Contents lists available at ScienceDirect



International Journal of Greenhouse Gas Control

journal homepage: www.elsevier.com/locate/ijggc

Life cycle assessment of hydrogen production via iron-based chemicallooping process using non-aqueous phase bio-oil as fuel



Greenhouse Gas Control

Lijun Heng^{a,b}, Rui Xiao^{a,*}, Huiyan Zhang^a

^a Key Laboratory of Energy Thermal Conversion and Control of Ministry of Education, School of Energy and Environment, Southeast University, Nanjing 210096, China ^b School of Energy and Architectural Environment Engineering, Henan University of Urban Construction, Pingdingshan 467036, China

ARTICLE INFO

Keywords: Life cycle assessment Chemical-looping process Hydrogen production Fossil energy input Global warming potential

ABSTRACT

This study is conducted to quantify the fossil energy input (FEI) and the global warming potential (GWP) of hydrogen production through iron-based chemical-looping process with CO₂ capture using non-aqueous phase bio-oil (NAPB) from biomass fast pyrolysis as fuel. The eBalance software with Chinese Life Cycle Database is employed to implement this work based on the method of life cycle assessment (LCA). The LCA results indicate NAPB production consumes the largest fossil energy and contributes the largest GWP while chemical-looping hydrogen production (CLHP) plays a critical role in lessening greenhouse gas (GHG) emission. The net FEI and the net GWP of hydrogen production is, respectively, 0.597 MJ and -0.0767 kg CO_{2, eq.} per MJ hydrogen gas via the proposed production pathway, far below those of the conventional hydrogen production via natural gas steam reforming and coal gasification. The sensitivity analysis shows the data uncertainty of the discussed parameters except the electricity consumption for NAPB production has no significant impact on the net GWP. The chemical-looping produce hydrogen gas especially using renewable biomass as fuel.

1. Introduction

The massive fossil consumption has caused increasingly serious environmental concerns especially global warming. This has aroused great interest in developing new technologies to produce alternative fuels from renewable biomass (Gunukula et al., 2017). Biomass is a cheap and abundant renewable resource in the nature, of which agricultural residues as a by-product in the crop production are considered to be a promising feedstock (Zhang et al., 2013). Biomass fast pyrolysis is considered as one of the most promising technologies of converting biomass into biofuels for its high efficiency and low cost compared with the technologies of gasification and fermentation (Zhang et al., 2009). Moreover, some commercial-scale demonstration plants of fast pyrolysis with different handling capacity of biomass have been established in multiple regions or countries in the world (Cai and Liu, 2016). The operation practice from the demonstration plants can contribute to the industrialization process of fast pyrolysis technology. However, pyrolysis bio-oil cannot be directly applied to the transport vehicles due to its poor physicochemical properties (e.g. high water content, high oxygen content, high acidity, high viscosity, etc.) to date. Pyrolysis biooil needs to be upgraded for practical application (Bridgwater, 2012). The catalytic hydrogenation of bio-oil is considered to be a feasible approach (Vispute and Huber, 2009). However, it is not cost-effective to hydrodeoxygenate bio-oil completely owing to the lower yield of single target product and lots of worthless water produced. Some studies indicate that aqueous phase bio-oil (APB) from phase separation of bio-oil can be easily converted into alcohols via hydrogenation process (de Miguel Mercader et al., 2011; Huber et al., 2005). But there still exist many difficulties during converting non-aqueous phase bio-oil (NAPB) from phase separation of bio-oil into the transport fuels through catalytic hydrogenation (Xiao et al., 2014; Zhang et al., 2014). If NAPB with a larger calorific value is discarded, the utilization rate of bio-oil will be greatly reduced. Meanwhile, hydrogen gas (H₂) needs to be purchased from the outside for the hydro-upgrading of APB.

Hydrogen gas is not only clean fuel with zero-emission, but also an important feedstock widely used for refining crude oil and ammonia synthesis (Kathe et al., 2016). As a secondary fuel or feedstock, H₂ is mostly produced from primary energy source such as coal, natural gas, heavy oil, and naphtha (Navarro et al., 2007; Paltsev et al., 2011). About 96% of the world's H₂ is produced through natural gas steam reforming (NGSR) and coal-gasification (CG) without CO₂ capture, which lead to large amounts of greenhouse gas emission (Cormos et al., 2008). Additionally, these processes are not only energy-intensive, but also high-cost in post-purification and CO₂ capture (Zafar et al., 2005).

E-mail address: ruixiao@seu.edu.cn (R. Xiao).

https://doi.org/10.1016/j.ijggc.2018.06.020

^{*} Corresponding author.

Received 8 February 2018; Received in revised form 24 June 2018; Accepted 24 June 2018 1750-5836/@2018 Elsevier Ltd. All rights reserved.

Nomenclature		GWP	Global warming potential
		ILUC	Indirect land use change
APB	Aqueous phase bio-oil	IPCC	Intergovernmental panel on climate change
AR	Air reactor	LCA	Life cycle assessment
CG	Coal gasification	NAPB	Non-aqueous phase bio-oil
CLCD	Chinese life cycle database	NCG	Non-condensable gas
CLHP	Chemical-looping hydrogen production	NGSR	Natural gas steam reforming
FEI	Fossil energy input	SM	Supporting Material
FR	Fuel reactor	SOC	Soil organic carbon
FU	Functional unit	SR	Steam reactor
GHG	Greenhouse gas		

With the increase of H_2 demand, it is desired that the new technologies of hydrogen production be high efficient and environment-friendly. The chemical-looping process with inherent CO₂ separation is considered as a promising option of H_2 production in order to reduce the dependence on fossil energy and CO₂ emission (Cormos, 2015; Li et al., 2010).

Considering the above-mentioned situation, a new upgrading pathway of pyrolysis bio-oil has been proposed by our research group (Heng et al., 2016; Zeng et al., 2016). It mainly includes two important parts: 1) Iron-based chemical-looping hydrogen production (CLHP) using NAPB as fuel. 2) Esterification reaction and sequent catalytic hydrotreatment of APB for polyol production. The target products mainly comprise polyols containing C2 to C6 and hydrogen gas. The iron-based chemical-looping process plays a role of hydrogen provider for hydroprocessing of APB. The overall thermal performance, including the total thermal energy conversion efficiency, the hydrogen energy efficiency, and the waste heat recovery scheme about the CLHP process with CO₂ capture using NAPB as fuel, had been investigated in the literature (Heng et al., 2016). On the basis of these research results, the environmental performance of the CLHP process with CO₂ capture is investigated using the method of LCA.

This LCA work mainly quantifies the fossil energy consumption using the cumulative energy demand inventory method and evaluates life cycle GHG emission from hydrogen production according to the GWP 100a method (Solomon et al., 2007). The required inputs of material and energy involved in the production of NAPB and hydrogen gas are taken from the process simulation results based on Aspen Plus software (V7.1). The eBalance software with a Chinese Life Cycle Database (CLCD) (V0.8) is employed to perform this LCA task (Integrated Knowledge for our Environment (IKE), 2010).

2. Description of hydrogen production pathway

Multiple unit processes are involved in converting biomass into polyols and H_2 . Biomass production, collection and transportation of biomass, biomass preprocessing, and bio-oil production are all important upstream processes involved in the production of polyols and H_2 . The production process flow diagram of bio-oil, H_2 and polyol fuel are described in detail in Fig. S1 in Support Material (SM).

The biomass processing capacity is 25 tonnes/day of dry corn stover according to the annual polyol output of 1000 tonnes from the demonstration plant under the assumption of 6000 operation hours per year. Ultimate analysis, proximate analysis and lower calorific value (LHV) of corn stover are shown in Table S1 in SM. The bio-oil production includes biomass pretreatment, biomass fast pyrolysis, solid removal, bio-oil recovery, and heat production. The harvested biomass with high moisture needs to be dried and smashed to increase the biooil yield. The biomass with 25 wt.% moisture (M) is firstly chopped to 10 mm particle diameter and then dried to 7 wt.% M, and finally ground to 3 mm particle diameter (Ringer et al., 2006). A fluidized bed pyrolysis reactor operates at 500 °C and at ambient pressure (Wright et al., 2010a; Brown et al., 2012). The pyrolysis products include bio-oil vapors, non-condensable gases (NCGs), and solid char with ash. The composition and yield of pyrolysis products are listed in Table S2 in SM. The yield of bio-oil, NCGs, and char is, respectively, 69.1 wt.%, 15.1 wt. % and 15.8 wt.% based on the dry basis of biomass. 99 wt.% of the entrained char and ash particles in the pyrolysis gas is assumed to be removed via a set of cyclones and baghouse filters in turn. The bio-oil vapors are recovered via the staged condensers. The by-products including NCGs and char serve as fuels to provide the process heat required by the pyrolysis reactor, steam generation, preheating combustion air, and preheating the reactants for the esterification reactor. A portion of flue gas from the combustor is compressed and sent to the pyrolyzer as the carrier gas, as shown in Fig. S1 in SM.

The bio-oil is separated into APB and NAPB via forced water separation in a liquid-liquid (L-L) extractor. The dry bio-oil is defined as the water-free bio-oil containing 62.2 wt.% of water-free APB and 37.8 wt.% of water-free NAPB. The detailed composition and LHV of APB and NAPB are shown in Table S3 in SM. The APB is mainly converted into polyol fuel and by-product (esters) through the esterification and hydrogenation processes, the detailed operation parameters of which can be found in the published literature (Heng et al., 2018). The NAPB as fuel is used for an iron-based CLHP process with CO₂ capture to produce H₂. Currently, the low-cost and environmentally-friendly ferric oxide (Fe₂O₃) is the most suitable oxygen carrier (OC) for the CLHP process according to the thermodynamic analysis (Kang et al., 2010). The alpha-corundum (Al_2O_3) as inert carrier plays a role of antisintering and heat-carrying agent. Therefore, Fe₂O₃ blended with Al₂O₃ acts as the OC. The NAPB is almost completely oxidized to CO2 and H2O by Fe₂O₃ and Fe₂O₃ is reduced to a lower valent state containing ferrous oxide (Fe_{0.947}O) and ferroferric oxide (Fe₃O₄) simultaneously in the fuel reactor (FR). Then the partially reduced OC from FR reacts with steam to produce H₂ and is oxidized to the ferroferric oxide (Fe₃O₄) in the steam reactor (SR). Lastly, Fe₃O₄ from SR is further oxidized to Fe₂O₃ by oxygen gas from air in the air reactor (AR). The mixtures produced in three reactors are separated into gases and solids through the cyclone separators, respectively. The solid particles of OC circulate among three reactors. High temperature gas mixtures from three reactors are transported into waste heat recovery system (WHRS) and cooled, as shown in Fig. S1 in SM. The heat from high temperature gases is utilized to produce superheated steam, preheat the air for AR and NAPB for FR. Then the cooled gas mixtures out of WHRS are further cooled to 25 °C. Finally, the separation of H₂ from water and the separation of CO₂ from water are completed via the flash separators. A part of compressed H₂ is delivered to the hydro-upgrading process of APB and the remaining part to the storage tank. The CO₂ captured can be delivered to the storage for CO2 sequestration or sold to some enterprises. Additionally, the hypoxic air out of AR is directly released into the atmosphere after cooled through WHRS.

In this study, the CLHP process is under the self-sustaining operation mode. The power consumption from this unit process is fully provided by the turbine generators and the process heat required by FR comes from AR by means of the circulating OC. The CLHP process simulation models established using Aspen Plus software and the scheme of waste heat utilization can be found in the published literature (Heng et al., Download English Version:

https://daneshyari.com/en/article/8089212

Download Persian Version:

https://daneshyari.com/article/8089212

Daneshyari.com