Energy 77 (2014) 125–132

Contents lists available at ScienceDirect

Energy

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

Production of methanol from a mixture of torrefied biomass and coal

P. Trop*, B. Anicic, D. Goricanec

University of Maribor, Faculty of Chemistry and Chemical Engineering, Smetanova ulica 17, 2000 Maribor, Slovenia

ARTICLE INFO

Article history:
Received 10 December 2013
Received in revised form
28 April 2014
Accepted 13 May 2014
Available online 13 June 2014

Keywords:
Torrefied biomass
Gasification
Methanol production

ABSTRACT

This paper investigated the influence of adding torrefied biomass within an entrained flow coal gasifier for the production of methanol. Computer simulations of gasifying a mixture of torrefied biomass and coal within an entrained flow gasifier, synthesis gas purification, and methanol synthesis were carried out using the Aspen plus program package. In addition, economic analyses are presented based on the net present value. It was shown that, based on the predictions for future prices of the raw materials and methanol, usage of a mixture of biomass and coal within entrained flow gasifiers would be feasible and could become economically even better than the usage of coal only. The net emissions of CO_2 would also be significantly lowered.

1. Introduction

Energy demands have increased substantially over the last decade [1] and consequently alternative energy sources are becoming a greater necessity [2]. Therefore researchers are focussing on the development of processes and technologies that are environmentally-friendly, whilst ensuring reasonable standards of living throughout our world [3]. Biomass is one of the more important potential sources for the production of synthetic fuels [4] and energy, especially in Slovenia being one of the more forested countries in Europe with over 50% of its area covered by forests. Furthermore, Slovenia is one of a few countries to have a positive increment of wood biomass. The annual increment is approximately 7 million cubic metres, of which about 4.9 million cubic metres are available for energy production [5]. This potential is not fully utilised presently because the properties of biomass restrict its wider uptake by industries. Furthermore, biomass is more expensive than coal but carbon-trading laws are a good motivation for greater usage of biomass [2].

A significant number of studies exist regarding techno-economic evaluations of methanol production. Methanol is usually produced from natural gas, coal, petroleum oil, etc. [6], however the future direction of methanol production technology is in replacing fossil sources with renewable energy sources and biomass has been considered within significant studies [7]. Another important approach is the integration of the methanol production process with chemical processes, refineries, the pulp and paper industry [6], and district heating systems [6,7].

The formations of tar and char during biomass gasification can be very problematic when using conventional biomass gasification systems such as the interconnected fluidised bed gasifier [8], causing pipe-blockages of the down-stream equipment. However, in order to use biomass in entrained flow gasifiers, the biomass must be pulverised to particle sizes of 100 μm, which is a necessity for these types of gasifiers [9,10] and large energy consumption is needed to pulverise raw biomass [11]. Over recent years several studies have been conducted in order to improve the properties of biomass, with one of the developed methods being considered as more promising. This is the so-called torrefaction of biomass. Torrefaction, also known as mild pyrolysis, is a process where biomass is exposed to 200–300 °C within an anaerobic environment [9,10]. During this process the water evaporates, together with certain other volatiles, and the lignocellulosic biopolymers partially decompose. This results in a loss of about 20% of the initial mass, and 10% of the initial heating value. Torrefaction technology greatly reduces the tenacity of biomass, therefore the power consumption needed for grinding torrefied biomass is reduced by 80–90% in comparison to raw biomass [11]. The grindability of torrefied biomass is comparable to that of coal; therefore it can be gasified in entrained flow gasifiers with high cold gas efficiencies [11]. The torrefaction process improves not only the energy density of the biomass but also other properties such as the ability of pelletisation, and hydrophobic nature [12]. Torrefaction also increases the homogeneity of the material and storing is also easier due to the hydrophobic properties of the torrefied biomass. It is for these reasons torrefied biomass is easily transported and can be used for

* Corresponding author. Tel.: +386 41 383057.
E-mail addresses: peter.trop@um.si, peter.trop@gmail.com (P. Trop), bozidar.anicic@student.um.si (B. Anicic), darko.goricanec@um.si (D. Goricanec).

http://dx.doi.org/10.1016/j.energy.2014.05.045
0360-5442/

high temperature gasification applications. The torrefied biomass could be partly or totally substituted for coal within the entrained flow gasifiers in order to obtain synthesis gas. The reason why biomass could be used is its high availability in Slovenia. Nonetheless, as biomass is considered as a renewable-energy source, it reduces the values of the carbon taxes that must be paid for fossil fuel usage. This is also the main reason why biomass is considered in this work, even though coal is cheaper.

Synthesis gas obtained from the gasifier is further used for methanol production. As the amount of hydrogen in it is insufficient, syngas firstly undergoes a WGSR (water–gas shift reaction) and is then conveyed to a methanol synthesis reactor. The needed amount of hydrogen can also be provided from water electrolysis [13] but this method is not used in this case as the WGSR is usually used for the industrial production of methanol.

The second part of this paper presents an economic analysis of the whole process, including torrefaction of biomass, gasification, and methanol production. It is for this purpose that some approximations and assumptions have been made due to the lack of information. Economic analysis is based on net present value. Predicted prices for the reactants and products have been used in order to calculate the future values of revenue. The predicted prices have been calculated using World Bank price indices, and such prices on average outperform the random walk forecasts or extrapolations of recent price trends [14].

1.1. Torrefaction of biomass

The process of biomass torrefaction is a promising process for increasing the amount of biomass used for gasification processes. As stated previously, raw biomass cannot be used within a high temperature coal gasifier but, on the other hand, torrefied biomass can.

The process of torrefaction consists of five stages. During the first stage biomass (usually wood) is initially heated, then drying occurs, and at the end of this stage the moisture starts to evaporate. Free water evaporates at a constant rate during the second stage. A constant rate of evaporation also means a constant temperature. During this stage the biomass loses from 5 to 10% of its initial mass, and after that point is reached, the rate of the evaporation decreases, indicating the end of the second phase. An additional amount of physically-bonded water is released during the third stage whilst the biomass is being heated to 200 °C. Some lighter organic compounds could also evaporate during the third stage, which is finished when the temperature exceeds 200 °C. At that point the fourth stage starts, which lasts until the temperature is decreased to 200 °C. The actual process of torrefaction occurs during this stage. The final (peak) temperature varies between 200 and 300 °C, and the residence time from 60 to 90 min. This stage consists of both heating and cooling periods. Devolatilisation begins during the heating period. The process of mass loss is continued during the period of constant temperature until the cooling period. The final stage of biomass torrefaction is further cooling from 200 °C [12].

The necessary heat for torrefaction and pre-drying is produced by the combustion of the liberated torrefaction gas. An auxiliary fuel could possibly be used when the energy content of the torrefaction gas is insufficient to thermally balance the torrefaction process [15].

Several choices should therefore be made as there are several ways of modelling the torrefaction process. For example, it should be decided as to whether biomass would be heated directly or indirectly. The process modelling and simulation of biomass torrefaction is outside the scope of this paper. The properties of the torrefied biomass that are needed for further simulations are given in Ref. [16].

1.1.1. Properties of torrefied biomass

The process of biomass torrefaction improves the properties of biomass, and consecutively increases its price. The properties of the torrefied biomass are similar to the coal properties. Even though coal has a lower price, and a slightly higher energy density, the torrefied biomass can produce a better way in practice. The main advantage of torrefied biomass over coal is carbon neutrality. This advantage can be considered through two aspects. Firstly, it is more environmentally-friendly, as it has zero carbon footprints. Secondly, the economics of its exploitation can be enhanced due to carbon taxes. The values of the taxes vary from country to country. In view of this it is reasonable to expect that over the years the use of torrefied biomass for gasification should become more interesting. Furthermore, it is possible, that at some point, it will become more cost-effective than coal. The current prices of coal, and torrefied biomass are 11.0 €/MWh and 26.7 €/MWh, respectively. It is obvious that coal is much cheaper than torrefied biomass but, on the other hand, biomass is a renewable energy-source and has lower sulphur content that reduces the costs of desulphurisation. Furthermore, the lower ash content is another advantage of the torrefied biomass as it reduces the costs of the ash handling process.

A mixture of coal and biomass in a ratio 1:1 was used during our calculations. This ratio was considered for simplicity, and further work would include optimisation of the whole process, including the aforementioned ratio. It is reasonable to expect that the optimal ratio would depend on the price ratio between coal and biomass.

2. Methods

All of the mentioned processes were modelled using the Aspen Plus program package. The Peng–Robinson thermodynamic method was chosen for the gasification, water–gas shift, and methanol production sections, whilst the PC-SAFT (perturbed-chain statistical associating fluid theory) [17] property method was employed for the Rectisol process. Czech coal from Ledvice and torrefied biomass from Ref. [18], having the compositions stated in Table 1, was used for all the simulations.

2.1. Gasification process

The process of gasification has been known for several centuries and until recently only coal had been used as a raw material. Due to the development of the torrefaction process and due to the introduction of carbon taxes, biomass is also being considered as a possible raw material for the high temperature gasification process. Two 500 MW gasifiers were used during our simulations, with a mixture of coal and torrefied biomass as the raw material. The amounts of coal and biomass were calculated in such a way that each of them ensured 250 MW within each gasifier. The calculations were carried out using lower heating values (Table 1),

Table 1
Composition and heating values of coal and torrefied biomass.

Parameters		Testing method	Coal	Torrefied biomass
Moisture	%wt	ASTM D 5142	14.15	35.63
Ash	%wt	ASTM D 5142	10.61	4.47
Volatiles	%wt	ASTM D 5142	40.48	20.69
C-fix	%wt	ASTM D 5142	34.76	39.21
Carbon	%wt	ASTM D 5373	56.36	78.76
Hydrogen	%wt	ASTM D 5373	4.40	4.29
Nitrogen	%wt	ASTM D 5373	0.83	0.05
Oxygen	%wt	Calculated	12.46	16.83
Sulphur	%wt	ASTM D 4239	1.19	0.07
LHV	MJ/kg	DIN 51900	21.73	18.09