# Performance Evaluation of Improved Biomass Cook Stove

**Parashuram Nandi[1], Amol Nayakappa Patil[2], Nagaraj Raikar[3], Sidharth Kasturi[4], Mahalingesh B[5]**

[1,2,3,4,5]Assistant Professor, Department of Mechanical Engineering, Agnel Institute of Technology and Design, Assagao,Goa, India

**Abstract:** ***In developing countries like India, cooking is mainly considered as responsibility of women, who spend a substantial amount of their time in preparing food for their families. Cooking is done by using traditional practices like chulha in villages and modern practices like Induction cooktop, LPG burners in cities. The proportion comparison shows chulha are greatly used with biomass fuel like wood log, crop residue, and cow dung as fuel. Cooking using biomass leads to soot, soot, haze, dust, black smoke, black carbon, fine particles, and ultrafine particles as by-product. These by-product leads to environmental pollution and along it is also harmful to human beings causing lungs diseases. In order to minimize environmental pollution and too lungs diseases it is prime important to utilize fuel in more efficient way minimizing pollution and maximizing heat produced. This paper, focuses mainly on the role of cook stoves in reducing emissions, eliminating drudgery, and improving overall quality of life. The work is carried out to design improved biomass cook stove and performance of improved biomass cook stove is evaluated using thermal efficiency, cooking duration and specific fuel consumption. The water boiling test demonstrates improvement in burning rate, thermal efficiency and specific fuel consumption of improved biomass cook stove in comparison with three stone traditional cook stove, leading to saving of annual thermal energy by 2.2GJ.***

**Keywords:** Improved Biomass Cook Stove (IBCS), Three Stone Traditional Cook Stove (TSTCS), Wood, Burning rate, Thermal efficiency, Specific fuel consumption

## 1. Introduction

In many developing countries over 60% of the households use biomass such as fuelwood, crop residue and cow dung as their major source of fuel for cooking. In the last few decades, most of these developing countries have experienced a rapid depletion of natural forest resources, which has resulted in hardship for the people living in rural areas, especially women and children who spend a considerable part of their time and energy in search of fuelwood and often have to cover long distances [1]. Women and children's in villages who spend considerable time near biomass cooking chulha have impact on their respiratory health and may lead to COPD which is a chronic inflammatory condition of the lower airways. The basic abnormality in COPD patients is airflow limitation, which causes shortness of breath, usually accompanied by chronic cough, wheezing, chest tightness and an increasing disability over time. The prevailing economic and energy supply situations in developing countries indicate that biomass will continue to be the major cooking fuel for villagers as they have less accessibility to modern cooking practices and also modern cooking practices are costlier compared to traditional cooking practices. There are 638,365 villages in India and about 74% population lives in these villages. Those 74% populations use the Chulha to cook the food and village women spend around 20% to 30% of day time to cook the food on Chulha. Using chulha consumes time, along with impacting health and also destroys natural resources which are non-renewable. Researches are continues focuses on different approaches and method to improve efficiency of chulha thus it save the time and daily utilized energy [2].

## 2. Improved Biomass Cook Stove Reaction Chamber Design

Energy needed by reaction chamber depends on the fuel used to produce heat. The energy Q, the energy, Q, required to cook food is estimated using expression given below [3].

$$Q = \frac{M_f \times E_s}{t}\ \text{kJ/h}$$

Where,
$M_f$ is the mass of food,
$E_s$ is the specific energy of the food and
t is the time

Assuming, for a small family, 0.5 kilogram of rice to be cooked within fifteen minutes (0.25h), the energy required is estimated, considering the specific energy to boil rice as 1700 kJ/kg,

$$Q = \frac{0.5 \times 1700}{0.25} = 3400\ \text{kJ/h}$$

The fuel consumption rate (FCR) is nothing but the energy input, FCR refers quantity of fuel fed into the stove, then FCR can be estimated using equation below [4].

$$FCR = \frac{Q}{H \times \eta}\ \text{kg/h}$$

Where,
H is the heating value of fuel and
η is the stove efficiency

Using wood as fuel for designing reaction chamber and taking average heating value of wood as17000kJ/kg and assuming a stove efficiency of 34%, the fuel consumption rate is estimated as, [4]

$$FCR = \frac{3400}{17000 \times 0.34} = 0.588\ \text{kg/h}$$

The reaction chamber diameter is a function of the fuel consumption rate and the specific gasification rate (SGR), Specific gasification rate for wood pieces is 75 kg/m$^2$h, with the producer gas to wood ratio being 2.39 at an optimum equivalence ratio of 0.3. Hence, the diameter is estimated as,

$$D = \sqrt{\frac{1.27 \times FCR}{SGR}} = \sqrt{\frac{1.27 \times 0.588}{75}} = 9.978 \text{ cm}$$

The height, H, of the reaction chamber determines how long the stove would operate in one loading of fuel, then height of the reaction chamber can be estimated using,

$$H = \frac{SGR \times T}{\rho} = \frac{75 \times 1}{450} = 16.66 \text{ cm}$$

Where,
T is the time the reaction chamber will operate, for design purpose value is assumed to be 1 Hr. and
$\rho$ being the bulk density taken to be 450 kg/m$^3$,

Based on design value, from expression for diameter and height, reaction chamber is fabricated with Diameter as 100mm and height as 180mm using GI steel. Table 1 represents Design Specification of improved biomass cook stove.

**Table 1:** Design Specification

| | |
|---|---|
| Total height of the stove | 38 cm |
| Combustion chamber height | 18 cm |
| Inside combustion chamber diameter | 10 cm |
| Outside diameter of stove | 20 cm |
| Insulation thickness (Ceramic clay) | 2.5 cm |
| Air gap Insulation | 2.5 cm |
| Grate with ash holder diameter | 10 cm |
| Grate with ash holder height | 5cm |
| Weight of stove | 6.5 kg |

**Figure 1:** Fabricated cook stove

**Figure 2:** Improved cook stove

**Figure 3:** Three stone traditional cook stove

Improved biomass cook stove is fabricated with GI steel because of its properties as well as available in market at less price as compared to stainless steel. Fabricated stove is shown in Figure-1 and Figure-2. On top of the stove is provided to place a pot with required size, on sides handles are provided for easy handling as well as to avoid direct contact of hot surface to the bare hands. At bottom of the stove sufficient stand height is given for fan operation and air supply for proper combustion. Three stone traditional cook stove is shown in Figure-3. The combustion chamber is made ready with the help of three stones and on top is provided to place a bowl or pot of the required size.

## 3. Performance Evaluation

There are number of standard methods for evaluating the performance of cook stoves. Such methods are the water boiling test, constant time, constant heat output and constant temperature rise. But water boiling test method is mostly used because it is short and provides a simple simulation of standard cooking procedures. It measures the quantity of fuel consumed and time required for the simulated cooking and usually employed in investigating the performance of cook stoves under different operating conditions. It also provides a quick method of comparing the performance of cook stoves. This method is therefore employed in evaluating the performance of the improved biomass cook stove and compared with the performance of the 3-stone traditional cook stove, which it intends to replace [1]..

The water boiling test consists of three phases: a high-power (cold start) phase, a high power (hot start) phase, and a low power (simmer) phase. These tests are indicators in evaluating the ability of cook stoves to conserve fuel. Each of these tests were performed three times after allowing the stove to cool down before starting the next round and the average of three test is taken to obtain the thermal efficiency of the stove. The test was conducted under controlled indoors conditions with sufficient ventilation and wind protection.

### 3.1 High-power (Cold Start) Phase Test

The improved biomass cook stove at room temperature and the 3-stone traditional cook stove with the pre-weighed 5kg of fuelwood were used to boil 2kg of water in two 18cm diameter pots. The two pots were weighed and 2kg of water was put into the pots. The ambient and the initial temperature of water in the two pots were recorded. The measured quantity of 30mm x 30mm pieces of fuel wood was loaded into the cook stove through the fuel inlet opening before the ignition, while the 3-stone fire was set up with pieces of fuelwood. The fuelwood was ignited to initiate burning. The two uncovered pots were placed on the improved biomass cook stove and 3-stone traditional cook stove and temperature of water was recorded at every 5mins interval till water reaches boiling point. The time and final temperature of the water in two pots were recorded. The pot was then removed and remaining water in the pot was weighed. The unburned wood left after burning was weighed to determine the amount of fuel consumed during the test period [1], [4].

### 3.2 High-power (Hot Start) Phase Test

High power hot start test was conducted immediately after cold start test, by pouring 2kg of fresh water in pot and renewed wood as fuel for both improved biomass cook stove and three stone traditional cook stove for performance evaluation [1], [4].

### 3.3 Low-power (Simmering) Phase Test

This phase proves the ability of the improved biomass cook stove and the 3-stone traditional cook stove to simmer water using minimum fuelwood. This test followed immediately after the second test. In this test, the two pots were filled with 2kg of fresh water. The initial temperatures of the water in the pots were recorded and the water was made to boil as described in the first test. The boiling time and temperature of the boiled water were recorded. The pots with the boiled water were weighed and quickly returned to the stoves. The remaining part of the pre-weighed 5kg of fuel wood was weighed and the fires of both stoves were reduced to keep the water as close to 30$^{o}$ C below the boiling point as possible. The fires were then maintained at this level for next 45minutes. After the 45 minutes the temperature of the water in the two pots were recorded. The remaining fuel wood removed from the improved biomass cook stove and the 3-stone traditional cook stove and the unused wood from the pre-weighed bundle were weighed. The pots with the remaining water were also weighed. The loose charcoal knocked off from the fuel wood together with the ones removed from both the stoves were weighed [1], [4]. Readings of all three test are recorded in Table 2.

**Table 2:** Test Result

| Description | High Power (Cold Start) | | High Power (Hot Start) | | Low Power (Simmer) | |
|---|---|---|---|---|---|---|
| | IBCS | TSTCS | IBCS | TSTCS | IBCS | TSTCS |
| Duration of phase (min) | 14 | 16 | 11 | 16 | 45 | 45 |
| Fuel wood consumed (kg) | 0.1003 | 0.360 | 0.090 | 0.180 | 0.360 | 0.450 |
| Weight of charcoal produced (kg) | 0.04 | 0.03 | 0.03 | 0.03 | 0.12 | 0.03 |
| Final water temperature (ºC) | 93.90 | 93.90 | 93.90 | 93.90 | 94.20 | 91 |
| Water temperature (ºC) | 32.40 | 32.40 | 32.40 | 32.40 | 97.50 | 97.50 |
| Weight of water evaporated (kg) | 0.180 | 0.075 | 0.300 | 0.057 | 0.610 | 0.410 |
| Initial weight of water in pot (kg) | 2 | 2 | 2 | 2 | 2 | 2 |
| Weight of aluminium pot (kg) | 0.261 | 0.261 | 0.261 | 0.261 | 0.261 | 0.261 |

## 4. Result Analysis and Discussion

Burning rate: This is a measure of wood consumed per hour for boiling water from room temperature. It was calculated dividing the dry wood consumed per time for boiling water [1] [5] [6] [8].

Burning rate (kg/hr.),

$$\dot{m}_f = \frac{m_f}{t} = \frac{0.1003 \times 60}{14} = 0.4298 \text{ kg/hr}$$

Firepower ($F_{po}$): This is a ratio of the wood energy consumed by the stove per unit time. It gives the average power output of the stove (in Watt) during the high-power test.

$$Fpo = \frac{m_f \times E_f}{t} = \frac{0.1003 \times 3500 \times 60}{14} = 1.504 \text{ kW}$$

Percentage Heat Utilized (PHU): This is a ratio of the work done by heating and evaporating water to the energy consumed by burning wood. It is calculated in the following way [1].

$$PHU = \frac{m_w \times c_p (T_{wf} - T_{wi}) + H_v \times (m_v)}{(\dot{m}_f \times E_f)}$$

$$= \frac{2 \times 4.186 \times (93.9 - 32.4) + 2260 \times 0.180}{0.4298 \times 3500}$$
$$= 64.06\ \%$$

The thermal efficiency measures how the heat generated by the stove is utilized in boiling the water or in cooking the food. The thermal efficiency ($\eta_{th}$) of the stove can be determined using the equation. [1], [6], [8]

$\eta_{th}$ = PHU × Burning Rate = 65.71 × 0.4298 =27.53 %

Useful Fire Power, [1]

= $\eta_{th} \times F_{po}$ = 0.2753 × 1.504 = 0.4141 kW

Specific Fuel Consumption (SFC), [1], [5], [6], [8]

$$SFC = \left[\frac{\dot{m}_f}{\text{Useful fire power}}\right] = \left[\frac{0.4298}{0.4141}\right] = 1.037\ \text{kg/kWh}$$

Table 3 summarizes calculation results for High power cold start, High Power hot start, and Low power simmer test of improved biomass cook stove (IBCS) and three stone traditional cook stove (TSTCS).

**Table 3:** Test Result Summary

| Description | High Power (Cold Start) | | High Power (Hot Start) | | Low Power (Simmer) | |
|---|---|---|---|---|---|---|
| | IBCS | TSTCS | IBCS | TSTCS | IBCS | TSTCS |
| Burning rate (kg/hr.), | 0.4298 | 0.620 | 0.4909 | 0.675 | 0.480 | 0.60 |
| Fire power (kw) | 1.504 | 2.170 | 1.718 | 2.362 | 1.680 | 2.100 |
| Percentage heat utilized (%) | 64.06 | 15.90 | 69.42 | 27.24 | 83.72 | 46.63 |
| Thermal efficiency ($\eta_{th}$) | 27.53 | 9.858 | 34.08 | 18.38 | 40.18 | 27.97 |
| Useful fire power (kW) | 0.4141 | 0.2139 | 0.5855 | 0.4341 | 0.6750 | 0.5875 |
| Specific Fuel Consumption (kg/kW h) | 1.037 | 2.898 | 0.8384 | 1.5549 | 0.711 | 1.0212 |

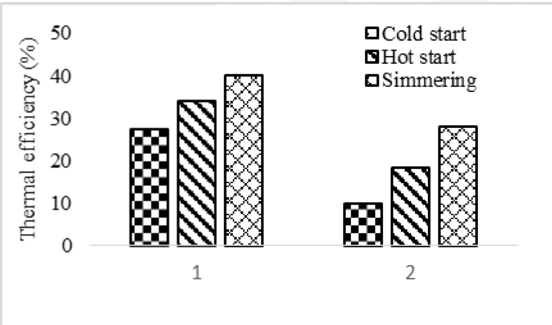


**Figure 4:** Thermal efficiency of IBCS and TSTCS stoves

Thermal efficiencies of two stoves are represented Figure 4. Thermal efficiencies of IBCS and TSTCS stoves at cold start, hot start and simmering are (27.53%, 9.8%), (34.08%, 12.54%) and (40.18%, 27.97%) respectively. Efficiency of stove depends on many factors either they will increases or decreases the efficiency.

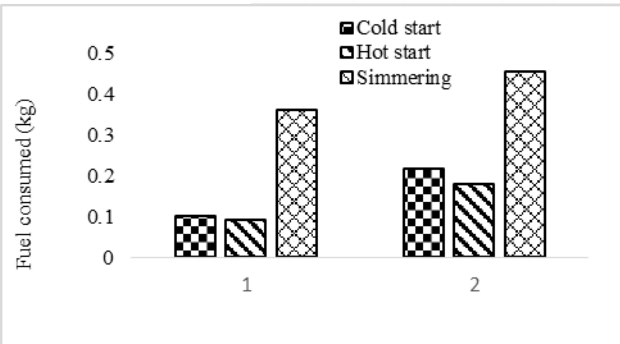


**Figure 5:** Fuel consumed by IBCS and TSTCS stoves

Figure 5. Indicate the values of fuel consumed (kg) during water boiling at cold start, hot start and simmering are (0.1003, 0.217), (0.090, 0.234) and (0.360, 0.450) respectively.

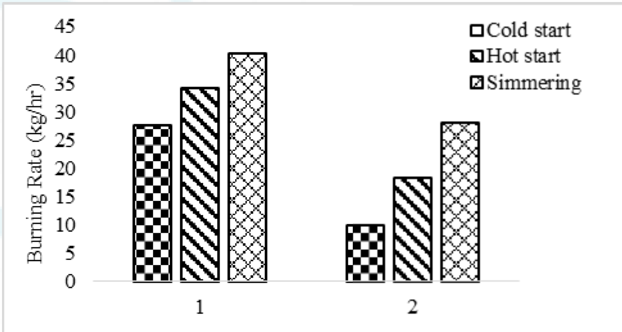


**Figure 6:** Burning rate of IBCS and TSTCS stoves

Burning rates of IBCS and TSTCS stoves is indicated on figure 6. The burning rate (kg/hr.) at cold start, hot start and simmering are (0.429, 0.620), (0.490, 0.880) and (0.480, 0.600) respectively.

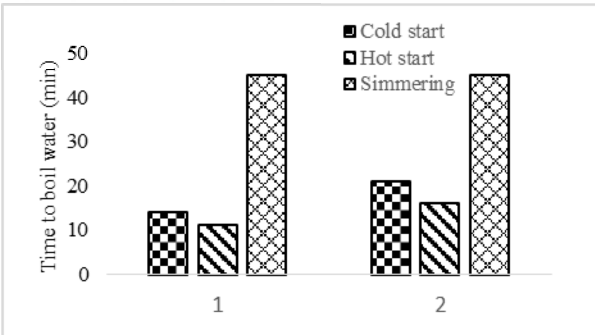


**Figure 7:** Boiling time of water by the IBCS and TSTCS stoves

According to the test, the least time taken to boil water was recorded during hot start by the IBCS and TSTCS stoves are 11min and 16min. whereas; the highest time taken to boil water was recorded during cold start by the IBCS and TSTCS stoves are 14min and 21min. Influence for the highest time taken to boil water in cold start is because at initial start some heat energy from fuel is required to warm the metallic body of the stove is presented on figure 7.

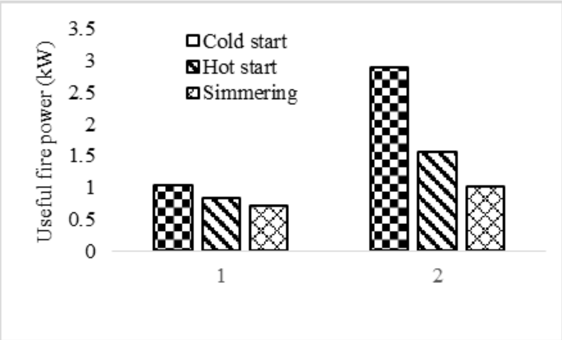


**Figure 8**: Useful fire power of IBCS and TSTCS stoves

Useful fire power (kW) for water boiling by the IBCS and TSTCS stoves at cold start, hot start and simmering are (0.4141, 0.219), (0.585, 0.090) and (0.6750, 0.5875) respectively are plotted on figure 8. Fire power can get by burning biomass fuel, but fire power is not remain same for variety biomass fuels.

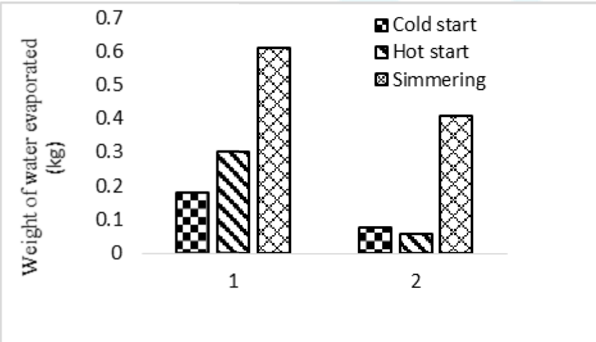


**Figure 9:** Weight of water evaporated by IBCS and TSTCS stoves

Amount of water evaporated (kg) during water boiling test by the two stoves at cold start, hot start and simmering are plotted on figure 9. And the values are (0.180, 0.075), (0.300, 0.057) and (0.610, 0.410) respectively.

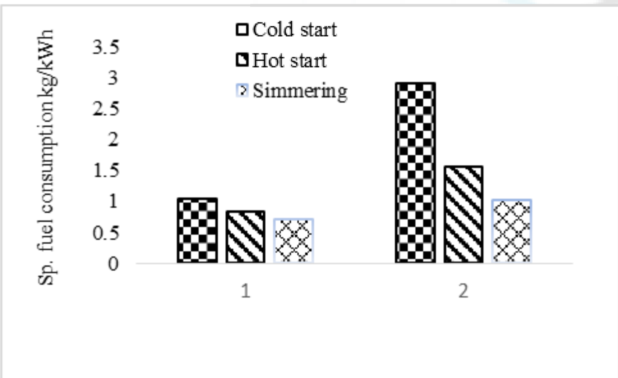


**Figure 10:** Specific fuel consumption of IBCS and TSTCS stoves

Specific fuel consumption rate of both the cook stoves is presented in figure.10. As compared to both of these stoves the specific fuel consumption rate for traditional cook stove is more than the improved cook stove. SFC which is inversely depends on the amount of useful fire power produced (size of fuel, moisture content of fuel).

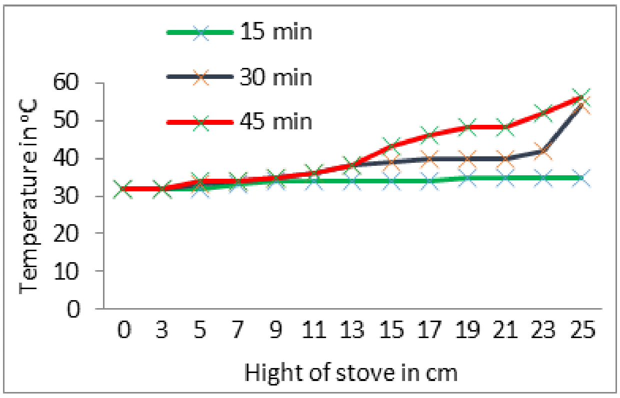


**Figure 11:** Height of stove vs temperature of outside surface of stove

Temperature V/s height of stove is plotted on figure 11. The values of temperatures on outside surface of IBCS stove for all tests are given. The values are obtained from bottom to top of the stove with intervals of 5cm. At top of stove after 15min it will be 36$^0$C, after 30 min it will be 42$^0$C and after 45 min the temperature will be 56$^0$C. If the temperature is more than 60$^0$C, it is dangerous to the person who is working with the stove that has to be avoid by maintaining less temperature on surface of the cook stove.

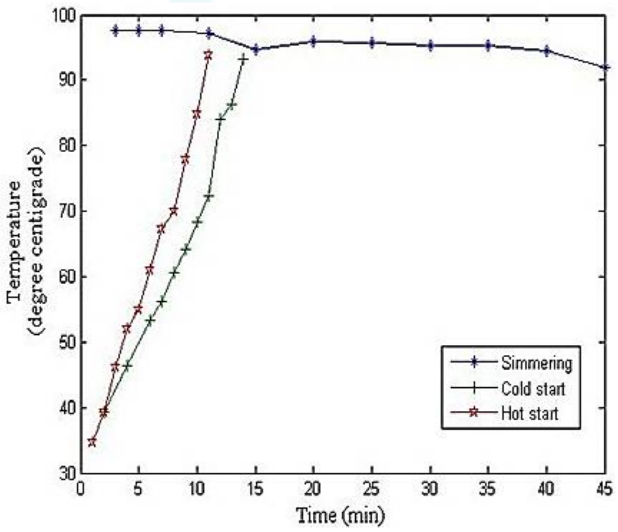


**Figure 12:** IBCS water boiling test temperature vs. time

Temperature and time of water boiling at cold start (high power), hot start (high power) and simmering test (low power) are indicated on figure 12. At cold start water is boiled to a temperature of 93.90 $^0$C and time taken was 14min. During hot start time taken for water boiling was 11 min and a temperature of about 93.90 $^0$C. During simmering test with a time of 45 min the temperature decreases from 97.50 to 92 $^0$C.

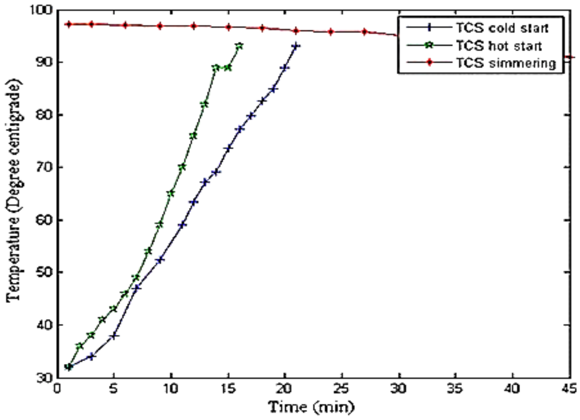


**Figure 13:** TSTCS water boiling test

During simmering test with a time of 45 min the temperature decreases from 97.50 to 92 $^0$C. For three stone traditional cook stove also presented on Figure 13. It gives the values of temperature and time of water boiling at cold start (high power), hot start (high power) and simmering test (low power). During the cold start water is boiled at a temperature of 93.90 $^0$C with time taken of 21min. During hot start time taken for water boiling is 16 min and a temperature of about 93.90 $^0$C. During simmering test with a time of 45 min the temperature decreases from 97.50 to 92 $^0$C.

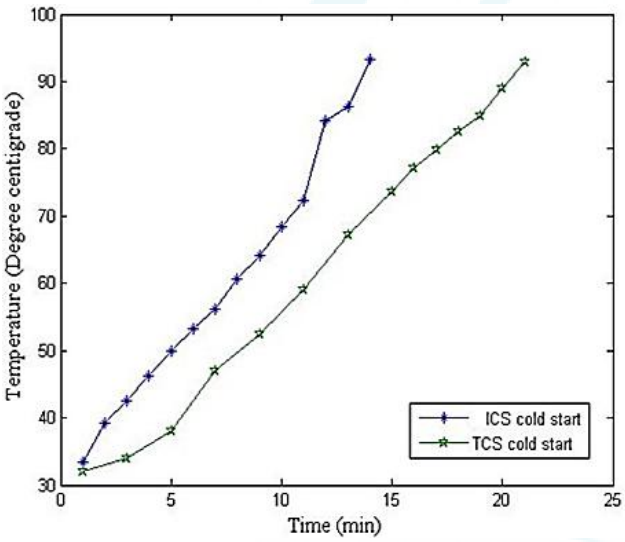


**Figure 14:** Temperature vs. time by IBCS and TSTCS stoves at cold start

Plot for the temperature and time at cold start by IBCS and TSTCS stove shown on figure 14. The temperature is same during the water boiling test by both the stoves but time taken by the TSTCS stove is more than the IBCS stove. The TSTCS stove takes 21 min to boil the water at a temperature of 93.90 $^0$C and by the IBCS stove which takes 14 min to boil the same amount of water for the same temperature of 93.90 $^0$C.

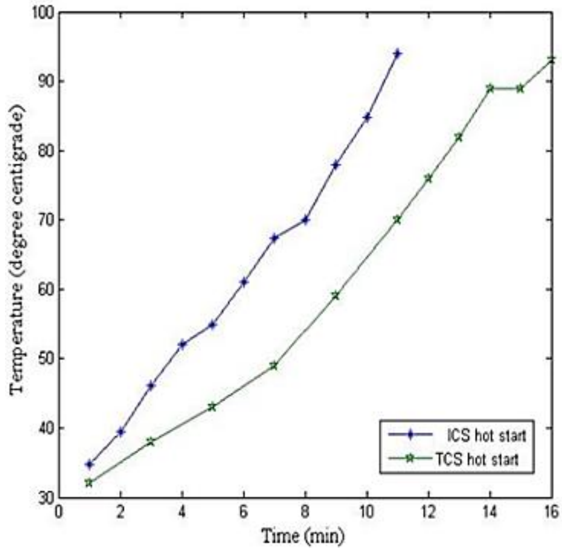


**Figure 15:** Temperature vs time by IBCS and TSTCS stoves at hot start

The figure 15 represents the values of temperature and time at hot start of IBCS and TSTCS stove. The temperature is same during the water boiling test by both the stoves but time taken by the TSTCS stove is more than the IBCS stove. The TSTCS stove takes 16 min to boil the water at a temperature of 93.90 $^0$C and by the IBCS stove which takes 11 min to boil the same amount of water for the same temperature of 93.90 $^0$C.

In figure 16 the value of temperature, decreases from 97.50 $^0$C to 92 $^0$C at simmering (low power test) by the IBCS stove and similarly in TSTCS stove the value of temperature decreases from 97.30 $^0$C to 91$^0$C. It indicates the stability of stove to supply the rated temperature even with less amount of fuel supplied.

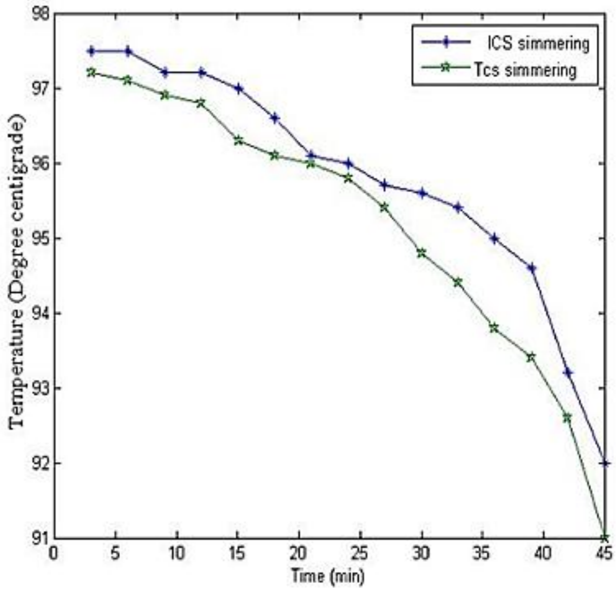


**Figure 16:** Temperature Vs time by IBCS and TSTCS stoves at cold start

## 5. Conclusions and Future Scope

The thermal efficiency of IBCS is 27.53 % whereas TSTCS 9.85% for high power cold start, it is 34.08% and 18.38% for high power hot start and for low power simmer test 40.18% and 27.97%. IBCS is having higher thermal efficiency for all test condition, which is indicative of complete biomass fuel consumption. Since IBCS consumes complete fuel, it is also easy to remove char and ash. Improved biomass cook stove is fabricated using GI steel, which resulted in weight reduction and hence easy to move given portability advantage. In IBCS complete fuel combustion minimizes smoke, environmental pollution and resulting reduction in lungs diseases. Complete combustion also reduces fuel cost.

Controlled Cooking Test (CCT) and the Kitchen Performance Test (KPT) could be conducted as extension to get detail information of fuel consumption in Household by IBCS and TSTCS. The tests could be conducted not only by the aluminum pots but by using pots with different material also to determine the performance of both the stoves. Other biomass fuels can also be used for the tests to determine performance of the stoves. Smoke emission test to determine smoke level could be one of research area as future study to minimize emission level thus reducing impact of global warming.

## References

[1] Okafor, I. F., and G. O. Unachukwu, "Performance Evaluation of Nozzle Type Improved Wood Cook Stove," American-Eurasian Journal of Sustainable Agriculture, 6 (3), pp. 195-203, 2012.
[2] Mohan, Ravindra, and Shankar Kumar, "Enhancement of Thermal Efficiency of Traditional Indian Cooking Furnace (Chulha)," Current World Environment 6 (1), pp. 61-66, 2011.
[3] S. J. Ojolo, J. I. Orisaleye; S. O. Ismail and A. F. Odutayo, "Development of an Inverted Downdraft Biomass Gasifier Cookstove," Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 3 (3), pp. 513-516, 2012.
[4] V. I. Umogbai and J. G. Orkuma, "Development and Evaluation of a Biomass Stove," Journal of Emerging Trends in Engineering and Applied Sciences (JETEAS) 2 (3), pp. 514-520, 2011.
[5] Gloria Boafo-Mensah, Kofi Ampomah-Benefo, Maame Adwoa Bentumah Animpong,William Owusu Oduro, Ebenezer Neequaye Kotey, Kisiedu Akufo-Kumi and Gabriel Nii Laryea, "Thermal efficiency of charcoal fired cookstoves in Ghana," Global Advanced Research Journal of Engineering, Technology and Innovation 2(3), pp. 102-110, 2013.
[6] C.A. Komolafe, COREN REG Engr; MNSE. And O. Awogbemi, COREN REG Engr; MNSE, "Fabrication and Performance Evaluation of an Improved Charcoal Cooking Stove," The Pacific Journal of Science and Technology, 11(2) November 2010.
[7] Berrueta, Victor M., Rufus D. Edwards, and Omar R. Masera, "Energy performance of wood-burning cookstoves in Michoacan, Mexico," renewable energy 33, 5, pp 859-870, 2008.
[8] Punam Singh, Haripriya Gundimeda, "Life Cycle Energy Analysis (LCEA) of Cooking Fuel Sources Used in India Households," AU J.T. 13(1), pp 12-18, July 2009.

## Author Profile

**Parashuram Nandi** is Assistant Professor in Department of Mechanical Engineering at Agnel Institute of Technology and Design, Assagao, Bardez Goa, India. He did his Masters from BVBCET-Hubli in Energy Systems Engineering. His areas of interest are Energy Management, Power Plant Engineering Refrigeration and Air-Conditioning, Turbo Machineries, CFD.

**Amol N. Patil** is Assistant Professor in Department of Mechanical Engineering at Agnel Institute of Technology and Design, Assagao, Bardez Goa, India. He did his Masters from BVBCET-Hubli in Production Management. His areas of interest are Six Sigma, Quality Management, Lean Management, and Supply Chain Mangement.

**Nagaraj Raikar** is Assistant Professor in Department of Mechanical Engineering at Agnel Institute of Technology and Design, Assagao, Bardez Goa, India. He did his Masters from BVBCET-Hubli in Production Management. His areas of interest are CAD/CAM, Engineering Measurement and Metrology, Manufacturing Technology, Six Sigma, Lean Management, Supply Chain Management.

**Sidharth Kasturi** is Assistant Professor in Department of Mechanical Engineering at Agnel Institute of Technology and Design, Assagao, Bardez Goa, India. He did his Masters from Govt. Tool Room and Training Center in Tool Engineering. His areas of interest are Rapid Prototyping, CAD/CAM, Tool Design, Engineering Measurement and Metrology, and Advance Materials Science.

**Mahalingesh B.** is Assistant Professor in Department of Mechanical Engineering at Agnel Institute of Technology and Design, Assagao, Bardez Goa, India. He did his Masters from BVBCET-Hubli in Energy Systems Engineering. His areas of interest are Energy Management, Power Plant Engineering, Thermodynamics, and Energy Conversion.