Energy xxx (2014) 1–5

Contents lists available at ScienceDirect

Energy

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

Syngas production from palm kernel shell and polyethylene waste blend in fluidized bed catalytic steam co-gasification process

Reza Alipour Moghadam [a], Suzana Yusup [a,*], Yoshimitsu Uemura [a], Bridgid Lai Fui Chin [a], Hon Loong Lam [b], Ahmed Al Shoaibi [c]

[a] Biomass Processing Laboratory, Centre of Biofuel and Biochemical Research, Department of Chemical Engineering, Universiti Teknologi PETRONAS, 31750 Perak, Malaysia
[b] Department of Chemical and Environmental Engineering, Faculty of Engineering, University of Nottingham Malaysia campus, Jalan Broga, 43500 Semenyih, Selangor Darul Ehsan, Malaysia
[c] Department of Chemical Engineering, The Petroleum Institute, P.O. Box 2533, Abu Dhabi, United Arab Emirates

ARTICLE INFO

Article history:
Received 13 December 2013
Received in revised form
14 April 2014
Accepted 19 April 2014
Available online xxx

Keywords:
Biomass
Energy
Hydrogen
Gasification
Syngas

ABSTRACT

Energy from renewable source is expected to complement the energy derived from fossil fuel resources. Gasification is a versatile thermochemical process for solid waste fuel conversion. In the current paper, syngas production from palm kernel shell (PKS) and polyethylene waste blend in a catalytic steam gasification process is studied. In order to acquire the optimum condition of syngas production, the effect of main variables such as reaction temperature, steam/feedstock (S/F) ratio, polyethylene waste/biomass (P/B) ratio on syngas production was investigated and optimized via Taguchi design of experiment approach. Under the optimized condition of 800 °C, P/B ratio: 0.3 w/w and S/F ratio: 1 w/w, the total syngas yield and hydrogen yield achieved are 422.40 g syngas/kg feedstock and 135.27 g H_2/kg feedstock, respectively.

1. Introduction

Due to increasing energy consumption and demand, limited supply of fossil fuels and along with issues related to environmental pollution due to usage of fossil fuels, alternative sources of renewable energies gain a lot of attention. Based on recent studies, the world CO_2 emission which is the main cause of global warming increased by 3% and reaching an all-time high of 34 billion tons in 2011 [1]. According to the Global Climate Change Initiatives (GCCI), the greenhouse gas intensity should be decreased by 18% by the year 2012 [2]. In addition, it is mandated in Doha amendment to the Kyoto Protocol that industrial countries that developed countries should reduce greenhouse gas emission to 30% by 2020 [3]. On the other hand, one of the serious problems related to the environment is an increasing amount of plastic waste that is growing year by year. The production of energy from polyethylene waste has been expected to be an effective solution to dispose this type of waste. Biomass is an abundant feedstock for renewable energy and if blended with polyethylene waste, it has significant economic and environmental potential as the energy resource for synthetic gas (syngas) production. Syngas is one of the gasification products and is the basic raw material for chemical industry. The energy density of syngas is about 50% of natural gas and is mostly suited for transportation fuels application and chemical production. In addition, hydrogen (H_2) is very important fuel and could be derived from syngas. In comparison to fossil fuels, the energy content is in the ratio of 0.38 kg H_2/kg gasoline [4].

Among the thermochemical conversion technologies, catalytic steam gasification is a promising option for utilization of mixed feedstock. The interest in production of syngas from mixed feedstock at a large scale can fulfil environmental, economical and social objectives. These advantages include preventing further global warming, ensuring sustainability resource of fuel and reducing the dependence on fossil fuel. The present work focused on utilization of a mixture of palm kernel shell (PKS) and polyethylene waste as feedstock to produce synthetic gas (syngas) from fluidized bed pilot gasifier unit. Syngas is defined as a gas that contains H_2 and CO (carbon monoxide) as the primary combustible components.

* Corresponding author. Tel.: +60 (0)5 3688208; fax: +60 (0)5 3688204.
E-mail addresses: moghadam.reza.utp@gmail.com (R.A. Moghadam), drsuzana_yusuf@petronas.com.my (S. Yusup), yoshimitsu_uemura@petronas.com.my (Y. Uemura), bridgidchin@gmail.com (B.L.F. Chin), honloong.lam@nottingham.edu.my (H.L. Lam), aalshoaibi@pi.ac.ae (A. Al Shoaibi).

http://dx.doi.org/10.1016/j.energy.2014.04.062
0360-5442/

He et al. [5] investigated on syngas production by applying catalytic steam gasification of polyethylene waste and studied the influence of temperature on gas yield and composition. They achieved the highest syngas content of 61.95 vol%. Another study by He et al. [6] using municipal solid waste (MSW) via catalytic steam gasification process resulted in maximum syngas content of 70.46 vol%. Luo et al. [7] studied on syngas production from MSW via catalytic steam gasification which resulted in higher H_2 and carbon monoxide (CO) content of 54.22 vol% and 22.72 vol%, respectively. Pinto et al. [8] performed co-gasification of coal and waste in pilot scale unit. They reported an effective reduction in tar and increasing in H_2 content of more than 50% by using dolomite and nickel (Ni) based catalyst. Huang et al. [9] investigated the conversion of biomass to syngas through steam gasification. They achieved maximum syngas content of 76.11 vol% at higher gasifier temperature of 850 °C. Kwak et al. [10] performed gasification of solid waste and obtained syngas at 1200 °C which contained 25–34 vol% of CO and 28–34 vol% of H_2. Chang et al. [11] optimized condition of biomass gasification for syngas production and identified maximum content of H_2 and CO of 29.54 vol% and 23.60 vol%, respectively. Atnaw et al. [12] investigated the gasification of oil palm fronds in downdraft gasifier to produce syngas. They claimed oxidation zone temperature above 850 °C is favourable for syngas production.

It can be concluded that the final product compositions depend on the fraction of the main components of feedstock. As stated, based on previous research studies, many operational parameters are involved to produce syngas. The purpose of this research is to optimize the catalytic steam gasification of blended feedstock for enhancement of syngas production and gasification efficiency of a pilot unit. The purpose of this research is to optimize the catalytic steam gasification of blended feedstock based on enhancing the syngas production and gasification efficiency at pilot scale through Taguchi method. The Taguchi approaches are divided into three stages which are system design, parameter design, and tolerance design. Among these stages, the parameter stage is considered to be the most essential stage [13]. The sequence in the Taguchi parameters are as follows: (1) selection of proper orthogonal array (OA), (2) running experiments based on the OA, (3) data analysis and optimum conditions are identified, and (4) verification of the optimum conditions by repeating experimental runs [14].

2. Materials and methods

2.1. Feedstock

PKS is a well-known biomass due to its high calorific value and fixed carbon content. For every ton of oil palm fruit bunch fed to the palm-oil refining process, about 0.1 t of PKS is produced as the solid wastes [15]. The total volume of certified sustainable palm kernel globally in 2012 was 1,896,702 Mt [16]. In this study, the PKS was obtained from local palm-oil factory. The polyethylene waste was obtained from high-density polyethylene (HDPE) waste grade 2. Samples were pulverized and sieved into a specific particle size between 1 and 2 mm. The proximate and ultimate analyses of the feedstock are reported in Table 1.

2.2. Experimental procedure

The experiments were carried out in pilot fluidized bed gasifier. Fig. 1 shows the process flow diagram of catalytic steam gasification unit. The pilot unit consists of two cylindrical reactors made of Inconel 625. The fluidized bed gasifier has the height of 2500 mm and internal diameter of 150 mm and 200 mm in gasification and free board zone, respectively. The fixed bed gasifier height is 2500 mm and internal diameter of 150 mm. The gasifiers equipped with four individual electrical heaters and eight thermocouples for controlling the temperature profile across each reactors.

Table 1
Proximate and ultimate analysis.

Proximate analysis (wt% wet basis)	PKS	HDPE	Ultimate analysis (wt.% dry basis)	PKS	HDPE
Moisture content	12.00	0.00	C	49.23	85.71
Volatile matter	30.53	99.67	H	5.04	14.29
Fixed carbon	48.50	0.00	O	44.94	0.00
Ash	8.97	0.33	N	0.74	0.00
Holocellulose	54.30	–	S	0.05	0.00
Alpha-cellulose	29.60	–	Density (kg/m^3)	733	1194
Lignin	59.30	–	HHV (MJ/kg)	24.97	45.98

Blended feedstock mixed with commercial Ni catalyst was used for the gasification process. Feedstock with feeding rate of 2 kg/h was continuously fed to the dense zone of the fluidized bed gasifier. The feeding system was cooled by water to avoid any clogging due to pyrolysis of polyethylene waste in the feeding system. Superheated steam at temperature of 300 °C was applied as the gasifying agent. Produced gas passed through the dolomite bed in the fixed bed gasifier and scrubber respectively to further convert any tar presence and for gas cleaning. Online gas analyzer (Teledyne 7500, 7600 and 4060) equipped with data acquisition was employed to determine the composition of the product gases. Chemical composition of local dolomite is reported in Table 2. Dolomite was applied as the catalyst for tar conversion in a fixed bed of the gasifier unit.

The usage of dolomite is to convert tar and hydrocarbons to syngas which will increase the economic viability and overall biomass gasification efficiency. Furthermore, dolomite is an inexpensive disposable catalyst that can significantly convert and reduce the tar content of the produced gas. The presence of CaO, MgO, and Fe_2O_3 in the dolomite catalyst enhances the tar cracking during the gasification process. The activity of the dolomite catalyst can be improved by increasing the Ca/Mg ratio and metal content. Eqs. (1)–(5) show the list of tar cracking reactions occurred when dolomite catalyst was used.

Reaction temperature, steam to feedstock ratio (S/F), and polyethylene waste to biomass (P/B) ratio were the three variables carried out in the study. The variables range for reaction temperature, S/F ratio, and P/B ratio are 650–800 °C, 1–3, and 0.2–0.3, respectively. The selection of the reaction temperature and S/F ratio are based on a previous study [17].

$$CaMg(CO_3)_2 \rightarrow MgO - CaO + CO_2 \quad (1)$$

$$C_nH_m\,(tar) + nCO_2 \rightarrow (m/2)H_2 + 2nCO \quad (2)$$

$$C_nH_m\,(tar) + nH_2O \rightarrow (n + m/2)H_2 + nCO \quad (3)$$

$$3Fe_2O_3 + CO \rightarrow 2Fe_3O_4 + CO_2 \quad (4)$$

$$CO_2 + CH_4 \rightarrow 2H_2 + 2CO \quad (5)$$

3. Results and discussions

3.1. Effect of temperature

Temperature exhibits the most crucial effect on catalytic steam gasification process and has major influence on the final product

Please cite this article in press as: Moghadam RA, et al., Syngas production from palm kernel shell and polyethylene waste blend in fluidized bed catalytic steam co-gasification process, Energy (2014), http://dx.doi.org/10.1016/j.energy.2014.04.062