MUNICIPAL SOLID WASTE AND PALM KERNEL SHELL MIXTURE AS FEEDSTOCK IN THE GASIFICATION PROCESS

AMADOU DIOULDE DONGHOL DIALLO, MA'AN FAHMI RASHID ALKHATIB*, MD. ZAHANGIR ALAM, MAIZIRWAN MEL

Bioenvironmental Engineering Research Centre (BERC), Department of Biotechnology Engineering, Faculty of Engineering, International Islamic University Malaysia, Jalan Gombak, 53100 Kuala Lumpur, Malaysia.

**Corresponding author: maan@iium.edu.my*

ABSTRACT: One of the renewable and sustainable energy sources to replace polluting fossil fuels is residues of municipal solids and biomass. The efficient management of this energy will help to solve the problems associated with fossil fuels. There are several routes to convert biomass into useful products depending on the biomass characteristics and the need of end product and its applications. Biomass gasification has considered being the preferred viable option to transform a variety of biomass feedstock. This study highlights the possibility of mixing biomass (palm kernel shell) and municipal solid waste (MSW) to make clean energy that regards the environment (climate change) and sustainable development. Chosen components of MSW, specifically plastics, textiles, foam, and cardboard mixed with PKS in desired proportions. Volatiles, and ash moisture content, have moderate concentrations that do not negatively influence the gasification process, according to the study results. The study established that the mixture MSW and PKS can be a raw material for the gasification process. Depending on the calorific value, this varies from 21.13 MJ / kg to 28.82 MJ / kg for an MSW + PKS ratio of 0.25 to 1.5 respectively. We found other polluting elements such as Chlorine (0.064 wt.% to 0.171wt.%), Sulfur 0.321wt.% to 0.512 wt. %. Elements such as antimony (Sb), arsenic (As), bromine (Br), lead (Pb), and mercury (Hg) were not found in any of the elements analyzed. Those who are present are within the standards set by the competent services. Therefore, this mixture of MSW and PKS can replace the polluting and depleting fossil fuel in the gasification process with little to no impact on the environment.

KEYWORDS: *Municipal solid waste; Palm kernel shell; calorific value; energy; Gasification*

1. INTRODUCTION

Municipal solid and biomass wastes are abundant in Malaysia, the estimated annual MSW generated is 13.68 Mt by year, at a 1.17 kg average rate per capita per day of waste, and Palm kernel shell estimated 4.72 Mt, [1]. Waste to energy technologies is the most appropriate options to solve municipal solid waste problems, allowing replacing fossil fuels [2]. It has demonstrated the abundance of biomass residues in several countries around the world, in Malaysia, Indonesia, Guinea Conakry, Ivory Coast, and Ghana, to cite these as examples. According to [3] micro plastics exist in landfills and that plastic waste buried in landfills is subject to much more severe environmental conditions, including pH of the leachate (sometimes varying from 4.5 to 9), physical stress, microbial degradation, varying temperature, gas making (carbon dioxide and methane, etc.).

Because of negative health and environmental effects, these wastes would have to be stored somewhere and be processed. This waste management becomes important in every country. Waste management means collection, transport, and processing or disposal of waste. Integrated waste management aims to minimize the negative impacts of materials that become waste; it also has to be beneficial for the economy. It has shown that the major sources of renewable and friendly energy are among others biomass within various forms and municipal solid residues.

Using biomass for power generation may reduce pollution and promote sustainable energy development. The net emission of carbon dioxide in biomass power generation is near to zero, as it absorbs the emitted carbon dioxide in the re-growing process. The sulfur content in biomass is very low, so there are almost no sulfur emissions. Therefore, the use of biomass as an alternative energy for power generation would be effective in improving the environment condition and decreasing the greenhouse gas effect. The lack of research and development in a particular biomass conversion technology would also obstruct the efficient uses of a variety of biomass resources to ensure uninterrupted and efficient power generation.

To prevent contamination of the environment from the accumulate the waste, some developed countries promoted to supply energy by converting MSW [4- 6]. The scarcity of fossil fuels and the environmental concern, the greenhouse gas emission, pollution, and other health sanitary are forcing the search for alternative energy sources.

The link between the produce of municipal solid waste and the increase of population throughout the world has shown, and the challenges to be meet to supply quality energy while protecting the environment. Thus, despite the increase in the volume of solid waste, new strategies emerge to meet the challenges, and additional problems arise [7-9]. Addressing the same research topic, the researchers advocated RDF / SRF technology to promote the create renewable energy from municipal solid waste and biomass [10 - 12]; the various aspects linked to the produce of these clean energies, characterization, composition, storage and transport [13,7]. Conversion of biomass to pellets allows producers to capitalize on biomass, in Malaysia, as an example, many pellet producers generate about 1,000 to 3,000 tons of pellets per month, it makes these pellets using sawdust as feedstock for export. The export demand for these pellets comes from Europe, Japan, Korea, and China [14]. To convert Municipal solid waste to energy searchers used many methods; the most important is thermochemical conversion, including combustion, pyrolysis, and gasification [15 - 17].

Many studies have done on transforming MSW into valuable product using combustion, pyrolysis, and gasification [18,19]. Gasification of MSW and biomass waste presents significant possibilities in energy security and mitigates climate change. Gasification converts solid or liquid waste feedstock into a gaseous product by exposing it to a range of high temperatures (> 700^{o}C) in a controlled supply of oxygen without burning it. Gasification is a thermochemical process that converts carbonaceous materials into syngas. We can divide the gasification process into four steps: biomass drying, pyrolysis, gasification, and combustion. The syngas derives from biomass comprises hydrogen and carbon monoxide, along with methane, carbon dioxide, water vapor, nitrogen, and impurities like tars, ammonia, hydrogen sulfide, and hydrogen chloride. High-quality syngas is characterized by low N_2 content, high H_2 content, low tar levels, little chlorine, and sulfur content and high heating value. They often select steam gasification as it improves the quality of the produced gas by enhancing the hydrogen concentration. Besides, the steam gasification process has additional advantages such as maximizing the heating value, has helpful residence time characteristics, and efficient tar and char reduction [20 - 23].

During a biomass gasification process at high temperatures, between 800- 900°C, the gas produced comprises a mixture of various gases such as carbon monoxide (CO), hydrogen (H_2), carbon dioxide (CO_2), Methane (CH_4), Nitrogen (N_2), water vapors (H_2O), and other undesirable impurities such as tar, solid particulates, ammonia, hydrochloric acid, sulfur compounds, and alkali metal species. They cannot use the gas as such in the end-use applications, because of the risk of several symptoms and odor annoyance mediated by perception about air pollution or evaluation of a resulting health risk [24]. Thus, it must be cooled and cleaned properly for smooth and efficient operations viz. engine application and biofuel production. As observed, an increase in the heating rate and residence time improves the gasification efficiency. The gasification efficiency strongly depends on the temperature and gasification agent.

It has done many studies in the energy field, in particular the choice of raw material for gasification. Also, some note that the feedstock for syngas production, the lesser the content of lignin, the better is the formed fuels. According to [25, 26] the higher the cellulose and hemicellulose content, the more gaseous products will form. Lignocellulose including cellulose, hemicellulose, and lignin biomass is the most abundant renewable feedstock and is significant, cheaper than crude oil. In the gasification process or the produce of biogas, lignocellulosic raw materials or food waste, or any solid waste such as municipal solid waste, can be used. Also, micro-algae are amongst the most with potential renewable feedstock for biofuel generation. In addition, the best choice as a raw material is one that is accessible and will not increase greenhouse gases. It defines cellulose as a straight-chain polymer comprising anhydroglucopyranose joined with ether bonds. Hemicellulose is an amorphous polysaccharide containing sugar units which branched and have varied sugar types. Lignin is the most complex constituent with a cross-linked 3-D polymer structure of phenyl propane units.

The challenges in power generation using gasification technology require more research to remove the tar and improve the syngas quality. To discover all biomass sources that could use as a feedstock for power generation will help to minimize the threat of the power plant interruption because of the seasonal shortage of the feedstock. According to the brief description above, it is possible to conclude that they vary the feedstock for the gasification process. The gas produced during the gasification process depends on the quality of the raw material used. They usually manage municipal solid waste through disposal at landfills, which experience severe environmental conditions, such as leachate, high salinity, and greenhouse gases (GHG) generation [1].

Technical challenges of biomass identified are low bulk, energy density and calorific value which, require upgrading and densification that make the feedstock costly. Biomass is more responsive to moisture or hydrophilic matters that lead to a problem for fuel storage and handling. Many power station operators were concerned about logistics and boiler issues like ash deposition, SOx, NOx emissions, fouling, corrosion of heat exchanger surfaces, and slagging. There is a demand for biomass pre-treatment to improve chemical and physical properties by increasing the energy content, grind ability and hydrophobicity. Therefore, the gasification process of the mixture of MSW and PKS is one of the potential technologies to tackle the issue of Landfill and palm oil mills residues. Based on our current knowledge, it did no research work on the mixture of municipal solid waste and palm kernel shell as feedstock in the gasification process.

This study aimed to use a mixture of Municipal solid waste and palm kernel shell as feedstock in the gasification process. It would highlight the trends of using biomass and Municipal Solid waste sources as sustainable energy, for different sectors to take a share in the overall energy supply and substitute the depleting and polluting conventional fuels in the future.

2. MATERIALS AND METHODS

It gets data for this study from experiments using proximate and ultimate analysis, and calorific value of palm kernel shell derived from biomass and municipal solid waste.

These experiments realized to investigate the effects of some parameters involved in the study, such as moisture content, temperature, steam to biomass waste ratio, and particle size on the gas composition. The thermal conversion method includes pyrolysis, combustion, gasification, and Refuse derived fuel, and Solid refuse fuel, to name a few, have many advantages over other technologies. The following sub-sections will explain the details of the materials used, and the methodologies applied.

2.1. Feed materials

Before proposing this study, we wanted to make sure that there was an abundant raw material. According to the investigation, Malaysia has sufficient municipal solid waste and biomass; the estimated quantities are 13.68 Mt by year, at a 1.17 kg an average rate per capita per day of waste, and Palm kernel shell 4.72 Mt [1].

Municipal solid waste including (plastics, textile, paper/ cardboard, and foam) are collected in the landfill Gombak MSW transportation Station and biomass waste (Palm kernel shell) from Sime Darby Research Center Carey Island, Banting Company (Selangor) with an average particle size of approximately 0.5-3mm and 0.5-5g, were used as feed material.

2.2. Proximate analysis

The proximate analysis summarizes the weight percentage of moisture content, volatile matter, ash, and fixed carbon. The values of these variables have a significant impact on fuel. The equivalence ratio (ER), is influenced by the amount of moisture and volatiles present in the feedstock. A high volatile fraction in the feedstock produces higher tar yield. Moisture content was analyzed using the standard method ASTM E 871-82 in a conventional oven at 105^{o}C.

The volatile matter performed by employing the standard method ASTM E 872 and the ash also determined using the standard method ASTM D 1102-84 in the muffle furnace. The fixed carbon determined through the difference of the sum of the others about the total sample. All analyses performed in duplicate.

2.3. Ultimate or Elemental Analysis

For the determination of carbon, hydrogen, nitrogen, sulfur and chlorine, standard methods have been used as follows: carbon and hydrogen (ASTM E-777), nitrogen

(ASTM E-778), Chlorine (ASTM E-776-87), and sulfur (ASTM E-775), Leco CHN628S was used for the analysis. In contrast, oxygen was determined by the difference of the sum of others from the total sample. All analyzes were performed in duplicate to verify the effectiveness of the analysis.

2.4. Heating Value

To determine the high calorific value (HHV) of samples of the MSW and PKS mixture, the Parr 1341 oxygen bomb calorimeter was used. Oxygen was connected to the unit to pressurize the chamber. Under standard conditions, the oxygen bomb calorimeter measures the energy released when the sample undergoes complete combustion in the presence of oxygen. All analyzes were performed in duplicate.

2.5. Chemical composition of PKS

Biomass contains an inorganic component which, is the source of ash, such as cellulose, hemicellulose, and lignin at different percentages. During the gasification process, the fractions of cellulose, hemicellulose, and lignin present in biomass feedstock degrade at temperatures ranges from 305^{o}C to 500^{o}C [4]. The variations in these constituents in biomass raw materials involve products with different calorific values. It shows the chemical composition of MSW and PKS in Tales 1 and 2. Table 3 illustrates the ratio of the MSW and PKS mixture.

Table 1: Chemical composition of MSW

No	Components	Percentage (%)
1	C	52.96
2	H	6.58
3	O	36.78
4	N	0.65
5	S	0.028
6	Cl	0.24

Table 2: Chemical composition of PKS [27]

No	Components	Percentage dry basis (%)
1	Cellulose	27.7
2	Hemicellulose	21.6
3	Lignin	44

Table 3: A mixing ratio of MSW and PKS

Samples No	Mixed elements wt.%	Total wt.%
1	20 (MSW) +80 (PKS)	100
2	30 (MSW) +70 (PKS)	100
3	40 (MSW) +60 (PKS)	100
4	50 (MSW) +50 (PKS)	100
5	60 (MSW) +40 (PKS)	100

3. RESULTS AND DISCUSSION

Proximal and elemental analyzes were performed on the municipal solid waste (MSW) and palm kernel shell (PKS) samples taken one by one, then their mixtures. Table 4 illustrates the results of the proximate analysis of MSW and PKS samples.

The minimum value of ash content, volatile matter and moisture content (2.99 wt. %, 3.50wt.%, and 7.50wt.% respectively) belong to the MSW sample. Moreover, the maximum values (3.94wt. %, 4.70 wt.%, and 8.61wt.% respectively) come from the PKS sample. Consequently, these results show that the calorific value is high for the MSW and the PKS 31.38 MJ/kg and 18.57 MJ/kg, respectively. High fixed carbon and volatile matter increase the heating value, which predisposes them to be used for the gasification process.

PKS has the lowest fixed carbon (82.76 wt.%) than that of MSW (86 wt.%). The (MSW and PKS) mix have the smallest contents of ash (2.34 wt.%). Higher ash can cause ignition and combustion problems. The moisture content (1.41 wt.%), volatile matter (1.35 wt.%), and fixed carbon (87.32 wt.%) are favourable in the gasification process. These fractions belong to the proportion (50:50; 60: 40; 30: 70 and 20: 80). The yield of the higher ash (5.45 wt.%), moisture content (5.24 wt.%), volatile matter (3.45 wt.%), and fixed carbon (93.21 wt.%), belong to (40:60; 20: 80; 60: 40 and 30: 70). A maximum in terms of energy would be the combination (60:40) whose calorific value is 28.82MJ/kg. Low moisture content is favourable since it has a lower energy penalty in the drying process before gasification. A similar result was observed by Nobre et al. [6].

Table 4 : Proximate analysis of MSW and PKS

Element (wt. %)	Moisture content (wt. %)	Ash content (wt. %)	Volatile matter (wt .%)	Fixed carbon (wt. %)	HHV (MJ/kg)
MSW	7.50	2.99	3.50	86.0	31.38
PKS	8.61	3.94	4.70	82.76	18.57

This study established that the mixture of MSW and PKS can be a raw material for the gasification process. Depending on the calorific value, this is 21.13 MJ / kg for an MSW + PKS ratio of 0.25 to 28.82 MJ / kg for an MSW + PKS ratio of 1.5. A similar result was reported by Liu et al. [2019].

Table 5: Proximate analysis of the MSW and PKS mixture

Mixed elements (wt. %)		Moisture Content (wt.%)	Ash content (wt.%)	Volatile matter (wt.%)	Fixed carbon (wt.%)	HHV (MJ/kg)
MSW	**PKS**					
20	**80**	5.24	4.27	3.17	87.32	21.13
30	**70**	1.63	3.81	1.35	93.21	22.41
40	**60**	3.31	5.45	3.21	88.03	23.69
50	**50**	4.50	2.34	3.25	89.91	23.58
60	**40**	1.41	4.23	3.45	90.91	28.82

Proximate analysis of the municipal solid waste (MSW) and palm kernel shell (PKS) mixture, shown in table 4. From the results of table 4 where MSW and PKS are mixed accordingly, ash content, moisture content, volatile matter, and fixed carbon, it emerges an irregular trend-based on the quantity of MSW supplied in the mixture. The calorific value rises proportionally with the growth of MSW in the compound. The elemental analysis of the different wastes is presented in tables 6, 7, 8, 9, 10 and 11 respectively. I n all the components analyzes, the major contribution in terms of carbon and oxygen being the plastics having the highest carbon fraction agrees with previous work on this type of material [10].

From Tables 6 to 11 the symbols H, N, S, O, Cl and HHV denote hydrogen, nitrogen, sulfur, oxygen, chlorine and high heating value respectively.

Table 6 : Ultimate analysis of PKS

Name	Mass	C (wt. %)	H (wt. %)	N (wt.%)	S (wt. %)	O (wt.%)	Cl (wt.%)	HHV (MJ/kg)
PKS	0.201	42.14	6.547	2.569	0.205	44.6	0.528	18.57
Std. deviation	0.002	0.080	0.005	0.0005	0.0011		0.001	
RSD	0.077	0.190	0.075	0.018	0.552			
Count	2	2	2	2	2		2	

Table 7: Ultimate analysis of MSW

Name	Mass	C (wt.%)	H (wt.%)	N (wt.%)	S (wt.%)	O (wt.%)	Cl (wt.%)	HHV (MJ/kg)
MSW	0.105	52.96	6.57	0.65	0.028	36.78	0.24	31.38
Std. deviation	0.003	9.454	0.7181	0.296	0.004		0.001	
RSD	2.881	17.85	10.92	45.43	15.41			
Count	2	2	2	2	2			

The HHV changed from sample to sample since they have very different fuel characteristics. Namely, the lowest HHV value was determined, as 18.57 MJ/kg for PKS waste, and the highest HHV value was 31.38 MJ/kg for MSW, as shown in Tables 7 and 8. Because of the constituent elements of MSW, including carbon and hydrogen in plastics (73 wt.% and 9.45 wt.% respectively), these elements considerably influencing the calorific value, refer to Table 8. Carbon, hydrogen, and oxygen content of the fuels are very important since they constitute the main fuel fraction of the waste. The highest calorific value of the MSW component is 42.96 MJ/kg being to plastics, as shown in Table 8. A similar finding was reported by [4, 10].

Table 8: Ultimate analysis of Plastics

Name	Mass	C (wt.%)	H (wt.%)	N (wt.%)	S (wt.%)	O (wt.%)	Cl (wt.%)	HHV (MJ/kg)
Plastics	0.102	73.00	9.45	0.52	0.0075	17.22	0.166	42.96
Std. deviation	0.003	0.227	0.0686	0.43355	0.00048		0.001	
RSD	2.564	0.310	0.725	81.89	6.476			
Count	2	2	2	2	2			

Table 9: Ultimate analysis of Cardboard

Name	Mass	C (wt.%)	H (wt.%)	N (wt.%)	S (wt.%)	O (wt.%)	Cl (wt.%)	HHV (MJ/kg)
Card-board	0.103	37.17	5.60	0.04	0.08	56.03	0.154	16.05
Std. deviation	0.005	0.096	0.0753	0.02328	0.001		0.002	
RSD	4.513	0.258	1.344	47.02	1.294			
Count	2	2	2	2	2		2	

Table 10: Ultimate analysis of Textile/foam

Name	Mass	C (wt.%)	H (wt.%)	N (wt.%)	S (w.t%)	O (wt.%)	Cl (wt.%)	HHV (MJ/kg)
Textile+ Foam	0.107	53.38	5.63	0.66	0.059	39.16	0.53	22.63
Std. deviation	0.001	0.340	0.1185	0.00975	0.018		0.001	
RSD	0.984	0.638	2.103	1.469	31.01			
Count	2	2	2	2	2	2	2	

Table 11: Ultimate analysis of MSW and PKS mixture

Mixed elements (wt.%)		C (wt.%)	H (wt.%)	N (wt.%)	S (wt.%)	O (wt.%)	Cl (wt.%)	HHV (MJ/kg)
MSW	**PKS**							
20	**80**	44.303	6.553	2.186	0.171	43.037	0.512	21.13
30	**70**	45.386	6.557	1.994	0.152	42.256	0.457	22.41
40	**60**	46.468	6.561	1.802	0.134	41.475	0.432	23.69
50	**50**	44.921	6.651	1.136	0.139	44.814	0.389	23.58
60	**40**	50.796	6.573	1.036	0.064	38.351	0.321	28.82

Table 11 shows the influence of the elemental composition of the different waste fractions on HHV experimental data. The increase in calorific value is proportional with the added amount of carbon, hydrogen and MSW. In contrast, a small amount of nitrogen promotes the quality of the fuel, because it (nitrogen) has no calorific value and Nitrogen content is significant because it determines the amount of NOx formation.

The highest value of sulfur is found in PKS fraction (0.205wt.%), followed by cardboard (0.0886 wt.%) and textile/foam (0.0594wt.%), as shown in Tables (6, 9 and 10 respectively). We find the lowest Sulfur in plastics waste (0.00751 wt.%), refer to Table 8. Sulfur is another important element, it increases the value of fuel, but an extensive amount of sulfur leads to smoky flame (generation of acid gases SO_2 and SO_3), which contribute to air pollution and corrosion. From these tables, we can deduce it that the HHV is a function of the amount of carbon and hydrogen in the raw material.

The chlorine content in these samples varies from (0.154wt.% (cardboard) to 0.531 wt.% (textile and foam). This is the average concentration of each component: cardboard (0.154wt.%), plastics (0.166 wt.%), textile and foam (0.531 wt.%), municipal solid waste (0.249 wt.%) and palm kernel shell (0.528wt.%. To summarize, in terms of comparison, PKS and textile + foam has almost the same chlorine values, as shown in tables 6 and 10. The same chlorine values for plastics and cardboards, as shown in Tables 8 and 9, respectively. According to these results, they can use the mixture of PKS and MSW for produce RDF or SRF fuel. Hamzah et al. [1] reported a similar finding.

We can classify the elements found in this study in class 1, 2 and 3 according to the standards of the European Union EN 15359 as the following (0.249 wt.%) of Cl is class 1, textiles (0.531 wt.% Cl) class 2, PKS (0.528 wt.% Cl) class 2, therefore the mixture of PKS and MSW (0.777 wt.% Cl) class 3, refer to Table 12.

Table 12: Waste classification criteria as SRF, according to EN 15359, [10]

Parameter	Statistical measure	Unit	Classes				
			1	2	3	4	5
Lower heating value	**Mean value**	MJ kg^{-1}	≥25	≥ 20	≥ 15	≥ 10	≥ 3
Chlorine content	**Mean value**	% (w/w)	≤0.2	≤ 0.6	≤ 1.0	≤ 1.5	≤ 3
Mercury content	**Mean value**	Mg MJ^{-1}	≤0.02	≤ 0.03	≤ 0.08	≤ 0.15	≤ 0.50

4. CONCLUSION

In this investigation, the goal was to assess the efficacy of mixing Palm kernel shell and municipal solid waste as feedstock on the gasification process. The proximate, ultimate analysis and calorific value carried out to characterize the different fuel. From the results, it can conclude that the moisture content, volatile matter, and ash, have moderate concentrations that do not influence the gasification process. Likewise, the calorific value of the mixture increases, with that the added amount of MSW from 21.13 MJ / kg to 28.82 MJ / kg. Environmental factors sulfur (0.064 to 0.171) wt.% and chlorine (0.321 to 0.512 wt.%) are also, agree with the European standard. Therefore, this mixture can use as raw material for the gasification process.

REFERENCES

[1] Hamzah, N., Tokimatsu, K., & Yoshikawa, K. (2019). Solid fuel from oil palm biomass residues and municipal solid waste by hydrothermal treatment for electrical power generation in Malaysia: A review. Sustainability (Switzerland), 11(4), 1–23. https://doi.org/10.3390/su11041060

[2] Kumar, A., & Samadder, S. R. (2017). A review on technological options of waste to energy for effective management of municipal solid waste. Waste Management, 69, 407–422. https://doi.org/10.1016/j.wasman.2017.08.046

[3] He, P., Chen, L., Shao, L., Zhang, H., & Lü, F. (2019). Municipal solid waste (MSW) landfill: A source of microplastics? -Evidence of microplastics in landfill leachate. Water Research, 159, 38–45. https://doi.org/10.1016/j.watres.2019.04.060

[4] Sikarwar, V. S., Zhao, M., Clough, P., Yao, J., Zhong, X., Memon, M. Z., Shah, N., Anthony, E. J., & Fennell, P. S. (2016). An overview of advances in biomass gasification. Energy and Environmental Science, 9(10), 2939–2977. https://doi.org/10.1039/c6ee00935b

[5] Beyene, H. D., Werkneh, A. A., & Ambaye, T. G. (2018). Current updates on waste to energy (WtE) technologies: a review. Renewable Energy Focus, 24(00), 1–11. https://doi.org/10.1016/j.ref.2017.11.001

[6] Nobre, C., Gonçalves, M., & Vilarinho, C. (2019). A brief assessment on the application of torrefaction and carbonization for refuse derived fuel Upgrading. Lecture Notes in Electrical Engineering, 505, 633–640. https://doi.org/10.1007/978-3-319-91334-6_86

[7] Makarichi, L., Jutidamrongphan, W., & Techato, K. (2018). The evolution of waste- to - energy incineration : A review. 91(November 2017), 812–821. https://doi.org/10.1016/j.rser.2018.04.088

[8] Ouda, O. K. M., Raza, S. A., Nizami, A. S., Rehan, M., Al-waked, R., & Korres, N. E. (2016). Waste to energy potential : A case study of Saudi Arabia. Renewable and Sustainable Energy Reviews, 61, 328–340. https://doi.org/10.1016/j.rser.2016.04.005

[9] Brunner, P. H., & Rechberger, H. (2014). Waste to energy – key element for sustainable waste management. Waste Management. https://doi.org/10.1016/j.wasman.2014.02.003

[10] Garcés, D., Díaz, E., Sastre, H., Ordóñez, S., & González-lafuente, J. M. (2015). Evaluation of the potential of different high calorific waste fractions for the preparation of solid recovered fuels. https://doi.org/10.1016/j.wasman.2015.08.029

[11] Elisabete, M., Brás, I., & Silva, M. E. (2017). Refuse Derived Fuel from Municipal Solid Waste rejected fractions- Case Study. Energy Procedia, 120, 349–356. https://doi.org/10.1016/j.egypro.2017.07.227

[12] De Gisi, S., Chiarelli, A., Tagliente, L., & Notarnicola, M. (2018). Energy, environmental and operation aspects of a SRF-fired fluidized bed waste-to-energy plant. Waste Management. https://doi.org/10.1016/j.wasman.2017.04.044

[13] Nizami, A. S., Shahzad, K., Rehan, M., Ouda, O. K. M., Khan, M. Z., Ismail, I. M. I., Almeelbi, T., Basahi, J. M., & Demirbas, A. (2017). Developing waste biorefinery in Makkah: A way forward to convert urban waste into renewable energy. Applied Energy, 186, 189–196. https://doi.org/10.1016/j.apenergy.2016.04.116

[14] Chala, G. T., Guangul, F. M., & Sharma, R. (2019). Biomass Energy in Malaysia-A SWOT Analysis. 2019 IEEE Jordan International Joint Conference on Electrical Engineering and Information Technology, JEEIT 2019 - Proceedings, 401–406. https://doi.org/10.1109/JEEIT.2019.8717475

[15] Vaish, B., Sharma, B., Srivastava, V., Singh, P., Ibrahim, M. H., & Singh, R. P. (2019). Energy recovery potential and environmental impact of gasification for municipal solid waste. Biofuels, 10(1), 87–100. https://doi.org/10.1080/17597269.2017.1368061

[16] Khuriati, A., Purwanto, P., Huboyo, H. S., Suryono, S., Putro, A. B. (2018). Application of aspen plus for municipal solid waste plasma gasification simulation : case study of Jatibarang Landfill in Semarang Indonesia. Journal of Physics: Conference series, 1025.

[17] Liu, Z. (2019). Gasification of municipal solid wastes: a review on the tar yields. Energy Sources, Part A: Recovery, Utilization and Environmental Effects, 41 (11), 1296–1304. https://doi.org/10.1080/15567036.2018.1548508

[18] Farzad, S., Mandegari, M. A., & Görgens, J. F. (2016). A critical review on biomass gasification, co-gasification, and their environmental assessments. Biofuel Research Journal, 3(4), 483–495. https://doi.org/10.18331/BRJ2016.3.4.3

[19] Molino, A., Chianese, S., & Musmarra, D. (2016). Biomass gasification technology: The state of the art overview. Journal of Energy Chemistry, 25(1), 10–25. https://doi.org/10.1016/j.jechem.2015.11.005

[20] Pala, L. P. R., Wang, Q., Kolb, G., & Hessel, V. (2017). Steam gasification of biomass with subsequent syngas adjustment using shift reaction for syngas production: An Aspen Plus model. Renewable Energy, 101, 484–492. https://doi.org/10.1016/j.renene.2016.08.069

[21] Gu, H., Tang, Y., Yao, J., & Chen, F. (2019). Study on biomass gasification under various operating conditions. Journal of the Energy Institute, 92(5), 1329–1336. https://doi.org/10.1016/j.joei.2018.10.002

[22] Acharya, B. (2018). Cleaning of Product Gas of Gasification. In Biomass Gasification, Pyrolysis and Torrefaction (Third Edit). Elsevier Inc. https://doi.org/10.1016/b978-0-12-812992-0.00010-8

[23] Sansaniwal, S. K., Pal, K., Rosen, M. A., & Tyagi, S. K. (2017). Recent advances in the development of biomass gasi fi cation technology : A comprehensive review. 72, 363–384. https://doi.org/10.1016/j.rser.2017.01.038

[24] Freiberg, A., Scharfe, J., Murta, V. C., & Seidler, A. (2018). The use of biomass for electricity generation: A scoping review of health effects on humans in residential and occupational settings. International Journal of Environmental Research and Public Health, 15(2). https://doi.org/10.3390/ijerph15020354

[25] Al-Hamamre, Z., Saidan, M., Hararah, M., Rawajfeh, K., Alkhasawneh, H. E., Al-Shannag, M. (2017). Wastes and biomass materials as sustainable-renewable energy resources for Jordan. Renewable and Sustainable Energy Reviews, 67, 295–314. https://doi.org/10.1016/j.rser.2016.09.035

[26] Zhang, J., & Zhang, X. (2019). The thermochemical conversion of biomass into biofuels. Biomass, Biopolymer-Based Materials, and Bioenergy. Elsevier Ltd. https://doi.org/10.1016/b978-0-08-102426-3.00015-1

[27] Afzanizam, N., Nazri, M., Jaafar, M., Tung, C., Jo-han, N., (2015). A Review of Palm Oil Biomass as a Feedstock for Syngas Fuel Technology. Jurnal Teknologi 72(5), 13–18.