Biomass and Bioenergy 88 (2016) 77–88

Contents lists available at ScienceDirect

Biomass and Bioenergy

journal homepage: http://www.elsevier.com/locate/biombioe

Research paper

Experimental investigation of the effect of physical pre-treatment on air-blown fluidized bed biomass gasification

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ARTICLE INFO

Article history:
Received 3 July 2015
Received in revised form
5 March 2016
Accepted 7 March 2016

Keywords:
Biomass gasification
Fluidized bed
Comminution
Drying
Pelletization
Biomass pre-treatment

ABSTRACT

The effect of comminution, drying, and densification on bubbling fluidized bed gasification was investigated by fractionating a forestry residue into a feedstock consisting of different particle sizes, moisture levels, and by densifying to pellets. The gasification performance was evaluated at nominal average bed temperatures of 725°, 800° and 875 °C at a constant fluidizing velocity (0.91 m s^{-1}) with feed input rates between 9 and 24 kg h^{-1}.

The gas composition was observed to be influenced by both the particle size and form. Smaller particles led to a gas richer in carbon monoxide and depleted in hydrogen. The gasification of pellets led to a gas with the greatest hydrogen to carbon monoxide ratio. The smallest particles tested resulted in the worst gasification performance, as defined by cold gas efficiency, carbon conversion, and tar production. Despite differences in the gas composition among the larger particles and the pellets, similar carbon conversion and cold gas efficiency was observed.

Relative to comparable test conditions with dry feed fractions (having a moisture mass fraction of 7–12%), an average 11% increase in carbon conversion was observed for the wetter feed fractions containing a moisture mass fraction of 24–31%. This increase in carbon conversion offset much of the expected decrease in cold gas efficiency by using a wetter feed material. A slight increase in hydrogen production and negligible change in tar production was observed for the wetter feed fractions relative to the dry feed fraction.

1. Introduction

Canada has significant biomass resources with the potential to displace fossil energy. Gasification is one technology for the conversion of wood wastes or other residual biomass materials into heat, power, fuels, or chemicals. These low cost residual biomass materials present a variety of process challenges because of high moisture, low bulk density, and heterogeneity. Some form of basic pre-treatment – comminution, drying, or pelletizing—may be necessary in order to allow these materials to be reliably conveyed to the gasifier and efficiently converted. There is a necessity to understand how these basic pre-treatment processes impact the performance of a biomass gasifier, to evaluate the trade-off between increased pre-treatment costs and improved gasifier performance.

A review on the effect of particle size, moisture content, and density of a wood particle on its thermal conversion characteristics has been presented elsewhere [1]. With respect to drying, the dominant impact of the additional moisture is due to the additional energy required for evaporation of water. In order to gasify a higher moisture feedstock material, either higher equivalence ratio (ER) is required to operate at the same bed temperature or external energy input is required to maintain the same bed temperature at the same ER. Often, additional moisture has been observed to have negative impacts on fluidized bed gasification of biomass. In air-blown circulating fluidized bed gasification, van der Drift et al. reported that for different feedstocks where the ER was adjusted to control temperature, high amounts of moisture relative to ash-free material led to decreases in the heating value of the gas and a decrease in cold gas efficiency [2]. Using an air-blown bubbling fluidized bed gasifier where the ER was fixed, Kaewluan and Pipatmanomai reported that additional moisture led to decreased reactor temperatures, lower cold gas efficiency, lower carbon conversion and a decrease in gas heating value [3]. However, some benefits of

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http://dx.doi.org/10.1016/j.biombioe.2016.03.009
0961-9534/

Nomenclature

Symbols

CGE	Cold gas efficiency
C	Concentration (g m-3)
x	Conversion
ER	Equivalence Ratio
K	Equilibrium constant
$\dot{m}$	Mass flow rate (kg h^{-1})
$\dot{n}$	Molar flow rate (mol h^{-1})
$\widehat{E}$	Specific higher heating value (MJ kg^{-1})

Subscripts

Eq,WGS	At equilibrium of the water-gas shift reaction
C	Carbon
C,feed	Carbon from feed material
C,dry gas	Carbon in the dry producer gas
H,feed	Hydrogen from feed material
biomass,db	Input biomass on a dry basis
O_2,air	Molecular oxygen from air
Obs	Observed
dry gas	Of the dry producer gas
O,feed	Oxygen from feed material

Abbreviations

BTEX	Benzene-Toluene-Ethylbenzene-Xylene
ER	Equivalence Ratio
GC	Gas Chromatograph
ISO	International Standards Organization
PAH	Polycyclic Aromatic Hydrocarbons

One cubic meter of gas (m^3) standardized to 0 °C and 101.325 kPa.

additional feedstock moisture have been observed. Using an air-blown bubbling fluidized bed gasifier while maintaining a constant reactor temperature and equivalence ratio using external heating, van Paasen and Kiel reported a reduction in the tar content of the gas and an increase in hydrogen concentration with additional moisture [4].

The impact of particle size has been studied in a handful of experimental works in fluidized bed gasifiers. At particle sizes below 2 mm, some studies reported that particle size has little impact on the producer gas composition and the gasifier performance, while others reported that smaller particle sizes improve carbon conversion, gas yield and gas heating value [5–7]. Literature on continuous fluidized bed gasification of the same feedstock at larger particle sizes is sparse. Raman et al. presents data using different sieve fractions between 0.4 and 11.2 mm [8]. The highest gas heating values and largest gas yields were produced at intermediate sizes, but conditions such as feed rate and reactor temperature were not constant throughout the experiments. van der Drift and van Doorn present data on three particle sizes with linear dimensions between 2 and 40 mm [9]. The data shows higher tar concentration for the smallest particles tested, but minimum heavy tar for intermediate sizes.

Only two published studies could be found where biomass pellets are compared to the same material in an unpelletized form in a fluidized bed gasifier [10,11]. In both of these studies, pelletizing the biomass led to a gas that was richer in H_2 relative to CO and that pelletization lowered the tar content of the producer gas.

The objective of this paper is to describe how the physical pre-treatment of biomass (drying, comminution, and pelletization) impacts the performance of a 40–120 kW thermal input fluidized bed. Drying, comminution, and pelletization processes all represent a substantial increase to the costs of feed pre-treatment for biomass gasification—an understanding of how feedstock pre-treatment can be used to alter or optimize gasification performance is critical for the gasification of biomass to be competitive with traditional routes of energy production.

2. Materials and methods

2.1. Bubbling fluidized bed gasification facility

The CanmetENERGY small pilot-scale bubbling bed gasifier (Fig. 1) has an inner diameter (ID) of 0.16 m for the first 1 m from distributor and tapers down to 0.13 m ID for the remainder of the freeboard. The total height of the system from the distributor to the top of the freeboard is 4.5 m. The distributor has eight 6.35 mm nozzles placed in a circular pattern. The flow rate of fluidization air is controlled through the distributor. The feed port is located 0.9 m above the distributor, which is above the expanded bed height but below the taper from 0.16 m ID to 0.13 m ID. Electric band heaters envelop the bed region to pre-heat the bed. The gasifier is instrumented with seventeen type K thermocouples and seven pressure transmitters.

In this work, olivine sand with a size distribution such that close to 90% of the particles were retained between 149 and 590 μm screens was used as the bed material. The Sauter mean diameter was determined to be approximately 350 μm and the particle density was reported by the supplier to be 2.83 g cm^{-3} on average. The minimum fluidization velocity was experimentally determined to be approximately 0.09 m s^{-1} at ambient temperature. The olivine sand had been previously conditioned during gasification of forestry residues in a 1 m diameter gasifier.

2.2. Sampling and characterization of gas and tar

The product gas was extracted from the system at the exit of the hot cyclone, labelled as “Gas Sampling Location” in Fig. 1. For all the gas sampling and characterization, the gas sample was first drawn through a stainless steel filter (nominal filtration size of 1 μm) maintained at 400 °C.

For tar sampling, a portion of the hot-filtered gas passed through heated lines (at 400 °C) followed by a set of seven impingers, each containing 200 cm^3 of isopropanol. The first three impingers were placed in a water bath kept at between 20 °C and 30 °C. The last four impingers were cooled down to between −5 °C and −20 °C. The gas was drawn at a rate of 3–7 dm^3 min^{-1} through the impinger set for approximately an hour. The isopropanol-tar solution from all seven impingers was mixed together and then analyzed for tar content by two methods: evaporation and gas chromatography/mass spectrometry (GC/MS). The evaporation method was carried out in a rotary evaporator in two stages using 50 cm^3 of the isopropanol-tar solution at 60 °C and a minimum pressure of 9 kPa absolute in order to recover the tar from the isopropanol-tar solution. The tar concentration determined in this