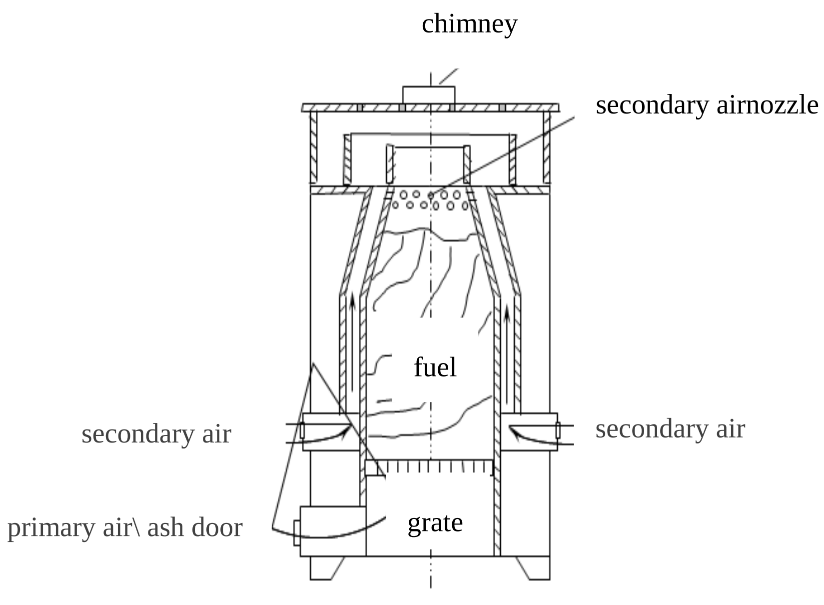

Fig.5-2 Schematic diagram of semi-gasified stove

The technology of biomass gasified stoves has been more mature, and its biggest advantage is no tar. Comparing to the gas stove, the semi-gasified stove can solve the problem of residual tar in a better way, which has greatly reduced the emission of the substances that is harmful to human health and which is also the advantage of the stove. This stove has two air supply vents, the primary air vent is at the bottom and the above is the secondary air vent. The primary air shall goes into the stove from the primary air vent, which is able to make the biomass fuel pyrolyzed and gasified. The air provided by the primary air vent can burn out the incomplete combusible gas and the gasified products shall get burned at the secondary air vent. The rational allocation of the primary air and secondary air will greatly improve the combusion efficiency of the biomass.

What happens in the semi-biomass gasified stove is the single-phase gas and air combustion. So the burning is more sufficiently and thereisno black smoke. There is only air spaying out of the secondary air nozzle. Blue and yellow gas flame can be seen in the actual combustion. The burning fuel in the bottom of the stove is black, but there is neither smoke nor particulates generated at the furnace mouth, which has greatly reduced the pollution emissions. In addition to thecharacteristic of low-emission, the biomass semi-gasified stove has high thermal efficiency, which can reach more than 35%generally. It is energy-saving and greatly improves the cooking efficiency comparing to the traditional stoves. The biamass fuels used in the biomass semi-gasified stove is processed by a molding technology, and the common one isthe biomass fuel.This fuel density is greatly increased in the combustion process and can extend the combustion time. Therefore, there is little unburned loss and nearly no black smoke during the combustion process.

The biomass stove has make a continuous progress in combustion technology. And the internal construction of the stove has also been undergoing changes and has become more efficient and complex. By a number of factor control analysis and tests as well as some field tests, the scholars at home and abroad have attempted constantly to improve the biomass stoves.On one hand, they try to enhance the thermal performance of the stove, on the other hand, they want to reduce emissions of the stove burning .

The primary air goes into the stove from the bottom of the grate. Add the secondary air nozzle in the upper outlet of stove to make the combustible gas in the combustor get fully burned. This semi-gasified combustion method willmake the fuels get fully burned, which reduces the emissions of the particulate and carbon monoxide, and significantly improves the indoor air quality[3].

Fig.5-3 Semi-gasified stoves

5.3 Traditional stoves

The traditional stoves are mostly made of clay and brick by farmers. At present, the traditional stoves are being widely used around the world [17] such as China's rural mud stove, Indian mud stove, South American baking pan stove, etc. The main fuel is straw and firewood. These stoves are usually made by people according to their experience and have very low thermal efficiency. But comparing to the primitive stoves, their performance has already get significantly improved.

 

Fig.5-4 Traditional Chinese cooking stove

5.4 Primitive stove

Three-stone stove is a representative of the primitive stovewhich uses three stones to stand up a pot. The burning wood is placed under the pot as shown in Figure 1-7. This kind of stove is still widely usedin some undeveloped or underdeveloped areas such as in Africa and some parts of Asia. But because of the bad air cannot circulation, it cannot get enough oxygen. As a result, there will be a large amount of smoke and pollution released due to the incomplete combustion. Such stoves are greatly influenced by the wind and cannot concentrate the heat when usedoutside. So the heat efficiency is very low [4].

Fig.1-7 Three stone stove

6.Historical development of biomass stoves

6.1The initial phase of the biomass stove development (before1980)

Before the 1980s, most of China's rural households used the traditional old stove which is artificially made of bricks and stones by farmers.

The main problems are high flame height, big stove door, big furnace, no grate, no air duct or no chimney, which results in incomplete combustion of all fuels and large amount of thick smoke. This will not only cause serious environmental pollution and damage to human health, but also will lose a lot of heat energy. . The thermal efficiency is very low at about 12%[5].

6.2Biomass stove improvement and promotion phase (1980s - mid-1990s)

6.2.1Promote the fuel-saving stoves

In early 1980s, Chinese government has planned to carry out the work of changing stoves and saving firewood in pilot counties in rural areas and has also included it in the Sixth Five-Year Plan. It was funded by the government for propaganda and training. There appeared a high tide of stove changing throughout the country. By the late 1990s, 200 million sets of improved stoves were successfully got promoted. Compared with the old stoves, the firewood saving stoves have optimized the relative distance between stove, pot and furnace and the design of flame height, smoke channel and ventilation etc. Besides, it has also made additional insulation measures and set up the waste heat utilization device in order to achieve thermal efficiency of 20% or more. Firewood saving stove is characterized by a fuel-saving, time-saving, easy to use, safety and hygiene.

6.2.2Stoves connected to kang(a heatable brick bed)

Most of people in the northern region have transformed the traditional kang. To connect the firewood saving stove with fuel-saving kang is namely the stove ground connected to kang which can be divided into floor type and elevated type. The former is connected to the ground and the flue of kang is also on the ground. This kind of kang is the most popular one. The latter flue of kang is not directly connected to the ground, which will not only save lots of building materials and avoid the loss of heat from the ground, but also increase the heat delivery surface of kang inside the room, letting more heat come in the room.

6.3Biomass stove technology innovation phase (the mid-1990s - 2005)

6.3.1Straw gasified stoves

This Gasified stove has connected the furnace directly to the hearth.The gasification conditions are difficult to control and the resulted combustible gas doesn't get any treatment.The gas quality and composition is unstable and discontinuous, whichwill affect the burning and even have safety problems. The more important question is the arbitrary discharge of tar and tar-contained water and causes pollution to the land and groundwater. In the combustion process, large amounts of harmful gas will be released, especially a lot of excessive carbon monoxide gas. It will do great harm to them if the farmers use it in this environment for a long time. It is better not to promote in the phase when the technology is immature.

6.3.2High efficiency and low-emission biomass stoves

The biomass fuel burns in the furnace of this stove. In order to increase the combustion efficiency, the primary air goes into the stove from the bottom of the grate. Add the secondary air nozzle in the upper outlet of stove to make solid biomass fuel and the gas in air get burned and transformed to single-phase gas combustion. This semi-gasified combustion willmake the fuels get fully burned, which reduces the emissions of the particulate and carbon monoxide, and significantly improves the indoor air quality. When using the fuel, it is usually ignited from the top and let it burn from top to the bottom, which is contrary to air flow. During the whole process from igniting the fuel to burning out, there is no black smoke. The tar and biomass carbon residue are all burned out completely. The stove has a strong competitiveness with the coal stove in performance. The high efficiency and low emission biomass stoveshould meet the following specifications:

Thermal efficiency: cooking stove> 35%

cooking and heating stove> 60%

heating stove> 65%

dust emission concentration <50mg / m3

SO2 emission concentration <30mg / m3

NOx emission concentration <150mg / m3

CO emission concentration <0.2%

6.4Rapid development stage (2005-present)

Since 2005, the production scale of stove enterprises has continued to expand. The production capacity of some biomass stove enterprises in Beijing, Shandong, Henan, Chongqing and other provinces has been over 30 thousand with increasingly higher production rate and gradually enhanced commercialization. And great efforts have been made in the research and development. Many coal-fired stove companies have begun to develop the biomass stoves, which makesthe biomass stove technology, obtain a rapid development. The international cooperation has also been strengthened. In 2005, Shell Foundationfunded the Sino-US excellent biomass stove selection project. There were altogether 46 enterprises to participate in which 19 enterprises passedthe primary selection and finally 4 enterprises won the Excellence Award. In August 2006, China's 15 biomass stoves were exported to India. the US and Chinese teams of graduate students conducted a field demonstration and market analysis in Phaltan town in western Pune city.Since 2007, The Ministry of Agriculture has carried out the project of "a furnace and a stove" project and run a large-scale pilot of biomass stove promotion in Sichuan, Gansu and other areas. 2007 US Environmental Protection Agency air partner organizations (PCIA) also funded China Rural Energy Industry Association in promotion of the excellent biomass stoves in the western region of China. During 2005 - 2009, Chinese experts were invited by some countries such as US, India, Indonesia, Thailand and Ugandato attend the International Conference on multiple biomass energy and introduce China's biomass stove technology and development, which has promoted international exchange and cooperation.

7.Research Progress in China and Foreign Countries

The Research of clean stoves is focused on thermal performance design, test analysis to pollution emissions, development of on-line detection of equipment, solid fuel technologies, air pollution and health effects, climate change analysis, carbon trading project methodologies, promotional models and policy interventions and other aspects. China has attached great importance to the promotion and industrial development of clean stoves and has also successfully implemented a number of projects. But in the study of cleanstoves, there are only a few number of research institutions such as Beijing University of Chemical Technology, China Agricultural University, Beijing Aerospace University, Tsinghua University, Peking University and Schindler Technology Group Co., Ltd working on the related researches. Their researches are mainly concentrating on the aspects of the stove thermal efficiency test, pollution emission of solid fuel combustion, biomass stoves and carbon trading development project. Now the researches are lack of systematicness and forwardness and still in the initial period.

In the developed countries, the cleaning stove research institutions are mainly located in the United States. The US government and research institutions have given great importance to its research and product development. The famous research institutions such as the UC Berkeley, the Lawrence National Laboratory of the United States, the California Institute of Technology USA,Oregon Approvach stove Research Center, Colorado State University and University of Illinois have made a large number of researches of the Chinese clean and efficient stove design, performance and pollution detection and health effects and has especially conducted an in-depth research ofstove thermal design and engineeringsimulation, indoor air pollution and automatic quick detection of smoke emissions,association analysis of pollution and health, climate change, international standards and carbon trading methodology .

8.IWA ClassificationSystem

In April 2012, IWA organization passed a cooking stove rating standard [6]which has divided the cooking stove performance test results into four levels and a fail-level. See the performance rating ranges in Table 8-1 and Table 8-2.

Table8-1 IWA stove tiers

Level	Description
0	Compared with field burning (baseline), there is no improvement
1	Compared to baseline, there is a certain improvement.
2	Significantly improved compared to baseline
3	The target of biomass stove can be realized at present
4	Able to meet the goals of health and environment

Table8-2 WBT test result tiers [7]

	Thermal efficiency and fuel use	
	High thermal strength（%）	Low thermal strength（MJ/min/L）
0	＜15	＞0.050
1	≥15	≤0.050
2	≥25	≤0.039
3	≥35	≤0.028
4	≥45	≤0.017
	COemissions	
	High thermal strengthCO-EF	High thermal strengthCO-EF（g/min/L）
0	＞16	＞0.20
1	≤16	≤0.20
2	≤11	≤0.13
3	≤9	≤0.10
4	≤8	≤0.09
	$PM_{2.5}$emissions	
	High thermal strength$PM_{2.5}$	Low$PM_{2.5}$（g/min/L）
0	＞979	＞8
1	≤979	≤8
2	≤386	≤4
3	≤168	≤2
4	≤41	≤1
	Indoor pollution discharge	

	IndoorCO-EF（g/min）	IdoorgPM$_{2.5}$-EF（mg/min）
0	＞0.97	＞40
1	≤0.97	≤40
2	≤0.62	≤17
3	≤0.49	≤8
4	≤0.42	≤2

9.Stove Performance Test Methods and Procedures

9.1 Laboratory equipments and materials

The basic test equipments and materials needed in the test are as follows:

1.Basic tools: electronic balance (measuring range: 220g, precision: 0.0001g and measuring range: 30kg, precision: 1g); K-type thermocouple thermometers; wet and dry thermometer; HI-Q environment glass fiber filters (with a diameter of 100mm); drier ; a standard evaporation pan (with an inner diameter of 28cm).

2.Stove Performance Test System(Portable Emission Measurement SystemPEMS)

The stove performance test system is able to monitor the stove emission situation in the test. The emission factors and real-time emission situation in the entire process of the experiment can be obtained through software processing. See Figure 2.1 for detailed information. The main monitoring objects are CO, CO2 and particulate matters (PM).

Figure 9-1 PEMS devices

The fan makes a negative pressure by exhausting the air at the end of the suction pipe. In the test, the gasgenerated by stove is collected by the gas trap hood at the front of the pipe, then mixed with the dilution air in the S-bend pipe and finally goes into the sampling pipe. The detectors on the sampling pipe include gas flowmeter, gas sampler, gas temperature detector as well as PM2.5 test system at the end of the pipe. The gas flowmeter is a differential pressure flowmeter which is used to calculate the real-time gas flow by measuring the gas pressure differences in the two ends. Test box is equipped with CO detector (electrochemical method), CO2 detector (non-dispersive infrared detection method) and PM detector (laser scattering method) which are connected to the computer through the data acquisition card. Gas temperature detector is applied to measure the flue gas temperature in the pipe for theconversion of the flue gas density with the purpose to calculate the emission factors. PM2.5 sampling system at the end of the pipe is consisted of a cyclone separator, a filter and a vacuum pump. Vacuum pump draws the flue gas into the sampling system with a sampling flow of 16.7L / min and removesthe particles whose diameter is greater than 2.5μm with the cyclone separator. PM2.5 will be collected by the filter. The detectors in the test box shall export the real-time test results via the acquisition card. The test results will be collected in the computer by the auxiliary software for analysis and calculation.

9.2 Experimental Method

The biomass wood particles(water content of about 10%) are selected as a fuel in the test and the top-ignition method (combustion selection of alcohol) is used. The experiment is carried out under the conditions when the ratio of primary air and secondary air remains the same and the fuel sizeand types as well as the other factors stay unchanged. At least three repeated experiments are conducted under each condition. Use PEMS to conduct a real-time measurement of the emissions of CO, PM and CO2.

To make a contrast of the stove performance before and after improvement, it is better to apply theexperiment method of CCT simulationcooking which is suitable for the situation of China. The research takes the experimenters as cooks,choose a simple common type of noodles of ingredients as the cooking standard. PEMS is adopted to collect the pollutants during the test process. The fuel consumption is calculated by comparing the fuel weight before and after cooking. Three repeated experiments will be carried out to make sure the coefficient of variation(COV) is less than 25%. The Specific operations is as follows:

Experiment preparations:

1.Dry the clean fiberglass filter in the drier one day earlier before the experiment. When there are a series of tests to be done, use markers to mark the filters lightly with numbers and place them in each layer of the steel frame orderly in the drier. Do not fold the filter paper.

2. Print and fill in the experimental record table in advance, the contents are as follows: Fill in the test-taker' name, experimental date, stove model number and repeat label, CSV file names of the experimental data records, laboratory testing fuel types (specify the fuel moisture content),room temperature, low heat value of firelighters, low heat value of the fuel, weightof the empty pan (no cover) and the filternumber used in the experiment in the experimental record table.Determine and record the fuel quantity needed for the experiment, firelighters' weight (early drying) as well as the weight of vegetables, noodles, spices and water. In the column of remarks, pre-fill in theoperational steps of the stove and calculate the operating time in advance.

3. The dried filter membrane shall be weighed for 10 times. Put down the results in the test record table. Install the filter membrane in the filter and connect to the vacuum pump and filter properly.

4. Check the chimney and make sure it is sealed. Check the vacuum pump, fan, stove performance test systems and computer power plug and make sure they are in good conditions. Check whether the ventilation duct, data acquisition card and filter membrane are installed properly.

Experimental Procedures:

1. Arrange the experimental ingredients as required in below table. Cut the carrot, turnip and potato cut into1cm3 cubes. Prepare the corresponding weight of flour, clear water, vegetable oil and soy sauce for spare use.

Table 2-1 cooking ingredients

Food ingredients	**Weight(g)**

carrot	100
turnip	100
potato	250
flour	300
clear water	1500
vegetable oil	70~100
soy sauce	25~30

2. Turn on the computer and enter into the logger software. Input the CSV file name of experimental data and name it in the way of "test time - Stove name – before or after improvement". Then open the stove performance test system and Livegraph Software for a two- minute warm-up.

3. Turn on the fan and the fume hood, check and make sure the ventilation duct is stable. Examine the pressure gauge to see if it is maintained at about 0.40. When the ventilation gets stable, we need keep the background value in more than 10 minutes.

4. Measure the required fuel and place it into the furnace (if there is a built-in fuel barrels, you need to weigh the empty barrels). Measure the firelighter's weight (and dish weight) and put it into the furnace. Write down the results in the record sheet.

5. As the background value is set, the test can be begun after the air temperature is recorded.

Operations of stove can be divided as ignition status, igniting while recording the time (realtime and logger time accurate to the second) and putting the pot. Turn on the vacuum pump after putting the pot and record the cooking time (realtime and logger time accurate to the second).

6. According to the normal daily cooking way, first add the cooking oil and put in the vegetables such as carrots, turnips and potatoes stir and fry when the oil temperature rise high. When the potato color begins to change, add 1500g water and 300g flour and waitfor the water to boil. When the water boils, record the boiling point and boiling time (realtime and logger time accurate to the second). Keep the water boiling for about 2 minutes, turn off the fire when the flour cooked and record the time.

7. Turn off the vacuum pump after the experiment comes to end. Quickly empty the charcoal and the remaining fuel at the bottom of stove's combustor into the vessel and close the lid to extinguish the still burning flame. After 10 minutes or so, when the charcoal and the remaining fuel temperature decrease, take out the remaining fuel in the vesseland weighthe charcoal. After that,remove the filter membrane and put it in the drier. After 24 hours, take the filter membrane out, measure its weight and record the data.

8. When the weighing is finished, ensure the ventilation of stove performance test system until the concentration of pollutants is reduced to the background value. Close logger and Livegraph software, turn off the stove performance test system, the fans and fume hoods, extractexperimental data of CSV file and save, turn off the computer.

9. Do some cleaning and make sure all the remaining fuel and charcoal are properly treated. Don't leave the lab until the stove becomes cool.

Experimental equipment and conditions.

10.Improved experimental design of semi-gasified biomass cooking stoves

Xunda C2.0-SW-IIO is a biomass cooking stove produced by Hunan Xunda Company mainly for domestic sales, as is shown in Figure 8-1.

Figure 10-1 Xunda C2.0-SW-IIO stove

Xunda C2.0-SW-IIO is an air forced biomass semi-gasified stove whose combustor is made of heat resisting materials. The combustor is 18 cm wide and 27cm high. On the top, there is a 12 cm mouth as burners. The stove is equipped with a 12 watt fan.

There are two kinds of secondary air vents on the stove, one kind is located around the burner as 16 holes with a diameter of 4 mm. The other kind is made up of 16 gaps which are 1cm long and 1mm wide. They are located under the top surface of the stove. The stove has one primary air vent which is composed of 8 holes with 1 cm diameter. They are located at the bottom of the combustor.Around the burner is also equipped with a metal ring to gather the fire.

The combustor is 5 cm away from the boiler, and there is a metal ring between the combustor and the boiler. The metal ring is to make a larger contact area for the hot flue gases and the boiler in order to increase the thermal efficiency. The fumes produced during cooking can be discharged by a 4 cm diameter smoke exhaust pipe.

XundaC2.0-SW-IIO is mainly for rural market in China. Due to Chinese people’s habit of quick stir and fry, most of them are not accustomed to cook with a low fire. Therefore, XundaC2.0-SW-IIO has been improved to adapt to China's rural market. Analog cooking experiment has also made to test it before and after the improvements

At present, Xunda C2.0-SW-IIO stove still has some problems:

1. The stove has low thermal efficiency. Large amount of heat has lost along with flue emissions. So the stove is lack of effective heat exchange;
2. Some of the charcoal is not burned completely after cooking, which causes fuel waste and is difficult to clean;
3. Sometimes the air is too strong in the charcoal burning process, which results in a lot of smoke and more particulate emissions;
4. The air control system cannot be precisely controlled and will result in pollution.

At the same time, the fire is easy to extinguish during the regulating process. There are four factors that will affect the stove performance, they are as follows:primary air and secondary air, height of combustion chamber, space for flame burn, tube for flue gas. Therefore, improvements can be made in above four aspects. Firstly, add a metal sheath at the top of the combustor. The metal ring can make the high temperature gas generated by the burning of fuels in the combustor go through the gap between the boiler and metal sheath and increase the heat exchange area and time. Secondly, add a metal pipe between the metal sheath and combustor. It gives the combustible gas and secondary air enough space and time to mix in it, making the burning cleaner. Finally, change the bottom of combustor into semicircular shape to allow the remaining charcoal to be mixed directly with the primary air in combustion.The charcoal can also stay in semi-circular bottom and be mixed with primary air for cleaner burning.

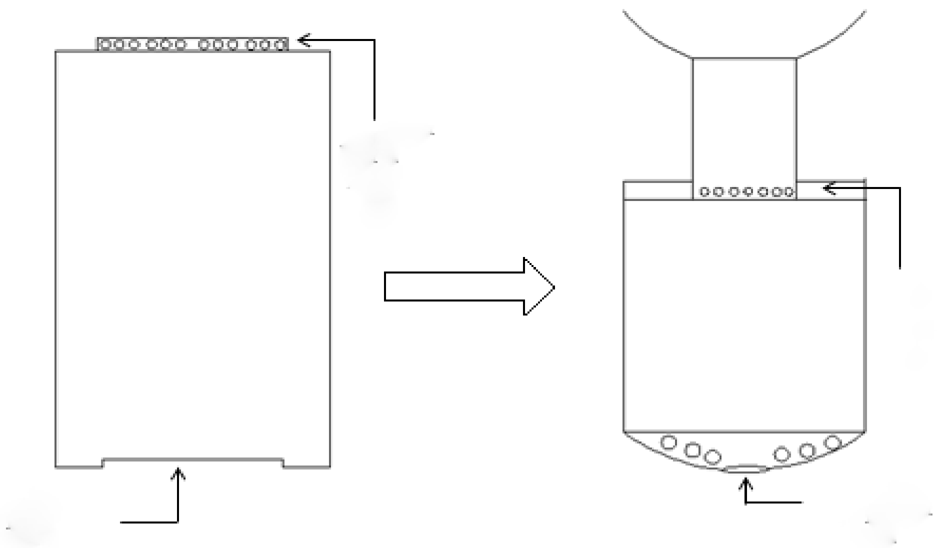

Figure 10-2 Simple sketch map for furnace improvement

Effects after improvement:

The cook thinks the unimproved stoves before have got slow fire and is not easy to control the fire intensity. They do not know when to changeeither. It will release smoke when the ratio of air is changed.After finish cooking, there leaves some fuels that are not completely burned out. The cook is generally satisfied with the improved stove. But the furnace is still too large and the stove overall safety performance needs to be further strengthened.

Table 5-2 Performance test of Xunda C2.0-SW-IIO stove after improvement

Parameter	Unit	Average	SD	Level
Thermal efficiency	%	45.79	1.51	4.0
CO Discharge	g/MJd	0.58	0.13	4.9
PM2.5 Discharge	mg/MJd	18.70	2.92	4.5
Indoor CO discharge	g/min	0.07	0.03	4.8
Indoor PM2.5 discharge	mg/min	1.95	0.03	4.0

The heat consumption has decreased by 7% after improvement; carbon monoxide emissions have fallen by nearly 50%; PM2.5 emissions have alsoreduced by 76%. The overall effect after improvement is very good.

[1] Fullerton D G, Bruce N, Gordon S B. Indoor air pollution from biomass fuel smoke is a major health concern in the developing world [J]. Transactions of the Royal Society of Tropical Medicine and Hygiene, 2008, 102(9): 843-851.

[2] Bryden M, Still D, Scott P, et al. Design Principals for Wood Burning Cook Stoves [M]. Aprovecho Research Center, 2005.

[3] Shen G F, Tao S, Wei S Y, et al. Reductions in Emissions of Carbonaceous Particulate Matter and Polycyclic Aromatic Hydrocarbons from Combustion of Biomass Pellets in Comparison with Raw Fuel Burning [J]. Environmental Science & Technology, 2012, 46(11): 6409-6416.

[4] Still D, Bentson S, Li H. Results of Laboratory Testing of 15 Cookstove Designs in Accordance with the ISO/IWA Tiers of Performance[J]. EcoHealth, 2014: 1-13.

[5] Xiaofu Chen，Guangqing Liu．Development and commercialization of improved stoves in China. Glow，Vol.39，2007．

[6] Lim S S, Vos T, Flaxman A D, et al. A comparative risk assessment of burden of disease and injury attributable to 67 risk factors and risk factor clusters in 21 regions, 1990 - 2010: a systematic analysis for the Global Burden of Disease Study 2010 [J]. The lancet, 2013, 380(9859): 2224-2260.

[7] IWA I. 11: 2012: Guidelines for evaluating cookstove performance [J]. International Organization for Standardization, 2012.