SECTION III

Development of the loose biomass briquetting value chain

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Abstract

Biomass (roundwood, agricultural residues, forestry residues, organic municipal waste) has the largest carbon reserve with potential to replace unsustainable fossil energy sources. Furthermore, off grid communities produce significant amounts of loose biomass through agricultural and forestry activities. These include maize stalks, tobacco stalks, ground nut leaves and stalks, tree leaves, elephant grass etc. These are traditionally burnt in fields after harvesting. In addition, annually, forestry residues such as elephant grass, yellow thatching grass, dry tree leaves etc. are destroyed in perennial veld fires. Such loose biomass can be harnessed for cooking and heating energy and thus minimise the use of round wood, which results in deforestation that cause desertification if not done sustainably. The major challenge in harnessing energy from loose biomass is their low energy density. This can be overcome by developing loose biomass briquetting technologies. This paper reports on the development of loose biomass briquetting technologies at the University of Johannesburg over the past five years. These include shredding, pre-treatment, compaction, off grid solar drying, and combustion. Briquetting required the selection of good feed stock and binders. Cow dung and cactus were found to be good binders producing briquettes with good combustion behaviour. The developed loose biomass briquettes were tested for moisture content, energy content and combustion behaviour and were found to be adequate for domestic cooking and heating requirements.

Keywords: Agricultural residue, Biomass, Biomass briquettes, Forestry residue, Loose biomass

Introduction

Biomass is the only source of energy with sufficient carbon to sustainably and reliably replace fossil based fuels as a source of energy. It has been a traditional source of energy for billions of people around the world for centuries (Wilke, et al. 2011). The International Energy Agency reports that 47.6 % of Africa relies on biomass as a source of energy (International Energy Agency (IEA) 2009). The proportion is higher at 61.2 % for sub-Saharan Africa while it's even more substantial at 81.2 % for sub-Saharan Africa excluding South Africa. Most of this consumption is round wood. This rate of consumption is unsustainable in this current age of global warming and climate change. Sub-Saharan Africa has notable potential to develop biomass based energy through loose biomass (agricultural and forestry residues), energy crops (jatropha, sugar cane etc.), solid wastes (municipal wastes) and round wood forests (Stecher, Brosowski and Thrän 2013). These segments are estimated to contribute a total of 13900 PJ/yr by 2020. Of this, loose biomass would contribute 5254 PJ/yr. This is a significant amount if properly harnessed. Already, large amounts of loose biomass are produced annually through agricultural activities. In sub-Saharan countries, Savannah grasslands are awash with elephant and yellow thatching grasses. These residues are destroyed annually after harvest by burning in the case of agricultural residues, and by wild veld fires in the case of forestry residues. There is currently no practice of harvesting such loose biomass residues for energy.

Loose biomass is not attractive as a source of energy (either for cooking or heating) due to its low energy density. Steam coal (1% water) has a calorific value of 36 MJ/kg compared to 16 MJ/kg for wood with 15% moisture content (National Physical Laboratory

2015). This poses serious challenges in terms of transportation and storage. Furthermore, large volumes (in their natural state) would be required to cook a normal meal. In addition, the type and quality of loose biomass available for potential energy use is site dependant. A number of studies have been conducted to quantify the energy content of various loose biomass available in various sites. A detailed study conducted on loose biomass samples collected from a village in the Limpopo Province of South Africa revealed that eucalyptus saw dust, peanut shells and Mopani leaves had the highest energy content and hence are suitable candidates for further development as an energy source for that region (Shuma, et al. 2015). However, energy content is not the only metric of interest. Taking into consideration material density, burn rate during combustion, moisture content and availability in the vicinity of the site of study, cow dung, ground nut leaves & stalks, yellow thatching grass and maize stalks and cobs were identified as good loose biomass energy feed stocks. Although cow dung has low energy content, it is widely available in most off grid communities in sub-Saharan Africa and has also been used as a binder for briquetting projects (Emerhi 2011).

To encourage use of loose biomass as an energy source, a number of interventions are required. One approach is the beneficiation of the energy value of the material by techniques such as loose biomass briquetting (Chen, Xing and Han 2009). Alternatively, the loose biomass can be converted into a higher energy content form by gasification methods (Yaman 2004). Loose biomass in green state can also be used for biogas production through anaerobic digestion (Ward, et al. 2008). Irrespective of the chosen technique, loose biomass requires pre-treatment (preparation and densification) to make it suitable for use. Densification has been the widely used approach.

This paper reports on biomass value chain that has been developed at the University of Johannesburg over the last five years. The aim is to improve the uptake of loose biomass as a source of sustainable, freely available renewable energy. This is done in a way that acknowledges the commercial value of the technology. This also opens up the potential for employment creation if implemented in support of the open community manufacturing (OCM) concept (Oosthuizen, et al. 2014), (Rebensdorf, et al. 2015). The developed technologies within the loose biomass value chain can be implemented in container based community factories in modular fashion that allows for progressive organic growth of the loose biomass processing centres. Commercially viable innovative and entrepreneurial solutions can be developed while at the same time mitigating deforestation and global warming challenges.

Loose biomass briquetting value chain

Background

Beneficiation of loose biomass as a source of energy has been achieved mainly by briquetting. However, traditional approaches have failed to attract widespread adoption due to high capital costs creating a commercialisation barrier. Simpler tools (appropriate technology) can be developed that are more affordable and attractive for widespread use. These tools can be developed for each of the identified steps in the loose biomass briquetting process enabling poor communities to access energy available in the loose biomass. These steps include:

1. Shredding
2. Preparation
3. Compaction
4. Drying
5. Briquettes packing
6. Briquette combustor

The aim is therefore to develop low cost technologies that can be used to process loose biomass into usable form. This has to be done in a sustainable manner. Technologies being developed include biomass shredding machines (manual or solar powered), biomass briquetting machines (manual), biomass briquette drying tools (solar powered), and biomass briquette packing machines (solar powered).

Shredding

In most cases, loose biomass exists naturally in a form that cannot be effectively used for briquetting. Loose biomass such as maize stalks, yellow thatching grass and ground nut stalks need to be reduced in size prior to briquetting. Studies conducted on mixtures of grass and dry eucalyptus leaves revealed that the loose biomass should be reduced to 20 mm size particles for optimum compaction. This can be achieved using various technologies. The technology of choice in this work was the disc cutter as shown in Figure 1.

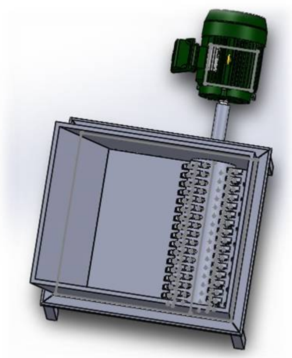


Figure 1: Biomass shredding machine

The machine has production capacity sufficient to produce 8000 briquettes per day. The machine is powered by a dc motor that can be powered by solar energy.

Preparation

Trying to compact raw dry lignin results in spring back and poor binding. Common approaches to resolve this include soaking the loose biomass in water to soften the lignin. Hot water has been reported to yield good results. Other researchers have also reported good performance when the loose biomass is preheated in the absence of moisture. It was also found to be more effective and less expensive to compost the loose biomass for 7 to 14 days to assist in breaking the lignin. In addition, various types of the loose biomass can be mixed to improve energy content and binding. Common binders include cow dung and cactus and these were employed in this work.

Compaction

The briquetting process involves the compaction of loose biomass under pressure. The compaction increases density and hence the energy content per unit volume. Various technologies have been applied which include piston and screw compaction. For off grid production, piston compaction is the preferred approach. Successful compaction depends on a number of factors such as the type of material being compacted, particle size, temperature and moisture content. Proportion of loose biomass to binder also determines the compaction performance. A study conducted on a mixture of leaves and grass in the absence of any binder revealed an optimum moisture content between 15 and 25% and compaction pressure of 35-40 MPa (Madyira and Kaymacki 2015). The variation of pressure with density is shown in Figure 2.

(a)

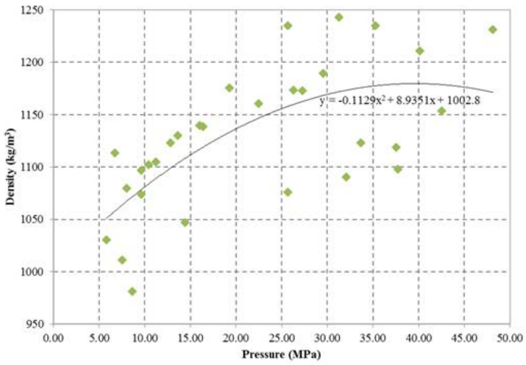
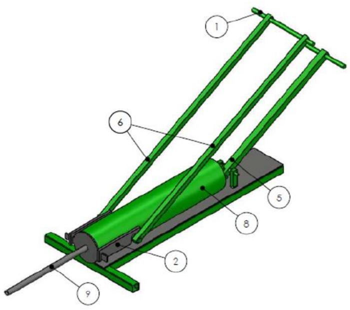
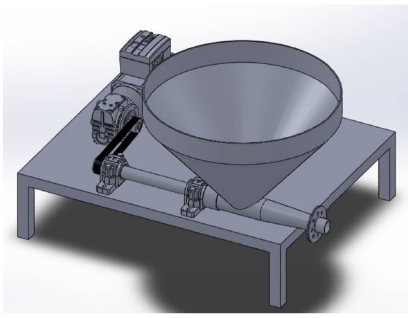


Figure 2: Effect of pressure on loose biomass briquette density

The briquetting was conducted using a piston/cylinder configuration. Figure 2 also shows that the density of the briquettes increases with increase in compaction pressure and stabilise after 30 MPa. In this work both screw type and piston type machines were developed. The two machines are shown in Figure 3. The piston machine (Figure 3(a)) is manually operated for full off grid capability whilst the screw type machine (Figure 3(b)) is powered by a dc motor that can be powered by electricity derived from a PV solar plant. The piston machine can produce 2000 briquettes per day while the screw ca produce an equivalent of 8000 briquettes per day.



(a)



(b)

Figure 3: Biomass briquetting machines (a) Piston manually operated (b) Screw type powered

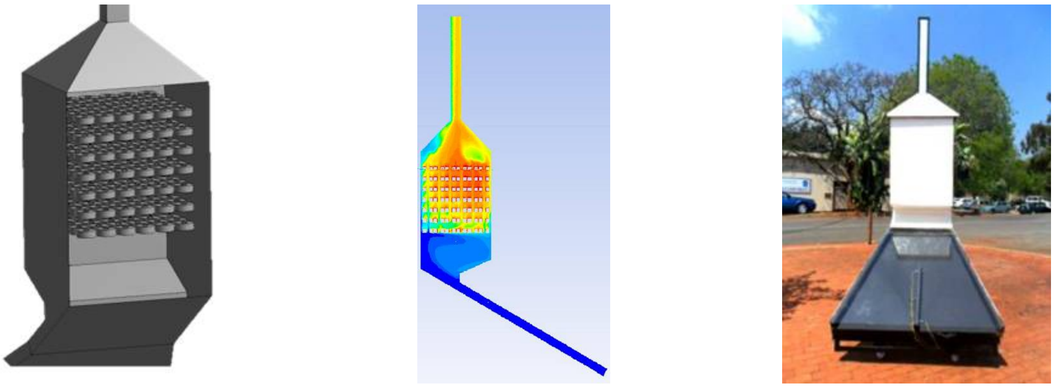
The biomass briquettes produced are shown in Figure 4. Figure 4(a) shows briquettes produced from various stock materials but with cow dung binder while the same is shown in Figure 4(b) with cactus binder. In general, both binders produced good quality briquettes.

(b)

Figure 4: Loose biomass briquettes produced (a) with cow dung binder (b) with cactus binder

Drying

For maximum energy extraction during combustion of the briquettes, the briquettes must be dried to a moisture content below 10 %. Solar drying was found to be the most sustainable way of drying the briquettes. A cabinet type indirect solar dryer was developed using a combination of numerical analysis tools (computational fluid dynamics (CFD)) and experimentation. The developed solar dryer is shown in Figure 5.



(a) (b) (c)

Figure 5: Cabinet solar dryer (a) Model of cabinet interior (b) Numerical model showing moisture distributions (c) Actual prototype tested

Figure 5(a) shows the geometrical model developed to represent the briquettes inside the cabinet, Figure 5(b) shows the distribution of moisture in the cabinet during drying and Figure 5(c) shows the actual prototype that was built and tested prior to optimisation of the dryer. The cabinet had the capacity to dry 250 briquettes over 16 hours of sunshine in summer and 24 hours in winter. This is equivalent to removal of 13 kg of moisture. Solar collector temperatures of about 80^{o}C were recorded leading to average cabinet temperatures of 45^{o}C in summer. This corresponded to solar collector efficiencies averaging 68%.

Briquette Packing

Once dried the briquettes must be packed either for storage, transportation or sale. To achieve this, a packing machine was developed. The objective was to design a machine that could measure a certain mass of briquettes that can then be delivered into a packaging container. The solution that was developed is shown in Figure 6. The machine is driven by a dc motor powered by electricity from a PV plant with capacity to pack 10000 briquettes per day.

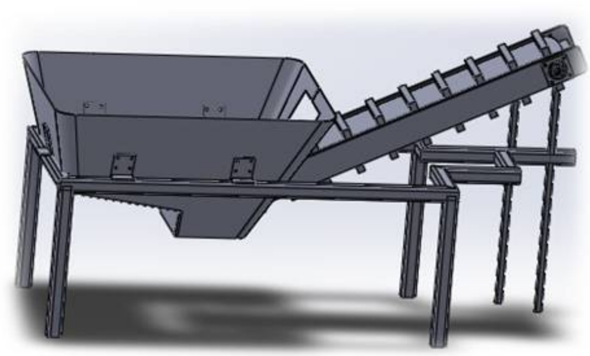


Figure 6: Biomass briquette packing machine

Combustion

A wide range of stoves have been developed which are able to combust biomass briquettes. However, some technologies have not been fully exploited. A good example is the down draft stove which has the main advantage of affording cleaner combustion. Work is therefore in progress to optimise the performance of this technology for biomass combustion. The main challenge with downdraft stoves is the extraction of heat especially for domestic cooking applications. Figure 7 shows solutions that are being optimised using CFD models to both improve the combustion and to develop heat extraction solutions.

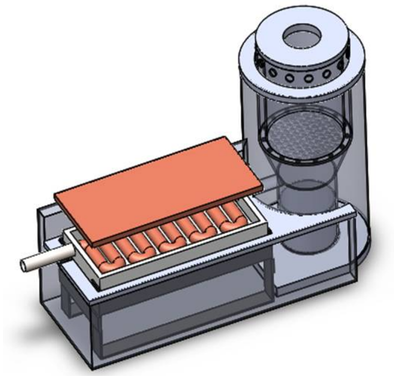


Figure 7: Model of down draft stove.

Summary

This paper has presented the work being done to develop an integrated production system for harnessing loose biomass as a source of energy. Key processes identified include shredding, preparation, compaction, drying, packing and combustion. Potentially effective solutions for each of these stages have been developed and described. The solutions that were implemented and tested produced good results. Work is still on going to optimise and finalise the system. Harnessing of loose biomass for energy, especially for off grid communities has significant potential socio-economic benefits that must be pursued and implemented.

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