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Techno-economic analysis of the biomass gasification and Fischer–Tropsch integrated process with off-gas recirculation

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ABSTRACT

The techno-economic analysis of a BG-FT (biomass gasification and Fischer–Tropsch) integrated process with different configurations, once-through and with recirculation concepts, for green fuel production is presented. Rice straw is considered a feedstock for the gasification process operated under the thermal self-sufficiency condition. Modeling of such an integrated process is performed by using Aspen Custom Modeler program. Regarding one technical aspect, the influence of changing an off-gas recycle fraction at different values of the FT reactor volume on the performance of the syngas processor, the FT synthesis and the energy efficiency is discussed. The production rate of syngas, diesel product and FT off-gas, as well as electricity from the BG-FT process, can be maximized via suitable adjustment of the recycle fraction and selection of the FT reactor volume. The economic analysis using an incremental NPV (net present value) as an economic indicator implies that the use of the recycle concept in the BG-FT process without the installation of any secondary equipment is less feasible than the once-through. Although the maximum diesel production rate is found when the FT reactor volume of 190 m^3 and the FT off-gas recycle fraction of 0.4 are chosen, the incremental NPV shows a negative value.

1. Introduction

Presently, the increasing rate of world energy consumption due to dramatic economic growth, especially in developing countries such as China and India, results in a decrease in the amount of globally reserved fossil fuel, which leads to a fossil fuel shortage. Moreover, the emission gases from the combustion engine also lead to air pollution, public health and global warming issues. The transportation sector is one which not only consumes a high amount of energy (liquid transportation fossil fuel, i.e., gasoline and diesel) but is also responsible for a large part of the CO_2 emission. Therefore, the production of liquid transportation fuel from renewable sources has been extensively studied. In the year 2012, approximately 28% of the total world energy consumption was used by the transportation sector [6]. In Thailand, this sector represented approximately 35% of the overall energy consumption. Moreover, the Ministry of Energy mandates a target for the use of renewable energy of 25% of total energy consumption by 2021, by which time diesel can be replaced by the new energy by approximately 25 million liters per day [4].

Using biomass as an energy source currently plays a major role in the energy production business because it is CO_2 neutral and environmentally friendly. Thailand is an agricultural country that has abundant agricultural products and residue. In the year 2010, rice was the second most grown agricultural product next to sugarcane, but it provides the highest amount of biomass residue, which is called rice straw. Based on rice production of 31.5 million tons, approximately 25.6 million tons of rice straw was produced [4]. Because rice straw mainly contains carbon and hydrogen [8] and approximately 90% of it is left as agricultural waste and burned in open fields during harvesting season, it causes air pollution and public health issues; therefore, the conversion of the rice straw into energy will have many advantages, including the reduction of agricultural waste generated by the rice industry, the reduction of environmental impact and the acquisition of a new alternative energy resource for in-house energy production. A BG-FT (biomass gasification and Fischer–Tropsch) integrated process is regarded as promising technology for producing green liquid fuels;

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this process is also known as a BTL (biomass to liquid) process [13,24]. The liquid fuel from FT synthesis is an ultraclean product that is free of sulfur and contains small amounts of aromatics, resulting in lower emission levels when used in a combustion unit compared with liquid fuel from crude distillation. Moreover, it can also be applied to the existing infrastructure and car technology very well.

The study of the BG-FT process has gained extensive attention with regard to both technical and economic feasibilities because of increasing concerns regarding the decrease of globally reserved fossil fuel and the increase of greenhouse gas emissions; however, it is still in the research and development phase. The technical feasibility of a bench-scale BG-FT process was proven by long-term operation for 500 h over several runs with stable conditions [20]. The high overall thermal process efficiency of 51%, which corresponded to 40% gasification and 75% Fischer–Tropsch, was reported by Leibbrandt et al. [22]; while that of the BG-FT pilot scale located at NSTDA (National Science and Technology Development Agency), Thailand was found to show 36.92% thermal process efficiency [14]. Exergy analysis was also performed and the highest exergetic efficiency of 36.4% was observed [27]. Tijmensen et al. [31] reported that overall LHV (lower heating value) efficiencies of the BG-FT process in the range of 33–40% and 42–50% could be achieved in atmospheric and pressurized gasification systems, respectively. They also found that the production costs of both concepts could not compete with current diesel costs. Furthermore, the techno-economic performance of the BG-FT process, including the influence of changes in the type of gasifying agent (i.e., air, enriched air and oxygen), gasifying pressure, plant configuration and plant scale on investment cost and electricity efficiency that resulted in the FT diesel price, was investigated by Hamelinck et al. [10]. Avella et al. [1] performed an economic analysis by investigating the influence of various costs associated with plant configurations (i.e., cost of investment, operating cost, maintenance, depreciation and financing charge) on the price of electricity and synthesized liquid fuel. They found that the cost of both products strongly depended on the plant configurations. Moreover, a decrease of investment cost was also found when the size of the production plant increased [14]. The improvement of the BG-FT process efficiency by designing a suitable heat integration and CHP (combined heat and power) network, as well as the enhancement of economic feasibility by employment of a full conversion configuration using bio-oil as a feedstock was also studied [29]. The two various pathways (i.e., the BG-FT process and the IGCC (integrated gasification combined cycle) in which biomass was co-fired with coal) used to produce liquid transportation fuel and electricity were analyzed in term of total product yield (electricity and liquid fuels), carbon dioxide emissions, and total production cost [28].

The previous studies usually performed the performance analysis of the BG-FT process from the aspect of technical and economic feasibilities for developing a new technology offering liquid transportation fuel that could be competitive with the existing one from crude distillation. Nevertheless, the analyses were mostly restricted to the once-through process. In general, the derived FT off-gas consisting of unreacted syngas (CO and H_2) can be recycled to upstream processes, e.g., gasifier or FT reactor, in order to improve the product yield. Moreover, CO_2 by-product can be used as a gasifying agent which offers several advantages; no energy input is required for vaporization, the synthesis gas product at a wide range of H_2/CO ratios could be achieved and more volatile components are derived in the devolatilization step caused by the Boudouard reaction [3,12,16]. The objective of the present study is therefore to perform the techno-economic analysis comparing two configurations of the BG-FT process with rice straw feedstock (i.e., the once-through and the included long recycle loop concept in which the various fractions of the FT off-gas is recycled to the gasifier) using the BG-FT model developed in ACM (Aspen Custom Modeler) program. Regarding the technical aspect, the influence of changes in the FT off-gas recycle fraction for each constant FT reactor volume on the performance of the syngas processor, the FT synthesis process as well as the overall BG-FT process are investigated. The economic analysis using the incremental NPV (net present value) as an indicator is performed to investigate the feasibility of the BG-FT process using the FT off-gas recycle, compared with the once-through concept. Analysis of uncertain parameters, such as

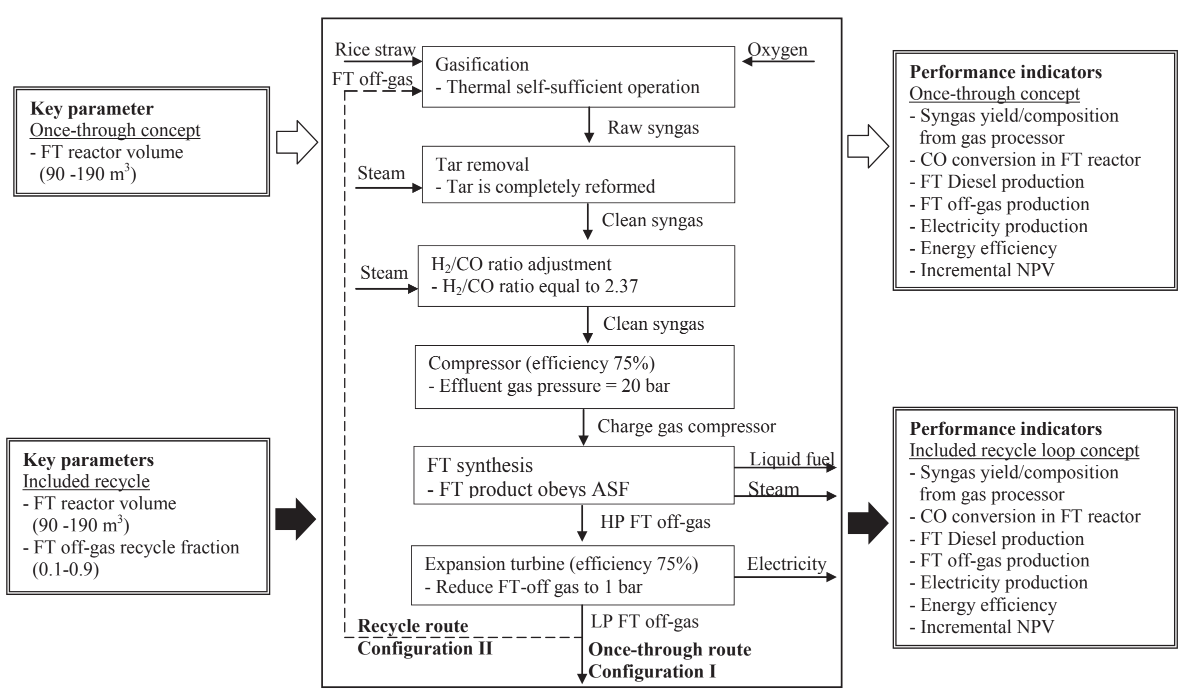

Fig. 1. The diagram of the BG-FT processes and the scope of work.