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Synthetic Natural Gas (SNG) Production via Gasification Process with Blend of Coal and Wood Chip as Feedstock

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The price of natural gas is relatively higher than that of coal and the capacity factor of NGCC (natural gas combined-cycle) unit is low in Taiwan. Synthetic natural gas (SNG) from solid fuel via gasification is possible to provide a relative lower price than that of natural gas to NGCC units and to decrease the cost of electricity. The commercial chemical process simulator, Pro/II® V8.1.1, is implemented to build the analysis model in the study. The four major blocks, consisted of air separation unit (ASU), gasification island, gas clean-up unit, and methanation processes, were built in the SNG production system model.
The biomass, wood chip, is introduced to blend with kaltim prima coal (KPC) from Indonesia to investigate the effect of system efficiency and CO_2 emission. The flow rate of feedstock is set as 2,000 t/d for a typical commercial gasifier with pure KPC feed. It is assumed that the total energy in feedstock is set as the same and 10 % flow rate increase is acceptable for the gasifiser. The percentages of wood chip in blended cases are introduced as 5 % and 10 %. Simulation results show that the cold gas efficiency of pure KPC, 5 % wood chip blend and 10 % wood chip blend are 77.64 %, 76.10 % and 74.35 %, respectively. It means the gasification performance is slightly decreased due to the blend of wood chip. The system efficiency for SNG production of KPC, 5 % blend and 10 % blend are 61.02 %, 60.10 % and 58.86 %, respectively. In order to adjust the syngas content with a specific ratio of CO to H_2, the amount of 63.51 %, 64.28 % and 64.97 % CO_2, respectively, is captured in the clean-up unit before entering the methanation processes. It means the CO_2 emission could be lower than 450 g/kWh, based on the situation that CO_2 is captured in the coal to SNG process. The biomass could further reduce the CO_2 emission due to the advantage of carbon neutral.

1. Introduction

British Petroleum (2014) reported that the world primary energy consumption increased by 2.3 % in 2013. It means the growth in global CO_2 emission from energy use also accelerated. The world reserves of oil, natural gas and coal at the end of 2013 are $1,687.9 \cdot 10^{12}$ bbl, $185.7 \cdot 10^{12}$ m^3 and 891,531 Mt, while the reserve-to-production ratios for oil, natural gas and coal are 53.3, 55.1 and 113 y.
Taiwan is an isolated island with a dense population and limited natural resources. In 2014, the dependence on imported energy of Taiwan is 97.75 %, it means Taiwan is highly dependent on fossil fuels. The status of energy supply in Taiwan, by primary energy statistics, is described as follows: the percentages of crude oil, coal, natural gas, nuclear and others are 48.52 %, 29.20 %, 12.23 %, 8.33 % and 1.73 %, respectively. The portfolio of electricity generation spreads over coal, gas, oil, nuclear, pumped hydro and renewable (conventional hydro, wind, solar, biomass and waste), with the portions of 46.94 %, 28.97 %, 2.79 %, 16.3 %, 1.20 % and 3.80 %, respectively. (Bureau of Energy, 2015) It could be expected that the power generated from fossil plants will be increased to cover the shortage of electricity supply in Taiwan.
Taiwan government has inaugurated planning to reduce CO_2 emission in order to solve the issues of global warming and climate change. One of the activities is to increase the amount of natural gas in electricity generation, because the capacity factor of NGCC (natural gas combined-cycle) unit is low. The price of natural gas is relative higher than the counterpart of coal in Taiwan. It is possible to convert solid

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fuel to synthetic natural gas (SNG) via gasification to provide a relative lower price than that of natural gas to decrease the cost of electricity. Chen et al. (2014) reported the efficiency study of NGCC plant fed with SNG and mixture gas of syngas and SNG in Taiwan. The purposes of the present study are to perform the system efficiency and CO_2 emission of blend of coal and biomass, which is converted to SNG via gasification.

2. Process description

Blending two and more fuels as feedstock and feeding to gasifier is general used to handle coal, biomass, and waste. Brar et al. (2012) have reported the co-gasification of various types of coal and biomass using different types of gasifiers under various sets of operating conditions. André et al. (2014) have investigated the co-gasification of rice husks and PE waste blends. The kaltim prima coal (KPC) and biomass, wood chip, are introduced in the study to investigate the effect on the system efficiency from solid fuel to SNG. The proximate and ultimate analyses of the two solid fuels are shown in Table 1.

Table 1: The proximate and ultimate analyses of KPC and wood chip

	kaltim prima coal (KPC)	wood chip
Total Moisture % as received	10.5	-
Proximate Analysis % air dried basis		
Moisture	5	15.67
Ash	5	4.51
Volatile Matter	41	
Fixed Carbon	49	
Calorific Value kcal/kg		
Air dried	7,100	3,974.70
Gross as received	6,689	
Net as received	6,389	
Ultimate Analysis (DAF) %		
Carbon	80	45.22
Hydrogen	5.5	5.56
Nitrogen	1.6	0.50
Sulfur	0.7	0.27
Oxygen	12.2	48.46

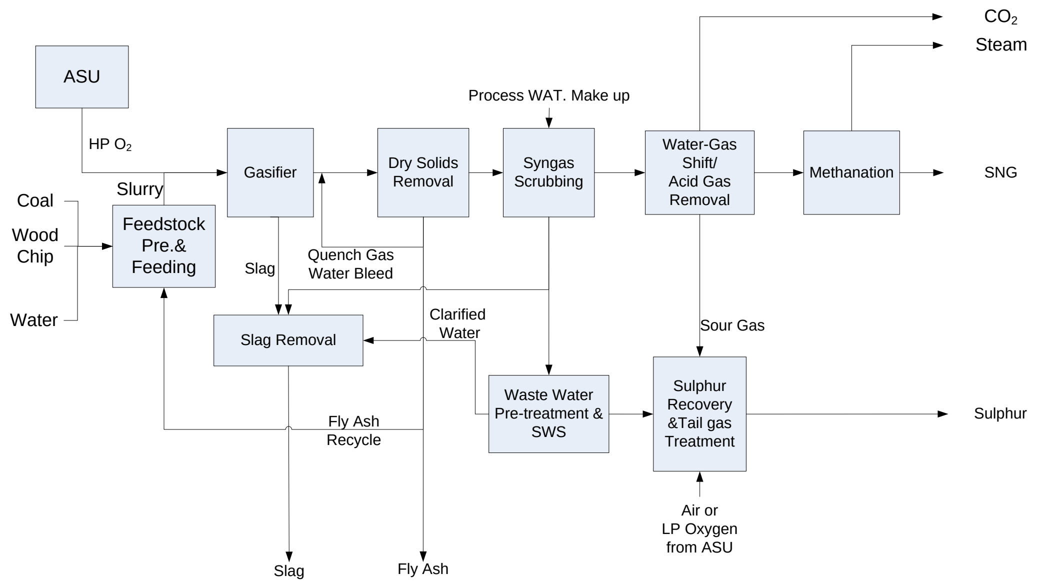

Figure 1: Process flow diagram of solid fuels to synthetic natural gas

The four major blocks were built in the SNG production system model with commercial chemical process simulator, Pro/II® V8.1.1. The four major blocks are air separation unit (ASU), gasification island, gas clean-up unit, and methanation processes. The process flow diagram of solid fuels to synthetic natural gas is shown as Figure 1, and processes are described in the following sections.

2.1 4au04Air separation unit (ASU)

Cryogenic air separation technology is introduced in the study to produce large quantities of oxygen and nitrogen as gaseous or liquid products. It is the most common technology for mass production of oxygen. A conventional, multi-column cryogenic rectifying process, which produces oxygen from compressed air at high recoveries and purities, is used in ASU. There are five major unit-operations to cryogenically separate air into useful products. An air pre-purification unit, located in the downstream of the air compression and after cooling, removes process contaminants, including water, carbon dioxide, and hydrocarbons. Then, the air is cooled to cryogenic temperatures. The oxygen with purity of 95 % by volume is produced as gasification agent delivered to the gasification island.

2.2 Gasification island

Gasification reaction is a partial-oxidation reaction and solid fuel can be converted to gas fuel with a useable heating value. The gasifier operates at a high temperature in the range of 800 °C to 1,800 °C. The exact temperature depends on the characteristics of the feedstock and operation conditions (Higman and Burgt, 2003).

The main compositions of syngas in the gasification reaction are H_2 and CO. There are three major reaction equations for gasification, which are listed as follows. Eqs.(1) and (2) are endothermic gasification reactions, to which the heat is supplied from pyrolysis. Eq.(3) is the CO shift reaction that can decide the ratio of H_2 and CO in the syngas.

$$C + CO_2 \rightarrow 2\,CO \qquad \Delta hr^0 = 167\ kJ/mol \tag{1}$$

$$C + H_2O \rightarrow CO + H_2 \qquad \Delta hr^0 = 125.4\ kJ/mol \tag{2}$$

$$CO + H_2O \rightarrow CO_2 + H_2 \qquad \Delta hr^0 = -\ 42\ kJ/mol \tag{3}$$

where Δh_r^0 is the heat of reaction at standard temperature and pressure, i.e. 298 K and 1 atm

GE entrained-bed gasifier is adopted to convert coal to synthesis gas (syngas) in this study. The temperature level in an entrained-bed gasifier (the designated reactor in the present study) is well above the aforementioned threshold. The reduced reactor, i.e. Gibbs reactor, could be employed and gives acceptable simulated data (Chen et al., 2013). Syed et al. (2012) have used Gibbs function to represents reaction in the gasification. The flow rate of pure KPC fed is set as 2,000 t/d for typical GE gasifier, and kept the total energy in feedstock as the same for the blend fuel with KPC and wood chip. It means the mass flow rate increases due to the lower heating vale of wood chip than KPC. In general, 10 % flow rate increased is acceptable for commercial gasifiser. The percentages of wood chip in blend cases are introduced as 5 % and 10 %, and the flow rates are 2,045.01 t/d and 2,092.09 t/d. (Lim and Lam, 2013). The slurry concentration and ratio of mass of oxygen from ASU to mass of feedstock are set as 66.5 % and 0.88.

2.3 Gas clean-up unit

The water-gas shift reaction, Selexol-based absorption process, and sulfur recovery processes are included in the clean-up unit. Due to the fact that a specific ratio of H_2 to CO is needed for the requirement from methanation processes, water-gas shift reaction is implemented to adjust the syngas composition to meet the designated value. Selexol absorption process is used to remove sulfur compounds and CO_2 in the syngas. The sulfur recovery process includes Claus process, Shell Claus off-gas treatment (SCOT) process and combustion of tail-gas is used to produce elemental sulfur from H_2S stream.

In general, syngas from gasification is delivered to the water gas shift reactor to increase H_2 content to adjust the requirement of specific ratio. If the ratio of CO converted to H_2 is lower than typical equilibrium value in water-gas shift reaction. The partial syngas goes through the water gas shift reactor to increase H_2 content, and the other one goes bypass. Finally, the two streams are mixed into one to make sure the gas composition meets the requirement of methanation processes.

2.4 Methanation processes

The adjusting syngas after gas clean-up unit is delivered to methanation processes to generate methane. The main components used to be converted to methane are carbon monoxide and hydrogen. Methanation is general used for years in the final purification step in ammonia plant or H_2 plant. For SNG production application is at a different level due to the higher content of CO and CO_2. The ruthenium, cobalt, nickel and iron are the main catalysts used for this reaction. (Mills et al. 1974) The following main process describes the methanation:

$$CO + 3H_2 \leftrightarrow CH_4 + H_2O \qquad \Delta h_r^0 = -206 \text{ kJ/mol} \tag{4}$$

$$CO_2 + 4H_2 \leftrightarrow CH_4 + 2H_2O \qquad \Delta h_r^0 = -165 \text{ kJ/mol} \tag{5}$$

where Δh_r^0 is the heat of reaction at standard temperature and pressure, i.e. 298 K and 1 atm
The major reaction to form methane is based on CO and H_2, and the stoichiometric ratio between H_2 and CO is 3. The CO_2 content in the feeding gas affects the production rate of methane based on Eq. (5). In order to take the effect of CO_2 in methanation, the specified parameter "M" is adopted and shown as follows.

$$M = (H_{2,mol\%} - CO_{2,mol\%}) / (CO_{mol\%} + CO_{2,mol\%}) \tag{6}$$

In general, the value of M is from 2.9 to 3.1 and the best one is 3.
The four reactors and six exchangers are built in the model to convert H_2, CO, and CO_2 to CH_4. Heat is generated since methanation is an exothermic reaction. Partial product gas is needed to recycle back to the reactor in the first reactor to maintain the temperature in a setting temperature. The compression power and the size of reactor could be reduced with the recycle gas flow rate decreasing. It means the first methanation reactor operated with a higher temperature to decrease the flow rate of recycle gas is beneficial.

3. Results and discussion

The coal and blend with wood chip converted to SNG were simulated with the software, Pro/II® V8.1.1. There are three cases investigated that include pure KPC case, 95 % KPC blend with 5 % wood chip case, and 90 % KPC blend with 10 % case. To keep the total energy in the feedstock the same, the flow rate of feedstock is slightly increased with the increase of percentage of the wood. Table 2 shows the raw syngas composition after the gasification in the three cases. Due to the fact that slurry concentration and ratio of mass of oxygen from ASU to mass of feedstock are set as 66.5 % and 0.88, it means the atomic oxygen content in the feedstock increases with the increase of percentage of wood chip in feedstock as the oxygen content in wood chip is higher than that in coal. As increasing the percentage of wood chips in feedstock, the more atomic oxygen in the gasifier results in the more CO_2 and H_2O generated and higher temperature. It means lower CO and H_2 content in the syngas and the cold gas efficiency could be found in the results.

Table 2: The raw syngas composition after the gasification

		kaltim prima coal (KPC)	5 % wood chip blending	10 % wood chip blending
Feedstock Flow Rate	t/d	2,000	2,045	2,092
Temperature	°C	1,187	1,267	1,345
Flow Rate	kmol/h	9,564	9,654	9,742
Composition	%			
H_2		29.38	27.81	26.15
CO		42.36	41.58	40.74
CO_2		9.81	10.03	10.29
H_2O		16.34	18.50	20.73
H_2S		0.16	0.16	0.15
N_2		1.89	1.90	1.91
Cold Gas Efficiency	%	77.64	76.10	74.35

It is seen in Table 2 that the CO and H_2 content in the syngas are slight different in the three cases, while the specified parameter, M, in the three cases are set around 3 in Table 3, which shows the system performance analysis from solid fuels to SNG. The CO_2 capture ratio is defined as the ratio of the weight of CO_2 captured from the syngas to that of CO_2 produced from fuel combustion. The total carbon in the feedstock decreases with the increase of percentage of wood chip in feedstock, since the carbon content in the wood chip is lower than the counterpart in the coal. Hence, the pure KPC case would have the highest amount of CO_2 produced, as compared to the 95 % KPC and 90 % KPC cases, if all the fuels are fully combusted. On the other hand, the two blended cases have more CO_2 existed in the raw syngas and captured by the clean-up system; hence, the CO_2 capture ratio of the pure KPC case is slightly lower than that of the other two cases. The CO_2 capture ratios in the three cases are 63.51 %, 64.28 % and 64.97 %, respectively. It means over 60 % of carbon in feedstock is removed in the processes. The wood chip could further reduce the CO_2 emission due to the advantage of carbon neutral from biomass. The energy of CO is released as heat and reacted with H_2O to form H_2 in water-gas shift reaction. It means the energy of CO converted to CO_2 is stored in H_2 and the H_2 is used to form CH_4 in later processes. And, partial product gas after the first methanation reactor is recycled back to the reactor to maintain the temperature, the heat generated in the reaction could be reused to increase the system efficiency. This is the reason for the CO_2 capture ratio is higher than 60 % but the efficiency of solid fuels to SNG can be higher than 40 %.

The system efficiency is defined as the ratio of energy of SNG to energy of feedstock. The efficiency in three cases are 61.02 %, 60.10 % and 58.86 %, respectively. The pure KPC case has more CO and H_2 in the syngas, which can be converted into CH_4, than the other two cases. Hence, the system efficiency of the pure KPC case is higher. The major advantage of biomass introduced in the SNG production is the CO_2 emission reduction. If the cost of biomass is lower than coal, it will be another beneficial for the system.

Table 3: The performances of SNG production with coal and blend with wood chip

		kaltim prima coal (KPC)	5 % wood chip blending	10 % wood chip blending
Ambient Temperature (Site Condition)	°C	25	25	25
Feedstock Flow Rate	t/day	2,000	2,045	2,092
Thermal Energy of Feedstock (Based on HHV) (A)	MWt	687.65	687.65	687.65
Specified Parameter, M		3	3	3
Ratio of CO_2 Capture	%	63.51	64.28	64.97
CH_4 Production	kg/h	27,299	26,890	26,336
CH_4 High Heating Value	kJ/kg	55,331.73	55,331.73	55,331.73
CH_4 High Heating Value Production (B)	MWt	419.59	413.29	404.78
Efficiency (B/A *100) (Based on Coal HHV)	%	61.02	60.10	58.86

4. Conclusions

The effects of blend of coal and biomass (wood chip) on the system efficiency of solid fuels convertion to SNG were shown in the study. The cold gas efficiency is slight decreased as content of wood chip in the feedstock increased. The CO_2 capture ratios in the three cases are 63.51 %, 64.28 % and 64.97 %, respectively. The system efficiency of SNG production in three cases is 61.02 %, 60.10 % and 58.86 %, respectively. The major advantage of biomass introduced in the SNG production is the CO_2 emission reduction, since biomass does not produce any net CO_2 emission. If the cost of biomass is lower than that of coal and the supply is enough to offset more fossil fuel, it will be another benefit for the system. The effect of operation parameters, such as ratio of oxygen to carbon, pressure, temperature, recycle flow rate, steam integrated, and others, will be performed in the further work to find out the optimal and cost-effective operation condition in the system of coal blended with biomass for SNG conversion. Then, SNG could be delivered to Natural Gas Combined Cycle (NGCC) to generate power, and activate the idle capacity factor of NGCC power plants in Taiwan. Furthermore, some domestic industry has shown interest in conversion of biomass or waste to multi-production and recycling the process residues via gasification. The working team will cooperate with industry to pursue follow-up efforts for mitigating greenhouse gas emissions from sustainable development viewpoints. The processes design and optimization for specified applications from domestic industry with gasification technology will be carried out in the future work. The end product could be electricity, chemical, or fuel, which is dependent on the requirement from the industry in Taiwan.

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