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VALIDATION OF MODIFIED RURAL LAXMI CHULA DESIGN USING CONTROLLED COOKING TESTING

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ABSTRACT

Traditional cooking practices are inefficient which works on poor efficiency and produces very high level of household air pollution. Lot of research activity took place in order to tackle Chula inefficiency so as to increase SFC and improve cooking time. Various Chula testing protocols are used from decades to evaluate Chula performances. Many have used WBT protocol versions as well as CCT and KPT test. The testing protocol development had elaborated in the literature. Rural Chula is developed with the change of material of which Chula is made up of. Traditional Chula uses a mixture of rock granules, rock powder and cement with water. The CCT test protocol was used to compare improved Chula with the traditional one. The results are helpful in reducing SFC and cooking time when compared to traditional Chula.

Keywords: Chula, Controlled Cooking Test (CCT), Kitchen Performance Test (KPT), Water Boiling Test (WBT).

I. INTRODUCTION

Around the world, 3 billion people cooks their food by using solid fuel such as wood, waste of crops, charcoal, coal and dung in open fires specially three stone fire or other inefficient practices [1] such inefficient cooking practices were so inefficient that it produces very high levels of house hold pollutants. It not only generates air pollutants but also produces small sooth particles that penetrate deep into the lungs.

The simplest three fire stone is then changed to U-shape mud Chula called traditional Chula. In India, biomass-based Chula started the development in early 1940s. Much extensive research and development activities on the improved biomass Chula took place all over the world after the 1970s oil crisis due to which many improved Chula programs (ICPs) were started in many developing countries to including India to fight the energy crises, deforestation, pollution reduction in households etc. Although these improvement programs started in many countries implemented by various different government agencies, NGOs etc., they could not achieve the required objectives due to various reasons and constraints [2]. Due to fuel scarcity and deforestation issues during the 1980s and 1990s, the research and development activity work was mainly related to household energy issues in the developing countries. Because of the indoor air pollution (IAP) issues which subsequently affect the health, became the main focus during the beginning of 1990s [3]. The challenges of designing improved Chula in not only related to technical parameters but it also related to human parameters since the type of cooking is always related to society culture, availability of resources and the lifestyle of users. [4]

In the last 5 years of study it was found that the climatic changes have become the major concern all over the world. It was also revealed that annually 730 tons of biomass fuel burned developing countries by the users which generate green house gas in the atmosphere. [5].

The analysis of the performance of the traditional Chula revealed a number of design options which might provide a significant improvement in fuel efficiency. New wood burning Chula require careful design, construction and operation in order to conserve significant quantities of fuel [6]. Many researchers have worked on either natural draft Chula or forced draft to improve the overall efficiency, but due to the high upfront cost, 75% people in the rural India, cannot afford because of their low monthly income. Hence, it remains a challenging task to design and develop a Chula at an affordable price for the rural people with better efficiency. Therefore, the second objective of the research was to make it cost-effective so that people can use the Chula in their daily lives. [7].

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II. IMPROVED COOK-STOVE PROGRAMS

In the recent decades, various agencies including NGOs had been working toward the dissemination of the improved biomass Chulas, although the modified Chulas could not be disseminated more in numbers when compared to targeted community in these improvement programs. The major difficulty that encountered in the Chula dissemination was not adopting the improved Chula by the rural households. On investigating it was found that household uses local material as fuel like wood etc. Therefore, NGOs and other agencies involved in dissemination programs had to establish reliable systems for the production, distribution, installation and maintenance of improved Chulas.

Table 1 described the various ICS program in the world. This table covers only some of the important program of ICS. If we see, there are more than 50 such programs are available in the world.

Table 1: Summarized Improved Cook-stove Program in the world [8]

Sr. No	Year	Improved Cook-stove Program	Description
1	1964-2002	National Program On Improved Chulhas (NPIC)	Over 12 million improved cookstoves disseminated by 1992. Install 18 million units in 8th phase (1992-1997)
2	2009	National Biomass Cookstoves Initiatives (NBCI)	Disseminate 2.75 million
3	2011	Community Based Cookstoves In India	3,6102 stoves distributed; 980 Climate change awareness trainings given to 17,832 end users; more than 400 other related trainings, tree planting given to over 12,000 people. To Install ICS in 21,500 households.
4	2014	Tata Trust Clean Cooking Program	Approx. 5,000 modified Chula sold to users around 500 villages
5	2014	Indonesia Clean Stove Initiative (CSI)	Attracted 10 private entities and over 100 agents and supported market deployment of about 10,000 eligible clean stoves in the pilot areas. Targeted 24.5 million families
6	2018-2023	Stoves For Myanmar	Over 30,000 fuel efficient stoves sold
7	2018-2022	Bangladesh Clean Cooking Program	1.6 million ICS distributed as of June 2018. ICS coverage 30 million households by 2030.
8	2012-2040	Improved Cook Stoves Program (SSA Region)	36,167 tons CO2-e emission reduction per year on average. Significantly reduce wood consumption by replacing 3 stone/traditional Chulas
9	2014-2024	Improved Cook Stove Project With Carbon Finance (ICF) –Nepal	12,418 ICS installed. 1.3+ Million Mud and Metallic Improved Cookstoves and 400,000+ Biogas Plants 600+ Solar Cookers installed until 2017

III. CHULA TESTING PRACTICES

Stove testing is the systematic measuring of the advantages and limitations of a particular stove model. Its primary aim is to help identify the most effective and desirable stoves for a specific social and economic context. With ongoing stove production, a testing program provides essential quality control and may lead to important design modifications. [9]

Chula testing compares the different traditional stoves used in various countries w.r.t. their performance and emission standard. Eilenberg et al (2018) had done similar exercise to compare emission parameters from uncontrolled cooking practices in 41 households in China, Honduras, Uganda, and India using a portable sampler. [10]

A testing protocol for Chula usability was developed by Moses et al (2019) to help stove designers and implementers evaluate user needs for a given stove technology and cooking culture, to get technical design parameters much effectively. The protocol is based on established usability practices and includes ethnographic testing methods to increase validity in cross-cultural testing applications. [11]

Piedrahita et al (2020) reported that improved Chula adoption monitoring and its usage in various developing countries may reduce environmental pollution which will benefit the users. This study explores stove-usage monitor derived usage data from field studies and that could be possible only through Chula testing. [12]. Chula performance is related to its secondary air supply design parameters, and therefore any new designs must be experimentally validated to optimized. [13] Arora et al (2020) used Controlled Cooking Test (CCT) protocol to compare four different types of Chula with different combination of wood [14]

Various research groups formulated testing method of Chula by many different sources before any development of any standards. However, these protocols have been questioned from time to time owing to increased awareness about the uncertainty attached to methodologies adopted. Various recommendations have been made by scientists and engineers to make the results of the Chula testing protocols repeatable and at the same time close to field conditions.

3.1 Laboratory Based Chula Test

Chula tests, initially started with a lab-based approach with a gradual shift towards field test. Further, Chula test methods have also been modified by various countries to.

3.1.1 Testing Protocol

Laboratory-based protocols developed in 1980, when the Intermediate Technology Development Group (ITDG) made a first attempt to define a procedure for testing a Chula in laboratory. [15]

Between 1982 and 1985, Volunteers in Technical Assistance (VITA) developed the first version of the Water Boiling Test (WBT), aimed at measuring how much wood is used to boil water under fixed conditions. First version of WBT specify two phases as high power and low power where the rapidly water boiling will simmered after boiling for 30 min. No pollution testing was described during this period. [16]

Baldwin (1987) in his technical report on Chula had made a first revision and discussion of the VITA's WBT one of the most widely cited references for Chula developers (it will be referred to as WBT 2.0). [17]

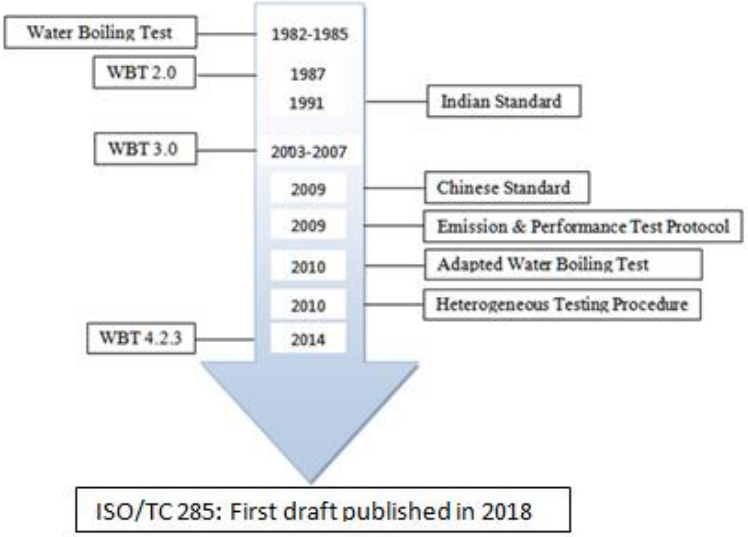

Figure 1: Protocols evolution summary over time.

Figure 1 described the various testing protocols developed over time. The latest protocol ISO/TC 285 is under development by the committee of "Clean Cookstoves and Clean Cooking Solutions" team. However, its first draft is published on 16th October 2018 for the review to the team of alliances. The standard comprised of some of the world's leading specialists from the clean cookstoves and fuels sector, with special expertise on testing, design, business and policy.

3.2 Field Based Chula Testing

The literature shows several attempts have been made to validate the Chula performance results through field based studies. The standard test methods that were formulated along with WBT were designed to assess the field based performance assessments of Chulas.

3.2.1 Controlled Cooking Test (CCT) and Kitchen Performance Test (KPT)

The latest version of Controlled Cooking Test is CCT 2.0 published in August 2004 by Household Energy and Health Programme, Shell Foundation. The controlled cooking test (CCT) is prepared to compare the modified Chula performance parameters with the locally used Chula which is going to replace it. Chulas are compared in a similar manner to that of locally used cooking methods on daily basis. [18]

KPT measures the rate of wood used by two stoves as they are used in the normal household environment. It is a lengthy test conducted with the family of users by the families. Compared to the CCT test, the results of the KPT can provide the most reliable indication of stove performance under actual household conditions. The methodology adopted in CCT and KPT has been improvised to a lesser extent since its inception as compared to WBT. Studies conducted using CCT and KPT are less in number compared to studies conducted using WBT. [19]

Teune et al (2020) in their low cost modifications of open fired Chula also compared CCT version 2.0 and KPT test apart from WBT based emission test. [20]

3.2.1.1 Performance Parameters in CCT:

The controlled cooking test (CCT) is used to compare two Chula one is modified and another one is traditional Chula in terms of their performances so that the modified one can be replaced later on. Total 3 tests of each Chula / stove are performed. After the test completion, the recorded date is then used to calculate the Chula performance. Descriptions of test performance are as stated;

- Wt of cooked food (W_{cf}) – Calculated by subtracting empty pot weight from the cooked food.
- Weight of char/wood remaining (W_C) – include mass of charcoal in the Chula and charcoal removed from un-burnt wood.
- Wt of wood consumed (W_d) – it is defined as the total wood used subtracting the weight of char/wood remain after the test.
- Specific fuel consumption (SFC) – This is the principal indicator of stove performance for the CCT. It tells the tester the quantity of fuel required to cook a given amount of food for the "standard cooking task". It is ratio of the wt of wood consumed ($W_{d)}$ to the wt of food cooked (W_{cf}) calculated

$$SFC = \frac{\text{Wt of wood consumed (Wd)}}{\text{Wt of cooked food (Wcf)}}$$

- Total cooking time – Time required to cook the food.

IV. MODIFICATION OF RURAL LAXMI CHULA:

4.1 Design Details:

The design of the Laxmi Chula was done by using CATIA V5 according to the dimensions given by Appropriate Rural Technological Institute which are as follows:

4.2 Dimensions and drawings:

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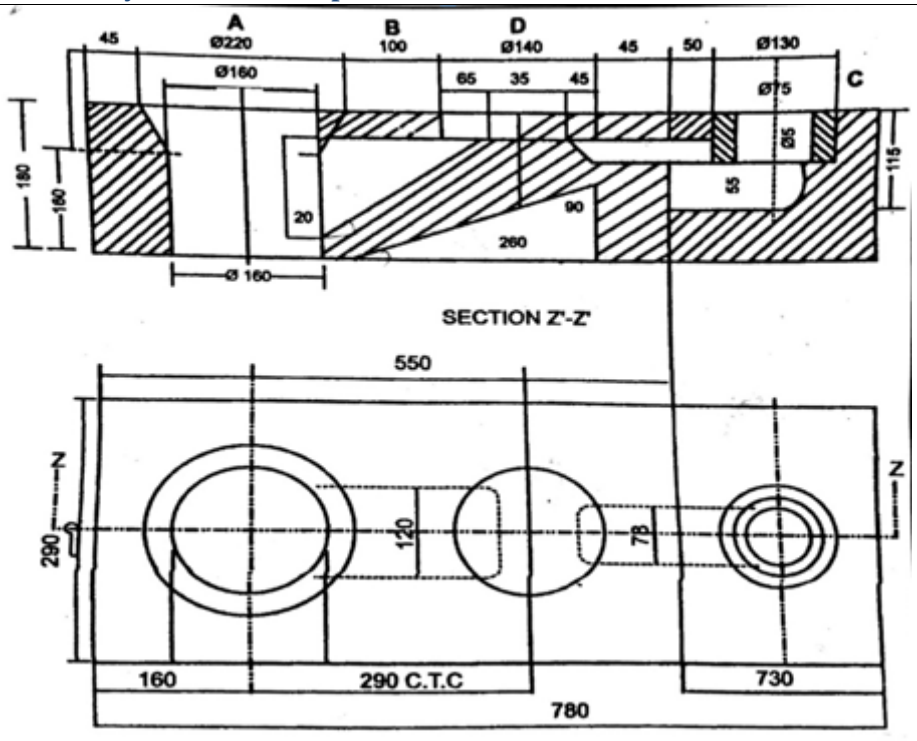


Figure 5: Front Sectional View and Top View of Laxmi Chula

Laxmi Chula is traditionally used by the local users. The idea behind to choose this stove was to compare the performance of traditional stove with the improved Chula.

4.3 CATIA Design:

A CATIA model of the Chula was prepared using CATIA V5 version. This model was used for the purpose of visual clarity while manufacturing Chula. The same model can further be used for CFD analysis as a future scope of work.

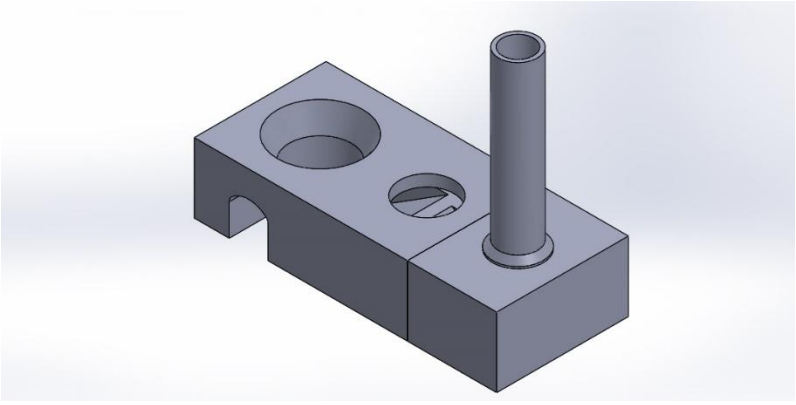


Figure 6: CATIA V5 Model of Laxmi Chula

4.4 Material Selection:

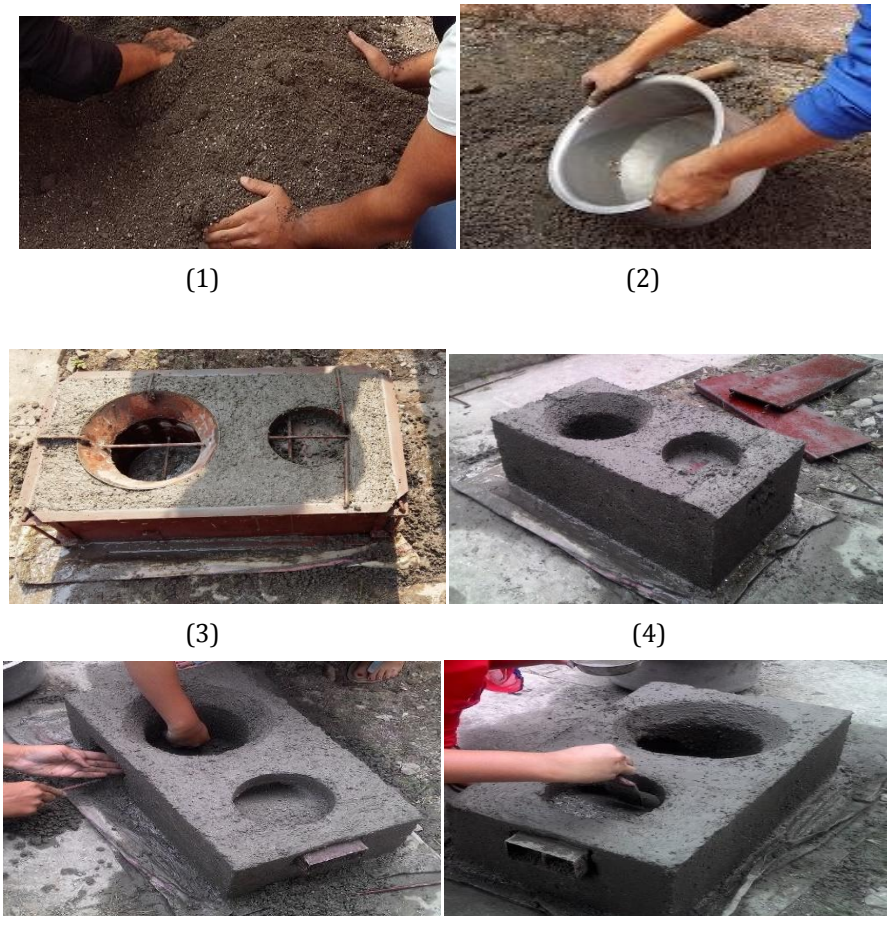
The material of the cook stove was of prime importance. Traditional Chula uses a mixture of rock granules, rock powder and cement with water. This material is found thermally conductive in nature and also of heavy weight. Therefore, due to its thermal conductive property, some amount of heat released by the fuel would be absorbed by this material and thus would lower the thermal efficiency of the cook stove thereby increases the consumption of fuel. Due to its weight, the stove was found difficult for transportation from manufacturing center to the customer premises and also the installation becomes a difficult task. Furthermore if the customer wanted to move the stove somewhere else in the house, it would prove extremely strenuous for the customer.

Therefore, it becomes necessary to change the material to get the benefit of fuel saving. From all the materials reviewed, "Perlite" was found to be the best. The properties of perlite make it suitable for making a cook stove. Perlite has a considerable low thermal conductivity and cost. Also the maximum temperature sustained by perlite is fairly high. The bulk density of perlite is 30-150 kg/m^3 which is very less as compared to other materials. Moreover it is not harmful to environment as well as to human or animal life. It doesn't react under high temperatures and is stable. It doesn't emit any harmful fumes or radiations. Hence considering all the factors as mentioned above, Perlite is chosen as the material for cook stove.

After the selection of the base material, it becomes necessary to choose the secondary material. The secondary material does the job of binding the primary material and gives it enough strength to sustain shocks. Fire clay and cement were tested as the secondary materials and cement proved to have the upper hand. Although cement when mixed with water adds considerable amount of weight, choosing proper proportion of cement and perlite was of utmost importance. For finding out the optimum proportion of perlite and cement, the mixture in various proportions was tested for strength. The testing started with the 1:1 proportion of cement and Perlite by volume and ended with 1:5. The 1:1 proportion gave high strength but was very heavy. The 1:5 proportions gave optimum strength to weight ratio.

4.5 Manufacturing of Chula:

Figure 7 showing Stages of stove manufacturing. (1- material mixing, 2- water addition, 3- pouring material in to stove mould, 4- mould removal after 30 min, 5- Excess material remove, 6- Stove finishing)



(1) (2)

(3) (4)

(5) (6)

Figure 7: Stages of stove manufacturing

The finished stove is further assembled for CCT testing. Figure 8 represents the images of finished Chula.

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(1) (2)

Figure 8: (1), (2) Actual Photograph of Assembled Finished Chula

V. EXPERIMENTATION THROUGH TESTING:

The performance of Chula is evaluated by Controlled Cooking Test

5.1 Controlled Cooking Test (CCT):

The controlled cooking test (CCT) protocol is used to check the efficiency of the modified Chula when the modified Chula is to be replaced. Chula is compared with the cooking methodology of the users as they used in their day today cooking tasks which is near to the actual cooking practices. The test is conducted as far as possible without the influence of external factors which can result in test repetition work. [21] [22]

5.2 Equipment And Materials:

The equipment required to conduct the test of CCT is similar to the equipment required to perform the water boiling test.

Fuel: preferably dried fuel to be procured. It can be air dried. Wood must be in sufficient amount to be purchased in order to keep the ready stock. For 3 tests to perform, we need to have 40 to 45 kg of wood in advance before the test to begin. The calculation is based on the fact that user need average 2 to 2.5 kg wood per meal. Example,

$$2.5 \frac{\text{Kg}}{\text{meal}} \text{ x } 3 \text{ Chula x } 3 \frac{\text{tests}}{\text{stove}} \text{ x } 2$$

- Food and water: Must be sufficiently available in advance just like wood.
- Cooking pot: the cooking pot must be similar to the pot used in both the test. It means the pot size, its weight and material must be same otherwise test results will differ. Also pot lid should also be used as the users use it during their meal preparation.
- Measuring scale: It is used to measure the test result before and after tests. Electronic scale is preferred with 1gm accuracy.
- Wood moisture testing meter.
- Timer.
- Thermometer: used to measure ambient temperature only.
- Spatula: for the purpose of removing char from Chula to measure.
- Pan: used to move char.
- Heat –resistant hand gloves.

5.3 CCT Testing Procedure:

The CCT is used to compare the performance of modified Chula with the traditional Chula as per the given standard procedure to perform cooking task. This procedure is common for all types of Chula used locally to compare any modified Chula.

In the first step of conducting the CCT, the local user is to be consulted where the test is to be performed. All the equipments and material must be ready in advance as stated above. For home meal test, typical meal of some

regular food preparation is required in test. All tests must be measure and record in data sheet for calculation purpose.

- One the test is decide, the test operating procedure must be written down in details so that the user and the tester should understand it and follow without any ambiguity. This step is important to conduct cooking task identically to both Chula.

  Once all inpatients as well as the procedural work is over, the actual cooking test start. The activity of cooking is performed by the local user or tester who does the activity daily. This is preferable but not compulsion. For any new type of stove design is to be tested which is different that the regular practice that users must be given training in order to operate the Chula before begin of tests.. Record all local condition for further calculations.
- Conduct Weigh of each inpatients required in tests and do the activity of food preparations..
- Keep the fuel ready, in this case weighted wood bundle. Measure all the activity.
- Start Chula when it is in room temperature and ask the user to ignite ithe fire as per their local practices. Do all data recording by timer as soon as the fire start.
- After finishing the cooking activity, record the finished time of cooking for further calculations.
- Take the weight of cooked food on weighing balance and record it.
- Take out the un-burnt wood from the fire. Remove the char from the end of un-burnt wood. Take the wt of un-burnt wood and record it.
- Each Chula to be tested for 3 times in order to get consistency in results.

Figure 9 and 10 represents the actual images of testing protocol.

Figure 9: Weighing of Food (Rice) and rice with water

Figure 10: Rice cooking on Chula and then weight measurement

5.4 Controlled Cooking Test (CCT) Observations:

Total 3 tests were conducted on improved Chula well as on traditional Chula to find out the Specific Fuel Consumption (SFC) and time required to cook food. Following table described the test details of Chula.

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Table 3: Controlled Cooking Test Observations on improved Chula

Sr. No.	Observations	Unit of Measurement	Test1	Test2	Test3	Average of Test
1	Weight of Fuel Used	Kg	1	1.02	1	1.01
2	Weight of Uncooked Rice	Kg	0.464	0.484	0.475	0.47
3	Weight of Unburnt Fuel	Kg	0.724	0.712	0.73	0.72
4	Weight of Cooked Food	Kg	1.102	1.192	1.092	1.13
5	Time Required for Cooking	Minutes	15	15.5	15	15.17

Table 4: Controlled Cooking Test Observations on traditional Chula

Sr. No	Observations	Unit of Measurement	Test1	Test2	Test3	Average of Test
1	Weight of Fuel Used	Kg	1.12	1.06	1	1.06
2	Weight of Uncooked Rice	Kg	0.464	0.484	0.475	0.47
3	Weight of Unburnt Fuel	Kg	0.272	0.278	0.276	0.28
4	Weight of Cooked Food	Kg	0.968	0.985	0.952	0.97
5	Time Required for Cooking	Minutes	22	23	22	22.33

Traditional Chula took more time to cook food and consumed more fuel as compared to improved Chula. Using above observations, Chula performance is calculated.

5.5 Performance Calculations:

Specific Fuel Consumption (SFC): Specific Fuel Consumption of biomass Chula is defined as the ratio of mass of consumed fuel to the total mass of cooked food. For finding out the specific fuel consumption, the burnt fuel and the cooked food is measured on a measuring instrument separately. The measured weight is recorded on a recording sheet.

5.5.1 Specific Fuel Consumption of Traditional Chula:

$$S.F.C. = \frac{\text{Mass of Consumed Fuel}}{\text{Total Mass of Cooked Food}}$$

$$S.F.C. = \frac{1.06 - 0.28}{0.97}$$

$$S.F.C. = 0.810$$

5.5.2 Specific Fuel Consumption of Improved Chula:

$$S.F.C. = \frac{\text{Mass of Consumed Fuel}}{\text{Total Mass of Cooked Food}}$$

$$S.F.C. = \frac{1.01 - 0.720}{1.13}$$

$$S.F.C. = 0.252$$

5.6 Discussion:

As we can see from the below graph, the cooking time, Specific Fuel Consumption and the mass of fuel consumed has reduced significantly in the improved Chula stove as compared to traditional Chula. Thus we can say that the overall performance is improved.

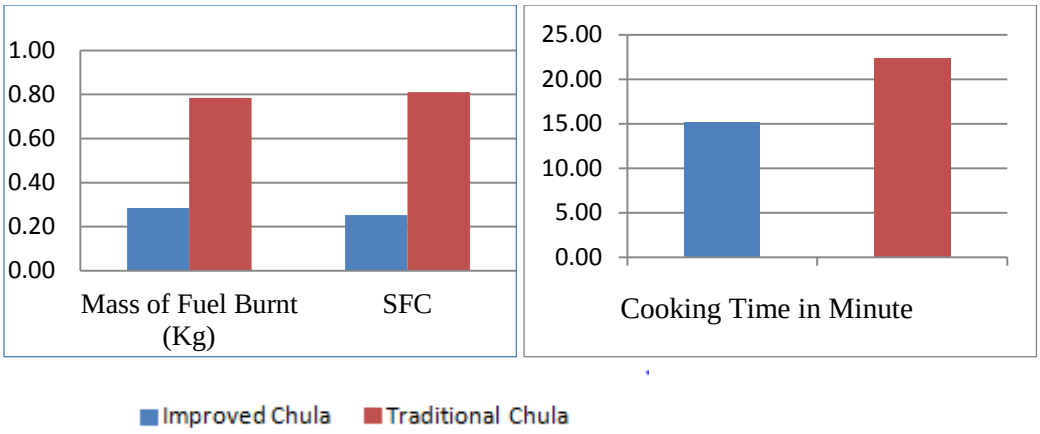

Figure 10: Mass of Fuel Burnt, SFC and Cooking Time of Chula

Table 5 shows the comparison between traditional and improved Chula performance parameters.

Table 5: Chula Performance Parameters Comparison

Sr. No.	Observations	Improved Chula	Traditional Chula
1	Mass of Fuel Burnt (Kg)	0.28	0.78
2	SFC	0.25	0.81
3	Cooking Time (Min)	15.17	22.33

Reduction in cooking time, specific fuel consumption and fuel requirement for performing a specific task is the necessity of the Chula users. This will also reduce the pollution and emission parameter. All of the above factors improve the thermal efficiency of the Chula.

VI. CONCLUSION

Present work is carried out for Laxmi Chula. The test results when compared with traditional Chula with the new developed Chula found encouraging. Reduction in Specific Fuel Consumption (SFC) reduces mass of fuel burnt and cooking time. There is a reduction 68% Specific Fuel Consumption, 63% reduction in fuel usage and 47% reduction in cooking time.

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