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System analysis of dry black liquor gasification based synthetic gas production comparing oxygen and air blown gasification systems

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HIGHLIGHTS

- Circulating fluidized bed system for black liquor gasification with direct causticization.
- Effects of gasifying medium i.e. oxygen or air, on gasification are studied.
- Direct causticization eliminates energy intensive limekiln reducing biomass use.
- Results show 10% higher SNG production from O_2 blown system than air blown system.
- SNG production is higher in O_2 blown system than air blown system.

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ABSTRACT

The black liquor gasification based bio-fuel production at chemical pulp mill is an attractive option to replace conventional recovery boilers increasing system energy efficiency. The present paper studies circulating fluidized bed system with direct causticization using TiO_2 for the gasification of the black liquor to the synthesis gas. The advantage of using direct causticization is the elimination of energy-intensive lime kiln which is an integral part of the conventional black liquor recovery system. The study evaluates the effects of gasifying medium i.e. oxygen or air, on the fluidized bed gasification system, the synthesis gas composition, and the downstream processes for the synthesis gas conversion to the synthetic natural gas (SNG). The results showed higher synthetic natural gas production potential with about 10% higher energy efficiency using oxygen blown gasification system than the air blown system. From the pulp mill integration perspective, the material and energy balance results in better integration of air blown system than the oxygen blown system, e.g. less steam required to be generated in the power boiler, less electricity import, and less additional biomass requirement. However, the air blown system still requires a significant amount of energy in terms of the synthesis gas handling and gas upgrading using the nitrogen rejection system.

1. Introduction

1.1. Background

According to Energy Information Administration, the fossil fuel consumption is expected to expand by 50% from 2005 to 2030 that would raise issues like greenhouse gas (GHG) emissions and future fuel security [1]. In future energy systems, bio-fuels replacing fossil fuels are considered to play a vital role due to GHG reduction policies. The European Union (EU) in renewable directive 2009 has set a target of 20% of energy supplied in EU shall come from renewable energy resources by 2020 [2]. As per the directive, the share of biofuels in the transport sector shall be 10% [2]. Sweden has set a goal of introducing 50% of the energy supplied shall come from the renewable energy resources by 2020 [2].

To meet such challenging targets, a large scale bio-fuel production would consume a substantial amount of bio-resources especially forest-based biomass. This leads to a very efficient use of biomass. The pulp and paper industry has a potential to become a bio-refinery, as a key producer of bio-fuels in future energy systems due to an established infrastructure. The pulp and paper industry can co-produce pulp and paper products together with different types of bio-fuels, e.g. synthetic natural gas (SNG), dimethyl ether (DME), or methanol, etc., using black liquor gasification technology.

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Nomenclature

ADt	air dried tonnes
ASU	air separation unit
BL	black liquor
BLG	black liquor gasification
BLS	black liquor solids
CBLG	Chemrec black liquor gasification
CFB	circulating fluidized bed
CNG	compressed natural gas
DBLG	dry black liquor gasification
DME	dimethyl ether
DMPEG	dimethyl ether of polyethylene glycol
EU	European Union
GHG	greenhouse gas
KAM	Kretslopps Anpassad Massafabrik (The Eco-cyclic pulp mill)
LHV	lower heating value
MeOH	methanol
MW	mega watt = 10^6 watt
RB	recovery boiler
Relox	relative oxidation
SNG	synthetic natural gas
tDS	tones dry solids
TWh	Tera watt-hour = 10^{12} W h

Black liquor (BL) is a major energy resource in countries with large pulp and paper industry, e.g. about 40 TW h of energy is available in the form of black liquor in Sweden [2].

Black liquor, spent cooking liquor, contains lignin obtained after the delignification process from the wood and in-organic cooking chemicals used for the delignification process. In conventional pulp mills, black liquor is fired in the recovery boilers to generate steam and electricity for pulp mill operations. The in-organic chemicals are recovered to re-use in the delignification process. However, black liquor can be gasified to the synthesis gas containing CO, H_2, and CH_4 as raw constituents for various bio-fuel production alternatives increasing overall energy efficiency of the mill. Among various alternatives, the synthetic natural gas (SNG) production is an interesting option to reduce natural gas dependency and associated GHG emissions. The black liquor gasification (BLG) route to SNG could be advantageous in terms of fuel security, current fuel supply infrastructure, and in a wide range of industrial applications. A basic concept of bio-fuel production at the pulp mill as a bio-refinery is shown in Fig. 1.

1.2. Previous studies

A number of studies have been made previously to investigate the most efficient route for the production of bio-fuel using different black liquor gasification technologies as a replacement of the conventional black liquor recovery cycle, e.g. DARS process, SCA-Billerud process, dry BLG with direct causticization, Manufacturing and Technology Conversion International process, and Chemrec gasification process [3–8]. The combined heat and power concept and various power cycles with black liquor gasification integrated with the pulp and paper mill haven been analyzed [9,10]. The studies on the consequences of various bio-fuel alternatives as transport fuels replacing petroleum fuels using Chemrec black liquor gasification process resulted in substantial improvement in the pulp and paper mill energy system [11–15]. The hydrothermal gasification system using supercritical oxidation process for direct methane production was proposed and showed a large potential of SNG production from wet biomass [16–18]. The dry black liquor gasification system with direct causticization using titanium dioxide (TiO_2) is experimentally analyzed using air as gasifying medium [19–21].

1.3. Objective and motivation

In a conventional circulating fluidized bed (CFB), air is generally used as a gasifying medium diluting the produced synthesis gas with a high concentration of nitrogen. This lowers the heating value of the synthesis gas due to dilution with nitrogen which cannot be easily separated from the synthetic natural gas. However if oxygen is used for the gasification process, there is an increased possibility of bed material agglomeration due to the formation of local hot spots in the gasification zone.

The present paper addresses reduced risk of agglomeration formation in the case of black liquor as raw material for the synthesis gas production in oxygen blown circulating fluidized bed (CFB) gasifier as compared to other conventional biomass resources. This paper is continuation of our previous published research work on black liquor gasification based bio-refinery systems [15,17,32–34]. The

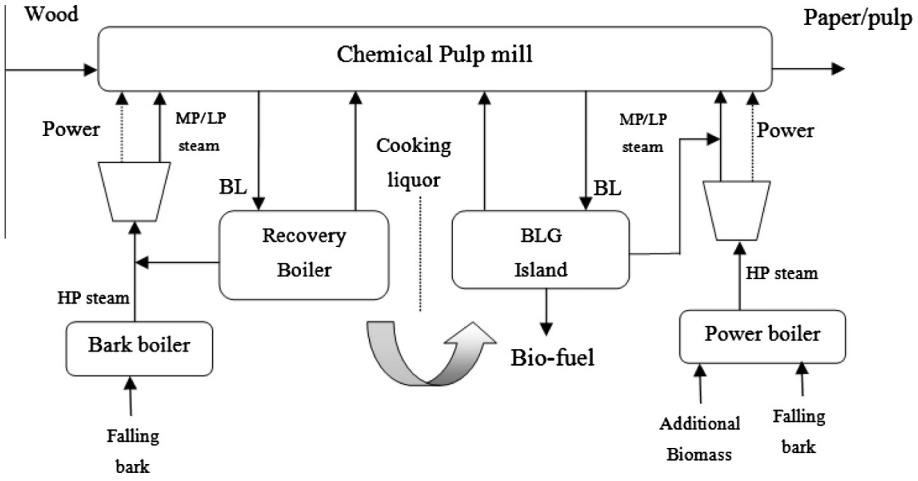

Fig. 1. Bio-refinery concept using BLG technology for bio-fuel production at the chemical pulp mill.