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Comparison of the air-blown bubbling fluidized bed gasification of wood and wood–PET pellets

T. Robinson [a], B. Bronson [b,*], P. Gogolek [b], P. Mehrani [a]

[a] Department of Chemical and Biological Engineering, University of Ottawa, 161 Louis Pasteur Street, Ottawa, Ontario K1N 6N5, Canada
[b] Natural Resources Canada, CanmetENERGY, 1 Haanel Drive, Ottawa, Ontario K1A 1M1, Canada

HIGHLIGHTS

- Co-gasification of wood pellets and PET pellets caused coking in the bed.
- Composite wood–PET pellets were gasified without coking.
- Wood–PET pellets resulted in more tar formation than wood pellets.
- Tar reduction methods to make gas suitable for engine use were evaluated.

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ABSTRACT

Air-blown bubbling fluidized bed gasification of wood pellets and wood–PET (polyethylene terephthalate) pellets was conducted at 725 °C, 800 °C, and 875 °C. Gasification of mixtures of wood and PET pellets was attempted; however, rapid formation of coke above the fluidized bed prevented steady state operation of the gasifier. Coking was prevented when wood and PET were formed into composite wood–PET pellets. The performance of wood pellets was better than wood–PET pellets. Tar concentrations were lower, while, heating values, thermal outputs, and efficiencies tended to be higher for wood pellets than wood–PET pellets. The addition of secondary air above the fluidized bed was explored as a means of reducing the tar content of the produced gases. The influence of the produced gas tar concentrations on down-stream tar removal units was considered.

1. Introduction

1.1. Remote communities

The provision of electrical power to small off-grid remote communities in Canada is problematic. These communities cannot be cost-effectively connected to the North American power grid, so power is mostly supplied using diesel engines [1]. Limited accessibility to many of these communities makes diesel fuel expensive, and, consequently, electricity is very expensive. In 2011, the most recent year for which data is available, the average un-subsidized price of diesel generated electricity was 1.3 $/kW h [2].

The high cost of electricity in remote communities makes exploration of alternative fuels attractive. If a locally available resource was used for generation of electricity the cost of importing diesel could be avoided. Dual fuel operation using combustible gases produced from wood has been found to be a promising means of generating power in remote communities [3,4]. Remote communities might also be able to extract energy from refuse.

Co-gasification of biomass and refuse is attractive since remote communities have limited waste management capabilities. The authors have previously studied the bubbling fluidized bed co-gasification of biomass and a commercially available refuse derived fuel (RDF) [4]. It was found that the commercially available RDF tended to cause agglomeration of the bed material at temperatures above 800 °C. This limited operation of the gasifier to a temperature range which was not optimal for conversion of biomass. Dunnu et al. also noticed agglomeration when conducting fluidized bed gasification experiments, at 850 °C, on a different commercially available RDF, but in this case the agglomeration did not cause a loss of fluidization [5]. Additionally, Van Caneghem et al. provide a thorough discussion of the factors involved in bed agglomeration during fluidized bed incineration of waste materials [6]. Agglomeration is caused by the presence of silica and alkali

* Corresponding author. Tel.: +1 613 797 3097.
E-mail address: Benjamin.Bronson@Canada.ca (B. Bronson).

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metals [6], which are present in the RDF since it is manufactured from mixed waste. These materials are present despite the intervention of sophisticated, large scale, commercial processes, which seek to deliver a high quality fuel. Remote communities do not have access to the economy of scale required for the implementation of such a process so any mixed waste derived fuel manufactured in a remote community would certainly be of a lower quality than commercially produced RDF.

While it might be possible to produce an RDF from mixed waste with lower concentrations of silica and alkali metals than the RDF previously investigated by the authors the process required to produce such a fuel would likely be too complex to be implementable on the scale of a small remote community. A more appropriate option for a remote community might be to target certain waste items or materials for separation within households. Non-biodegradable plastic waste such as water bottles and plastic food containers could be diverted from the community landfill. Co-gasification of biomass and plastic in a remote community might be feasible if clean plastic materials were source-separated and subjected to minimal processing. In order to understand the gasification performance of biomass and a sorted plastic stream, gasification of wood pellets and polyethylene terephthalate (PET) was investigated in this work.

1.2. Co-gasification of biomass and plastic

Differing motivations exist for the gasification of biomass and plastic materials. Displacing fossil fuels with a carbon neutral energy source is the clearest motivation for the gasification of biomass. Globally, there is much concern about the release of greenhouse gases from the use of fossil fuels, and much research has been conducted on the extraction of energy from biomass as a means of reducing these emissions. On the other hand, reducing the amount of material sent to landfill is the clearest motivation for the gasification of plastic materials [7–10]. However, energy derived from plastic materials is not carbon neutral. If the goal of gasifying biomass is to reduce emissions of fossil carbon to the atmosphere, then co-gasification with plastic is counter-productive, since the fossil carbon in the plastic could be interred in a landfill, where, due to its non-biodegradability, it would be sequestered. If the goal of gasifying plastic is to reduce the volume of material sent to landfill then mixing biomass with plastic may be counter-productive since biomass tends to yield more ash and more char than most plastics [11]. Additionally, high quality biomass such as virgin wood is not classified as waste material for the purposes of regulation [12,13]. When virgin wood is mixed with waste the mixture becomes waste and this classification complicates utilization of the material since the disposal of waste is heavily regulated.

This aside, benefits have been realized from the co-gasification of biomass and plastic. During steam gasification, increasing the fraction of plastic in a biomass-plastic feed has been found to increase the conversion of the fuel to gas, since addition of plastic reduces the production of char and ash [11]. Also, co-gasification of biomass and plastics has been conducted to overcome difficulties with the seasonal availability of biomass [14,15], overcome difficulties encountered when plastic is fired alone [16,14], modify the composition of the produced gas [14], and allow plastic to be fired in a downdraft gasifier [17]. Though a large body of work exists on the gasification of plastics and the co-gasification of biomass and plastics, most of that work focuses on polyethylene. Only a few references could be found to the gasification of PET.

Matsunami et al. [18] investigated the use of PET in a simulated solar gasification process. Gil et al. [19] investigated the CO_2 gasification of char produced from PET. Kannan et al. [20] simulated the co-gasification of polyethylene and polyethylene terephthalate. The use of PET in plastic bottles and the problems associated with disposal of those bottles is a motivation for the study of PET gasification [18]. The paucity of literature concerning the gasification of PET may be related to recycling of plastic bottles. The use of PET bottles for packaging of drinking water, soda, and other beverages has caused issues with disposal, but these problems are being overcome by significant demand for used PET bottles [21]. Problems providing drinking water to remote communities have been overcome, in the short term, by importing bottled water, which causes an accumulation of bottles in community landfills [22]. Normally it would not make sense to consider thermal conversion of plastic when there is demand for the unconverted material. However, remote communities are too far from recycling markets to make recycling of plastic bottles economical.

The use of local biomass resources to produce electrical power via fluidized bed gasification and dual fuel engine operation has been found to be a promising alternative for remote communities [3]. Thus, the air blown fluidized bed co-gasification of wood and PET was investigated in this work to determine the feasibility of incorporating polymeric waste such as PET into biomass based power generation systems based on dual fuel operation of diesel engines.

2. Materials and methods

Commercial hardwood pellets were used to represent locally available biomass. The PET was obtained from a recycled plastics supplier. It was scrap material from the production of food containers. Experiments were conducted using wood pellets, PET pellets, and wood–PET composite pellets. All pellets had diameters of 6 mm (1/4 in.). Wood pellets were used as received while the PET and the wood–PET pellets were manufactured using a California Pellet Mill. The PET pellets were produced by feeding the PET to the pellet mill without any binders or pre-treatment. Wood–PET composite pellets were made by mixing wood and PET pellets at a ratio of 50:50 by mass, grinding the mixed pellets using a knife-mill equipped with a 6 mm screen, mixing 10 kg batches of the ground mixture with 500 g of water and 500 g of cornstarch (binder) in a cement mixer, and pelletizing the mixture using a California Pellet Mill. Table 2.1 contains the results of proximate and elemental analysis on the wood and wood–PET pellets.

Pellets were gasified in a 0.15 m internal diameter, 4.5 m tall bubbling fluidized bed gasifier located at NRCan, CanmetENERGY (Ottawa, Ont). 12 kg of synthetic olivine sand with a Sauter mean diameter of 600 μm was used as the bed material. For all experiments the bed was fluidized with 0.0038 kg/s (175 SLPM) of air metered by a mass flow controller. Depending on the bed temperature, this air flow is equivalent to 3.8–4.7 times the minimum fluidization velocity. Experiments were conducted at nominal average bed temperatures of 725 °C, 800 °C, and 875 °C. The feed flow rate was used to control the bed temperature. The range of temperature used in this work is low compared to the range of

Table 2.1
Fuel proximate, elemental and calorific analysis of fuel pellets on an as received basis.

	Wood pellet	Wood–PET pellet	Analysis method
Moisture (wt.%)	6.18	5.12	ASTM D7582
Volatiles (wt.%)	78.98	84.76	ISO 562
Fixed carbon (wt.%)	14.43	9.88	ASTM D7582
Ash (wt.%)	0.41	0.24	ASTM D7582
Carbon (wt.%)	46.5	52.5	ASTM D5291
Hydrogen (wt.%)	5.54	4.95	ASTM D5291
Oxygen (wt.%)	41.4	37.2	By difference
Gross calorific value (MJ/kg)	18.41	19.96	ISO 1928