CHAPTER 5

BRIQUETTING OF COIRPITH

5.1 INTRODUCTION

Many developing countries are keen in utilizing agricultural residues for the useful purpose, as it is possible to produce energy and to develop clean environment. The agricultural residues are considerable in quantity and it can be effectively used as a fuel. Some of the major agricultural residues are rice husk, coffee husk, coir pith, jute sticks, bagasse, groundnut shells, mustard stalks and cotton stalks. Sawdust is another milling residue available in huge quantity. The major problems associated with these residues are transportation, storage, and handling. Further, direct burning of loose biomass in conventional grates has the problems of very low thermal efficiency and environmental pollution. In order to overcome these difficulties, briquetting is one of the better options as it solves the transportation, storage and handling problems. The combustion efficiency has also been increased considerably and reduces the pollution problems.

The process of compaction of residues to higher bulk density is called densification. The briquetting process consists of applying pressure with or without binding material in order to convert as a compact agro-mate. Agricultural residues can be briquetted by overcoming its elastic property by the application of high pressure. Generally the briquettes of agricultural residues exhibit relaxation of its density after the removal of applied pressure. The density after complete relaxation of such briquettes is referred as Relaxed
Density (RD). Moisture content and pressure influence the process of densification.

### 5.2 REVIEW OF LITERATURE

The briquetting process and its characteristics on biomass was studied and reported by different researchers. Ooi Chin and Siddiqui (2000) have studied biomasses like sawdust, rice husk, peanut shell, coconut fiber and palm fiber on its densification and described its characteristics. They observed that the maximum relaxation occurred up to 10 minutes after the compaction pressure released and it continues at the reduced rate for about 2 hours. Further the relaxation decreases as the die pressure increases. But, the moisture content of these biomasses is not stated. A logarithmic relationship (Equation 5.1) between die pressure and the RD was also proposed by them as shown below:

\[ RD = (a \ln P) + b \quad (5.1) \]

where
- \( P \) - Die pressure in bar
- \( RD \) - Relaxed density in \( \text{kg/m}^3 \)
- \( a, b \) - Empirical constants

They proposed values of constants ‘a’ and ‘b’ for various biomasses are listed in Table 5.1.

Various researchers reported the effects of moisture content on densification of different biomasses. Wamukonya and Jenkins (1995) have produced relatively high quality briquette from agricultural residues and wood wastes by hydraulic press with optimum moisture content of 12 to 20% (wb). O'Doghtery and Wheeler (1984) tested straw wafer with varying moisture content and reported that high relaxation ratio is beyond 35% of moisture
content. Srivastava et al (1981) also noted for the same straw wafer, the RD increases with moisture content ranges from 11% to 23% and observed that the maximum durability associated with 11% of moisture content.

Table 5.1  Relationship Between Die Pressure and RD for Various Biomass Briquettes

<table>
<thead>
<tr>
<th>Type of biomass</th>
<th>a</th>
<th>b</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sawdust</td>
<td>78.3</td>
<td>185.6</td>
</tr>
<tr>
<td>Rice husk</td>
<td>20.5</td>
<td>344.1</td>
</tr>
<tr>
<td>Peanut shell</td>
<td>36.5</td>
<td>415.4</td>
</tr>
<tr>
<td>Coconut fiber</td>
<td>60.6</td>
<td>54.1</td>
</tr>
<tr>
<td>Palm fiber</td>
<td>67.1</td>
<td>1.3</td>
</tr>
</tbody>
</table>

Test reports on hay pellets were proposed by Bellinger and McColly (1961) as the moisture content decreases from 21% to 5% causes the increase in energy requirement for compression. Gustafson and Kjelgaard (1963) noted decrease in RD with 28 to 44% variation of moisture content in the same hay pellets.

Mohsenin and Zaske (1975) reported in their findings on alfalfa pellets with varying moisture content of 8 to 25% and observed high durability with the moisture content of 19%. Orth and Lowe (1977) reported that grass briquettes produced through extrusion die showed the highest density in the moisture content range of 14 to 16% (wb).

A study by Bilanski et al (1985) found that consolidated wafers from grasses and alfalfa at 13.3% (wb) moisture content had maximum cohesive (tensile) strength.
5.3 EXPERIMENTAL

5.3.1 Determination of Moisture Content

The moisture content in wet basis ($m_c$) of coir pith was investigated by adapting the ASAE S358.2 DEC99 moisture measurement method. A sample contains 30 grams of coir pith was taken for testing. The weight of the moist sample with container was found out using an electronic balance. Then, the sample was dried in an oven at 103°C for 24 hours then the dried material with container was placed in desiccators and allowed to reach room temperature. The sample was then weighed, and the moisture content in the sample thus found out on wet basis by the following equation (Equation 5.2).

$$m_c = \frac{\text{Initialweight} - \text{Finalweight}}{\text{Initialweight}} \quad \text{(5.2)}$$

Initially, the samples with different unknown moisture content were taken. Then it is brought to the desired level by adding moisture or drying the samples. Samples with different moisture content of 10%, 14%, 16%, 18% and 20% on wet basis were prepared and used for the densification study. A lot containing three same types of samples were tested simultaneously and the average percentage of moisture content is assumed for that lot. The electronic balance used for the test purpose has the accuracy of 0.001gm. Thermocouple used in the furnace having accuracy of ± 0.5°C was used to measure the temperature. The digital clock used for measuring time has an error of 1 sec per year.

5.3.2 Determination of Porosity

Porosity is defined as the ratio of the volume of voids to the total volume (voids plus solid). The bulk porosity of the coir pith was determined by pressure bottle method (Mohsenin 1978) and the apparatus used for this purpose is shown in Figure 5.1. The bottle-1 was completely filled with the
coir pith. The valves 2, 3 and 4 were closed. By opening the valve-1 air was blown into the bottle-2 and the valve-1 was closed. The air pressure inside the bottle-2 was measured by ‘U’ tube manometer fitted to this experimental set up by opening the valve-2 and the value is noted as ‘P₁’. Then the valve-4 was opened and sufficient time was allowed for the air in bottle-2 to fill the porous space available in bottle-1. Now the pressure shown by the manometer was noted as ‘P₂’. The porosity (Pₒ) was calculated by the Equation (5.3).

\[ Pₒ = \frac{(P₁ - P₂)}{P₂} \]  

(5.3)

The difference in liquid level of the manometer was measured using digital height gauge of accuracy 0.01mm. The experiment was repeated for three times and the average values were recorded.

![Diagram showing the setup for porosity measurement](image)

**Figure 5.1 Porosity Apparatus**

### 5.3.3 Determination of Bulk Density

Bulk density of coir pith was determined by gently filling in a cylindrical jar of known volume with the material and weighed. The knowledge of bulk density will be useful while handling the material from the coir industries to the processing units and also for the compaction process.
The electronic balance was used to measure the weight that will measure nearest to 0.001gm. The volume of the coir pith was measured by a graduated cylindrical jar. In order to check the accuracy of the jar, certain quantity of water was taken in the jar and it was weighed in the electronic balance. The specific volume of water was verified and found correct. The bulk density was calculated for three times and the average value was recorded. The bulk density and porosity of coir pith at different moisture level are given in Table A1.1.

5.3.4 Compression Test

In order to compress the samples, a press (Figure 5.2) consists of die with three cylindrical holes and plungers were used. Three samples with same moisture content were taken in the die and compressed to the order of 193.61 to 322.67 bar using compression testing machine (Figure 5.3). The compression testing machine was calibrated and it has ±1% limit for error. Briquettes (Figure 5.4) were taken out and allowed for free relaxation. It is found that the free relaxation cease after 24 hours. The relaxed size of the briquettes was measured with the digital vernier caliper (accuracy ± 0.01mm) and RD was calculated by taking average value of three-test specimen.
5.4 RESULTS

5.4.1 Effect of Moisture Content on Bulk Density of Coir Pith

The bulk density of the coir pith under different levels of moisture content is shown graphically in Figure 5.5. It was seen that the bulk density increased with increase in moisture content. Sreenarayanan and Chattopadhyay (1986), reported that the bulk density was increasing with increase in moisture content for rice bran. A relationship (Equation 5.4) between the bulk density of coir pith and moisture content was developed and
furnished below. The correlation coefficient for the proposed model (R^2 value = 0.9973) indicates that the model has good fit.

\[ B_d = 0.0017 \, m_c + 0.1037 \]  
(5.4)

where \( B_d \) - Bulk Density in gm/cc
\( m_c \) - Moisture Content in %wb

### 5.4.2 Effect of Moisture Content on Porosity of Coir Pith

The porosity of coir pith under different levels of moisture content is shown graphically in Figure 5.5. It was seen that the porosity of the coir pith was decreased with increase in moisture content. Viswanathan et al (1990) reported similar results for minor millet grains.

![Figure 5.5](image.png)

**Figure 5.5** Effect of Moisture Content on Bulk Density and Porosity of Coir Pith

A relationship (Equation 5.5) between the porosity of coir pith and moisture content was developed and furnished below. The correlation
coefficient for the proposed model \((R^2\ \text{value} = 0.9997)\) indicates that the model has good fit.

\[
P_o = 0.8681 - 0.0029 \ m_c
\]  \hspace{1cm} (5.5)

where  
\(P_o\) - Porosity  
\(m_c\) - Moisture Content in %w.b.

### 5.4.3 Effect of Die Pressure on Relaxed Density

The coir pith biomass with various percentage of moisture content was taken for testing. Moisture content of the sample varies as 10\%, 14\%, 16\%, 18\% and 20\% whereas the pressure applied varies as 193.61, 225.87, 258.14, 290.40 and 322.67 bar. A lot contains three samples in each percentage of moisture with particular pressure was prepared and RD was measured for each sample. Hence, totally 75 samples were taken for study and their results are given in Table A1.2.

Using the data given in Table A1.2 an expression has been developed for the Relaxed Density of coir pith briquette in terms of percentage moisture content of coir pith and die pressure as below:

\[
RD = 20.47 \ m_c + 1.34 \ \ P - 78
\]  \hspace{1cm} (5.6)

The \(R^2\) value of the Equation (5.6) is 0.93858. The Equation (5.6) satisfies the observed value with \(\pm 8\%\).

The graphs were plotted between the die pressure and RD of coir pith briquettes for various moisture content which is shown in Figure 5.6.
Figure 5.6  Effect of Die Pressure on Relaxed Density of Coir Pith Briquette

The Figure 5.6 reveals that the RD is increasing with respect to die pressure. At higher pressure material is heated due to friction and the bonding between the particles becomes strong. Further increase in die pressure is not contributing effectively for increasing its RD after 258.14 bar.

5.4.4  Effect of Moisture Content on Relaxed Density

O’Dogherty and Wheeler (1984) have proposed a relationship between the relaxed density (RD), and the moisture content ($m_c$) in wet basis (wb) for the different biomasses as show in Equation (5.7).

$$\text{RD} = c \exp (d \ m_c)$$

(5.7)

where ‘c’ and ‘d’ are empirical constants. Ooi Chin and Siddiqui (2000) have verified the relationship for the different biomasses and proposed the values of ‘c’ and ‘d’ for different biomasses, which are listed in the Table 5.2.
Table 5.2  Relationship Between Moisture Content and RD for Various Biomass Briquettes

<table>
<thead>
<tr>
<th>S.No.</th>
<th>Type of briquettes</th>
<th>‘c’</th>
<th>‘d’</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Saw dust</td>
<td>415.2</td>
<td>0.43</td>
</tr>
<tr>
<td>2</td>
<td>Rice husk</td>
<td>608.4</td>
<td>1.82</td>
</tr>
<tr>
<td>3</td>
<td>Peanut shell</td>
<td>612.1</td>
<td>-0.24</td>
</tr>
<tr>
<td>4</td>
<td>Coconut fiber</td>
<td>200.1</td>
<td>1.42</td>
</tr>
<tr>
<td>5</td>
<td>Palm fiber</td>
<td>349.5</td>
<td>1.72</td>
</tr>
</tbody>
</table>

Using the results of coir pith briquettes given in Table A1.2 another graph between moisture content and RD for different die pressure was plotted and it is shown in the Figure 5.7. The graph reveals that the RD increases up to 18% of moisture content after that the change in RD is minimum.

![Figure 5.7 Effect of Moisture Content on Relaxed Density of Coir Pith Briquette](image.png)
ENERGY REQUIRED FOR DENSIFICATION

The energy required to form briquettes is one of the important factors. A number of investigators have studied densification by compressing raw materials inside a cylinder with a piston (Butler and MacColly 1959, O’Dogherty and Wheeler 1984). In such cylinders as the pistons moves forward the raw material undergoes compaction and the force needed to move the piston further increases. The area under the force-displacement curve gives the energy required for compaction. The specific densification energy requirement (energy requirement per unit mass) can be found by dividing the total work requirement by the mass of the compacted raw material.

Specific energy required for compression in closed die is much smaller than extrusion through tapered dies. This is because in a tapered die a component of the axial compressive force acts normally to the wall, with much greater resulting frictional force than for a parallel sided die, where friction results only from the wall forces resisting lateral strain of the material. In piston press the power consumption is 50 kWh/ton (Grover and Mishra 1996).

Therefore, from the literature it is observed that the power required for producing 1 kg coir pith briquette by piston press is 0.05 kWh. It means that 600 kJ of heat energy is required for producing 1 kg of the briquette by assuming 30% efficiency for the conversion of heat energy in to electrical energy. The calorific value of coir pith is 12.6 MJ/kg. Hence, 4.76% of calorific value of the coir pith is required for producing the coir pith briquette.

Volume Reduction

The bulk density of coir pith with 18% of moisture is 0.135 gm/cc. The bulk density of coir pith briquette of size 25mm diameter and 25 mm
length thus produced is 0.39 gm/cc. Therefore, the volume reduction is 2.9 times.

5.6 ENERGY REQUIRED FOR TRANSPORT

Trucks are used to transport briquette from the briquetting plant to the place of utilization. The usual truck size is 18’ × 8’ × 7’. The bulk density of the briquette is 0.39 gm/cc. Therefore; approximately 10.614 tones of briquette can be transported in a single trip. The approximate fuel consumption of the truck for 10 km travel is 3 liters of diesel or 2.55 kg of diesel by taking the specific gravity of diesel as 0.85. The calorific value of diesel is 45 MJ/kg. Thus the amount of energy to be spent for transporting 1 kg of briquette for 1 km is 1.08 kJ. The calorific value of coir pith is 12.6 MJ/kg. Therefore, the amount of energy required for transportation of coir pith briquette per kilometer is 0.00857% of its calorific value. The transport cost for all the biomass is almost the same. It is approximately Rs.3/kilometer. The maximum distance up to which the coir pith can be transported is depends upon the contribution of fuel cost in the cost of production of electricity.

5.7 CONCLUSION

The briquetting of coir pith was carried out with various pressures and moisture content. From the result it is evident that it can be briquetted effectively at the pressure of 258.14 bar and the moisture content of 18%. A model has been developed for RD in terms of moisture content and die pressure. The densification process consumes the energy equivalent to 4.76% of the heat value of the coir pith whereas the transportation of coir pith briquettes consumes 0.00857% of its calorific value per kilometer. By briquetting the volume of coir pith can be reduced to 2.9 times. Therefore, the gasifier size can also be reduced by approximately 3 times.