The technical pre-feasibility to use briquettes made from wood and agricultural waste for gasification in a downdraft gasifier for electricity generation

Pholoso Malatji
Department of Forest and Wood Science, Stellenbosch University

Ntshengedzeni Sampson Mamphweli
Institute of Technology, University of Fort Hare,

Martina Meincken
Department of Forest and Wood Science, Stellenbosch University

Abstract
Biomass can be converted to energy through various thermochemical and biological processes. Gasification is one of the thermochemical processes that has recently gained popularity, because it achieves higher conversion efficiencies than, for example, incinerators, boilers or furnaces. Fixed-bed downdraft gasifiers are preferred for electricity generation, because they produce very little tar, but on the other hand, they are limited with regard to biomass properties, such as particle size, bulk density and moisture content. Biomass material with a heterogeneous size is usually processed into pellets or briquettes, which have to be mechanically strong enough to be handled. Cohesive strength is provided by residual moisture and lignin present in most biomass. However, the briquetting process becomes more complicated if one wants to add agricultural waste products that do not necessarily contain lignin as binders. The aim of this work was to process wood chips, grape skins and chicken litter into briquettes that are mechanically stable and have a sufficiently high energy content, as well as adequate bulk density for gasification. The performance of these briquettes in a downdraft gasifier was simulated with a program developed for wood, which was modified to optimise the briquette yield. The results showed a gasification performance comparable to solid pine wood, implying that the blended briquettes could be used as fuel for a downdraft biomass gasifier. Unfortunately, the briquettes proved too instable to experimentally verify the performance in a gasifier. This paper describes the properties of the briquettes as well as the gasification simulation results.

Keywords: gasification performance, simulation, various biomass, briquettes

1. Introduction

Wood and agricultural residues are major choices as feedstock for energy production and they can either be converted through thermo-chemical or biological processes. The most common, though inefficient, thermochemical conversion process is direct burning in an open fire for heating or cooking, which is used particularly in rural areas. Gasification would present a more energy efficient way of thermochemical conversion. Wood and agricultural residues are found in abundance in most rural areas in South Africa; however most of these biomass materials are not suitable for direct gasification because they are bulky, heterogeneous in size and shape and might differ in density. These differences not only make it difficult to handle, transport and store the biomass, but also to convert it, as most gasifiers cannot handle heterogeneous particle sizes.

There are numerous ways to resolve these problems, of which briquetting or pelleting are the most commonly utilized technologies (Kaliyan and Morey, 2009). This entails condensing the previously comminuted biomass into densified particles of uniform size, shape and density. Briquettes are typically larger than pellets with a diameter of about 8 cm and a length of about 10-20 cm, while pellets have dimensions of only a few cm and less. This pre-processing of biomass into briquettes improves the handling characteristics, as well as the bulk density and ultimately the calorific value [Wilaipon, 2008]. The bulk density of loose biomass is typically between 40-200 kg/m^3 and can be increased to densities as high as 600-800 kg/m^3 by compressing it into briquettes. The combustion efficiency of the resulting briquettes depends on density, chemical composition and moisture content (Shaw, 2008).

Biomass can be derived from various resources, which differ in their chemical composition. Lignin is the structural component of wood that acts as a natural adhesive and its amount varies for different species (Walker, 2006). Lignin facilitates the compression of small particles into briquettes, as it facilitates the adhesion between particles. Biomass other than wood, such as agricultural waste or chicken litter may contain less or no lignin and will therefore be less easy to compress into mechanically stable briquettes.

Downdraft gasifiers have specific fuel requirements, such as fuel size and type, form, moisture content, ash and slagging characteristics, energy content, bulk density and tolerable tar content. Thus, a downdraft gasifier is very fuel specific because its performance depends on the fuel properties, as well as the operating conditions, maintenance level and user experience.

Moisture affects the combustion efficiency negatively (Demirbas, 2004). In downdraft gasifiers, the moisture is driven off in the drying and carbonization zones of the gasifier, which consumes energy that would otherwise be available for reduction reactions that form the major part of the producer gas, thereby lowering the conversion efficiency of the system. Downdraft gasifiers require fuel with less than 30% moisture content. On the other hand, a certain amount of moisture is necessary to press briquettes and make sure that the biomass particles adhere to each other via hydrogen bonds. If the briquettes are pressed too dry, they will disintegrate which leads to biomass loss and makes it difficult to handle the briquettes.

Agricultural residues typically have moisture contents and calorific values different from wood (White and McGrew, 1976). The moisture content of chipped wood that has been air dried for several weeks varies between 10 and 20%, whereas agricultural biomass contains between 50% and 85% moisture (Hagström, 2006), depending on the type of feedstock. High moisture content also puts strain on cooling and filtering equipment by increasing the pressure drop across these units because of condensing liquid. A moisture content around 10-20% is ideal for gasification in downdraft gasifiers (Sims *et al*, 1996), which implies that most biomass has to be dried before it can be used as fuel for these gasifiers.

Typical energy contents range from 0. 5 to 17 MJ/kg at 10-15% moisture content, depending on the type of biomass (Maciejewska *et al.,* 2006). An additional consideration with regard to the biomass fuel choice is the ash content. Ash consists mainly of elements, such as K, Ca, S, Na, Fe, Si and other trace elements and it is the inorganic matter that cannot be combusted and remains in the gasifier in the form of ash and has to be discarded after combustion. Wood typically has a low ash content around 0. 5%, whereas many other agricultural residues can have ash contents as high as 20% or more. The amount of inorganic matter in biomass also affects its ultimate calorific value (Strehler, 2000). Ash can present problems, such as slagging, clogging and build up of debris in the gasifier (Higman and van der Burgt, 2003).

Biomass usually also contains tar, which can form deposits in the inlet valves of the reactor, which can block the gasification unit (Rajvanshi, 1986) as a product of an irreversible process that takes place in the pyrolysis zone (Kaupp, 1982). The gasification temperature and heating rate determine the appearance of tar. Generally downdraft gasifiers produce less tar than other gasifiers (Remulla, 1982). However, because of localized inefficient processes taking place in the throat of the downdraft gasifier, it does not allow the complete dissociation of tar (Kaupp, 1982).

The main aim of this work was to determine the feasibility of briquettes consisting of wood, grape skins and chicken litter for gasification in a downdraft gasifier. The briquettes were produced in a small-scale manual press that could potentially be used in a rural setup. The briquettes were then tested in a small scale spark-ignition down-draft gasifier for their performance, but unfortunately these experiments failed due to the disintegration of the briquettes. The pressure produced by the hand press proved to be too low and although the briquettes were stable enough for handling and transport, they disintegrated too quickly when heated. This setup will have to be improved in further experiments. The feasibility was then evaluated with a simulation model as an appropriate alternative. The model, developed by Jayah, *et al.* (2003) takes all relevant parameters of down-draft gasifiers into account and the biofuel parameters were adjusted according to the properties of the briquettes.

2. Materials and methods

2. 1 Sample collection and preparation

Grape skins and chicken litter were collected from disposal piles on farms in the Western Cape, South

Africa. The material was sun-dried for about 72 hours and cleared of large foreign objects, such as stones, feathers and twigs. Pine and eucalyptus wood chips were collected from the Department of Forest and Wood Science, Stellenbosch University. A blend of the chips was further comminuted with a Retsch mill. Particles were not screened for size in order to simulate the 'real-life' scenario at the farm. The moisture content of all types of biomass was determined after milling with the oven-dry method and moisture was either added or reduced (by oven drying) to obtain the desired moisture content.

2. 2 Briquetting

Briquettes were pressed in a custom built hydraulic, manual laboratory press according to the optimum process parameters determined in a previous study (Malatjie and Meincken, 2009). The press was designed to be used in a rural, domestic setup and will have to be improved to obtain better results. The briquettes were observed for stability and density after two weeks of conditioning at 20°C and 65% RH and the briquettes with the highest density and best stability were used for further experiments. However, the maximum pressure that could be obtained per briquette was only about 19 kPa, as opposed to 100 KPa in typically found in industrial presses. Furthermore, no frictional forces to facilitate lignin flow were present, because the hydraulic press system is stationary. This resulted in briquettes with lower density (about 550 kg/m^3) and lower internal bonding than could be achieved when using an industrial press. The raw materials were blended in a ratio of 50:30:20 wood:grape skins:chicken litter.

2. 3 Briquette properties

2. 3. 1. Ash content

The ash content was determined according to TAPPI standard T 211 om-85 (1985). Ovendried pieces of the briquettes were weighed before they were placed in a furnace at 575˚C for 3 hours. After combustion the samples were placed in a desiccator to prevent moisture absorption while cooling. The ash content was determined according to:

$$\text{Ash content} = m_{ash} \times 100/m_{briquette} \quad (1)$$

Where m_{ash} is the mass of the ash and $m_{briquette}$ is the mass of the oven dry briquettes.

2. 3. 2. Energy content

The energy content was determined with an Eco Bomb Calorimeter from CAL2k. The instrument was calibrated with about 0. 5g of benzoic acid before measurements. The energy content of about 0. 5g of biomass was determined in a pressurized oxygen atmosphere of 3000 kPa.

2. 3. 3. Elemental analysis

The chemical composition of the blended briquettes was determined by inductively coupled plasma atomic emission spectroscopy (ICP-AES) by the company BEM Labs, Somerset West, South Africa. The elemental analysis of pine wood was obtained through the microwave digestion method and is reported in a previous study of Mamphweli and Meyer (Mamphweli and Meyer, 2009).

2. 4 Gasification simulation

A DOS based program used to simulate the performance of a downdraft gasifier was developed by Jayah *et al.,* 2003. In this study pine wood and blended briquettes were used as biomass feedstock and their performance compared. The obtained gas profiles were used to calculate the gas heating value from the percentage composition of combustible gases as follows:

$$CV = \frac{(H_{2\,Vol} \times CVH_2) + (CO_{vol} \times CVCO) + (CH_{4\,vol} \times CVCH_4)}{100\%} \quad (2)$$

where CV is the gas calorific value/heating value (MJ/Nm^3), H_{2vol} is the volume concentration of hydrogen gas (%), CVH_2 is the calorific value of hydrogen (10. 1 MJ/Nm^3), CO_{vol} is the volume concentration of carbon monoxide (%), $CVCO$ is the calorific value of carbon monoxide gas (12. 64 MJ/Nm^3), CH_{4vol} is the volume concentration of methane gas (%) and $CVCH_4$ is the calorific value of methane gas (38 MJ/Nm^3) (Mamphweli and Meyer, 2010). The calorific values of the various gas species were obtained from the standard gas table. The following equation was used to determine the conversion efficiency of the gasifier:

$$\eta = \frac{H_g \times 2Nm^3/h}{H_w} \times 100\% \quad (3)$$

Where η is the efficiency, H_g is the heating value of the gas and H_w is the heating value of the pine wood and/or briquettes.

3. Results and discussion

3. 1 Proximate and ultimate analysis

Proximate and ultimate analysis results of briquettes made from a blend of wood, grape skins and chicken litter and of solid pine wood are presented in Table 1.

The parameters presented in Table 1 were used to simulate the performance of the biomass feedstock in a downdraft gasifier. Briquettes and pine wood differed significantly in the carbon and nitrogen content, as well as the bulk density. All these values are expected to affect the gasification performance. For instance the critical minimum bulk density for gasification in a downdraft gasifier is 200 kg/m3, which is necessary to avoid fuel hang-up (i. e. fuel congestion and blockage of the hearth) that could lead to hearth damage.

Table 1: Ultimate and proximate analysis of briquettes and pine wood

Parameters	*Briquettes*	*Solid pine wood*
Moisture content (%)	12	15
Ash content (%)	0. 66	0. 45
Carbon (%)	22. 81	54. 41
Fixed carbon (%)	1. 6	12
Hydrogen (%)	5. 4	5
Oxygen (%)	41	37
Nitrogen (%)	1. 92	0. 22
Density (kg/m^3)	570	430
Fuel diameter (cm)	8	8

3. 2. Gasification simulation

Table 2 shows the design of the small scale gasifier used in the experiment and the optimised operating conditions used for the simulations.

Table 2: Gasifier design and operating conditions

Gasifier parameters	*Value*
Throat diameter (cm)	5
Throat angle (degrees)	30
Insulation thickness (cm)	2
Thermal conductivity (W/cm K)	2
Feed input (kg/h)	65
Temperature (input air) (oC)	27
Air input (kg/h)	44. 5
Heat loss (%)	0. 5

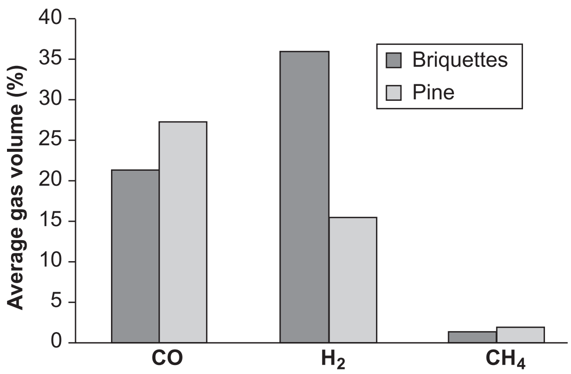

Figure 1: The average combustible gas composition obtained using pine wood and briquette parameters under similar gasifier operating conditions

Figure 1 shows the volume of combustible gases obtained using pine wood and briquette parameters with the same gasifier operating conditions. Pine wood was used as a reference to establish the performance of the briquettes since it has been tested experimentally and found to achieve high conversion efficiency (76%) in a downdraft gasifier (Mamphweli and Meyer, 2010). However, some gasifier parameters and operating conditions, such as feed input and throat diameter had to be altered for the briquette simulations in order to establish the highest possible efficiency that could be reached. The same gasifier parameters and operating conditions were then used for the simulation of pine wood performance. Table 3 (overleaf)shows the parameters that were altered.

The altered parameters were the throat diameter, the throat angle as well as the feed input rate as indicated in Table 3. The final parameters that were regarded as the optimum gasifier parameters that resulted in the highest conversion efficiency are highlighted in the final column (E).

The producer gas obtained with above parameters resulted in significantly higher volumes of hydrogen and lower volumes of carbon monoxide when briquettes were used as fuel. The methane output was comparable. These two gasses have a huge impact on the efficiency of the gasifier and therefore the heating value of the gas, which depends on the composition and ratio of combustible gases and is directly proportional to the conversion efficiency.

Figure 2 shows the higher heating value of the producer gas and the conversion efficiency obtained from pine wood and briquettes, respectively under the same gasifier operating conditions. Briquettes produced a gas with an average heating value of 6. 8 MJ/Nm^3, while the average of pine wood was 5. 7 MJ/Nm^3. Both gas heating values corresponded well with the producer gas heating values expected for downdraft gasifier systems (Quaak *et al.,* 1999, Stassen, 1995). On average the amount of producer gas obtained from the briquettes was 20% higher than the gas obtained from pine wood.

The conversion efficiency was found to be higher for briquettes (approximately 80%) than for pine wood (approximately 68%). This was in accordance with the volume concentration of the combustible gasses and the gas heating value, as the latter is directly proportional to the conversion efficiency as evident from equation 3. On average the briquettes showed a 17% higher conversion efficiency than pine wood.

The poorer performance of pine wood during these simulations result from the fact that the gasification conditions were optimised for the briquettes and are somewhat different from the optimum settings for pine wood, because the main purpose of

Table 3: Gasifier parameters altered to establish the highest possible efficiency for the gasification of briquettes

Parameters	*Pine wood*	*Briquettes A*	*Briquettes B*	*Briquettes C*	*Briquettes D*	*Briquettes E*
Carbon (%)	54. 41	22. 81	22. 81	22. 81	22. 81	22. 81
Hydrogen (%)	5	5. 4	5. 4	5. 4	5. 4	5. 4
Oxygen (%)	37	41	41	41	41	41
Nitrogen (%)	0. 22	1. 92	1. 92	1. 92	1. 92	1. 92
Fixed carbon (%)	12	1. 6	1. 6	1. 6	1. 6	1. 6
Bulk density (kg/m3)	430	570	570	570	570	570
Diameter of wood particle (cm)	5. 5	5	5	5	5	5
Throat diameter (cm)	15	25	20	15	10	5
Throat angle (degrees)	45	45	30	40	30	30
Insulation thickness (cm)	2	2	2	2	2	2
Thermal conductivity (Insulating material) (W/cm K)	2	2	2	2	2	65
Moisture content (%)	15	12	12	12	12	12
Temperature of input air (°C)	27	27	30	27	27	27
Feed input (kg/h)	65	70	60	65	30	65
Air input (kg/h)	44. 5	44. 5	44. 5	44. 5	44. 5	44. 5
Heat loss (%)	0. 5	0. 5	0. 5	0. 5	0. 5	0. 5

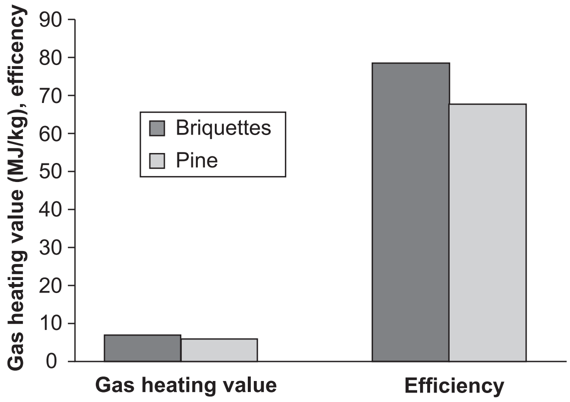

Figure 2: The average higher heating values of the producer gas and the conversion efficiency obtained using pine wood and briquette parameters under the same gasifier operating conditions

this study was to establish the optimum operating conditions and design for the briquettes. It could, however be shown that solid wood and briquettes made from a blend of wood and agricultural waste resulted in comparable gas yield, heating value and conversion efficiency.

Unfortunately, it was not possible to verify the simulated results with experimental values, because the briquettes made with a manual press proved to be too unstable to be converted in a down-draft gasifier and disintegrated in the combustion zone, which led to an inadequate air flow and subsequent process failure. This problem would be easy to overcome by using an industrial briquette press with sufficient pressure and internal friction, which would lead to a higher internal bonding strength between particles as well as a higher briquette density. The aim of this study, however, was to manufacture briquettes in a small hand press, which will have to be improved in further experiments.

4. Conclusion

Briquettes for gasification in a downdraft gasifier were produced with a small scale manual press from a blend of wood, grape skins and chicken litter. This yielded briquettes stable enough for transport, but unfortunately they disintegrated in the combustion zone of the gasifier. The gasification performance was then simulated and compared to pine wood, which is a commonly used fuel for gasification. The simulation results showed that the blended briquettes were comparable to pine wood in their performance and the simulation suggested that the briquettes could even perform better than pine wood, if the gasifier operating conditions were optimised for the briquettes. The results show that a combination of wood and agricultural residues can be used as biofuel for gasification with the same, if not better, efficiency as solid pine wood.

Acknowledgements

The authors wish to acknowledge T. H. Jayah, Lu Aye, R. J Fuller and D. F. Stewart for provision of the downdraft gasifier simulation program.

References

Demirbas A., (2004). Combustion characteristics of different biomass fuels, *Progress in Energy Combustion Science* 30 219-230.

Hagström P., (2006). Biomass potential for heat, electricity and vehicle fuel in Sweden, PhD dissertation, Department of Bioenergy, Swedish University of Agricultural Sciences, Acta Universitatis Agriculturae Sueciae Vol. 11.

Higman C., van der Burgt M., (2003). Gasification, Elsevier Science, Burlington, USA, p. 67-70.

Jayah T.H., Lu A., Fuller R.J., Stewart D.F, (2003). Computer simulation of a downdraft wood gasifier for tea drying, *Biomass and Bioenergy* 25, p. 459-465.

Kaliyan N., and Morey V. N., (2009). Factors affecting strength and durability of densified biomass products, *Biomass and Bioenergy* 33 337-359.

Kaupp A., (1982). Myths and Facts About Gas Producer Engine Systems, presented at the First International Producer Gas Conference, Colombo, Sri Lanka, 8-12 November 1982.

Maciejewska A., H. Veringa, J. P. M. Sanders, and S. D. Peteves, (2006). Co-firing of biomass with coal: Constraints and role of biomass pre-treatment, Luxembourg: Office for Official Publications of the European Communities, 113.

Malatji P., and Meincken M., (2009). Processing of wood an agricultural waste for gasification, presented at the South African Chemical Engineering Conference, 20-23 September 2009, Somerset West, South Africa.

Mamphweli N.S., and Meyer E.L., (2009). Implementation of the biomass gasification project for community empowerment at Melani village, Eastern Cape, South Africa, *Renewable Energy* 34, p. 2923–2927.

Mamphweli N. S., and Meyer E.L., (2010). Evaluation of the conversion efficiency of the 180Nm^3/h Johansson Biomass gasifier, *International Journal of Energy and Environment* 1, p. 113-120.

Quaak P., Knoef H., and Stassen H. E., (1999). Energy from biomass: a review of the combustion and gasification technologies, World Bank Technical Paper No 422, Washington DC, USA.

Rajvanshi A. K., (1986). Biomass Gasification, Alternative Energy in Agriculture, Vol. II, CRC Press, p. 83-102.

Raveendran K., Ganesh A., and Khilar K. C., (1996). Pyrolysis characteristics of biomass and biomass components, *Fuel 75* 987-998.

Remulla J. A., (1982). Gas Manufactures in the Philippines: Status and Prospects, presented at the Technical Consultation Meeting between the Peoples Republic of China and Philippines, 20-23 June 1982.

Sims C. H., Hassler C. C., and Bean T. L., (2008). Wood Densification, West Virginia University Publication No. 838, 1988. www. wvu. edu/~agexten/forestry/wood838. pdf, accessed 14/08/2008.

Shaw M. D., (2008). Feedstock and Process Variables Influencing Biomass Densification, MSc thesis, Department of Agricultural and Bioresource Engineering, University of Saskatchewan, Canada.

Stassen H. E., (1995). Small scale biomass gasifiers for heat and power: a global review, World Bank Technical Paper No. 296, Washington DC, USA.

Strehler A., (2000). Technologies of Wood Combustion, Ecological Engineering (Supplement) 16 25-40.

Walker C. F. J., (2006). Primary Wood Processing: Principles and practice, Springer, Netherlands, p 596.

Wilaipon P., (2008). Physical Characteristics of Maize Cod Briquettes under Moderate Die Pressure, http://www. doaj. org/doaj?func=abstrac&id=266609&recNo=7&toc=1, visited 10/03/2008.

White J. W., and McGrew W., (1976). Clean fuels from Biomass, Sewage, Urban Refuse, Agricultural wastes. Symposium Papers presented at the Institute of Gas Technology, Orlando, USA, January, p. 459.

Received 28 October 2010; revised 2 June 2011