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System Analysis of Poly-Generation of SNG, Power and District Heating from Biomass Gasification System

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A transition towards synthetic fuels such as synthetic natural gas (SNG) is a requirement that can contribute to future energy security and sustainable development. Conventional coal gasification could be replaced with biomass gasification to produce synthetic natural gas that can be used in existing natural gas distribution infrastructure, transport, domestic and industrial sectors with almost no or little modifications. This study evaluates the integration of synthetic natural gas production using biomass gasification with combined heat and power plant (CHP). Various system performance indicators are used for comparing different systems such as carbon conversion, energy efficiencies, economic feasibility and commercial viability of technologies. For the evaluation of studied system, 100 MW of dried biomass is used as input for synthetic natural gas production together with power and district heating. The results obtained by integration of process showed a substantial synthetic natural gas production potential i.e. about 74.3 MW based on 100 MW biomass input. The process heat requirement of the system is about 26.60 MW and 0.60 MW for electrification. The results indicate that 27.35 MW heat is available for district heating and about 3.4 MW net amount of heat is available for power production by organic Rankine cycle (ORC). The results also show that the system is 74.3 % efficient based on lower heating value. Poly generation concept of SNG production along with power and district heating system claims its economic viability.

1. Introduction

Growing environmental concerns and fossil fuel depletion are a motivation to look for alternative energy resources. Natural gas has proved to be a clean fuel among other fossil fuel like crude oil and coal (Li et al., 2014). The importance of natural gas due to its vast applications as domestic and commercial fuel, raw material of chemicals, heat and power production and specially in transport as compressed natural gas (van der Meijden et al., 2010). Natural gas has not gained importance due to abundance and low price of crude oil in past decades. Natural gas importance has increased drastically in the last few years due to fluctuation in crude oil price (Hamilton et al., 2014). The natural gas reserves are also limited and may not be enough in the next 50 to 60 y at the current pace of usage (Li et al., 2014). Research has been triggered to produce it synthetically. Synthetic natural gas (SNG) production techniques from coal were developed in the last quarter of 20th century. SNG production from coal is not attractive due to its higher GHG emission and limited reserves. Biomass is a possible option for SNG production that not only addresses the environmental issues but solves the issues of sustainability and waste utilization. Synthetic natural gas has many advantages which make it an attractive option. It can be used in existing natural gas distribution network, transport, domestic and industrial sector with almost no or little modifications (Molino et al., 2015). It can also produce new job, promote indigenous resources, lower trade deficient and huge import bills for conventional fossil fuels.

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The efficient utilization of biomass for energy production is very important (Arvidsson et al., 2012) due to its competition of land utilization with food crops. Biomass is one of the largest energy source and it shares about 9 % in 2010 for world energy mix and it is expected to be 18 % in 2050 (Lauri et al., 2014). The integration of SNG production from biomass with power production and district heating is a step to enhance the efficient utilization of biomass to firm the bio refinery concept (Arvidsson et al., 2014). This cogeneration and polygeneration helps to meet the future energy requirement (Rudra et al., 2015). Combine heat and power (CHP) is considered an alternative to convention energy system in terms of energy saving. Significant work has been done for CHP especially in Europe. Biomass is the only source that can be used for both liquid and chemical products (Khan et al., 2014). The SNG production through thermochemical gasification of biomass has good impact on carbon foot print by replacing coal. The efficiency of process has increased 20 % in CHP by using thermal process integration (Mertzis et al., 2014). The integration of power production and use of waste heat for district heating with bio-SNG from biomass gasification made the process to be economical and cut GHG emission. The SNG production has been tested on pilot scale successfully in Güssing Austria for I MW plant (Rehlinget al., 2009).
Biomass is used in both dried and wet form for biomass gasification. Drying is the most energy consuming part of the whole process. It almost required 10-25 % of whole process energy requirement (Görling and Westermark, 2010). The effect of integrated dryer and humidifier for SNG production from biomass with integrated power and DH is not well reported.
The aim of this research work is to develop a system for SNG production from biomass gasification with combine heat and power cycle. For this purpose a process scheme is designed which includes biomass drying, SNG production, cleaning of product gas and combined heat and power cycle. A system analysis is made to evaluate the SNG production in terms of MW on LHV (lower heating value) of biomass input and determine the power and district heating (DH) potential after process integration. The effect of integrated dryer and humidifier on SNG, district heating H and power production are also analyzed.

2. Methodology

This study is conducted to produce SNG from Scots pine wood biomass gasification and to find the power and district heating potential by using process integration concept. For this purpose a process was developed after evaluation of commercial and developed techniques on the basis of carbon conversion of biomass and energy efficiency. The system consists of drying, humidification, gasification, gas cleaning, methanation for SNG production, gas upgrading, CO_2 removal and organic Rankin cycle (ORC) for power production as described in Figure 1. The reference capacity is selected for 100 MW of biomass on LHV basis. The LHV and composition of Scots pine find experimentally are given in Table 1. The process was developed on the basis of stoichiometric calculation of gasification, methanation reactions and considering physical operation like cooling and heating. A material and energy balance was conducted with the help of computer aided technique. The important process requirement, parameters and mass flow rate after material balance are given in Table 2.

Table 1: Biomass composition and heating value

Biomass Composition (wood chips 1 ~ 5 mm)	Wt (%)
Carbon	50.63
Hydrogen	5.94
Oxygen	42.74
Nitrogen	0.62
Sulfur	0.06
Chlorine	0.01
LHV(MJ/kg)	18.82

2.1 Process scheme

The process flow was developed as shown in Figure 1. The biomass particles in the range of 1-5 mm entered into the dryer where the moisture was reduced from 50 % to 15 %. High pressure steam was used at 12 bar pressure and 350 °C. It produced 3 bar low pressure steam at 150 °C that was available for steam cycle for power and DH through process integration. Recycled CO_2 from CO_2 removal unit used to transport dried biomass at higher pressure into circulating fluidized bed gasifier (CGB) coupled with humidifier.
Pure oxygen from air separation unit at the rate of 1.5 kg/s along with steam 1.3 kg/s was supplied for combustion and gasification reaction. Air separation unit consumed 0.9 MW energy for 100 MW biomass

input. The gasifier was operated at 10 bar and 850 °C in the presence of Ni-olivine based catalyst. Ni-olivine based catalyst enhanced the methane production as well as suppressed the tar formation. The produced gas obtained from gasifier consists of CO, CO_2, CH_4, HCl, H_2O and H_2S were cooled from 850 °C to 371 °C in cooling unit. This cooling process produced super-heated steam that is utilized in gasifier and methanator to fulfil energy demand. The removal of HCl and H_2S was done in the cleaning section by using bauxite and zinc oxide respectively. Both units consumed 0.173 MW. The methanation of cleaned gas was carried out in the methanator and High temperature reactor (HT) at 300 °C in the presence of Ni catalyst. The high pressure steam converted the gases into methane.

Heat of reaction is produced due to exothermic nature of methanation reaction. Part of the heat was utilized in high pressure steam dryer and high temperature reactor using integration concept. The CO_2 removal was done by using slexol process in order to upgrade the SNG. The refrigeration of slexol consumed 0.3 MW. The SNG is ready for distribution network. Part of the high pressure steam is sent to organic Rankin cycle (ORC) for power generation and low temperature and pressure steam after process integration is sent to district heating unit. The efficiencies of turbine, compressor and pumps used in process are given in Table 2.

Table 2: Process parameters and flow rates

Process requirement and parameters		Feed flow rates	
Gasifier catalyst	Ni+Olivine	Biomass flow(wet)	11.22 kg/s
Alkali removal	Bauxite	Biomass flow (dry)	5.60 kg/s
Sulphur removal	ZnO Bed	HHV 100% dry	18.85MJ/kg
Compressor efficiency	0.70	LHV 100 % dry	18.80MJ/kg
Turbine efficiency	0.85	CO_2 recycle	1.4 kg/s
Pump efficiency	0.70	Gasifying steam	1.3 kg/s
Methanator	Isothermal tubular	O_2 combustion	1.5 kg/s
Methanator catalyst	Nickel		

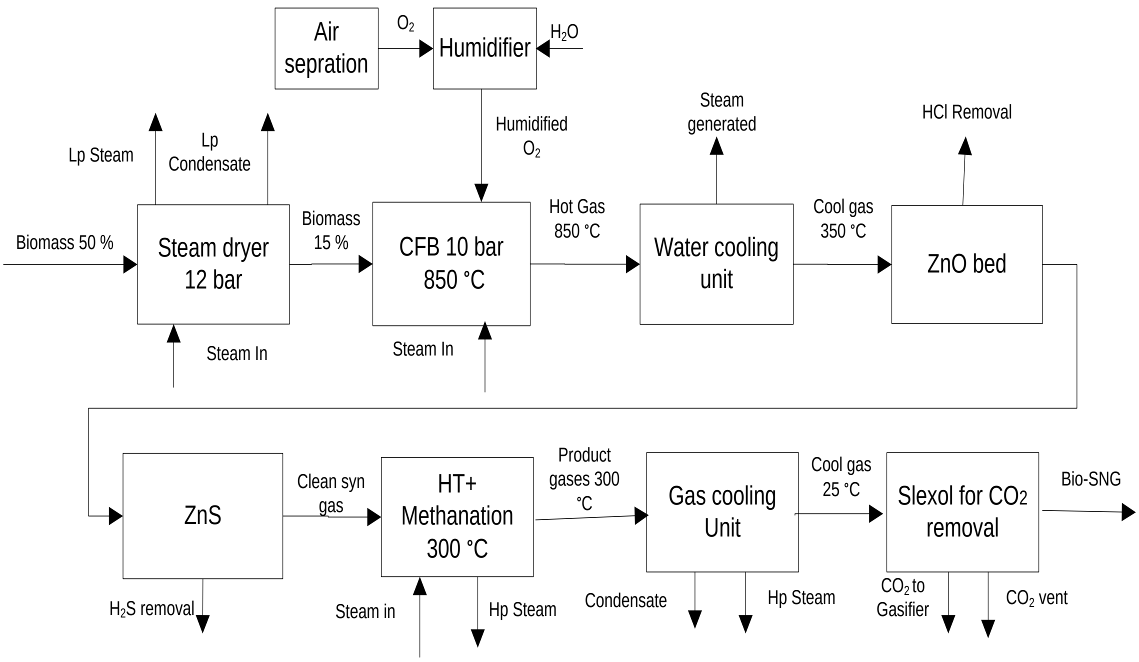

Figure 1: Developed process flow of SNG Production from Biomass gasification

3. Results and Discussion

A simple input and output balance has been made to validate the process analysis. The analysis is shown in Table 3. It shows that for gasification of 100 MW biomass large amount of process steam is required. A substantial amount of energy is needed for pre heating process and 2.26 MW electric powers is required to run the whole process. The most important thing is 74.3 MW SNG (on LHV basis) being produced along with 30 MW steam and 3.4 MW power has been obtained by combine heat and power (CHP). The heat available for DH is 27.33 MW. The energy balance is given in Figure. 2.

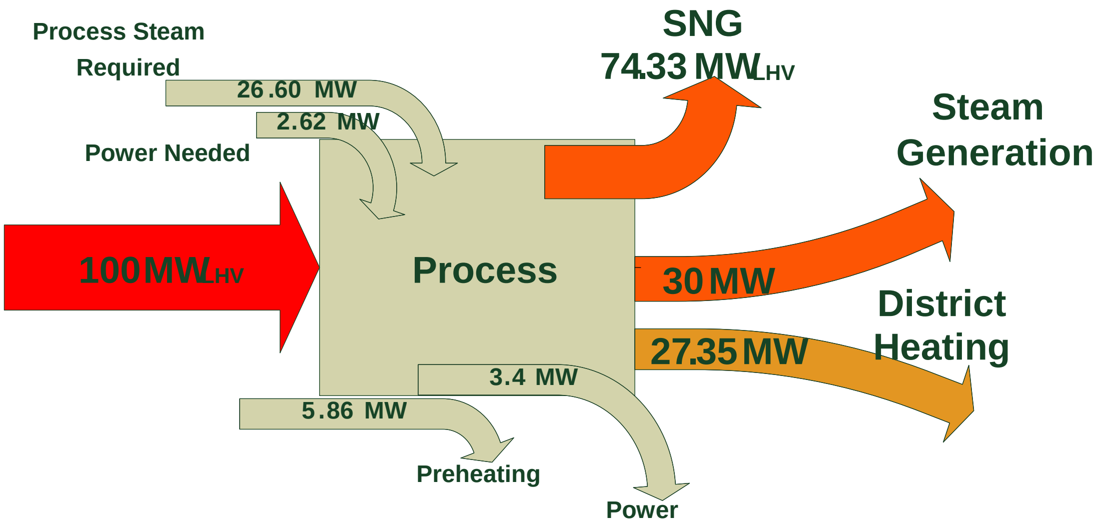

Figure 2: Energy balance of the system

3.1 SNG Production

The SNG production is 74.3 MW on LHV basis from 100 MW biomass input. The use of steam at 10 bars as gasifying agent has not only increased the CH_4 yield to about 93.04 mole% but also suppress the coke formation. The compression of coke formation is very important as it will deactivate the downstream catalyst. In addition the use of pressurized steam is also helpful for better fluidization that enhanced the gasification efficiency by increasing the contact between gasifying agent and bed material. In the presence of steam in gasifier also increased the H_2/CO ratio in product gas due the activeness of water gas shift reactions also reported in literature (Ahmed et al., 2012).The increase in H_2/CO ratio is important as the required ratio in methanation step should not be less than 3 (Jan et al., 2010). Jan et al. (2010), reported that for higher methane yield in methanator reactor the H_2/CO ratio should be in the range of 3 - 5. In addition, the use of Ni-Olivine instead of sand not only acts as energy flowing medium but also provides the active sites for methanation reaction. The cold gas efficiency of 74.3 % was obtained for SNG production from biomass input LHV basis.

3.2 Energy requirement and steam generation

The process steam requirement of the whole process is 26.60 MW. Energy requirements for different processes are shown in Table 3. It was observed that the dryer has the highest energy consumption about 13.04 MW. On the other hand, 9.46 MW energy is required for high temperature shift convertor (HTSC) and methanator. The amount of energy required for gasification unit is 4.10 MW is less than dryer and methanation units. This study utilized process integration so that the amount of energy generated by the system at different steps is recovered in the form of steam. Steam is produced during methanation due to exothermic reaction is about 20.67 MW and 9.33 MW from cooling of syngas. The total steam generation is 30 MW and detail is given in Table 3. The steam generation detail is given in Table 3. The use of humidifier has increased the steam generation. Energy demand of gasifier and fluidized bed dryer fulfill by acquiring energy from methanation and waste heat recover from syngas cooler. Dryer is the most energy consuming part of system. The heat load of dryer is provided to the system using heat integration concept and remaining amount is used for power production and make whole process CHP to utilize poly generation benefits.

Table 3: Energy requirements and steam generation system

Equipment	Energy (MW)	Steam Generation	Energy (MW)
High temperature shift convertor + Methanation	9.46	Heat of reaction (Methanator)	20.67
Gasification	4.10	Syngas cooler	9.33
Drying	13.04		
Total	26.60		30

3.3 Pre heating energy requirement

The system requires energy for pre-heating in high temperature shift convertor, methanator, gasifier and dryer. From heat integration concept these demands of energy is fulfilled by recovering heat from system. 5.86 MW heat is required, 1.86 MW is obtained from condensate of flue gases during cooling of SNG while 2.10 MW is recovered from flue gases and 1.92 MW waste heat from district heating system is then integrated in the process as shown in Table 4.

Table 4: Pre heating energy

Process	Energy (MW)
Flue gas condensate	1.84
Flue gas recovered	2.10
Waste heat from DH	1.92
Total	5.86

3.4 District heating and power production

The utilization of waste heat is the prime focus of this study. The purpose of utilization of heat through process integration is to make SNG economical. Low pressure steam is generated at different steps from dryer, cooler and other units are utilized for district heating system. The energy available for DH was about 27.3 MW as shown in Figure 2. The energy available for power production after fulfilling dryer and gasifier energy demand is 3.4 MW. The amount of energy available is 3.4 MW for power generation and organic Rankine cycle (ORC) (Walraven et al., 2015) was used for power production. Many studies have been done to analyze the ORC and Rankine cycle for CHP (Stoppato, 2012) and more recently (Baral et al., 2015). The use of ORC is economical for lower power generation than Rankine cycle. In summer there is no requirement of district heating so the heat load used for power production increased the power production in that time. The DH and power efficiency on the LHV basis of biomass input is 27.33 % and 3.4 %.

4. Conclusions

This study was conducted to analyse the process for SNG production from biomass gasification with integration of power and district heating. The SNG production is about 74.3 MW from 100 MW biomass input on LHV basis after the process integration. On the other hand, heat load for district heating is 26.7 MW and for power production is 3.4 MW. The thermal efficiency of the integrated system is 74.33 % SNG on LHV basis and district heating efficiency is 26.7 % basis. ORC is used for power production and power efficiency is 3.4 %. The Energy requirement of dryer and gasifier is fulfilled within the system using heat integration of process. The higher production of SNG is due to the use of humidifier that increased gasification process by increasing CO/H_2 ratio. The Combine heat and power production with SNG production make the process economical by utilization of waste heat. In summer power production is increased by utilizing energy of district heating due to lower demand for heating.

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References

Ahmed T. Y., Ahmad M. M., Yusup S., Inayat, A., Khan Z., 2012, Mathematical and computational approaches for design of biomass gasification for hydrogen production: A review, Renewable and Sustainable Energy Reviews, 16, 2304-2315.

Arvidsson M., Heyne S., Morandin M., Harvey S., 2012, Integration opportunities for substitute natural gas (SNG) production in an industrial process plant, Chemical Engineering Transactions, 29, 331-336.

Arvidsson M., Morandin M., Harvey S., 2014. Biomass Gasification-Based Syngas Production for a conventional oxo synthesis plant process modeling, integration opportunities and thermodynamic performance, Energy & Fuels, 28, 4075-4087.

Baral S., Kim D., Yun E., Kim K. C., 2015. Energy, exergy and performance analysis of small-scale organic Rankine cycle systems for electrical power generation applicable in rural areas of developing countries, Energies, 8, 684-713.

Görling M., Westermark M., 2010, Increased power generation by humidification of gasification agent in biofuel production. World Renewable Energy Congress XI, Abu Dahbi, UAE.

Hamilton J. D., Wu J. C., 2014, Risk premia in crude oil futures prices, Journal of International Money and Finance, 42, 9-37.

Kopyscinski J., Schildhauer T.J., Vogel F., Biollaz S.M., Wokaun A.., 2010, Applying spatially resolved concentration and temperature measurements in a catalytic plate reactor for the kinetic study of CO methanation. Journal of Catalysis, 271, 262-279.

Khan Z., Yusup S., Ahmad M. M., Chin B. L. F., 2014, Hydrogen production from palm kernel shell via integrated catalytic adsorption (ICA) steam gasification, Energy Conversion and Management, 87, 1224-1230.

Lauri P., Havlík P., Kindermann G., Forsell N., Böttcher H., Obersteiner M., 2014, Woody biomass energy potential in 2050, Energy Policy, 66, 19-31.

Li S., Ji X., Zhang X., Gao, L., Jin H., 2014, Coal to SNG: Technical progress, modeling and system optimization through exergy analysis, Applied Energy, 136, 98-109.

Mertzis D., Mitsakis P., Tsiakmakis S., Manara P., Zabaniotou A., Samaras Z., 2014, Performance analysis of a small-scale combined heat and power system using agricultural biomass residues: The smartt-CHP demonstration project, Energy, 64, 367-374.

Molino A., Braccio G., 2015, Synthetic natural gas SNG production from biomass gasification–Thermodynamics and processing aspects, Fuel, 139, 425-429.

Rudra S., Rosendahl L., Blarke M. B., 2015, Process analysis of a biomass-based quad-generation plant for combined power, heat, cooling, and synthetic natural gas production, Energy Conversion and Management, 106, 1276-1285.

Stoppato A. 2012, Energetic and economic investigation of the operation management of an Organic Rankine Cycle cogeneration plant, Energy, 41, 3-9.

Van Der Meijden C. M., Veringa H. J., Rabou L. P., 2010, The production of synthetic natural gas (SNG): A comparison of three wood gasification systems for energy balance and overall efficiency, Biomass and bioenergy, 34, 302-311.

Walraven D., Laenen B., Dhaeseleer W., 2015, Minimizing the levelized cost of electricity production from low-temperature geothermal heat sources with ORCs: Water or air cooled, Applied Energy, 142, 144-153.