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DESIGN AND FABRICATION OF HYBRID COOKING STOVE TO USE RENEWABLE ENERGY IN NON-URBANIZED AREAS

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ABSTRACT

Traditional stoves are mostly used for cooking in non-urbanized areas. Biomass such as wood, leave, cow dung, crop residue, etc. are used for this purpose. But these stoves emit huge smoke, causing indoor air pollution and health problems. To prevent these harmful effects a greener form of cook stove required. Numerous studies in biomass stoves have been carried out in order to improve performance while minimizing negative effects on human health and the global climate. In this study, a Hybrid Stove (FPM-HS) was designed, fabricated, and tested. The stove was made of concrete and operates in a dual fuel mode. It emits much lesser indoor air pollutants compared to a traditional cooking stove. So, it is a perfect alternative to the traditional cooking stove. When there is availability of sunlight, the solar panel generates electricity which is passed to the electric heater of the hybrid stove through a wire. As a result, the electric heater gets heated and can perform cooking operation. In the absence of sunlight, the tray is opened and the gas burner appears. The gas burner is connected to a biogas tank via a gas line pipe. When the nozzle is turned on, the gas from the gas line pipe enters the burner. When the knob is turned on oxygen mixes with the gas leading to combustion and thus flame appears. The thermal efficiency of the biogas section of the manufactured Hybrid Cooking Stove was 30.87%, the burning rate was 12.16g/min, and the specific fuel consumption was 0.025g/g of water. The efficiency of the solar electric section of the Hybrid Stove was 72.07%. The calculated electric energy consumption was found 5kWh/day for 5hrs cooking. The study suggested that this technology might be suitable for cooking in non-urbanized areas as well as reduce environmental pollution and meet up the energy crisis.

Keywords: Hybrid Stove, Traditional Cooking Stove, Biomass, Solar, Biogas

1. Introduction

Bangladesh is a densely populated country with an estimated 166 million inhabitants. Around 61% of them live in non-urbanized areas [1]. Most of the population in these areas uses traditional stoves made of mud and uses biomasses as their fuel. In Bangladesh, biofuels for cooking with traditional stoves are consumed. With unsatisfactory thermal efficiency, the traditional cook stove has many disadvantages, including deforestation, indoor air pollution, adverse health impact, and climate change. [2].

Regardless of the discomfort caused by the smoke which surrounds or precedes its use, many people in rural and urban areas continue to use charcoal for cooking. Along with a typical metal stove that used charcoal as fuel, an upgraded charcoal cooking stove was conceived, built, and tested. The thermal efficiency, specific fuel consumption, and burn rates are 34%, 0.52 g/g, and 5.666667 g/min was obtained for the improved stove and 11%, 1.23 g/g, and 1.66667 g/min for the traditional metal stove respectively [3].

Biofuel usage affects household economics, women's time and activities, gender roles, safety and cleanliness, and the overall ecosystem. It is estimated that 50% of the global wood harvest is used for fuel [4]. Gas stoves are also used by the people of non-urbanized regions. The emission of indoor air pollutants in this stove is much less but the drawback here is that gas supply is not available in all non-urbanized areas. Even in some urbanized areas, the gas supply is not available. People have to purchase LPG gas cylinders for cooking but it may not be available in non-urbanized areas and even if it is available, it may be unaffordable to people of that region.

The use of electric stoves has increased in both urban and non-urbanized areas. Compared to gas stoves, electric stoves cost less money at the time of purchase. Electric stoves are also eco-friendly. The supply of electricity and load shedding can be a matter of concern while using electric stoves. To solve this issue solar energy can be used to provide electricity to electric stoves through solar panels. As an alternative to conventional cooking techniques, the government and non-governmental organizations have been working to give people access to cleaner and more effective cook stoves. Development of a solar electric stove with an input power of 12V DC [5]. A Hybrid Solar-Biomass Cook Stove was designed which had 5% thermal efficiency increase and 6g/L reductions in fuel usage in comparison to a biomass stove [6]. All of these advancements have enabled stove designers and manufacturers to deliver better cook stoves.

This study was initiated to overcome the drawbacks of the available stoves in the rural market by designing a

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hybrid cooking stove. The hybrid stove is a stove that is made by combining an electric stove that functions with the help of solar energy and a biogas stove. It can run on dual fuel mode. It is designed and constructed by utilization of biogas and solar energy. In the presence of sunlight, the solar electric section of the stove could be used and, in its absence, we can use the biogas section of the stove. The performance of the hybrid stove was also investigated. The stove is more sustainable than traditional stoves as renewable energy is being used here. Both Solar energy and biogas are eco-friendly and do not have an adverse effect on the environment.

This project was developed with the intent of gaining the advantages of both biogas and a solar electric stove and is constructed to be used interchangeably which will enable saving the environment from the emission of harmful indoor air pollutants.

2. Materials and Methods

Careful consideration is needed to select appropriate methods, procedures, and equipment for designing the Farm Power and Machinery-Hybrid Stove (FPM-HS).
The materials used to construct the FPM-HS are Portland cement, sand, gravel, mild steel rod, gas burner, control knob, electric coil plate, gas flow pipe, and nozzle. The tools and machines used are measuring tape, steel scale, screwdriver, welding machine, hammer, mortar and pestle, wooden mold, pointing trowel, finishing trowel, color, and brush.

2.1 Design Considerations

While designing the stove size, material cost, durability, portability, approximate cooking time, indoor air pollution, congregation, safety, materials availability, overall efficiency, etc. characteristics were considered.

2.2 Design Parameters

The stove was developed to suit the energy needs to cook for a five-person family. The length, width, and height of the Hybrid Stove will be 10.5inch, 11.5inch, and 6.5inch respectively. The diameter of the Hole for Burners should be 5.5inch. The diameter of Gas Burner should be 4inch. There should be 45 holes in gas burner. The diameter of gas the pipe should be 1.5inch. The length, width and thickness of the tray should be 10inch, 9.2inch and 0.5inch respectively. The diameter of the electric heater should be 7.5inch and that of the height should be 0.5inch. The power of electric coil should be 1000W.

2.3 Computer-Aided Design

AutoCAD 2020 was used as the computer-aided design program to design the Farm Power and Machinery-Hybrid Stove (FPM-HS) according to the determined dimensions. The design of the Hybrid stove is shown below:

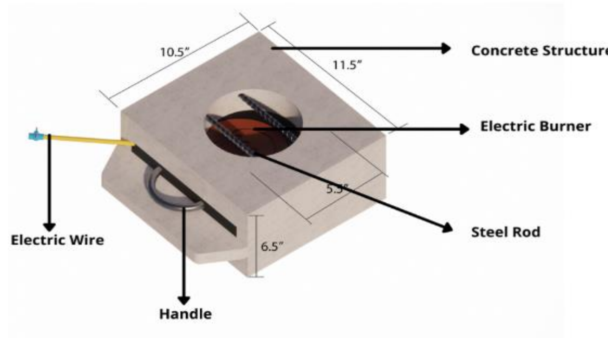

Fig.1 Design of Hybrid Stove when tray is closed

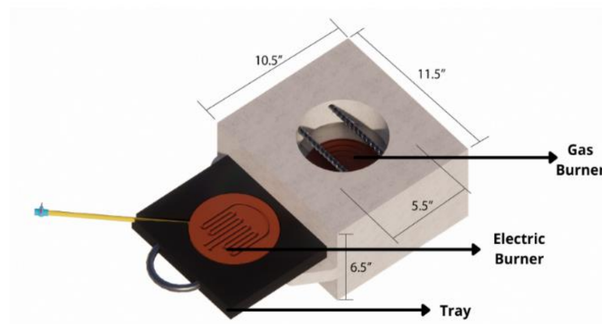

Fig.2 Design of Hybrid Stove when tray is open

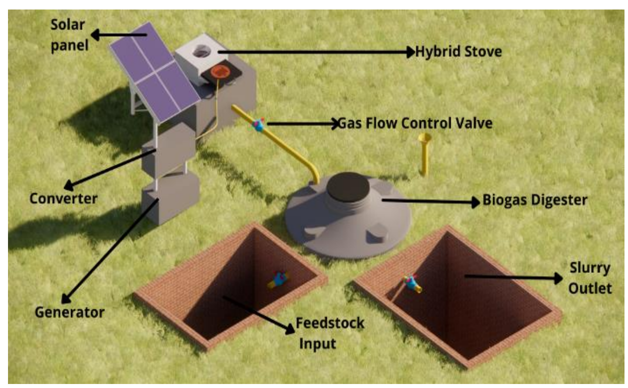

Fig.3 Schematic diagram of Hybrid Cooking System

2.4 Methods of Fabrication

To construct the FPM-HS, the following methods were taken.
1. The materials required to build the stove were measured and specified.
2. Pointing trowel was used to mix sand and cement. Wooden mold was used to give shape to the stove and the electric heater. A finishing trowel was used to provide a smooth finish to the concrete structure.
3. Parts were assembled in the Lab. A welding machine was used for the Attachment of gas pipe. The attachment of pipe and burner with nozzle was done with a wrench.
4. Painting and other aesthetic works were completed.

2.5 Experimental Methods

Experiments should be conducted to test the feasibility and performance of the hybrid stove. Equipment used in the study are K-Type Thermocouple, Steel Scale, Stopwatch, and Weight Balance.

A 3000L fixed-dome biogas plant with a fixed, non-movable gasholder was used in this experiment. The plant was built underground to shield it from physical harm while also saving space. To link the digester to the water cum gas chamber, a 12.7 mm GI pipe was used, and a 10 mm hose pipe was used to collect biofuel in the form of biogas in the top section of the digester.

The performance of the biogas part of the hybrid stove was determined by Water Boiling Test (WBT). Thermal efficiency, burning rate, and specific fuel consumption of the stove were calculated in the test. At first, the cooking pot was weighed before the test. Then measured water was poured into the pot. The stove knob was turned on and was set on full flame. The pot filled with water was placed on the stove. The initial temperature of the water was recorded. The water was let to be boiled. The pot was removed from the stove when the water started to boil. The fire was instantly put down. The final temperature and weight of the water were measured. The parameters mentioned above were calculated using their respective formulas. The test was repeated five times with mass of 2000g, 1750g, 1500g, 1250g, and 1000g of water and then the average of the values of the parameters was determined.

In this experiment, five solar panels each capable of 250W maximum power were used in this experiment for the electric section. The electric energy stored in the battery is then transferred through the inverter to the electric heater as an AC supply.

The performance test of the solar electric part of the hybrid stove was conducted by connecting the electric heater with the electric line. This experiment is done by WBT. Thus, the input and output powers are electrical energy and heat energy respectively. The heat energy is converted by the resistive circuit (twisted coils). Water was heated to the boiling point, and the time it took to boil a particular amount of water, as well as specific power consumption, were recorded in addition to analyzing thermal efficiency. Efficiency, utilized energy, and energy consumption were determined.

2.6 Data Calculation

2.6.1 Calculation of Biogas part of FPM-HS

Thermal Efficiency

It was measured by the following equation:

$$\eta = \frac{Q_{heating}}{Q_{combustion}}$$

$$= \frac{c \times m \times \Delta T}{q \times m'} \quad (1)$$

Burning Rate

Eq. (2) was used to measure the burning rate:

$$r_{\text{b}} = \frac{Amount\ of\ fuel\ burnt}{Time\ to\ boil\ water}$$

$$\therefore r_{\text{b}} = \frac{m'}{\Delta t} \quad (2)$$

Specific Fuel Consumption

In the case of WBT, specific fuel consumption was measured by Eq. 3:

$$SC = \frac{Amount\ of\ fuel\ Consumed}{Weight\ of\ Water\ boiled}$$

$$\therefore SC = \frac{m\prime}{m} \quad (3)$$

2.6.2 Calculation of Solar Electric Section of FPM-HS

Energy Consumption

The measurement of energy consumption was determined by Eq. 4:

$$Electric\ Consumption\ (kWh) = \frac{power \times hours\ of\ operations}{1000}$$

$$= \frac{P \times t}{1000} \quad (4)$$

Utilized Energy

Utilized energy was measured by Eq. (5):

$$Utilized\ Energy = \Delta m C_{\text{v}} + \Delta T m_{\text{f}} C_{\text{p}} \quad (5)$$

Efficiency

The efficiency was measured by Eq. (6):

$$\text{Efficiency, } \eta = \frac{Utilized\ Energy}{Input\ Energy}$$

$$\therefore \eta = \frac{\Delta m \times \text{C} + \Delta\text{T} \times \text{m}_{\text{f}} C\prime}{P \times t} \quad (6)$$

2.7 Data Analysis

Recorded data from this study were coded and entered in Microsoft Excel worksheet, organized, and processed for further analysis.

3. Results and Discussion

After accomplishing all the steps mentioned the FPM-HS was fabricated (Fig.4 and Fig.5)

Fig.4 Hybrid Stove when tray is closed

In case of electric section of the Hybrid Stove, solar energy was utilized to cook. When there is the availability of sunlight, the solar panel converts solar energy to electricity. This electricity is passed through a wire that connects the solar panel to the electric heater. As a result, the electric heater gets heated and can heat the pot for cooking.

Fig.5 Hybrid Stove when tray is opened

When there is no availability of sunlight, the tray is opened thus the electric heater comes out and the gas burner appears. The nozzle is turned on so that the gas from the gas line pipe enters the burner. Oxygen mixes with the gas, rendering it combustible. Then the mixture of oxygen-gas is flushed into the burner and a flame appears. So, that’s how a solar biogas hybrid cooking stove will operate.

3.1 Performance Test of Biogas Section of FPM-HS
3.1.1 Burning Rate

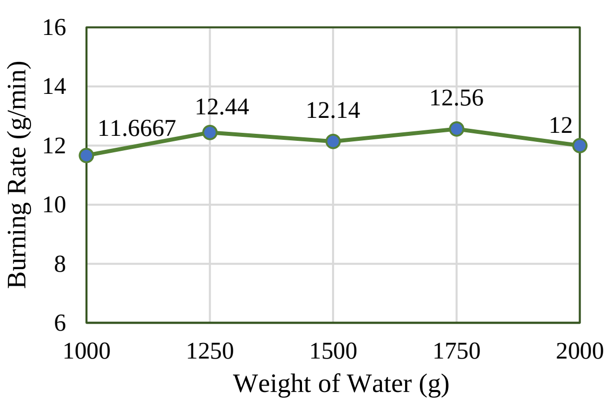

Fig.6 Burning rate at different weights of water

In Fig.6, it was demonstrated that the relationship between the weights of water used for WBT and the burning rate. The burning rate changes with the amount of water to boil. This change depends on the surrounding environment of the stove. The higher the amount of oxygen to burn the higher the burning rate.

3.1.2 Specific Fuel Consumption

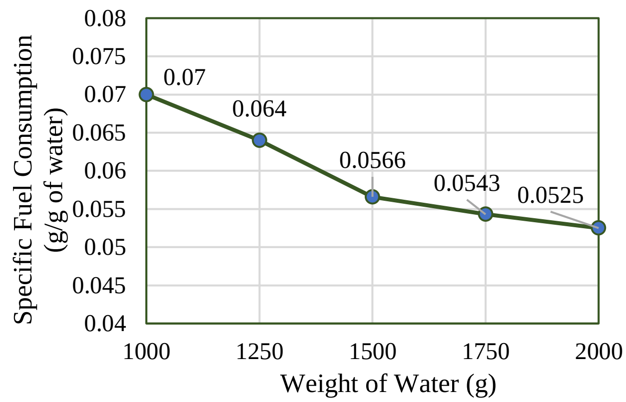

Fig.7 Specific fuel consumption of hybrid stove

The result of the analysis in Fig.7 is clearly showing that there is a strong negative relationship between the weight of water and specific fuel consumption. Hence, it is clear that with the increase in the weight of water, specific fuel consumption decreases. Due to the continuous use of fuel, the pressure of the gas has decreased. As a result, specific fuel consumption has also decreased.

3.1.3 Thermal Efficiency:

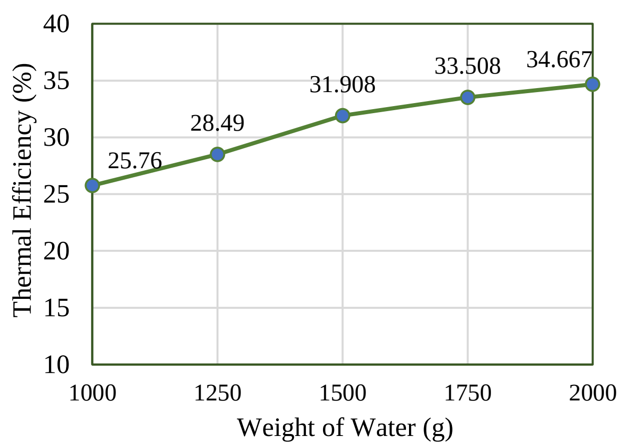

Fig.8 Thermal efficiency at different weight of water

The result of the analysis in Fig.8 is clearly showing that there is a strong positive relationship between the weight of water which is used for WBT and thermal efficiency. Hence, it is clear that with the increase in the weight of water, the thermal efficiency increases. The reason behind this relationship in WBT is that the weight of water to the weight of fuel burnt ratio is comparatively higher for 2000g than the lower weight of water. This occurs due to the same amount of fuel needed to heat the pot for boiling takes about the same time. Then, through convection, the water gets heated and reaches the boiling point. In this case, the amount of fuel needed to boil the higher amount of water is slightly more than the less amount of water to boil. Which in terms causes the weight of water and the weight of fuel burnt ratio to be higher for the higher amount of water to boil and therefore increases the thermal efficiency.

3.2 Performance Test of Solar Electric Section of FPM-HS

3.2.1 Energy Consumption

Hybrid stove having a power rating of 1000W operated for 5 hours a day has the following electric consumption:

Electric Consumption = 5KWh

3.2.2 Utilized Energy

Utilized Energy = 42.2×10^4 J

3.2.3 Thermal Efficiency

Efficiency, η = 72.07 %

4. Conclusion and Recommendation

4.1 Conclusion

In non-urbanized parts of developing countries, cooking energy accounts for a significant portion of total energy usage. The use of biofuels in traditional stoves to consume energy for cooking leads to global warming and is responsible for climatic change. Furthermore, the increasing demand for petroleum fuels, combined with their restricted availability around the world, has forced the search for alternatives. This study demonstrates the solar-biogas hybrid system to cook in dual fuel mode which reduces the emission of greenhouse gas and thus ultimately prevents global warming. The stove facilitates lesser daily fuel usage by utilizing solar energy and it encourages season-independent cooking, as biogas can be utilized in place of solar energy when it is inadequate. So, the study concluded the Hybrid Stove is an excellent alternative to a traditional cook stove. Not only is its performance better than the traditional stoves it also uses renewable energy to cook.

4.2 Recommendation

1. Grates should be introduced to the stove to allow sufficient air supply.

2. Besides the parts of the hybrid stove is irreparable. Their dimensions and alignments are fixed when constructed. So, modification of design is recommended.

3. Efficient gas burner should be used. Better the burner better the efficiency.

4. The developed Hybrid Stove is heavy. Its weight is more than what is desirable. So further modification of the design of the stove is required.

5. References

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NOMENCLATURE

η	: Thermal Efficiency (%)
c	: Specific heat of water (J/kg˚C)
m	: Weight of water (kg)
m'	: Weight of fuel consumed (kg)
q	: LHV of biogas (J/kg)
ΔT	: Temperature difference between initial and final temperature of water
r_b	: Burning rate (g/min)
Δt	: Time taken to boil water (min)
SC	: Specific Fuel Consumption (g/g of
P	: Power (Watt)
t	: Time of operation (hr)
Δm	: Difference in initial and final weight of water (g)
m_i	: Initial weight of water (g)
m_f	: Final weight of water (g)
C	: Water vaporized heat (J/g)
T_f	: Final water temperature (°C)
T_i	: Initial water temperature (°C)
C'	: Water specific heat (J/g°C)