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Fabrication of a cyclone gasifier for gasification of sugarcane bagasse

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Abstract
The world is facing serious environmental problems due to the green house gas emissions from the use of fossil fuels. Renewable energies like biomass fuels can play an important role in reducing green house emissions and other pollution. A research study was carried out to pre-treat sugarcane bagasse through torrefaction process for generating a non-cohesive powdery bagasse and to fabricate a cyclone gasifier for gasification of sugarcane bagasse. A 1D1.5D nomenclature of the cyclone was selected for fabrication of a cyclone gasifier. The cyclone having a barrel of 150 mm diameter, cone of top and bottom diameter are 150 and 75 mm respectively, tangential inlet duct of rectangular cross-section (38x75 mm), cleaned gas outlet of 93.7 mm diameter, dust outlet of 78 mm diameter and 50 mm in length was developed. The biomass feeding rate was kept as 40 kg/h for the selected particle size range of 0.18-0.70 mm. The heating value of the producer gas at an equivalence ratio of 1:4 was about 5.0 MJ/Nm^3. The present study concludes that the torrefaction of biomass improves grindability, proximate composition by increasing the carbon content with a decrease in moisture and oxygen content, and biochemical composition by decomposition of hemicelluloses and softening of lignin. As per cyclone separator design standards, the coarse and fine particles in the size ranges of 0.35-1.40 mm and 0.18-0.70 mm can be best separated and gasified in a cyclone separator of 1D2D and 1D1.5D nomenclature respectively.

Keywords: gasification; cyclone; equivalence ratio and producer gas

Introduction
The world is currently challenged to reduce dependence on fossil fuels and achieve a sustainable, renewable energy supply. Increasing biomass use for energy can help to reduce the greenhouse gas (GHG) emissions. The growing interest in biomass as a solid fuel includes combustion to produce steam for electrical power, as well as gasification to produce a combustible gas and syngas. The characteristics of the fuel (bagasse) can be improved by torrefaction process. Torrefied biomass, in general, defines a group of products resulting from partially controlled and isothermal pyrolysis of biomass occurring at the 200-300ºC. The most common torrefaction reactions include devolatilization, carbonization of hemicelluloses, and depolymerisation, devolatilization of lignin and cellulose. Torrefaction of the biomass helps in developing a uniform feedstock with minimum variability in moisture content.
Bagasse is not suitable for gasification in its raw form because of its non-uniformity, low bulk density and flow problems due to cohesive nature of its powder. Gasification of powdery bagasse after the torrefaction and grinding of raw bagasse is one of the promising options for utilizing the bagasse in a cyclone gasifier (Bhardwaj M, 2016) [3, 4].
Gasification is a process that converts organic or fossil fuel-based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide (Anon 2018).Thermo-chemical processes such as gasification, pyrolysis and direct combustion can be used for conversion of biomass (including sugarcane bagasse) to bio-energy. The direct combustion takes place in excess of air (over stoichiometric) and heat is the desired end product. The pyrolysis process takes place at low temperatures (400 - 600 °C) and here the goal is to maximise liquids production. The gasification involves partial oxidation (air, O_2, steam) of fuel and here the goal is to maximise gaseous products (mainly CO and H_2) (Baumlin *et al.*, 2006) [2].
Cyclones have conventionally being used for removing particulate matter from air streams at low cost and low maintenance. The use of cyclone as a gasifier is done for avoiding excessive amounts of alkali compounds in the producer gas. The advantage with this technique is that the gasification temperature might be kept at a level where the volatilization of corrosive elements such as sodium and potassium is reduced to a great extent.

The sodium and potassium can then be separated with the char residue. The cyclone gasifier holds the potential for gasifying problematic fuels like bagasse, miscanthus, switchgrass and paddy straw which have high ash content (Wang *et al*., 2006) [9].

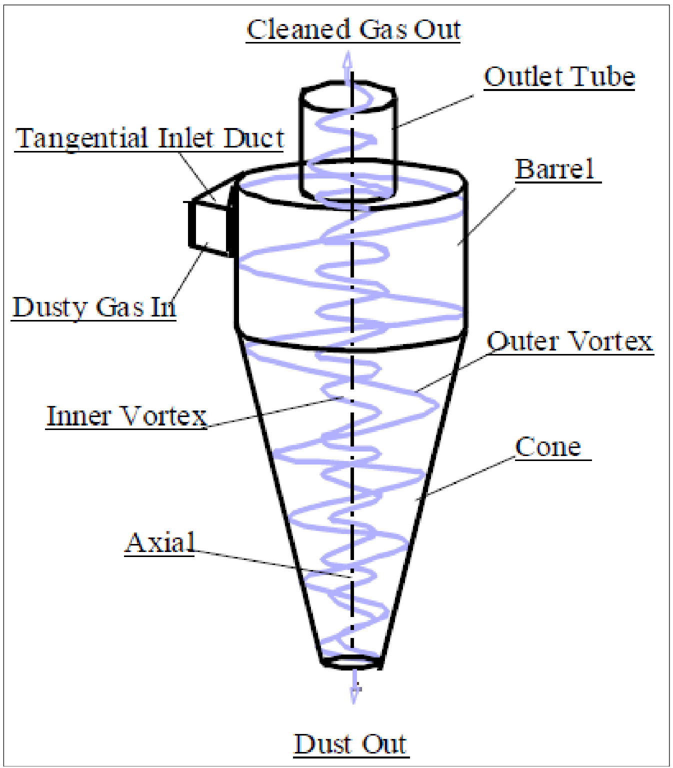

Fig 1: Schematic flow diagram of a cyclone, Wang *et al* (2006) [9].

Cyclone gasification is a process for combined heat and power production. Cyclone gasifier consists of powder hopper, screw feeder, ejectors, cyclone gasifier and char bin. Through powder hopper, material was fed continuously and with the help of screw feeder and ejectors material was carried out further to cyclone gasifier. Inside cyclone gasifier, material moves centrifugally while char was collected at the bottom and producer gas was collected from the top of the cyclone (Risberg *et al*., 2015) [8]. Gabra *et al*., (1997) [6] found that for the smooth and continuous operation of a cyclone gasifier working on bagasse, fuel was fed continuously and without interruption or large fluctuations. A feeding system was developed consisting of a feeding bin with four feeder screws in the bottom which delivers the fuel to two downcomers from which the fuel is injected by steam into the gasifier. Low bulk density and cohesive characteristics of a crushed bagasse were found to cause an accumulation of the fuel in the feeding system, creating difficulties for the flow into the gasifier. This problem was eliminated by changing the shape of the slivers of the crushed bagasse to render them more homogeneous. This was achieved by pelletizing the crushed bagasse or cane trash before grinding it to powder but in present study torrefied bagasse is used as a fuel in cyclone gasifier and fuel is injected by air into the gasifier.
Gabra *et al*., (2001) [5] evaluated cyclone gasifier as a means for avoiding excessive amount of alkali compounds and carryover particles in producer gas from gasification of sugarcane residue. Bagasse powder was injected into the cyclone with air and steam as transport medium. Gasification tests were made with two feeding rates, 39 and 52 kg/h, heating values of the producer gas are sufficient for stable gas turbine combustion.

Material and Methods

While developmentofcyclone gasifier, the different components viz. barrel, cone, tangential inlet duct, hopper, square flange, circular flange, cleaned gas outlet, burner, dust outlet, base and pipe were considered. Accessories viz. axial flow blower (0.5 hp), gasket, gate valve, vane anemometer and digital thermometer (Cr/Al type) of range of 1200º C were used.
The feed rate of the hopper was computed by using a pipe of 1 inch indiameter and 1 foot in length. Every time, the free flowing bagasse was passed through thepipe for 5 minutes. The processwas repeated four times to determine feed rate of sugarcane bagasse flowing freely under gravity. CATIA software had been used for drawing of parts and assemblies of those parts.

Barrel Unit assembly

Barrel unit is the assembly of a cyclone gasifier. It was made up of M.S. sheet of 12.5 gauge i.e. 4mm thickness.

Cone Unit assembly

Cone unit is the assembly of a cyclone gasifier. After barrel unit, air and torrefied bagasse has entered the cone in a centrifugal motion and ash gets collected at the base.
The ratio of barrel to cone is 1: 1.5 unlike of cyclone separator in which cone length is more as compared to barrel and moreover cyclone separator separates dust particles only but cyclone gasifier will do both things i.e. gasification as well as separation of dust particles.

Tangential inlet duct and hopper unit assembly

Tangential inlet duct and hopper unit is the assembly of a cyclone gasifier. Through blower air is blown inside the tangential inlet duct and torrefied bagasse particle spun in a centrifugal motion. Hopper is placed above the tangential inlet duct so that bagasse will be fed uniformly. Tangential inlet duct and hopper unit is placed above the barrel unit.

Dust outlet and base unit assembly

Dust outlet and base unit is the assembly of a cyclone gasifier. After cone unit, ash will be passed through dust outlet and collected at the base. The complete 3D-drawing of a 1D1.5D cyclone gasifier is shown in Fig. 2.

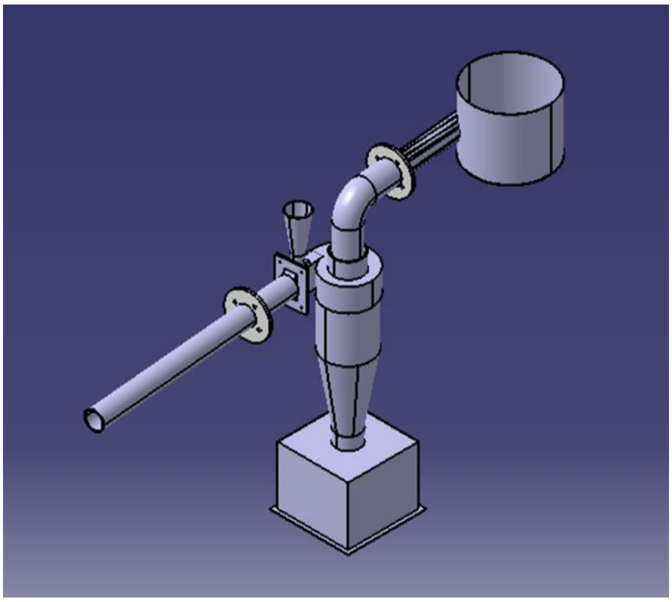

Fig 2: 3D-drawing of a 1D1.5D cyclone gasifier

Results and Discussion

Wang *et al*., (1999) [10] reported that 1D2D cyclone is a better design for high-lint content trash compared with 1D3D and 2D2D cyclones.

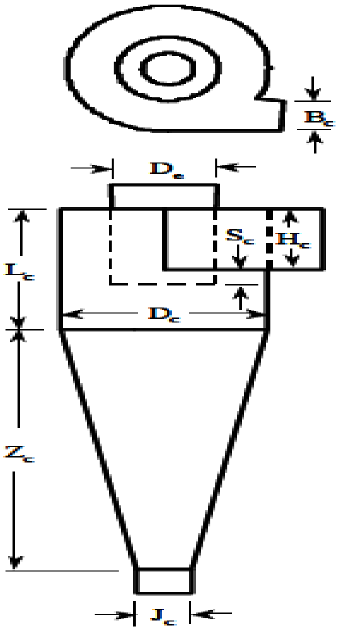

Fig 3: Design of a 1D1.5D cyclone gasifier

In the present study, the 1D1.5D nomenclature of the cyclone was chosen for fabrication of cyclone gasifier. Considering an equivalence ratio of 1:4, the cyclone specifications, inlet air flow rate and the inlet dimensions were determined. The values of feed rate of sugarcane powdery bagasse flowing freely under gravity are presented in table 1. The average freely flowing bagasse feed rate was worked out to be 42.66 kg/h.

Table 1: Feed rate of sugarcane bagasse flowing freely under gravity

Sr. No.	Bagasse (g) (collected after 5s)	Feed rate (kg/h)
1	58.60	42.19
2	59.50	42.84
3	58.90	42.41
4	60.00	43.20

According to Kaupp and Goss (1984), the carrying velocity requirement for the dry density medium dust is 15 m/s. The cyclone gasifier was operated with selected particle size mainly in the range of 0.18 to 0.70 mm. Hence, a little lower velocity of 12 m/s was selected. The 1D1.5D cyclone design computations are shown in table 2.

Table 2: Calculation of a 1D1.5D cyclone gasifier

Parameter	Formula	Dimension (mm)
Dia. of blower, B_c	$B_c= D_c/4$	37.5
Dia. of dust outlet, J_c	$J_c= D_c/2$	75.0
Dia. of cleaned gas outlet, D_e	$D_e = D_c/1.6$	93.7
Distance between cleaned gas outlet bottom and tangential inlet dust base, S_c	$S_c = 5D_c/8$	93.7
Height of tangential inlet duct, H_c	$H_c = D_c/2$	75.0
Length of barrel, L_c	$L_c= 1 \times D_c$	150.0
Distance between the top and bottom of the cone, Z_c	$Z_c= 1.5 \times D_c$	225.0

A feeding system for bagasse was developed for providing the cyclone gasifier with a reliable and controllable fuel flow. The first feeding test were performed with torrefied bagasse (0.18-1.40 mm). The low bulk density and cohesive character of powdery bagasse initially created a great number of difficulties concerning the flow of the fuel. Initially, angle of repose was determined as 50º. Accordingly, 38 inches long hopper with an inclination of 82º was manufactured. While using this system for feeding the torrefied powdery bagasse in the range of 0.18 to 0.70 mm, no flow occurred. Thereafter, the angle of repose was again measured with more precision. Although, the exact value of angle of repose could not be ascertained, it was apparent that value was close to 55º. A long feeding pipe of 50 inches was used to allow for sufficient fuel for one observation of the relevant gasifier parameters. The fuel was fed manually through this pipe. The blower was fitted with circular pipe along with agate valve. The purpose of this gate valve was to control the air flow rate.
The chemical analysis of sugarcane bagasse is summed up in the table 3.

Table 3: Chemical analysis of sugarcane bagasse

Parameter	Results (in %)
Hemi- cellulose	25.6
Cellulose	45.2
Lignin	14.4
Ash	4.9
Others	9.9

Conclusion

The present study concludes that the torrefaction of biomass improves grindability, proximate composition by increasing the carbon content with a decreasein moisture and oxygen content, and biochemical composition by decomposition of hemicelluloses and softening of lignin (Bhardwaj *et al*., 2016) [3, 4]. As per cyclone separator design standards, the coarse particles in the size range of 0.35-1.40 mm can be best separated in a cyclone separator like 1D2D nomenclature and fine particles in the size range of 0.18-0.70 mm can be separated and gasified in a 1D1.5D nomenclature.

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