Available online at www.sciencedirect.com
ScienceDirect
Energy Procedia 68 (2015) 157 – 166
Energy Procedia

2nd International Conference on Sustainable Energy Engineering and Application, ICSEEA 2014

Torrefaction of Indonesian sugar-cane bagasse to improve bio-syngas quality for gasification process

Daniyanto[a,b], Sutidjan[b], Deendarlianto[c,d], Arief Budiman[b,d,]*

[a]*Polytechnic of LPP - Plantation Training Institute, Yogyakarta, Indonesia*
[b]*Chemical Engineering Department, Gadjah Mada University, Yogyakarta, Indonesia*
[c]*Mechanical Engineering Department, Gadjah Mada University, Yogyakarta, Indonesia*
[d]*Center for Energy Studies, Gadjah Mada University, Yogyakarta, Indonesia*

Abstract

Bio-syngas from gasification of sugarcane bagasse is one of the most promising sources for renewable energy. As an agriculture-based biomass, sugarcane bagasse has a high content of moisture (46-52%), fibrous (43-52%) and low bulk density (80-120 kg/m^3). This quality of bagasse will tend to initiate agglomeration and cause de-fluidization. It will disturb the gasification process and finally will decrease yield and quality of syn-gas. Its chracteristics in low quality can be improved by pretreatment, *i.e.,* torrefaction process, addressed by slow heating of biomass on wet or dry conditions on atmosphere pressure for 1 hour before it is used as feedstock gasification.

This preliminary work features an experimental investigation of torrefaction process of Indonesian sugarcane cane bagasse. Temperature of torrefaction varies from 150, 175, 200, 225, 250 and 300 °C. For bagasse gasification process, the optimum temperature of dry torrefaction is 150 °C. At this temperature, yield of syngas will higher than other torrefaction temperature. Temperature of dry torrefaction will give energy saving opportunities than that's of wet torrefaction (180 °C, 1 hr).

Analysis ultimate and proximate also indicate that sugarcane bagasse with temperature torrefaction 150 °C give better result than other torrefaction's temperature in high content of hydrogen and low content of carbon.

Peer-review under responsibility of Scientific Committee of ICSEEA 2014

Keywords: bagasse; biomass; gasification; syngas torrefaction

* Corresponding author. Tel.: +62-274-902171; fax: +62-274-902170.
E-mail address: abudiman@chemeng.ugm.ac.id

Peer-review under responsibility of Scientific Committee of ICSEEA 2014
doi:10.1016/j.egypro.2015.03.244

1. Introduction

Fossil fuels, including coal, oil and natural gas, are currently the world's primary energy source and they account for more than 80 percent of the world's energy consumption resulting in rising price and declining oil reserves. Meanwile, in developing countries energy consumption is projected to increase 65% by 2040 against 2010 that caused by increasing prosperity and expansion their economic [1]. If the new reserves of fossil fuels not founded, it's estimated that petroleum will run out in 40-60 years while coal are still more than 100 years [2]. Fossil fuels, however, are the largest greenhouse gas emitters in the world, contributing 3/4 of all carbon, methane and other greenhouse gas emissions. Burning coal, petroleum and other fossil fuels at extremely high temperatures (combustion) is the primary means by which electricity is produced, but also leads to heavy concentrations of pollutants in our air and water. This condition will cause increasing surface temperature of the earth and climate change. Figure 1 shows production and projection of CO2 emission by 2040.

The climate change has already started influencing energy demand patterns in most countries. This situation encourage us to discover the renewable resources of fuels that environmental friendly. One of the renewable resources that are promising for substitution of fossil fuel in the future is biomass. Indonesia has abundant resources of biomass as listed in Table 1. The potential of biomass is 46.7 million tons per year [3, 4] and equivalent with 49,810 MW of its energy and just only 1,709 MW is utilized.

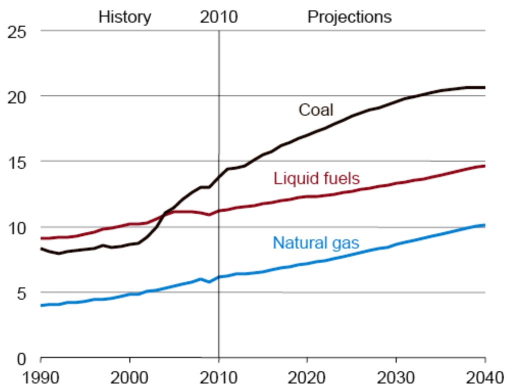

Fig. 1. Production and projection of CO2 emission (metric tons).

Among several types of biomass, sugarcane is one of the most promising agricultural sources of energy in the world. Production of sugarcane in Indonesia was 53,612,133 tons [5]. One ton of sugar cane yields 115 kg of sugar and about 300 kg of bagasse as biomass residues, 30-40 kg of filter-cake, 30-50 kg of molasses, 3.5 kg furnace ash, and other materials [6, 7]. Bagasse is the main fuel in sugar mills. Sugarcane possessed more valuable than other biomass, due to period of planting faster than timber. Each hectare of land can produce up to 30 tons of bagasse with the planting period 12-14 months, while the timber will result lesser in weight than sugarcane with the same growing season [8]. Mostly in Indonesia's sugar factory, bagasse is directly used as fuel for the boiler. One kilogram of bagasse will produce 1.8 to 2.4 kilograms of steam with the boiler efficiency 40 to 55 % [6].

Utilization of sugarcane as a biomass feedstock has long history, either directly used as fuel, electricity generation, briquette, charcoal, methane fermentation (bio-gas), and methanol production. Utilization of bagasse as raw material for making producer gas has been done in the past. In year of 1940 was published the results of research related to the bagasse and gas producer [7]. On the other hand, bagasse has been traditionally used as a fuel in the sugar mill itself, to produce steam for the process and electricity for its own use. Low pressure boilers and low efficiency steam turbines are commonly used in sugarcane factory. It would be a good business proposition to upgrade the present cogeneration systems to highly efficient, high pressure systems with higher capacities to ensure utilization of surplus bagasse. On the other hand, bagasse has the potential for added-value to improve the economic viability of sugar mills in Indonesia by gasification process in gasifier to produce electricity.

Table 1 . Potential and utilization of biomass-based energy in Indonesia [9].

New and Renewable	Resources	Province	Annual Capacity (MW)					
			2005	2006	2007	2008	2009	2010
Hydro	75,000 MW	Sumatra	924.61	924.61	924.61	924.61	1,607.50	1,687.48
Geothermal	29,164 MW	Java	10.90	10.90	10.90	10.90	10.90	11.44
Biomass	49,810 MW	Kalimantan	N/A	N/A	N/A	N/A	N/A	N/A
Solar	4.8 kWh/m^2/day	Sulawesi	N/A	N/A	N/A	N/A	N/A	N/A
Wind	3-6 m/s	Bali, NTT, NTB	N/A	N/A	N/A	N/A	N/A	N/A
Ocean	49 GW	Maluku, Papua	N/A	N/A	N/A	N/A	N/A	N/A
Uranium	3,000 MW	Total	9.35.51	935.51	935.51	935.51	1,628.40	1,709.92

(Source: Directorate General of EBTKE, Ministry of ESDM, updated on March 2011)

Economic analysis of gasifier for electricity generation indicate that direct heating is more advantageous than used for power generation with sugarcane leaf as raw material. Value of diesel saving and thermal efficiency will decrease if it given load [10]. Utilization of fixed bed gasifier with bagasse and sugar cane leaves to heating industry has shown good results. Similar results were also shown by the use of low density of biomass in gasification such as sorghum stems etc. It has been tested in laboratory and resulting in output levels of 288-1080 MJ / h and 3.56 to 4.82 MJ/m3 HHV gas (STP). Char produced 24 % by weight of raw materials and briquettes used for fuel furnace or soil conditioner [11]. Electrical potential generated from sugarcane biomass is 60-180 kWh per tonne of sugarcane. When all fibrous biomass is used for a raw material in producing electricity, it will produce electricity 678 kWh/ton cane [12].

Bagasse can be utilized by pyrolisis process to produce carbon material. An effective technology for carbonization of bagasse is using thermo-reactor combined with a rotary drum furnace. This process using a closed system between pyrolysis vapor and the heat carrier to address the fibrous structure and high content of fine particles of bagasse. Pyrolysis carried out in two stages, heating at temperature 350 °C and annealing of charcoal phase at a temperature of 475-500 °C. This proces has yield of charcoal 23-28 % in dry basis in the form of briquettes and granules for household fuel or industry [13].

Pre-treatment of biomass with washing using water, HCl and HF showed ash from char will catalyze polymerization reaction and increase viscosity of bio-oil. Ash removal will increase distribution of total energy in product of oil fractions pyrolysis. The process of pre-treatment showed no improvement of oil stability [14].

Bagasse cannot be used in fluidized bed gasification directly, because it’s high moisture, fibrous and low density. It will influence fluidization of bagasse in gasification. Bench-scale gasification tests that conducted in two steps showed gasification process are completed. Tar and carbon formation can be eliminated. The use of a nickel catalyst will make syngas composition approaching equilibrium conditions [15]. Formation of syngas from pyrolysis of sugar cane in a batch reactor showed 40% syngas derived from sugarcane biomass can be converted into electricity with a fuel cell system and has a high efficiency [16].

Cogeneration integrated with biomass gasification provides potential combination of supercritical steam cycles and biomass gasification in sugar mills [17]. Reaction kinetic of pyrolysis is influenced by the process conditions, material balance & heat, chemical & physical heterogeneity of sample, and systematic errors. Data of thermal analysis decomposition two agricultural waste (*i.e.*, bagasse and peanut shells) reveals the difficulties and risks which accompany in heterogeneous system modeling. The exact mechanism of the pyrolysis of biomass is still a mystery [18].

Conversion of bagasse at low temperatures into bio-oil is strongly influenced by the hydrolysis pretreatment. Pre-treatment is done with acid, alkaline and acid-base balance. Low temperature conversion is conducted at a temperature of 350 – 450 °C and atmospheric pressure of He or O_2/He gas. The main components of bio - oil obtained in the form levoglucosan. Bio-oil yield increases with pretreatment but will decrease in the presence of O_2. Acid pre-treatment will also increase the yield of bio-oil [19].

Mechanism of reaction in steam gasification of bagasse is studied in a semi-batch reactor with variation of reaction temperatures 800, 900 and 1000 °C. At temperature of 1000 °C occured total gasification between pyrolysis step and char gasification step is happened. These conditions accelerate the gasification reaction of char and steam hydrocarbon reforming reaction. Inthis case, hydrocarbon will trigger to the char formation and aromatization re-polymerization [20]. Co-gasification of low sulfur petroleum coke CO_2 and bagasse with TG-FTIR analysis techniques (thermogravimetry-fourier transform infrared spectoscopy) showed first-order reaction is the best mechanism for the entire process. The resulted gases include CO_2, CO, CH_4, HCOOH, C_6H_5OH and CH_3COOH [21].

Auto-thermal gasification with solar energy as a conventional heating process results syngas with superior quality and higher yield per unit of feed. When, steam-based gasification reactor with solar energy use drop-tube combination and fixed-bed reactor used for gasification prosess, reaction were performed in the temperature of 1073 – 1573 °K, syngas is produced with high quality by H_2/CO molar ratio = 1.6 and CO2/CO = 0.31, calorific value of 15.3 to 16.9 MJ/kg. Here, enhancement factor (upgrade factor) is 112% [22]. Analysis influence of energy, ecology and dynamics of fluid has studied in fluidized bed gasifier for bagasse [23].

The main problem which often encountered for agriculture biomass is bed agglomeration. In decreasing fluid properties (de-fluidization) of biomass cause unplanned stop time and additional costs. Also, it will increase the ash and alkali content. Wood biomass is less susceptible to this trend. De-fluidization and agglomeration properties are closely related to the process and the nature of glass. Properties of glass-forming materials are quartz and silicon dioxide (SiO_2). Softening point of quartz glass is 1500 °C with the addition of alkali to drop to 500 – 1000 °C. Stabilizers are usually used *i.e.* alkali metal oxides (group II) such as calcium and magnesium [24].

One of the main obstacles encountered in bagasse gasification is the nature of bagasse. It has high moisture, fibrous and low density. This obstacle is addressed by slow heating of biomass on wet or dry conditions on atmosphere pressure for 1 hour before it is used as feedstock gasification. This treatment is referred as torrefaction. This technology can be applied to improve the properties of dry biomass (cotton, prosopis, and bagasse) by slow heating for 1 hour at temperatures 150-300 °C at atmospheric conditions. Torrefaction results uniform solids, low moisture content and higher energy content than raw biomass [25].

Wet torrefaction with water or dilute sulfuric acid is conducted by heating at a temperature of 180 °C. This method gives 20.3% increase in heat content, lower temperatures (100 °C lesser than dry torrefaction). Wet Torrefaction provide a promising method to improve the quality of biomass as fuel [26]. Kinetics of bagasse thermogravimetry which treated with hot water will cause decreases the second phase activation energy. It caused pyrolysis will more energy efficient. Pre-treatment of bagasse with hot water gives good results [27].

Gasification of biomass with torrefaction (280 °C, 1 hour) is a promising way to produce syngas with higher quality than ever before. Three different materials are used to evaluate the effect of this method in the entrained-flow gasification reactor models and uses O_2 as gasification agent. The study obtained carbon conversion >90% for 3 type of materials. Torrefaction also give significant effect on improvement of gasification performance at the same conditions. Torrefied bamboo in cold gasification increase efficiency 88% as compared to raw bamboo [2].

Performance of gasification switchgrass conducted in fixed-bed externally heated reactor and air as oxidizing agent. In this research, switchgrass as raw material is torrefied at temperature of 230 and 270 °C and gasification conducted in three gasificiation temperatures of 700, 800 and 900 °C. This research indicated pretreatment of torrefaction and temperature of gasification give significant effects on yield and quality of syn-gas. Gasification with combination of torrefaction and densification resulted in the highes of H_2 (0.03% w/w of biomass) and CO (0.72% w/wof biomass), highest syn-gas LHV (5.08 MJ/m^{-3}) [28].

Effect of torrefaction of Miscanthus x giganteus (MG) to gasification conducted in temperature of torrefaction 230 to 290 °C for residence time 10 to 30 minutes. It's resulted increasing in properties of MG as raw material for gasification i.e. reduced moisture and hemicelluose content a lower ratio of O/C, a more porous structure with larger specific surface area as well as higher content of alkali metals. These results features have positive effect on gasification reactivity [29].

Laboratory work for effect of torrefaction to wheat and barley straw observed using microwave irradiation. The torrefaction effect was studied by varying the microwave power level (200–300 W), reaction time (10–20 min) and moisture content of biomass (5–15%). Both H/C and O/C ratio decreased with increase in power and reaction time. Grindability of the biomass improved significantly after torrefaction. Microwave irradiation can be used effectively for torrefaction of the two biomass investigated at moderate power and short process time [30]. This preliminary work features an experimental investigation of torrefaction process of Indonesian sugarcane cane bagasse. Effects of main parameter, especially temperature was examined to determine the optimal operation condition resulting the best quality of bagasse as feedstock for gasification.

2. Experimental

2.1. Materials

Sugarcane bagasse is taken from PT Madubaru Sugar Mill, Jogjakarta, Indonesia on year of milling season 2013. Physical composition of bagasse was fiber content, 43-52%; water content, 46-52%; bulk density 80-120 kg/m^3 and soluble solids, 2-6%. Proximate and ultimate analysis of bagasse is presented in Table 2.

Table 2. Proximate analysis dan ultimate analysis of fresh-sugarcane bagasse.

Proximate Analysis	(%weight)	Ultimate Analysis	(%weight)
Fixed Carbon	7	Carbon (C)	23,7
Volatile Matters	42,5	Hydrogen (H)	3,0
Moisture	49	Oxygen (O)	22,8
Ash	1,5	Moisture (H2O)	49,0
		Ash	1,5

2.2. Apparatus

Torrefaction process of biomass of bagase has been caried out in a miniplant of gasifiers as shown in Figure 2. Gasifier unit consists of a gasification reactor with a diameter of 20 cm and height of 80 cm, it's equipped with a cyclone, cooler column and vacuum pump. Cyclone is used to separate entrained solid, while cooling column is used to separate bio-oil from gases and vacuum pump to draw gasification air. For heating process of bagase used air tight oven with temperature of 30 – 250 °C.

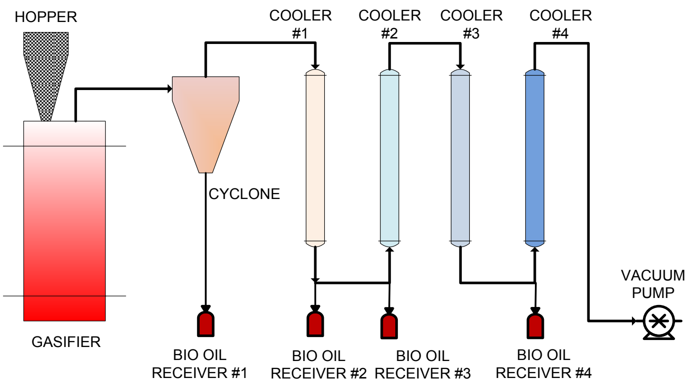

Fig. 2. Configuration of experimental equipment.

The study was conducted in ambient temperature & atmospheric pressure and air flow for gasification reaction in the gasifier is pulled down using a vacuum pump. Before gasification process, bagasse from sugar mills is sun dried for 8 hours until naturally has moisture content in range 3-5%. A certain amount of sun-dried bagasse is then torrified in 1 hour with temperature variations 100, 125, 150, 175, 200, 225 and 250 °C. Heating process is carried out in an air tight oven. Weight and moisture content before and after heating weighed to determine physical changes of biomass.

Torrified bagasse is gasified in a fixed-bed gasification reactor for 1 hour. Gases from the gasifier is separated from the solids using a cyclone, and further cooled in four installed coolers using a water cooler. Cooling water inputted at ambient temperature. During the gasification reaction, change of gasifier temperature observed. Charcoal removed from the bottom side of the gasifier. Then, after certain hour of gasification, bio-oil and charcoal produced is weighed.

In addition to the above research results, torrified-bagasse iss also observed its quality using ultimate and proximate analysis. It will determine the quality of torrified-bagasse. Ultimate and proximate analyzes are performed in the Center of Research and Development of Minerals and Coal Laboratory, Bandung, Indonesia. Samples that give better results tendency are selected and analyzed, namely torrified-bagasse with temperature of torrefaction 150, 175, 200, 225, 250, and 275 °C.

Bio-syngas which obtained from torrified-bagasse is analyzed to determine the quality of resulted-syngas. Gas samples which is choosen and analyzed are taken from torrefied-bagasse in temperature of 150, 175, 200 °C. GC's Gas analysis carried out in the Laboratory of Analysis and Instrumentation, Chemical Engineering Department, Gadjah Mada University, Yogyakarta, Indonesia.

3. Results and discussion

Torrefaction is a promised pretreatment to increase the quality of the raw material as feed-stock biomass gasification. Torrefaction process is done by slow heating of biomass within a certain temperature for one hour. During torrefaction, drying of biomass will result limited moisture content. Group-OH will be destructed. The ability to bind H will be reduced and unsaturated structures formed will be non-polar. Biomass biological reaction stops. Hemicellulose structure will be changes to the structure of char and volatile matter. Weight of biomass will loss during torrefaction, it's caused by changes in the structure of hemicellulose. Torrified biomass is containing lignin and cellulose [25].

Figure 3 shows relationship between temperature of torrefaction and temperature of gasification reactor. It shows that temperatures increase by increasing the time. Higher temperature were happened at around 10 to 30 minutes, then they decrease to 60 minutes. Since then, they were relatively constant.

Figure 4 shows the effect of torrefaction temperature on yield volatile matter (VM), syngas, bio-oil, and bio-char. At a temperature of 100 °C, the yield of bio-char, bio-oil and syngas is relatively higher than the temperature above 125 °C. This condition caused by water content remains relatively high in bagasse with torrified temperature 100 °C. These data is reinforced by value of VM at temperature of torrefaction 100 °C, value of VM is relatively small compared to others. Resulted syngas and bio-oil contain more water than non water-orgnanic components.

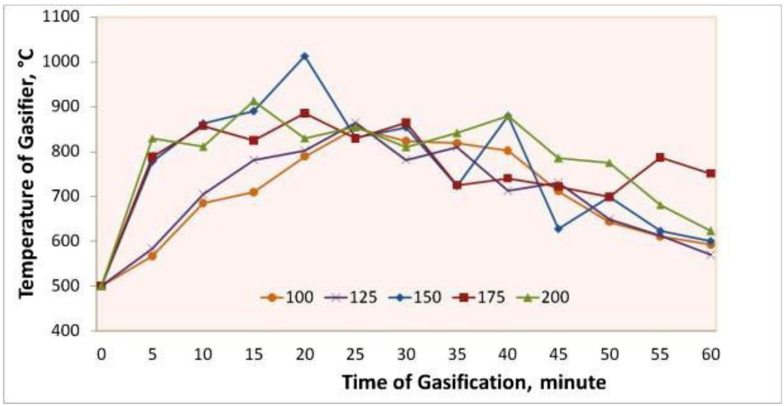

Fig. 3. Influence of torrefaction temperature on gasification temperature.

At range of 125 and 150 °C, yield of syngas is relatively constant, but the value of bio-oil and VM increased. This is showed by yield of bio-char at temperatures over 125 and 150 °C. At temperatures above 150 °C, it is known that yield of bio-oil and VM increased, but decreased in yield of syngas. Carbon conversion into bio-oil is higher than into syngas.

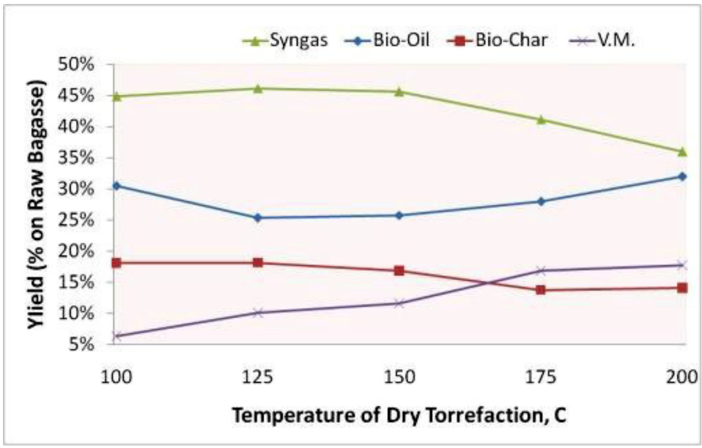

Fig. 4. Influence of torrefaction temperature on yield.

The above description gives suggestion that optimum torrefaction temperature is 150 °C. At this temperature, sugarcane bagasse will result yield of syngas relatively higher than other temperatures. If desired bio - oil yield higher, Torrefaction temperature 200 °C will give better results. In this study also attempted to torrefaction temperature above 200 °C, but at temperature of 225 °C carbonization of bagasse was occured. Dry torrefaction of sugarcane bagasse produces a lower temperature when compared wet torrefaction. Bagasse gasification with wet torrefaction provides optimum results if carried out at a temperature of 180 °C. Dry torrefaction with temperature of 150 °C will provide energy savings opportunities than wet torrefaction.

Ultimate and proximate analysis is conducted subsquently to reinforce the above results. This analysis is done for torrefied-bagasse at temperature 150 through 275 °C. Proximate and ultimate analysis results are shown in Tables 3 and 4.

Table 3. Proximate analysis of torrefied-bagasse at various temperature of torrefaction.

Temperature of Torrefaction, °C	Proximate Analysis (% weight)				GCV
	Moisture	Ash	V.M.	Fixed Carbon	kal/g
150	9,53	4,54	71,66	14,27	4.034
175	9,24	3,79	73,44	13,53	4.060
200	8,72	3,29	74,34	13,65	4.087
225	8,05	3,46	77,73	10,76	4.120
250	8,16	7,28	43,68	40,88	4.717
275	8,36	7,46	31,91	52,27	5.067

Note: V.M : volatile matter; GCV: Gross Caloric Value

From Table 3, we may see that results of analysis at temperature under 200 °C did not denote significant different in results exceptly at temperatures above 200 °C. VM content in bagasse decreased significantly when temperature of torrefaction above 200 °C, it's caused by carbonization process. Decreasing volatile matter would be influence procee of gasification, quality and yield of syn-gas is influenced by VM content. Table 4 indicate that composition of bagasse will significant changes in temperatures above 200 °C. Highest result of hydrogen content obtained at temperature of 150 °C and lowest result at a temperature of 275 °C. Increasing temperature of torrefied-bagasse will tend to decrease hydrogen and oxygen content in syn-gas. At other side, content of carbon, nitrogen and sulfur tends to increase with increasing temperature. This results indicate torrefaction temperature at 150 °C tend to result better quality of syn-gas. Gas analysis also conducted to find temperature of torrefaction which will obtain better quality of syn-gas. It is done at temperature of torrefaction between 150 – 200 °C. The results of GC analysis of syn-gas are shown in Figure 5.

Table 4. Ultimate analysis of torrefied-bagasse at various temperature of torrefaction.

Temperature of Torrefaction, °C	Ultimate Analysis (% weight)				
	Carbon	Hidrogen	Nitrogen	Sulfur	Oxygen
150	42,77	6,52	0,23	0,04	45,9
175	43,18	6,48	0,26	0,04	46,25
200	45,36	6,24	0,18	0,04	44,89
225	44,01	6,43	0,25	0,03	45,82
250	55,18	4,23	0,39	0,07	32,85
275	60,66	3,42	0,42	0,07	27,97

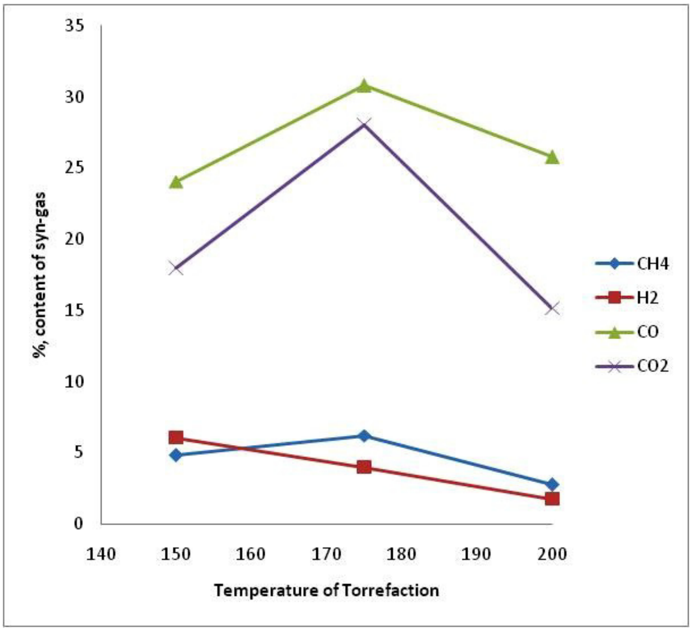

Fig. 5. Content of syn-gas at various temperature of torrefaction.

From Figure 5 we may see that content of methane and hydrogen tends to decrease while temperatures of torrefaction increase. Meanwhile, content of Carbonmonoxide tend to increase when temperature of torrefaction increase. From this figure, we also identify that temperature of torrefaction 150 °C will give better quality of syn-gas as compared to other temperature of torrefaction.

4. Conclusions

Bagasse has a high moisture content, bulk density of the fibrous and will cause obstacle in gasification process. To improve the quality of bagasse as feedstock gasification can be done with torrefaction pretreatment. This study provides conclusions that pretreatment torrefaction able to improve the quality of biomass as feedstock of gasification. For the Indonesian bagasse gasification process, the optimum temperature of dry torrefaction is 150 °C. At this torrefied-temperature, process of gasification will result yield and quality of syngas better than other torrefaction temperature. At 150 °C, dry torrefaction temperature during one hour will gives energy savings opportunities than wet torrefaction (180 °C, 1 hours). Torrefaction of bagasse with temperatures above 200 °C will tend to undergo carbonization reaction, decreasing hydrogen and methane content in syn-gas and decreasing quality of bagasse as raw material for gasification.

Acknowledgements

The authors would like to acknowledge to Dik Aksa Wachid Nugroho and Awang Dermawan Maris of Process System Engineering research group (PSErg), Chemical Engineering Department Gadjah Mada University for their valuable assistance with the experiments.

References

[1] Exxon Mobil, 2013, *The Outlook for Energy: A View to 2040*.

[2] Chen,W.H., Chen,C.J., Hung,C.I., Shen, C.H., and Hsu, H.W., 2013, "A Comparison of Gasification Phenomena Among Raw Biomass, Torrefied Biomass and Coal in an Entrained-Flow Reactor", *Appl Energy*, vol. 112, pp.421-430.

[3] ZREU (Zentrum fur rationell Energyeanwendung und Umwelt GmbH), 2000, *Biomass in Indonesia-Business Guide*. German Energy Saving Project.

[4] Abdullah, K., *Biomass Energy Potentials And Utilization In Indonesia*, Department of Agricultural Engineering, IPB And Indonesian Renewable Energy Society (IRES), www.bioenergylists.org accesed date 5 Juni 2013.

[5] Indonesian Statistics, 2012, www.bps.go.id.

[6] Hugot,E., 1986, *Handbook of Cane Sugar Engineering*, 3rd., *Elsevier Publishing Company*, Amsterdam.

[7] Paturau,J.M, 1982, *By Product of The Cane Sugar Industry,* Elsevier,Amsterdam.

[8] Kurniawan, Y., Saechu, M., dan Mirzawan, PDN., 2008,*Industri Gula Membangun Kompetensi*, *IKAGI*, Jakarta.

[9] Directorate General of EBTKE, 2011, www.esdm.go.id, Ministry of ESDM, Republic of Indonesia.

[10] Jorapur, R. and Rajvanshi, A., 1995, "Sugarcane Leaf-Bagasse Gasifiers for Electricity Generation", *Biomass Bioenerg*, 8, 91-98.

[11] Jorapur, R. and Rajvanshi, A., 1997, *Sugarcane Leaf-Bagasse Gasifiers for Industrial Heating Applications*, *Biomass Bioenerg*, 13, 141-146.

[12] Beeharry, R.P., 1996, Extended Sugarcane Biomass Utilisation for Exportable Electricity Production in Mauritius, *Biomass Bioenergy*, 11, 441-449.

[13] Zandersons, J., Gravitis, J., Kokorevics, A., Zhurinsh, A., Bikovens, O., Tardenaka, A. and Spince, B., 1999, "Study of The Brazilian Sugarcane Bagasse Carbonisation Process and Products Properties", *Biomass Bioenergy*, 17, 209-219.

[14] Das, P., Ganesh, A. and Wangikar, P., 2004, "Influence of Pretreatment for Deashing of Sugarcane Bagasse on Pyrolisis Products", *Biomass Bioenerg*, 27, 445-457.

[15] Filippis, P.D., Borgianni, C., Paolucci, M., and Pochetti, F., 2004, "Gasification Process of Cuban Bagasse in a Two-Stage Reactor", *Biomass Bioenerg*, 27, 247-252.

[16] Al Arni, S., Bosio, B. and Arato, E., 2010, "Syngas from Sugarcane Pyrolisis: An Experimental Study for Feul Cell Applications", *Renew Energ*, 35, 29-35.

[17] White, J.E., Catallo, W.J. and Legendre, B.L., 2011, "Biomass Pyrolisis Kinetics: A Comparative Critical Review With Rekevant Agricultural Residue Case Studies", *J Anal App Pyrolisis*, 91, 1-33.

[18] Pellegrini, L.F., Junior, S.O. and Burbano, J.C., 2010, "Supercritical Steam Cycles and Biomass Integrated Gasification Combined Cycles for Sugarcane Mills", *Energy*, 35, 1172-1180.

[19] Cunha, J.A., Pereira, M.M., Valente, L.M.M., Piscina, P.R., Homs, N. and Santos, M.R.L., 2011, "Waste Biomass to Liquids: Low Temperature Conversion of Sugarcane Bagasse to Bio-Oil The Effect of Combined Hydrolisis Treatments", *Biomass Bioenerg*, 35, 2106-2116.

[20] Ahmed, I.I. and Gupta, A.K., 2012, "Sugarcane Bagasse Gasification: Global Reaction Mechnism of Syngas Evolution", *Appl Energy*, 91, 75-81.

[21] Edreis, E.M.A., Luo, G., Li, A., Chao, C., Hu, H., Zhang, S., Gui, B., Xiao, L., Xu, K., Zhang, P., and Yao, H., 2013, "CO_2 co-gasification of Lower Sulphur Petroleum Coke and Sugarcane Bagasse via TG-FTIR Analysis Technique", *Bioresour Technol*, 136, 595-603.

[22] Kruesi, M., Jovanovic, Z.R., dos Santos, E.L., Yoon, H.C and Steinfeld, A., 2013, *Solar-driven Steam-Based Gasification of Sugarcane Bagasse in a Combined Drop-Tube and Fixed-Bed Reactor-Thermodynamic, Kinetic, and Experimental Analysis,* Biomass and Bioenergy, 52, 173-183.

[23] Filho, P.T.D., Silveira, J.L., Tuna, C.E., and Lamas, W.Q., 2013, "Energetic, Ecologic and Fluid-Dynamic Analysis of a Fluidized Bed Gasifier Operating With Sugarcane Bagasse", *Appl Thermal Eng*, 57, Issue 1-2, 116-124.

[24] Liliedahl, T., Sjostrom, K., Engvall, K., and Rosen,C., 2012, "Defluidisation of Fluidised Beds Gasification of Biomass", *Biomass Bioenerg*, 35, S63-S67.

[25] Patel, B., Gami, B., and Bhimani, H., 2011, "Improved Fuel Characteristics of Cotton Stalk, Prosopis and Sugar Cane Bagasse Through Torrefaction", *Energ Sust Dev*, 15, 372-375.

[26] Chen, W.H., Ye, S.C. and Sheen, H.K., 2012, "Hydrothermal Carbonization of Sugarcane Bagasse via Wet Torrefaction in Association with Microwave Heating", *Bioresour Technol*, 118, 195-20.

[27] Wang, Q., Liu, S., Yang, G., and Chen, J., 2013, "Thermogravimetric Kinetics of Sugarcane Bagasse Pretreated by Hot-Water", *Bioresour Technol*, 129, 676-679.

[28] Sarkar,M., Kumar,A., Tumuluru, J.S., Patil,K.N., and Bellmer, D.D., 2014, Gasification performance of switchgrass pretreated with torrefaction and densification , *Applied Energy*, *127*, *194-201*.

[29] Xue,G., Kwapinska, M., Kwapinski, W., Czajka, K.M., Kennedy,J. and Leahy, J.J., 2014, Impact of torrefaction on properties of *Miscanthus* × *giganteus* relevant to gasification, *Fuel*, *121*, *189-197*.

[30] Satpathy,K.S., Tabil, L.G., Meda,V., Naik,S.N. and Prasad,R., 2014, Torrefaction of wheat and barley straw after microwave heating, *Fuel*, *124*, *269-278*.