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Gasification of 'Loose' Groundnut Shells in a Throatless Downdraft Gasifier

Aondoyila Kuhe^a and Samuel Jacob Aliyu^b

^aDepartment of Mechanical Engineering, University of Agriculture, Makurdi, Benue State, Nigeria

^bDepartment of Mechanical Engineering, Landmark University, Omu-Aran, Kwara State, Nigeria

Abstract: In this paper, gasification potential of biomass residue was investigated using a laboratory scale throatless downdraft gasifier. Groundnut shells gasified in a throatless downdraft gasifier could be used to produce a clean gas with a calorific value of 5.92 MJ/Nm³ and a combustible fraction of 45% v/v. Low moisture (8.6%) and ash content (3.19%) are the main advantages of groundnut shells for gasification. Gasification of shell waste products is a clean energy alternative to fossil fuels. The product gas can be used efficiently for heating and possible usage in internal combustion engines.

Keywords: Groundnut shells, Gasification, throatless downdraft gasifier, Biomass energy

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1. Introduction

Present energy sources, especially fossil fuels, are being used at an accelerating rate with fear of depletion. On the other hand, there is also an increasing awareness about environmental pollution that has drawn worldwide attention. Due to these concerns, the potential offered by renewable sources of energy is enormous, as they are not depleted by time. One of the most promising renewable sources of energy is the energy from biomass. Bapat et al. (1997) stated that biomass is the third largest primary energy resource in the world, after coal and oil. It can be used to produce a producer gas which can be used to generate power by running internal combustion engines as well as gas turbines. According to Hall et al (1991) biomass provides about 1250 million TOE (The tonne of oil equivalent: a unit of energy defined as the amount of energy released by burning one tonne of crude oil) which is about 14% of the world's annual energy consumption. According to Hall et al. [1991] and Werther et al. (2000) biomass is a major source of energy in developing countries, where it provides 35% of all the energy requirements. In developed countries,

biomass energy use is also substantial as stated by Werther et al. (2000). As an energy resource, biomass ranks fourth in the world, and provides about 14% of the world's energy needs as stated by Hall et al. (1992) and McGowan. (1991).

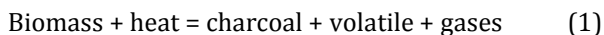
When these characteristics are considered, biomass seems to be one of the most important renewable energy sources. In the future, biomass has the potential to provide a cost-effective and sustainable supply of energy, while at the same time aiding countries in meeting their greenhouse gas reduction targets (Balat and Gunhan, 2005). Also biomass, unlike other energy sources, can be harmful if it is not utilized. Unused biomass fuels would otherwise be burnt, landfilled, or accumulated as excess biomass in forests. Biomass landfill burial leads to greenhouse gas emission and soil and water contamination. Biomass accumulation in forests increases wildlife hazards and depresses watershed and productivity (Akay et al. 2005).

However, direct combustion of Agro-residues in furnaces, semi open pits, and other open burning application is rather poor (Singh et al., 2006). Combustion efficiency is low with high smoke emission,

*Corresponding Author: +2348125125190 or +2348033647246
Email: moseskuhe74@gmail.com

and process control can be limited. Alternative utilization method is therefore needed (Bridgwater, 2003; Mohod et al., 2008). Gasification is viewed to be a suitable conversion technology for the biomass residues available that offers high thermal efficiency and environmental acceptability. Conversion of crop residues into energy increases the value of agricultural output and reduces the need for fossil fuel input. The technology is a relatively economical alternative for use in small scale industries and in rural areas, especially in oil importing countries. The production of a gaseous fuel from a solid fuel makes gasification very appealing. Biomass gasification is a thermochemical conversion of a solid, such as biomass, which this agro wastes belong to, into a combustible gas known as producer gas. Gasification involves four stages of: pyrolysis, oxidation, and reduction, which produce combustible gases like CO, H₂, and hydrocarbons (Tippayawong et al. 2011).

Complete gasification of biomass involves several sequential and parallel reactions. Most of these reactions are endothermic and must be balanced by partial combustion of gas or an external heat source (Buekens and Schoeters, 1985). As the biomass particle is heated, it initially pyrolysis to form charcoal plus gases and vapors.

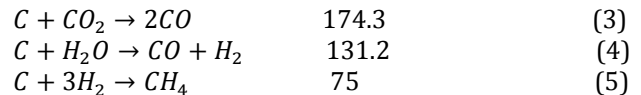


After pyrolysis is completed, the charcoal can react with oxygen and steam or the products of pyrolysis according to:



In addition, the vapors formed initially from the solid may undergo cracking to form secondary products [Buekens and Schoeters, 2002], either gases or other condensable species. Gasification produces combustible gas that is rich in carbon monoxide and hydrogen. With insufficient amount of oxidant (pure oxygen, air, or steam), oxidation is limited and the thermodynamics and chemical equilibrium of the system shift reactions and vapor species to a reduced rather than an oxidized state. Consequently, the elements commonly found in fuels and other organic materials (C, H, O, N, S) end up in the gas stream as CO, H₂, H₂O, CO₂, N₂, CH₄, and lesser amounts of H₂S, COS, NH₃, elemental carbon, and trace quantities of other hydrocarbons.

The Boudouard and water gas reactions (No. 3 and 4) are endothermic, and the energy required both for these reactions and for drying is derived from the hot gases and the partial-oxidation zones of the gasifiers. The most important gasification reactions are No. 3, 4, and 5. According to Mamphweli and Meyer (2009), these four reactions are sufficient to describe the gasification process.



Nigeria is the fourth largest producer of groundnut in the world, with 2 million metric tons production representing 5% world production. Every year approximately 13,000 tons of groundnut shells are produced (Freeman, 1999). At present, groundnut shells are discarded by local groundnut processors. During the harvesting time, shells (mechanically separated from the seed) is greatly available and without any utilization. Usually it is simply heaped at the corner of the roads, in the fields or around processing area and burnt as a means of waste management. Because groundnut shell used majorly in simple combustion conditions, little research has been carried out to investigate the gasification of loose groundnut shells in a downdraft gasifier, much of the data on groundnut shell gasification is sourced from fluidized bed gasification of groundnut shells. Because of the flow problem experienced during the gasification of loose biomass feedstock in a throated downdraft gasifier (Jain and Goss, 2000), which may in turn affect the quality of the producer gas since the quality of the product gas, is found to be dependent on the smooth flow of the fuel and the uniformity of the pyrolysis. For this reason most groundnut shell gasification in downdraft gasifiers is done with the fuel densified as either pellets or briquettes (Varshney et al. 2011).

The purpose of this study is to investigate the potentials of biomass gasification in a throatless downdraft gasifier using a laboratory scale (5 kW electrical output) downdraft gasifier. In this study, the experiments were carried out in the pilot gasification plant consisting of a throated down-draft gasifier and a gas clean-up unit placed before the sample port. Fixed bed gasifiers are simple to use and downdraft gasifiers have been successfully used in other bio-fuels to generate a cleaner producer gas than other fixed bed systems (Dogru et al. 2002, Midilli et al. 2001). While, the specific objective is to carry out a fuel characterization of the producer gas generated from the closed-top throatless downdraft gasifier using groundnut shell fuel.

2. Materials and Methods

2.1 Biomass feedstock and its analysis

Groundnut shells were used as the feedstock. Standard procedures for proximate analysis of groundnut shell samples were used: ASTM E1755-01(2002) for ash and ASTM D3175-89a (1994) for volatile matter. Biomass fixed carbon was determined by balance. The procedure used for determining the bulk density of the groundnut shell samples was ASAE

Standard S269.4 DEC 91(ASABE Standards, 2007) for cubes, pellets, and crumbles.

2.2 Gasifier details

All experiments were carried out in the closed top 'throatless' fixed-bed downdraft gasifier reactor using air as the oxidant. The process is energetically self-sustaining auto-thermal as no thermal input is required at steady-state conditions. The gasifier is a cylindrical-shaped vessel in which all the components except the grate are constructed of 10 mm thick high carbon steel as shown in figure 1. The grate however is made of stainless steel, which ensures that the oxidation zone is able to withstand the extreme temperatures (up to 1200 oC) that occur in this area.

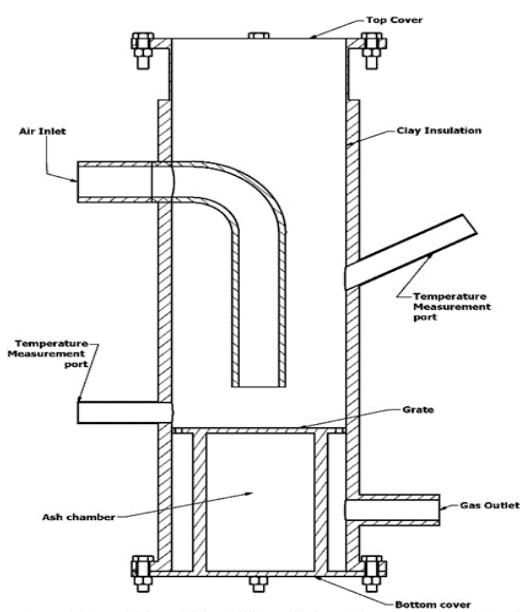


Fig 1. Configuration of the downdraft fixed-bed gasifier reactor

In order to obtain a simple and repetitive series of experiments, the experimental facility presented in Figure 2 was designed and constructed. The installation consists of an air compressor, a downdraft fixed bed gasifier reactor unit and a burner for flaring the producer gas. Along the main pipe supplying producer gas from the reactor to the gas burner, a sample of the gas was collected via a sampling point, after the producer gas sample was cooled in a cooling unit and cleaned by a system of filters before collection. The compressor (model super poschi HP 2.0) is used to introduce air into the reactor chamber at the bottom of the gasifier (oxidation zone). The reaction front of the gasification process is at the bottom of the gasifier with the biomass feedstock dropping top-bottom. The clay in between the inner and outer wall of the gasifier reactor helps in reducing heat loss thereby increasing the amount of heat energy available for reactor reactions. The groundnut shell is manually fed into the gasifier in

batches. The producer gas leaves the gasifier just below the base of the throat at approximately 270-4000C. The gasifier was simple to operate. The grate is attached to the ash collection unit. The ash collected can be disposed of at end of each run.

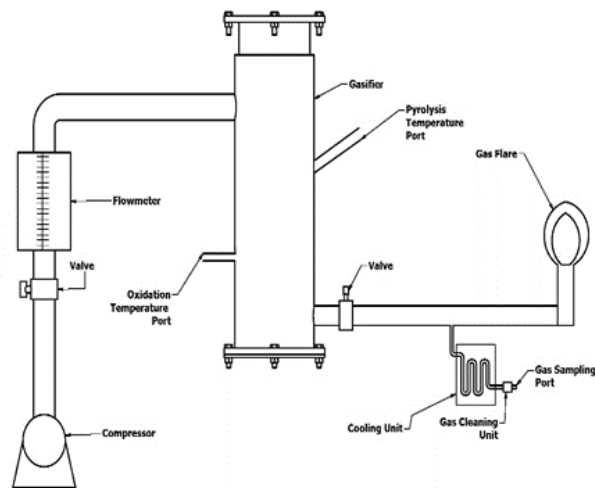


Fig 2: Gasifier system experimental unit

2.3 Gasifier start-up

A small amount of charcoal was placed over the grate; a fire was then lit by burning oil soaked papers on top of the charcoal to spread the fire across the surface. The blower was started, drawing air in to the gasifier reactor just above the charcoal bed on the grate until the charcoal bed was glowing red hot. Immediately afterwards, groundnut shell was loaded fully and the top cover was closed. Air was supplied and regulated by means of valves. Initially, white non-combustible opaque smoke was released, but after 10-15 min, the producer gas obtained became opaque and combustion could be sustained. A gas flare was established at the flare port.

The grate and pyrolysis zone temperature were measured using K-type thermocouples probes (Omega Engineering, Stamford, CT), digital thermometers (Extech Instrument model EA 11A) were used to monitor and record temperature data. Gas samples were taken with Teflon gas sample bags at regular intervals from the gas sample taken from the main pipe passed through cooling coils of copper tubes and then cleaned using a car air filter unit and analyzed at a nearby refinery using HP 58900 Series 2 gas chromatograph. When the gas sample is being taken, the valve supplying gas to the flare port is momentarily locked to increase pressure of gas flowing through the gas sample line. The air flow rate into the reactor is measured using a Rotameter (Model FL 3540 C Omega Engineering, Stamford, CT).

3. Results and discussion

To maintain a satisfactory gasification process a regular cleaning of the gasifier reactor unit and gas piping must be undertaken. Table 1 shows the chemo-physical properties of groundnut shells in comparison with fuel wood as reported by Tippayawong, et al (2009).

Table 1

Comparison of chemo-physical properties of groundnut shells and fuel wood

Property	Unit	Groundnut shells	Fuel wood (Tippayawong et al. 2009)
Apparent particle density	Kgm ⁻³	90.36	-
Bulk density	Kgm ⁻³	75	-
Fractional voidage	(-)	0.17	-
Moisture content(%wt./wt.)		8.6	-
Volatile matter (%wt./wt.)		65.11	79.0
Fixed carbon (%wt./wt.)		22.28	14.8
Ash (%wt./wt.)		3.19	5.9
C (%wt./wt.)		47.97	45.7
H (%wt./wt.)		5.79	3.7
N (%wt./wt.)		0.93	0.2
O (%wt./wt.)		39.70	44.6
HHV	MJ/kg	17.69	-

From the biomass chemo-physical properties obtained from the laboratory analysis shown in Table 2, it was clear that the proximate and ultimate analysis results of groundnut shells were comparable with fuel wood. Its ash content was very low, reducing the need to frequently removal of ash and the possibility of the occurrence of clinkering and slagging. The volatile content is not too high for the producer gas to be fed directly into an IC engine, which makes it much easier for direct burning of the producer gas. A number of test runs on the system were carried out to observe the effect varying air flow rate on the gas composition. Average values of the measurement taken at intervals

during each run after stable combustible gas has been achieved to when the feedstock has stopped producing combustible gas. The producer gas from the groundnut shells was combustible, with basically green flame. Table 2 shows the composition of the gas as determined under varying air flow rates.

Table 2

Average gas composition

Run	Percentage composition (%)					%v/v
	N ₂	CO	CO ₂	H ₂	CH ₄	
1	42.71	19.84	11.43	21.62	2.82	45.0
2	42.71	20.73	10.27	22.11	3.38	46.8
3	41.78	19.56	11.82	21.37	3.18	45.2
4	42.73	18.72	12.83	20.57	2.78	43.1

%v/v is the percentage ratio of the combustible component of the producer gas.

The shape and size of the shells were uniform, and even though the density appeared not to be sufficient (<< 200 kg/m³) (Dogru et al. 2002) to be used as a suitable feed for an Imbert gasifier (throated downdraft gasifier), but it worked in this throatless downdraft gasifier without any flow problems.

The performance characteristics of the closed top throatless fixed-bed downdraft were determined and are shown in Table 3. The lower heating value of the producer gas was estimated to be 5.58, 5.92, 5.62 and 5.33 MJ/m³ for the respective air flow rates of 0.00064, 0.00071, 0.00078 and 0.00092 m³/s. This is in the high end of the documented average gas heating value of producer gas from downdraft gasifier systems (Memphweli and Meyer, 2009).

Table 3

Gasifier performance characteristics

Run	Gas flow rate (m ³ /s)	A/F (m ³ /kg)	ER (φ)	Groundnut consumption Rate (kg/s)
1	0.00117	1.30	0.224	0.000552
2	0.00134	1.34	0.237	0.000599
3	0.00145	1.35	0.243	0.000649
4	0.00168	1.42	0.254	0.000730

A/F is the air-fuel ratio and ER (φ) is the equivalence ratio.

Fig. 3 illustrates the effect of airflow rate on the rate of groundnut shell consumption. The graph shows that the increase in the rate of groundnut shell consumption varies linearly with airflow rate increase. Increase in the airflow rate introduces more oxygen into the gasifier thereby enhancing the oxidation rate of

groundnut shell, which results to more groundnut shell combustion. The energy released will increase the rate of drying and enhance pyrolysis. Therefore, the biomass consumption rate increases not only due to a higher combustion rate, but also due to the enhanced pyrolysis and drying rate.

The effect of airflow rate on the rate of groundnut shell consumption is shown in Fig. 4. The graph shows that the increase in the rate of groundnut shell consumption varies linearly with increase in airflow rate. Increase in the airflow rate introduces more oxygen into the gasifier thereby enhancing the oxidation rate of groundnut shell, which results to a higher groundnut shell combustion. The energy released will increase the rate of drying and enhance pyrolysis. Therefore, biomass consumption rate increases not only due to a higher combustion rate, but also due to the enhanced pyrolysis and drying rate.

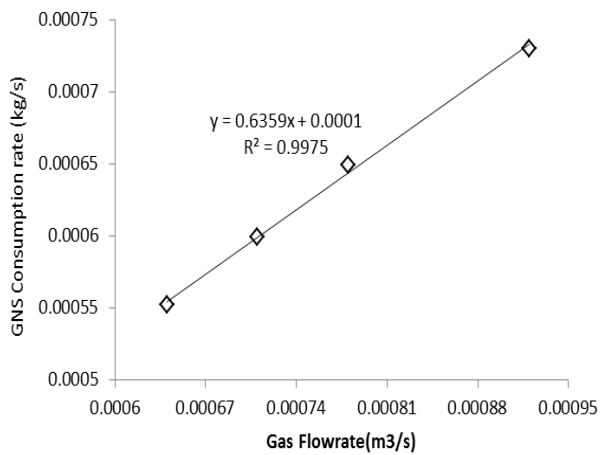


Fig 3 Effect of Air flow rate on groundnut shells consumption rate

The effect of the varied air flow rate into the gasifier reactor on the average gas composition of the producer gas samples collected from the gas sample ports during groundnut gasification is shown in Fig. 5. Volume fraction of nitrogen (N₂) and carbon dioxide (CO₂) decreases with an increase in air flow rate up to an air flow rate of 0.00071 m³/s. For air flow rates higher than 0.00071 m³/s, the volume fraction of N₂ and CO₂ shows an increasing trend. The fraction of carbon monoxide (CO) and hydrogen (H₂) shows an increasing trend opposite to that of N₂ and CO₂. As the air flow rate increases, more CO₂ is produced in the combustion zone and more N₂ flows in. The conversion of CO₂ to CO depends upon the rate of reactions occurring in the reduction zone and length of the reduction zone. With an increase in airflow rate from 0.00064 to 0.00071 m³/s, more amount of CO₂ in the combustion zone is converted into CO and H₂, and therefore CO and H₂ fractions increases with air flow rates up to 0.00071 m³/s and after which fractions of CO₂ and N₂ start decreasing. The increase in CO₂ and

decrease in CO and H₂ fractions for air flow rates higher than 0.00071 m³/s indicates that CO₂ produced in the combustion zone is in excess to that of the conversion capacity of reduction bed.

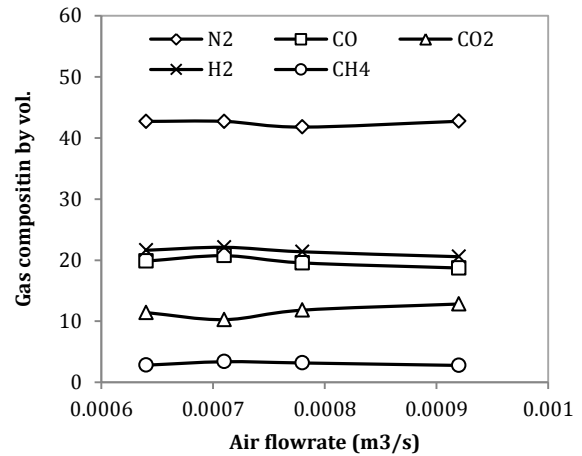


Fig 4 Effect of air flow rate on gas composition

The fraction of N₂ is constant for a particular equivalence ratio (a particular equivalence ratio is determined by a particular air flow rate) as N₂ is inert but its composition varies due to the changes in the fraction of other components of gaseous mixture.

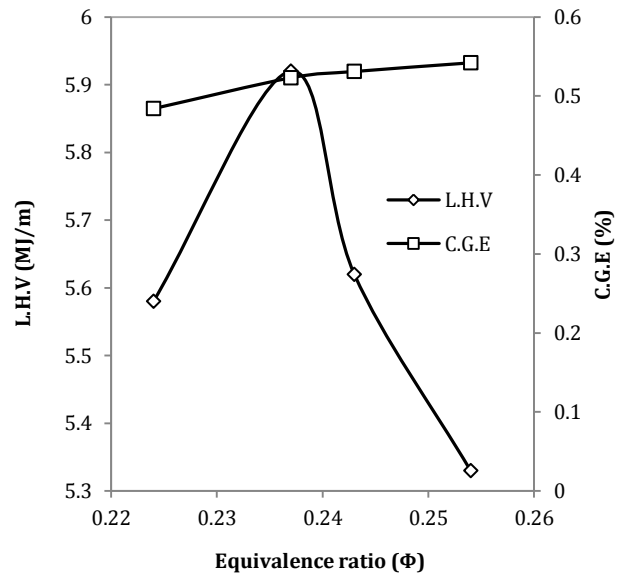


Fig 5 Effect of Equivalence ratio on Lower heating value and Cold gas efficiency

Figure 6 shows the effect of equivalence ratio on the LHV and CGE. The equivalence ratio is mainly influenced by the air flow rate when using a particular feedstock. Its influence on any parameter of the gasifier follows the same trend as the influence of the air flowrate. The C.G.E is a measure of the conversion efficiency of the gasifier, the L.H.V is the heating value of

the producer gas. The slightly higher values of the L.H.V of the producer gas can be attributed to the simple but significant air delivery arrangement mentioned earlier. This favors the production of the combustible components in the gasification reactions.

4. Conclusions

The potential use of loose groundnut shells as replacement fuel for wood and briquetted biomass in fixed-bed downdraft gasification was considered in this study. It was observed that it can be smoothly gasified in a throatless fixed-bed downdraft gasifier with minimal flow problems and further energy input to densify into briquettes or pellets can be avoided. It produces a gas with an energy content that can be used in an ICE and the feedstock has a chemical composition similar to fuel wood. Air biomass gasification was investigated in an experimental gasification system keeping to selected experimental conditions.

From the experimental investigations the gasifier was efficiently and consistently operated within the biomass consumption rate between 0.000552 and 0.000730 kg/s. The lower heating value of the obtained producer gas was within the range of 5.33 to 5.92 MJ/m³ being dependent mainly on the air flow rate into the gasifier reactor. There were no problems of ash sintering with the investigated fuel.

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