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Analysis of Downdraft Low Rank Coal Performance Gasification by Variations Coal to Syngas Products

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Abstract

Coal resources are inclusive (reserves are part of the resource), of which 48% is located in South Sumatra, with 70% of the deposits being brown or low-quality coal. With the high amount available, the direct use of coal has several shortcomings, one of which is that coal releases gases (CO_2, N_2O, NO_x, SO_x and Hg) which cause global warming. Coal gasification is a process for converting solid coal into a gas mixture that has a fuel value. Coal gasification will yield producer gas in the form of synthetic gas (syngas) with the main components consisting of carbon monoxide (CO), hydrogen (H_2), and methane gas (CH_4). By converting coal using gasification as a clean energy producer, a blower as a regulator of air flow, a cyclone as a tar separator and a gas cooler. Based on the results of testing the variation of coal used, the variation of 5515 kcal /kg coal has a rapid rise in temperature and is able to produce a flame for 115 minutes. with the composition of Syngas CO and CH_4 of 12.4% an 1.2%, while the coal variation of 4640 kcal/kg produces the highest H_2 of 6.9%. Coal 5515 kcal/kg produces the largest percentage of syngas conversion, carbon conversion, Low Heating Value, power output and stove efficiency, namely 13.46%, 70.397%, 2.427 MJ/kg, 18.403 kW and 31.23%.

Keywords: Downdraft gasification, coal variation, temperature rise, flame time, syngas,

Abstrak (Indonesian)

Sumber daya batubara bersifat inklusif (cadangan adalah bagian dari sumber daya), dimana 48% berada di Sumatera Selatan, dengan 70% depositnya adalah batubara coklat atau batubara berkualitas rendah. Dengan jumlah yang tersedia yang tinggi, penggunaan batubara secara langsung memiliki beberapa kekurangan, salah satunya adalah batubara melepaskan gas (CO_2, N_2O, NO_x, SO_x dan Hg) yang menyebabkan pemanasan global. Gasifikasi batubara adalah proses untuk mengubah batubara padat menjadi campuran gas yang memiliki nilai bahan bakar. Gasifikasi batubara akan menghasilkan gas produser berupa gas sintetis (syngas) dengan komponen utama terdiri dari karbon monoksida (CO), hidrogen (H_2), dan gas metana (CH_4). Dengan mengkonversi batubara menggunakan gasifikasi sebagai penghasil energi bersih, blower sebagai pengatur aliran udara, cyclone sebagai pemisah tar dan pendingin gas. Berdasarkan hasil pengujian variasi batubara yang digunakan, variasi batubara 5515 kcal/kg memiliki kenaikan suhu yang cepat dan mampu menghasilkan nyala api selama 115 menit. dengan komposisi Syngas CO dan CH_4 sebesar 12,4% dan 1,2%, sedangkan variasi batubara 4640 kcal/kg menghasilkan H_2 tertinggi sebesar 6,9%. Batubara 5515 kcal/kg menghasilkan persentase terbesar konversi syngas, konversi karbon, Low Heating Value, output daya dan efisiensi kompor yaitu 13,46%, 70,397%, 2,427 MJ/kg, 18,403 kW dan 31,23%.

Kata Kunci: Gasifikasi downdraft, variasi Batubara, kenaikan Temperatur, lama nyala api, syngas.

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INTRODUCTION

Indonesia has a potential for abundant reserved-coals. According to the Ministry of Energy and Mineral Resources data in 2021, The updating of the balance of coal resources and reserves by a team from the Center for Coal and Geothermal Mineral Resources is carried out every semester of the current year [1]. Increasing energy consumption in Indonesia encourages energy conservation in the field of renewable energy [2]. The results of the update of the coal balance in Semester 1 of 2021 resulted in coal resources of 142,659 million tons, with coal reserves of 37,524 million tons. Coal resources are inclusive (reserves are part of the resource), which 48% out of 100% is in South Sumatra and about 70% of the deposits of the coal is a lignite or lowest grade coal. According to the Ministry of Energy and Mineral Resources data in 2019, a production of coal increased to 528 billion tons compared to the production in 2017 that has a yield of 461 billion tons [3]. Most of the installed-capacity of power plants are from conventional power plants such as coal (50%), natural gas (29%), refined fuel oil (7%) and also non-conventional (renewable) energy (14%) in particular. This situation happened because the amount of coal production which still being abundant. The cost of coal that is still affordable and inexpensive. If it is assumed the growth rate of coal production reached 12,4% per year, so coal that is in Indonesia can be utilized up to 2166 [4]. The other reason behind selecting coal as an energy power plant resource, there are deficiency of using coal directly. Coal also contains of considerable pollution that is risk to the environment. Coal releases gases (CO_2, N_2O, NO_x, SO_x and Hg) which caused global warming [5]. Therefore, the net and efficient utilization of coal is still being a challenge extensively for extending the time of its existence. In addition to minimize the load of global environment, a way for increasing the efficient utilization of coal is to use another process of using coal named coal gasification. Coal gasification is a process for converting solid coal to the composite of coal-gas that has caloric value [6].

Coal gasification will have a yield of gas producer in the form of synthesis gas (syngas) with its primary component consist of carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2) and nitrogen (N_2) and low-pollutant. So that the experts of Energy Resources have focused on the development of coal gasification for supplying energy consumption in the future [7]. As of the problem that people have discussed, the aim of this research is to analyze the effect of the types of the coal using caloric 4640 kcal/kg, 4867 kcal/kg, 5108 kcal/kg, 5515 kcal/kg to the increasing result of temperature and how long does the flame last, the composition of gas, the percentage of syngas conversion, Low Heating Value and the output power also the increasing of gasification syngas result of water temperature for the efficiency of the stove that is used as flame testing of the syngas result. With the result that obtained the effect of the types of coal to the increasing in temperature in combustion chamber and the long – time flame, the composition of syngas, the percentage of syngas conversion, low heating value, output power also the increased water temperature in gasification syngas result for discovering the efficiency of the stove that is used as flame testing of the yield of the syngas.

Coal

Coal is a solid organic fuel sediment formed from plants that have undergone biochemical, chemical and physical decay in oxygen-free conditions that take place at certain pressures and temperatures for a very long period of time [8]. The plants are buried in a sufficient depth and exposed to high temperature and high pressure so that caused amendment process of physics and chemical and changed plants into peat and coal. The forming of coal started since carboniferous period which lasts for 360 million until 290 million years ago.

The trait for each type of coal is not the same. The factor that caused it is the initial decomposition of coal origin through a diagenetic process and coalification [9]. Heterogeneity of its character is assumed in various constituent content such as a relation between hydrogen and carbon, between oxygen and carbon, and between volatile content and caloric value. That relation has variation to one another in a range called coal band [10]. The quality of each sediment is determined by temperature and pressure and long formation time, as we called “organic maturity”.

Types of coal: Classification by ASTM: according to American Society for Testing Material (ASTM), coal classified into 4 based on C and H_2O that are anthracite, bituminous, subbituminous, lignite and peat [11].

The analysis of the composition between Ultimate and Proximate can be seen in Table 1.

Coal Gasification

Gasification technology is a form of energy enhancement contained in coal through a conversion from the solid phase to gas phase using thermal degradation process with organic materials in high

temperature going through incomplete combustion using confined air (20% - 40% stoichiometry air) [6]. Fuel that is used for gasification process using materials contained hydrocarbon such as coal from biomass. The whole process of gasification happened in the gasifier. Water vapor and carbon dioxide from the combustion process are reduced into gas that can be burnt (flammable), those are carbon monoxide (CO), hydrogen (H_2) and methane (CH_4) which can be utilized for the power plant as well as stove [13].

Table 1. The analysis of composition between Ultimate and Proximate [12]

Analysis		Coal Variation (kcal/kg)			
		4640	4867	5108	5515
Proximate	TM (%)	16.38	15.32	13.04	12.77
	VM (%)	42.00	37.80	35.15	33.82
	Ash (%)	5.60	4.95	4.63	4.18
	FC (%)	36.02	41.93	47.90	49.22
Ultimate	C (%)	59.01	60.30	61.87	65.66
	H (%)	6.72	6.55	6.31	5.85
	O (%)	25.18	25.09	24.94	23.60
	N (%)	2.89	2.54	1.76	0.41
	S (%)	0.60	057	0.49	0.30

Downdraft Gasification

With the growing of the development gasification technology makes the process of researching and developing itself continue to be made. The advancement is done by various on considerations, reducing water content and sulfur in between to the yield of syngas. Gasifier downdraft is a reactor with the direction of air flow and raw materials leading down. Syngas flows downwards and gasifier [14]. stated that the reason of selecting downdraft gasifier was caused by 4 things [6]:

1. The cost of manufacturing is less expensive
2. Gas which produces more heat compared to draft
3. Easier to continue for the next combustion process
4. Tar that is lower compared to updraft.

The Stages of Coal Gasification

In the process of gasification, there are some stages of coal, thus becoming flammable gas [15]:

a. Drying
b. Pyrolysis
c. Gasification
d. Partial Oxidation

Gasifying Agent Type

Gasifying agent has an impact on the quality and quantity of syngas and affect the composition of gas, the amount of tar and heating value. There are 4 gasifying agents that are in common use: air, vapor, oxygen and mixed air-vapor [16]. The usage of air as gasifying agent is mostly used since it is easier for supplying than any other gasifying agents. Conducted experiments to figure out the effect of gasifying agent on the composition of syngas, heating value, the tar content and yield gas. [17] Table 2 revealed that gasifying agent can be added or subtracted the heating value of syngas.

Table 2. The Characteristic of syngas based on gasifying agent [17]

Gasification Agent	T(˚C)	Gas Composition (Dry Basis)		Yield		
		H_2 (%)	CO (%)	Tar (g/Kg)	Gas (Nm^3/Kg)	LHV
Air	780-830	5.0-16.3	9.9-22.4	3.7-61,9	1.25-2.45	3.7-8.4
O_2 + Steam	785-830	13.8-3.7	42.5-52.0	2.2-46	0.86-1.14	10.3-13.5
Steam	750-780	38-56	17-32	60-95	1.3-1.6	12.2-13.8

The Effect of Kinds of Coals to The Result of The Syngas

Kinds of coals are essential to the desired result of syngas. Stated that the result of gas conversion of H_2 from gasification produced more by lignite than subbituminus or antrasite [18]. However, for the kind of coal that produced the conversion of CO, antrasite has the highest conversion of CO content, afterward bituminus and lignit. This state based on the content of carbon from the kinds of coals. Based on its content, gasification is divided into 3 products: Gasification of Low-Btu gas (150-300 Btu/scf), Mediu-Btu gas (300-550 Btu/scf) and High-Btu gas (980-1080 Btu/scf) [19] The composition of the products showed in table 3.

Table 3. Classification of gasification products [19]

Product	Composition
Low-Btu gas (150-300 Btu/scf),	50% ≥ nitrogen with slightly compound of H_2 and CO, CO_2 and slightly methane
Medium-Btu gas (300-550 Btu/scf)	Preponderance of CO and H_2, non-reactive gases and slightly of methane
High-Btu gas (980-1080 Btu/scf).	Closer to pure methane

MATERIALS AND METHODS

Experimental Treatment and Design

In the research of the analysis of the performances of gasification downdraft low-rank coal reviewed the variation of coals to the result of the

syngas was conducted in Laboratorium Teknik Energi Politeknik Sriwiijaya from July 6-August 10 in 2020. Fixed variable in this research is the percentage of the opening-valve (100%) amounted 3.2 m/s with the size of coal 7-8 cm, the problem that to be analyzed in this research is the effect of the variation of coal with the caloric value 4640 kcal/kg, 4867 kcal/kg, 5108 kcal/kg, 5515 kcal/kg, the result of the increasing temperature and the flame time, the composition of syngas, the percentage of syngas conversion and LHV. This research was done the first analysis for figuring out the composition of the content of proximate and ultimate. The analysis of proximate using the analysis of ASTM D 3173-03 for moisture, ASTM 3175-07 for Volatile matter, ASTM 3175-02 for ash and for fixed carbon. The analysis of Ultimate cooperated with PT. Geoservices Palembang using the method of ASTM-D4239 methode A-2017 for the total sulfur, ASTM-D5373-2016 for Instrumet Ultimate, ASTM-D3176-2015 for Oxygen by its difference. To determine the composition of syngas value using GC-MS (ASTM D-2163) instrument from Pertamina RU III Plaju –Palembang.

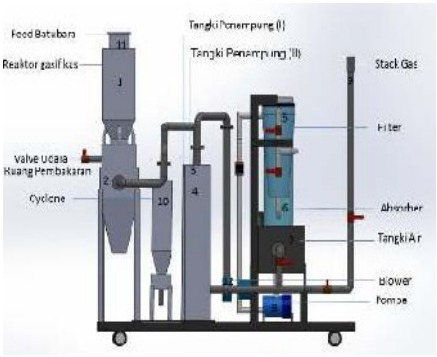


Figure 1. Design specification of gasification reactor

RESULTS AND DISCUSSION

The Effect of Variety of Coals to The Increased Temperature and The Flame Time

On the Figure 2 can be shown that caloric value of coal affects the increasing of combustion temperature. Coal has the details of components that can affect the caloric value of the coal. One of the factors that can affect the caloric value is moisture content. The low caloric value showed the high amount of value of the moisture content. Stated that in a combustion reaction, the water that is in coal blocks the heating rate of coal and hampered the process of coal contacting to oxygen [20]. The moisture content of coal also reduced the amount of heat energy that can be utilized because half of the heat energy be used to evaporate the endothermic water content in coal.

On the Figure 2 can be shown that the highest temperature is coal with the caloric value 5515 kcal/kg, this was due to the low water content in coal hence the temperature reached higher than other coal that has the caloric value under 5515 kcal/kg.

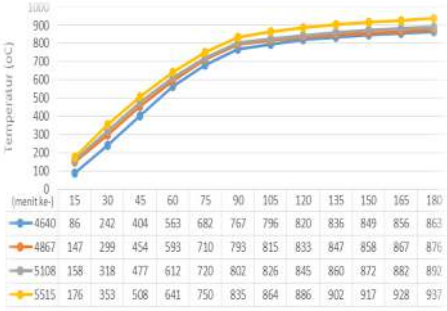


Figure 2.Variation of coal to the increased temperature

Rahma *et al.* described that the lower water content in raw materials and the higher caloric value can affect the time of the flame from the produced syngas [21]. Based on the research, the effect of coal variety to the length of time of the flame that showed on Figure 3 has the increased of the length of the time of the flame from 76 minutes to 115 minutes. The shortest is on coal with the variation of the caloric value 4640 kcal/kg for 76 minutes. While the longest is on the variation of the caloric value 5515 kcal/kg for 115 minutes.

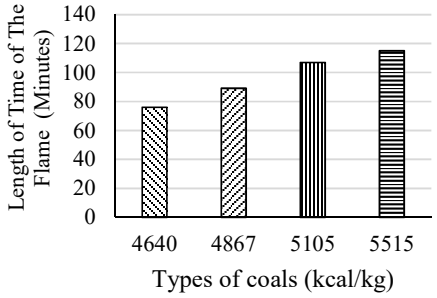
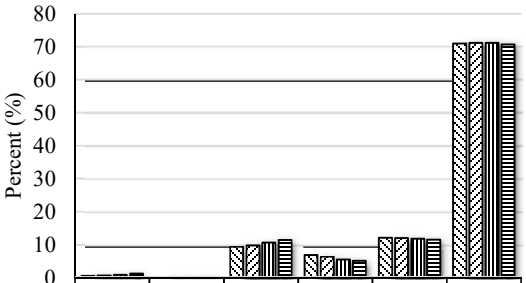


Figure 3. The Effect of the variation of coal to the caloric value

Not only the kinds of the coal that can affect the increasing in temperature but also the effect from the environment air where the research was done at. In doing data retrieval, the air temperature can also affect the increasing of the temperature in the process of oxidation in gasifier. The low temperature of air caused the slow progress in increasing the temperature in gasification. It was from the heat that should be used for the combustion and can be utilized

for heating the air for making the process of the combustion happened.

The Effect of Types of Coals to The Composition of Syngas



	CH4	CO2	CO	H2	O2	N2
4640	0.6	0.1	9.3	6.9	12.1	71
4867	0.7	0.1	9.8	6.3	12	71.1
5105	0.9	0.1	10.6	5.5	11.8	71.1
5515	1.2	0.1	11.4	5.1	11.5	70.7

The Composition of The Substances in Gas

Figure 4. The syngas content

Based on Figure 4 can be seen that the higher the caloric value which be used, can be shown the amount of carbon content in coal. It caused gasifier having more CO content than H_2. [22] in his research showing that the value of the composition of CO, H_2 and CH_4 depends on the composition of the ultimate fuel that be used. Based on its factor, the higher the carbon value contained in fuel will have more substances of CO, CO_2 and CH_4. At the same time the fewer H_2 value from raw materials caused the lower H_2 contained in its materials. The high composition of nitrogen is caused the size of diameter of the pipes for the air going in, so that the amount of the air going into it getting bigger and make the value of the equivalent ratio (ER) also getting bigger. The value of the equivalent ratio matters in gasification. Equivalent ratio aimed to figure out the comparing between air fuel ratio combustion gasification for the actual and air fuel ratio completed combustion (stoichiometry), if the value of ER reached 1, thus can be said that its gasification is close to the completed combustion. If the value of ER is 1 that will create an effect to the content of the produced of CO, H_2 and CH_4 which decreased and increased the nitrogen in gas. On the appendix II of the calculations showed that ER value was 0,9. Stated that for equivalent ratio in a good quality of gasification is on 0,2-0,3, but if the ER value is up to 0,3 caused the low of the syngas conversion [23]. As on its composition, the gasification is a product of Low-Btu gas.

The Effect of the Various Coals to The Syngas Conversion

The percentage of syngas conversion is counted based on the amount mol of syngas to the amount mol of fuel and air. This conversion depends on the type of raw materials that be used. This variable can affect the process in gasifier, mainly on the process of oxidation and reduction. Oxidation is a combustion process which aimed for oxidizing fuel substance to produce heat energy needed in the process of gasification to distribute to another process. The heat which is produced in the process of oxidation is the formation of CO, H_2 and the reaction of methanation for producing CH_4. The high value of caloric can be as a barometer of the syngas that will be produced. Stated that the higher caloric value of raw materials, the higher temperature that has in oxidation phase so that can produce more heat and can convert more substances to syngas [24].

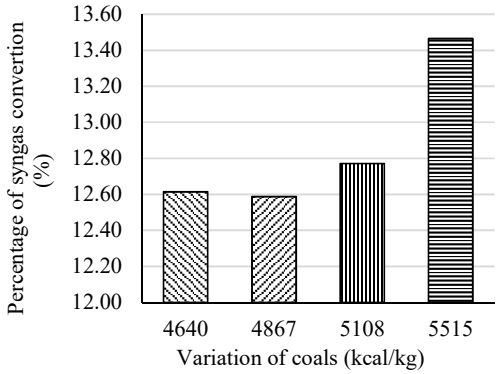


Figure 5. Syngas conversion

Based on Figure 5 Chart of Percentage of Syngas Conversion showed a decrease on coal 4867 kcal/kg, it was the effect of density from each syngas. Based on Table Properties of Gases at 1 atm Pressure, the higher output temperature will decrease the density of its syngas so that will also decrease the produced syngas and it affects the lower mol of syngas conversion. On coal type 5108 kcal/kg, there is an increase for the syngas conversion although the temperature is sufficiently high, it's because the caloric value for the process of oxidation sufficiently high to distribute high heat so that the result of the syngas is fairly enough although the density of the syngas decreased aftermath the high output temperature.

Data Calculation of the Effect of Types of Coal to Low Heating Value

Low Heating Value is an important indicator in all materials. LHV indicates the amount of caloric which can be produced by fuel. LHV of syngas effects on the types of coal that is used. Based on the calculation that have been done, on Figure 6can be seen that the types of coal affect the LHV value of the produced syngas. It was due to the lower caloric value of the coal, the lower composition of syngas which if converted to LHV will make the value of LHV to be low.

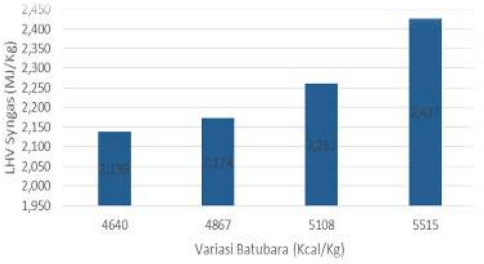


Figure 6. Chart of low heating value of syngas (MJ/kg)

LHV is affected by the amount of syngas composition in a fuel, the syngas is CH_4, CO and H_2. The higher the value of the composition of CH_4, CO and H_2, the higher heat of syngas formation in reduction phase. This is also in proportion to the higher LHV, the higher heat needed. [25] in his research stated that the higher energy content that belonged to the fuel, the higher the result of gasification cause its energy conversion that is also sufficiently high.

CONCLUSION

From the result of the observation and experimental that have been done, then had acquired to the conclusion that:

1. The fastest rising temperature showed by coal 5515 kcal/kg type with the length of time of the flame around 115 minutes. The rising of the temperature and the length of time of the flames caused by the moisture content which contained in coal.
2. Coal 5515 kcal/kg type is one variation that produced the highest composition of CH4 and CO compared to the other coals with the value of CH_4 = 1,2% and CO = 11,4 %. And coal 4640 kcal/kg type is the highest producer of hydrogen, amounted to 6,9%.
3. The high value of caloric in coal caused the reaction of oxidation can be produced the high of heat so that can be used for the reaction of reduction to convert the substances in coal to be syngas. It showed on coal 5515 kcal/kg type which converted coal to syngas, it was from the high of caloric value.
4. Thermal efficiency of downdraft coal gasification ranges from 24,42 to 31,23%., with the highest efficiency valued 31,23% from the LHV of coal 5515 kcal/kg type.

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REFERENCES

[1] Q. W. Harahap, P. Ginting, H. Distincta, M. Rushdi, and E. Burmansyah, “Low Carbon Development of South Sumatra Has the Potential to be Hampered by Low Quality Coal Investment,” *AEER Climate Emergency Mitigation Monitoring Program*,2021.

[2] Rusdianasari, Y. Bow and R. A. N.Moulita, “Temperature effect on the biodiesel quality from waste cooking oil by induction heating,” *IOP Publishing. Journal of Physics: Conference Series*., vol. 1450 no. 012003, 2020.

[3] A. C. Adi and F. Lasnawatin, “Handbook of energy & economic Statistic of Indonesia,”*Head of Center for Data and Information Technology on Energy and Mineral Resources*, 2021.

[4] A. F. Yudha, *"Characteristic Test on the Combustion Unit of a Coal Gasification System Using a Fixed Bed Updraft Gasifier,"* Theses, University of Indonesia, Depok, 2010.

[5] A. Zulatama, A. Syarif, M., 2021, Effect of Oxygen Flow Rate on Combustion Time and Temperature of Underground Coal Gasification. International Journal of Research in Vocational Studies (IJRVOCAS) Vol. 1, No. 2, August 2021.

. [6] Sarmidi, M. Yerizam , A. Syarif, 2021, Syngas Characteristics from UCG Gasification Process with Lignite and Subbituminous Coal Types. International Journal of Research in Vocational Studies (IJRVOCAS) Vol. 1, No. 2, August 2021

[7] D. E. Pranata, A. Syarif, M. Yerizam **"**Characterization of Fly Ash Catalyst Using XRD Method for Biofuel Production from Used Cooking Oil, Indonesian Journal Fundamental and Applied Chemistry, IJFAC, unsri.ac.id, 2021

[8] Romeo.M. Flores, *Coal and coalbed gas: fueling the future*,1 st edition,ISBN13-978-0123969729 Elsevier Science 2013.

[9] A. Smolinskiv and N.Howaniec, "Co-gasification of coal/sewage sludge blends to hydrogen-rich gas with the application of simulated high temperature reactor excess heat,"*Int. J. Hydrog. Energy.*,vol. 41, no. 19, pp. 8154-8158, 2016.

[10] S. Niksa, *Process Chemistry of Coal Utilization Impacts of Coal Quality and Operating Conditions*, Woodhead Publishing, 2020.

[11] G. H. Wood,T. M.Kehn, M. D Carter, and W. C.Culbertson, *Coal Resource Classification System of the U.S. Geological Survey*, Geological Survey Circular, 1983.

[12] G. Atkinson, R. C. R. Davison, and A. M. Nevill, 2004, *Performance Characteristics of Gas Analysis Systems: What We Know And What Need To Know*, Int J Sport Med 2005;26 (Suppl 1): S2-S10 Georg Thieme Verlag KG. Stuttgart. New York. DOI 10.1055/;s-2004-830505. Published online December 22, 2004

[13] C. Z. Zaman, K. Pal, W. A. Yehye, S. Sagadevan, S. T. Shah, G. A. Adebisi, E. Marliana, R.F. Rafique and R. B. Johan, "Pyrolysis: A Sustainable Way to Generate Energy from Waste", IntechOpen: Rijeka, Coratia, 2017.

[14] J. G. Speight, *Gasification of Unconventional Feedstocks*, Gulf Professional Publishing, 2014.

[15] H. Susanto, *Pengembangan Teknologi Gasifikasi untuk Mendukung Kemandirian Industri Energi dan Kimia*, Forum Guru Besar ITB, 2018.

[16] D. R. Ependi, A. R. Saleh, and B. Sudarmanta, "The Experimental Study of The Effect of Air Preheating in MSW Pellet Multi-Stage Downdraft Gasifier", *IPTEK The Journal for Technology and Science*, vol. 30 no. 2, pp. 2088-2033,2019.

[17] I. Ahmed and K. Gupta, "Characteristic of hydrogen and syngas evolution from gasification and pyrolysis of rubber,"*Int. J. Hydrog. Energy*., vol. 36, pp. 4340-4347, 2011.

[18] A. H.Tchapda and S. V. Pisupati, "Review A Review of Thermal Co-Conversion of Coal and Biomass/Waste,"*Energies*, vol. 7, pp. 1098-1148, 2011.

[19] J.G. Speight,*The Chemistry and Technology of Coal*, CRC Press, 2013.

[20] M. Onifade and B Genc, "A review of research on spontaneous combustion of coal, "*Int. J. Min. Sci. Technol*., vol. 30, no. 3, pp. 303-31, 2020.

[21] F. N. Rahma, C. Tamzysi, A. Hidayat, M. A. Adnan,"Investigation of Process Parameters Influence on Municipal Solid Waste Gasification with CO2 Capture via Process Simulation Approach,"*Int. J. Renew. Energy Dev.*, vol. 10 no. 1, pp. 1-10, 2021.

[22] P. Basu, *Biomass Gasification and Pyrolysis Practical Design*, Academic Press, 2010.

[23] M.U.A Hafiz, J.P. Sang and B. Michael, *Biomass to Syngas: Modified Stoichiometric Thermodynamic Models for Downdraft Biomass Gasification*, Department of Chemical and Biochemical Engineering, Dongguk University, 2020. Article in Energies October 2020 DOI: 10.3390/en13205383. See discussions, stats, and author profiles for this publication at: https://www.researchgate.net/publication/344736594

[24] U. I. F. Styana, R. Indrawati, M. S. Cahyono, "Karakterisasi Proses Gasifikasi Sampah Organik dengan Variasi Jenis Bahan,"*J. Engine*, vol. 3 no.1, 2019.

[25] P. Basu, *Biomass Gasification, Pyrolysis and Torrefaction 2nd Edition*, Academic Press, 2013.