Determining Optimum Parameters for Manual Compaction of Loose Biomass

Daniel M. Madyira
Department of Mechanical Engineering Science
University of Johannesburg
Johannesburg, South Africa
dmadyira@uj.ac.za

Abdullah Kaymakci
Department of Mechanical Engineering Science
University of Johannesburg
Johannesburg, South Africa
abdullahkaymakci@gmail.com

***Abstract* - Significant amounts of loose biomass are produced annually through agricultural and forestry activities. It is common practice to burn these loose biomass deliberately after harvesting or in accidental veld fires in the case of forestry. This energy could be harnessed for cooking and heating. The challenge with the use of loose biomass lies in its low density and hence low energy content which can be improved through densification. The aim of this paper is to determine the optimum densification parameters that can be used to develop manual briquetting technologies to empower poor communities to harness the energy available in loose biomass that they dispose annually. This forms part of a larger project aimed at developing off grid biomass value chain technologies. Using loose grass and loose leaves, experimental data revealed an optimum density of 1250 kg/m^3 and a corresponding densification pressure of 40 MPa. In addition, a comparison of the thermal profile of solid round and round hollow briquettes showed more superior performance of the round hollow briquette based on recorded maximum combustion temperatures. Briquettes with a hole in the middle are therefore preferred to solid briquettes.**

Keywords— Briquetting, Loose biomass, Manual, Optimum parameters Introduction

I. INTRODUCTION

Shortage of energy is becoming a major hindrance to the economic development of many countries. South Africa is currently in the middle of a severe energy shortage characterized by almost daily load shedding with severe implications on industrial and mining output [1]. This can lead to job losses and social unrest. In addition, the majority of Sub-Saharan communities (80%) depend on round wood as a source of energy for cooking and heating [2]. Most of this round wood is harvested unsustainably from natural forests leading to deforestation and desertification. Vegetation loss has negative effects on global warming and climate change. This is despite the large amounts of loose biomass that is produced annually through agricultural and forestry activities that can be harvested sustainably as a source of energy. Common such loose biomass sources include maize leaves, stalks and cobs; groundnut leaves, stalks and shells and natural residues including veld grass and tree leaves. The potential for use of biomass, especially loose biomass, as a sustainable energy source remains largely unexploited [3].

The major challenge in harnessing energy from loose biomass is their low energy density. Recent work by Shuma, Madyira, Oosthuizen and Makonese [3] revealed that the calorific values of most loose biomass available in a rural location in the Limpopo Province of South Africa peaked at 20 MJ/kg for ground nut shells and eucalyptus saw dust compared to 40 MJ/kg [4] for common household coal. Other common loose biomass materials such as yellow thatching grass, sugar cane leaves and Mopani tree leaves recorded calorific values of about 17 MJ/kg. One, therefore, requires large volumes of such materials for cooking or heating during which the combustion occurs quickly and in an uncontrollable way. In addition, loose biomass is difficult and expensive to handle or store due to its low density. There is therefore a need to improve the energy density of loose biomass to improve its chance of adoption as a source of energy by communities that are currently relying on round wood for energy. This can be done through densification by compaction to produce biomass briquettes. For low income communities, densification technologies have to be affordable, appropriate and off grid.

The success of loose biomass briquetting is affected by many parameters that include nature of material being briquetted, moisture content, process temperature, and pressure [6], [7]. Densification technologies for off-grid may require different parameters to electrical powered systems as they are largely manually operated. Manual systems are also preferable to ensure the overall sustainability and carbon neutrality of the biomass processing value chain. For example solar drying technologies are currently being developed to ensure that the drying process remains off grid and sustainable [8]. There is therefore a need to understand the manual processing parameters that affect the performance of loose biomass briquetting in order to develop effective solutions for off grid rural communities.

This work is, therefore, focused on determining the optimum operating parameters that can be implemented in the briquetting of loose biomass using manual processes. If successful, this will lead to utilization of loose biomass as a source thermal energy.

II. MATERIALS AND METHODS

A. Aim of the Experiments

The aim of the experiments was to determine the variation of biomass density with compaction pressure, the effect of the compaction displacement on density and to compare the thermal profile of solid round briquettes with solid round briquettes with center holes.

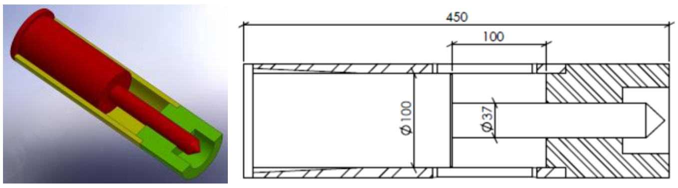
B. Materials

Loose biomass material used for this investigation was composed of loose grass and gum tree leaves. These were dry materials collected in the veld in Johannesburg, South Africa. In general the grass was found to have higher moisture content compared to the leaves.

C. Equipment

A special cylindrical mold was developed to compact the loose biomass. The design of the mold allowed monitoring of the overall displacement of during compaction. The mold was made of mild steel with an inside diameter of 100 mm. Provision was made for inclusion of a cylindrical rod inside to create a hollow briquette. This was done by using a separate set of piston and base as shown in Fig 1. The overall length of the mold was 450 mm.

The mold was then mounted onto a standard hydraulic press as shown in Fig. 2. The hydraulic press was a 55 ton heavy duty Carolina Press with a manually operated hydraulic pump as seen on the top right corner in Fig. 2. It had a pressure gauge allowing monitoring of compaction pressure.



(a) (b)

Fig. 1: Biomass compaction mold (a) 3D model (b) Dimensions

Fig. 2: 55 ton heavy duty Carolina hydraulic press with biomass compaction mold

Thermal profile during combustion were measured using FLIR infrared thermal imaging camera.

D. Procedure

To determine the relationship between density and compaction pressure, equal amounts (by volume) of shredded grass and leaves were mixed and placed in the mold to the upper fill level. The piston was placed in the mold and the initial displacement (compaction) of the biomass recorded. The mold was then placed in on the press and the loaded in increments of 2 tons while recording the pressure and the displacement. This data was used to determine the variation of density with pressure. This was done for both round solid briquettes and round solid briquettes with central holes.

To determine the thermal profile of the various briquettes produced, the briquettes were first dried in the sun and ignited with the aid of a fire lighter. Each was allowed to burn for five minutes, transferred to a cold surface and thermal images taken to study the maximum temperatures and thermal profiles.

III. Results and Discussion

A. Compaction Performance

The performance of the compaction process with varying compaction pressure is illustrated in Fig. 3. Fig. 3(a) shows poor bonding of the loose biomass due to low pressure for a briquette with a central hole while Fig. 3(b) shows a well formed round solid briquetted. The shows that elevated pressure results in significant improvement in briquetted formation.

(a) (b)

Fig. 3: Compaction progression (a) Low pressure with hole (b) High pressure solid

B. Optimum Pressure

The variation of density with compaction pressure is shown in Fig. 4.

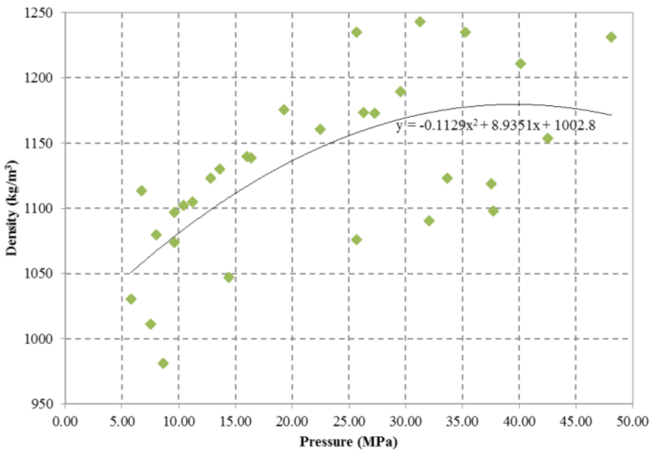


Fig. 4: Effect of pressure on biomass briquette density

It is clear that the curve initially has a steep slope and then, at around 20 MPa, it begins flattening out. If the trend line is ignored and only the data points are observed, it can be seen that from 25 to 48 MPa none of the data points exceed 1250 kg/m^3. This suggests the existence of a limit to the density that can be achieved through compaction of the biomass and this shows that the saturation pressure occurs just above 35 MPa.

Fig. 5 shows the variation of density with displacement. In this case different quantities of biomass were used. This was done to find the effect, is any, of the biomass quantity on the experiments. Thus data points on the left side of Fig. 5 are for lower quantities of biomass. The first point to note is that the final stage of the compaction occurred for about 5 mm of displacement compared to 80 mm for the first stage. Secondly the maximum density does not seem to be significantly affected by the amount of biomass used. Both low and high quantity biomass test reveal an optimum density of 1250 kg/m^3.

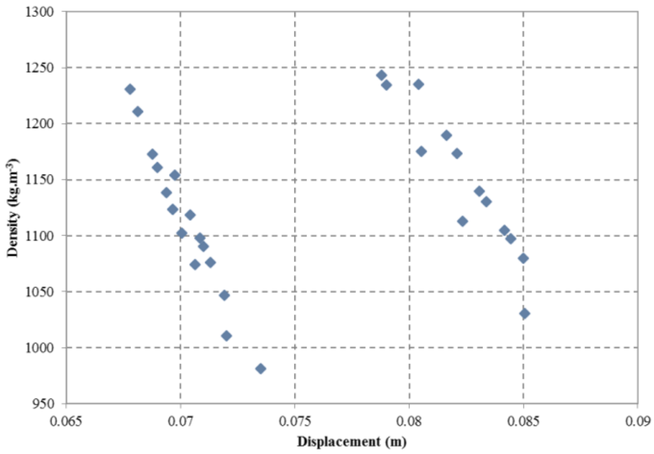


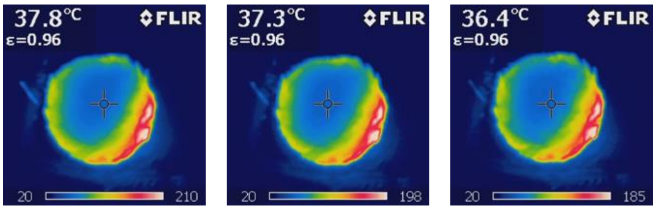
Fig. 5: Effect of displacement and initial biomass quantity on briquette density

C. Thermal Profile

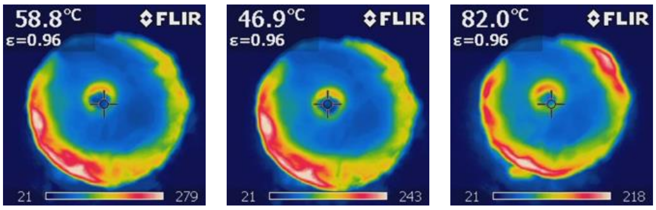
The burning behavior of a typical biomass briquette is shown in Fig. 6. In this case a single solid round briquette is shown about two minutes after being ignited in a common domestic braai (barbeque) stand.

Fig. 6: Combustion behavior of typical loose biomass briquette

The typical thermal images of the briquettes 5 minutes into the combustion are shown in Fig. 7. Fig. 7(a) shows typical profiles for solid round briquettes while Fig. 7(b) shows the profiles for typical sound hollow briquettes. The temperatures in the figures are the temperatures at the location of the cursor. However, the maximum temperatures for each sample were also recorded. The average maximum temperatures for five samples of the solid round briquette was found to be 210ºC while that for the hollow solid briquettes was recorded as 280ºC. The presence of a central hole in the hollow round briquette provided additional surface area for combustion. This therefore resulted in higher overall briquette body temperature which facilitated drying and hence produced faster combustion and heat concentration. Moisture removal (drying) is one of the key processes during the combustion of biomass [8]. Therefore, the solid round briquette has lower combustion effectiveness when compared to the hollow round briquette. This help to explain the proliferation of round briquettes for domestic cooking. However, round solid briquettes may burn longer which may be desirable for space heating and other heating applications. Furthermore, round solid briquettes possess higher overall density which saves storage space.



(a)



(b)

Fig. 7: Combusting briquette thermal profiles (a) Solid round briquette (b) Hollow round briquette

IV. Conclusions and Recommendations

In this paper, compaction pressure and compaction displacement behavior were investigated for loose briquetting using grass and leaves. In addition, the combustion behavior for solid round and round hollow briquettes were investigated. Base on the obtained results, the following conclusions can be made:

- The density of loose biomass composed of equal quantities of leaves and grass depends on pressure
- An optimum or saturation density occurs at a pressure of 35 MPa beyond which no further increase in density is observed
- The optimum density of loose biomass briquettes composed equal quantities of dray leaves and grass is 1250 kg/m^3
- Solid round briquette combustions achieved a maximum temperature of 210ºC while the hollow

round briquette achieved 280°C after five minutes of combustion

- The hollow round briquette was found to be the preferred geometry for combustion efficiency

The current work was conducted on two selected loose biomass stock without due consideration of energy content or other properties. The stock used was mainly based on availability. It is recommended that this work be conducted for a range of biomass stock especially that which is available in remote communities such as agricultural waste (maize leaves, rice stalks etc.) to ensure that developed technologies are effective for target communities.

Further work is also required to determine the optimum shape and geometry for effective combustion and energy extraction for such applications as space heating and cooking. Energy balance tests should yield more positive indication of the best geometries for such applications.

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