Mass Yield Improvement of Liquid Fuel from RMSW Using Long Catalyser Downstream in Stage Pyrolysis

I M Gandidi[1] A Wiyono[1] Purnawan[1] Amrul[2]

[1] Department of Mechanical Engineering Education, Faculty of Technology and Vocational Education, Universitas Pendidikan Indonesia. Jl. Dr. Setia Budi 299, Sukasari, Bandung, Indonesia
[2]Department of Mechanical Engineering, Faculty of Engineering, Universitas Lampung. Jl. S. Brojonegoro No. 1, Bandar Lampung, Indonesia
[*]Corresponding author. Email: indra.gandidi@upi.edu

ABSTRACT
Thermal degradation at 500 ºC to a Real Municipal Solid Waste (RMSW) has leave a footprint of problem with very low mass yields of liquid fuel. Therefore, in the presence research, it has been attempted to increase the mass yield of liquid fuel by using Long Catalyzer Downstream (LCD) equipped with top and bottom outlet in stage pyrolysis. Two types of natural catalysts (zeolite and kaolin) that have been activated at 500 ºC for 2 hours were used in this experiment. Also, LCD temperatures were varied from 200-300 ºC with pyrolizer temperature were hold at 500 ºC. The experimental results revealed that there was a significant increase in the mass yield of liquid fuels compared to pyrolysis without catalysts and direct catalyst of pyrolysis. The presence of LCD was making a major contribution to generate secondary cracking and producing more products of short hydrocarbon ranges from MSW feedstock. Among natural zeolite and kaolin catalysts, natural zeolite catalysts have productivity behavior better than natural kaolin. The higher mass yields in liquid fuels have been demonstrated by natural zeolite catalysts.

Keywords: *Thermal Degradation, Real Municipal Solid Waste, Liquid Fuel, Long Catalyser Downstream*

1. INTRODUCTION

Considering the worries of the future energy crisis and the significant increase in the growth of municipal solid waste, converting RMSW into liquid fuel is a best solution that should be considered to solve both of problems simultaneously. Pyrolysis is a well-established method of thermal degradation that can convert waste into energy. This method is considered as a flexible method because it is very simple and produces three types of energy products simultaneously namely liquid fuel, solid fuel and gas fuel [1]. Syngas is a permanent gas such as methane and hydrogen and liquid fuel is a product obtained from the condensation of volatile products [2]. Syngas and liquid fuel can be used as electrical gas engine fuels, integrated with a turbine cycle that convert the fuel energy into electricity [3] on which it has better combustion efficiency compared to direct burning process [4] and very low environmental impact [5,6]. The percentage of the results of pyrolysis between solid, liquid and gaseous products is very dependent on the type of pyrolysis process namely slow pyrolysis, fast pyrolysis and flash pyrolysis [7,8]. Slow pyrolysis will result in the same amount of gas and liquid, liquid fuel is a bigger part of product of fast pyrolysis and flash pyrolysis will produce most of the liquid fuel [9,10].

Therefore, the various groups have conducted experiments using mixed MSW as a resource of raw materials for liquid fuels production. Some researchers have performed experiments to convert MPW into liquid fuel[11,12,13,14,15] and some others have taken place to focused on the use of biomass waste as resource of raw materials for bio oil [16,17,18,19,20].However, the RMSW material have a lot of variety of feedstock composition including biomass waste, many kind of paper waste, mixed plastics waste, rubber waste, textile waste, inorganic waste and it is not easy to separate because it available in abundant and dirty condition.

Hence, the research of pyrolysis with RMSW as a feedstock was indispensable. Auxilio. RA et al (2017) have conducted some experiments by using single plastic waste and mixed plastic waste. Their results show that HDPE raw material produces more gasoline fractions and the others kind of plastic tend to be a diesel fraction [21]. A. López et al (2011) and Kyaw. KT et al (2015) have investigated the effects of various types of catalysts on the pyrolysis results of plastic waste mixtures which show that the use of suitable catalysts will result in increased of liquid fuel mass yield [22,23]. In the catalysed pyrolysis process, the presence of biomass in mixed plastic and biomass feedstock can inhibit the influence of catalysts in the degradation process. Reduction of this inhibitory effect can be done by using the higher of catalyst ratio [24].Further, the addition of catalyst in mixed plastics sample will reduce the amount of liquid fuel but liquid fuel product significantly in the range of light molecular weight or gasoline fraction [25] and among of direct and separated (two stages) catalyst cracking process by use mixed plastics sample, higher gas yields are obtained using a two stage process [26].Nevertheless, the investigations to increasing the mass yield of liquid fuels on municipal solid waste with completed mixtures of RMSW such as mixtures in biomass waste, various plastics, textiles, various paper and rubber waste are reported very rarely. In addition on the previous research, pyrolysis of RMSW with and without and direct catalytic were reported. The High yields on the solid residues and low yield products on the pyrolytic oil have been obtained [27,28].Thus, this study has been carried out to continue from the previous one in which to increase the mass yield of liquid fuel products using LCD in stage pyrolysis in which involves two types of natural catalysts, i.e. natural zeolite and kaolin catalysts with the bed temperature was varied between 200-300^{o}C.

2. MATERIAL AND METHODS

2.1. Materials

Six types of waste material in municipal solid waste (biomass, HDPE, LDPE, rubber, paper and textile) were used in this study. This garbage is taken directly from the final disposal garbage in Bandung City. Then, the RMSW sample was dried by solar drying for 3-5 days before being chopped into small pieces between 5–10 cm, the appropriate size for the reactor capacity. The composition of mixed waste refer to waste from disposal based air dried including biomass 34%, mixed plastics 52%, paper 9%, rubber 3% and textile 2%. Further, natural zeolite and kaolin were obtained from local source in Lampung Province. Then zeolite and kaolin were activated thermally at 500 °C for 2 hours to improve the active site and crystallinity. The characteristics of both natural catalyst have refer to [29].

Figure 1 The RMSW sample composition in pyrolysis experimental

2.2. Methods

In consecutive of thermal and catalytic cracking were used in this study to investigate the effect of bed temperature and catalyst in the long catalyzer. Pyrolizer for thermal cracking was performed by using bench scale reactor that be made from stainless steel cylinder, 310 mm in height and 160 mm in width by an electrical heating jacket around the cylinder. The pyrolizer was set vertically and nitrogen gas was introduced for 3 min from the top. This flow of nitrogen was to replace the air inside, creating the necessary vacuum conditions for a pyrolysis reaction and afterward, the nitrogen flowed out through the top of the reactor again. Meanwhile, catalyzer for upgrading of gaseous from the pyrolizer was performed in the long catalyzer downstream that placed prior to condenser (Figure 2). The long catalyzer has length 100 cm and 10 cm in diameter and this catalyzer equipped by top and bottom outlet. Among of pyrolizer and LCD, it has been installed a valve to control the reaction time.

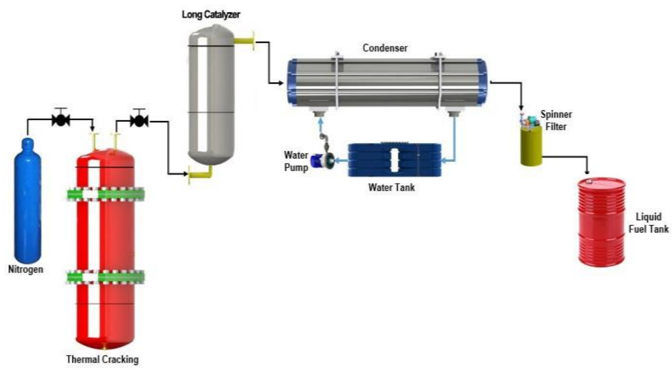


Figure 2 Experimental Setup

In the pyrolysis experimental, 500 gram of RMSW sample (unwashed) was loaded into pyrolizer from the top and then the pyrolizer was heated by electrical heater jacket until the pyrolizer's temperature was achieved 500 ^{o}C by thermo controller and held for 60 minutes. Afterward, the temperature of LCD was set varies from the 200-300 ^{o}C. When the reaction time was held for one experimental, the valve control was opened to discharge the gaseous phase from the pyrolizer to LCD and then condenser. Liquid fuel fraction from condenser was flow to spinner filter and liquid tank. The permanent gaseous fraction from condenser was burned to avoid environmental pollution. Finally, the mass yield of liquid fuel pyrolytic and solid residue were counted by Tora TR-DS11030 of electronic digital scales and then tabulated.

3. RESULTS AND DISCUSSIONS

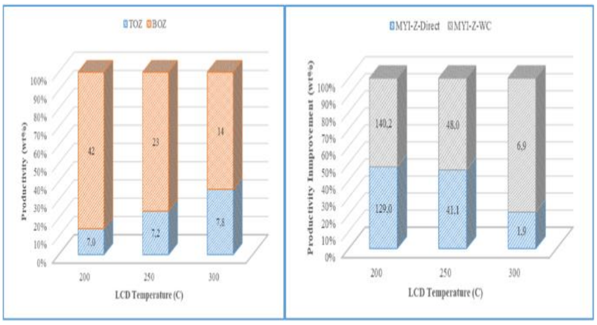
The liquid fuel, gas and solid mass yields (wt%), obtained with the two mentioned pyrolysis methods and two the conventional one step thermal with (direct) and without catalyst are presented in Table 1. From the Table 1, it seen that the catalytic process will increased the gaseous and liquid yield compared with non-catalytic pyrolysis. It was indicate the catalyst has an important role in the pyrolysis process to increase the productivity of product. However, the direct catalyzed pyrolysis has a problems with the presence of catalyst particles carried in the gas pyrolysis. If direct catalytic cracking and stage pyrolysis with LCD equipment are compared, it can be explained that the LCD presence has given a higher yield on liquid fuels. Secondary cracking along the LCD results in an increase on the number of short hydrocarbon chains and it was converted into liquid fuel and gaseous fraction. While the amount of solid residue is significantly reduced.

Table 1. Mass yield pyrolysis

Methods	LCD Temp (ºC)	Mass Yield (%)			
		Solid Residue	Fuel on Top	Fuel on Bottom	Gaseous
Without Catalyst	-	32	20.4	-	39.6
Direct Catalytic-Zeolite	-	30	21.4	-	51
Direct Catalyst-Kaoline	-	28.4	23.6	-	49.2
Stage Pyrolysis-Zeolite	200	38,4	7,0	42	12,6
	250	38	7,2	23	31,8
	300	26,6	7,8	14	51,6
Stage Pyrolysis-Kaoline	200	36,8	5,6	21,8	35,8
	250	28,8	6,8	20,4	44
	300	22,6	4,8	24	48,8

But on that, if temperature on the LCD was increased, the liquid fuel yield will be decreased and gaseous fraction will be increased significantly. Further, the solid residue was still high and it can be related to short reaction time and presence the biomass feedstock and impurity in the MSW sample.

Figure 3 illustrates the effect of natural catalyst and bed temperature of LCD to the mass yield and improvement result were achieved after pyrolysis process by using LCD device.



(a) (b)

Figure 3 a) Productivy of product, b) Improvement result by catalyst

Both of the graph, pyrolytic liquid fuel was higher flow out on the bottom (BO) compared flow out on the top (TO) and it was reveal that pyrolytic liquid fuel by use natural zeolites catalyst has always higher yields than using kaolin catalyst for all reaction condition. It was indicate that zeolite catalyst has productivity behaviour better than the kaolin catalyst. For zeolite, the maximal yield around 42wt% was obtained at 200ºC and 24 wt% at 300ºC for kaolin. Anyhow, at 200ºC of the LCD bed temperature, pyrolytic liquid fuel by zeolite that flow out at bottom (BOZ) and top (TOZ) section (Fig. 3a) has sticky behaviour physically that usually was called wax product [30,31]. It was described that TOZ and BOZ can be classified as a long chain hydrocarbon compound and re-cracking was necessary. Whereas, pyrolytic liquid fuel by kaolin on the top and bottom (TOK and BOK) were seen more aqueous and classified as short chain hydrocarbon compound. The optimum yield of pyrolytic liquid fuel for zeolite can be obtained at 250ºC and it was it has been the best result for all experiments on both of catalysts.

Furthermore, if the mass yield of liquid fuel from stage pyrolysis, direct catalytic and pyrolysis without catalyst were compared, the pyrolytic liquid fuel was increased significantly for both natural catalyst (Fig. 3b). It can be related to the use of LCD and catalyst that allow secondary cracking repeatedly in the LCD and it will increase the short chain hydrocarbon compound in the gaseous fraction. And among of reaction bed temperature varies on LCD, 250oC bed temperature was suitable reaction condition for pyrolysis of RMSW. However, the GCMS analysis was desired to assess the quality of the pyrolytic liquid fuel obtained.

4. CONCLUSION

The presence a LCD equipment that equiped by natural zeolite or kaoline on the stage pyrolysis will increase the pyrolysis performance. Natural zeolite catalyst have good performance compared with natural kaoline catalyst that operating on low reaction bed temperature.

ACKNOWLEDGMENTS

This work was funded by grant research from Universitas Pendidikan Indonesia. Supported by team of Refrigeration and Air Conditioning Laboratory and Universitas Pendidikan Indonesia, Bandung and we would not forget to thank them. I respect and thank to Mr. Dr.DediSuryadi, M.Pa, Mr. Dr. Bambang Darmawan, M.M and Mr. Dr.DediRohendi, M.Pd as head of department for giving us an opportunity to do this work and providing us all support and guidance in which make us complete this work successfully.

ABBREVIATION

MSW	Municipal Solid Waste
LCD	Long Catalyzer Downstream
HDPE	High Density Polyethylene
LDPE	Low Density Polyethylene
BOZ	Bottom Outlet with Zeolite catalyzed on LCD [%]
TOZ	Top Outlet with Zeolite catalyzed on LCD [%]
BOK	Bottom Outlet with Kaolin catalyzed on LCD [%]
TOK	Top Outlet with Kaolin catalyzed on LCD [%]
MYI-Z-Direct	Mass Yield Improvement by stage pyrolysis compared with Direct catalytic - zeolite catalyzed [%]
MYI-Z-WC	Mass Yield Improvement by stage pyrolysis with zeolite catalyzed compared with Without Catalysts [%]
MYI-K-Direct	Mass Yield Improvement by stage pyrolysis compared with Direct catalytic - kaolin catalyzed [%]
MYI-K-WC	Mass Yield Improvement by stage pyrolysis with kaolin catalyzed compared with Without Catalysts [%]
GCMS	Gas Chromatography Mass Spectrometry

REFERENCES

[1] KumarAjay,Jones D. David, Hanna A. Milford, 2009, Thermochemical biomass gasification: a review of the current status of the technology, *J. of Energies*, V**.** **2**, P. 556-581

[2] Neves Daniel, Thunman Henrik, Matos Arlindo, Tarelho Luis, Barea G. Alberto, 2011, Characterization and prediction of biomass pyrolysis products, Progress in *Energy Comb Sci*, V**. 37**, P. 611-630

[3] HaqZia, 2002, Biomass for electricity generation, *Energy Infor. Adm.Annual Energy Outlook*, Washington, DC, P. 1-18

[4] Klein Alexander, 2002, Gasification: an alternative process for energy recovery and disposal of municipal solid wastes,*Thesis, Dept. of Earth and Environt. Eng*, Fu Foundation School of Engineering and Applied Science, Columbia University

[5] Pambudi A. Nugroho, Torii Shuichi, Syamsiro M, Saptoadi Harwin, Gandidi I. M, 2012, Emission factor of single pellet cake seed jatropha curcas in a fix bed reactor,*J. of the Braz. Soc. of Mech. Sci. & Eng*, V. **XXXIV**, No. 2, P. 179-183

[6] Dion L. Martin, Lefsrud Mark, Orsat Valérie, Cimon Caroline, 2013, Biomass gasification and syngas combustion for greenhouse co_2 enrichment, *BioResources*, V. **8,** No. 2, P. 1520-1538

[7] MeierDietrich, De Beld V. Bert, Bridgwater V. Anthony, Elliott C. Douglas, Oasmaa Anja, Preto Fernando, 2013, State-of-the-art of fast pyrolysis in IEA bioenergy member countries, *Renew. and Sust. En. Rev*., V. **20**, P. 619–641

[8] Ronsse F,Dickinson D, Nachenius R, Prins W, 2013, Biomass pyrolysis and biochar characterization, 1st Forebiom Workshop, Department Of Biosystems Engineering, Faculty of Bioscience Engineering, Ghent University, Belgium

[9] Demirbas A, 2009, Pyrolysis Mechanisms of Biomass Materials, *Energy Sources*, Part A, V. **31**, P, 1186–119

[10] Basu Prabir, 2010, Biomass Gasification and Pyrolysis: Practical Design and Theory, *Academic Press*, Elsevier

[11] Elizabeth A. Williams, Paul T. Williams, 1997, The Pyrolysis of Individual Plastics and a Plastic Mixture in a Fixed Bed Reactor, *J. Chem. Tech. and Biotech*., V. **70**, P. 9-20

[12] Lopez A, De Marco I, Caballero B.M, Laresgoiti M.F, Adrados A, Torres A, 2011, Pyrolysis of municipal plastic wastes II: Influence of raw material composition under catalytic conditions, *Waste Manag*. V. **31**, P. 1973–1983

[13] Adrados A, De Marco I, Caballero B.M, Lopez A, Laresgoiti M.F, Torres A, 2012, Pyrolysis of plastic packaging waste: A comparison of plastic residuals from material recovery facilities with simulated plastic waste, Waste Manag., V. **32**, P. 826–832

[14] Surahmanto Fredy, Saptoadi Harwin, Sulistyo Hary, Rohmat T. Agung, 2017, Effect of heating rate on the slow pyrolysis behaviour and its kinetic parameters of oil-palm shell, *Int. J.of Renew. Energy Res*., V.**7**, No.3

[15] Muhammad Chika, Onwudili A. Jude, Williams T. Paul, 2015,Thermal degradation of real-world waste plastics and simulated mixed plastics in a two-stage pyrolysis–catalysis reactor for fuel production, *Energy Fuels*, V. **29**, P. 2601-2609

[16] Jahirul I.Mohammad, Rasul G. Mohammad, Chowdhury A. Ashfaque, Ashwath Nanjappa, 2012, Biofuels production through biomass pyrolysis - a technological review, *Energies*, V. **5**, P. 4952-5001

[17] Yan Qiangu, Toghiani Hossein, Yu Fei, Cai Zhiyong, Zhang Jilei, 2011, Effects of pyrolysis conditions on yield of bio-chars from pine chips, J. of Forest Products, V. **61**, No. 5, P. 367-371

[18] DemirbasAyhan, 2004, Effects of temperature and particle size on bio-char yield from pyrolysis of agricultural residues", *J. Anal. Appl. Pyrolysis*, V. **72**, P. 243–248

[19] Demiral İlknur, Eryazıci Alper, Şensöz Sevgi, 2012, Bio-oil production from pyrolysis of corncob (Zea mays L.), *Bio. and Bioenergy*, V. **36**, P. 43-49

[20] Jourabchi A. Seyed, Gan Suyin, Ng Kiat Hoon, 2016, Comparison of conventional and fast pyrolysis for the production of Jatropha curcas bio-oil, *App. Thermal Eng*., V. **99**, P. 160–168

[21] Auxilio R.Anthony, Choo Wei-Lit, Kohli Isha, Srivatsa C. Srikanth, Bhattacharya Sankar, 2017, An experimental study on thermo-catalytic pyrolysis of plastic waste using a continuous pyrolyser, *Waste Manag*., V. **67**, P. 143-154

[22] Lopez A, De arco I, Caballero B. M, Laresgoiti M. F, Adrados A, Aranzabal A, 2011, Catalytic pyrolysis of plastic wastes with two different types of catalysts: ZSM-5 zeolite and Red Mud, *App. Catalysis B: Env*., V. **104**, P. 211–219

[23] KyawT. Khaing,HmweS. Chaw, 2015, Effect of various catalysts on fuel oil pyrolysis process of mixed plastic wastes, *Int. J. of Adv. in Eng.& Tech*., Vol. **8**, Issue **5**, P. 794-802

[24] Sebestyén Z, Rajnai Barta E, Bozi J, Blazsó M, Jakab E, Miskolczi N, Czégény Zs, 2017, Catalytic Pyrolysis of Biomass and Plastic Mixtures using HZSM-5 Zeolite, *Ener. Proc*., V.**105**,P. 718 – 723

[25] Onwudili A. Jude, Muhammad Chika, Williams T. Paul, 2018, Influence of catalyst bed temperature and properties of zeolite catalysts on pyrolysis-catalysis of a simulated mixed plastics sample for the production of upgraded fuels and chemicals, *J. of the Energy Ins*., V. **92**, P. 1337-1347.

[26] SójaJános,MiskolcziNorbert, 2017, Recycling of ELV waste plastics by one-stage and a two-stage thermo-catalytic pyrolysis, Chem. Eng. Trans., V. **61**, P. 1909-1914.

[27] Gandidi M. Indra, Susila M. Dian, Pambudi A. Nugroho, 2017, Co-cracking of real MSW into bio-oil over natural kaolin, J.of Physics: Conf. Series, V. **60**, P. 1-8

[28] Gandidi M. Indra, Susila . Dian, Pambudi A. Nugroho, 2017, Production of valuable pyrolytic oils from mixed Municipal Solid Waste (MSW) in Indonesia using non-isothermal and isothermal experimental, *J. of CSiTE*, V.**10**, P. 357–361

[29] Gandidi M. Indra, Susila . Dian, Rustamaji Heri, 2018, Effect of natural zeolite and kaolin as a catalyst in the isothermal-catalytic cracking of real municipal solid waste (MSW) for bio-oil production, IOP Conf. Series: Earth and Environmental Sci.., V. **160**, P. 1-9

[30] Umaru I. Halima, Yakubu K. Mohammed, Kolawole G. Emmanuel, Baba A. Mohammed, 2014, Effect of pyrolysis temperature and time on wax production from waste polyethene, *Asian J. of App. Sci*., V. **2**, P. 644-649

[31] Aguado Roberto, Olazar Martín, San José J. María, Gaisán Beatriz, Bilbao Javier, 2002, Wax formation in the pyrolysis of polyolefins in a conical spouted bed reactor, *Energy & Fuels*, V.**16**, P. 1429-1437