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Methanol production via pressurized entrained flow biomass gasification – Techno-economic comparison of integrated vs. stand-alone production

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ABSTRACT

The main objective with this work was to investigate techno-economically the opportunity for integrated gasification-based biomass-to-methanol production in an existing chemical pulp and paper mill. Three different system configurations using the pressurized entrained flow biomass gasification (PEBG) technology were studied, one stand-alone plant, one where the bark boiler in the mill was replaced by a PEBG unit and one with a co-integration of a black liquor gasifier operated in parallel with a PEBG unit. The cases were analysed in terms of overall energy efficiency (calculated as electricity-equivalents) and process economics. The economics was assessed under the current as well as possible future energy market conditions. An economic policy support was found to be necessary to make the methanol production competitive under all market scenarios. In a future energy market, integrating a PEBG unit to replace the bark boiler was the most beneficial case from an economic point of view. In this case the methanol production cost was reduced in the range of 11–18 Euro per MWh compared to the stand-alone case. The overall plant efficiency increased approximately 7%-units compared to the original operation of the mill and the non-integrated stand-alone case. In the case with co-integration of the two parallel gasifiers, an equal increase of the system efficiency was achieved, but the economic benefit was not as apparent. Under similar conditions as the current market and when methanol was sold to replace fossil gasoline, co-integration of the two parallel gasifiers was the best alternative based on received IRR.

1. Introduction

An increased share and a sustainable use of renewable energy are necessary both in the stationary and in the transportation sectors to reduce emissions of greenhouse gases [1,2]. Increasing the efficiency of the vehicle is the most cost-effective way to reduce greenhouse gas emissions in the transportation sector [1], but it is also important to replace fossil automotive fuels with non-fossil alternatives, i.e.

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Nomenclature

Abbreviations

BLG	black liquor gasification
CECPI	chemical engineering's plant cost index
CFB	circulating fluidized bed
EFG	entrained flow gasification
IRR	internal rate of return
MILP	mixed integer linear programming
O&M	operation and maintenance
PEBG	pressurized entrained flow biomass gasification
PI	process integration

biofuels. The latter is particularly important in those countries where internal combustion engines will still be needed due to cold climates [1], e.g. the countries of Scandinavia.

In Sweden, a long term targets have been set to make the Swedish vehicle fleet independent of fossil fuels in the year 2030. In the year 2050, Sweden should not contribute with any net emissions of greenhouse gases to the atmosphere [3]. Currently, Sweden has a general energy tax put on most fuels based on their energy contents. In addition, the country has a carbon tax, which is proportional to the fuel carbon content. In order to promote an increased share of biofuels for transportation, such fuels are subject to a full tax exemption.

In the year 2006, a tax on new motor vehicles was introduced. The tax has one fixed part and one variable based on the specific emissions of CO_2 [4]. From year 2009, the system supports purchases of environment-friendly cars through a tax exemption throughout the first five years after the purchase. This incentive has recently been strengthened with the introduction of an extra subsidy for cars that emits less than 50 g of CO_2 per km. Sweden also requires fuelling stations with an annual selling volume exceeding 1000 m^3 to offer a renewable fuel (e.g. the pump law) [4].

Biomass based methanol is one good alternative to replace fossil petrol in conventional spark engines, only requiring moderate changes in the vehicles and the fuel distribution infrastructure [5]. In 2007, the annual global methanol production rose to 40 million tons [5], where the largest share is used as a feedstock to the chemical industry. Methanol is currently almost exclusively produced via syngas (H_2 and CO) derived from fossil resources, such as natural gas, coal, petroleum oil, naphtha, etc. Production of biomethanol via gasification of lignocellulosic biomass is one alternative that could help decarbonize the transportation sector. Biomass based motor fuels will most likely be produced in existing pulp mills and other large scale forest industries due to the fact that they already have the required biomass handling infrastructure in place [6]. At the pulp mills an important raw material for motor fuel production will be black liquor from pulp production. Previous studies (e.g. Refs. [7–9]) have shown that an investment in black liquor gasification (BLG) is advantageous regarding efficiency and economic performance compared to a new recovery boiler investment for pulp mills. However, the availability of black liquor is limited and it is also strongly connected to the production of pulp and paper limiting the maximum amount of fuel production. Another opportunity, besides black liquor gasification, is direct gasification of forest residues. This alternative is mainly limited by the overall availability of biomass and it can work with low-grade biomass, e.g. logging residues and stumps. This alternative could become particularly attractive if combined with BLG since both upstream (oxygen plant) and downstream process equipment (catalytic conversion into motor fuels) can be co-utilized improving the economies of scale.

A large number of studies exist regarding techno-economic evaluations of motor fuel production systems using biomass based gasification technologies [8,10–18]. Integration of biomass gasifiers in existing industries has been analysed in Refs. [7,8,17,18]. Wetterlund et al. [18], showed important advantages regarding economic performance and energy efficiency when integrating a biomass circulating fluidized bed (CFB) gasifier for production of bio-DME (dimethyl-ether) in a pulp and paper mill compared to a stand-alone production unit. Consonni et al. [7] showed that solid biomass and BLG technologies integrated in a pulp and paper mill for both motor fuel production (DME, Fischer–Tropsch liquids or ethanol-rich mixed-alcohols) and power production would result in good investment opportunities and provide environmental benefits. However, benefits from integrating gasification processes in pulp and paper mills may diminish depending on final products as well as gasification technology [17]. Moreover, integrating a gasification based process in an existing industry may involve an increased operational risk. If for example a BLG plant is deployed, the plant availability must be higher than the host mill to ensure that the spent cooking chemicals (the green liquor) can be recovered, in order to make the overall process efficient and economically feasible.

The entrained flow gasification (EFG) concept is well-known from direct coal gasification and thoroughly presented in the literature, e.g. by Higman et al. [19]. The main advantages of using this concept in coal-based applications are the flexibility in firing a wide variety of coal feedstocks, and the production of a clean, tar-free product gas. However, the main drawbacks (from an energy point of view) are the relatively high oxygen consumption and the need for a finely ground feedstock. EFG reactors usually operate at pressures between 20 and 70 bar and temperatures in the range of 1200–1800 °C, depending on the type of fuel and application. The pressurized entrained flow biomass gasification (PEBG) concept is described in general in Ref. [20] and in more detail in Ref. [21]. In order to obtain an optimal gasification process of the fuel particles, it is important to apply suitable burner design, reactor shape and fuel powder characteristics. The favourable result, which is strived for at these conditions, is a syngas with very low tar content. For synthetic fuel applications (i.e. production of fuels and chemicals from syngas) the requirements on syngas purification are very high. If not, the catalysts used in the synthesis of the fuel product will be deactivated prematurely, which in turn will be costly. Basically, all components other than H_2 and CO need to be removed below ppm levels. The exception is CO_2, which for some reactions is even used at a small concentration like the synthesis for methanol. In some catalytic systems, inerts such as N_2 and CH_4 will accumulate and will therefore have to be