Applied Thermal Engineering 73 (2014) 238–244

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Fluid-dynamic assessment of sugarcane bagasse to use as feedstock in bubbling fluidized bed gasifiers

Nestor Proenza Pérez*, Einara Blanco Machin, Daniel Travieso Pedroso, Julio Santana Antunes, Jose Luz Silveira

São Paulo State University, Faculty of Engineering of Guaratinguetá, Department of Energy, LOSE Laboratory, Brazil

HIGHLIGHTS

- The ideal range of diameters of sugarcane bagasse particles was proposed in the range between 0.8 and 1.21 mm.
- The behavior of the main fluidization parameters for the range of diameters proposed was studied.
- The composition of the producer gas was modeled, as well as its LHV reaching 4560 kJ/Nm^3.

ARTICLE INFO

Article history:
Received 28 March 2014
Accepted 17 July 2014
Available online 25 July 2014

Keywords:
Biomass
Bubbling fluidized bed gasifier
Renewable energy
Sugarcane bagasse

ABSTRACT

The fluid bed gasification of a sugarcane bagasse is a promising option for the large-scale production of fuel gas in order to increase the energetic efficiency of the sugar industry. A fluid-dynamic and thermodynamic assessment of the use of sugarcane bagasse as feedstock for a bubbling fluidized bed gasifier was performed. It was determined the required range of sugarcane bagasse particles sizes to permit the use this biomass as feedstock in bubbling fluidized bed gasifiers and the main fluidization parameters for the range of diameters proposed, with good agreements with the experimental values reported for the same Geldart's type of particles. A range of particle sized between 0.8 and 1.21 mm was suggested. The producer gas composition was modeled using air as gasification agent, obtaining a theoretical LHV of 4.56 MJ/Nm^3.

1. Introduction

Lignocellulosic biomass wastes are featured by their non-edible characteristic; hence, they have no risk causing food shortage when the wastes are consumed for energy. For this reason, the utilization of lignocellulosic biomass wastes as fuels has attracted remarkable interest in the development of bioenergy.

Sugarcane is cultivated in more than 80 countries and the by-products obtained from the sugar production process represent a great biomass potential. The harvest of sugarcane in the producing countries is about 1.2 Gt and potentially its residue can be used for an electric power production of about 300 TWh y^{-1} [1]. Sugarcane has a great capacity to produce biomass, yielding about 100 t/ha.

The sugarcane bagasse is undoubtedly the most representative biomass in the Brazilian energy matrix, being responsible for the supply of thermal, mechanical and electrical power to the industry units that produce sugar and alcohol through cogeneration.

Bagasse is the crushed outer stalk material formed after the juice extraction from sugarcane, in sugar mills. This by-product represents between 25% and 40% of the total processed material in the juice extraction, depending of the sugarcane fiber contents and the efficiency of the process.

Traditionally, sugar mills use bagasse and cane trash with a high moisture content as fuel for low-pressure boilers to generate steam, using a conventional condensing-extraction steam turbine (CEST) technology, to provide the plant of heat, electricity and mechanical power. In recent years have seen more modern systems for burning bagasse in suspension, that allow to raise the steam pressure and temperature for the purpose of obtaining a higher electric power cycle cogeneration [2–4]. The thermal efficiency of the plant is usually in the range of 15–30% [5], consequently the size of conventional combined heat and power generation plants from

* Corresponding author. Tel.: +55 12 3123 2240.
E-mail addresses: nestor@feg.unesp.br, nestorproenza@yahoo.es (N.P. Pérez), einara@feg.unesp.br (E.B. Machin), danieltravieso@feg.unesp.br (D.T. Pedroso), santana@feg.unesp.br (J.S. Antunes), joseluz@feg.unesp.br (J.L. Silveira).

http://dx.doi.org/10.1016/j.applthermaleng.2014.07.048
1359-4311/

Nomenclature

LHV	lower heating value [MJ Nm^{-3}] [MJ kg^{-1}]
$x_n X$	Predicted value in mol of element X [mol]
K_1	methane formation constant [−]
K_2	constants of shift-gas reaction [−]
ΔG^0	standard Gibbs function of formation [kJ kmol^{-1}]
J,I	integration constants
ΔH^0	heat of formation [J mol K^{-1}]
A,B,C,D	constants for determination specific heating [−]
K	equilibrium constant [−]
$\varepsilon_{\mathrm{mf}}$	minimum fluidization porosity [−]
ε_f	bed porosity [−]
A_r	number of Archimedes [−]
d_P	particle diameter [−]
ρ_f	density of the air at the temperature and pressure of entry in the gasifier [kg m^{-3}]
ρ_p	density of bed material [kg/m^{-3}]
μ_f	air viscosity at the temperature and pressure of entry in the gasifier [Pa s]
g	gravity acceleration [m^2 s^{-1}]
V_{mf}	minimum fluidization velocity [m s^{-1}]
ϕ	sphericity of bed particles [−]
V_t	fluidization terminal velocity [m s^{-1}]
C_D	drag coefficient [−]
V_f	fluidization velocity [m s^{-1}]
R_{emf}	Reynolds's number at minimum fluidization estate [−]
ρ_a	bulk density [kg m^{-3}]

bagasse, have been limited by these low efficiencies and the amount of fuel within an economical transportation radius.

In the wake of past developments of coal gasification, biomass gasification is one of the most scrutinized avenues to biomass thermochemical conversion where the produced gas can be used either for energy production (heat, electricity) or as a starting material for the production of fuels and various chemicals [6].

The Biomass Integrated-Gasifier/Gas Turbine Combined Cycle (BIG/GTCC) technology has being identified by several authors [7,8] as an advanced technology with potential to be cost-competitive with CEST technology using the biomass by-products of sugarcane-processing as fuel, while dramatically increasing the electricity generated per mass unit of sugarcane processed.

Numerous studies have identified fluid bed gasification of a sugarcane bagasse as a promising option for the large-scale production of fuel gas from this biomass, in order to increase the energetic efficiency of the sugar industry [5,9–11]. However, there are limited information about the sugarcane bagasse requirements as well as the thermodynamic and fluid-dynamic behavior of this feedstock in bubbling fluidized bed reactors.

Against this background, the goal of this paper is a fluid-dynamic assessment of the use sugarcane bagasse as feedstock for a bubbling fluidized bed gasifier.

2. Gasification in fluidized bed reactors

Gasification is a thermochemical process in which a carbonaceous substrate (biomass) is transformed into a fuel gas (producer gas), through a number of reactions that take place at a high temperature in the presence of a gasifying agent (air, oxygen or water vapor). The producer gas is the principal product of gasification, and its heating value (LHV) varies depending on the composition of biomass and the gasifying agent utilized. Using air as the gasifying agent for biomass gasification, the LHV of the producer gas is in the range of 4–6 MJ/Nm^3 and using water vapor and oxygen the LHV is between 8 and 20 MJ/Nm^3 [12].

Fluidized bed reactors are those in which the gasification agent circulates inside of the reactor bed at a rate in which the bed material remain in a fluidization state, increasing the energy transfer intensity between the inert material and the fuel, as well as the homogenization of the temperature in the reactor bed. There are two categories within these types of gasifiers: bubbling and circulating (Fig. 1).

In the circulating fluidized bed (CFBG), the velocity of the gasification agent is high, resulting in a fuel circulation, enabling a high energetic efficiency of the gasification process in these reactors. This solid is recirculated to the reactor by the use of a cyclone and a return system to the gasifier.

In the bubbling fluidized beds (BFBG), the fluidization velocity of the gasification agents is low enough that do not causes a significant movement of the fuel in the bed. The size of the bubbles principally depend of the size of fuel particles and the height of the reactor bed.

The main advantages of fluidized beds include better control of temperature and reaction rates, high specific capacity, potential scaling to larger sizes than fixed bed reactors and possibility to manage a wide biomass types. As drawback, this technology show moderate-high tars and particulates levels in the exhaust gas and the fuel conversion are not as high as in the fixed bed gasifiers.

The technology of CFBG is more adequate for big power generation systems (greater than 100 MW), due to its high operation cost and complexity, compared to the BFBG. The BFBG are suitable for smaller power generation systems (less than 100 MW), that is our case of study, where be used as feedstock the surplus bagasse of the plant. The scaling of this technology to a larger capacity is limited by the operation difficulties observed during the handling, transportation and feeds of large quantities of sugarcane bagasse to a fluidized bed gasifier, in previous experiences [13]. The sugarcane bagasse gasification in a BFBG is the objective of this work.

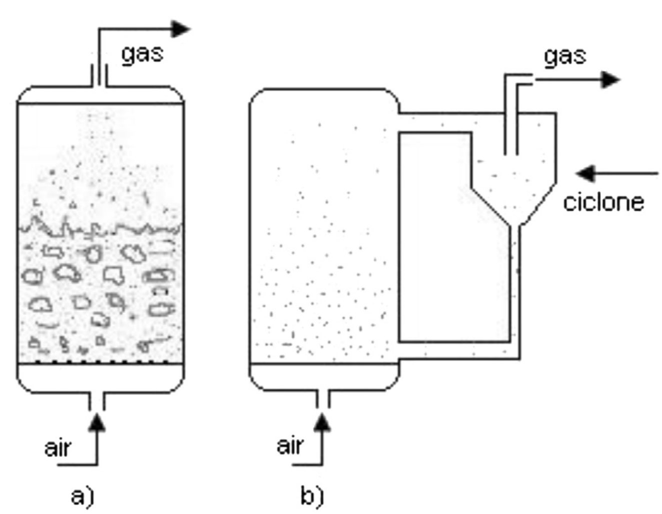

Fig. 1. a) Bubbling fluidized bed gasifier. b) Circulating fluidized bed gasifier.