Research Article

Experimental investigation on energy-efficient twin-mode biomass improved cookstove

Himanshu Kumar[1] · N. L. Panwar[1]

Abstract
This study deals with the design and development of a gasification-based wood gas stove for energy demand of a six-member family. The novelty of the designed cookstove is that it works in the natural draft as well as in forced draft air supply mode efficiently. The performance of the developed stove was examined as per the Bureau of Indian Standard (IS: 13152; Part-I) test protocol. The stove was tested with babul (*Acacia nilotica*) wood and groundnut (*Arachis hypogaea*) shell pellet in dual draft air supply mode. In the forced draft air supply mode with *A. nilotica* wood, the average thermal efficiency, power rating, CO and CO_2 emissions and total particulate matter were estimated at around 36.56%, 3.15 kW, 0.2 ppm and 10.4 ppm, and 134.1×10^{-6} g kJ^{-1}, respectively. The economic assessment was carried out as per the supply and market rates in India, which may vary from country to country. The capital cost of the cookstove is around 11 US$, which makes it economically viable for the people residing in rural areas with the payback period of 20–29 days.

Keywords Thermal efficiency · Wood gas stove · Power rating · Dual draft · Emissions · Fuel saved

List of symbols

A	Area of opening for primary air passage (m^2)
BIS	Bureau of Indian Standard
C_o	Capital cost of cookstove (US$)
C_2	Calorific value of kerosene (kJ kg^{-1})
C_v	Specific heat of material of the vessel (kJ kg^{-1} °C^{-1})
C_w	Specific heat of water (kJ kg^{-1} °C^{-1})
CV_f	Calorific value of fuel (kJ kg^{-1})
d	Diameter of secondary hole (m)
d_r	Depreciation rate (%)
D	Diameter of reactor (m)
FCR	Fuel consumption rate (kg h^{-1})
H	Height of the reactor (m)
H_{in}	Heat input into the stove (heat produced) (kJ)
H_{out}	Heat output of the stove (heat utilized) (kJ)
M	Mass of vessel with lid and stirrer (kg)
m	Mass of water in vessel (kg)
n	Total number of vessel
n_m	Minimum number of food to be cooked to get economic
n_y	Numbers of meal in a year
NPV	Net present value (US$)
P_o	Power output (kW)
p	Money value saved per cook (US$)
PP	Payback period
Q_n	Heat energy needed (kJ h^{-1})
SGR	Specific gasification rate (kg m^{-2} h^{-1})
t	Duty hour (h)
t_c	Life span of cookstove (year)
T_1	Initial temperature of water (°C)
T_2	Final temperature of water (°C)
T_3	Final temperature of water in the last vessel at the completion of test (°C)
v	Velocity of air (m s^{-1})
x	Mass of kerosene use for ignition (kg)

Greek symbols

ε	Equivalence ratio
α	Repair and maintenance cost (US$)
η_g	Gasifier stove efficiency (%)
η_{th}	Thermal efficiency (%)

✉ N. L. Panwar, nlpanwar@rediffmail.com | [1]Department of Renewable Energy Engineering, College of Technology and Engineering, Maharana Pratap University of Agriculture and Technology, Udaipur 313001, India.

SN Applied Sciences (2019) 1:760 | https://doi.org/10.1007/s42452-019-0804-x

Received: 22 March 2019 / Accepted: 18 June 2019 / Published online: 21 June 2019

ρ_a Air density (kg m^{-3})
ρ_d Bulk density of biomass (kg m^{-3})
ρ_k Density of kerosene (kg m^{-3})

1 Introduction

India is a developing country where 65–70% of the total population resides in the rural setup. Frequent power cut is a major problem of the rural areas, and the main cause for this is rapid increment in energy demand and shortage of power supply. Therefore, since many decades, it remained as a questionable mark against the reliable power supply system for the rural areas in the country [1]. The Indian Government started a program called "decentralized system" to secure and provide a reliable power supply to the people residing in the rural setup. Under this program, solar cooker and solar water heater are disseminating to fulfill the energy demands for cooking and water heating, which are two basic activities of the rural households [2]. Although the perennial sources of these systems are renewable, they are dependent on weather conditions and stop working in rainy season [3, 4]. In this condition, fuel wood will be a better option, which is renewable as well as abundantly available in the country [5, 6]. Presently, around 85% of the people in rural parts of the country are dependent upon fuel wood as a major source for cooking energy requirement because of the poverty, unemployment and due to the rising cost of the liquid fuels [7]. Raman et al. [8] also reported that of the total cooking and water heating energy demand, almost 75–95% energy was met by fire wood and charcoal only. Meanwhile, this fuel is burnt in a traditional cookstove to get the energy for cooking and water heating. Due to incomplete combustion of the fuel in same practice, cause emissions of high pollutant level inside the dwelling which leads to the health disorders. The traditional cookstove is also characterized by lower thermal efficiency of about 5–10%, where almost 90–95% energy is wasted [9]. As per the present situations and trend of the energy sources used by the rural people, the first objective of the research was to design and develop a "wood gas biomass improved cookstove" with improved efficiency and less emissions to fulfill the cooking energy demand.

Many researchers [10–12] have worked on either natural draft cookstove or forced draft to improve the overall efficiency, but due to the high upfront cost [13], 75% people in the rural India, whose monthly income is less than 77 US$, cannot afford. Hence, it remains a challenging task to design and develop a cookstove at an affordable price for the rural people with better efficiency. Therefore, the second objective of the research was to make it cost-effective so that people can use the cookstove in their daily lives.

The idea was also to develop such a cookstove, which will operate in forced draft mode, when electricity is available using charged battery and even during off-electricity hours, when battery is discharged, the cookstove can be operated in natural draft mode with better efficiency. The low cost with better thermal efficiency and reduced emissions makes it most adoptive.

2 Materials and method

2.1 Design of the cookstove

A portable biomass gasification-based cookstove was designed as per the methodology adopted by Belonio [14] for a family of six members. The per-capita energy consumption of the people living in the rural parts of the country was assessed from Ingole et al. [15]. Few assumptions taken from Rathore et al. [16] were taken initially for the cookstove sizing and are given in Table 1.

The size of the cookstove was estimated by computing the various design parameters [14], which are given below,

2.1.1 Energy required (Q_n)

$$Q_n = \text{no. of family members} \times \text{per capita energy required for cooking} \quad (1)$$

2.1.2 Energy input (FCR)

$$\text{FCR} = \frac{Q_n}{\text{CV}_f \eta_g} \quad (2)$$

2.1.3 Reactor diameter (*D*)

$$D = \sqrt{\frac{1.27\ \text{FCR}}{\text{SGR}}} \quad (3)$$

2.1.4 Height of the reactor (*H*)

$$H = \frac{\text{SGR} \times t}{\rho_d} \quad (4)$$

Table 1 Assumptions made for cookstove designing

Parameters	Value
Hot gas efficiency, η_g (%)	60
Specific gasification rate of biomass, SGR (kg m^{-2} h^{-1})	140
Duty hour, *t* (h)	1
Equivalence ratio, ε	0.4
Stoichiometric air requirement of biomass, SA	6.1
Air velocity at primary air inlet, *v* (m s^{-1})	1.2
Diameter of secondary air hole, *d* (m)	0.01

2.1.5 Amount of air needed for gasification (AFR)

$$AFR = \frac{\varepsilon \times FCR \times SA}{\rho_a} \quad (5)$$

2.1.6 Area required for primary air passage (*A*)

$$A = \frac{AFR}{v} \quad (6)$$

2.1.7 Secondary air requirement

By examining the general composition of producer gas (H_2—20%, CO—18%, and CH_4—1%), the secondary air requirement ($m^3\ h^{-1}$) for burning of producer gas is calculated [16]. The corresponding oxygen required for different combustion reactions is given below,

Combustion reactions for producer gas are as follows:

$$2H_2 + O_2 \rightarrow 2H_2O \quad (7)$$

$$2CO + O_2 \rightarrow 2CO_2 \quad (8)$$

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \quad (9)$$

2.1.8 Stoichiometric air requirement for combustion

Stoichiometric air requirement for combustion was adopted as per the methodology suggested by Mukunda [17]. The stoichiometric air is around 6.1 kg air per kg biomass.

2.2 Cookstove description

The cookstove consisted of two co-centric cylinders made of 0.1-cm-thick MS sheet. The diameter and height of the outer cylinder are 24 cm and 30 cm, and the same for inner cylinder are 18 cm and 25 cm, respectively. The schematic diagram is shown in Fig. 1. To minimize the heat losses, combustion chamber was insulated using refractory cement of 3 cm thickness. The reactor height and diameter are 20 cm and 12 cm, respectively. The cross-sectional area required for the secondary air supply was estimated by calculating the volume of secondary air supply per second (m^3/s) divided by velocity of air (m/s) at the secondary air holes. The numbers of holes were then calculated by area required for secondary air supply divided by area of single hole by taking 1 cm diameter of each hole. Eighteen numbers of holes were provided near the top of the combustion chamber of 1 cm diameter each for secondary air passage to burn producer gas. A 10-cm-diameter air opening at the bottom was given for the passage of primary air.

To cover the air opening, a manually operated circular-shaped cover plate of 11 cm diameter was fitted at the bottom so that air passage from the bottom can be restricted during forced draft mode. A blower (0.16 A, 12 V) was mounted at the middle of the outer body of the cookstove with a casing to provide primary air and secondary air required for combustion during forced draft mode. A rechargeable battery (12 V, 1800 mAh) was used to power the blower. The technical specification of the designed cookstove is presented in Table 2.

2.3 Cookstove operation

The cookstove is working in the gasification principle. The fuel is fed from the top up to 3/4th of the height of reactor. During the forced draft convection mode, the primary air and secondary air is met through the blower. At the same time, the cover plate (11 cm) at the bottom remains closed. When the cookstove was tested in natural draft mode, the amount of air needed for combustion was met by the natural convection through the air opening (10 cm diameter) provided at the bottom only.

3 Instrumentation and measurements

The moisture present in the fuel was measured using a moisture analyzer (Make: Sartorius MA35M-000230V1). Flame temperature and surface temperature of the cookstove were recorded using digital temperature scanner (DTSC-3508, ADI Vadodara) coupled with NiCr-Ni thermocouple (Type-CR/AL, 1000 °C, IP 65). A digital Bomb calorimeter (Khera Instrument Pvt. Ltd., Delhi) was used to determine the calorific value of fuels. The CO and CO_2 emissions during the operation were measured using a gas analyzer (HORIBA VA-3000), and total particulate matter (TPM) was measured using 2.5-µm filter paper through stack monitoring system (Model: PEM SMS4, Polltech, India).

4 Fuel collection and processing

The wood fuel (*Acacia nilotica*) and pellet (*Arachis hypogaea*) were collected from the local area of Udaipur, Rajasthan (India), at US$ 0.06 kg^{-1} and US$ 0.11 kg^{-1}, respectively. The size and shape of the babul (*Acacia nilotica*) wood were taken as per the Bureau of Indian Standard (BIS-IS: 13152; Part-I), given in Table 3. Meanwhile, the shape and size of the groundnut (*Arachis hypogaea*) shell pellet were used as per the pellet manufacturer and are given in Table 4. The biomass fuel collected for performance evaluation was characterized by ASTM [18].

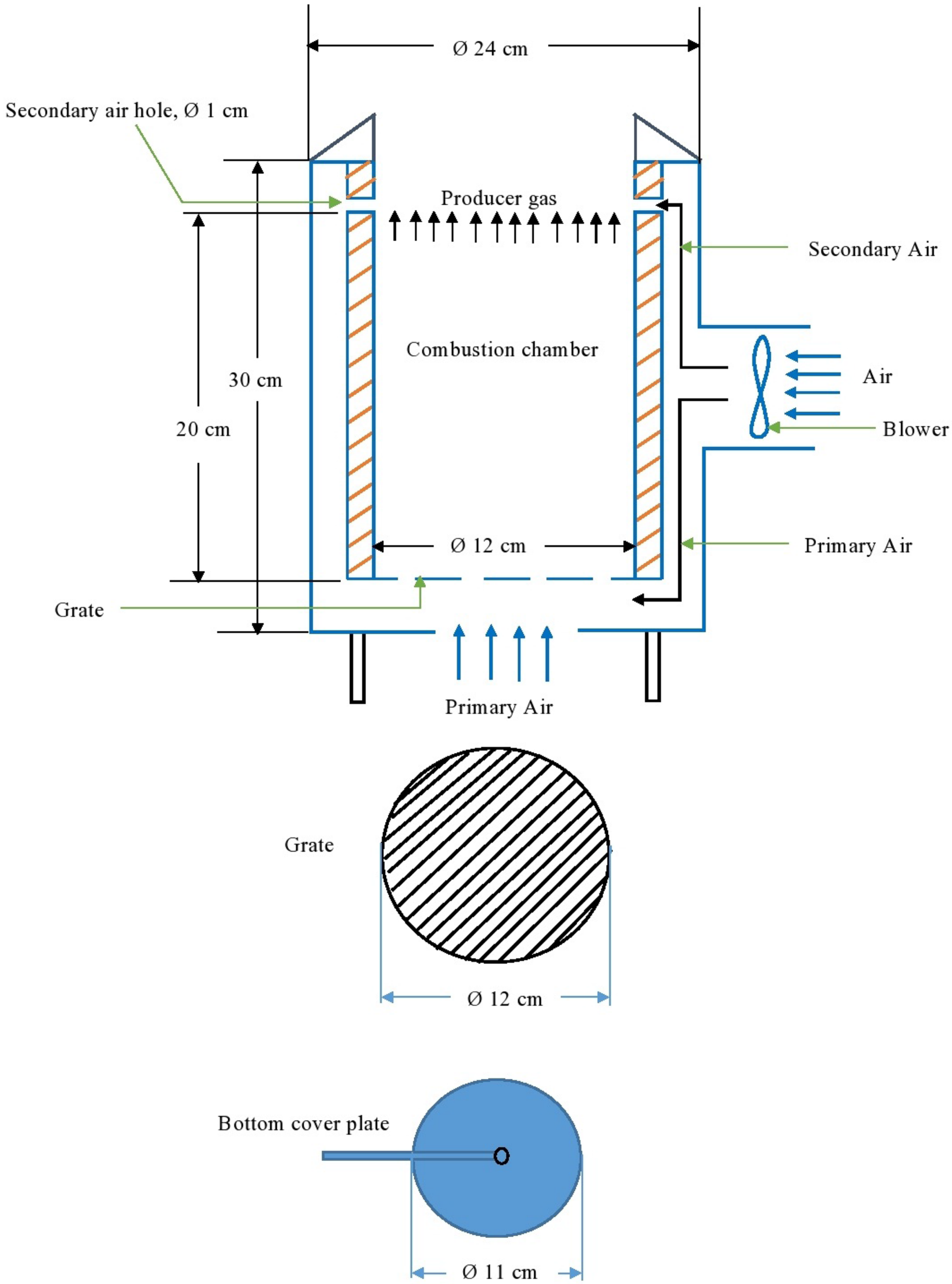

Fig. 1 Cross-sectional view of the designed cookstove

Table 2 Technical specifications of the cookstove

Parameters	Value
Gross energy required, Q_n, kJ	13,489.8
Fuel consumption rate, FCR, kg h^{-1}	1.55 and 1.64
Reactor diameter, *D*, cm	12
Reactor height, *H*, cm	20
Height of inner cylinder, cm	25
Height of outer cylinder, cm	30
Total height of cookstove, cm	38
Area for primary air requirement, *A*, cm^2	0.07
Secondary air requirement, m^3 h^{-1}	6.14
Number of holes for secondary air	18

Table 3 Characteristics of babul (*Acacia nilotica*) wood

Sr. no.	Characteristics	Value
1	Size (cm)	2–3
2	Length (m)	4–6
3	Bulk density (kg m^{-3})	280
4	Angle of slide (°)	16
5	Moisture content (% wb)	9.8
6	Volatile matter (% db)	82.5
7	Ash content (% db)	1.05
8	Fixed carbon (% db)	16.45
9	Calorific value (MJ kg^{-1})	16.5

5 Performance evaluation

Performance evaluation of the cookstove was carried out as per the Bureau of Indian Standard (BIS-IS: 13152; Part-I) at the Biomass Cookstove Testing Centre (Ministry of New and Renewable Energy approved laboratory), College of Technology and Engineering (MPUAT), Udaipur, Rajasthan (India). Eighteen replications were taken to examine the performance. Thermal efficiency, power rating, CO and CO_2 emissions and total particulate matter (TPM) were assessed with babul (*Acacia nilotica*) wood and groundnut (*Arachis hypogaea*) shell pellet.

5.1 Thermal efficiency

Thermal efficiency of the developed cookstove was assessed in the laboratory using water boiling test (WBT). The formula used for determining thermal efficiency is given below:

$$H_{\text{out}} = \left[(n-1)\times\left(W\times C_{\text{V}} + w\times C_{\text{w}}\right)\times\left(T_2 - T_1\right)\right] + \left[\left(W\times C_{\text{V}} + w\times C_{\text{w}}\right)\times\left(T_3 - T_1\right)\right] \quad (10)$$

Table 4 Characteristics of groundnut (*Arachis hypogaea*) shell pallet

Sr. no.	Characteristics	Value
1.	Diameter (cm)	0.6–0.8
2.	Length (cm)	1–3
3.	Bulk density (kg m^{-3})	600
4.	Angle of slide (°)	13.5
5.	Moisture content (% wb)	6.4
6.	Volatile matter (% db)	74.3
7.	Ash content (% db)	2.1
8.	Fixed carbon (% db)	23.6
9.	Calorific value (MJ kg^{-1})	17.9

$$H_{\text{in}} = \left(\text{FCR}\times\text{CV}_{\text{f}}\right) + \frac{x\times C_2\times\rho_{\text{k}}}{1000} \quad (11)$$

$$\eta_{\text{th}} = \frac{H_{\text{out}}}{H_{\text{in}}}\times 100 \quad (12)$$

5.2 Power rating

The power rating was assessed using the following formula,

$$P_{\text{o}} = \frac{\text{FCR}\times\text{CV}_{\text{f}}\times\eta_{\text{th}}}{3600\times 100} \quad (13)$$

5.3 Emissions and total particulate matter (TPM) measurement

The developed cookstove was tested for its emissions simultaneously along with the testing of thermal efficiency using stack monitoring system, a multi-component gas analyzer connected online for continuous measurement of CO and CO_2.

6 Economic assessment

Economic assessment of the cookstove was evaluated as per methodology adopted by Panwar et al. [19]. The capital cost (C_{o}), net present value (NPV), minimum number of feed to be cooked by cookstove to make economic (n_{m}), and payback period (PP) were determined. Few assumptions were made to access the economic feasibility of the system and are given below:

(a) Depreciation rate (d_r), 10%
(b) Repair and maintenance cost (α) at 5% of the capital cost of cookstove
(c) Number of meals in a year (n_y), 600 (twice in a day)
(d) Life span of the cookstove (t_c), 5 years

For economic feasibility, the cookstove was compared with a traditional cookstove of 10% thermal efficiency as reported by Mehetre et al. [9], kerosene stove of 53.08% [20] and LPG stove of 65% thermal efficiency [21] by considering the same energy input for a six-member family.

7 Result and discussion

7.1 Thermal efficiency

Average thermal efficiency of the system was found to be around 36.56% and 36.79% in forced draft air supply mode working on babul (*Acacia nilotica*) wood and groundnut (*Arachis hypogaea*) shell pellet, respectively, which is slightly higher than that of the cookstove tested by Panwar and Rathore [22]. In natural draft air supply mode with *Acacia nilotica* wood, the average thermal efficiency was found to be around 33.44%, which is also higher than the cookstove tested by Mehetre et al. [23] of 28.83% and Darfur cookstove recently tested by Suthar et al. [24] of 29%. Meanwhile, the thermal efficiency of various natural draft cookstoves approved by Ministry of New and Renewable Energy, Govt. of India [25], is also less than the developed stove.

7.2 Power rating

The average power output rating of the cookstove was found to be around 3.15 kW and 2.95 kW in forced draft mode with *Acacia nilotica* wood and *Arachis hypogaea* shell pellet, respectively, while in natural draft mode, it was about 2.5 kW with *Acacia nilotica* wood.

7.3 Emissions from cookstove

The average CO and CO_2 emissions in forced draft mode operating with *Acacia nilotica* wood and *Arachis hypogaea* shell pellet were found to be 0.2 ppm and 10.4 ppm and 0.07 ppm and 12.9 ppm, respectively. In natural draft mode, using *Acacia nilotica* wood, the average CO and CO_2 emissions were recorded at around 0.24 ppm and 8.8 ppm, whereas a cookstove tested on multi-fuel by Panwar [11] reported 17–25 ppm (CO_2) and 3–6 ppm (CO). Therefore, the developed cookstove is working within the safe limit in both the air supply modes.

The average total particulate matters (TPM) emitted during operation of the cookstove in forced draft mode with *Acacia nilotica* wood and *Arachis hypogaea* shell pellet were recorded as 134.1×10^{-6} g kJ^{-1} and 132.73×10^{-6} g kJ^{-1}, respectively. In natural draft mode, it was observed to be around 298.8×10^{-6} g kJ^{-1}, which is much lower than the particulate matter emission limit set by the test protocol BIS: IS; 13152 (Part-I).

7.4 Economics of the cookstove

7.4.1 Capital cost

The capital cost of the cookstove is around 11 US$ (INR 70.54 US$$^{-1}$), and the details are presented in Table 5.

7.4.2 Cost of cooking

The cost of cooking was calculated using data presented in Table 6. The CO_2 emission equivalent was taken from the generalized approach as proposed by Emission Guidelines [26]. The prices of the fuels are taken as per local market cost (US$ kg^{-1}). The cost reliability was checked with respect to the LPG and kerosene fuel. When compared with a conventional cooking liquefied petroleum gas (LPG) stove [21], it employs an annual saving of around 227.6 US$ and 161.1 US$ in forced draft mode on babul (*Acacia nilotica*) wood and groundnut (*Arachis hypogaea*) shell pellet, respectively. Meanwhile, in natural draft mode, 218.4 US$ could be saved with *Acacia nilotica* wood. Similarly, with respect to a pressurized kerosene stove [20], around 263.67 US$ and 197.2 US$ in forced draft mode and 254.48 US$ in natural draft mode could be saved, whereas in comparison with a traditional cookstove, around 206.2 US$ and 193.7 US$ could be saved in forced draft mode on *Acacia nilotica* wood and *Arachis hypogaea* shell pellet, respectively. In natural draft mode, it is in a position to save around 251 US$.

Table 5 Cost paid against different items for cookstove fabrication

Item (s)	Cost (US$)
MS sheet used (0.54 m^2)	0.57
Cast iron for grate and stand	0.57
Welding cost	0.85
Insulation cost	0.43
Blower cost	0.71
Battery (12 V, 1800 mAh)	2.13
Fabrication charge	5.67
Total	10.93

Table 6 Cost of the cooking and CO_2 emissions equivalent

Fuel and stove	Calorific value (MJ kg^{-1})	Stove efficiency (%)	Price of fuel per unit (US$)	Quantity of fuel required to meet the energy demand (kg)	Total cost of fuel (yearly) (US$ kg^{-1})	CO_2 emission per unit (kg kg^{-1})	CO_2 emission (annually) (tons $year^{-1}$)
Kerosene stove	43.2	53.08	0.84	0.59	361.79	3.1	1.35
Traditional coal stove	29.3	28.2		1.63	–	2.9	9.74
LPG stove	45.5	65	0.97	0.46	325.72	9.74	3.45
Traditional cookstove	16.5	10	0.06	8.18	358.28	1.59	9.49
Developed stove on babul (*Acacia nilotica*) wood	16.5	36.56	0.06	2.24	98.12	1.59	2.60
Developed stove on groundnut (*Arachis hypogaea*) shell pellet	17.9	36.79	0.11	2.05	164.62	1.64	2.45
Developed stove in natural draft mode on *Acacia nilotica*	16.5	33.44	0.06	2.45	107.31	1.59	2.84

Table 7 Economic parameters of the designed cookstove

Economic parameters	Force draft mode *Acacia nilotica*	Force draft mode *Arachis hypogaea*	Natural draft mode *Acacia nilotica*
Net present value, NPV (US$)	764	525	737
The minimum number of feed to be cooked to get economic, n_m	10	15	11
Payback period, PP (days)	20	29	21
Money value for fuel saved per cook, p (US$)	0.34	0.23	0.33

7.4.3 Net present value, payback period and money value for fuel saved

The estimated economic parameters compared to a traditional stove are given in Table 7.

8 Conclusions

In forced draft mode in comparison with a traditional stove of 10% thermal efficiency [9], the developed cookstove is enabled to save around 6.89 tons and 7.04 tons of CO_2 annually with respect to the fuel used, whereas in natural draft mode, the stove working on *Acacia nilotica* wood is saving around 6.65 tons of CO_2 annually. When the cookstove was compared with a traditional coal stove of around 28.2% thermal efficiency [27], it is enabled to save around 0.85 tons, 1.0 ton and 0.61 tons of CO_2 annually. It was found quite interesting that the developed cookstove is working efficiently in dual draft mode and saving considerable amount of CO_2 emission. The rural people can easily afford the developed cookstove. The cost spent for cookstove purchasing can only be recovered within 20–29 days, which makes a more attractive feature toward its adoption.

Acknowledgements The authors are grateful to Indian Council of Agricultural Research (ICAR), Govt. of India, for providing financial support, and author (Himanshu Kumar) is highly thankful to the ICAR to avail the Junior Research Fellowship (ICAR-JRF) during Master of Technology Program to conduct the research successfully.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

References

1. Abrar MM (2016) Power cut off and power blackout in India a major threat: an overview. Int J Adv Res Technol 5:8–15
2. Decentralized System. Ministry of New and Renewable Energy. Government of India. http://mnre.gov.in/schemes/decentralized-systems/. Assessed 15 Nov 2018
3. Rai GD (2013) Non-conventional sources of energy. Khanna Publishers, New Delhi
4. Ronge H, Niture V, Ghodake MD (2016) A review paper on utilization of solar energy for cooking. IJET 1:121–124
5. Bhat PR, Chanakya HN, Ravindranath NH (2001) Biogas plant dissemination: success story of Sirsi, India. Energy Sustain Dev 5:39–46
6. Hiloidhari M, Das D, Baruah DC (2014) Bioenergy potential from crop residue biomass in India. Renew Sustain Energy Rev 32:504–512
7. Waris WS, Antahal PC (2014) Fuelwood scarcity, poverty and women: some perspectives. IOSR-JHSS 19:21–33
8. Raman P, Ram NK, Gupta R (2014) Development, design, and performance analysis of a forced draft clean combustion cookstove powered by thermoelectric generator with multi-fuel options. Energy 69:813–825
9. Mehetre SA, Panwar NL, Sharma D, Kumar H (2017) Improved biomass cookstoves for sustainable development: a review. Renew Sustain Energy Rev 73:672–687
10. Dixit CB, Paul PJ, Mukunda HS (2006) Part I: experimental studies on a pulverised fuel stove. Biomass Bioenergy 30:673–683
11. Panwar NL (2009) Design and performance evaluation of energy efficient biomass gasifier based cookstove on multi fuels. Mitig Adapt Strateg Glob Change 14:627–633
12. Panwar NL, Rathore NS (2008) Design and performance evaluation of a 5 kW producer gas stove. Biomass Bioenergy 32:1349–1352
13. Jeuland MA, Pattanayak SK (2012) Benefits and costs of improved cookstoves: assessing the implications of variability in health, forest and climate impacts. PLoS ONE 7(2):e30338
14. Belonio AT (2005) Rice husk gas stove handbook. Appropriate Technology Center, Department of Agricultural Engineering and Environmental Management, College of Agriculture, Central Philippine University, Iloilo City
15. Ingole SS, Bhuyar LB, Deshmukh SJ (2013) Micro-level analysis of rural domestic energy consumption pattern in India: a case study of Daryapur block. IJIET 2:208–219
16. Rathore NS, Panwar NL, Kothari S (2007) Biomass production and utilization technology. Himanshu Publication, Udaipur. ISBN:81-7906-139-6
17. Mukunda HS (1989) Understanding combustion. Universities Press (India) Private Limited Publication, Hyderabad. ISBN: 978-8173716850
18. ASTM (1983) Annual book of ASTM standard. American Society for Testing and Materials, Philadelphia, p 19103
19. Panwar NL, Kothari S, Kaushik SC (2013) Techno-economic evaluation of masonry type animal feed solar cooker in rural areas of an Indian state Rajasthan. Energy Policy 52:583–586
20. Saptoadi H, Pratama NN (2015) Utilization of plastics waste oil as partial substitute for kerosene in pressurized cookstoves. Int J Environ Sci Dev 6(5):363
21. Muthukumar P, Shyamkumar PI (2013) Development of novel porous radiant burners for LPG cooking applications. Fuel 112:562–566
22. Panwar NL, Rathore NS (2015) Environment friendly biomass gasifier cookstove for community cooking. Environ Technol 36(18):2308–2311
23. Mehetre SA, Sengar SH, Panwar NL, Ghatge JS (2016) Performance evaluation of improved carbonized cashew nut shell based cookstove. Waste Biomass Valoriz 7(5):1221–1225
24. Sutar KB, Singh R, Karmakar A, Rathore V (2019) Experimental investigation on thermal performance of three natural draft biomass cookstoves. Energy Effic 12:749–755
25. Approved models of portable improved biomass cookstoves. https://mnre.gov.in/file-manager/UserFiles/approved-models-of-portable-improved-biomass-cookstove-manufactures.pdf. Accessed 14 Dec 2018
26. Consultancy AE (2010) Guidelines to Defra/DECC's GHG conversion factors for company reporting; produced by AEA for the Department of Energy and Climate Change (DECC) and the Department for Environment, Food and Rural Affairs (Defra), Version 1.2. 1. https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/69554/pb13773-ghg-conversion-factors-2012.pdf. Accessed 15 Mar 2016
27. Bolaji BO, Olalusi AP (2009) Development of an improved coal stove for cooking in developing countries. AU J Technol 12(3):182–187