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Cost analysis model for catalytic conversion of syngas in to light hydrocarbon gases

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A B S T R A C T

Bio-gasification is a new technology and considered as a more efficient way to utilize bio-energy. The economic feasibility becomes one of the greatest issues when we apply this new technology. Evaluation of economic feasibility of a bio-gasification facility needs better understanding of its production unit cost under different capacities and different working shift modes. The objective of this study was to evaluate the unit cost of biofuel products (Liquid HCs, Light HCs and Oxygenates $C_xH_yO_z$) under different capacities using a modeling method. The cost analysis model was developed using Visual Basic Microsoft 2008, computer programming language and mathematical equations. The modeling results showed that the unit costs of biofuel product from bio-gasification facility were significantly affected by production capacities of facilities. As the facility capacity increased from 65 to 10,000 $N\,m^3\,h^{-1}$, the biofuel production unit cost of gas (Light HCs), oil (Liquid HCs), and aqueous (Oxygenates $C_xH_yO_z$) decreased from $38.92 per MMBTU, $30.89 per gallon and $25.74 per gallon to $2.01 per MMBTU, $1.59 per gallon, and $1.33 per gallon, respectively. The results of the sensitivity analysis showed that feedstock cost was the most sensitive cost factor on unit costs for all biofuel products at high capacity. The cost analysis model developed in this study could be used to optimize production unit costs of bio-fuel products from bio-gasification facility.

1. Introduction

To reduce dependency on fossil fuels, research on development of biofuel from renewable biomass resources has been conducted all over the world [1,2]. Among methods of generating energy from biomass, bio-gasification has been considered one of the most commonly used conversion techniques because the produced gases play an important role as intermediates in the production of high-efficiency power or synthesis of chemicals and fuels [3–5]. Bio-gasification is a thermochemical transformation of a raw biomass material into combustible gases through chemical reactions [6–8]. The produced gaseous mixture, called a synthetic gas (syngas), contains hydrogen (H_2), carbon monoxide (CO), carbon dioxide (CO_2), methane (CH_4), and other impurities such as nitrogen (N_2), alkali compounds, sulfur compounds, and tar [6,9]. The cleaned syngas containing H_2 and CO can be converted into light hydrocarbon gases (Light HCs), liquid hydrocarbons (Liquid HCs), and aqueous (Oxygenates $C_xH_yO_z$) through the catalytic conversion process based on modified Fischer–Tropsch catalyst [10].

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The interest in these biofuel industries has been increasing rapidly over the past decade. The increased importance of the biofuel development has stimulated an interest to improve economic efficiency. Consequently, economic analysis is required to evaluate an economic feasibility of the new technology for biofuel production prior to the application of it. For example, William et al. [11] conducted a cost-benefit assessment of methanol and hydrogen produced from the bio-gasification facility. Phillips [12] analyzed the cost to produce the ethanol from hybrid poplar wood chips based on gasification process. Swanson et al. [9] carried out the economic analysis of liquid transportation fuels produced from corn stove through gasification. These researches focused on the economic analysis of the biofuel production from the large-scale facilities which were designed with a feedstock feed rate of more than 1500 Mg per day.

However, to date, the economic analyses of biofuel production from syngas produced from the micro-scale bio-gasification facility have not been conducted. Therefore, this study aims to evaluate the unit cost of biofuel products (Liquid HCs, Light HCs and Oxygenates $C_xH_yO_z$) under different capacities using a modeling method.

2. Materials and methods

2.1. *Production system and cost analysis*

The process design developed for this study was based upon the current operation for the small-scale biomass gasification facility with a capacity of 65 N m^3 h^{-1}, which was established at Mississippi State University [10]. As shown in Fig. 1, the biomass gasification facility comprised four steps: biomass handling and preparation, gasification, syngas cleaning and conditioning, and catalytic conversion. The pilot-plant scale cleaning unit is built in the bio-gasifier located at Mississippi State University. In this study, the biomass species was set to woodchips. Raw woodchips are first treated by drying and grinding into proper sizes. The treated woodchips are then fed into the gasifier. In the gasification process, the biomass is converted into syngas through a series of chemical reactions such as drying, pyrolysis, oxidation, and reduction. After syngas cleanup and conditioning, the unwanted impurities from raw syngas were removed. In this study, the catalytic conversion of syngas into light hydrocarbon gases (Light HCs), liquid hydrocarbon (Liquid HCs), and aqueous (Oxygenates $C_xH_yO_z$) was considered.

The cost analysis for the biofuel production was carried out on the basis of total capital cost, total operating cost, and revenues from the sale of the recovered heat produced in the process for the biofuel production. In this study, feedstock preparation was selected as a starting point for the cost analysis, while the biofuel product output including oil, gas, and aqueous was chosen as an end point. The costs associated with the biofuel production were estimated using a combination of capacity factored and equipment-based methods. This method has been used frequently since it has been considered a useful tool when there are little measured data for the feasibility analysis of a project [5]. A more specific description of the cost analysis is described in the following sections.

2.1.1. *Capital cost*

The capital cost was estimated based on the total project investment (TPI) and loan interest cost. More specifically, the TPI was calculated by adding the total installed cost (TIC) to the total indirect cost (TIDC). The TIC and TIDC were estimated based on the equipment purchase cost. This method of cost estimation has an expected accuracy of −10% to 20% [13]. The equipment purchase cost (C_{eq}) can be estimated by using the capacity factored method [13,7,5], as expressed in Eq. (1).

$$C_{eq} = C_{ex}\left(\frac{P_{c\_new}}{P_{c\_ex}}\right)^n \quad (1)$$

where C_{ex} is the equipment purchase cost of the existing bio-gasification facility, P_{c_ex} is the production capacity of the existing facility (N m^3 h^{-1}), P_{c_new} is the production capacity of the new facility (N m^3 h^{-1}), and n is a characteristic scaling exponent that is based on characteristics of the equipment related to production capacity. In this study, the n value was assumed to be 0.6 [13,7,5].

Once the equipment purchase cost was calculated, the TIC was determined using the related cost factors obtained from previous literature [12] in which the TIC was ranged from 12% to 247% of the total purchased equipment cost (TPEC) for installed costs of purchased equipment installation, instrumentation and controls, piping, electrical systems, buildings, and yard improvements. The TIDC was also estimated using cost factors from previous literature [12] in which the % of total installed cost (TIC) ranged from 3% to 39% for indirect cost of engineering, construction, legal and contractor fees, and project contingency.

The total project investment cost can be paid as a portion of production cost each year because the initial cost is very large [13]. As a result, this cost is depreciated during the facility's economic lifetime. In this study, a straight line depreciation method was used. Therefore, the annual capital cost (C_{ac})

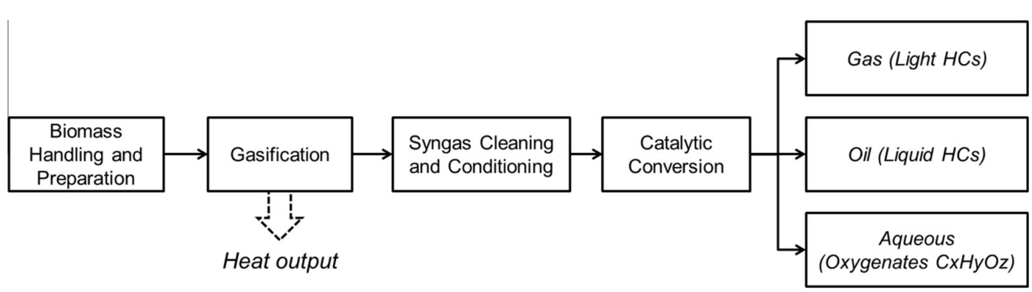

Fig. 1 – Process flow diagram of biofuel production system.