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Research paper

# In-depot upgrading the quality of fuel chips for a commercial gasification plant

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ABSTRACT

Uncertainties in quality and timely availability of feedstock are among major issues in planning an economically viable bioenergy enterprise. Reported studies in open literature on feedstock supply logistics are either the results of modeling or from laboratory scale investigation with limited usefulness to commercial operations. The objective of this research is to quantify the sensitivity of steam production rate in a commercial updraft gasifier to several critical feedstock quality attributes like moisture, ash, and particles size. The specific case study is a 7 MW thermal gasifier at the University of British Columbia that supplies process steam to campus facilities. The wood fuel is collected from a large number of urban waste wood sources, sorted, and blended in a recycling yard (depot) prior to delivery to the gasification plant. Several improvements in particle size uniformity, reduction in wood contamination with dirt, and dryness of the feedstock were made within a two-year period of recorded data (2013–2014). As a result, the overall percent of operating hours of the gasification plant increased from 75% to 94% while the average steam production increased by 30%. Most of the earlier variability in fuel properties was traced to the blending of dry fuel chips at a moisture content of 17% wet basis with a high moisture green wood at a moisture content of 40% wet basis.

## 1. Introduction

Gasification is a thermal process in which material such as biomass is exposed to an oxygen deficit environment undergoes a sequence of two endothermic transformations. The biomass breaks down into volatiles and char during the first transformation at around 600 °C. The resulting gas contain hydrocarbon gases, methane, hydrogen, carbon monoxide, carbon dioxide, tar, water vapor and nitrogen. The char is mostly made up of fixed carbon and ash. The char is gasified or burned to produce heat during the second transformation at temperature that exceeds 1000 °C. The combustible gases are eventually burned in an oxidizer to generate process heat. Gasification reaction, operating conditions, and gas composition depend on the physical characteristics and composition of the biomass (IEA Task 33 [1]). According to V. Kirsanovs [2], the gasifier's operating temperature tends to decrease at the feedstock moisture content increases. The equivalence ratio ER (oxygen/fuel) must be increased to increase the operating temperature and in order to maintain a stable bed-zone operating condition.

In general, the types of biomass gasifiers are classified as fixed bed, fluidized bed, and entrained bed [3]. The maximum size of particles for fixed/moving bed is specified at less than 51 mm, for fluidized bed at less than 6 mm and for entrained bed at less than 0.15 mm. The 51 mm maximum particle size specified in Ref. [3] is probably related to the maximum size a screw auger could handle. The maximum size of 75 mm for the fixed bed gasifier used in the present research (to be discussed later in this paper) is based on the ability of the screw feeder to negotiate the delivery of particles from a horizontal auger to a vertical auger. Fixed bed gasifiers are simpler than the other types but their thermal output is typically lower than 10 $MW_{th}$ [4]. Fixed bed gasifiers are further classified as updraft, downdraft and cross flow depending upon the flow direction of gas and biomass particles. The updraft gasifiers can operate with high moisture biomass up to 60% moisture content (wb) whereas the downdraft gasifiers operate with biomass less than 25% moisture content (wb). Updraft gasifiers are also suitable for high ash but the volatiles contain large concentration of tar that can make the gas more difficult as a fuel for internal combustion engines

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[5].

Dai and Cui [6] showed that the analysis of biomass physical properties and chemical compositions was important for feeding, reactor performance, downstream operations and equipment for all biomass-related processes. For quality control, the most important fuel parameters for wood chips for end-users are: species, moisture content, calorific value, particle dimensions (including low amount of fine and coarse fractions), and absence of impurities like sand, stones, plastics and so on [7]. Other quality influencing factors that are important and relevant for biofuels (such as wood chips, hog fuel, and wood pellets) include weather conditions, storage time, selection of machinery for pre-processing operations (such as debarking, chipping, grinding, drying), the number of handlings, and microbial activities [8].

Biomass is a widely spread resource with low energy density. Thus, significant volumes of biomass must be collected across over large areas, which can lead to complicated logistics and expensive transportation [9]. Anon [10] showed that feedstock cost represented as high as 40–50% of the total cost of a heat or power generation unit. The consistency of biofuel properties will affect the cost of supply logistics. Using covered storage can help to control the fuel moisture content.

Consistent moisture content is essential for the smooth operation of a gasifier [11,12]. The gasifiers have high sensitivity to the moisture content of fuel [13].The mass of water in living trees, newly cut logs, and freshly sawn lumber can be greater than the mass of the wood. In such cases, moisture content often reaches up to 67 wt% [14]. Ease of fuel transport is affected by feedstock moisture and sizing. To increase the efficiency of gasification systems, pre-treatment of the biomass feedstock such as drying and screening is required. Optimal biomass gasification requires dry fuels with uniform particle sizes and moisture content less than 20% [15]. Demirbas [16] suggested making moisture adjustment before storage or utilization is critical to the operation of gasification reactor. High moisture content can lower the operating temperature and the heat content of biomass in combustion processes [17].

Alfonso et al. [18] considered ash content as one of the major fuel properties that play important roles in process of converting biomass to energy. The quantity and quality of ash depend on factors such as the type of tree, the part of the tree (wood, bark, leaves), and the amount and type of soil contaminants. Melin [19] found that the overall ash content of the hard wood was noticeably higher than that of the softwood.

Uniformity in feedstock size is important both for feeding and stable gasification. According to Kaupp and Goss [20] longer residence time is required to avoid the incomplete utilization of oversize feedstock. Smaller particles have larger surface area-to-volume ratio per unit mass, which leads to faster heat transfer and gasification process [17,21]. Lv et al. [22] and Feng et al. [23] have also shown that smaller particles will increase the yield of CO and $CH_4$. Kumar et al. [24] showed the high gas yield and energy efficiency are dependent on the particle heat transfer characteristics. The authors found that smaller particles (0.075 mm) increase the efficiency compared to larger particle (1.2 mm). On the other hand, particulate matter in gas streams contains a significant portion of ash and dust. These small particles cause plugging in downstream equipment and engine components [25]. In addition, to control particulate emission levels, we need to remove the particulate from producer gas. Rapagna and Latif [26] found a strong relationship between particle size (0.287–1.90 mm) and the syngas concentration.

This paper is a detailed analysis of the feedstock characteristics and improvement in the performance of the University of British Columbia (UBC) gasifier in operational reliability and thermal output over a three-year period (2012–2015). Feedstock quality data as well as the data relevant to gasifier operation were taken on a regular basis at the gasification plant. The objective was to quantify seasonal variations in the feedstock quality characteristics, plausible causes of the variations in feedstock quality, and the impact of feedstock quality on system reliability and steam output. The UBC gasifier with its fuel supply system provides a real case study and an example of ways to improve the design and reliability of future biomass supply and gasification systems.

### *1.1. Overview of fuel supply and gasification system*

Given the goal of reducing GHG emissions, UBC installed an updraft biomass gasification system at the Point Grey Campus in Vancouver in 2012. The gasification facility is called Bioenergy Research & Demonstration Facility (BRDF). The gasifier was designed to provide up to 5% of 40 MW campus power and 30% of 40 MW thermal based heat [27]. UBC has a limited term contract with a waste wood recycling yard (depot) to deliver chipped and ground wood waste fuels to the gasification plant based on a set of schedule and feedstock specifications. The depot is located in Langley, BC, a township 50 km from the gasification plant. The sources of feedstock are urban wood waste generally obtained from within a 100 km radius of depot. The urban wood wastes consist of two major types of materials: woody scraps from construction and demolition (C&D) waste, and green wood (which is the woody parts of the tree trimmings) collected from Metro Vancouver's curbsides and landfills. In Metro Vancouver 54% of the C&D materials (595,000 tonnes) are woody wastes [28].

The UBC gasification plant consists of a woodchip receiving area, feeding system, silo for temporary storage, gasifier, thermal oxidizer, boiler for steam production and an internal combustion engine (GE/Jenbacher). The fixed bed updraft gasifier (4.9 m diameter, 4.9 m tall) was designed to generate about 7 MW thermal energy in the form of steam with the use of boiler (Fig. 1). The engine that was originally designed to use syngas from biomass is currently operating with renewable natural gas purchased from a local gas utility.

Table 1 lists the initial specifications of the gasifier for the physical and compositional make-up of the biomass fuel. The plant specifies 6 mm −76 mm particle sizes, and 10–55% moisture content (wb). The manufacturer states that the gasifier can tolerate an ash content of 10%. A preliminary analysis showed that the feedstock from recycled clean wood in Metro Vancouver met these specifications. The annual fuel requirement for the UBC gasification plant is estimated to be 13,000 dry tonnes.

Fig. 2 shows a schematic diagram of the fuel supply and pre-processing operations at the Cloverdale Fuel Limited (depot). The depot is a privately owned commercial operation that handles more than 200,000 tonnes of recycled wood annually. The supply of wood to UBC is less than 7% of their total annual volume of wood being handled. The depot collects the urban biomass from 114 sites using collection bins placed at each site. When these bins are full, the depot dispatches a truck to pick up the full bin and replace it with an empty bin. The City of Vancouver also sends green wood to the depot. The recorded data for each supplier consists of the distance between the depot and the supplier, tonnage of supplied woody biomass per year, per month, and per week when any or all of these data are available. Besides, the type of wood and the frequency of collection are recorded. Upon arrival at the depot, a truck unloads the materials in a pile. The material is sorted visually using a front-end loader. The sorted material is ground and blended for specific applications and customer requirements. Fig. 3(a) shows the shed for temporary storing the processed materials at the depot before delivery, and Fig. 3(b) shows the storage area at UBC.

About 35% of suppliers are less than 20 km away; 40% of the suppliers are located at a distance 20–40 km from the depot. A few of the suppliers are farther than 40 km. About 20 suppliers provided 80% of the clean wood, and about 90 suppliers provided the remaining 20% of the clean wood. Clean waste wood come from pallet manufacturing operations, scrap lumber from saw mills, and scrap pallets from various local companies that use wood pallets to handle packaged goods. Most of the clean wood originated from lumber grade wood and hence had low variability in their properties.