



Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Techno-economic analysis of power plant via circulating fluidized-bed gasification from woodchips

Truong Xuan Do^a, Young-il Lim^{a,*}, Heejung Yeo^b, Uen-do Lee^{c,d}, Young-tai Choi^c, Jae-hun Song^e

^a Lab. FACS, RCCT, Department of Chemical Engineering, Hankyong National University, Jungangno 327, Anseong-si 456-749, Gyeonggi-do, Republic of Korea

^b Department of International Trade, Keimyung University, Daegu 704-701, Republic of Korea

^c Energy System R&D Group, Korea Institute of Industrial Technology (KITECH), Cheonan 331-825, Republic of Korea

^d Green Process and Systems Engineering, University of Science and Technology, Cheonan 331-825, Republic of Korea

^e Hansol SeenTec Co., Ltd, Sangnam-dong 74-6, Changwon-si 642-831, Gyeongnam, Republic of Korea

ARTICLE INFO

Article history:

Received 27 August 2013

Received in revised form

15 January 2014

Accepted 10 April 2014

Available online xxx

Keywords:

Woodchips

Syngas

Circulating fluidized-bed

Power plant

Techno-economic analysis

Process simulation

ABSTRACT

Biomass has emerged in the renewable energy area with high potential to contribute to the energy needs in both the industrialized and developing countries. The objective of this study is to evaluate and compare the economic feasibility of three different configurations of a woodchips power plant based on the circulating fluidized-bed (CFB) gasification: (1) a gas engine, (2) a gas turbine, and (3) gas & steam turbines. A comprehensive model of the power plant was developed employing the process simulator, Aspen Plus. The economic feasibility was analyzed in terms of the payback period (PBP), return on investment (ROI), and discount cash flow rate of return (DCFROR). It was proposed that the power plant has an economic benefit for plant sizes of over 150 t/d of dry woodchips in all the three cases. The gas engine was a better choice for the power plant sizes smaller than 200 t/d or 22 MW_e, while the gas & steam turbines had the highest benefit at big plant sizes over 200 t/d. A sensitivity analysis was performed for the 150 t/d plant to identify key variables that have a strong impact on DCFROR. The total capital investment (TCI) and plant size had a major influence on DCFROR.

© 2014 Elsevier Ltd. All rights reserved.

1. Introduction

Renewable energy sources currently contribute 19% of the global final energy consumption, half of which is supplied by biomass [1]. Biomass energy is produced from 64% wood and wood waste, 24% municipal solid waste, 5% agricultural waste, and 7% other materials [2]. Biomass can be converted into useful forms of energy by three main pathways: thermo-chemical, bio-chemical/biological, and mechanical extraction [3]. Within thermo-chemical conversion, four process options are available: combustion, pyrolysis, gasification and liquefaction [4]. Gasification is the conversion of biomass into a combustible gas mixture (synthesis gas or syngas) by the partial oxidation of biomass at high temperatures, typically in the range of 800–900 °C [4]. There are gasifying agents such as air, oxygen, steam, CO₂, or mixtures of these components [5].

Syngas has many uses which range from heat or power applications such as integrated gasification combined cycle (IGCC), to a variety of synthetic fuels [6].

Gasifiers are classified by the gasification agents like air-blown, oxygen-blown or steam-blown, by the operating pressure like atmospheric or pressurized, by the temperature like slagging or non-slagging, by the flow pattern like updraft, downdraft, fluidized-bed or entrained flow, and by the heat supplying method like indirectly or directly heated [5]. The indirect gasification produces the higher heating value of about 12–20 MJ/m³ in fluidized-bed. The circulating fluidized-bed (CFB) gasifiers (CFBGs) have been considered as the promising biomass gasification technology due to low investment cost, being suitable for small and medium scales, their relatively low temperature operation and the availability to generate heat and power [7,8].

Biomass gasification for electricity generation through a gas engine or turbine has a net conversion efficiency around 25% [9–12] or a range of 12–35% [13,14], respectively. Biomass combustion produces steam and then electricity using a steam turbine, having a net conversion efficiency between 10% and 35% according

* Corresponding author. Tel.: +82 31 670 5207; fax: +82 31 670 5209.

E-mail addresses: xuantruongnil@yahoo.com (T.X. Do), limyi@hknu.ac.kr (Y.-i. Lim), heejungyeo@kmu.ac.kr (H. Yeo), uendol@kitech.re.kr (U.-d. Lee), ychoi@kitech.re.kr (Y.-t. Choi), jhsong@hansol.com (J.-h. Song).

Abbreviations

ASR	annual sales revenue (\$/yr)
CCGT	combined cycle gas turbine
CEPCI	chemical engineering plant cost index
CF	cash flow (\$/yr)
CFB	circulating fluidized-bed
CFBG	circulating fluidized-bed gasifier
CHP	combination of power and heat
DC	depreciation cost (\$/yr)
DCFROR	discount cash flow rate of return (%)
EPR	electricity production rate (kWh/yr)
ER	equivalent ratio
FCI	fixed capital investment (\$)
GP	gross profit (\$/yr)
<i>i</i>	interest rate
IC	indirect cost (\$)
IGCC	integrated gasification combined cycle
IRR	internal rate of return
LHV	lower heating value (MJ/kg)
MW _e	electrical MW (=10 ⁶ J/s) for electricity production rate

MW _{th}	thermal MW (=10 ⁶ J/s) for biomass feeding rate converted into energy rate
MWh	MW for 1 h (=3600 MJ)
NP	net profit (\$/yr)
NPV	net present value (\$)
PBP	payback period (yr)
PC	project contingency (\$)
PFD	process flow diagram
REC	renewable energy cost (\$/kWh)
ROI	return on investment (%)
SCC	specific capital cost (\$/(kWh/yr))
SOFCs	solid oxide fuel cells
TCI	total capital investment (\$)
TDIC	total direct and indirect cost (\$)
TIC	total installed cost (\$)
TPC	total production cost (\$/yr)
TPEC	total purchased equipment cost (\$)
WC	working capital (\$)

Greek letters

η	electrical efficiency (%)
ϕ	income tax rate (%)

to the plant size [11]. A combined heat and power (CHP) production shows an overall system efficiency ranging from 50% to 80% [11,15]. When the steam turbine is integrated into the gas turbine power plant, a hot flue gas leaving the gas turbine [16,17] and excess heat of the fluidized-bed gasifier [18] are used to produce steam for additional electricity generation. That increases the electrical conversion efficiency to 25–55% [9,12–14,19–22] at the cost of the total capital investment (TCI). A thermodynamic analysis was performed for biomass gasification plants by Datta et al. and Bhattacharya et al., where the effects of operating parameters on the thermal efficiency were studied [23,24]. Kucukvar and Tatari studied coal–algae cofiring scenarios in a 360 MW_e power plant utilizing an ecology-based life cycle assessment methodology, in which the impacts on the ecological system were calculated in terms of cumulative mass, energy, industrial exergy, and ecological exergy [25]. Bang-Møller et al. investigated options for increasing the net electrical efficiency of biomass combined heat and power (CHP) plants. A high net electrical efficiency of 45% was achieved in a 3 MW_{th} plant combining a two-stage biomass gasification with solid oxide fuel cells (SOFCs) [26].

Electricity generation is considered as the most lucrative opportunity for commercial exploitation of biomass by virtue of the high value of electricity [27]. Many studies have addressed the power generation from biomass via gasification pathway [9–13,19–22,27–34]. Arena et al. evaluated the techno-economics based on a gasification system with two energy generation devices: a gas engine and an externally-fired gas turbine [29]. Pihl et al. presented a techno-economical analysis on integrating biomass gasification with the combined cycle gas turbine (CCGT) power plant, where biomass of about 50 MW_{th} is gasified, and the syngas and natural gas are co-fired to generate electricity in the capacity of 800–1400 MW_{th}. Clear efficiency improvement and possible cost reduction were found in the hybrid CCGT power plant compared to the stand-alone plants [30]. Power productions from biomass fast pyrolysis and gasification were compared by Bridgewater et al. and Voets et al. They showed that at a small electrical capacity of 5–10 MW_e, pyrolysis is more profitable than gasification [27,33]. Moon et al. performed an economic comparison of biomass generation schemes via gasification and combustion with

government financial support for renewable energy and heat sale in Korea [11]. They stated that there are about 10–20 sites that can supply 50–300 metric tons of woody biomass per day in Korea, and several small-scale biomass CHP systems can be operated [11]. Tock and Maréchal assessed the trade-off between H₂ and electricity co-production, and only H₂ or electricity generation from lignocellulosic biomass with regard to energy, economics and environmental considerations [34].

Table 1 lists recent studies of the power plant via the gasification pathway from biomass or low calorific syngas fuels. The plant size, gasifier type, power generator type, and economic criteria such as DCFROR (discount cash flow rate of return) and EPC (electricity production cost) are also summarized in Table 1. The gas & steam turbines have been often used for big plant capacities over 30 MW_e, while the gas engine was employed for relatively small plant sizes. However, in the woodchips power plant the economic feasibility has not been evaluated according to the power generator type, nor compared for the gas engine, the gas turbine, and the gas & steam turbines systems in the wide range of plant size.

This study evaluates economic feasibility for the power plant via CFB gasification of three cases: (1) a gas engine, (2) a gas turbine, and (3) gas & steam turbines. For the three cases, the effect of the plant size is investigated on the payback period (PBP), return on investment (ROI), and discount cash flow rate of return (DCFROR). Sensitivities of DCFROR to eight parameters (woodchips cost, income tax rate, TCI, net efficiency, plant size, electricity price, renewable energy cost (REC), and hot water heat price) are analyzed to look for key variables influencing economic feasibility. As indicated in the last line of Table 1, this study concerns the plant sizes of 0.5–46 MW_e.

The paper is organized as follows. Section 2 presents pilot-scale experiments, process description and modeling. Section 3 describes the methodology of economic analysis. The results are discussed in Section 4 and the conclusions are followed in Section 5.

2. Pilot-scale experiments, process description and modeling

The power plant consists of five main areas: A100 (feed handling to dry woodchips and reduce their size), A200 (gasification to

Download English Version:

<https://daneshyari.com/en/article/8077857>

Download Persian Version:

<https://daneshyari.com/article/8077857>

[Daneshyari.com](https://daneshyari.com)