# DEVELOPMENT OF ENERGY EFFICIENT COOKING SYSTEMS FOR RURAL MASSES

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***ABSTRACT*: In this experimental research study three different designed improved cooking stoves, Priyagni, Harsha and proposed modification of Modified multifuel cook stove developed on the basis of application of Dr Winiarski design principles and tested in fuel laboratory and compared in terms of efficiency and emission. The main focus was on the new modified stove design, which is so far a prototype. This stove, which can be locally produced with local materials, consists of an insulated combustion chamber with the comparative energetic analysis based on the experimental observation using different biomass(cow dung, babul wood and mango wood) available at the time of experiment, The merits and demerits of each cook stove model have evaluated experimentally and it is found that each model has expected the efficiency and other parameters of the modified multi-fuel cook stove is in the range of 30-35 % better than from the Priyagni and Harsha cook stove models and the thermal efficiency has been increased by the convective heat transfer co- efficient by forcing the flue gases to flew through the enclosure skirt between pot bottom and pot surrounding and heat transfer increased through preheating the secondary air. The India National Programme on Improved Chulas (NPIC) was only concerned about government design specification and did not respond to need for rural people. There is no option but to look for efficient improved cook stoves on the basis of application of Dr Larry Winiarski design principles during design and development of cook stoves. This paper presents the design principles to develop energy efficient cook stove model for rural masses and to improve the stove efficiency up to 40%.**

**The application of design principles of Dr. Larry Winiarki, the efficiency test results indicates that the modified cook stove performed better in combustion of wood and heat output. The rate of fuel saving from the modified cook stove was quite significant in comparison with the Priyagni and Harsha Stove of NPIC on average saved 30% of fuel wood per day. This was with the improvement in the combustion efficiency and the expenditure can be reduced by about 34 %.This is possible because of the application of design principles. This research paper brings out the minimization of thermal energy losses to get cooking efficiency of cook stoves up to 30-35% and flame temperature measurement under various combustion conditions. Reduction of heat losses by allowing the gases remain in contact with cooking vessel for more time in the insulated chamber of the combustion chamber.**

***KEYWORDS:* - Combustion chamber, Efficiency, Flue gases, heat transfer, Modified cook stove**

## 1 INTRODUCTION

The cooking stoves being used by the rural communities, they waste enormous amount of biomass, time and efforts in collecting avoidable additional biomass. It also renders too much release of smoke which has health hazard like eye sore, breathing/asthmatic trouble etc. However, several researchers have tried and developed a large number of energy efficient cook stoves for which energy efficiency was claimed to be between 22-25%, remained up to the laboratory only. However, in these various developmental efforts, the level of achievement of some of the objectives still leaves a lot of room for improvement. This research is an attempt to address such a need and endeavours to provide a challenge to stove experts to improve on the technological developments, to develop energy efficient cook stoves which should be user friendly for the large scale adoption of the rural masses. Although the stove design offered several promises of efficient and smoke free cooking programme posed several problems leading to rejection of the stoves in house hold, stove-builders do not have an in-depth understanding of the design, the stove users were never informed about the stove design were not developed to cater to cooking practices of various regions/communities and the way in which it should be operated.

The design principles of Dr Winiaraki were incorporated while designing the modified cook stoves to improve the efficiency and compared with some identified model in respect of their efficiency, reduction of heat losses by allowing the flue gases to remain in contact with cooking vessel/pot in the insulated combustion chamber.

Considering the above points, the objectives of study:

1. Reduction of heat losses by allowing the flue gases to remain in contact with cooking vessel/pot in the insulated combustion chamber.
2. Air fuel ratio to get the optimum thermal energy release.
3. Combustion analysis, measurement of polluting gases.
4. Design and development of energy efficient cook stoves.

The following steps for achievement of thermal energy losses to get cooking efficiency of cook stoves up to 30-35%, biomass fuel composition is obtained from selected standard Institutions, fuel composition of fuels like wood and animal dung, flame temperature measurement under various combustion conditions. This study contributes to the existing literature in the following three importance aspects. It provides comparative insight in to possible range of effective performance of three different type of improved cook stoves used in the study, describes the relevance of the energy of each of the stoves and important factors that influenced fuel and type of cook stove.

### 1.1 National programme on Improved Cook stoves (NPIC)

The NPIC follows a multi model and multi-agency approach on dissemination levels and adoption of improved cook stoves (chulas) and improved phases in stove performance. The criteria that were used to evaluate the success of improved cook stove programme in different phases for research and development in fuel saving, improved air quality, annual growth rate in dissemination and degree of dissemination to low income populations and increase in improved cook stove and net improvements in stove performance. The NPIC was discontinued in 2002 and the major shortcoming that has been cited is its top-down approach. The central government subsidy went directly to stave producers, yet it is apparent that many producers did not consider consumer preferences when designing and marketing stoves.

### 1.2 Biomass Fuel

Biomass fuel or biofuel is defined as any plant or animal based material deliberately burned by humans. Biomass consists of three major elements: carbon, oxygen and hydrogen with the approximate proportion of about 50%C, 6% H and 44% O on a moisture and ash free basis. The heat of combustion of biomass based fuels is dependent on the percentage of the three main constituents. Lignin has the highest (26.63MJ/kg), while holocellulose has a value of 17.46% MJ/Kg. Therefore, wood with a greater percentage of lignin has higher heat of combustion.

### 1.3 Fuel Consumption and Efficiency

The amount of fuel consumed during cooking is the simple measurement that can be carried out. Fuel consumption is measured by weight rather than by volume since it is difficult to measure accurately the volume of a non-uniform fuel such as wood. Fuel wood consumption can be converted into units of energy consumption of multiplying by the calorific value of the fuel the calorific value of solid fuel is measured using a bomb calorimeter.

## 2 TECHNOLOGY AND MODELS OF BIOMASS COOK STOVES

Biomass cook stove is defined as a stove for cooking especially a wood or biomass burning kitchen stove. Traditional cook stoves refer to either open fire or cook stoves constructed by the household. Improved cook stoves means the cook stove usually with a fire box or chimney but without standards. Improved /modified cook stove is designed to consume less fuel and save cooking time, offers convenience in cooking process and create smokeless environment in the kitchen or reduction in the volume of smoke produced during cooking against the traditional stove. Such stoves offers advantages like reduction in health problems due to low smoke, forest conservation, reduction of cooking indoor air pollution and all this leads to healthy environment**.** The cook stoves are of different types, natural draft side/top continuous feed, forced draft side/top continuous feed and forced draft self-power generating. The power output rating of cook stove is a measure of total useful energy produced during one hour by fuel (biomass). Power output rating in KW above 1.0 and up to 3 three is considered.

### 2.1 Combustion Process and Factors Influences the Cook stove Efficiency

During the combustion process a number of chemical reactions take place. These reactions do not simply involve the addition of oxygen to carbon and hydrogen, in the fuel, to produce heat. There is a combination of a number of primary, as well as secondary reactions in which the products of the primary reactions also take part. Performance of a combustion system on the whole, depends on the physico-chemical and thermo chemical properties of the fuel. The incomplete combustion is resulting in the emission of pollutants, the chemical composition, and energy density biomass and process factors. There are number of factors affecting the cook stove efficiency, which must be taken in to consideration so as to maximize efficiency and minimize emissions. The design of improved cook stoves involves the application of heat transfer, combustion and fluid flow principles in order to attain complete combustion of the fuel with a minimum amount of excess air, maximum transfer of heat from the flame and the flue gases to the cooking vessel, and a minimum loss of heat to the surroundings. This can be accomplished by optimizing and/or incorporating various subsystems in the stove. These subsystems are: firebox/combustion chamber and stove walls, grate, air/fuel inlet, flue/chimney, baffles, dampers and connecting tunnels. The combustion process in a cook stove is greatly influenced by important factors which influence combustion are: (a) Physical and chemical properties of the fuel(b) Fuel/air ratio(c)Temperature of the flame/envelope(d) Mode of fuel supply(e) Primary and secondary air supplies.

### 2.2 Design principles of Dr. Larry Winiarski

Dr. Larry winiarski's design principles out of 10 principles only 6 principles i.e. 1, 3,5,8,9 & 10 has been used to create successful multi fuel cook stove approach.

Principle 1**:** Insulate around fire using lightweight, heat resistant materials ash/mud.
Principle 2: Place an insulated short chimney right above the fire to burn.
Principle 3: Heat and burn the tips pieces of the sticks as they enter the fire to make flame.
Principle 4: High and low heat is created by how many sticks are pushed in to the fire.
Principle 5: Maintain a good fast draft under fire through primary and secondary air inlet.
Principle 6: Too little draft being pulled in to the fire will result in smoke & excess charcoal.
Principle 7: Keep in restricted airflow by maintaining constant cross sectional area
Principle 8**:** Use a grate under the fire.
Principle 9: Insulate the heat flow path, from the fire to around the pot
Principle10**:** Maximize heat transfer to the pot with properly sized gaps.

### 2.3 Design Analysis and Calculation

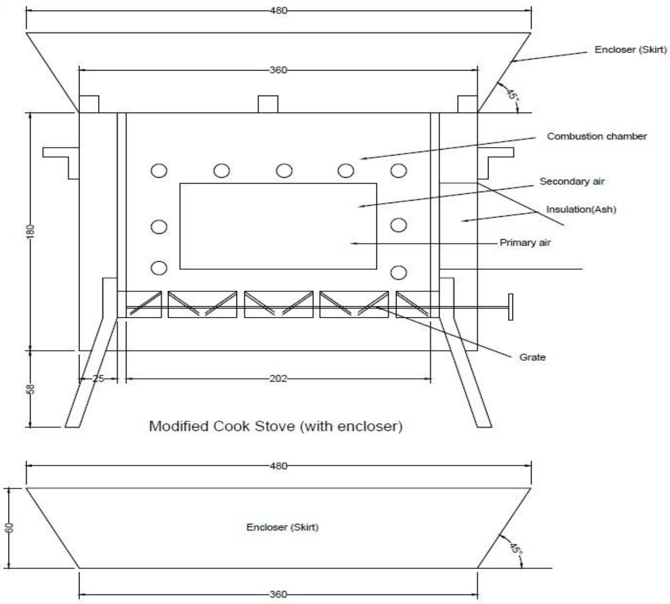
The following parameters are selected for design: Height of the combustion chamber = internal radius of combustion chamber r1= internal radius of insulation, external steel casing height of pot seat chamber and external temperature of combustion chamber to measured internal temperature of the combustion chamber , the thermal conductivity of fibre glass k1 =0.037w/mk: thermal conductivity of mild steel= 39m/mk. The combustion analysis based on the ultimate analysis by mass gives, A/F=4.6107 kg air/kg fuel, for an actual air supply which is 20% in excess of stochmetry actual air/fuel ratio A/Factual=5.5328 kg air/kg fuel
The enhanced performance is attributed to a number of factors the first is the insulation provided round the combustion chamber this minimises the rate of heat loss across the wall of combustion chamber for conduction and radiation and ensures that a good proportion of heat is conserved within the chamber and directed towards the top of the chamber. The second factor is the design of pot seat and the position of the flue gas enclosure.

### Modified multi fuel Cook Stove

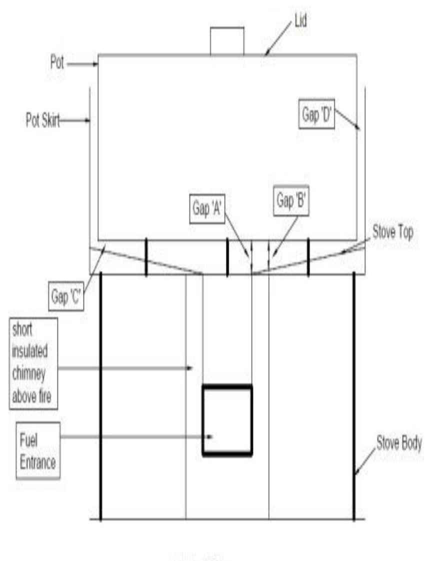
Dr Larry winiarski method of maintaining a constant cross sectional area under the pot need to calculate the correct gap under the pot from the centre of the combustion chamber out to edge of the pot calculate the needed gap at the edge of the square combustion chamber (20 cm X 20 cm) and at the edge of the pot.
(Determine of the area of the combustion chamber
For square combustion chamber the area is calculated as
$A_c = l.w$ , Where l is the length and w is the width/breath is 20 cm (1)
$A_{c\,=}$ 20x20= 400 cm2,
(ii) Determine the circumference associated with the distance. (2)
$C_c = 2\,\pi.\, r_{c,}$ where, rc combustion chamber outlet to the edge = 14.14 cm
$C_{c\,=}\ 2\,\pi$ x14.14 =88.89 cm
(iii) Determine the needed gap between bottom of the pot and the edge of the combustion.
$G_c = A\,/C_{c\,,}$ Where, $G_c$ is the needed gap, $G_{c\,=}$ 400/88.89 = 4.5cm (3)
(iv) Determine the optimal gap at the edge of the pot.
Diameter of pot is 30 cm, $C_p = 2.\pi.r_{p,}$ $C_p = 2.\pi$ x15= 94.28 cm (4)
(v) Determine needed gap at the edge of the pot.
$G_p = A\,/\,C_{p,}$ $G_{p\,=}$ 400/94.28= 4.24 cm (5)

### 2.4 Modified Multi Fuel Cook stove

The Modified multi fuel cook stove is a portable metallic, single pot stove without chimney. This prototype stove has a design that is based on combustion chamber, enclosure (skirt) which uses Dr Larry Winiarski's design principle. This design is using the advantage of the insulation properties of the material combination ash/clay, which has a very low thermal conductivity (about 0.12 W/mK), waste flue gas with the help of enclosure. The design creates a draft in the stove, which supports the fire with the necessary air for a complete combustion. The above principles are based on following advantages (a) Insulated combustion chamber, with low mass, heat resistant material in order to keep the fire as hot as possible and not to heat the higher mass of the stove body (b) Within the stove body, above the combustion chamber, use an insulated, upright chimney of a height that is about two or three times the diameter before extracting heat to any surface (griddle, pots, etc.). (c) The cross sectional area (perpendicular to the flow) of the combustion chamber should be sized within the range of power level of the stove. (d)Throughout the stove, where hot gases flow, insulate from the higher mass of the stove body, only exposing pots, etc. to direct heat.(e) Transfer the heat efficiently by making the gaps as narrow as possible between the insulation covering the stove body and surfaces to be heated.



Modified Cook Stove (with encloser)



Winiarski Stove

## 3 METHODS

The methodology used in the experimental study, seeks improvement on the existing designs by making the following design considerations: enhancing the combustion process by providing for means of introducing sufficient air for combustion, further reducing the amount of heat loss from the combustion chamber by insulating with ash or mud, reducing the amount of heat loss by radiation by a careful design of the pot seat, and reducing the level of pollution of the kitchen environment.

### 3.1 Water Boiling Test (WBT)

Water boiling test is a relatively short, simple simulation of common cooking procedures. It measures the fuel consumed for a certain class of tasks. It is used for a quick comparison of the performance of different stoves. Simmering involves the heating of boiling water at a constant temperature for about thirty minutes. The procedure for the test is the same as that for the boiling test. At the end of the test, measurements are taken and recorded accordingly. Thermal efficiency of a cook stove is defined as the ratio of heat actually utilized to the heat theoretically produced by complete combustion of a given quantity of fuel wood, which is based on the calorific value of a particular fuel wood. To carry out thermal efficiency of a cook stove few measurements were carried out and determination of burning capacity rate, if the fuel burning rate per hour is determined in order to choose the capacity of cooking pot and the amount t of water to be taken at a time as per BIS standard.

### 3.2 Emission Measurement

The flue gas composition analyses were done with a multi flue gas analyzer. It can measure different values like, CO, CO2, CO-O2, O2, SOx and NOx, at the same time. The first values were taken when the fire in the stove was well burning at the upper rim of the stoves between the pot and the stove skirt. Other values were taken after boiling of the water and at the end of the test. The results can be converted in volume percent or parts per million with the conversion factor 0.01 volume %=100 ppm. These results, which were taken from a stove operated in optimal conditions.

**<u>Calculation of Thermal Efficiency of different Cook Stoves with different type of Fuels</u>**

**<u>Determination of Burning Capacity Rate of cook stove</u>**

The fuel quantity of 0.5 kg, 0.75 kg and 1 kg cow dung is used.

1) Fuel Consumed (FC) = $M_1 – M_2$

2) Burning capacity rating (F) = $(M_1 – M_2) / (T/60)$ kg/hr.

3) Heat input per hour = Burning capacity x CV kJ/hr. Where,

M1 = initial mass of fuel taken

$M_2$ = final mass of fuel consumed and

CV = calorific value of the fuel in kJ/kg

**<u>1. Determination of Thermal efficiency of cook stove</u>**

w = mass of water in vessel, in kg,

W = mass of vessel with lid, in kg

$M_3$ = mass of kerosene used for ignition,

$CV_k$ = calorific value of kerosene, in kJ/kg

$t_1$ = initial temperature, in degree C

$t_2$ = final temperature, in degree C

$C_w$ = specific heat of water (=4.186 kJ/kg/$^oC$),

$H_i$ = heat input into the stove, in kJ

$C_v$ = specific heat of vessel made of aluminum (= 0.896 kJ/kg/$^oC$)

$H_{in}$ = heat input into the stove, in kJ,

$H_{out}$= heat output of the stove

n = efficiency in %,

$H_{out} = (W \times C_v + w \times C_w) \times (t_2 – t_1)$

$H_{in} = (FC \times CV) + (M_3 \times CV_k)$,

$n = 100 \times (H_{out} / H_{in})$

**<u>2. Power Output Rating</u>**

Po = Power output, in kW,

F = rate of fuel consumption, in kg/hr

CV = calorific value of fuel, in kJ/kg

n = thermal efficiency

Po = (F x CV x n) / 360000

## 4 RESULTS AND DISCUSSIONS

The performance evaluation and experimental study of three different cook stove models such as Priyagni and Harsha and Modified multi fuel cook stoves, have been carried out for water boiling test following BIS standard. All these cook stove models were evaluated for water boiling test and emission test with specific quantity of water in the Aluminium container using the same type of fuel wood prepared as per the BIS standard. Fig. 4.1 Photographic view of various cook stove models during experimental study.

Priyagni cook stove

Harsha cook stove

Modified Multifuel cook stove

The following tables shows the tested stoves efficiency comparison between the Priyagni, Harsha and Modified multifuel with different fuel (cow dung, babul and mango wood) types. The tests were done in two phases, the boiling phase and the simmering phase. Table 1 compare the typical temperature profile for three stoves.

| S.No. | Parameters | Priyagni cook stove | | | Harsha cook stove | | | Modified Multi fuel | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Fuel consumed | Cow | Babul | Mango | Cow | Babul | Mango | Cow | Babul | Mango |
| | 0.5 kg | 0.43 | 0.370 | 0.37 | 0.427 | 0.329 | 0.39 | 0.365 | 0.325 | 0.41 |
| | 0.75 kg | 0.431 | 0.368 | 0.37 | 0.408 | 0.36 | 0.386 | 0.393 | 0.32 | 0.4 |
| | 1 kg | 0.428 | 0.365 | 0.369 | 0.4 | 0.326 | 3.384 | 0.382 | 0.316 | 0.39 |
| 2 | Burning | Capacity kg/hr. | | | | | | | | |
| | 0.5 kg | 1.312 | 1.142 | 1.233 | 1,281 | 1.169 | 1.57 | 1.196 | 2.01 | 2.13 |
| | 0.75kg | 1.281 | 1.143 | 1.238 | 1.224 | 1.2 | 1.61 | 1.347 | 2.03 | 2.148 |
| | 1 kg | 1.318 | 1.151 | 1.342 | 1.33 | 1.176 | 1.68 | 1.432 | 2.09 | 2.156 |
| 3 | Heat Input | KJ | | | | | | | | |
| | 0.5 kg | 7238.3 | 6201.2 | 6216.0 | 7033.3 | 6172.2 | 6384.6 | 6649.3 | 5821.8 | 5711.3 |
| | 0.75 kg | 7231.4 | 6209.6 | 6222.4 | 6739.0 | 6598.7 | 6314.4 | 6506.6 | 5814.8 | 5702.1 |
| | 1 kg | 7235.9 | 6129.6 | 6161.9 | 6615.0 | 6160.8 | 6254.3 | 6336.2 | 5803.4 | 5694.3 |
| 4 | Heat output | kj | | | | | | | | |
| | 0.5 kg | 1479.1 | 1461.9 | 1440.8 | 1484.4 | 1479.1 | 1490.8 | 1440.8 | 1692.6 | 1708.9 |
| | 0.75 kg | 1492.7 | 1461.8 | 1448.1 | 1484.7 | 1484.4 | 1498.0 | 1484.4 | 1698.9 | 1710.3 |
| | 1 kg | 1484.7 | 1472.1 | 1462.2 | 1484.7 | 1485.5 | 1501.3 | 1484.4 | 1701.2 | 1722.1 |
| 5 | Thermal | Efficiency % | | | | | | | | |
| | 0.5 kg | 20.43 | 23.56 | 23.17 | 21.1 | 23.96 | 23.34 | 22.34 | 29.07 | 29.92 |
| | 0.75 kg | 20.51 | 23.57 | 23.27 | 22.02 | 22.49 | 23.72 | 22.84 | 29.2 | 29.99 |
| | 1kg | 20.57 | 24.01 | 23.73 | 22.44 | 24.11 | 23.89 | 23.42 | 29.31 | 30.24 |
| 6 | Power | Output KW | | | | | | | | |
| | 0.5 kg | 1.122 | 1.12 | 1.163 | 1.163 | 1.172 | 1.534 | 1.15 | 2.446 | 2.668 |
| | 0.75 kg | 1.136 | 1.127 | 1.206 | 1.174 | 1.187 | 1.599 | 1.32 | 2.481 | 2.697 |
| | 1kg | 1.141 | 1.157 | 1.33 | 1.178 | 1,208 | 1.65 | 1.44 | 2.569 | 2.729 |
| 7 | $CO/CO_2$ | | | | | | | | | |
| | 0.5 kg | 0.269 | 0.269 | 0.269 | 0.269 | 0.264 | 0.269 | 0.264 | 0.269 | 0.269 |
| | 0.75 kg | 0.257 | 0.261 | 0.269 | 0.261 | 0.269 | 0.269 | 0.269 | 0.269 | 0.269 |
| | 1 kg | 0.284 | 0.269 | 0.269 | 0.269 | 0.308 | 0.3 | 0.308 | 0.269 | 0.267 |

**Table 1 Comparison of test performance of cook stove fuels ( Cow dung/Babul wood/Mango wood)**

From the below tables the energy efficiencies were evaluated and plotted against the heating time, Energy efficiency increases with time, Energy efficiency increases ,slightly decreases as the heating/boiling time increases. Maximum energy gain is observed, the performance of Priyagni model is found to be lowest whereas the performance of Harsha model is found to be the better, and modified multi fuel cook stove is found to be much better than other types of cook stoves models followed by the Harsha model cook stove.

The following tables show the similarities and comparison between the Priyagni, Harsha and Modified multifuel with stove parameters. Table .2 similarities and comparison of cook stoves.

| Sno | Stove Parameters | Priyagni cook stove | Harsha cook stove | Modified multifuel |
|---|---|---|---|---|
| 1 | Construction material | Metal | Metal | Metal &Nonmetal |
| 3 | Type of fuel | Wood, cow dung | Wood, cow dung | Cow dung, wood, Agri resedue |
| 4 | Combustion efficiency | Incomplete | Incomplete | complete |
| 5 | Application of Design principles | No | No | Yes |
| 6 | Thermal Efficiency | 22-24% | 24-26% | 30-35% |
| 7 | CO/CO2 Level | 0,280 | 0,269 | 0.251 |
| 8 | Cost of cooking &cook time | More fuel& time consumed | More fuel& time consumed | Less fuel& less time consumed |
| 9 | Cost of cook stove | Rs 350 | Rs 450 | Rs 550 |
| 10 | Safety at work | Outer body temperature 300-350C | Outer body temperature 350-400C | Safe outer body temperature 10-20C |
| 11 | Expected service life | 4-5 years | 4-5 years | 7-8 years |
| 12 | Cleanliness of kitchen place | Smoke & soot generation | Smoke & soot generation | Less Smoke & soot generation |
| 13 | Heat loss to the environment | Heat loss to the environment | Heat loss to the environment | No heat loss to the environment |
| 14 | Portability | Portable | Portable | Portable |

**Table 2 Similarities and Comparison of cook stoves**

**4.1 Effect of Five Experimental Variables**

Five experimental variables were compared using a analysis of variance. The analysis of variance (ANOVA) was used to detect the effect of fuel consumed, burning rate, heat input per hour, heat input of stove, heat output of stove, thermal efficiency and power output. Analysis of data is observed highly significant of the parameters are heat input per hour and similarly parameter Heat input of stove. However other remaining parameters having no significant role in the all experiment due to less variability among the activities

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Stove performance is dependent of quantity of water used and the wood type. The other factors, stove type, the use of lids, size of wood had significant effect on emission at 95% the test. It is there for important in designing modified multi fuel cook stove emission testing method that these parameters are specified precisely.

The findings of the efficiency test results which are summarised above indicate that the modified multifuel cook stove performed better in combustion of wood and heat output to the pot. It is clear from the test results above that the effective heat transfer from the wood to the pot are the combustion process which releases heat and the second is transfer of heat to the pot. This combustion efficiency also has the added benefit of reducing emissions. On the other hand, the modified multi fuel cook stove achieved more complete combustion of the fire burnt hot and clean. The insulation around the fire box shielded the flame from the contact with cool outside air and the square shape of the combustion chamber allowed enough oxygen to participate in the reaction. It describes the relevance of the efficiency of each of the stove It highlights the important factors that influenced fuel and the type of wood stoves which are vital when planning any energy technology. Further importance of this study is that it has shown that modified multi fuel cook stove that standard comparisons of fuel saving efficiency can be made across all improved cook stoves. The average comparison for total energy efficiencies among all three cook stove model is shown in table for a typical set of operating parameters mentioned above. It is seen from the table that performance of all cook stoves model, the modified multifuel model cook stove is found to be much better than other type of cook stove model followed by Harsha model cook stove, the energetic performance of the Priyagni cook stove is found to be lowest.

**4.2 Economic Quantification of Fuel wood saving benefits of Modified multifuel wood stoves**

The Economic profitability of using modified cook stove is done in the study; the qualification of economic benefit has specially been calculated using the following economic ratios. The length of the payback period in the determined by the following three parameters: The price of the stove, fuel wood saving through the use of modified wood stove and Price of fuel wood. The payback period for using the cook stoves used in the study, the calculations in the table are according to the following formula: PPN= C/St, Whereas PPN = payback period for a new investment C= purchase cost of the improved modified cook stove, St= saving in expenditure for fuel wood during period. Use of 2 Kg of wood per day @ cost of Rs 11 per Kg of family of 5-6 persons

| Cook Stove | Purchase price | Saving in expenditure for wood monthly | Saving in expenditure for fuel wood day - | Payback period In months |
|---|---|---|---|---|
| Priyagni | Rs.350 | Rs 66 | Rs 2.2 | 3 months 3 days |
| Harsha | Rs.450 | Rs 79 | Rs2.64 | 3 months 15 days |
| Modified | Rs.550 | Rs 198 | Rs 6.60 | 2 months 7 days |

**Table 3 Payback period**

## 5. RECOMMENDATION FOR FUTUTRE RESEARCH

This research paper is essentially based on laboratory experimental data. The analysis of data observed highly significant parameters are of heat input per hour and heat input of stove. The analysis is partial in the sense that it looked at no specific effects on the variables in question i.e. effect of fuel consumed, burning rate, heat output of stove, thermal efficiency and power output.

The design principles of Dr Larry Winiarski may further apply to improve the stove efficiency. At present out of 10 principles only 6 principles were used to have better results, i.e. improve stove efficiency, saving of fuels and reduction in emission level as well as saving of time.

The following areas require further study; the design of portable cook stove to further improve stove efficiency from 35-45% and examination of other types of wood to determine whether the fuel woods, emission as an independent of wood type.

## 6. CONCLUSION

In this research study three different designed improved cooking stoves, multifuel modified, Harsha and Priyagni cooking stove were tested and compared in terms of efficiency. The main focus was on the new modified multifuel Harsha stove design, which is so far a prototype. This stove, which can be locally produced with local materials, consists of an insulated combustion chamber. As essential parameters for the stove test the ambient temperature and amount of water in the pot were detected. As expected, the efficiency and other parameters of the multifuel modified Harsha cook stove is in the range of 30-35 % better than from the Priyagni and Harsha cook stove.

The following conclusions are drawn.

(1) Both the efficiencies of Modified multi fuel is found to be the higher than that of rest of the two models, i.e.
. Performance of Modified multi fuel is found to be the best among the all three models.

(2) For all cook stove models, the energy efficiency is found to be much higher than that of energy efficiency, which can be explained in terms of the quality of energy gained in the hot water. The energetic performance of the Priyagni model cook stove is found to be the lowest whereas the energetic performance of the Harsha model and Modified multi fuel model cook stove are found to be much better.

(3) Modified cook stove was quite significant in comparison with the Priyagni and Harsha Stove of NPIC on average saved 30% of fuel wood per day. This was with the improvement in the combustion efficiency and the expenditure can be reduced by about 34 %.This is possible because of the application of design principles.

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