Final Report for Nirma University Funded Minor Research Project

1.	**Project Title:**	Design, fabrication and investigations of an improved biomass cookstove for rural development
2.	**Name of the Principal Investigator:**	Dr. D S Upadhyay & Prof. S A Memon
3.	**Project Approval Letter No. and Date:**	NU/DRI/MinResPrj/IT/2019-20/5504 dated 21st Dec 2019
4.	**Date of the Project Commencement:**	01/04/2020
5.	**Progress Report No.**	2
6.	**Period of Report:**	
	From (dd/mm/yyyy):	01/04/2020
	Up to (dd/mm/yyyy):	30/06/2021
7.	**Details of the Committee Members (Name, Designation)**	
	Member -1	Dr. B A Modi, Professor, MED
	Member -2	Dr. N K Shah, Asso.Professor, MED
	Member -3	Dr. S V Jain, Asso.Professor, MED
8.	**Details of Fund Utilization:**	
	Total Budget Sanctioned (in Rs.)	1,00,000/-
	Total Expenditure Incurred (in Rs.)	63,282/-
9.	**Please enclose a summary of the work done so far and results achieved.**	Attached
10.	**Attach copy of the papers published / presented, etc., if any.**	Attached
11.	**Is the work progress as per the original plan of work and towards achieving the objectives? If not, state reasons.**	Yes
12.	**Any other Information:**	N/A

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Remarks by the Committee Members:

HoD / Area Chair Concerned:

HoI/Dean Concerned:

Report No. 2: April 2020 to June 2021

1. Objectives of project

- Design and fabrication of a user friendly natural draft cookstove useful for the rural people.
- To demonstrate the operation and perform parametric study of the device to explore the sensitivity of the performance.
- Identify potential improvements using thermodynamic analysis.

2. Introduction

The invention of cooking has made the easily digestible food available to the human societies and thereby has made the room for the pursuit of higher purposes other than the acquiring the food at all the times. The cooking is the biochemical process whereby the complex compounds in eatables deconstruct into simpler forms of organic structures by raising and maintaining high temperatures. Pre-dominant source of the heat for the culinary has been the biomass traditionally. The modern times have brought in the availability of fuels like fossil gases and electricity based devices. Still large chunk of population depends on the biomass as their main source of fuel [1] for cooking purposes due to various reasons including the lack of last mile supply chain infrastructure and inability of hinterland people to afford them. The traditional biomass cookstoves have been pretty inefficient in terms of combustion efficiency and harmful emissions. The indoor pollution as the result of the use of traditional cookstoves has been responsible for chronic and severe repository illnesses in the traditional biomass cookstove using population. The large number of premature deaths are attributed [2] to the use inefficient traditional biomass cookstoves.

In addition to that, the time and effort (resources) put in by the people for acquisition of the biomass is substantial. This also results in the loss of green cover of the tress, when cut for the firewood purposes.

Literature available in the field of biomass cookstove improvements shows the attentiveness displayed by the research community especially in developing countries including by the welfare organizations, government departments and international alliances.

Improved cookstoves are classified into two types, namely natural draft and forced draft cookstove. In natural draft design, air required for combustion is provided by the draft created due to the density difference between hot and cold air, which results in density difference and consequent natural circulation. While on the other hand, in the forced draft cookstove, air is provided using an external source such as fan or blower [3].

The forced draft biomass cookstove requires the blower for the high availability of the draft through the stove, which may not be feasible for rural people despite their high combustion efficiency.

The natural draft cookstoves are available in single or double pot option, while the forced draft cookstove uses single pot cooking at a time. Natural draft cookstove efficiency ranges in 19-36%, while the forced draft cookstove can operate with hiked efficiency up to 44% [4]. Various researchers have found various efficiencies in variety of cookstove models.

Kshirsagar and Kalamkar[5]during their work, identified an important term i.e. Inlet area ratio. It is defined as the fraction of stove cross-section area, which is available for entry of air at the inlet. For an efficient combustion process to happen, the value of the inlet area ratio is found to be more than 0.7 [6].Insulation of cookstove is very important to increase the performance, as it reduces the heat loss through the heated walls. With proper insulation of the cookstove, efficiency was found to increase by 8% and consumption of fuel was found to be reduced by almost 5% [7]. The conductivity of material highly influences the selection of insulating material. Glass wool, ceramic wool, fire brick etc. are widely used as cookstoves' insulation. The increase in the thickness of insulating material, efficiency increases since it reduces heat losses. But after certain thickness insulation, the decrease in the heat loss reduces and makes it economically non-beneficial to add more insulation thickness. The optimum thickness of insulation should be selected by the parametric study of the cookstove under consideration.

With a decrease in pot gap width, efficiency increases. However, a very small pot gap width is not recommended, because it leads to blockage with soot deposition, which will decrease its efficiency[6]. Pot gap depends on the rate of fuel combustion. Minimum gap required for burn rate greater than 2 kg h^{-1} is 15mm [8]. If the pot gap is too large, flue gas will not make complete contact with pot surface and if it is too small then air supply becomes limited[8][9]. As an engineer, one knows the type of burners used in the boiler of thermal power plants, where turbulence in the flame is utilized for better mixing of air with fuel and higher combustion efficiency. Similarly swirling airflow condition is created in cookstove to increase the efficiency. It increases combustion efficiency and gives a stable flame [7]. A gasifier stove with central holes for gasification gas and channels around them for swirling airflow was suggested by Deng et al. [10]. With this design, the thermal efficiency of the stove is observed to increase by 10% and gasification efficiency by 2%. Skirt is a metallic part which is placed circumferentially around the pot. It is used to guide the flame on the pot increasing heat transfer, decreasing fuel combustion and hence efficiency [7]. 25-30% improvement in fuel consumption and CO emission are observed when pot with skirts was used [11].

The survey of literature shows the room for the proposed natural draft cookstove, where air cushion directed from the primary vent can work as insulation and the pre-heated air can be used for the secondary combustion to improve the combustion efficiency.

3. Design of Improved biomass cookstove

3.1 Geometric parameters

Assumed parameters

Power Rating: **3.5 kW**

Efficiency: **30% = 0.3**

Lower calorific value of wood (LCV) = 4300 kcal/kg

= **18000 kJ/kg**

Fuel consumption rate (FCR) = $\frac{Power}{C.V.*\eta}$

$= \frac{3.5*3600}{18000*0.3}$

= **2.34 kg/hr**

Specific Gasification Rate (SGR) for wood = **75 kg/hr**

Bulk density of wood (r) = **413 kg/m^3**

Time for cooking = **1.5 hr**

Reactor diameter (D) = $\frac{\sqrt{1.27*FCR}}{SGR}$

$= \frac{\sqrt{1.27*2.33}}{75}$

= 0.199 m

= 199 mm ~ **200 mm**

Height of reactor (H) = $\frac{SGR*T}{\text{density of wood}}$

$= \frac{75*1.5}{413}$

= 0.2724 m

= 272.4 mm ~ **275 mm**

Height above secondary air holes (h) = $\frac{H}{3}$

$= \frac{275}{3}$

= 91.6 mm **~ 90 mm**

Total height = H+h = 90+275 = **365 mm**

Stoichiometric air of biomass (SA) = 1.6

Equivalence ratio (E) = 0.3

Air density (r_a) = 1.225 kg/m^3

Primary air requirement

Air Flow Rate (AFR) = $\frac{Equilanceratio*FCR*SA}{airdensity}$

$= \frac{0.3*2.34*1.6}{1.225}$

= **0.913 m^3/hr**

For natural draft, primary air velocity is assumed 0.1 m/s.

AFR for primary = $\frac{n*\pi*d*d*v}{4}$ where n = no. of holes

Assuming diameter as **20** mm, **8** no of holes are required for primary.

Secondary air requirement

Assuming general composition of producer gas after primary combustion

Gas	%
H_2	14.1
CO	16.72
CH_4	1.04
CO_2	12.94
N_2	55.2

$CH_4+2O_2 \longrightarrow CO+2H_2O$

$CO+ 0.5\ O_2 \longrightarrow CO_2$

$H_2+ 0.5\ O_2 \longrightarrow H_2O$

Moles of O_2 needed for CH_4 = 0.0104*2 = 0.0208

Moles of O_2 needed for CO = 0.1672*2 = 0.0836

Moles of O_2 needed for H_2 = 0.141*0.5 = 0.0705

Total moles of O_2 needed = 0.0208+0.0836+0.0705 =**0.1749 moles**

For 1 mole of producer gas: in air 21 % oxygen is present

Air requirement = $\frac{0.1749*100}{21}$ = **0.83 moles**

Gas output from 1 kg of wood (theoretically) = 2.2 m^3

Total gas output rate = 2.2* FCR

= 2.2* 2.33

= **5.126m^3/hr**

Moles of gas output rate = $\frac{5.126*1000}{22.4}$

= **228.84 moles/hr**

For **228.84** moles of gas = **189.94** moles of air is required

Air flow rate = (kilo-moles of air* specific volume of air)

= 0.18994*24.465

= **4.6468**$\mathbf{m^3/hr}$

For natural draft, secondary air velocity is assumed 0.2 m/s.

Area of secondary holes = $\frac{AFR}{v} = \frac{4.6468}{3600*0.2}$ = 0.00645 m^2

AFR for secondary = $\frac{n*\pi*d*d*v}{4}$

Assuming diameter **25.4** mm, **12** no. of holes are required for secondary.

Air requirement	Number of holes	Hole diameter (mm)
Primary	8	20
Secondary	12	25.4

3.2 Ash tray calculation

Height of wood stack inside chamber = **260 mm**

Diameter of chamber = **200 mm**

Volume for wood = (22*200*200*260)/7

= **8168000** $\mathbf{mm^3}$

Bulk density of wood = 420 kg/m^3 (approx.)

Mass of wood = 420*0.008168

= **3.373 kg.**

Assuming 30% ash content

Mass of ash = 0.3*3.373 = **1.012 kg.**

Bulk density of ash = 750 kg/m^3 (approx.)

Volume of ash = **1350000** $\mathbf{mm^3}$

4. Experimental work

4.1 Material

Wood was selected as a primary food for the experimentation purpose due to its abundant and inexpensive nature especially in the rural area. In the world, most of the cookstoves are operated by wood only. Teak wood was collected from the nearby furniture factory. It was cut and sized before utilizing it in a cookstove. Leco AC-350 Bomb Calorimeter [Test method: IS 1350 (part II)-1970] was used to measure the heating value of the wood. Heating value and ultimate analysis were expressed on a dry basis whereas proximate analysis was carried out on a wet basis. Proximate [Test method: IS 1350 (part I)-1984] and ultimate analysis of the wood is mentioned in Table 1.

Table 1. Properties of feedstock.

		Wood
Physical Properties	Bulk Density (kg m-³)	413
	Particle Size (mm)	25×25×5
	Heating Value (MJ kg^{-1})	16.82
Ultimate analysis	Carbon	45.8
	Hydrogen	6.3
	Nitrogen	0.4
	Sulphur	0.002
	Oxygen[a]	40.79
Proximate analysis	Fixed Carbon[a]	5.92
	Volatile matter	82.84
	Ash	4.55
	Moisture	6.69

[a]*by Difference*

4.2 Experimental set-up

3.5 kWth top-lit updraft micro biomass gasifier-based cookstove is designed as per the stoichiometric calculation. It is prepared by mild steel 3 mm thick sheet. Grate and ashpit are added to collect char and ash particles after the combustion process of the feedstock. A number of Primary holes (20 mm) & secondary holes (25.4 mm) and total height were kept 8, 12, and 365 mm, respectively. The shape of the combustion chamber is kept cylindrical whereas the shape of the ashpit is kept rectangular. For the experimentation, two aluminum pots (18L capacity) were used to heat the water. CAD model of biomass cookstove is shown in Figure 1.

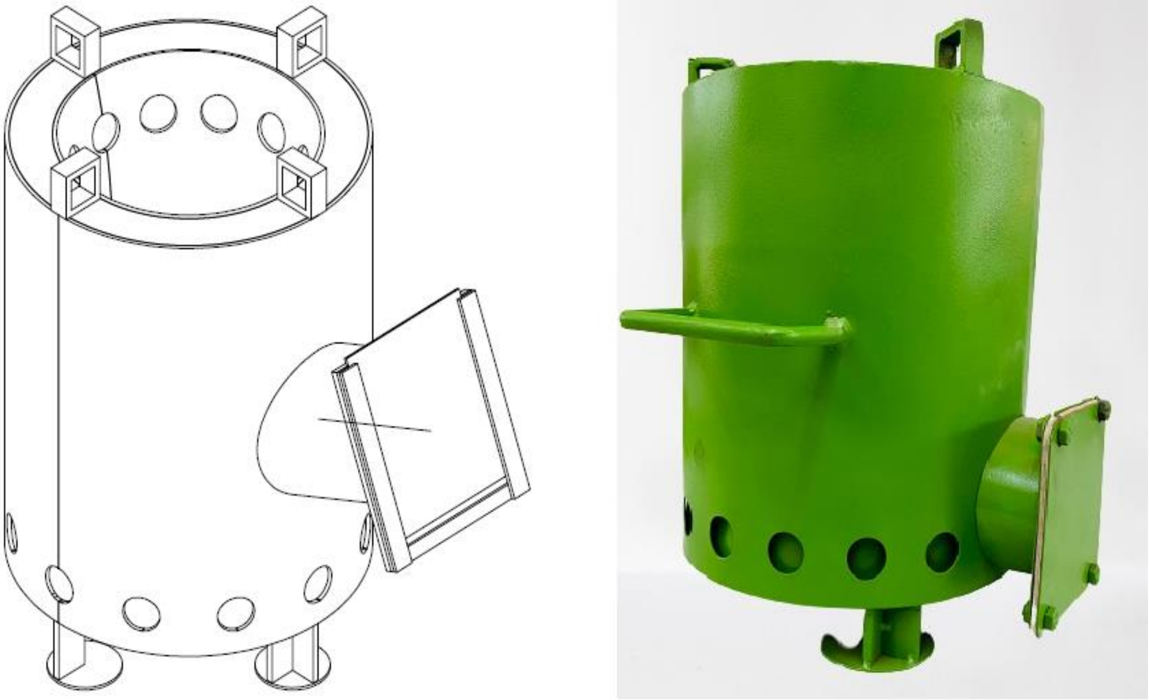

Fig. 1. CAD model and actual image of an improved biomass cookstove

4.3 Methodology

The experiments were performed on the improved biomass cookstove based on the gasification principle (at atmospheric pressure). Before starting the experiments, the setup is cleaned properly, and then after sized biomass is fed to the reactor. The feedstock is heated by the torch and combustion was taking place. The experiments were carried out three times with the same condition to check the repeatability of the results. To check the performance of the cookstove, three major tests (Water boiling for calculating thermal efficiency, emission, and particulate matter) were carried out.

For the water boiling test, two pots were filled with 18 kg water as per the Bureau of Indian Standards (BIS)[12]. There were two phases in the experiment. In the first phase, an aluminum pot was filled with 18 kg of water and 850 gm of teak wood was filled in the combustion chamber. The initial temperature of the water was measured at the beginning of the experiment along with time. The temperature of the water was constantly monitored at the interval of 5 min until it reaches 95˚C with the help of the laboratory thermometer[13]. When 850 gm wood was partially burnt, then again add the remaining wood (350 gm). When the temperature of the water reaches 95˚C then pot 1 was replaced by pot 2. The same process was repeated till the utilization of all the fuel in the chamber [12].

An emission test was carried out with five gas analyzer (i3Sys make, EPM 1601 model). Without interfering in any process of combustion in a cookstove, the flue gases were collected in a hood. In order to take a sample of flue gases, this analyzer was fitted to the hood [14]. By this procedure, HC, NO_x, O_2, CC, CO_2 CO, and NO_x were measured relatively in ppm or %.[15]Total Particulate Matter (TPM) was measured as per the guideline of the Ministry of New and Renewable Energy (MNRE), Govt. of India [15][16]. Axiva make glass fiber filters (25 mm diameter, 2.5-micron) were used to measure TPM through the gravimetric method. For suction of the flue gas from the hood to the TPM arrangement, a vacuum pump was used[17]. At the center axis of a duct nozzle, anemometer mounting was placed. Testing of water boiling, gaseous and particulate emission was carried out along with simultaneously during the experimental run. A flow rate of the gas and air was measured with an Amprobe TMA-21HW Hotwire anemometer with a data logger. The temperature of the combustion zone was measured by K (Chromel-Alumel) type thermocouple.

Experiments were carried out on traditional cookstove and improved cookstove with four different primary to secondary air ratios. For creating different conditions, few air vents are kept open and close. The opening to the closing ratio of primary to secondary air vents is maintained at 50/50, 50/100, 60/100, and 80/100, respectively. Example: 80/100 means 80% primary vent open and 100% secondary vent open. The exact mass flow can be found from mass balance Table 2.

4.4 Important Parameters and Thermal Analysis

Important parameters of a cookstove performance such as burning rate, firepower, specific fuel consumption (SFC), power output rating are defined as per their definitions available in the literature [12][15]. Mass, energy, and exergy analysis are carried out as per the authors' previous work [18][19][20][21].

Burning rate

$$Burning\ Rate = \frac{Equivalent\ mass\ of\ biomass\ consumed\ in\ kg}{Time\ of\ test\ in\ hour} \tag{1}$$

Firepower

$$Firepower = \frac{Equivalent\ mass\ of\ biomass\ consumed\ in\ kg * CV}{Time\ of\ test\ in\ hour * 3600} \tag{2}$$

Specific fuel Consumption

$$Specific\ Fuel\ Consumption = \frac{Burning\ Rate}{Firepower} \tag{3}$$

Thermal Efficiency

$$\text{} = \frac{(m * cp * \Delta T)water + (\Delta m * \lambda) + (m * cp * \Delta T)pot}{(m * cv)wood} \tag{4}$$

Useful firepower

$$Useful\ firepower = firepower * \text{} \tag{5}$$

Mass balance

Mass balance was carried out by considering the output mass from a cookstove and input mass to a cookstove. The total input mass of a cookstove consists of air (primary and secondary), fuel while the total output mass of a cookstove consists of gas, char, PM, water, and ash. In the mass balance, the inconsistency finds by mass balance closure. It is defined by the ratio of the total mass output to the input mass. It should close to one proposed the mass balance is accurate.

Mass balance is done by the following equation.

$$M\,fuel\ + M\,air - p\ +\ M\,air - s\ =\ M\,gas\ +\ M\,char\ +\ M\,PM\ +\ M\,ash\ +\ M\,water \tag{6}$$

M fuel was calculated by weighing machine, Mair and Mgas were converted from respected volumes measured by hot-wire anemometer. M char and M ash were calculated by weighing machine. In fact, both were collected from the same ashpit. However, based on the ash content available in the fuel, ash and char content could be calculated separately. M PM is a mass flow rate of total particulate matter. Mwater was calculated by psychometric chart by considering DBT and WBT observation[20].

Energy balance

Energy balance was carried out by considering output energy from flue gas (utilized or unutilized) and input energy especially from feedstock [22]. The energy balance equation is expressed as:

$$E\,fuel\ +\ E\,air = E\,gas\ +\ E\,char\ +\ E\,pot\ +\ E\,ash\ +\ E\,water\ +\ E\,losses \tag{7}$$

The energy available from fuel and air was calculated by:

$$E\,fuel = m\,fuel * CV\,fuel \tag{8}$$

$$Eair = mair\ *\ Cp, air\ (Tair\ -\ Tref) \tag{9}$$

Similarly, energy from char, water, gas, pot and ash were calculated.

Exergy analysis

Exergy efficiency (or second-law efficiency) computes the effectiveness of a system relative to its performance in reversible conditions. It can also be described as the ratio of the useful work output of the system to the reversible work output for work-consuming systems. It is normally ambient temp and atmospheric pressure [12].

Exergy Efficiency (φ) is expressed as,

$$Exergy\ efficiency\ (\varphi) = \frac{Exergy\ output}{Exergy\ input} \tag{10}$$

Exergy input is calculated based on the following equation:

$$Exi = mwd * \ cv\ (1 - \frac{Ta}{Tfuel})\text{□}c \tag{11}$$

Exergy output is calculated based on the following equation:

$$Exo = mw * cpw * (Tfw - Tiw) * \left(1 - \frac{Ta}{Tfw}\right) + mpot * cp\ pot * (Tfp - Tip) * (\ 1 - \frac{Ta}{Tfp}) \tag{12}$$

5. Results and Discussion

5.1 Effects on Useful firepower and firepower

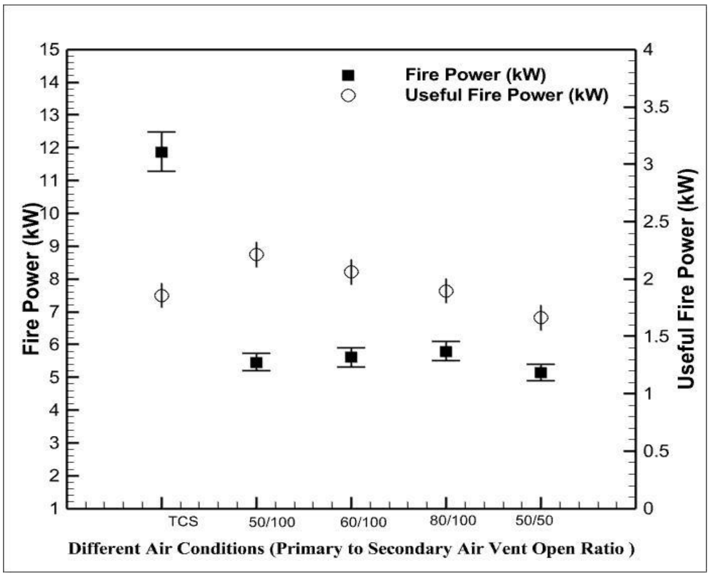

Figure 2. Effects on useful firepower and firepower.

Figure 2 represents the effect of firepower and useful firepower with different airflow. It was observed that TCS has maximum firepower among selected cases, however, the useful firepower of TCS is very less. It is because most of the energy liberated from TCS was not utilized properly and went to the atmosphere. Firepower is depending on the burning rate and rate of oxygen involved in the reaction. Due to the same 50/50 ratio has lower firepower and 80/100 ratio with ICS has higher firepower, comparatively. Useful firepower is depending on efficiency as well as firepower. Due to the same, it is observed that 50/100 ratio has the highest useful firepower compared to other cases due to higher thermal efficiency.

5.2 Effects on burning rate and specific fuel consumption

SFC and burning rate are expressed in Figure 3. More air is involved in the reaction when vents are open to large extents. This process leads to a higher rate of combustion. Due to the same, TCS has a higher burning rate (excess air) whereas ICS with a 50/50 ratio has a lower burning rate. SFC is depending on the thermal efficiency of the system. Therefore, 50/100 ratio has a lower SFC compared to other cases. It is obvious fact that the SFC of TCS is extremely high due to the uncontrolled combustion process.

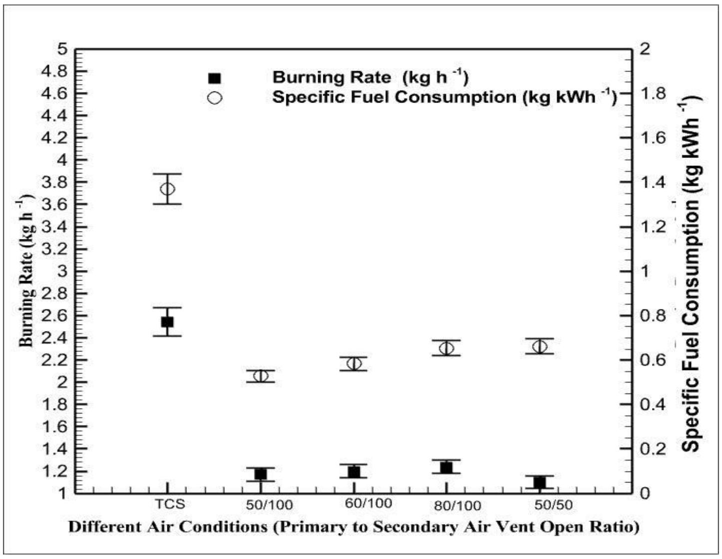

Figure 3. Effects on Burning rate and specific fuel consumption.

5.3 Effects on Thermal Efficiency and Exergy Efficiency

Figure 4 presents the effects on thermal efficiency and exergy efficiency of the biomass cookstove. Thermal efficiency and exergy efficiency were observed in the range of 32.34% -

40.54% and 7.79% - 7.95%, respectively for ICS. For TCS, thermal efficiency was observed only 15.64% and exergy efficiency was observed only 3.93%. It was observed that good quality producer gas may be generated for 50/100 ratio leads to a higher temperature at the secondary air inlet.

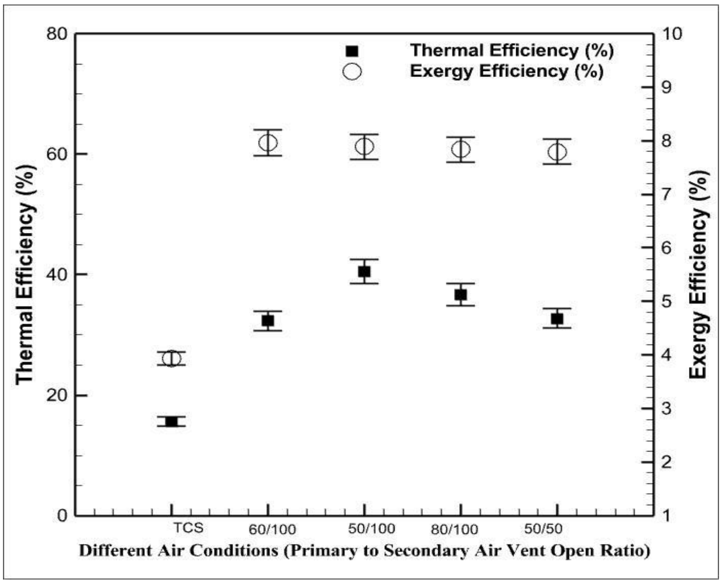

Figure 4. Effects on Thermal efficiency and exergy efficiency.

5.4 Effects on PM and Combustion temperature

Effects on PM and combustion temperature at different airflow are illustrated in Figure 5 Combustion temperatures of TCS and ICS (all cases) were observed in the range between 415ºC to 596ºC. Temperature with TCS was found lower due to improper combustion process. Due to improper combustion, a higher amount of HC and CO was observed in the flue gas for TCS. Due to the same, combustion efficiency was found lower for TCS as compared to ICS. 50/100 and 60/100 ratios offered good combustion temperature comparatively. Particulate emission was found lower as an increment of temperature. It is due to the fact that the vent of the primary holes was placed above the ashpit. Due to the same, fewer particles were carried along with producer gas in the cookstove. Moreover, at a higher temperature, cracking of coarse particles may have resulted in fine particles.

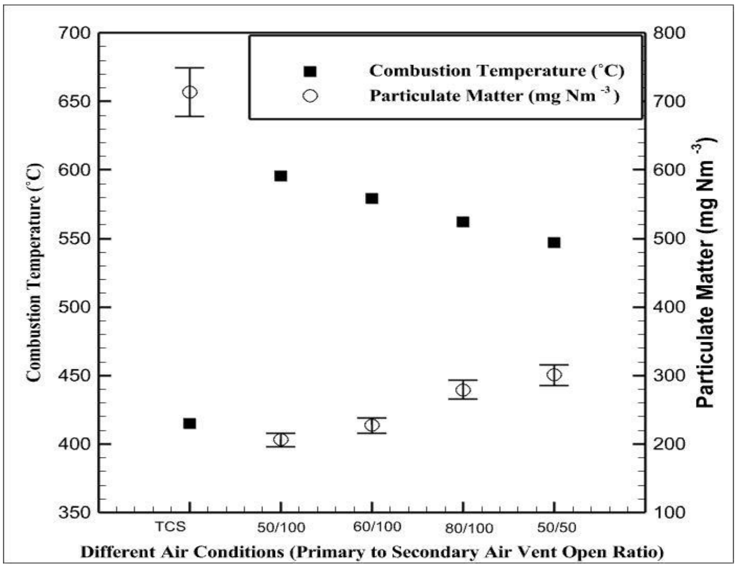

Figure 5. Effects on PM and combustion temperature.

5.5 Effects on Emission gas

Gaseous emissions such as CO, HC, O_2, CC, NO_x, CO_2 are shown in Figure 6 Emissions have a direct relation to combustion characteristics. from figure 6 it is observed that TCS has higher CO and HC contents. These data reveal that combustion products of TCS have the potential to generate more energy. However, due to the unavailability of a sophisticated system, the same components were thrown into the atmosphere. ICS with 50/100 ratio has minimum O_2 and CO_2 compounds. It is because producer gas was combusted properly with secondary air in the combustion chamber.

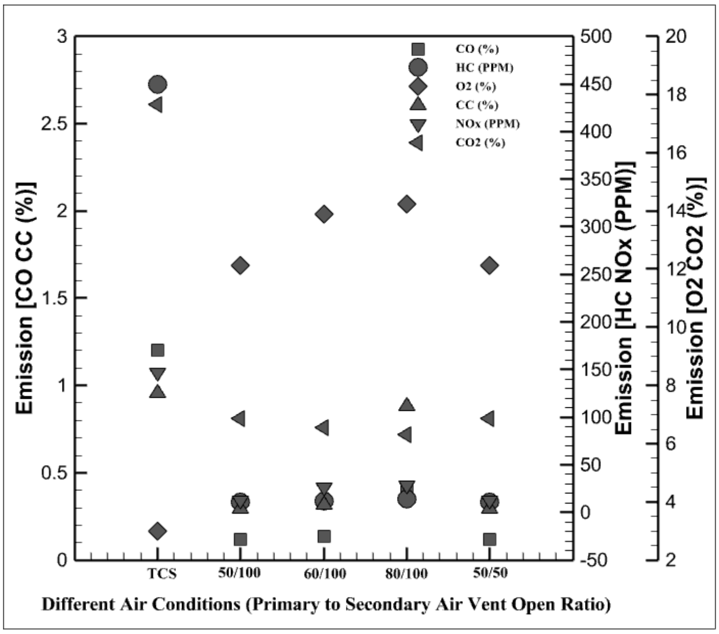

Figure 6. Effects on gaseous emission.

5.6 Mass balance

Table 2 shows a mass balance of different airflow for biomass cookstove. MBC was found in the range of 0.96 to 0.99. 50/50 ratio with ICS has a lower mass of gas. It is due to the lower secondary air providence compared to other cases.

Table 2. Mass balance of different air flow conditions.

Different Airflow (%)	Input Masses (kg h^{-1})			Output Masses (kg h^{-1})					MBC (%)
	Mfuel	Mair-p	Mair-s	Mgas	Mchar	Mash	MPM	Mwater	
50/50	1.041	1.039	2.01	3.80	0.015	0.062	0.000022	0.085	0.968
50/100	1.178	0.831	4.02	5.69	0.020	0.054	0.000013	0.094	0.971
60/100	1.200	1.039	4.02	5.94	0.018	0.060	0.00001	0.113	0.980
80/100	1.241	1.662	4.02	6.62	0.021	0.064	0.00002	0.144	0.990

5.7 Energy balance

Energy balance was carried out and shown in Table 3 EBC was found in the range of 0.83-0.90. The reason behind lower EBC may be due to the following reasons: 1. No heat loss was considered (pot and reactor), 2. Combustion efficiency was not considered in Efuel, and 3. Unaccounted losses.

Table 3. Energy balance of different air flow conditions.

Different Airflow (%)	Input Masses (kJ h^{-1})		Output Masses (kJ h^{-1})				EBC (%)
	Efuel	Eair	Egas	Echar	Eash	Ewater+pot	
50/50	20184	30.64	4772.04	267.77	2.71	12530.41	0.86
50/100	21462.3	48.75	4245.42	334.72	2.53	14704.09	0.83
60/100	20184	50.84	4614.62	301.24	2.62	13419.37	0.90
80/100	20184	57.10	5040.57	351.45	2.71	12616.32	0.88

6. Conclusions

Experiments were carried out with wood feedstock on TCS and ICS with different air conditions. The opening to the closing ratio of primary to secondary air vents was taken at 50/50, 50/100, 60/100, and 80/100, respectively. Following are the major conclusions from this study.

1. TCS has poor thermal efficiency (15.64%) and higher gaseous and particulate emission (>550 mg Nm-3). Even the combustion temperature of TCS is very less compared to ICS in all cases.
2. Burning rate and SFC are found in the range of 1.1 kg h^{-1} to 1.24 kg h^{-1} and 0.52 kg kWh^{-1} to 0.66 kg kWh^{-1} for different cases of ICS.
3. Firepower is found higher for 80/100 ratio (5.79 kW) whereas useful firepower is found higher for 50/100 ratio (2.21 kW).
4. 50/100 ratio has obtained maximum combustion temperature (596 ºC) and minimum PM as compared to other selected cases.
5. The thermal efficiency of ICS with 50/100 ratio is found maximum (40.54%). In fact, all ICS air conditions offer good thermal efficiencies in the range of 32.34% to 40.54%.
6. ICS with 50/100 ratio offers better output (better thermal efficiency and lower gaseous – particulate emission) compared to other selected conditions. It is due to the generation of good quality producer gas and achieved better stoichiometry during the combustion process.

Prior literature review-based publication

Sr. No.	Paper Title	Name of Journal	Volume, Page No.	Impact Factor
1	A comprehensive review and a systematic approach to enhance the performance of improved cookstove (ICS)	Journal of Thermal Analysis and Calorimetry, Springer Publication	141, pages 2253–2263, May 2020	4.626

Publication during Project

Sr. No.	Paper Title	Name of Journal/Conference	Volume, Page No.
1	Experimental investigations and thermal analysis of a natural draft improved biomass cookstove with different air conditions	IOP Conference Series: Materials Science and Engineering*	1146 (2021) 012010

*Conference Proceeding from Advances in Thermal-Fluids Engineering (ATFE 2021), 25th-26th March 2021, Gandhinagar, India

One paper is under preparation which will be submitted in a referred international journal.

References:

[1] "Census of India :HH10 : Households By Availability Of Separate Kitchen And Type Of Fuel Used For Cooking." https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&cad=rja&uact=8&ved=2ahUKEwjVgNyG2tXxAhXzQ3wKHRCRBJ8QFjAAegQIAhAD&url=https%3A%2F%2Fcensusindia.gov.in%2F2011census%2FHlo-series%2FHH10.html&usg=AOvVaw05Y9qfuwu_2abcfAxv7Y-S (accessed Feb. 21, 2020).

[2] "Household air pollution and health." .

[3] P. Raman, J. Murali, D. Sakthivadivel, and V. S. Vigneswaran, "Performance evaluation of three types of forced draft cook stoves using fuel wood and coconut

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