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EFFICIENT USE OF BIOMASS IN IMPROVED COOKSTOVES

R. K. PAL

Department of Mechanical Engineering,
Panjab University SSG Regional Centre, Hoshiarpur (Pb.)
E-mail: ravinder_75@yahoo.com

Abstract

Traditional biomass cookstoves have very low efficiency. The improved cookstoves have very high efficiency. These improved cookstoves with high efficiency saves biomass fuels. Biomass can be saved in case of rocket elbow cookstoves. The amount of biomass which can be saved in case of rocket elbow cookstoves is 65.88 MT. More biomass can be saved in case of gasifier fan cookstoves. The amount of biomass which can be saved is 155.71 MT. The pollutants like particulate matter, black carbon, carbon mono-oxide and carbon dioxide emission is lesser in case of rocket elbow cookstoves. The pollutants are least in case of gasifier fan cookstoves. The reduction in particulate matter, black carbon, carbon mono-oxide and carbon dioxide emission in gasifier fan cookstoves is 1.77 MT, 0.24 MT, 0.71 MT & 151.64 MT respectively in comparison to traditional cookstoves. Therefore indoor air pollution is greatly reduced in case of improved cookstoves especially in case of gasifier fan cookstoves as compared to traditional cookstoves.

Keywords: Biomass, Improved cookstoves, Renewable energy, Indoor air pollution, Global warming.

1. Introduction

A major part of the World's and Asian population depend on biomass for heating and cooking. Biomass energy will play an essential role in fulfilling the future energy needs of India. The availability of biomass in India is very high. The annual availability of biomass is almost 565 million tonnes in India [1]. The estimate tells about 47% of total residue produced is used as fodder [2 - 4]. The remaining residues are available for use in cookstoves. Main uses of bioenergy are for cooking, boiling water and heating with a very low efficiency. World's 50% population and more than 75% of south Asians use biomass as primary source of energy for heating and cooking [5 -7]. In urban regions of developing

Nomenclatures

E_b	Energy available from biomass, PJ
E_c	Energy available after combustion, PJ
E_h	Energy required per house per stove day, PJ
E_t	Total biomass energy consumed in India, PJ
f_h	Fraction of houses using biomass energy
h	Number of house using biomass energy
M_a	Biomass available for combustion, MT
M_b	Total biomass available in India, MT
m_{bc}	Black carbon emission factor, g/kg of fuel
M_{bc}	Total black carbon emission, MT
M_c	Biomass consumption, MT
m_{co}	Carbon mono-oxide emission factor, g/MJ of energy produced
M_{co}	Total carbon mono-oxide emission, MT
m_{co2}	Carbon dioxide emission factor, g/litre of water boiled
M_{co2}	Total carbon dioxide emission, MT
M_{cs}	Comparative biomass saved, MT
m_{pm}	Particulate matter emission factor, g/kg of fuel
M_{pm}	Total particulate matter emission, MT
M_s	Biomass saved, MT
M_{s_ics}	Biomass saved in improved cookstoves, MT
M_{s_tcs}	Biomass saved in traditional cookstoves, MT
n	Total number of houses in India
Q_b	Heat required to boil 1 litre of water, PJ
x	Fraction of biomass used as fodder

Greek Symbols

η_t	Thermal efficiency of cookstove

Abbreviations

BC	Black Carbon
CO	Carbon Monoxide
CO_2	Carbon Dioxide
LPG	Liquefied Petroleum Gas
PM	Particulate Matter

countries natural gas, charcoal, kerosene, wood, liquefied petroleum gas or electricity is used for cooking according to income [8 - 12]. In rural regions limited income and free availability of biomass encourage people to keep using biomass for cooking. Interventions for disseminating improved cookstoves date back to the 1970s. Until the new millennium the design were mainly for increasing fuel efficiency because of a seeming link between household energy and deforestation [13, 14]. The domestic consumption of liquefied petroleum gas was around 12.3 million tons in 2008–2009 in India, translating to about US$4 billion (Rs.17600 crores) in subsidies [15].

Biomass combustion inside the house is the main cause of indoor air pollution [16]. Indoor air pollution is the largest factor for female deaths; around 5% of all female deaths in the developing world are due to indoor smoke [6]. Epidemiological studies discover powerful associations between indoor air pollution exposure and acute respiratory infections symptoms [7, 16, 17]. Other health impacts from the air pollution are pneumonia and low birth weight in children and cataracts, chronic lung disease, and heart disease in women. About 420 thousand persons die prematurely every year in India by household fuel air pollution [5]. Carbon monoxide (CO) and fine particulate matter are currently the main components of performance measures of stoves for health. Other important pollutants are methane and nitrous oxide. These have much higher global warming potentials per ton than carbon dioxide (CO_2) [18]. CO and the entire mixture of non-methane volatile organic compounds in biomass smoke also act as indirect warming agents [19]. The extent of warming due to particles in biomass smoke depends on the ratio of black warming particles to organic lighter coloured and cooling particles. There are emissions of nitrogen and sulphur oxides from burning of biomass to give some cooling from the nitrate and sulphate particles created downwind. The CO_2 created by renewable biomass combustion like residue of crops or dung does not contribute to global warming. Black carbon (BC) is the principal cause after carbon dioxide which gives rise to global warming. Combustion and gasification of biomass often give lower emissions of oxides of nitrogen and sulphur than combustion of fossil fuels. Combustion of solid fuels also generates bottom ash and fly ash. The development of combustion technology that minimize the formation of fly ash and flue gas treatment technology that effectively can handle this problem are important.

Most traditional biomass cookstoves are inefficient and use six to seven times more energy input than non-biomass stoves [20]. Improved cookstoves can ensure higher efficiency in utilizing biomass fuels [21]. Improved cookstoves saves cooking time and can be lighted easily. Estimated mean end-use energy need is of 11 MJ/ (stove day) for cooking in India [22]. The biomass needed in a traditional cook stove for cooking was estimated to be 4 kg/day with an efficiency varying from 11 to 18% depending on biomass type. Currently there are two broad categories of improved cookstoves namely gasifier stoves with two-stage combustion and improved one-stage burning using the rocket elbow combustion chamber. StoveTec, the most recent edition of the rocket stove has an efficiency of about 35-40%. Gasifier technology based stove have maximum water boiling efficiency of 70% and CO emissions of just 0.4 g/MJ on large scale [23]. In gasification solid fuel is converted into a gaseous fuel by a process of high temperature oxidation-reduction reactions. The product of gasification is a fuel and it can be further used for combustion purposes. Undesired emissions can be minimized in gaseous fuel combustion. The stoves that employ gasifier technology give consistent fuel savings over the open fire though there are some difficulties in operation [24]. The gasifier cookstoves can save forests because they use a variety of non-wood and waste-wood fuels. The gasifier cookstoves have better the combustion efficiency & heat-capture efficiency [25]. The international price of LPG will continue to increase faster than rural incomes. Thus making the transition to modern household fuels difficult.

The present work is to estimate the potential of biomass conservation in India using the improved gasifier fan cookstoves and to compare it with traditional cookstoves and improved rocket cookstoves and compare emissions in these cookstoves. Parameters like biomass saving, particulate matter, black carbon, carbon monoxide and carbon dioxide emission etc. are computed from the literature available.

2. Materials and Methods

The traditional cook stove is shown in Fig. 1. It is usually made from mud and bricks or mud alone. It has one side open to atmosphere and the air enters from this side for combustion. Burning takes place at the top. The efficiency of traditional cookstove is very less. It is of the order of 0.11 to 0.18% [26].

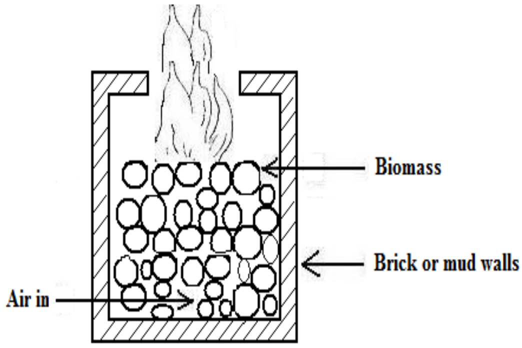

Fig. 1. Traditional cook stove.

The rocket elbow cookstove is shown in Fig. 2. Stainless steel or cast iron is mainly used for construction of the rocket elbow stove. Kiln-fired ceramic tiles can also be used to form a rocket elbow stove. In this the air enters from the bottom elbow and combustion takes place at the bottom of the stove. Chimney is provided for better draught. The efficiency of the rocket elbow cookstove is higher than traditional cookstove. It is of the order of 0.4% [23].

The gasifier fan cookstove is shown in Fig. 3. The galvanized iron sheets can be used to manufacture the gasifier cookstoves. The air enters from bottom and passes through biomass, pyrolysis zone and charcoal zone and converting the biomass into gas. Secondary air enters at the top for combustion of the gas. The efficiency of the gasifier fan cookstove is higher than both traditional and rocket elbow cookstove. Its value is usually of the order of 0.7% [23].

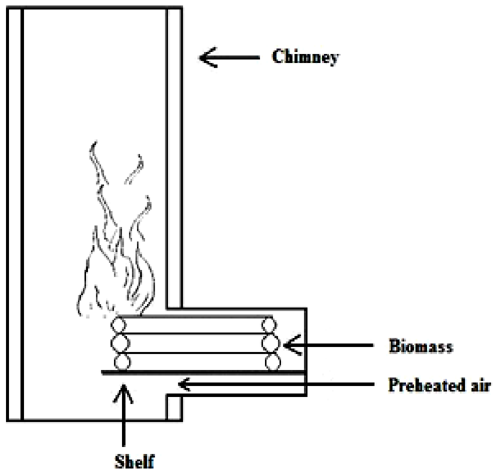

Fig. 2. Rocket elbow cookstove.

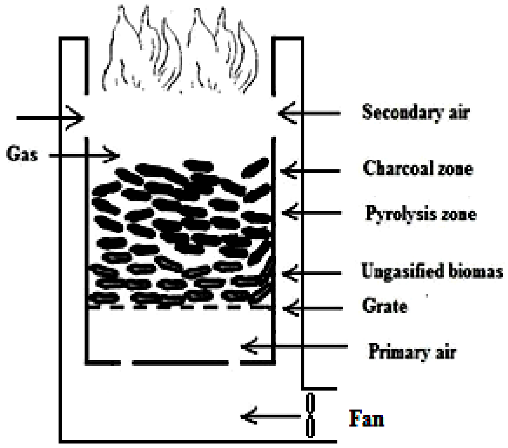

Fig. 3. Gasifier fan cook stove.

The emission factors for various pollutants were taken from the literature available and the values of these factors are given in the following paragraph.

Particulate matter emission factor is 6.3 g/kg of fuel in case of traditional cookstove [26]. The particulate matter emission factor from rocket elbow and gasifier fan cookstove is 1.71 and 0.2 g/kg of fuel burned [27]. The BC emission factor for traditional, rocket elbow and gasifier fan cookstove is 0.88, 1.16 and 0.06 g/kg of fuel burnt [27]. The CO_2 emission from traditional, rocket elbow and gasifier fan cookstove is 536, 206 & 277 g per litre of water boiled and then simmered for 30 minutes [27]. The CO emission factor is 1.5, 1 and 0.4 kg/MJ of energy consumed in traditional, rocket elbow and gasifier fan stove [23].

The various parameters like biomass saved & emission of CO, CO_2, PM and BC in India are computed using the following relations.

$$M_a = (1 - x) M_b \quad \text{(MT)}$$

$$h = f_h \times n$$

$$E_c = \eta_t \text{ CV } M_a \quad \text{(PJ)}$$

$$E_t = 365\ hE_h \quad \text{(PJ)}$$

$$M_s = \frac{(E_c - E_t)}{CV} \quad \text{(MT)}$$

$$M_c = \left(M_a - M_s\right) \quad \text{(MT)}$$

$$M_{cs} = \left(M_{s\_ics} - M_{s\_tcs}\right) \quad \text{(MT)}$$

$$M_{cs} = \left(M_{s\_ics} - M_{s\_tcs}\right) \quad \text{(MT)}$$

$$M_{pm} = m_{pm}\ M_c \quad \text{(MT)}$$

$$M_{bc} = m_{bc}\ M_c \quad \text{(MT)}$$

$$M_{\text{co}} = m_{\text{co}}\ E_t \quad \text{(MT)}$$

$$M_{\text{co}_2} = \frac{m_{\text{co}_2}\ M_c}{Q_b CV \eta_t} \quad \text{(MT)}$$

3. Results and Discussion

The potential for biomass conservation by using gasifier fan cookstoves is immense as the efficiency of traditional cookstoves and that of rocket elbow cookstoves is very less as compared to gasifier fan cookstoves. Therefore less amount of biomass is used in the gasifier fan cookstoves to produce same amount of heating as compared with traditional or rocket elbow cookstoves. Biomass can be saved in case of Rocket elbow cookstoves (Table 1, Fig. 4) as compared to traditional cookstoves. This is because the efficiency of rocket elbow cookstoves is much higher than that of traditional cookstoves. The amount of biomass which can be saved in case of rocket elbow cookstoves in India is 65.88 MT as compared to traditional cookstoves. More biomass (Table 1, Fig. 4) can be saved in case of gasifier fan cookstoves than that in rocket cookstoves or traditional cookstoves. This is due to the fact that the efficiency of gasifier fan cookstoves is higher than that of the rocket stove and traditional cookstoves. 155.71 MT of biomass can be saved annually in India by using gasifier fan cookstoves.

Table 1. Comparison of cookstoves in India (Annual basis).

Cook Stoves	Biomass Saved (MT)	CO emission (MT)	PM emission (MT)	BC emission (MT)	CO_2 emission (MT)
Traditional	-	0.97	1.81	0.25	164.44
Rocket elbow	65.88	0.65	0.38	0.26	21.89
Gasifier fan based	155.71	0.26	0.03	0.01	12.80

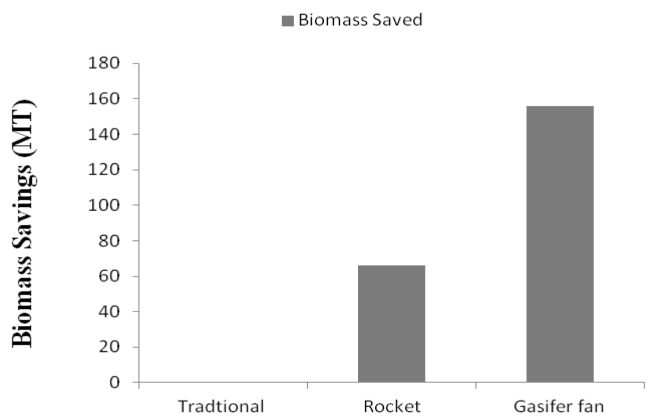

Fig. 4. Biomass saved in improved cook stoves.

Annual emission of pollutants like CO (Table 1, Fig. 5) and particulate matter (PM) (Table 1, Fig. 5) is very less in case of rocket elbow cookstoves in comparison to traditional biomass cookstoves. This is due to higher efficiency of the former cookstoves. This will reduce the consumption of biomass for same heating required for cooking. The black carbon (BC) emission is of the same order as that in case of traditional cookstoves. Annual emission of pollutants like CO (Table 1, Fig. 5), particulate matter (PM) and black carbon (BC) (Table 1, Fig. 5) is very less in case of gasifier fan cookstoves in comparison to traditional and rocket elbow cookstoves. This is due to higher efficiency of the gasifier fan cookstoves in comparison to the other two cookstoves. The reduction in particulate matter, black carbon and carbon mono-oxide emission in gasifier fan cookstoves in India is 1.78 MT, 0.24 MT and 0.71 MT respectively in comparison to traditional cookstoves.

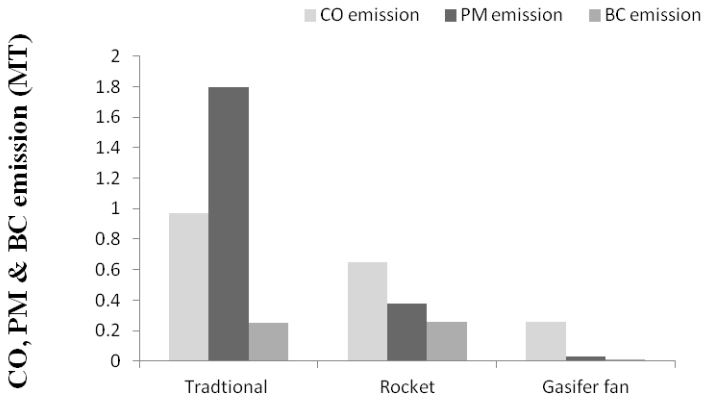

Fig. 5. CO, PM & BC emission comparison for various cookstoves.

Also the CO_2 emission (Table 1, Fig. 6) is very less in case of rocket elbow cookstoves in comparison to traditional cookstoves. This is again due to higher efficiency of the rocket elbow cookstoves in comparison to traditional cookstoves. Because of which less biomass is used for same amount of heating required for cooking. The CO_2 emission (Table 1, Fig. 6) is least in case of gasifier fan cookstoves due to less use of biomass because of highest efficiency of the cookstoves in comparison to the other two cookstoves. The reduction in carbon dioxide emission in gasifier fan cookstoves is 151.64 MT in comparison to traditional cookstoves. Therefore the indoor air pollution is greatly reduced in case of gasifier fan cookstoves and the problem of indoor air pollution can be solved by using gasifier fan cookstoves.

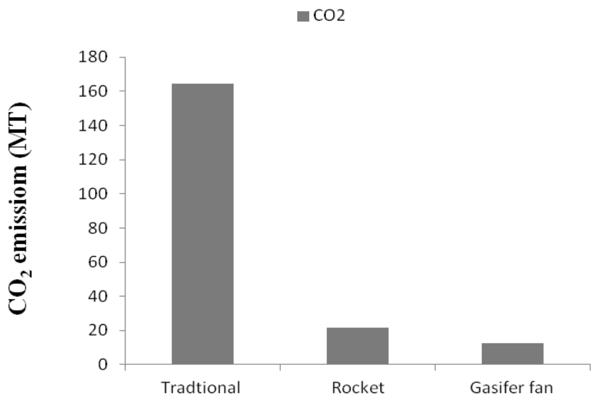

Fig. 6. CO_2 emission comparison for various cook stoves.

4. Conclusions

The potential for biomass conservation is immense in case of gasifier fan cookstoves. More biomass can be saved in case of gasifier fan cookstoves as compared to rocket stoves. The amount of biomass saved is 155.71 MT in case of gasifier fan cookstoves. The emission of pollutants like particulate matter, black carbon, CO and CO_2 are very less in case of gasifier cookstoves in comparison to traditional biomass cookstoves. Therefore the indoor air pollution is greatly reduced in case of gasifier fan cookstoves.

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