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Original Article

Performance Improvement of Biomass Cookstove with the Help of Swirl Inducement

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Abstract - *In developing countries, most of the population lives in rural areas. They mostly use coal or biomass for heating their homes and preparing food. This process would increase indoor air pollution, which is detrimental to the health of the family members who live in those houses. The experiment has been carried out to increase the performance of biomass cookstoves both in terms of efficiency and pollution by incorporating a swirl vane instrument made up of a galvanized iron sheet. The experiments have been conducted with a 3-stone open fire stove, an improved natural draught cookstove with and without attaching a swirl vane burner. Water boiling tests, emission tests, and particulate matter measurements have been done for the various parameters. It has been found that the swirl helps mix secondary air with the hot gases, resulting in an evenly distributed heat beneath the pot and cleaner Combustion of fuel. The efficiency of the improved biomass cookstove is enhanced by 4% with the help of a swirling flame, and the reduction in the usage of fuel, particulate matter, carbon monoxide, hydrocarbons, etc., is noted. It can be said that the mere incorporation of a swirling instrument into a biomass cookstove will help to reduce indoor air pollution and fuel usage, which improves the health of poor people.*

Keywords – *Biomass cookstove, Combustion, Efficiency, Emission, Swirling flame*

1. Introduction

There is a widespread biomass cookstove with coal and biomass in developing countries like wood, animal dung, etc. Besides, these cookstoves release greenhouse gases into the air and increase indoor air pollution [1]. Indoor burning of these solid fuels emits dangerous particulate matter (PM), carbon monoxide (CO), and many other toxic pollutants in the atmosphere [2]. Pollution levels in the house with traditional stoves are often 20 to 100 times greater than the air quality guidelines given by the World Health Organization (WHO) [3]. The efficiency of a three-stone cook stove is merely 12 to 14% which requires more fuel. Additionally, these traditional cookstoves release heavy smoke, responsible for many chronic obstructive lung diseases and acute lower respiratory infections [4].

Incomplete biomass combustion releases the considerable emissions of CO, unburned Hydrocarbons, fly-ashes, oxides of nitrogen, etc. [5]. Today, researchers try to enhance the efficiency of the stove and reduce emissions of the pollutant. There are many novel ways and designs to improve the performance of biomass cookstoves [6, 7]. Forced ventilation is used mostly to achieve great performance [8, 9, 10]. Raman et al. [11] developed the forced draft cookstove, which runs on the thermos electric generator. The cookstove works with an efficiency of 44% with clean Combustion; it also generates some voltage with the help of temperature difference. Thacker et al. [12] used pot skirts to improve efficiency and reduce the fuel consumption of traditional stoves. Panwar and Rathor [13] developed a biomass cookstove for community cooking and were able to get around 37% efficiency. There was also a nationwide program to improve cookstoves in India [14].

One of the methods of increasing the performance of the cookstove is by inducing a swirler inside the burner model. Swirler means guided vane, which can deflect the gas flow direction [15]. That will rotate the stream. This swirling flow produces a recirculation bubble that plays a significant role in stabilizing the flame [16, 17]. In engineering, combustion setups with swirling play a significant role in mixing fuel gases and oxidizers, which results in more heat generation and less smoke [18]. It also significantly influences heat and mass transfer. Swirl generates axial and tangential components of flame coming out by Combustion. The axial flame component directly heats the bottom part while the radial component evenly distributes the heat beneath the cooking pot. This results in efficiency increment and clean combustion [19].

Bhandari et al. [20] have experimented with 2, and 4-bladed swirlers made up of GI sheets and two twisted tapes made up of clay and bamboo create, respectively. The swirler was set on the top of the stove. Similarly, the twisted tape was also fixed with the help of vertical and horizontal rods at the outlet of the flame. The 4-blade swirler and 6-0 cm clay twisted tape gave efficiencies of more than 42%. The clay twisted tape can reduce a considerable amount of smoke. The 'bamboocrete' twisted tape proved to be a failure. The experiment suggests that a strong swirl of hot gases helps to increase efficiency considerably. Honkalaskar et al. [21] experimented with the twisted tapes of mild steel.

The 7 tapes were fixed with the horizontal steel rod to make a twisted tape pack which was easily placed over the hearth of the stove to evenly covered it. The Experiment was carried out laboratory as well as in the field. The introduction of twisted tapes assembly successfully decreases firewood consumption by 21%, soot accumulation by 38%, and time for cooking by 18%. Kumar [22] found that the emission of CO is considerably reduced with the help of twisted tapes. Surjosatyo and Ani [23] experimented with swirl vane burners where vanes are placed at different angles of 20°, 30°, and 40°. They found that the 40° angled swirl vane gave cleaner Combustion and high flame temperature. They optimized the 40° swirl vanes angle for more combustion efficiency.

2. Experimental Setup

In the experiment, three cookstoves are used one 3 stone traditional open fire, an improved natural draught cookstove, and a natural draught cookstove with a swirl vane burner setup.

2.1. Test Improved Cookstove

A natural draught biomass cookstove is used for the experiment. This cookstove is an improved one. It has two air inlets at the bottom, which is responsible for the natural draft and Combustion, and the secondary air inlet at the upper part of the stove, which enhances the effective burning of hot gases in the upper part. The stove body is covered with insulation to reduce heat loss (See figure 1 and figure 2).

Fig. 1 Improved cookstove

Fig. 2 Top view of test improved cookstove

2.2. Swirl Vane Burner

The swirl burner was made up of a GI sheet, 6 vanes evenly spaced on it. The fabrication of vane has been done by using the process of brazing (See figure 3). This material can resist temperatures below 1000 K in continuous operation. Vane angel was decided to keep 40° to minimize pressure drop and effective flame swirling [23]. Other dimensions of the swirl vane are given in the table.

Fig. 3 Swirl 6-vane burner

Table 1. Characteristics of swirl burner

Parameter	Size
Diameter of burner	**170 mm**
Length of vane	**70 mm**
Width of vane	**35 mm**
Thickness of vane	**0.4 mm**
Material used	**Galvanized iron**
Joining process	**Brazing**

After setting up the swirl vane burner on the mouth of the improved cookstove, (See figure a), all the tests have been carried out.

Fig. 4 Swirl set up on top of the improved cookstove.

3. Test Methods

Three types of testing have been carried out. The first is Water Boiling Test (WBT) for efficiency measurement, the second is the Particulate Matter test for measurement of Particulate Matter (PM), and the third is the emission test for measurement of five pollutant gases.

3.1. Efficiency Measurement

The efficiency of all three stoves was measured using Equation 1. From the above equation and value from the experiment, calculate the thermal efficiency of the cookstove.

$$\eta_{th} = \frac{\left\{(mCp\Delta T)_{water} + (mCp\Delta T)_{pot} + \Delta m\lambda\right\}_{1-vessel} + \left\{(mCp\Delta T)_{water} + (mCp\Delta T)_{pot} + \Delta m\lambda\right\}_{2-vessel}}{(M_f\ C.V.)_{fuel}} \quad (1)$$

Where m is the mass of water, C_p is the specific heat of water, ΔT temperature difference, Δm is the mass of evaporated water, λ is the latent heat of water, M_f is the mass of fuel, and C.V. is the Calorific value of wood.

3.2. Particulate Matter Test

In biomass cookstove, particulate matters are present in the exhaust gas, so it is necessary to know the amount of particulate matter [25]. This test used filter paper of 25 mm diameter, a vacuum pump with a 30 mm diameter holder, and an anemometer for particulate matter measurement. The vacuum pump sucks the exhaust gas passing through the filter paper. Anemometer is used for the measurement of the velocity of exhaust gas. Pre weighed filter paper was set at the one end of the pipe connected to a vacuum pump, and another end of the pipe was used to suction gases. The stove is covered with a heat box to restrict atmospheric air from mixing with the exhaust gases of the stove. This process was continued for 15 minutes, then the filer paper was taken out, and its weight was measured again.

$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \quad (2)$$

pressure is taken as atmospheric pressure (P_1=P_2)

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} \quad (3)$$

$$PM = \frac{post\ weight - pre\ weight}{V_2} \quad (4)$$

After calculating the initial volume flow rate (V_1) by multiplying the area of the holder pipe and the velocity of air sucked by a vacuum pump. The air temperature values at the outlet (T_1) and reference temperature (T_2) of air 298 K are put in Equation 3. To find out the Volume flow rate at the outlet of pipe (V_2), which helps to find the PM with the help of Equation 4.

3.3. *Emission Test*

This test is carried out to find five different gases present in the coming gas by five gas Analyzer equipment [25]. Five gases that are measured are Carbon monoxide (CO), Carbon content (CC), Hydrocarbon (HC), Nitrogen oxides (NO_X), Oxygen content (O_2), and Carbon dioxide (CO_2).

4. Results and Discussion

We can see the swirling flow of flame in figure 5. After measuring all parameters with various instruments, we can compare them for better understanding.

Fig. 5 Swirling flow of flame

4.1. Efficiency Test Results

The water temperature in the water boiling test took 43 minutes to reach 95 °C in 3 stone open fire stove, while it took 33 minutes in an improved cookstove. When swirl was attached to it, this time was reduced by 7 minutes. (See figure 6).

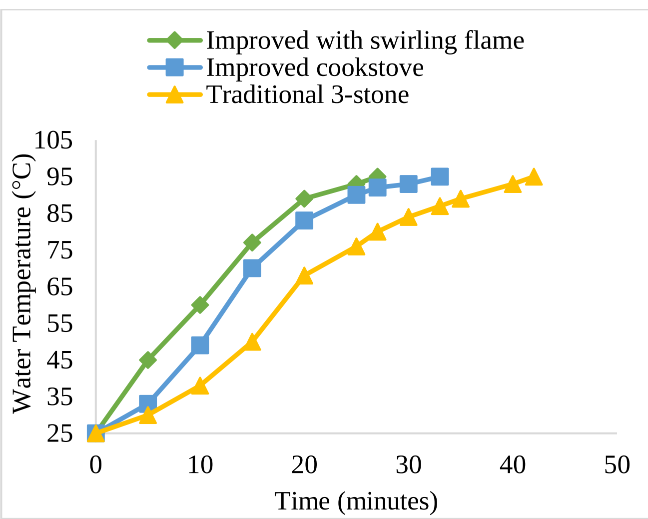

Fig. 6 Variation of the temperature of the water with time in all three cookstoves

The efficiency (using equation 1) of a traditional 3-stone open fire is 12.88%, which is much lower than an improved cookstove's efficiency is 33%. When swirl is introduced in an improved cookstove, this efficiency is increased by 4.7 % and is reached 37.7%. Fuel consumption is almost half in an improved cookstove compared to a traditional 3 – stone open fire. A much lower difference is noticed in fuel consumption when swirl is induced. Swirl-induced cookstove utilized 210 g/h less fuel than the former. (See the figure 7)

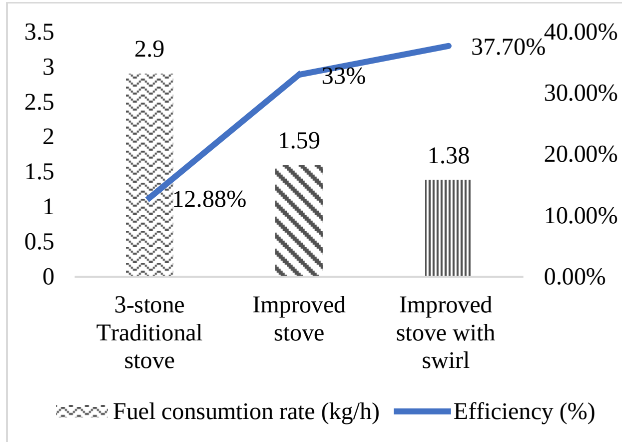

Fig. 8 Efficiency and fuel consumption in stoves

4.2. Particulate Matter Test Results

Tradition opens fire stove releases a tremendous amount of particulate matter, which is more than 500 mg/m3 of air, which would result in respiratory disease. On the other hand, between improved stoves without swirling and swirling difference is 7.69 mg/m3. Still, the improved stove with Swirl releases the lowest particulate matter in the atmosphere. (See the figure 8)

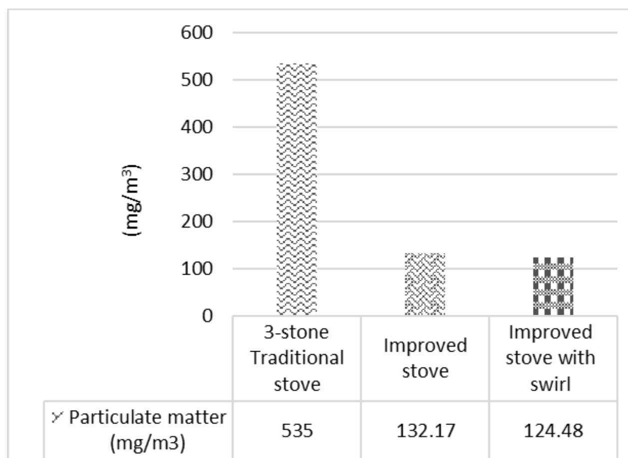

Fig. 9 Particulate matter test results

4.3. Emission Test Results

Table 1. Data of emission test of the improved stove with and without swirl.

Particulars	Unit	Improved cookstove	Improved cookstove (With swirl)
CO	%	0.590	0.268
HC	PPM	55	42
CC	%	0.792	0.285
O_2	%	10.00	6.24
CO_2	%	10.58	13.62

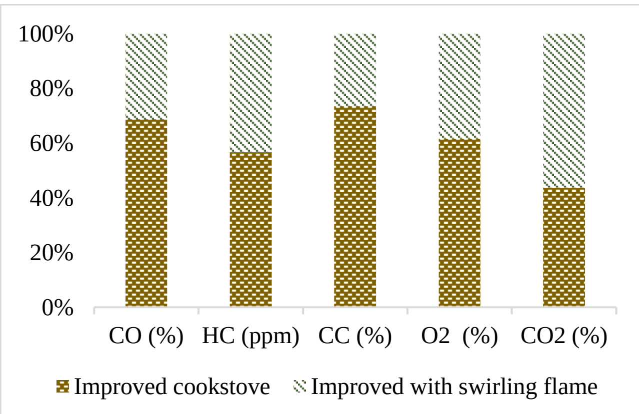

Fig. 10 Emission results of stoves

In emission test results are given in Table 2. The improved cookstove with swirl vane significantly reduces more than half of the carbon monoxides (CO) amount compared to without swirl improved cookstove. The swirl vane effectively mixes the secondary air with the hot gases and gives more clean Combustion than without a swirl. As a result amount of CO decrease but CO_2 increase. A decrease in Oxygen percentage also shows that more oxygen is used in Combustion. The tremendous reduction in Carbon content (CC) from 0.792 to 0.285 and a 23% reduction in Hydrocarbon (HC) is also the notable result of swirl (See the figure 9)

5. Conclusion

The swirl vane burner in our setup can reduce 54% CO formation, gives clean Combustion comparatively, and increase by 4.7% efficiency. Swirl influences heat and mass transfer significantly. It improves the efficiency of the Combustion, and swirl flow provides environmentally cleaner fuel combustion by reducing the formation of hazardous pollutants like Carbon monoxide, PM2.5, Carbon content, Hydrocarbon substances, etc. It is a very low-cost, simple designed instrument, which can bring significant change in efficiency and pollutant of any stove.

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