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Developing an Innovative Gasification Based Bio-char Stove in Nepal

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Abstract: This paper on Nepali bio-char stove is a genuine effort to make the cooking practice in Nepal cleaner, efficient and cost effective. The main aim of the project was to develop a bio-char yielding gasifier stove so that not only user is benefited by clean, efficient and cost effective cooking also benefited by the by product of stove famously called bio-char which is reported to be a fertilizer. So, to meet the above two objectives, the stove was designed. The thermal efficiency of the stove was recorded to be 34%. The total cost of fabrication is NRs. 2500. NPV is positive, payback period is 6 months and 1 day and IRR is found to be 190%.The calorific value of charcoal obtained from the stove is found to be 6363 kcal/kg. The design, test results and analysis are presented in this paper.

1. Introduction

Energy is an important development indicator, which provides vital inputs for survival and economic development. The energy resource base in Nepal consists of biomass, hydroelectricity, petroleum products, and natural gas and coal reserves. Among these entire bases, biomass is the dominant form of energy resources of the country with respect to its utilization especially in rural sector. According to Energy Sector Synopsis Report, WECS in July 2010, about 87.1% of overall energy consumption is through biomass within which 77% of energy consumption is met by firewood alone. Energy consumption trend in biomass in Nepal is so high that it is not possible to swap into other energy resources immediately. Instead energy obtained from biomass can be ameliorated in more systematic and scientific way unless other sustainable form of energy resource is implemented.

Around 3.6 million households or 17 million people (~2/3 of the nation) in Nepal are cooking in traditional using firewood fuel [7]. This practice exerts immense pressure on the forest resources of country with negative impacts on environment like excessive deforestation, global warming and indoor air pollution. Thus better efficiency and emissionless cook stove is needed. Traditional biomass cook stoves have low thermal efficiency and high flue gas emission compared to improved cookstove but the gasifier stove even has the potential to replace improved cookstove since the combustion of the gaseous mixture of CO and H_2 can be complete, thus minimizing the emissions of products of incomplete combustion (PIC), which is a major problem with solid fuel combustion [2]. The gasifier stove works on the concept of gasification. There are two types of gasifier stove viz updraft gasifier and downdraft gasifier stove.

The Nepali bio-char stove is based on downdraft gasification principle. The bio-char stove basically consist of two cylinders: inner cylinder and outer cylinder. The combustion and gasification occurs in the inner cylinder. Bio-char stoves involve two processes. First, solid bio-fuel is gasified into a mixture of hydrocarbon-containing gases and charcoal. Second, thegases are burnt with a clean (smokeless) flame. When the stove is used to make charcoal, the operation of the stove is stopped at this stage and the charcoal is removed as a byproduct.A primary air flow is required for gasification, while a secondary air flow is introduced into the hot gas above the fuel in order to assist the gas burn. Organic matter used as fuel in stoves is converted thermally into syngas, solid residue (including bio-charand ash) and liquid (including tars). The stove is one-pot, batch feeding type in which wood pallets or wood chips are fed into the combustion chamber from the top allowing to cook traditional meal viz. Daalbhat (Nepali meal) for a family of five members.

2. Materials and Method

The primary purpose of the study was to design and test the Nepali bio-char stove for domestic cooking purpose and the secondary purpose was bio-char production. The commencement of the project began with the study of existing gasification cook stove. Different books, journal, reports and website have been accessed. Then, a tin-can model of bio-char stove was constructed on the basis of the study based on Dome School Bio-char stove by Kelpie Wilson (2010). The model gave satisfactory result which in turn leads to the formal designing of bio-char stove prototype. All the component of Nepali bio-char stove were designed keeping in the view to make it simple and easy to use for people in rural area with less maintenance and operating cost at the same time considering safety, fuel reduction, smoke reduction and time saving in cooking. After that the stove had been materialized using locally available material i.e. cast iron. The stove test include water boiling test version 3.0 and controlled cooking test version 2.0 prepared by Rob Bailis for Household Energy and Health Programme (HEH), Shell Foundation. The char test include proximate analysis following JIS 8812 standard method and char calorific value test using bomb calorimeter following American Society for Testing Materials (ASTM), D5865-03a.

3. Design

The design of component parts of Nepali bio-char stove is based on the input energy consumption equivalence of the metallic improved cooking stove for cooking one kg of rice. The stove is designed for average five people for one time meal. The Nepali bio-char stove basically consists of two coaxial cylinders, among which the inner one is critical from the design and functional point of view. It also confines the overall shape and dimension of the stove. Other components are designed based on intuition and suggestion from the workshop personalities.

The design conditions of inner cylinder are: Wood consumption 624 gm/kg rice [1], Rice requirement (rice + rice equivalent of curry) is 4.0 kg, total wood required 2.496 kg, Wood density 670 kg/m^3, wood volume 3725.373 cm^3, and wood pellet void factor, k_v = 1.3 (Void factor is a multiplicative factor of volume, to take into the consideration of the air entrapped in between the biomass twigs or chips, such that the volume so obtained contains the required biomass along with the air), minimum inner volume required, V = 3725.373 × 1.3 cm3= 4842.985 cm3, Cylinder aspect ratio, k (=h/d) =1.2, Inner diameter, d = (4V/πk) 1/3= (4×4842.985/ (π×1.2)) 1/3cm = 17.2592 cm, Minimum inner height, h = k×d = 1.2×17.2592 cm = 20.71104 cm, Lid clearance = 1 cm, Mixture hole diameter = 1 cm, and Total inner cylinder height = 20.71104 + 1 + 1 cm = 22.71104 cm. Other relevant components and their designed and fabricated dimensions are presented in Table 1.

Table 1: Fabricated Dimension

Components	Calculated dimensions	Fabricated dimensions	Holes	Qty.
Inner cylinder	Diam. 17.25 cm, height 22.71cm	Diam. 18 cm, height 23 cm, thickness 2.5 mm	38 x10 mm diam., at the top	1
Inner base plate	Diam. 17.25 cm	Diam. 18 cm, thickness 2.5 mm	60 x10 mm diam.	1
Outer cylinder	Diam. 22.37 cm, height 23.58 cm	Diam. 23 cm, height 24 cm, thickness 2.5 mm	35 x12 mm diam. at the bottom	1
Top plate		Diam. 29 cm, thickness 2.5 mm	-	1
Bottom plate		Diam. 29 cm, thickness 2.5 mm with 12 cm pot opening	-	1
L-supports		2.5 x1.5x1 cm^3	-	3
Support rods		Diam. 10 mm, height 30 cm	-	3

Figure 1: Nepali Biochar Stove

Figure 2: Nepali Biochar in test

4. Results, Analysis and Outcomes

The following tests were carried out for different stove design variations. The wood we had used was commonly available *Pinusroxburgii* (Salla) which is typical softwood with gross calorific value of 18 MJ and moisture content of 15 %.

The water boiling test is conducted by using WBT protocol version 3.0. The Nepali bio-char stove is a compact stove which burns producer gas rather than burning wood pellets directly.

Hence, some adjustments were done in the method, but not in a way that hampers the original purpose of the WBT protocol. First of all, sample tests were conducted only to determine the amount of char and un-gasified wood at the end of cold start and simmer process. Along with the above data, amount of water boiled and temperature at the end of the process is noticed. This process was conducted for three times and during the above sample tests the data obtained were almost similar. Hence, actual tests were later conducted without any interruption so as to make the test and consequently result accurate.

The stove when tested did not show the result expected and hence was modified in its geometry. This modified design is called first modification. First modification showed positive results but not satisfactory. Further, the stove was modified second time. This design is termed as second modification and the results obtained were satisfactory. Hence, the second design is the final design of Nepali bio-char stove. Following important points were observed during the testing and modification process.

Observation in initial designed stove is full combustion with red flame, smoke formation, combustion doesn’t leads to pyrolysis therefore; and complete ash formation. Possible reasons might be air flow through primary outlet so it affects pyrolysis, low effective height of the pot holder.

First modification was made in holes at the bottom of combustion chamber are transferred on circumferential side at 2 cm above the base. Air supply holes level is placed at bottom of the outer chamber as low as possible. Pot holder height is now increased to 4 cm. Number of holes at primary outlet and secondary inlet is now reduced.

Observation is as follows: pyrolysis happens but takes time. Syngas starts to emit after 8^{th} minute of ignition. Smoke concentration reduces and flame sustains for 27^{th} minutes. The possible reasons may be though pyrolysis happens but take significant time (8 min) this may be because combustion chamber is thick enough and took considerable time to heat up.

Then second modification was made as thickness of combustion chamber reduced to form 2.5 mm to 0.35 mm, Diameter of combustion chamber is increased from 18cm to 21 cm, and material now used is steel sheet metal. Observation is as Pyrolysis occurs at 4^{th} minutes from ignition, Virtually No Smoke, and Flame sustains for whooping one hour and seven minutes.

4.1 Water Boiling Test Results

4.1.1 Thermal Efficiency vs. Stove Design Variations

The Figure 3 shows the thermal efficiency vs. stove design variations. The initial stove design has 17 % thermal efficiency but it did not follow gasification process. Since the stove could not burn for the significant amount of time, simmer test could not be performed. The thermal efficiency of first modification is 35% in cold start and the thermal efficiency for simmer is 12%. The second modification has cold start thermal efficiency of 34% and simmering thermal efficiency of 20.5 %. This modification finally covers the full simmer phase and hence shows the real time cooking thus concluded for final design.

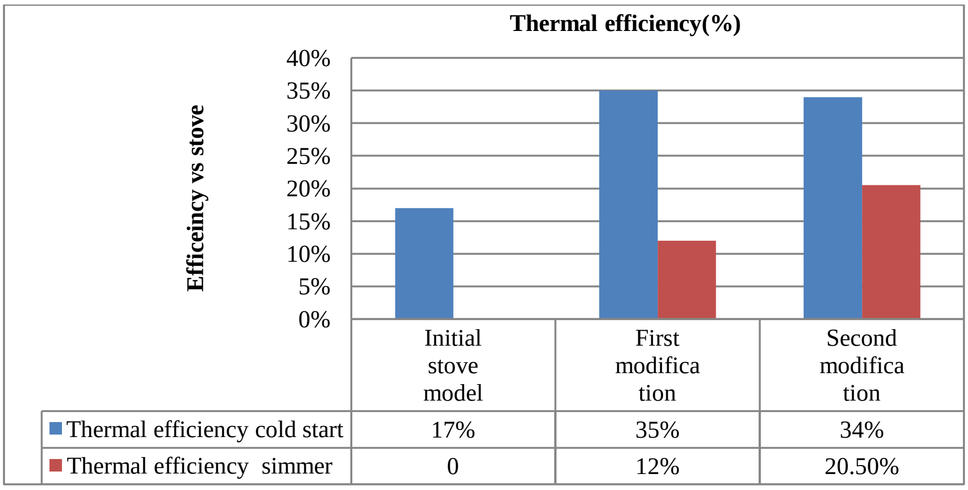

Figure 3: Thermal efficiency of initial stove and its modifications

4.1.2 Char Yield vs. Stove Design Variations

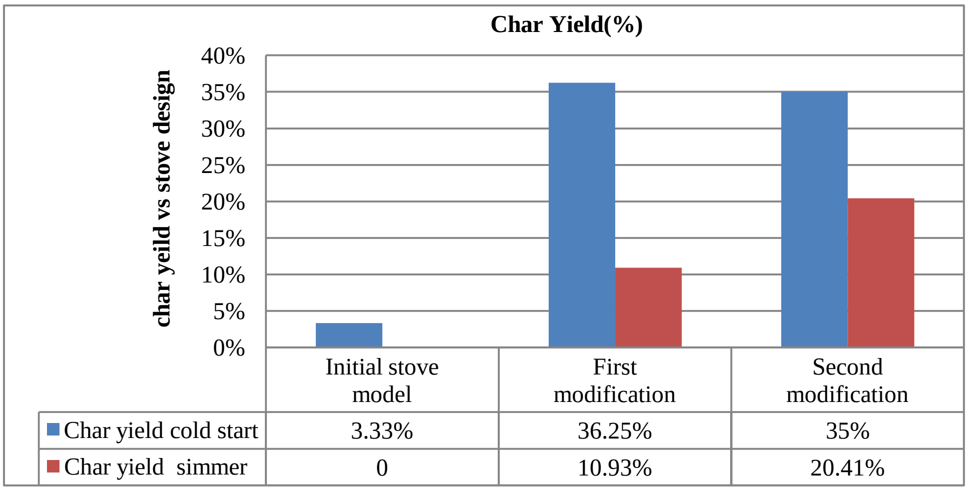

Figure 4: Char yield of initial stove and its modifications

In the Figure 4, the initial design gives the char yield of only 3.33 % during cold start. The first modification of the stove gives the char yield of 36.25% during cold start and the char yield during simmering phase is 10.93%. The second modification of the stove gives the char yield of 35% during cold start and 20.41% during simmering phase. The simmering phase shows better char yield than first modification because of prolonged gasification and greater biomass feed.

4.1.3 Flame Sustainability Vs. Stove Variations

The Figure 5 shows the Flame sustainability (in min) Vs. Stove design variations. It shows that initial stove design gives 33 minutes of burning time which is purely through combustion of wood. The first modification burns for 27 minutes but follows the gasification process. The flame sustainability for second modification is 67 minutes, which is higher than the first modification because greater biomass feed and uniform gasification.

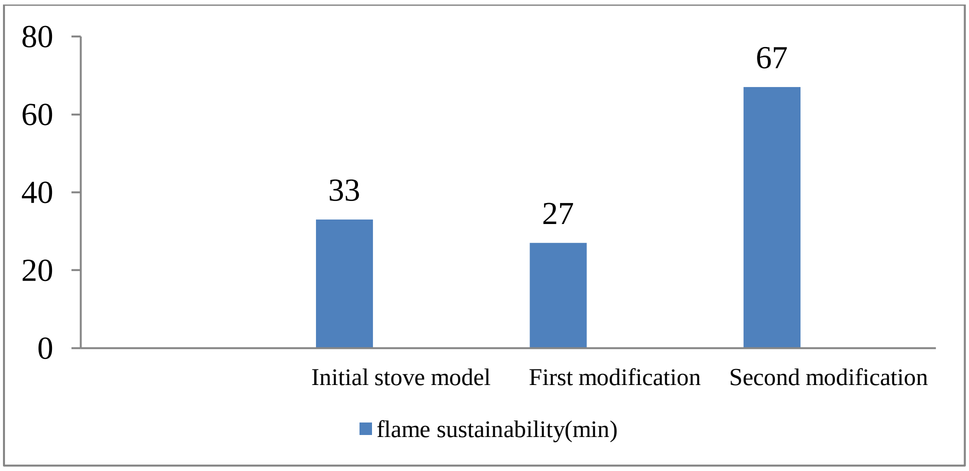

Figure 5: Flame sustainability of initial stove and its modification

4.1.4 Water Temperature vs. Time

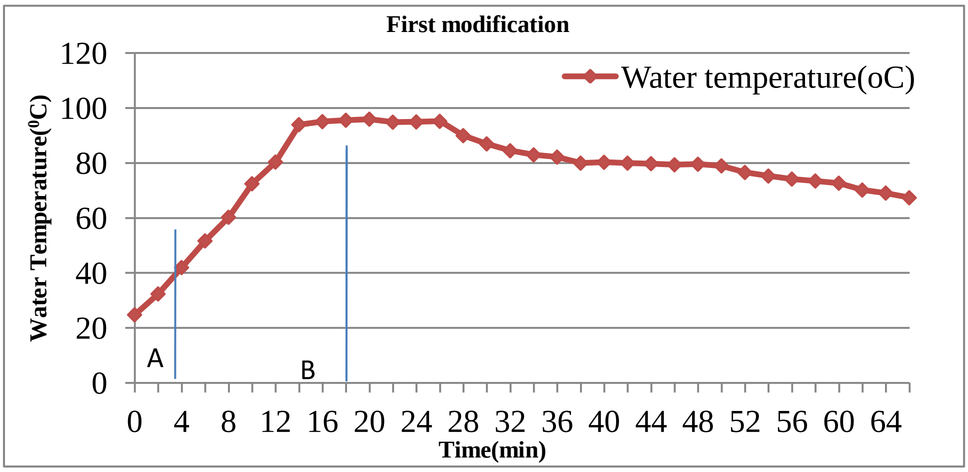

Figure 6: Variation of water temperature with time for first modification
(A = Combustion region B= Pyrolysis region)

The Figure 6 shows the temperature vs. time graph for the first modification. The first eight minutes of ignition, accounts for the combustion, while thereafter there is gasification process upto the 28th minute of ignition time. Gasification is observed visually when the flame comes out from the upper holes with somehow blue color.

Then Figure 7 shows the water temperature (^{o}C) vs. time (min) for the second modification. Gasification starts from the 5th minute of ignition and lasts till the 67th minute of ignition. And the major portion of the graph lies in the gasification zone which indicates that second modification is better gasifier stove design than the first modification.

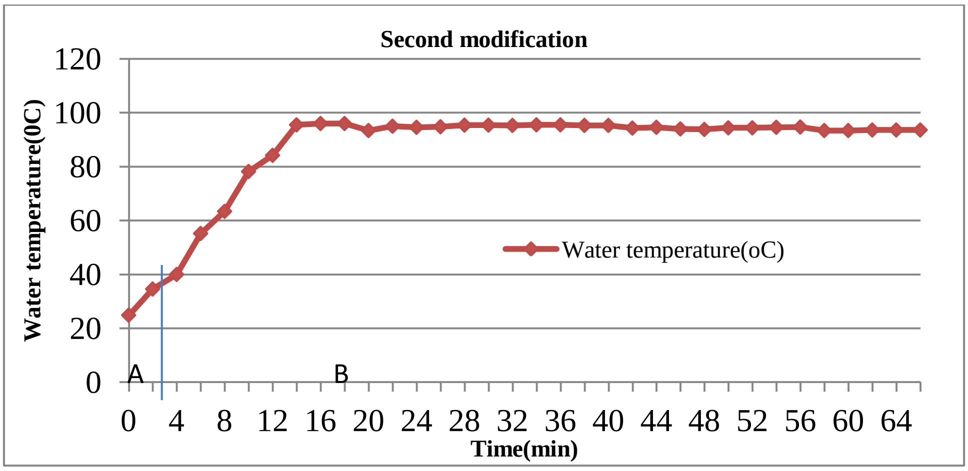

Figure 7: Variation of water temperature with time for second modification

4.2 Controlled Cooking Test Results

The controlled cooking test was conducted in Center for Energy Studies (CES) lab at IOE, Pulchowk Campus to determine the stove performance at actual cooking condition. The procedure and necessary data for the test was taken as per the instruction provided by shell foundation for household energy and health program. The result obtained from the test is as below:

Table 2: Test result of CCT

Parameters	Test
Weight of raw food (gm)	760+200=960 (Rice + Pulse)
Wood Supplied (gm)	1500
Wood Remaining (gm)	525
Weight of Char (gm)	260
Equivalent Dry Wood consumed (gm)	585
Time (min)	34
SFC (g/kg)	609

It is seen that only 975gm of wood is consumed for cooking one time meal for a typical family. The SFC obtained from the test is 609 g/kg means 609gm of wood is required to cook 1kg of meal. The total cooking time for both rice and pulses are observed as 34 min.

4.3 Char test

4.3.1 Proximate Analysis

Proximate analysis of the char was done to know the carbon content and information related to moisture content, volatile matter present and ash content so as to assess the produced char to be used as a charcoal fuel. The proximate analysis was conducted at Center for Energy and Environment, Nepal (CEEN) by the help of Prof. Ramesh Man Singh. The proximate analysis was carried out by following JIS 8812 standard method. The test results are as follows:

Table 3: Proximate analysis report of Pine Char

Sample Name	Pine Char	Standard (NAST)
Moisture Content (%)	5.57	7.5
Volatile Matter Content (%)	36.50	17.96
Ash Content (%)	1.85	5.39
Total Fixed Carbon Content (%)	56.09	69.15

- Moisture Content: Moisture affects the combustion efficiency negatively and the moisture content should typically be as low as possible [4]. Optimum moisture content that can be allowed to use in charcoal briquettes is 10-12% [6].
- Volatile Matter Content: According to the report published by FAO (1985) volatile matter in charcoal can vary from a high value of 40%. The high value of volatile charcoal tends to be stronger, heavier, harder and easier for the ignition than low volatile charcoal but at the same time burn with some smokes too.
- Ash Content: Biomass residues normally have much lower ash content (except for rice husk with 20% ash) but their ashes have a higher percentage of alkaline minerals, especially potash. Pine charcoal had 5.39% of ash content (Standard). The good quality charcoal (1.2% to 8.9%) range set by FAO (1987).The low values of ash content obtained could be due to the high heating value of the fuel wood.
- Total Fixed Carbon Content: Fixed carbon content is the amount of the carbon present in the sample. Value set by National Academy of Science and Technology (NAST) for making good quality of charcoal is 69.15% [5]. The charcoal yield from our Nepali bio-char stove is less than the standard value because the char was taken in early stage of gasification process as the sample was taken just at the end of cold start process.

4.3.2 Calorific Value of char

Another most important feature of a solid fuel is its calorific value. It determines the commercial value of fuel. Hence the char from bio-char stove was tested in the laboratory of Nepal Environmental & Scientific Services (NESS).The test was conducted with bomb calorimeter that follows American Society for Testing Materials (ASTM), D 5865- 03a. The calorific value of char was found to be 6363 Kcal/kg. The calorific value used for making good quality briquette is 6447 kcal/kg [3].This result shows that the calorific value of charcoal from Nepali bio-char stove is very close to the calorific value required for good quality briquette making.

5. Financial Analysis

First of all, a project should be technically sound. The second criteria for the project to be successfully implemented are that it should be economically feasible to implement. There are various methods for the financial analysis. Some of the methods used are: Payback period, NPV, and they are found as 6 months, Rs. 7,317 respectively, where as IRR is found to be 0, and IRR is 190%.

6. Conclusion

After the fabrication of the stove various tests were carried out with the initial stove andits modified form and the following conclusions were derived:

- The Nepali bio-char stove was designed and fabricated as per objectives.
- The efficiency of initial stove was 18%, that of first modification was 35% and that of second modification was 34%.
- The SFC and total cooking time of Nepali bio-char stove from CCT was found tobe 609 gm/kg and 34 minutes respectively.
- The char yield from initial stove was 0%, from first modification was 36.25% and from second modification was 35%.
- The calorific value of the char obtained from the stove is obtained to be 6,363kcal/kg. This calorific value is very much suitable for the making of briquettes.

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