Methods to Improve Thermal Efficiency of Domestic Portable Solid Biomass Cookstove Working on Gasification Technology

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Abstract: In today’s world, the entire energy requirements are being fulfilled through non-renewable source of energy (mainly fossil fuels). The demand for these fossil fuels is increasing day by day at a rapid rate. Therefore there is a need of an alternative source of energy (renewable). Some of these energy sources are solar, wind, tidal, geothermal, biomass etc. which can be utilized to substitute the fossil fuels. The search for alternative fuels has come to a conclusion with solar energy and biomass being the frontrunners.

Due to lack of technology and awareness regarding biomass and its derivatives, this field has not been tapped up to its true potential. Hence we are utilizing biomass energy in the form of pellets (sawdust, garden waste) which can be used as a fuel to run cooking stove to replace fossil fuels (LPG). These pellets are burned using gasification processes a fuel in specially designed biomass cooking stoves. Currently there are many such stoves in the market but they are not energy efficient (>35%). Therefore we are working on developing a biomass cook stove which will be more energy efficient (as per BIS). The challenge in this field is not only to develop such a stove but it should also be technologically feasible, environmentally sustainable, economically viable and socially acceptable.

Keywords: Thermal efficiency, cook-stove, biomass, pellets, gasification, energy-efficient, renewable energy.

1. Introduction.

The greatest challenge the mankind is facing currently is the need for an alternative source of energy. The world energy sources are depleting due to ever increasing demand for fossil fuels. The demand for fossil fuels is of inelastic nature. The global conventional energy prices are increasing. Still the demand grows on day by day. The excessive use of these fossil fuels have affected environment as well.

The quest for alternative source of energy has led to the increase in the awareness regarding the use of renewable source of energy. One of the potential alternative sources of energy is biomass energy. The biomass can be compressed using suitable processes in the form of pellets and briquettes which can be used as a fuel. One such application where these biomass pellets can be used is the specially designed biomass cooking stove. These cooking stoves work on gasification process and produce almost smokeless flame with very less amount of emissions.

2. Problem Statement.

To increase the efficiency of biomass stove working on sawdust pellets as per BIS.

Objectives -
1. To develop and deploy improved biomass cook-stoves for providing cleaner cooking energy solutions in rural, semi-urban and urban areas using biomass as fuel for cooking.
2. To mitigate health problems of women and children using traditional chulha for cooking.
3. To avoid climatic changes by reducing the black carbon and other emissions resulting from burning biomass for cooking.

3. Literature Study.

3.1 Why improved cook stoves are needed in India?

The use of open fires and traditional stoves leads to incomplete combustion of fossil fuel, causing high Black Carbon (BC) emissions. Furthermore, open fires and traditional stoves have low combustion efficiency, leading to higher cooking times and inefficient use of fuel wood. Black carbon (BC) exists as particles in the atmosphere and is a major component of soot. Black carbon results from the
incomplete combustion of fossil fuels, wood and other biomass. Complete combustion would turn all carbon in the fuel into carbon dioxide (CO$_2$). In practice, combustion is never complete and CO$_2$, carbon monoxide (CO), volatile organic compounds (VOCs), organic carbon (OC) particles and BC particles are all formed. On a global basis, approximately 20% of black carbon is emitted from burning biofuels, 40% from fossil fuels, and 40% from open biomass burning. The largest sources of black carbon are Asia, Latin America, and Africa. Some estimates put that China and India together account for 25-35% of global black carbon emissions. [1]

3.2 Chemical composition of sawdust pellets
Wood pellets are made from dry sawdust compressed under high pressure and extruded through a die. The fuel used for the test is made up of sawdust and binder. It has 80-85% of sawdust and remaining 10-15% of binder. These pellets are uniformly sized, easy to store and cheaply available. They come in a range of sizes: for domestic and relatively small scale systems 6 or 8 mm is typical, while for larger systems 10 or 12 mm are common. The pellets used for the test trials were of 10 mm diameter.

![Sawdust Pellets](image)

<table>
<thead>
<tr>
<th>Table No.1 Properties of Sawdust Pellets</th>
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<tbody>
<tr>
<td>Parameter</td>
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<tr>
<td>Calorific Value(kcal/kg)</td>
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<tr>
<td>Ash Content (%)</td>
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<tr>
<td>Toxic</td>
</tr>
<tr>
<td>Density(kg per cu. m)</td>
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<tr>
<td>Ignition Time (sec)</td>
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<tr>
<td>Carbon Credits</td>
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<tr>
<td>Cost/kg (Rs.)</td>
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</tbody>
</table>

3.3 Thermal efficiency formulae of water boiling test

\[ w = \text{mass of water in vessel, in kg.} \]
\[ W = \text{mass of vessel with lid, in kg.} \]
\[ X_{\text{fuel}} = \text{mass of solid fuel consumed, in kg.} \]
\[ H_{\text{fuel}} = \text{net calorific value of solid fuel, in KJ/kg;} \]
\[ X_k = \text{mass of kerosene for ignition, in kg.} \]
\[ H_k = \text{calorific value of kerosene, in KJ/kg} \]

\[
t_1 = \text{initial temp of water} \\
t_2 = \text{final temp of water} \\
t_3 = \text{final temp of water in last vessel at the completion of test} \\
n = \text{total no. of vessels used} \\
C_w = \text{specific heat of water i.e. 4.186KJ/kg} \\
C_v = \text{specific heat of the material of the vessel i.e. of Aluminium = 0.896} \\
C_v \text{ of kerosene} = 10400\text{KJ/Kg} \\
\text{Water equivalent of Aluminium = 0.82 [2]} \\
\]

\[
H_{\text{out}} = \text{heat output of the stove i.e. heat utilized in KJ} \\
= ((n-1)\left(w*0.896*0.214+W*4.186}\right)\left(t_1-t_2\right) + \left(w*0.896*0.214+W*4.186}\right)\left(t_1-t_3\right)) \\
H_{\text{in}} = \text{heat input into the stove i.e. heat produced in KJ} \\
= \left[\left(X_{\text{fuel}}*4400\right) + \left(X_k*0.82*10400/1000\right)\right]*4.186 \\
\%
= \left[\left(\frac{H_{\text{out}}}{H_{\text{in}}}\right) * 100\right] \\
\]

3.4 Working Principle: Gasification Technology
Gasification is a two-stage reaction consisting of oxidation and reduction processes. These processes occur under sub-stoichiometric conditions of air with biomass. The first part of sub-stoichiometric oxidation leads to the loss of volatiles from biomass and is exothermic; it results in peak temperatures of 1400 to 1500 K and generation of gaseous products like carbon monoxide, hydrogen in some proportions and carbon dioxide and water vapor which in turn are reduced in part to carbon monoxide and hydrogen by the hot bed of charcoal generated during the process of gasification. Reduction reaction is an endothermic reaction to generate combustible products like CO, H$_2$ and CH$_4$ as indicated below.

\[
C + CO_2 \rightarrow 2CO \\
C + O_2 \rightarrow C_2O +H_2 \\
C + 2H_2 \rightarrow CH_4 \\
\]

Since char is generated during the gasification process the entire operation is self-sustaining.

In a Gasifier, the carbonaceous material undergoes several different processes:
1. The dehydration or drying process occurs at around 100 °C. Typically the resulting steam is mixed into the gas flow and may be involved with subsequent chemical reactions, notably the water-gas reaction if the temperature is sufficiently high.
2. The pyrolysis process occurs at around 200-300 °C. Volatiles are released and char is
produced, resulting in up to 70% weight loss for coal. The process is dependent on the properties of the carbonaceous material and determines the structure and composition of the char, which will then undergo gasification reactions.

3. The combustion process occurs as the volatile products and some of the char react with oxygen to primarily form carbon dioxide and small amounts of carbon monoxide, which provides heat for the subsequent gasification reactions. Letting C represent a carbon-containing organic compound, the basic reaction here is \( C + O_2 = CO_2 \).

4. The gasification process occurs as the char reacts with steam to produce carbon monoxide and hydrogen, via the reaction \( C + H_2O = H_2 + CO \). \(^{[3]}\)


1. Fill the combustion chamber up to its maximum capacity with pellets.
2. Add 10-15 ml of Kerosene for pre-ignition of pellets.
3. Ignite the pellets with match-stick or suitable equipment.
4. Turn on the fan and keep it at low speed.
5. Wait for 10-15 min till the flame bed is formed.
6. Regulate the fan speed according to the flame intensity.
7. After complete combustion of pellets wait till the cook stove is cooled completely.
8. Remove the ash and clinker with the help of tongs by removing the ash grate.
9. Clean the combustion chamber.

5. Design Parameters.

To increase the thermal efficiency the following parameters should be examined carefully and verified by conducting WBT mentioned by BIS.

1. Insulation:
The suitable insulation sustaining temperature upto 1200°C (flame temperature) should be selected and applied.
2. Air flow:
The optimum air to fuel ratio should be maintained at 6:1 for complete combustion of fuel. Accordingly the appropriate forced draft equipment (fan, blower) should be selected for air circulation.
3. Material of chamber:
The material of the chamber must be selected such that it should sustain flame temperature, it should have low thermal conductivity and should possess sufficient strength to avoid failure due to thermal and fatigue stress.

4. Secondary air flow pattern:
The secondary hole pattern should be selected such that sufficient secondary air is supplied to the producer gas for complete combustion. (For blue flame)
5. Flame to vessel distance:
The distance should be such that it provides necessary back pressure for gasification.
6. Pot Skirting:
Pot skirting should be provided to concentrate the flame tips towards the vessel which would reduce the unnecessary heat transfer.
7. Use of suitable biomass fuel pellets:
The fuel should have high calorific value, low ash content, low flash point, bulk density should be more and volatile matter should be less. \(^{[4]}\)

6. Conclusion.

By implementing above changes the thermal efficiency can be increased upto 5 – 7 % by conducting water boiling test as given by BIS (IS 13152 - Part1)

7. References.