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Techno-economic Analysis of Biomass to Fischer-Tropsch Diesel Production With and Without CCS under Norwegian Conditions

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Abstract

This article deals with techno-economic analysis for production of transportation liquid fuel from biomass (biomass to liquid - BTL fuel) under Norwegian conditions, via thermal gasification followed by Fischer-Tropsch (FT) synthesis, integrated with combined heat and electricity production. The production plant is fuelled by 150 MW (LHV basis) of biomass in the form of raw woodchips or torrefied woodchips. The plant design is based on high temperature entrained flow gasification followed by catalytic Fischer-Tropsch synthesis. The plant efficiency based on FT-crude efficiency, thermal power efficiency, and electrical efficiency was predicted for two cases: with and without carbon capture and storage (CCS). In addition, it was also estimated for the production cost of FT-crude in terms of ($/GJ) in various plant operating conditions with varied feedstock quality, gasification temperature, and gasification equivalence ratio.

"Keywords: Gasification, Fischer-Tropsch, Techno-economics ;Carbon capture and storage"

1. Introduction

The worldwide consumption of liquid fuels for transportation is continuously increasing and is likely to double between 2000 and 2050[1]. At the same time, there is a gradual decrease in the known reserves of fossil-fuel feedstock. This decrease is coupled with an increase in the emissions of greenhouse gases, mainly CO_2, these being responsible for global warming. The *EU Renewables Directive* [2] has put

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forward the 20/20/20 targets to combat the greenhouse gas emissions. This Directive also includes targets for the transport sector; to reach 10% share of renewable energy within 2020, whereof a substantial part should be biofuels. Estimates carried out by Eurostat states that around 25% of Europe's transport energy demand will be supplied by advanced sustainable biofuels in 2030 [3], saving over 90 million tonnes of mineral oil per year, while the IEA [4, 5] roadmap envisions that 32 EJ of biofuels will be used globally by 2050, providing 27% of the world transport fuel need. A recent Norwegian study [3] shows that biofuels may be expected to be the second most important contributor to lower greenhouse gas emissions from the Norwegian transport sector in the future. This message is coherent with recently established policies, both Norwegian [6, 7] and international (e.g. the *EU Renewables Directive*) [2]. Presently, 3.5% of the total fuels used for road transport in Norway shall be biomass-derived. Currently, biofuels are produced at commercial scale mainly from biomass resources which are also competing with food supply, using the so-called "First Generation Biofuel" technologies. In achieving commercialization at large scale, first generation biofuels appear to have many shortcomings, which include land-use conflict, increasing food prices, and limited CO_2 reduction. In order to overcome these issues, the so-called "Second Generation Biofuel" technologies for the production of transport fuels from a wide range of ligno-cellulosic biomass feedstock, non-competing with food supply, have been proposed. Among second generation biofuels, liquid fuels produced via biomass gasification followed by Fischer-Tropsch (FT) synthesis have gained particular interests since the technology can meet present quality requirements of fossil-derived diesel. However, despite the numerous resources and extensive research work worldwide on developing FT fuel production technologies during the last decades, the progress in industrialization and commercialization of second generation biofuels has been very limited mainly due to the low biomass-to-liquid (BTL) conversion efficiency and the large scale requirement to make it cost-effective. This requirement may be even more critical for countries like Norway, where ligno-cellulosic biomass is dispersed and, therefore, the costs and environmental impact of biomass transport is significant. In this context, present work investigates the techno-economic analysis of a 150 MW BTL plant. The focus is to study the influence of biomass thermal pre-treatment, under Norwegian conditions, and the main operational parameters of gasification on the overall efficiency of the FT-crude production plant integrated with combined heat and power generation (CHP). The main FT-crude production process involves feed preparation, including drying or torrefaction and particle size reduction, high temperature entrained flow gasification, syngas cooling and conditioning, CO_2 capture and compression, FT synthesis and separation of FT-crude. The plant process design also involves optimization of heat recovery and steam generation from the main process and electric power production in order to improve the overall efficiency of the plant.

2. Plant process design approach

Figure 1 shows process flow diagram for the CHP-integrated FT-crude production plant considered in this work. The main process steps for the biomass to FT-crude conversion are fuel preparation, high-temperature oxygen-enriched entrained flow gasification, syngas cooling, water-gas shifting (WGS), CO_2 separation and compression and Fischer-Tropsch (FT) synthesis including gas/liquid separation and FT-crude/water separation.The main product of the plant is the so-called FT-crude, which is the oily product part obtained from FT synthesis after the FT-crude/water separation step. Further refining of the FT-crude is excluded from the analysis. Available heat from the syngas cooling, off-gas combustion, water-gas shifting and Fischer-Tropsch synthesis is recovered for steam generation at three different pressure levels: high pressure (HP) P_{stm}^{HP} (80 bar), intermediate pressure (IP) P_{stm}^{IP} (25 bar) and low pressure (LP) P_{stm}^{LP} (10 bar). The steam produced is then utilized for electricity production in a three-stage steam turbine with extraction at the intermediate pressure level, for steam supply to gasification and WGS, and additional injection of the steam produced from FT at the low pressure level. The performance of each stage of the steam turbine is defined by the isentropic efficiency, respectively denoted as η_s^{HP}, η_s^{IP} and η_s^{LP}. The saturated steam is leaving the steam turbine is then cooled in a condenser, which is specified by the steam-turbine back pressure P_0^{LP}. In addition, a combined cycle is introduced into the system to utilize the energy content in the off-gas stream from the FT synthesis unit, which include a gas turbine and steam generation at high pressure. Process simulations of the plant are performed in Aspen Plus for a base-case plant capacity of 150 MW biomass input. The costing of equipments was done based on a custom built spreadsheet and economic analysis and the methods were explained elsewhere in RS Kempegowda et.al [8]. Parametric expressions are also derived for the main energy flows and efficiencies based on fuel properties, composition of the syngas produced from gasification and the main process design parameters.

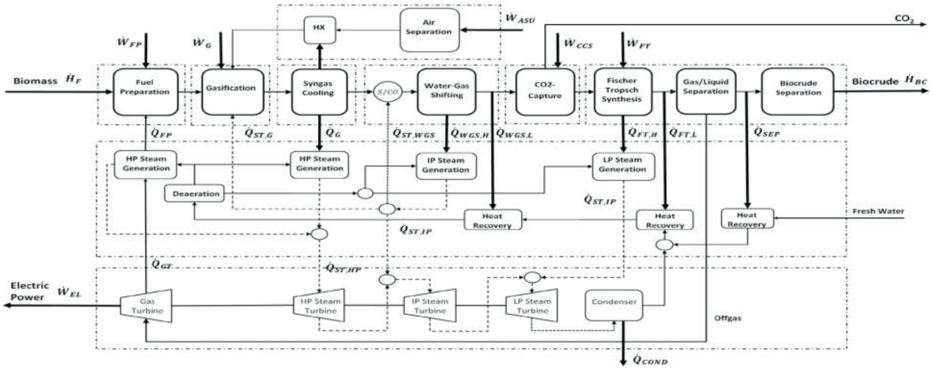
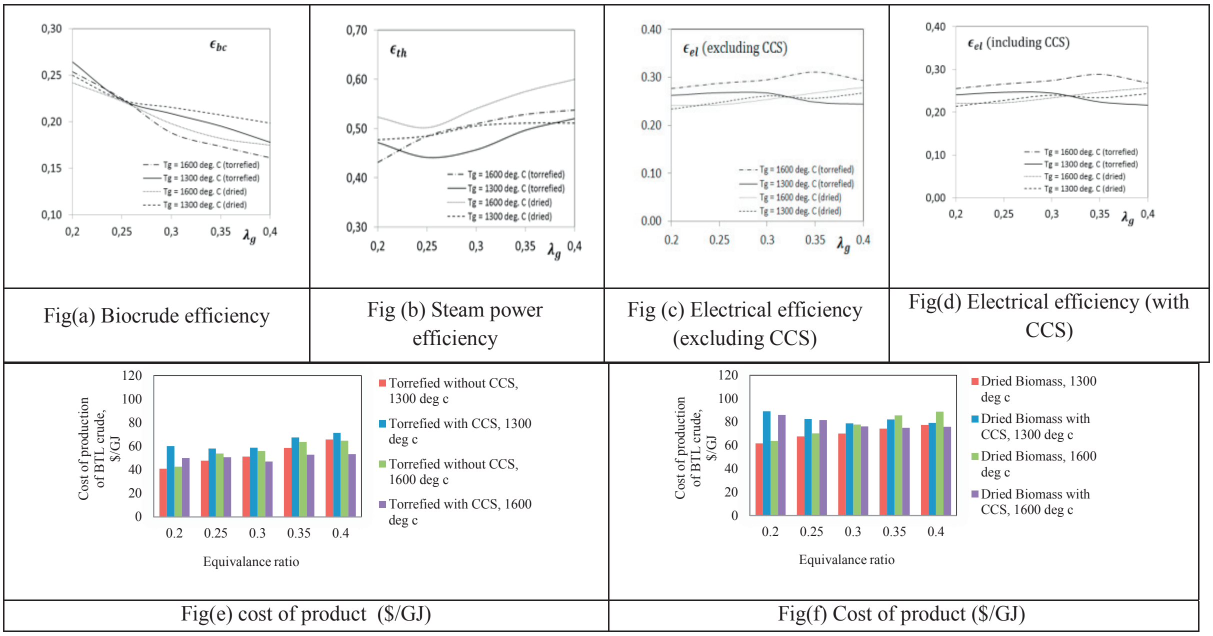


Fig. 1. BTL plant process diagram

3. Results and discussions

Figure 2 (a) shows that, as the equivalence ratio (ER) ratio increased from 0.2 to 0.4 at two different gasification temperatures (1300 deg c and 1600°C), there is a decreasing trend in FT-crude efficiency for both dried and torrefied material. This is due to the decrease in quality of syngas as the oxygen concentration increased. However, the steam power production efficiency increases as the ER ratio increased for all the cases as shown in Figure 2(b). This clearly indicates excess available heat in the gasification heat recovery section. For dried biomass the net thermal power increases with temperature but an opposite trend is shown for torrefied biomass. These results indicate that, for increasing values of the equivalence ratio for gasification of torrefied biomass, the thermal power losses associated to the steam consumed become larger than the increase of steam production with increasing temperatures. However, an opposite behaviour occurs with dried biomass. As the equivalence ratio decreases to below 0.3, the net thermal efficiency reaches a minimum and then increases when using either torrefied biomass at lower gasification temperatures or dried biomass at higher temperatures. The variations in the net electric-power production efficiency for with and without CCS are showed in the Figure 2 (c) and Figure

2 (d). The overall techno-economics is expressed in the form of \$/GJ for both scenarios with and without CCS as shown in Fig 2 (e) and (f).



Fig(a) Biocrude efficiency

Fig (b) Steam power efficiency

Fig (c) Electrical efficiency (excluding CCS)

Fig(d) Electrical efficiency (with CCS)

Fig(e) cost of product (\$/GJ)

Fig(f) Cost of product (\$/GJ)

Fig. 2. Efficiency and cost of production at varied Gasification equivalence ratio

4. Conclusion

Techno-economics of BTL plant capacity of 150 MW was studied in detailed for biocrude with coproduction of electricity. Operating conditions such as temperature and equivalence ratio influences the overall cost of the BTL plant. Overall cost of BTL production reduced with inclusion of torrefaction process. Cost of biocrude production is 41 \$/GJ for torrefaction at selected (ER: 0.2) but for dried biomass is 60 \$/GJ at 1300 ^{o}C(ER: .2), with CCS estimated to be 51 \$/GJ at 1300 ^{o}C (ER: .3) and 89 \$/GJ at 1600 ^{o}C (ER: .2) for torrefied and biomass operating conditions. Selection of equivalence ratio and steam to biomass ratio influences on designing optimum gasification to biocrude process. Further work will be conducted by considering natural gas co-feeding for improved biocrude production.

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