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Research paper

# Torrefaction of biomass from municipal solid waste fractions II: Grindability characteristics, higher heating value, pelletability and moisture adsorption

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A B S T R A C T

The microwave-assisted torrefaction of woody construction demolition waste (CDW) and grass clippings (GC) from municipal solid waste (MSW) was investigated under nitrogen-activated inert condition with respect to microwave power (250, 500 and 750 W), residence time (15, 30 and 45 min), moisture content (12, 16 and 20% w.b.) for CDW and 64% w.b. for GC. The results show that grinding energy consumption decreases as the microwave power level increases, indicating a significant improvement in the grindability of the material after torrefaction. Depending on the treatment combination, grinding energy savings of about 29–70% and 30–68% resulted after microwave-assisted torrefaction of CDW and GC, respectively. The higher heating value (HHV) increases with increasing microwave power level and torrefaction residence time. For CDW, the HHV increased by about 3–39% having HHV of 25,691 MJ/t. While for GC, the HHV increased by about 8–24%, having HHV of 20,936 MJ/t. This investigation further demonstrates that torrefaction reduced moisture adsorption of CDW and GC, which significantly improves their storage capability in humid locations. The moisture uptake ratios for torrefied CDW were found to be 0.66–0.96 and about 0.92 for torrefied GC, against a moisture uptake ratio of 1.0 for raw CDW and GC. However, biomass subjected to severe torrefaction process conditions produced pellets having poor physical quality. Microwave irradiation can be used effectively for torrefaction of MSW investigated at moderate microwave power level and short torrefaction residence time.



## 1. Introduction

Municipal solid waste (MSW) is a domestic energy resource with the potential to provide a significant amount of energy to meet Canada's energy requirements. MSW is defined as household waste, industrial and commercial solid waste, and hazardous and non-hazardous waste. It includes food waste, residential rubbish, commercial and industrial wastes, and construction and demolition debris [1]. MSW is appealing as a potential feedstock because it is readily available in the near-term and may be cost-effective; it can be converted into bioethanol, advance biofuels, electricity and/or heat, and biochemicals (fertilizers, animal absorbents, road materials, etc.). MSW has a pre-existing collection/transportation infrastructure and fee provided by the supplier that does not exist for conventional biomass resources. There are two main conversion processes that have been developed for biomass (forest residues and agricultural wastes) which can be applied to MSW. Such technologies are biochemical conversion (fermentation and anaerobic digestion) and thermochemical conversion technologies (gasification, carbonization, combustion, torrefaction and pyrolysis) [2,3]. The technology that is applied on the feedstock determines the end products.

The non-recyclable MSW fraction needs to be processed and used in a more sustainable manner. The goal is to prevent the emissions of methane, $CO_2$ and other pollutants to the environment [4]. However, MSW is a heterogeneous feedstock, a combination of organic and inorganic wastes containing unsorted materials with widely varying sizes, shapes, and of different chemical compositions. If the MSW is used as received as feedstock for waste-to-energy processing plants, there will be variability and instability in the operating conditions, which can lead to fluctuations in the quality parameters of the end product(s) [1,5]. Therefore, initial treatment needs to be performed to avoid such variability.

Giroux et al. (2014) [6] reported that Canada has a poor record

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on waste management according to a recent international ranking of the Organization for Economic Cooperation and Development (OECD) countries; Canada is 17th out of 17. Canada produced 777 kg per capita of municipal waste in 2008, twice as much as the best performer, Japan [7]. Nationally, the quantity of non-hazardous total waste (residential and non-residential) sent to disposal in 2010 was 25 million tonnes [6]. This waste is costly to manage, it places high demand on natural resources and represents a missed opportunity to extract value from materials in the waste stream [6]. Therefore, there is a need to develop techniques of converting this readily available waste to high value product. In 2010, local governments Canada-wide spent an average of $15 per person on the operation of disposal facilities, $5 per person on the operation of recycling facilities, and $2 per person on the operation of organics processing facilities [6].

One of the current challenges of the world energy network is to reduce its dependence on fossil fuels and to achieve a reliable sustainable environmental condition. Increasing the fraction and variety of MSW in the energy supply would contribute to diminishing the adverse environmental impact of $CO_2$ and subsequently leads to the actualization of the Paris 2015 agreement on keeping global warming below 2 °C. MSW is one of the readily available feedstocks to complement the existing non-renewable sources of energy. However, the use of raw MSW material or non-treated MSW feedstocks as a fuel are known to have certain unfavorable characteristics such as highly hydrophilic in nature, high moisture content, poor grinding characteristics, and relatively low calorific value, low energy density and thermal instability during combustion due to the high oxygen content. Torrefaction of MSW is one of the treatment options that can address most of these inherent disadvantages and subsequently upgrade non-treated MSW to a higher quality and more attractive product [8].

Torrefaction process is a relatively mild thermochemical process that involves heating the feedstock at 250–350 °C in an inert atmospheric condition [9]. At such temperatures, there is decrease in the moisture content; various low-calorific components contained in the biomass are driven out [9–11]. Grinding is considered as one of the most energy-intensive processes during pelletization (densification), fast pyrolysis, gasification, biochemical conversion, among other processes [9]. Torrefaction increases the grindability characteristics and subsequently decreases the grinding cost [10–12]. Torrefied products are also hydrophobic, making the torrefied product to be easy to handle and convenient to store and transport [13]. Therefore, torrefaction can be used to treat MSW, increase the energy density value, and also decrease the preprocessing cost of MSW as a feedstock for biofuel industry.

Densification is an important strategy for the biomass transportation and marketing, because it improves the convenience and accessibility of biomass as a result of the uniform size and shape. Densified biomass can be handled more efficiently using the handling and transportation infrastructure of commodity grains, because the handling properties of pellets are similar to grains [14,15]. If the biomass were to be used for direct combustion purposes, biomass pellets provides stable, clean fuel, enhances its volumetric calorific value, and can be easily adopted into the direct-combustion or co-firing with coal using pyrolysis, gasification, and biomass-based conversion reactors [14–17]. Despite the challenges involved in the handling, storage and transportation of loose biomass, the direct combustion of loose biomass material in conventional grates results in very low thermal efficiency. The conversion efficiencies are as low as 40% (about 40% of feed burnt are generated as ash) with widespread air pollution in the form of very fine particulate matter [18]. However, modern-day large-scale grate furnaces are equipped with exhaust gas treatment systems to meet some of the most stringent emission standards and avoid emitting such fine particulate matter into the atmosphere. The development of a large-scale biomass unit, necessitates conversion of biomass material into a high-density and high-value solid material like pellets/briquettes [15,18]. Pelleting of biomass is necessary to enhance storage and handling characteristics, savings in transportation, its uniformity, consistency, combustion behaviour, and calorific value [9,19]. In the same manner, torrefied MSW can be densified into pellets before transportation or introducing it into the grate furnace, to minimize transportation costs and increase the efficiency and quality of the process. Perusal of literature shows that very few studies have been published on using torrefied pretreated MSW in the pelletizing process. Wang (2013) [20] reported that torrefied sawdust produces low quality pellets due to the structural changes in the feedstock matrix. During torrefaction process lignin undergoes structural changes and loss of properties, thereby reducing the possibility of utilization as binding agent during pelletization process.

Previous researchers have been using the conventional heating method for torrefaction process having focussed their investigations on the mass loss of biomass during torrefaction, and evaluation of the effect of the process conditions on the chemical properties of the torrefied biomass. With less attention given to the grindability and moisture adsorption characteristics of torrefied MSW. The objective of this research work is to investigate the physical quality characteristics of microwave-assisted torrefied pellets from fractions of municipal solid waste (MSW), namely, woody construction demolition waste (CDW) and grass clippings (GC). As specific objective, the effect of microwave power level, residence time and MSW moisture content on the grinding performance, gross/combustion energy (HHV) and moisture adsorption were determined.

## 2. Materials and methods

### *2.1. Sample collection, preparation, and conditioning*

Construction demolition waste (with particle size of 50–76 mm) was obtained on the 16th July 2015 from City of Edmonton Waste Management Centre, Edmonton, AB, while the GC was received on the 22nd July 2015 from Saskatoon, SK. The initial moisture content of the CDW was about 12.35%. The moisture content was measured based on ASABE standard method, ASAE S358.2 DEC1988 (2008) replicated three times. The moisture content of the CDW was adjusted and conditioned to the required moisture content into three levels (20, 16, and 12.35% w.b.). This was done by carefully and uniformly spraying the samples with calculated amount of water based on mass balance. The conditioned material was placed in a hermetic glass bottle and stored at room temperature (25 °C) and 52% relative humidity for a minimum of one week for moisture equilibration. The moisture content of GC was determined to be about 74–76% (w.b.). The GC was frozen and stored for about 90 days in a laboratory freezer at −18 °C to avoid growth of microorganism and spoilage. The frozen GC was thawed for 24 h before subjecting it to torrefaction. The moisture content of the thawed GC was also re-determined to be about 65% (w.b.). For the purpose of comparison, coal was collected from a Saskatchewan company (brand and company name withheld). The thermochemical properties: CHNS (carbon, hydrogen, nitrogen, sulfur) of the coal were compared with that of the torrefied CDW and GC.

### *2.2. Determination of ash content of construction demolition waste and grass clippings*

The ash content, a measure of the extractable or structural mineral content and other inorganic matter of CDW and GC, was