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# Effect of Thermal Insulation on Thermal Efficiency of Portable Solid Biomass Cookstove

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**ABSTRACT**:In 21st century, most of the energy requirements are being fulfilled through fossil fuels (mainly non-renewable sources of energy). The demand for these fossil fuels is increasing day by day at an exponential rate. Therefore there is a need of an alternative, renewable energy source. 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 researched upto its true potential. Hence the utilization of biomass energy in the form of pellets (sawdust, garden waste, etc.) can be used as a fuel to run the cooking stove to replace conventional fuels (LPG). These pellets are ignited, which thereafter undergo gasification process and are used as a fuel in specially designed biomass cooking stoves. The thermal efficiency of these stoves is obtained by performing water boiling test (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. So as to meet these aspects, one of the most effective ways is to provide suitable thermal insulation to enhance thermal efficiency and to reduce thermal dissipation.

**KEYWORDS**:Renewable energy, biomass, pellets, gasification, cook-stove, thermal efficiency, water boiling test, BIS, thermal insulation.

## I. 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 an 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.

In order to design such energy efficient stoves, use of suitable thermal insulation is a must to enhance thermal efficiency and to reduce thermal dissipation. This can be achieved using appropriate insulators. A thermal insulator is a poor conductor of heat and has a low thermal conductivity. Insulation is used in buildings and in manufacturing processes to prevent heat loss or heat gain. Although its primary purpose is an economic one, it also provides more accurate control of process temperatures and protection of personnel. It prevents condensation on cold surfaces and the resulting corrosion. Such materials are porous, containing large number of dormant air cells.

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## II. LITERATURE REVIEW

### 2.1 Heat and Heat Transfer

There are many forms of energy conservation and this handbook is only concerned with the methods of conserving energy by means of thermal insulation. To change the temperature of an object, energy is required in the form of heat generation to increase temperature, or heat extraction to reduce temperature. Once the heat generation or heat extraction is terminated a reverse flow of heat occurs to revert the temperature back to ambient. To maintain a given temperature considerable continuous energy is required. Insulation will reduce this energy loss.

Heat may be transferred in three mechanisms: conduction, convection and radiation. Thermal conduction is the molecular transport of heat under the effect of a temperature gradient. Convection mechanism of heat occurs in liquids and gases, whereby flow processes transfer heat. Free convection is flow caused by differences in density as a result of temperature differences. Forced convection is flow caused by external influences (wind, ventilators, etc.). Thermal radiation mechanism occurs when thermal energy is emitted similar to light radiation.

Heat transfers through insulation material occur by means of conduction, while heat loss to or heat gain from atmosphere occurs by means of convection and radiation.

Heat passes through solid materials by means of conduction and the rate at which this occurs depends on the thermal conductivity (expressed in W/mK) of the material in question and the temperature drive.

In general the greater the density of a material, the greater the thermal conductivity, for example, metals has a high density and a high thermal conductivity. Materials, which have a low thermal conductivity, are those, which have a high proportion of small voids containing air or gas. These voids are not big enough to transmit heat by convection or radiation, and therefore reduce the flow of heat.

### 2.2 Thermal Insulation

Thermal insulation is defined as the method to reduce the heat transfer from one medium at high temperature to another medium at low temperature (may/may not be in contact) or vice-a-versa using materials having low thermal conductivity (W/mK).

The Insulation can be classified into three groups according to the temperature ranges for which they are used.

1. Low Temperature Insulations (up to 90 °C)

This range covers insulating materials for refrigerators, cold and hot water systems, storage tanks, etc. The commonly used materials are Cork, Wood 85% magnesia, Mineral Fibers, Polyurethane and expanded Polystyrene etc.

2. Medium Temperature Insulations (90 – 325 °C)

Insulators in this range are used in low temperature, heating and steam raising equipment, steam lines, flue ducts etc. The types of materials used in this temperatures range include 85% Magnesia, Asbestos, Calcium Silicate and Mineral Fibers etc.

3. High Temperature Insulations (325 °C – above)

Typical uses of such materials are super-heated steam system, oven dryer and furnaces etc. The most extensively used materials in this range are Asbestos, Calcium Silicate, Mineral Fiber, Mica and Vermiculite based insulation.[1]

2.2.1 Glass wool

Glass wool is an insulating material made from fibres of glass arranged using a binder into a texture similar to wool. The process traps many small pockets of air between the glass, and these small air pockets result in high thermal insulation properties. [2]

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Table 1: Glass wool Properties

| Parameter | Glass wool |
|---|---|
| Fibre length | Long |
| Density | 11 to 45 kg/m3 |
| Thermal conductivity | 0.032 to 0.044w/mK |
| Max working temp | 230°C |
| Melting temperature | 700°C |
| Tensile strength | High |
| Elasticity | High |
| Applications | Piping and household |

Table 1 shows the properties of glass wool. It depicts that; it can be used upto 230°C temperature in applications like industrial piping and some household insulation. Benefits of using this insulation in the applications are having high tensile strength and elasticity.

### 2.2.2 Rockwool

Mineral wool (or stone wool) is a non-metallic, inorganic product manufactured using stone/rock (volcanic rock, typically basalt or dolerite) together with blast furnace or steel slags as the main components (typically 97%). The remaining 2-3% organic content in the product as sold is generally a thermosetting resin binder (adhesive) and a little oil.[3]

Table 2: Rockwool Properties

| Parameter | Rockwool |
|---|---|
| Fibre length | Short |
| Density | 30 to 200kg/m3 |
| Thermal conductivity | 0.035 to 0.039w/mK |
| Max working temp | 750°C |
| Melting temperature | 1000°C |
| Tensile strength | Low |
| Elasticity | Low |
| Applications | HVAC and solar |

Table 2 shows the properties of rock wool. The maximum temperature it can sustain with its thermal conductivity is upto 750°C. As it has comparatively high temp range, it is widely used in the HVAC industry and new upcoming renewable energy field, solar applications .It has low tensile strength and elasticity as compared to glass wool.

### 2.2.3 Calcium Silicate

Calcium silicate is used to insulate high-temperature pipes and equipment and for fire endurance applications. It is manufactured and sold in three different forms: preformed block, preformed pipe, and board.[4]

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Table 3: Calcium Silicate Properties

| Parameter | Calcium silicate |
|---|---|
| Structure | Granules |
| Density | 220 kg/$m^3$ |
| Thermal conductivity | 0.06 W/mK |
| Max working temp | 650°C |
| Melting temperature | 900°C |
| Applications | Power plants, refineries |

Table 3 shows properties of the calcium silicate as an insulator. Due to its medium working temperature range it is used in industries like refineries and power plant applications. Compared to glass wool and rock wool, it has slight higher thermal conductivity which leads to slight low applicative material.

### 2.2.4 Cerawool Blanket

Cerawool blanket is produced from exceptionally pure oxides of alumina and silica using the spinning process. The resultant quality spun fibers have been optimized for high handling strength, with on average the highest tensile strength of any Thermal Ceramics ceramic fiber blanket. Cerawool blanket is available in a wide variety of densities and sizes. Cerawool blanket offers excellent handle ability and high temperature stability which allows it to meet a wide range of hot face and back up insulation applications in furnaces, kilns and other equipment requiring high temperature heat containment.[4]

Table 4: Cerawool Properties

| **Properties** | **High Temp.** | **Regular Temp.** | **Low Temp.** |
|---|---|---|---|
| Maximum use temperature, ºC | 1400 | 1260 | 980 |
| Dimensions, mm | Width:610,1220<br>Length: 7620 | | |
| Density, kg/$m^3$[lbs./$ft^3$] | 64, 96 and 128 [4, 6 and 8] | | |
| Thickness, mm | 13, 19, 25, 38 and 50 | | |
| Thermal Conductivity for 128 kg/$m^3$ at mean temp. of 550ºC, W/mºK[BTU-in/hr$ft^2$ºF] | 0.11 [0.76] | | |
| Applications | Crude oil, reformer and pyrolysis heater linings, high temperature pipe, duct and turbine insulation, tube seals, gaskets and expansion joints, heat treating and annealing furnaces, reheating furnaces, soaking pit covers and seals, furnace hot face repairs, kilns and kiln car insulation and seals. Stress relieving insulation, ovens and stack linings. Boiler and air preheater insulation. Fire protection applications etc. | | |

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Table 4 shows the properties of Cerawool as an insulator. It has wide temperature sustaining range on higher side. The insulation implemented on the modified stove was selected based on this data sheet, having density 64 kg/m3 and 610 mm of width. It is widely used in furnace applications.

The apt material for the biomass cook stove should be selected from the above given tables.For solid biomass cook stove using sawdust pellets as a fuel, Cerawool blanket is selected.

### 2.3 Critical Thickness of Insulation

The critical radiuseffect is an interesting phenomenon of heat transfer in insulated solids. Insulating a cylinder or sphere larger than the critical radius has the expected effect of retarding heat loss. If the radius of cylinder or sphere is smaller than the critical radius, adding insulation will actuallyincrease heat loss .The additional insulation increases the conduction resistance of theinsulation layer but decreases the convection resistance of the surface because of the increase in the outer surface area for convection. Therefore the net heat transfer from the pipe may increase or decrease, depending on which effect dominates. Critical radius is independent of radius of circular pipe/tube. It depends on conductivity of insulation ‘k’ and the convective heat transfer coefficient ‘h’, between exposed surface of insulation and its surroundings. The value of the critical radius ‘Rc’ will be the largest when conductivity of insulation ‘k’is large and convection heat transfer ‘h’ is small.

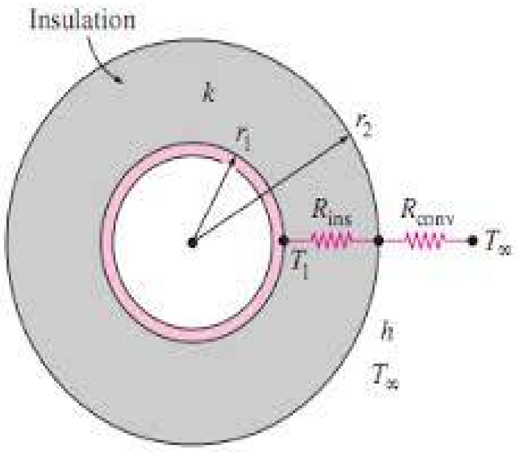


Fig.1: Critical Radius of Insulation

Figure 1 illustrates the critical radius of insulation around a cylinder, representing total convective and insulated resistance. The radii, r1 and r2 represent cylinder and insulator respectively.

Notations:

1. Convective coefficient of heat transfer (W/m^2*K) = h
2. Conductive coefficient of heat transfer (W/m*K) = k
3. Critical Thickness of Insulation (mm) = $T_c$

Formula:

Critical Thickness of Insulation ($T_c$) = k/h

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## III.OBSERVATIONS AND CALCULATIONS

The following observation and calculations were carried out in order to find out the total heat transfer.
Notations:
1. $R_{outer}$ = Radius of Outer Cylinder
2. $R_{inner}$ = Radius of Inner Cylinder
3. $T_{out}$ = Temperature of Outer Cylinder
4. $T_{in}$ = Temperature of Inner Cylinder
5. σ = Stefan Boltzmann's Constant
6.ε= Emissivity Constant

Formulae:
1. Conductive resistance (K/W) = $\frac{[\ln (R_{outer}/R_{inner})]}{(2*\Pi*L*K)}$
2. Convective resistance (K/W) = $\frac{1}{(h*2*\Pi*R*L)}$

3. Heat dissipated by Radiation ($W_1$) = $\sigma*\varepsilon*Area*T^4$

4. Heat dissipated by Conduction and Convection ($W_2$) = $\frac{(T_{in-}T_{out})}{R_{(convective)} + R_{(conductive)}}$

5. Total Heat dissipated= $W_1 + W_2$

6. Efficiency (%) = $\left[\frac{(\text{Heat input} - \text{Total Heat Dissipated})}{(\text{Heat input})}\right] *100$

## IV.EXPERIMENTAL RESULTS

Results of heat transfer calculations for various thicknesses of insulations are as follows:

### 4.1 Theoretical Calculations for Heat Transfer

Table 5: Theoretical heat transfer:

| Sr. No. | Insulation thickness (mm) | Heat Generated ($W_g$) | Total heat dissipated ($W_1 + W_2$ ) | Net heat utilized ($W_u$) | Efficiency (%) |
|---|---|---|---|---|---|
| 1 | 0 | 3860 | 2218.68 | 1461.32 | 39.71 |
| 2 | 6 | 3860 | 1920.23 | 1759.77 | 47.82 |
| 3 | 12 | 3860 | 1629.51 | 2050.49 | 55.72 |
| 4 | 15 | 3860 | 1610.74 | 2069.26 | 56.23 |
| 5 | 25 | 3860 | 1578.36 | 2101.64 | 57.11 |

Table 5 represents the theoretical heat transfer calculations calculated by taking corresponding temperatures on the modified stove with increasing thickness of insulation around it. It is clear from the table that, heat dissipation decreases with increase in the insulation thickness.

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### 4.2 Practical Calculations for Heat Transfer

Table 6: Practical heat transfer:

| Sr. No. | Insulation thickness (mm) | Heat Generated ($W_g$) | Total heat dissipated ($W_1 + W_2$ ) | Net heat utilized ($W_u$) | Efficiency (%) |
|---|---|---|---|---|---|
| 1 | 0 | 3860 | 2379.49 | 1301.00 | 35.34 |
| 2 | 6 | 3860 | 2221.99 | 1458.01 | 39.62 |
| 3 | 12 | 3860 | 2071.11 | 1608.89 | 43.72 |
| 4 | 15 | 3860 | 1959.24 | 1720.46 | 46.76 |
| 5 | 25 | 3860 | 1943.41 | 1736.59 | 47.19 |

Table 6 shows the variation of heat dissipation and the thickness of insulation. The insulation when increased around the chamber reduces the heat dissipation and the efficiency is calculated according to the BIS. The net heat utilized and thus efficiency is calculated using experimental procedure and results.

### 4.3Comparison of Actual and Theoretical Heat Transfers according to Thickness of Insulation

Fig.2 Actual and Theoretical Heat Transfer vs Thickness of Insulation

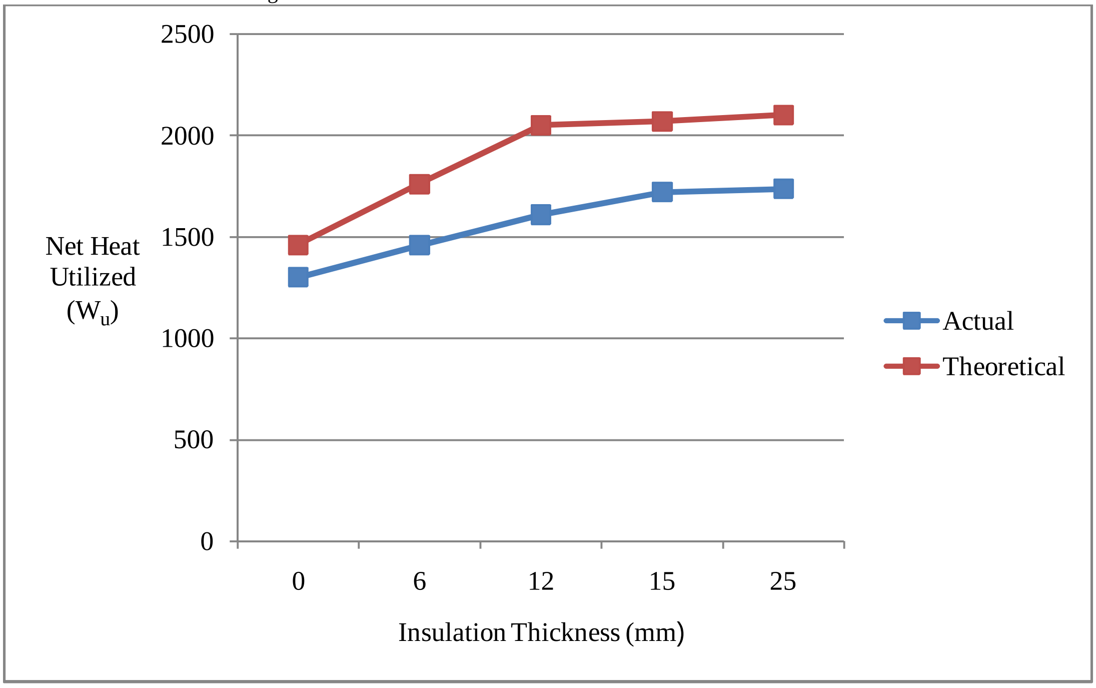


Fig.2 illustrates the comparative graph of net heat utilized by both the ways versus the thickness of insulation. The nature of graph shows that, net heat utilized in both the methods increases with increase in the thickness of insulation.

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### 4.4Comparison of Cost of Insulation according to Thickness of Insulation

Fig.3 Cost of Insulation vs Thickness of Insulation

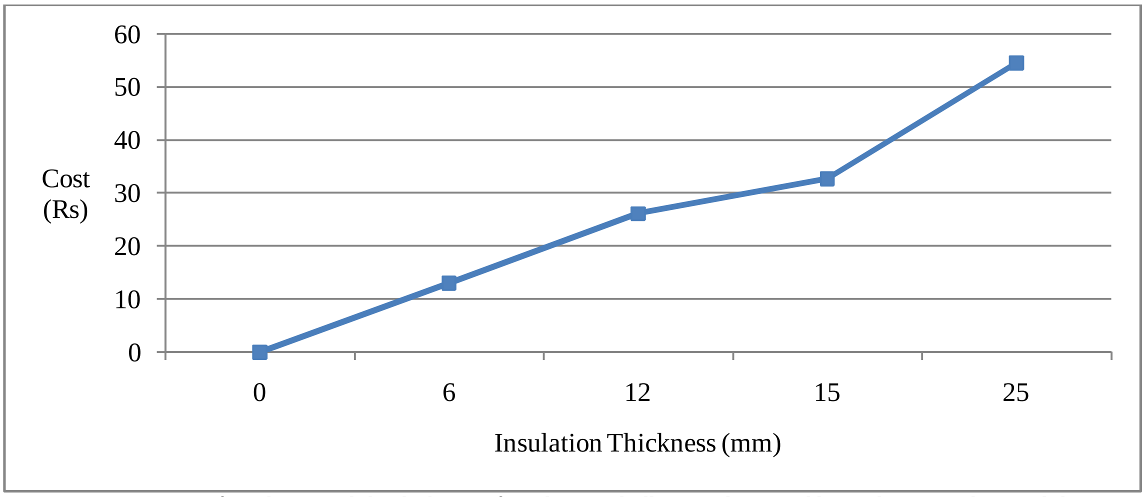


Fig.3 shows increment in cost of insulation and the thickness of insulation. Ideally according to table 5and 6, it can be noted that using 25 mm thickness of insulation we get maximum efficiency. But this graph shows that it is not economically viable to apply the insulation of such thickness due to its high cost (about twice as of 15 mm thickness cost). Hence it is desirable to apply 15 mm of insulation thickness instead of 25mm.

## V. CONCLUSIONS

1. With increase in the thickness of insulation, total resistance first decreases, attains minimum value and then increases gradually.
2. The purpose of insulation is to reduce the total unwanted radial heat dissipation. Hence, the optimum thickness of insulation should be greater than critical thickness of insulation and should be economical.
3. Providing greater thickness of insulation is not economically viable due to its high cost.(Refer Fig 3)

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