Biomass and Bioenergy 87 (2016) 131–143

Contents lists available at ScienceDirect

Biomass and Bioenergy

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

Research paper

Techno-economic assessment of pellets produced from steam pretreated biomass feedstock

Hassan Shahrukh [a], Adetoyese Olajire Oyedun [a], Amit Kumar [a,*], Bahman Ghiasi [b], Linoj Kumar [b], Shahab Sokhansanj [b,c]

[a] Department of Mechanical Engineering, 10-263 Donadeo Innovation Centre for Engineering, University of Alberta, Edmonton, Alberta, T6G 1H9, Canada
[b] Department of Chemical and Biological Engineering, 2360 East Mall, University of British Columbia, Vancouver, BC, V6T 1Z3, Canada
[c] Environmental Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN, 3783, USA

ARTICLE INFO

Article history:
Received 21 July 2015
Received in revised form
27 February 2016
Accepted 1 March 2016
Available online xxx

Keywords:
Biomass
Pellets
Techno-economic model
Production cost
Steam pretreatment
Economic optimum size

ABSTRACT

Minimum production cost and optimum plant size are determined for pellet plants for three types of biomass feedstock – forest residue, agricultural residue, and energy crops. The life cycle cost from harvesting to the delivery of the pellets to the co-firing facility is evaluated. The cost varies from 95 to 105 $ t^{-1} for regular pellets and 146–156 $ t^{-1} for steam pretreated pellets. The difference in the cost of producing regular and steam pretreated pellets per unit energy is in the range of 2–3 $ GJ^{-1}. The economic optimum plant size (i.e., the size at which pellet production cost is minimum) is found to be 190 kt for regular pellet production and 250 kt for steam pretreated pellet. Sensitivity and uncertainty analyses were carried out to identify sensitivity parameters and effects of model error.

1. Introduction

Fossil fuels have long been a source of energy worldwide. However, fossil fuels are used faster than they are generated, as the world's population is growing faster than the generation and extraction of fossil fuels [1]. In addition, fossil fuels have long been considered non-environmentally friendly since burning them produces large amounts of greenhouse gases (GHGs), which contribute to global warming. An 80% increase in fossil fuel use will increase GHG emissions by 70% [2]. This could have significant impact on the environment globally. All these factors have led to the focus on the use of renewable energy sources, and biomass-based energy production is a key component of this. Biomass-based energy and fuels are considered nearly carbon neutral [3].

Biomass-based facilities face a number of challenges that has limited their development. The quality and quantity of the biomass produced from various feedstocks vary significantly, and this is one of the key factors affecting their large-scale practical use in a biomass-based facility. Typically, biomass has low calorific value, density, and yield (i.e., amount produced per unit area), all of which increase biomass delivery cost, which in turn increases biomass conversion costs [3]. Biomass pre-processing helps to reduce some of these barriers.

Pelletization is a biomass pre-processing method. The pelletization process starts with biomass collection. Forest residues are then chipped; wheat straw and switchgrass are chopped. The chipped/chopped biomass is then transported to a pellet mill to be pelletized. Biomass is dried before it is comminuted and pelletized [4,5].

Regular pellet production refers to the production of pellets without steam pretreatment. While pelletization improves the bulk density and calorific value of the fuel, the bulk density and calorific value need to be improved significantly in order to co-fire the pellets with coal [6,7]. Steam pretreatment, is a non-chemical pretreatment that exposes biomass to high pressure and high temperature steam in the range of 1–3.5 MPa and 180–240 °C, respectively [6,7]. Steam pretreatment of biomass pellets can make it feasible to use pellets for co-firing. Steam pretreatment, moreover, is essential to ensure high energy output and improve thermal efficiency [6].

Steam pretreatment prior to bioconversion has been proposed

* Corresponding author.
E-mail address: Amit.Kumar@ualberta.ca (A. Kumar).

http://dx.doi.org/10.1016/j.biombioe.2016.03.001
0961-9534/

Table 1
Feedstock properties.

Characteristic	Wheat straw	Forest residue	Switch grass	Source
Moisture mass fraction (%)	14	45	14	[3,10,13]
Regular pellet HHV (MJ kg^{-1})	17.8	19.2	18.1	[25]
Steam pretreated pellet HHV (MJ kg^{-1})	19	19.5	19	[25]
Regular pellet bulk density (kg m^{-3})	780	800	660	[22]
Steam pretreated pellet bulk density (kg m^{-3})	1086	1112	834	[22]

by Lam [6] and Tooyserkani [7] as a means of improving the mechanical strength, hydrophobicity, and calorific values of the biofuels produced from biomass. These improvements can reduce biomass storage costs, thereby reducing the cost of fuel production from biomass. Steam pretreatment also improves the bio-chemical conversion, which leads to higher yield. However, this research focused specifically on improving biomass pellet energy density through steam pretreatment.

Previous studies have evaluated the economics of biomass-based energy from the perspective of generic models [2,8–13]. The cost of producing pellets from sawdust has been reported by Mani et al. [14], who found that pellets can be produced from sawdust at a cost of 51 $ t^{-1} at a plant capacity of 45 kt. A European pellet production scenario has been reported by Thek and Obernberger [15,16], they predicted the production cost of sawdust-based pellets in a European setting. They reported a production cost of 95.56 $ t^{-1} of pellets at a plant capacity of 24 kt [16]. Urbonowski [17] used their study to evaluate the capital cost of a regular pellet production plant. Other researchers evaluated the production cost of pellets in Europe and elsewhere [18–21]. However, little research evaluates the production costs of steam pretreated pellets or compares production costs of regular and steam pretreated pellets. In addition, there is limited focus on the effects of the economic optimum size of the feedstock on both processes. While life cycle analyses have been carried out by many researchers, to date there has been no techno-economic assessment of steam pretreatment processes. There is a need to evaluate the economics of pretreated biomass-based pellets.

The overall objective of this research is to determine the costs of steam pretreated pellet production from three feedstocks – forest residue, wheat straw, and switchgrass – and compare them with the costs of regular pellet production. The key objectives for the study are:

- To develop a data-intensive techno-economic model to evaluate the costs of steam pretreated biomass-based pellet production.
- To estimate the costs on a mass and energy basis of steam pretreated biomass-based pellet production for three feedstocks (forest residues, wheat straw, and switchgrass).
- To evaluate the economic optimum production plant size for steam pretreated biomass-based pellets from all three feedstocks.
- To determine the effect of various parameters on the cost of production through a sensitivity analysis.

2. Biomass sources, yields, and properties

2.1. Forest residues

Forest residues are a by-product of the pulp and lumber industry and may be available as an alternative fuel source in the bio-fuel industry. The limbs and tops of trees are left by the side of the road but can be collected and used. These are the residues considered in this study. Although costs are incurred through collection and delivery, existing logging roads are used and hence do not add to construction costs [3].

2.2. Agricultural residues

Agricultural residues form the largest concentration of field-based residues in western Canada. A recent study estimated the amount of agricultural wheat straw available in Alberta to be more than 6 Mt of dry biomass [10]. It is possible to generate 2000 MW of power from the available uncollected wheat straw; this shows the value of available wheat straw [3].

2.3. Energy crop

The energy crop considered in this study is switchgrass (*Panicum vigratum, L.*). Switchgrass is a hot weather perennial grass native to North America. The grass can grow in dry weather and is suitable for marginal land. The above-ground biomass yield reported by Vogel et al. [23], is from 3 to 30 t ha^{-1}. This yield is dependent upon soil fertility, location, variety, and number of harvests per season [13,22]. The yield considered for the purpose of this research is 3 t ha^{-1}; this figure is low because the weather in western Canada is mostly cold and the warm season lasts only 4 months.

The feedstock properties and yields data for all three feedstocks considered here are listed in Tables 1 and 2, respectively.

Table 2
Calculation of net yield for wheat straw and switch grass.

Crop	Yield grain/straw (t ha^{-1})[a]	Grain ratio	Gross yield (t ha^{-1})[a]	Level of straw retained for soil conservation (t ha^{-1})[a]	Mass fraction of straw harvest machine can remove (%)	Mass fraction removed for animal feeding and bedding (t ha^{-1})[a]	Mass fraction of straw loss from harvest area to pellet plant (%)	Moisture mass fraction (%)	Net yield (t ha^{-1})[b]	Source
Wheat straw	2.66	1.1	2.93	0.75	70	0.66	15	14	0.63	[10]
Switch-grass	–	–	3.5	0.75	70	0.66	15	14	1.56	[10,13]

[a] Calculated on 'as received' basis i.e. actual wet yields of the biomass.
[b] Calculated on dry basis i.e. actual wet yields are adjusted to zero moisture mass fraction.