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Experimental investigation on gasification characteristic of high lignin biomass (Pongamia shells)

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ABSTRACT

Pongamia residue (shells) is the byproduct from the biodiesel processing industry, which is a lignocellulosic biomass material. It is not suitable as feedstock in downdraft wood gasifier due to low bulk density (146 kg/m^3) of shells as compared to wood (more than 350 kg/m^3). Pelletization and gasification of pelletized shells was carried out in the present work. The heat transfer analysis in pellets of 17 mm and 11.5 mm was also carried out to evaluate thermal properties of this biomass. Shell pellets of 17 mm and 11.5 mm diameter and length in the range of 10–60 mm were gasified in a 20 kW$_e$ downdraft wood gasifier. The complete gasification of pellets with 17 mm diameter could not be achieved because of less porosity and presence of larger thermal gradient within the pellets. The gasification efficiency was 73% for 17 mm diameter pellets which is lower than that of 11.5 mm diameter pellets which was 95%. The calorific value of producer gas generated from smaller diameter pellets was higher (4.66 MJ/N m^3) as compared to larger diameter pellets (3.98 MJ/N m^3). Tar formation during gasification of smaller diameter pellets was low as compared to larger diameter pellets.

1. Introduction

India, one of the leading developing countries, has huge potential of the biomass resources consisting about 321 million tons per year in agro-ecological zones [1]. Pongamia pinnata is a forest tree belonging to the family of Leguminosae, grown in all parts of India, particularly in Tamil Nadu, Andhra Pradesh and Karnataka, for its ecological advantages. The Pongamia seed contains 27–39% oil, 20–30% protein and a group of furano-flavonoids that constitute 5–6% by weight. The estimated production of seed is nearly 0.11 million tons per annum in India. The projected production of oil is nearly 30,000 tons per annum, at present [2]. Pongamia plant has potential as a renewable energy crop as its oil may be used directly with low speed compression ignition engines or upgraded via transesterification to conventional biodiesel. Extraction of oil from its seeds results in residue (shells and de-oiled cake) that needs to be disposed of. The collection and disposal of residues are becoming more difficult and expensive and may create environmental problems if they are not properly utilized. It does not find application in either agriculture farming or as animal feed due to their toxicity.

The Pongamia shells have higher lignin content (40.5% by weight) as compared to the woody biomass (from 18 to 35% by dry weight). High lignin content (>35%) biomass affects the gasification process as follows: (i) lignin is more difficult to decompose and has slower pyrolysis rate, (ii) produces more yield of char, liquid products and less gaseous products during pyrolysis, (iii) requires high temperature in gasifiers and more residence time, (iv) releases out much more hydrogen and methane in product gas, (v) higher heating value (HHV) of product gas.

Greater use of renewable energy sources is of pinnacle importance especially with the limited reserves of fossil fuels. It is expected that future energy use will have increased utilization of different energy sources, including biomass, municipal solid wastes, industrial wastes, agricultural wastes and other low grade fuels [3]. Biomass is the fourth largest source of energy in the world, accounting for about 15% of the world's primary energy consumption and about 38% of the primary energy consumption in the developing countries [4]. Woody biomass is essentially made of three major polymers namely cellulose, hemicellulose and lignin and their composition lies in the range of 40–44%, 20–30% and 18–35% dry weight respectively [5]. The pyrolysis and gasification

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provide new opportunities for the conversion of the biomass residue to clean fuel with no environmental impact [6]. However, pyrolysis is an extremely complex process; it generally goes through a series of complex reactions and can be influenced by many factors namely temperature, heating rate, reactor type, and biomass particle size [7,8].

Many types of gasifiers were reported in the past and they can be broadly categorized based on the direction of air/gas in a gasification reactor, the gasifiers are classified as up draught, down-draught and cross-draught gasifiers [9]. Biomass gasification is one of the most promising low carbon emission technologies. It enables to convert lignocellulosic matter, such as woody biomass, industrial wastes or agricultural residues, into syngas (producer gas). Producer gas has a great potential since it can be directly used for the production of heat and electricity [10].

A study on Jatropha seed shells was carried out for small scale combustion units. The combustion of Jatropha seed shells was achieved for heat generation without pelletizing or briquetting of seed shells [11]. The potential of utilization of all parts of the Jatropha curcas fruits may be used for energy generation through thermochemical gasification. Jatropha seed shells were used as feedstock in small-scale gasifiers for the generation of producer gas [12]. The gasification study on Pongamia de-oiled cake pellets. They found that pellets were not suitable for gasification in downdraft gasifier [22]. An experimental and modelling study was carried out on a downdraft gasifier and gas engine fuelled with producer gas generated from olive oil industry wastes. The calorific value of producer gas generated from crushed olive pits and small branches and leaves was 5.1 MJ/kg and 3.7 MJ/kg respectively. They found that the small branches and leaves may be used in combustion application but not for gasification [13].

Biomass briquetting and pelletization are another efficient bioenergy technology which involves densification through the application of temperature and pressure, converting low bulk density biomass into high density and energy concentrated fuel briquettes/pellets [14].

Pongamia residue is one of the abundant biomass byproduct of the biodiesel processing industry. This biomass residue (shells) consists of lignocellulosic material (cellulose and hemicellulose 59.5% and lignin 40.5% by wt.) and energy content of the shells is comparable to Jatropha shells, rice husk, which are the main energy sources in rural areas of developing countries like India. The thermochemical gasification of the Pongamia residue could be a promising residue management option to convert this residue to the useful products. However, the information on gasification of Pongamia residue is not reported in the literature. In view of above context, the objective of present work is focused on the study of Pongamia shells as an alternative source of energy through gasification. A previous study at IIT Delhi shows that Pongamia shells are not a suitable feedstock for downdraft gasifier because of its low bulk density (146 kg/m^3). The better option is to pelletize the Pongamia shells. The producer gas generated from the pellets may be used for heat and or power generation for rural areas.

2. Experimental setup and methodology

2.1. Feedstock characterization

In the present work, the Pongamia fruits were collected from the District Park of Delhi Development Authority, Hauz Khas, New Delhi and IIT Delhi campus area, New Delhi. The decortication of fruits was carried out in IIT Delhi called Pongamia shells. The Pongamia shells were air dried and crushed in the hammer mill to produce fine powder. The physical and chemical properties (proximate and ultimate analysis) of the pongamia shells are given in Table 1. The proximate analysis of the samples was carried out by using (Indian Standards) IS: 1350(P-1)1984 test method and ultimate analysis was done by IS: 1350(P-4) (Sec-1)1974 and IS: 1350(P-4) (Sec-2)1975.

2.2. Pelletization of pongamia shells

Many researchers [24–28] have studied the influence of process parameters (pressure and temperature) and biomass characteristics (moisture content and particle size) on some mechanical properties (density and durability) of various biomass and biomass residues pellets. The published literature by above researchers indicates that the bulk density of pellets decreases with increase in moisture content and particle size of the biomass material. The bulk density of pellets also increases with the increase in the die temperature. The applied pressure on the die is of marginal importance and represents the least correlated factor with density. The durability of pellets increases with increasing moisture content of biomass material. The application of high temperatures and pressures also increases the durability of the pellets.

The pelletization of Pongamia shells was carried out in two steps, namely crushing of raw material and pelletization. A special hammer mill was used for crushing of raw material. An existing hammer mill with 32 numbers of hammers and screen size of 8 mm holes was used to crush the shells into fine powder. A mixture of fine powder, water and bonding agent (if required) was prepared for production of pellets. A pelletizing machine with a flat die was used to make the pellets. The flat die has total 33 holes of 18 mm diameter with a working width of 77.5 mm and effective compression length of 45 mm, total thickness 53 mm and has a maximum output of 100 kg per hour. The power consumption of the pelletization machine was measured to be in the range of 6.8–7.0 kW at full load condition.

Another die plate of 12 mm hole diameter was fabricated. All other dimensions of the die plates were the same as the older die plate. The purpose of fabrication of this die plate was to study the effect of hole diameter on the bulk density of pellets, length of pellets, thermal properties of the pellets and quality of the producer gas generated with smaller diameter pellets.

The Pongamia shell pellets (SP) of 17 mm and 11.5 mm diameters were produced as shown in Fig. 1. These pellets were air dried and stored in the 15 kg plastic bags. The bulk density of

Table 1
Proximate analysis (% wet basis) and ultimate analysis (% dry basis) of Pongamia shells.

Sample	Proximate analysis (% wet basis)				Ultimate analysis (% dry basis)					
	Moisture (%)	Volatile matter (%)	Fixed carbon (%)	Ash (%)	C (%)	H (%)	N (%)	O[d] (%)	Bulk density (kg/m^3)	Calorific value (MJ/kg)
Pongamia shell[a]	11.61	70.83	11.86	5.70	46.02	5.58	0.23	42.46	146	16.81
Hazelnut shell[b]	12.45	62.70	24.08	0.77	46.76	5.76	0.22	45.83	319	17.36
Wood[c]	10–15	70–80	15–20	1–3	52.30	5.20	0.50	42.00	330	18.50

[a] Present study.
[b] [21].
[c] [18].
[d] By difference.