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Biomethane production via anaerobic digestion and biomass gasification

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Abstract

The transport sector accounts for the second biggest greenhouse gas emission in the European Union (EU). In order to achieve the target of CO2 emission reduction there is a rapid growing interest in using biomethane as fuel for transport applications. Biomethane can be produced through anaerobic digestion or biomass gasification. Anaerobic digestion is a biochemical process. Since the raw gas contains approximately 65vol% CH4 and 35vol%, an upgrading process is needed to remove CO2. Göteborg biomass gasification project (GoBiGas) is the world's first demonstration plant for large-scale production of biomethane through the gasification of forest residues. To achieve high purity CH4, a methanation process is required after gasification. This work compares these two technologies from the perspective of energy efficiency. Simulation results show that they have similar efficiencies: 62-64% for AE and ~65% for GoBiGas.

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Keywords: biomethane, anaerobic digestion, biomass gasification, upgrading, efficiency

1. Introduction

The transport sector has the second biggest greenhouse gas emission in the European Union (EU). More than two thirds of transport-related greenhouse gas emissions are from road transport. Since 2008 greenhouse gas emissions from transport have started to decrease. Despite this trend transport emissions were in 2012 still 20.5 % above 1990 levels and would need to fall by 67 % by 2050 in order to meet the 2011 Transport White Paper target reduction of 60% compared to 1990 [1]. In this context, using biomethane, which is considered as carbon neutral, as vehicle fuel has attracted more and more attention.

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For example, according to Vanciu and Miresashvili [2], the number of biogas cars in Sweden has reached 40000 in 2012, which is more than double of that in 2008.

Biomethane is normally produced through anaerobic digestion (AE) or biomass gasification, which have their own characters. Anaerobic digestion is a biochemical process, during which complex organic matter is decomposed in absence of oxygen by various types of anaerobic microorganisms, with a low energy demand of heat and electricity; hence, it normally has a high energy efficiency. Nevertheless, biogas produced from anaerobic digestion contains a big fraction of CO2 (about 35-45vol%). In order to use biogas as vehicle fuel, it has to be upgraded to remove CO2 and achieve a purity of biomethane >95vol% [3]. However, since the costs of common technologies of biogas upgrading including water scrubbing, pressure swing adsorption, chemical absorption etc. are relatively high due to the use of either energy, chemicals or both [4], there is a big challenge to increase the production of biomethane in an energy and cost efficient way. Biomass gasification is another technology for efficient utilization of biomass. The produced syngas can be further used to generate power, heat and fuels, such as hydrogen and ethanol. It is also possible to produce biomethane. Whereas, due to the low content of CH4 in the syngas, it normally requires a methanation process, which can convert CO and H2 to CH4. Before methanation, the water-gas-shift (WGS) process is also needed, which can control the C/H ratio of syngas. The additional WGS and methanation processes result in a lower overall efficiency of gasification, a more complicated system configuration and higher investment costs and operation costs. Compared to anaerobic digestion, the advantage of biomass gasification is its ability to produce biomethane in a large scale.

Even though different feedstock is principally used for AE and gasification, there is a trend to use gasification to recover energy from waste, such as the municipal solid waste, sludge, agricultural waste which can also be the feedstock of AE. There have been many studies about either anaerobic digestion integrated with biogas upgrading or biomass gasification integrated with methanation; however, a comprehensive comparison about these two technologies concerning the biomethane production from the perspective of energy conversion efficiency is still lacking. Therefore, this work intends to fill in the knowledge gap. The results will provide further guidelines and insights regarding the selection of technologies.

Nomenclature

AE	Anaerobic digestion
DFB	Dual fluidized bed
EU	European Union
GoBiGas	Göteborg biomass gasification project
HHV	Higher heating value
LHV	Lower heating value
WGS	Water-Gas-Shift

2. Technology description

2.1. Anaerobic digestion

The study presented in this paper is based on the real data obtained from a wet anaerobic biogas plant in Sweden. The feedstock first undergoes a separation and pretreatment process. After removing impurities, the materials are crushed before being pumped to a buffer tank which allows continuous feeding of the digester. Sanitation is the last step before digestion, which takes place at 70 ºC for one hour to kill pathogenic micro-organisms. In the digester, the slurry mixes with active microorganisms. Anaerobic digestion of organic matters mainly composes of four processes: hydrolysis, acidogensis, acetogensis, and methanogenesis. The anaerobic microbial process can produce the biogas at a temperature of 37 ºC (mesophilic process). The produced gas is conditioned to remove H2S and other unwanted impurities before it is upgraded to vehicle fuel (>95mol% CH_4) [5]. The technology of water scrubbing is used for biogas upgrading, which uses water as a solvent. The theory is that the solubility of CH4 in water is much lower than that of CO2. The energy consumption of water scrubbing is about 0,45-0,90 kWh/Nm3 cleaned gas, mainly used for gas compression and water pumping [3].

2.2. Biomass gasification

Göteborg biomass gasification project (GoBiGas) is the world's first demonstration plant for large-scale production of biomethane through the gasification of forest residues. It is estimated that Göteborg energy will be able to generate 1 TWh biomethane with this process, which is approximately 30% of the current production of biomethane in Göteborg and has the capacity to supply about 15,000 cars or 400 buses per year [6]. In general, the GoBiGas can be divided into two processes: the gasification process and the methanation process. The gasification process mainly consists of a dual fluidized bed (DFB) biomass gasifier, a combustion chamber, a cyclone, a post combustion chamber, and a gas cleaning system. Biomass is gasified in the gasifer to produce syngas, which major components are CO, CO2, H2, CH4 and water vapor. The heat needed for gasifying the biomass is provided by the bed material, which is heated up in the combustion chamber and separated from the combustion gases in the cyclone. After gasification, the produced gas is cooled down and passes through a filter and scrubbers to remove particle, tar, water and H2S. The methanation process consists of a water gas shift reactor, a CO2 scrubber, a methanation reactor and a dehydration system. To maximize conversion of syngas into methane, the H2/CO-ratio is firstly adjusted to 3 in the shift reactor. After CO2 removal, CO reacts with H2 to form methane assisted by catalyst in the methanation reactor. Water needs to be removed before it can be injected into the natural gas grid.

3. Methodology

To analyze the anaerobic digestion, the material and energy balance were calculated based on the real operating parameters. The ultimate analysis of the digestate (solid residues) was measured, which gives the composition of carbon, hydrogen and oxygen (the major components) as well as sulfur and nitrogen in wt%. Assuming no element H is converted to H2O, based on the material balance, the mass flow and the ultimate analysis of feedstock can be estimated according to the mass flow and the ultimate analysis of digestate and the mass flow and gas composition of biogas. Then, the higher heating value (HHV) and lower heating value (LHV) of the feedstock were calculated as [7]:

$$HHV=341C+1323H+68S-15.3A-120(O+N)\ kJ/kg \quad \text{Equ. 1}$$
$$LHV=HHV-H_v(n_{H2O}/n_{solid}) \quad \text{Equ. 2}$$

where C, H, S, A, O and N are the element composition of ultimate analysis (in percentage); H_v is the heat of vaporization of water; n_{H2O} is the moles of water vaporized and n_{solid} is the number of moles of solid.

To simulate GoBiGas, a steady model was developed in Aspen Plus, which is a market-leading process modeling tool for conceptual design, optimization, and performance monitoring for the chemical, and power industries, as shown in Fig 1. The model was validated by comparing with the results from [8].

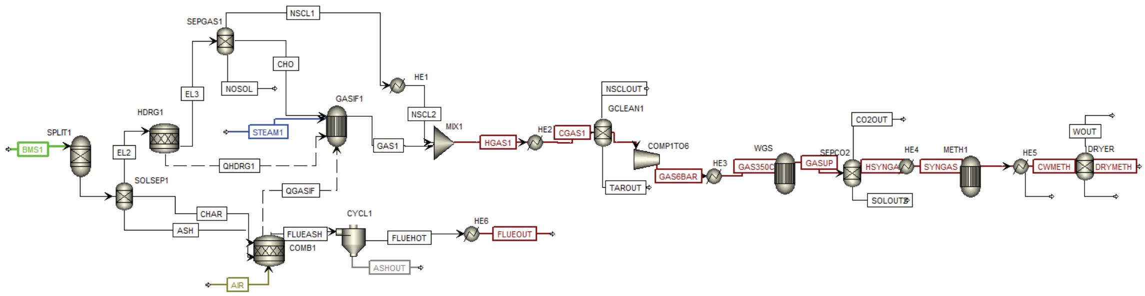

Fig. 1. Aspen Plus model for GoBiGas

To compare those two technologies, the energy conversion efficiency, which is defined as the ratio between the useful energy output and energy input, is employed as the key indicator. Therefore, for the anaerobic digestion and gasification, the efficiencies can be calculated by the following equations respectively:

$$\eta_{AE} = \frac{LHV_{bioCH4} \times m_{bioCH4}}{LHV_{feedstock} \times m_{feedstock} + Heat + Electricity} \qquad \text{Equ. 3}$$

$$\eta_{Gasification} = \frac{LHV_{bioCH4} \times m_{bioCH4}}{LHV_{feedstock} \times m_{feedstock} + Electricity} \qquad \text{Equ. 4}$$

4. Results

4.1. Anaerobic digestion

Table 1 The properties of the digestate and feedstock

	Anaerobic Digestion		Gasification [8]
	Solid digestate (measured)	Feedstock (calculated)	Feedstock
Mass flow (ton/yr) (dry)	1620	4420	6000*
Water content (wt%)	70,8	75,7	20
Ultimate, wt% (dry)			
Carbon	11.43	33,4	51,19
Hydrogen	8.70	9,5	6,08
Nitrogen	1.00	0,37	0,2
Sulphur	0.09	0,034	0,02
Oxygen	52.65	47,1	41,3
Ash	26.13	9,57	1,16
HHV (MJ/kg)	8,58	18,1	20,4
LHV (MJ/kg)	6,66	16,0	19,1

* The thermal capacity of gasifier is assumed to be 5,4MW and the yearly operation hour is assumed to be 7500hr.

For the biogas plant, the average period of anaerobic digestion is about 23 days. The measured ultimate analysis of the digestate is given in Table 2. The produced biogas has a composition of

$CH_4/CO_2/H_2O$=63/35/2 (mol%) and a flow rate of 2805 ton/yr. Consequently, the flow rate and the ultimate analysis of the feedstock are calculated and results are shown in Table 1 as well. Then HHV and LHV can be calculated by using Equ 1 and 2, which are 18,1MJ/kg and 3,48MJ/kg respectively. According to the operation information for year 2009, the total electricity consumption of the biogas plant is about 1485 MWh/yr, including pumps, fans, centrifuges etc. The heat demand is around 1753 MWh/yr at 70°C [5]. Corresponding to the energy consumption of water scrubbing (0.45–0.90 kWh/Nm3 cleaned gas), the electricity needed by biogas upgrading is estimated to be about 704-1377MWh/yr. Therefore, the energy conversion efficiency of the biomethane production via anaerobic digestion integrated with biogas upgrading can be calculated by using Equ 3, resulting in 62-64%.

4.2. Gasification

The feedstock for the gasification is assumed to be wood chips, which properties are also listed in Table 1. The key simulation results are shown in Table 2. The syngas composition agrees well with the results from Ref [8]. Since the dual fluidized-bed gasifier belongs to indirect gasifier, it can have a high CH_4 content in the syngas. In order to achieve a high CH_4 purity from the methanation process, it is done at a lifted pressure (6bar), which results in an electricity consumption of 0,2MW. According to Equ 2, the energy efficiency of GoBiGas can be estimated to be around 65%.

Table 2 Key results of GoBiGas model

Parameter	Value
Syngas composition (after gasification) vol% (dry)	
H2	46,2 (45,8*)
CO	20,5 (20,19*)
CO2	21,2 (21,59*)
CH4	11,6 (11,02*)
N2	0,5 (1,4*)
Biomethane (after methanation) vol% (dry)	
H2	1,4
CO	0,8
CH4	97,8
Thermal capacity of gasifier (MW)	5,4
biomethane flow rate (ton/yr)	2025

* Simulation results from [8]

4.3. Discussion

Based on the simulated results, it is clear that for the biomethane production, the anaerobic digestion integrated with upgrading and the gasification integrated with methanation have similar efficiencies. However, there are some issues that need to be noted:

- The GoBiGas model presented in this work was not optimized. There is much heat, which can be further used, for example, to produce electricity. The real GoBiGas project produces electricity and heat besides CH_4 and, therefore, has a much higher overall thermal efficiency.
- A large amount of low temperature heat is needed for anaerobic digestion, which lowers its energy conversion efficiency. On the contrary, the heat production from the real GoBiGas can improve the overall efficiency. However, the energy quality (exergy) of low temperature heat is much lower compared to that of the chemical energy contained in biomethane.
- Different feedstock, even though which has similar heating values, was used for AE and gasification. However, the feedstock properties can clearly affect the performance of AE and gasification. In order to compare them in a fairer way, the same feedstock should be used.

5. Conclusions and future work

Two technologies concerning the biomethane production have been studied, including the anaerobic digestion integrated with upgrading (AE) and the gasification integrated with methanation (GoBiGas). Simulation results show that they have similar efficiencies: 62-64% for AE and ~65% for GoBiGas. However, considering the different energy products, such as biomethane, electricity and heat, in order to compare the two technologies in a fairer way, exergy analysis should be done. In addition, the two technologies include different components, which imply different investment costs and operation and maintenance costs. Meanwhile, the prices of different energy products are also quite different. Therefore, an economic analysis is needed to further compare the technology feasibility.

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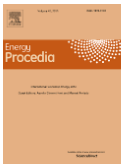

Biography

Dr. Hailong Li is currently a Senior Lecturer and Associate Professor at Mälardalen University, Sweden. His research interests lie in the smart energy management, focusing on the design and analysis of efficient and sustainable conversion and utilization of energy. He is serving as the Assistant Editor of Applied Energy