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EXPERIMENTAL STUDY OF HOUSEHOLD LOW EMISSIONS BIOMASS COOKSTOVE IN RURAL AREA OF INDIA

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Abstract- In rustic India a lot of women spending some hours a day cooking over an indoor open stove is a regular practice. What these women fail to recognize is that there is a hidden killer in their kitchen of burning biomass fuels causes nearly 500,000 deaths each year in India alone. In our country residential sector is a major consumer of energy whose energy require will grow with prosperity and population growth. About 67% of households in India, which is equivalent to 166 million households, remain wedded to traditional bio fuels for cooking. Solid biomass fuels will continue to play a significant role in energy mix of households and use of traditional cookstoves for utilizing these fuels in them will remain an area of concern for years to come. “Conventional Biomass Cookstove” is a physical structure that contains air-fuel ignition for heat release, and subsequently, directs the heat of ignition towards a cooking intention. The smoke emitted from such biomass Cookstove is made up of entirety suspended particulates and gaseous chemicals. The people in inaccessible and rustic areas cook their food on such poor thermal efficiency cookstoves that creates serious health problems for women and children. It was projected that about 3% of the diseases are caused due to partial combustion of biomass this results in around 1.6 million premature deaths every year including around 0.9 million children death. The scientific community around the globe is running on improving the cooking environment and has developed various models of improved biomass cookstoves. Apart from the type and eminence of the fuel used, intend of the cook stove chamber was the deciding factor for the associated emission causing by the fuel burning. Therefore, necessary to design and develop techno-economically feasible biomass cook-stove and civilizing the energy efficiency of biomass hygienic burning cook stoves, which potentially offers a highly cost-effective alternative for easing the burden of buying fuel by urban poor as well as rural population.

Keywords- Biomass cookstoves, Eco-friendly stove, Energy, Low pollution, Policy

1. INTRODUCTION

Energy is a crucial input for economic and social growth. In a world population of about 6.8 billion, around 3 billion people worldwide use solid bio fuels in different non-standard cooking vessels and various logistic constraints for cooking, heating and lighting. This number will boost to 2.6 billion by the year 2030 [1]. The combustion of such fuels results in extremely high levels of household air pollution which has been recognized as the leading environmental risk factor for cause of death worldwide [2]. In seven Asian countries (China, India, Pakistan, Nepal, Philippines, Sri Lanka and Vietnam), an expected biomass saving potential of 152 million tons of fuel wood and 101 million tons of agricultural residues, in the household cooking sector alone existed in early nineties [3]. Four main strategies have been employed to improve indoor air quality fist design and implementation of alternative cookstoves, second improved household ventilation, third increased use of efficient fuels and fourth changes in cooking behaviors. These strategies countenance numerous economic, engineering, and behavioral barriers for adoption. Improving combustion efficiency will not only reduce smoke and harmful emissions to human health, but also save on fuel cost by reducing bio fuel consumption. The Percentage of fuel used for cooking in ruler and urban India as shown in figure 1.1.

The factor that decides the cooking fuel choices are:

Biomass availability- Easy and almost free of cost availability of biomass fuels in rural areas is the main factor behind its high usage.

Economic condition- Income does influence fuel choice but not to the extent predicted by linear energy ladder.

Education and awareness- Education of the cook may affect fuel choice, but many a times she is not the decision maker for fuel purchasing for domestic usages.

Cultural practice and food preferences- Most of the household uses multiple fuels with clear preferences for a particular type of fuel for some food items.

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Therefore, the objective of present research is to study on cookstoves options with possible modifications and improved design models in terms of fuel characteristics, emission predictions and their energy utilization efficiency based on energy concepts.

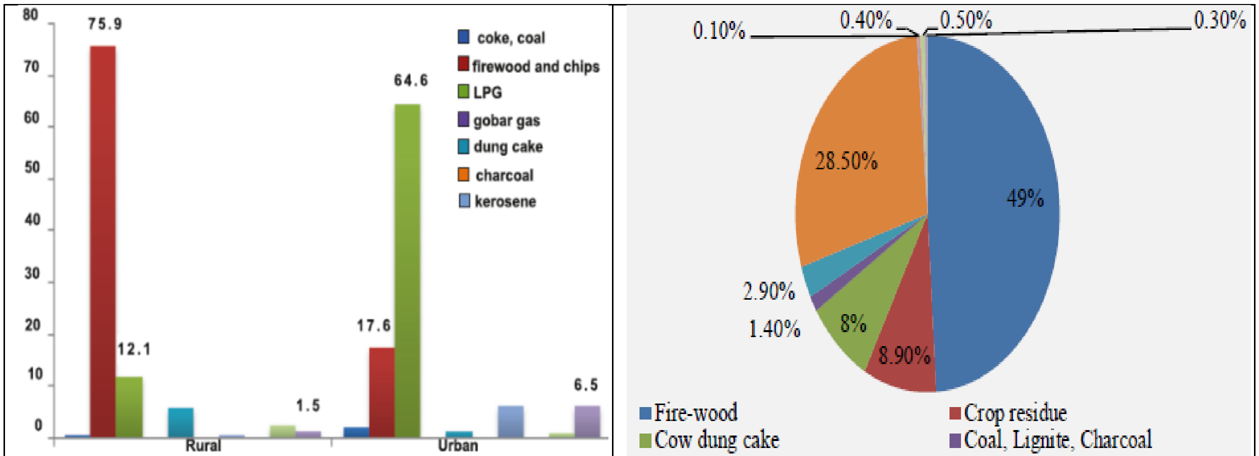

Fig. 1.1 Percentage of Cooking Fuel Used in Ruler and Urban India [4-6]

2. ENERGY SCENARIO AND BIOMASS COOKSTOVE

The energy demand is rising with growing population and prosperity. The residential sector is the major energy challenging sector in India, where highest percentage of thermal energy is used up in cooking. Therefore, both the commercial (electricity, kerosene, and liquefied petroleum gas) and non-commercial (direct use of biomass) energy are mandatory and used accordingly. According to the Census of India (2011), several households still rely on firewood fuel for cooking and approximately 20% rely on other forms of biomass fuels. In rural areas, about 80-90% of households are needy on biomass for cooking. In contrast to cleaner fuels, kerosene and LPG were accounted for 19% and 48%, respectively. Annual consumption of different fuels used in India as shown in table 2.1.

Table 2.1 Annual Consumption of Different Fuels in Indian

S. No.	Type of fuel	MT/Yr	Type of fuel	MT/Yr
1	Wood (She sham)	250	Diesel	68.75 (2013-2014)
2	Agro residue	120	Petrol	15.74 (2012-2013)
3	Dung	95	Gasoline	15.74 (2012-2013)
4	Coal	5	Natural Gas	34,638 MCM (2013-2014)
5	LPG	15	Kerosene	7.16 (2013-2014)

3. PAST EFFORTS TO IMPROVED COOK STOVES IN INDIA [6-8]

It is motivating that though the organized efforts at national and sub-national levels for enhanced cook stoves started nearly 30 years back, their extensive use and success has not been enough and consistent. The community scientists, voluntary organizations, academics, strategy makers have all done their bit and pieces for the improved cook stoves shown in table 3.1.

3.1 Improved Cook stoves Need in India

The use of open fires and conventional stoves leads to deficient combustion of fossil fuel, causing high black Carbon emissions as shown in figure 3.1. Moreover, open fires and conventional stoves have lower combustion efficiency, leading to higher cooking times and incompetent use of fuel wood. Black carbon exists as particles in the atmosphere and is a main ingredient of soot. Black carbon outcome from the deficient combustion of fossil fuels, wood and extra biomass. Complete combustion would convert all carbon in the fuel into carbon dioxide. In practice, combustion is never complete then CO_2, carbon monoxide, volatile organic compounds, organic carbon (OC) particles and black Carbon particles are all formed [9]. On a global basis, approximately 20% of black carbon is emitted from burning bio-fuels, 40% from fossil fuels, and 40% from open biomass burning. The major sources of black carbon are Asia, Latin America, and Africa. Some estimates put that China and India jointly account for 25-35% of universal black carbon emissions. The end-user wanted more versatility in the fuel usage and less time in cooking, while, the improved cook stoves were designed completes the objective of fuel economy and less smoke.

Fig. 3.1 Rural House Hold Fuel Option in India

Table 3.1 Past Effort to Improve Cook Stove in India

S. No.	**Manufacturers**	**Model & Fuel used**	**Performance parameters as per test testing conducted in MNRE supported test centers**
	I. Natural Draft Cook stoves- Domestic size		
1	**Unicus engineering private limited** Bhubaneswar	Harsha (CSIR, IMMT Design) (Fuel- Wood)	Thermal efficiency: 26.7 % CO : 5.10 g/MJ_d TPM : 272.07 mg/ MJ_d Power output : 1.83 KW
2	**Vikram stoves & fabricated** Osmanabad	Bio-classic (Fuel- Wood)	Thermal efficiency: 26.01 % CO : 4.54 g/MJ_d TPM : 315.38 mg/ MJ_d Power output : 1.49 KW
3	**Greenway grameen infra Pvt. Ltd.** Navi Mumbai	Greenway smart cook stove (Fuel- Wood)	Thermal efficiency: 24.1 % CO : 3.0 g/MJ_d TPM : 320 mg/ MJ_d Power output : 0.8 KW
4	**M/s Ravi engineering & chemical Works** New Delhi	Firenzel (Fuel- Wood)	Thermal efficiency: 26.62 % CO/CO_2 : 0.041 g/MJ_d TPM : 1.92 mg/ MJ_d Power output : 0.74 KW
5	**Adarsh plant protect Ltd.** Anand	Adarsh (Nirmal) (Fuel- Wood)	Thermal efficiency: 22.40 % CO : 3.81 g/MJ_d TPM : 303.02 mg/ MJ_d Power output : 0.89 KW
6	**Isquare D charitable trust** Bangalor	Chulika (Fuel- Wood)	Thermal efficiency: 29.77 % CO : 2.57 g/MJ_d TPM : 228.37 mg/ MJ_d Power output : 0.74 KW
	II. Forced Draft- Community size		
1	**Alpha renewable energy Pvt. Ltd.** Anand	Eco chulha-XXXL (Fuel- Wood)	Thermal efficiency: 32.28 % CO : 1.35 g/MJ_d TPM : 79.77 mg/ MJ_d Power output : 3.32 KW
2	**Sacks right energy innovations** Bangalore	Ojas- M06 (Fuel- pellets)	Thermal efficiency: 35.11 % CO : 1.05 g/MJ_d TPM : 69.01 mg/ MJ_d Power output : 5.43 KW
3	**Sacks right energy innovations** Bangalore	Ojas- M09 (Fuel- pellets)	Thermal efficiency: 29.77 % CO : 2.45 g/MJ_d TPM : 99.01 mg/ MJ_d Power output : 6.39 KW

III. Forced Draft- Domestic size			
1	**First energy Pvt. Ltd.** Pune	Oorja (Fuel- pellets) IIsc- Design	Thermal efficiency: 32.90 % CO : 3.956 g/MJ_d TPM : 111.23 mg/ MJ_d Power output : 0.7 KW
2	**The Energy and Resources institute (TERI)** New Delhi	TERI SPT- 0610 (Fuel- Wood)	Thermal efficiency: 36.84 % CO : 2.25 g/MJ_d TPM : 147.40 mg/ MJ_d Power output : 1.08 KW
3	**Alpha renewable energy Pvt. Ltd.** Anand	Eco Chula-XXL (Fuel- Wood)	Thermal efficiency: 31.50 % CO : 1.90 g/MJ_d TPM : 97.52 mg/ MJ_d Power output : 1.10 KW
4	**Navdurga metal industries** Faizabad	Agni star (Fuel- Rice husk)	Thermal efficiency: 34.54 % CO : 5.23 g/MJ_d TPM : 79.59 mg/ MJ_d Power output : 2.16 KW
5	**Sacks right energy innovations** Bangalore	Ojas (Fuel- pellets)	Thermal efficiency: 35.33 % CO : 2.569 g/MJ_d TPM : 99.01 mg/ MJ_d Power output : 1.99 KW
6	**Ram tara engineering company** Aurangabad	Ramtara (Fuel- pellets)	Thermal efficiency: 34.1 % CO : 1.0 g/MJ_d TPM : 86 mg/ MJ_d Power output : 1.0 KW

4. MATERIALS AND METHODS

4.1 Design of Biomass Cook Stove [9-10]

Design of biomass cook stove depends on type of fuel used and operational output required. It will design on the basis of following factors:

4.1.1 Energy Needed

Basically variation in the energy requirement depends upon what type of food is cooking. Some heavy foods required more energy to cook as compared to light food. The amount of energy required to cook food can be computed using the formula

$$Q_n = \frac{M_f \times E_s}{t}$$

Heating values of Wood (dry) fuels vary mainly 18.5-21.0 MJ/kg
Per capita energy consumption/day = 11.6 – 49.3 MJ
Energy to cook 1 kg of food = 7.0-22 MJ

4.1.2 Energy Input Required

It refers to the amount of energy needed in terms of biomass as fuel to be fed into the stove. This can be computed using the formula

$$FCR = \frac{Q_n}{C_{vf} \times \eta}$$

4.1.3 Reactor diameter

The reactor diameter (cross-section of the cylinder where biomass burn) can be computed using the formula

$$D = \left(\frac{1.27 \times FCR}{SGR}\right)^{0.5}$$

4.1.4 Height of the Reactor

This determines how long would the cookstove be operated in one loading of fuel. The height of the reactor can be calculated as given below

$$H = \frac{SGR \times t}{\rho_{rh}}$$

4.1.5 Amount of Air Needed for Gasification

The rate of flow of air needed to gasify the biomass. This can be computed using the formula

$$\mathrm{AFR} = \frac{\varepsilon \times \mathrm{FCR} \times \mathrm{SA}}{\rho_a}$$

4.1.6 Superficial Air Velocity

It refers to the speed of the air flow in the fuel bed. Its value can be computed using the formula

$$V_s = \frac{4 \times AFR}{\pi D^2}$$

5. METHODOLOGY

The experimental study was carried out at National Institute of Technology, Jalandhar (Punjab). Water Boiling Test was done systematically for wood fuel in stove combinations. This stove was tested in a lab by using wood fuel. Different type of biomass like wood chips, pellets, biomass briquettes, small twigs, wood chunks and charcoal will use in this stove. The emissions from most bio-fuels can contrast during the burning method; integrated sampling is needed to cover a entire burn cycle from fire initiate to fire extinction in order to obtain emission data for signify the real burning situation. The Portable natural draft bio stove is made up of stainless steel combustion chamber. Slope inner side is given because the flame will untouched with the surface of cookstove which leads to decrease in surface temperature and heat loss. Cast iron grate was used. At the bottom of stove, there is a provision of holes for primary air to enhance the combustion. Due to density variation between cold and hot air, expected draft stoves air gets sucked due to buoyancy of hot flue gasses. For gasification 10-20% oxygen needed therefore primary holes were minor in size as compare to secondary holes. Secondary holes used on upper side of combustion chamber those purposed to enlarge the combustion temperature and reduction in the emission from the cookstove. Burn rate was deliberate continuously with change in weight of fuel. Fuel stacked inside the combustion chamber in honeycomb fashion and placed on weighing balance to determine continuous loss in fuel weight. A heat resistance sheet was kept on weighing balance to prevent from heat and then stove was placed above it, as shown in figure 5.1 and 5.2.

Table 5.1 Technical specification of the biomass cook-stove

S. No.	Contents	Updraft biomass cookstove
1	Test product	Wood
2	Diameter (D_o)	25 cm
3	Diameter (D_i)	Conical (15 to 20 cm)
4	Weight of cookstove	7 kg
5	Height of reactor	29 cm
6	Air flow rate	1.75 m^3/hr
7	Thermal insulation	Perlite & clay with mix. Rato 1:1

Few ml of kerosene and easily combustible kindling used to ignite the fuel. Once combustion started, a pot containing known amount of water was placed on a cook stove during experiment. Data loggers were used to measure temperature at different location of gasifier cook-stove. Four K-type thermocouples were positioned at different locations. Two thermo couples were placed, one each at indoor and exterior of the combustion chamber. Additional two thermocouples were positioned at outer wall of designed hood and at exit of the flue gas to measure temperature of flue gases. Technical specification of the biomass cook-stove is given in Table 5.1.

Fig. 5.1 Design Process of Biomass Cook Stove

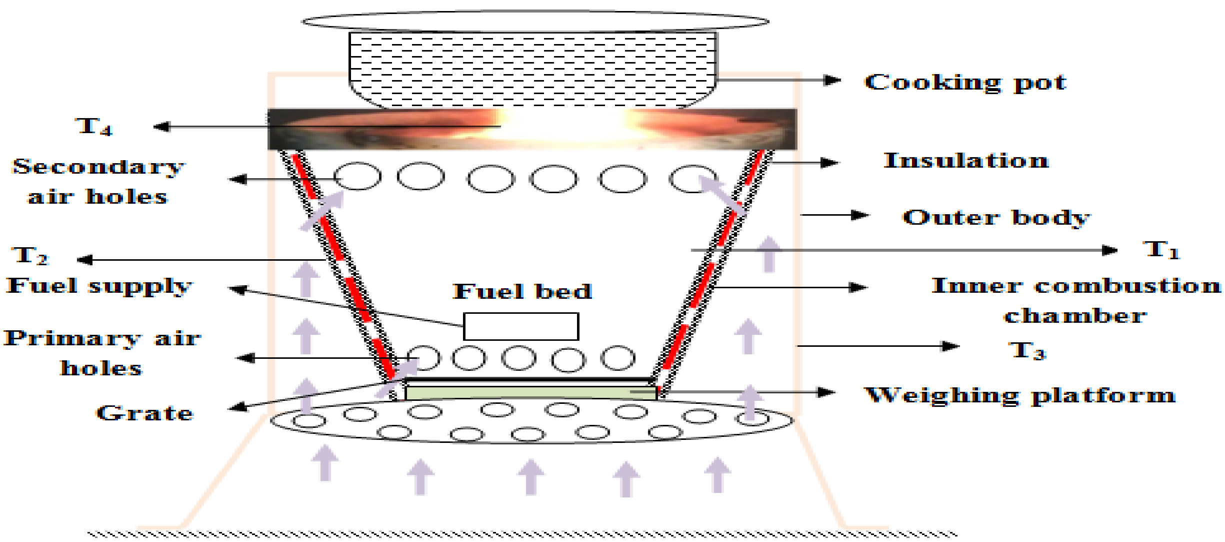

Fig. 5.2 Schematic of Experimental Setup for Biomass Cook Stove

6. TESTING OF COOKSTOVE

The cook-stove performance tests have been performed as per Indian standard 13152: Part 1. [6]

6.1 Burning Capacity Rate

Stack the fuel in a honey comb fashion in combustion chamber up to ¾ of the height

$$\text{Burning capacity Rating} = 2\,(M_1 - M_2) = 1.87\ \text{kg/hr}$$

$$\text{Heat input per hour} = 2(M_1 - M_2) * C_v\ \text{kcal/h}$$

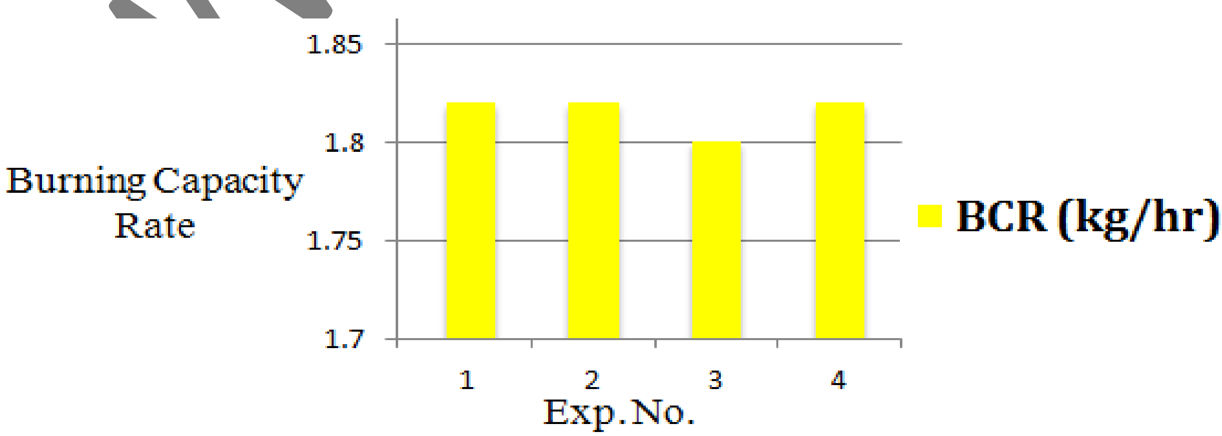

Fig. 6.1 Graph of Burning Capacity Rate

6.2 Thermal Efficiency

Heat output of the stove H_{out} (kJ):

$$H_{out} = [(n-1) * (W * C_v + w * C_w) * (t_2 - t_1)] + [(W * C_v + w * C_w) * (t_3 - t_1)]$$

Heat input of the stove (heat produced in kJ):

$$H_{in} = (X_{fuel} * H_{fuel}) + (X_k * H_k)$$

$$\text{Thermal efficiency } (\%) = \frac{\text{Heat actually utilized}}{\text{Heat theoritically produced}} = \frac{\text{Heat output of the stove}}{\text{Heat input of the stove}}$$

$$\eta = \frac{H_{out}}{H_{in}} = 30.186\ \%$$

6.3 Power Output

$$P_o = \frac{F * H_{fuel} * \eta}{3600} = 2.55 \text{ kW}$$

ABBREVIATIONS USED

M_1 = Initial mass of the cookstove with test fuel (kg)
M_2 = Mass of cookstove with fuel residues, after burning the test fuel for 30 minutes (kg)
C_v = 'Net' calorific value of the test fuel (kcal/kg)
P_o = Power output (kW)
F = Rate of consumption of fuel wood (kg/hr)
H_{fuel}= Calorific value of bio-fuel (kJ/kg)
η = Thermal efficiency of the Cookstove (%).
X_{fuel} = Mass of solid fuel consumed (kg)
H_{fuel}= Calorific value of wood/solid fuel (kJ/kg)
X_k= Mass of kerosene used for ignition (kg)
H_k = Calorific value of kerosene (KJ/kg)
w = Mass of water in vessel (kg)
W = Mass of vessel with lid (kg)
t_1 = Initial temperature of water (^oC)
t_2= Final temperature of water in (^oC)
t_3 = Final temperature of water in last vessel at the completion test (^oC)
n = Total number of vessel used
C_W= Specific heat of water (= 4.186 kj/kg/^oC)
C_v= Specific heat of material of the vessel (Al = 0.896 kj/kg/^oC)
Q_n = Energy wanted (Kcal/hr)
M_f = Mass of food (kg)
E_s = Specific energy use (Kcal/kg)
t = Cooking time per consume biomass (hour)
FCR = Fuel consumption rate (kg/hr)
Q_n = Heat energy needed (Kcal/hr)
C_{Vf} = Heating value of fuel (Kcal/kg)
η = Gasifier stove efficiency (%)
D = Diameter of reactor (m)
FCR = Fuel/Biomass consumption rate (kg/hr)
SGR = Specific gasification rate of biomass, (SGR of wood=75 kg/m^2-hr)
H = Length of the reactor (m)
ρ_{rh} = Biomass density (kg/m^3)
AFR = Air flow rate (m^3/hr)
Ɛ = Equivalence ratio, (in biomass gasification, the ER varies from 0.10 to 0.40)
SA = Stiochiometric air of fuel, (for wood, SA = 6.5 kg air/kg wood)
ρ_a = Air density (1.25 kg/m^3)
Vs = Superficial gas velocity (m/s)
AFR = Air flow rate (m^3/hr)
D = Diameter of reactor (m)

CONCLUSION

The biomass fuels will continue to use in future for many years. The requirement of efficient biomass cook stove for cooking, heating and lighting purpose in the rural/urban area is essential to save the environment and people from disease. We now understand that the international price of LPG which is petroleum product, likely will continue to increase faster than rural incomes. Biomass cook stove emission controlled by increasing the combustion temperature with the help of insulating materials proper selection and appropriate design for better ventilation. It was not only benefits the users but also various stake holders, who were active in the value chain smokeless stoves. The production and distribution of the biomass Cookstove stimulates the establishment of local entrepreneurial skills and provides low cost, affordable solutions that those who really want them. It became clear from the outcome of the research that the local design requirements called for a cooking solution able to complete the following physical and socio-cultural conditions i.e. adaptability to use dissimilar biomass fuels. A technical estimation of the Cook Stove had been tested in laboratory to define its eco-efficiency and low emission.

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