



CHARACTERISTICS OF LIQUID FUEL PRODUCED FROM CATALYTIC PYROLYSIS OF PLASTIC MIXTURE RESIN: NICKEL SUPPORTED WITH EITHER ALUMINA OR OIL PALM BIOMASS ASH CATALYST

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ABSTRACT

Million tons of plastics wastes are discarded into landfill each year and may remain in there up to 1,000 years before being decompose. With this, it is potential pollutant in the soil and water. Relatively small amount of plastics are recycled due their different chemical compositions and with the presence of other materials such as ink, paper and non-plastics. To separate and sort the plastics from non-plastic material is difficult and laborious. Catalytic pyrolysis of plastics waste is one of the processes to overcome this problem and able to generate alternative energy. This technology can reduce global warning and assist waste decomposition. The thermal and catalytic pyrolysis reaction of plastic resulted in producing fuel gas and liquid fuel. The objective of this work is to study the effect of nickel catalyst support either with alumina or oil palm biomass ash for liquid fuel production. Base on the Malaysian municipal industrial waste, a synthetic plastic mixture was used as a feed source for the catalytic pyrolysis. The composition of synthetic plastic mixture consists of (in weight percentage basis) 35% high density polyethylene (HDPE), 35% low density polyethylene (LDPE), 19% polypropylene (PP) and 11% polystyrene (PS). Nickel with 20% (wt) and consists of cerium with 10% (wt) supported either by alumina or palm oil biomass ash was used as a catalyst with 1:3 (catalyst to plastic weight ratio). The conditions used to pyrolyze the raw materials were with 25 ml/min nitrogen stream at 500 °C for 60 minutes. The products produced i.e. liquid oil, uncondensed gas, and spent catalyst were analyzed and characterized via BET, TGA, SEM, GC-MS, GC-TCD, and FTIR. The hydrocarbon fractions obtained from the catalytic pyrolysis using alumina and oil palm biomass ash as supported catalyst did not have much difference, where they gave the same area percentage of light (petrol), middle (petrol), and heavy (diesel). The FTIR spectra also showed the same profile for diesel and liquid fuel produced from both supported catalytic pyrolysis. Oxide compound were presence in both of nickel alumina and oil palm biomass ash, promoted cracking and aromatization reaction. However, nickel oil palm biomass ash which is filamentos carbon was a better catalyst than nickel alumina due to resistance coking affect that lead to higher catalytic activity and produces higher plastic conversion into valuable energy resource.

Keywords: plastic pyrolysis, catalytic cracking, nickel catalyst.

INTRODUCTION

It was reported that about 2 million tons of plastic resins were produced locally in Malaysia each year (JPSPN,2011). However, the information regarding plastic waste and plastic recycling activities are very limited where most of the solid waste studies are focusing on Municipal Solid Waste (MSW). Plastic waste constitute as the third largest waste after organic waste and paper (JPSPN,2011). It may take more than thousand years to decompose and cause pollutions to the environment. The cleaning and sorting process of plastic wastes are costly and time consuming. It would be less hassle to recycle plastic waste if our community start to separate the waste from their house and companies. The demand of recycled plastic is low because the cost of recycling plastic waste is very higher than producing a new plastic. The rapid development and growth population in Malaysia increased the amount of plastic waste generation in household and industries sectors. A total of 31.5 tonnes of solid waste generated per day by 2020, (The National Strategic Master Plan, 2005). The current solution of plastic waste were landfilling and incineration. However, landfill and incineration of plastic waste has potential problems because of land resource

limitation and incomplete incineration may generate poisonous substances. Poor plastic waste management leads to negative effect to health and environment.

The demand of energy is increasing but fossil energy and fuels sources are depleting. Plastic waste can be a potential resources for fuel production as it contains of high combustion heat capacity and able to reduce the emission of Green House Gases (GHG). Unlike organic waste such as food waste and wood, plastics do not absorb moisture. The conversion of plastic waste into fuel can be an alternative process to produce energy source for developing countries like Malaysia which mainly depends on natural resources. Pyrolysis is a technique that capable of turning plastic waste into high quality fuel-like hydrocarbon and chemicals.

Plastic pyrolysis requires high. Therefore, the application of catalyst reduces the reaction temperature and increases the decomposition rate. Nickel catalysts have been widely used in cracking process, due to their low cost and high activity for C-C bond rupture. Nickel catalyst usually are deactivated due to carbon deposition on active site of catalyst and resulting in decreased activity. Alumina element (Al_2O_3), is commonly used as a support due to its chemical and physical stability. A wide



varieties of other catalysts has been tested such as zeolite, red mud, silica alumina and FCC catalysts. Each catalyst has different characterization, which affect the fuel products. Reducing the catalyst cost in catalytic plastic pyrolysis is very interesting challenges. Thus, the oil palm biomass ash as nickel catalyst support was studied. Oil palm biomass ash is a waste generated from oil palm mill. The oil palm biomass ash is a renewable, and potentially sustainable source. This paper discusses on the liquid fuel production and characterization from nickel catalyst supported by either oil palm biomass ash catalyst or alumina.

EXPERIMENTAL PROCEDURES

Origin of plastics and catalyst

The virgin plastics used in this research are high density polyethylene (HDPE), low density polyethylene (LDPE), polypropylene (PP), and polystyrene (PS). The plastic resin acquired from one of the plastic manufacturer in Malaysia, Commercial Plastic Industries (CIP) Sdn Bhd. The composition of synthetic plastics mixture was obtained from data of municipal solid waste from industrial plants in Malaysia (Table-1). Previous investigation by (Miskolczi *et al.*, (2004), Marco *et al.*, (2009), and Lopez *et al.*, (2010)) used simulated virgin plastic based on actual plastic waste composition for better understanding on the thermo chemical activity during the pyrolysis reaction.

Table-1. Composition of municipal solid plastic waste from industrial plants in Malaysia (Miskolczi *et al.*, (2011)).

Type of plastic	Composition (weight %)
HDPE	35
LDPE	35
PP	19
PS	11

Nickel (II) nitrate hexahydrate $[\text{Ni}(\text{NO}_3)_6 \cdot 6\text{H}_2\text{O}]$ with 97.0 % concentration, cerium (III) nitrate hexahydrate $[\text{Ce}(\text{NO}_3)_6 \cdot 6\text{H}_2\text{O}]$ with 99.0 % trace metals basis, aluminum oxide $[\alpha\text{-Al}_2\text{O}_3]$ with 99.0 % concentration and oil palm biomass ash were used to prepare the catalyst. All chemicals were procured from Sigma-Aldrich while palm oil biomass ash was obtained from Felda Lepar Hilir palm oil mill. Nickel catalyst are promoted with cerium and supported by either aluminum oxide or palm oil biomass ash. The catalysts were prepared via wet impregnation method. The impregnated catalyst contained 20 wt% of nickel with fixed 10 % of cerium and balanced by the support contain oil palm biomass ash or alumina. Nickel (II) nitrate hexahydrate, cerium (III) nitrate hexahydrate and either alumina or palm oil biomass ash support was mixed in 80 ml distilled water and stirred at 80 °C for 4 hours. The samples was

then dried overnight in an oven at 105 °C followed by calcinations in a furnace for 4 hours at 750 °C. Finally, the catalyst was crushed and sieved to 125 μm size.

Pyrolysis experiment set up

All the experiments were carried out in 15 mm diameter and 400 mm length tube reactor as illustrated in Figure-1. Ratio one over three was used for catalyst to plastic in which one gram of catalyst over three grams of plastics. In this experiment, the catalyst and plastic resins was placed in between of glass wools (Figure-2). The experiment was carried out in a fixed bed reactor at atmospheric pressure with nitrogen gas at 25 ml/min. The system was heated at a rate of 100 °C/min to 500 °C, and then maintained at 500 °C for 60 minutes.

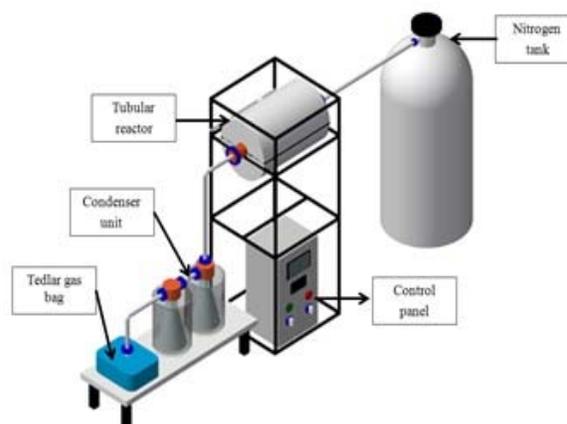


Figure-1. Experimental setup.

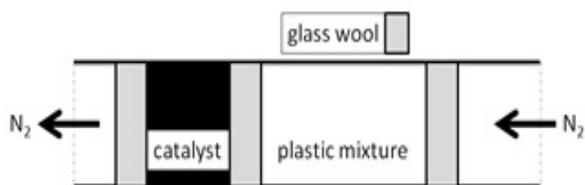


Figure-2. Placement of catalyst and plastic in tube reactor.

The gases produced during the experiment were flowed to a series of condensers. The first condenser was cooled with air and the second one with an ice in order to collect the liquids product. The uncondensed gasses were collected using a 2 L Tedlar gas sample bag. The reactor was weighted to determine the amount of char and catalyst coke. The condenser was weighted to determine the condensed liquid.

Analysis

The liquid fuel was analysed using gas chromatography (GC-MS) and FTIR to identify the hydrocarbon compound.

The collected liquid products were quantified by Gas Chromatography (GC) instrument from Perkin Elmer with Mass Spectrometry (MS) and equipped with DB-1



column with 60.0 m in length and 0.25 mm inner diameter. Samples were diluted with dichloromethane (DCM). The column oven temperatures was set at 50 °C. Helium was used as a gas carrier. The MS detector temperature was set at 200 °C.

Gases collected in the sample gas bag were analysed by gas chromatography (GC-TCD). The gas product was analyzed by GC instrument from Agilent 6890 Series with Thermal Conductivity Detector (TCD) and equipped with Hayasep DB packed column. The column oven temperatures was set at 135 °C. The detector was set at 200 °C. Helium gas was used as a carrier.

Each plastic resins were characterized with Thermogravimetric analysis (model TGA Q500 V6.7). Each plastics samples were heated from ambient temperature to 800 °C at the rate of 20 °C/min under a nitrogen stream.

Fresh and spent catalyst were analysed with Thermogravimetric analysis (TGA), Brunauer Emmett Teller analysis (BET), and Scanning Electron Microscope analysis (SEM), in order to determine their characteristic. The TGA (model TGA Q500 V6.7) was used. The fresh and used catalysts were heated from ambient temperature to 800 °C at the rate of 15 °C/min in air. To characterize the catalyst surface, the fresh and spent catalysts were degassed at 200 °C in nitrogen for more than 5 hours prior to analysis of Brunauer Emmett Teller (BET). Scanning Electron Microscope (SEM) (CARL-ZEISS) coupled to energy dispersive X-Ray spectrometry (EDXS) system was used to investigate the morphology structure and characterize of the catalyst. The catalyst in the stubs which are made from aluminum (10 mm diameter) and sample was placed in a high resolution coater and coated with Pt/Pd. The accelerating voltage was set up to 7kV with the working distance of 8 to 8.5 mm in a vacuum condition.

RESULTS AND DISCUSSIONS

Product yield

Three type of products were obtained from the plastic catalytic pyrolysis. Table-2 presents the pyrolysis yield from the experiment using nickel alumina catalyst and nickel palm oil biomass ash catalyst. The liquid fuel produced in plastic pyrolysis was solidified after a few hours when no catalyst is used. The results indicate that nickel oil palm biomass ash produced higher liquid fuel (65 %), compared to nickel alumina (60 %). It clearly proves that 5% increment of liquid fuel was obtained when oil palm biomass ash was used as a support in the nickel catalyst.

Table-2. Pyrolysis yields of plastic mixture.

Supported Catalyst	Liquid (wt %)	Gases (wt %)	Solid (wt %)
No Catalyst	46	44	10
NiAl ₂ O ₃	60	16	24
NiAsh	65	5	30

Previous researches, (Adrados *et al.*, 2012; Marco *et al.*, 2009; Laresgoiti *et al.*, 2004) have indicated that 500 °C is the optimum temperature for the treatment of polymeric waste (e.g., rejected polymer, SMC of polyester and fibreglass, used tires, and shredded residue from cars). They concluded that incomplete decomposition of organic material is achieved at lower temperature, while the reaction are tend to produce more gas yield from the expense of the liquid production at higher temperature.

Although many researchers have reported on plastic catalytic pyrolysis, however none of them focused on Municipal Plastic Waste in Malaysian landfill, and the plastic composition from each of the country are different. The liquid fuel product solidified after certain period when catalyst was not used. This indicates that, incomplete cracking occur during the noncatalytic pyrolysis.

Plastic thermal characterization via thermogravimetric analyzer (TGA)

Four types of plastics resins which are HDPE, LDPE, PP and PS were characterized via TGA analyser. Figure-3 presents the weight loss curve and thermal pattern of the resins. All four types of the plastics resins showed a similar behaviour that was in a single step, but different temperature ranges for the thermal decomposition. PP resins degraded in a temperature range of 275 °C to 400 °C. PS degraded within a range of 225 °C to 450 °C, while LDPE and HDPE degraded at higher temperature range which were 325 °C to 490 °C and 325 °C to 500 °C respectively. The degradation temperature at weight loss amount of 50% (T₅₀) were about 367 °C for PP, 408 °C for PS, 444 °C for LDPE and 458 °C for HDPE. Thus, the ascending order of degradation temperature for the plastic resins were in the following order: PP<PS<LDPE<HDPE. Therefore, 500 °C was the best temperature for complete plastic decomposition in pyrolysis. The results show that characteristics of plastic were based on the composition of the resin. Although (Lee *et al.*, 2007) claimed the plastic waste degradation were: PS<PP<HDPE<LDPE, that might be due to the presence of additives in plastic waste.

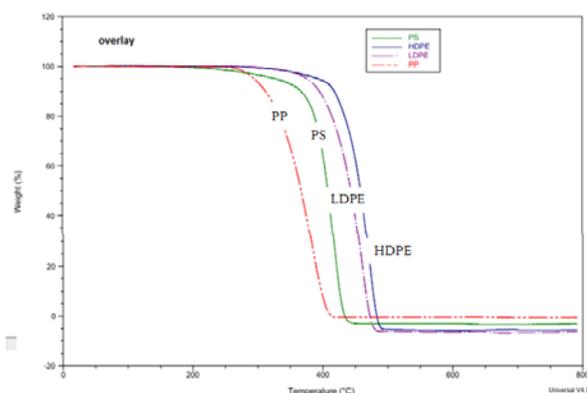


Figure-3. The decomposition of different type of plastics resins at various temperatures.



Catalyst surface characterization via brunauer-emmett-teller (BET)

The catalyst surface characterization was analysed via BET. The result of fresh and spent catalysts with different support; alumina and oil palm biomass ash, is tabulated in Table-3.

Table-3. BET Surface area of catalyst.

Catalyst	Surface Area (m^2g^{-1})	Pore Size (m^2g^{-1})	Pore Volume (cm^3g^{-1})
NiAl_2O_3 (fresh)	7.680	9.563	0.020
NiAl_2O_3 (spent)	5.760	1.328	0.007
NiAsh (fresh)	11.890	14.842	0.036
NiAsh (spent)	6.370	12.353	0.020

Fresh nickel oil palm biomass ash has larger surface area compared to fresh nickel alumina catalyst. The reduction of pore volume on the spent nickel alumina (86.1%) is obtained compared to the spent nickel oil palm biomass ash (16.8%). The BET surface area was $7.68 \text{ m}^2\text{g}^{-1}$ and $11.89 \text{ m}^2\text{g}^{-1}$ for fresh nickel alumina and nickel oil palm biomass ash catalysts, respectively. The surface area reduced to $5.76 \text{ m}^2\text{g}^{-1}$ and $6.37 \text{ m}^2\text{g}^{-1}$ for the spent nickel alumina and nickel oil palm biomass ash. Nickel oil palm biomass ash has higher pore size than nickel alumina catalyst, which indicates that nickel oil palm biomass ash relatively has higher porosity than nickel alumina.##

It can be seen that the pore size, pore volume and surface area of spent catalysts; with different support, significantly reduced after the catalytic pyrolysis process.

The spent catalysts for nickel alumina and nickel biomass ash have small pore volume which were $0.007 \text{ cm}^3\text{g}^{-1}$ and $0.02 \text{ cm}^3\text{g}^{-1}$, respectively. The surface area for nickel alumina indicates 25% reduction (from $7.68 \text{ m}^2\text{g}^{-1}$ to $5.76 \text{ m}^2\text{g}^{-1}$). Meanwhile, nickel oil palm biomass ash indicates 54% reduction (from $11.89 \text{ m}^2\text{g}^{-1}$ to $6.37 \text{ m}^2\text{g}^{-1}$).

Catalyst surface morphology via scanning electron microscope (SEM)

The surface morphology of the fresh and spent catalyst with different support are presented in Figure-4. Uniform crystal can be observed in the both fresh catalyst. As a consequence of agglomeration produced by the deposited coke, higher particles can be observed in the spent nickel alumina catalyst (Figure-4(b)) compared to the fresh nickel alumina (Figure-4(a)). The coke deposition cause catalyst to deactivate; due to the masking of carbon on the catalyst active sites. Similar observation is also achieved by, (Wu *et al.*, (2010)) in which catalytic activity decreased due to the amount and type of carbon deposits presence on the catalysts surface.

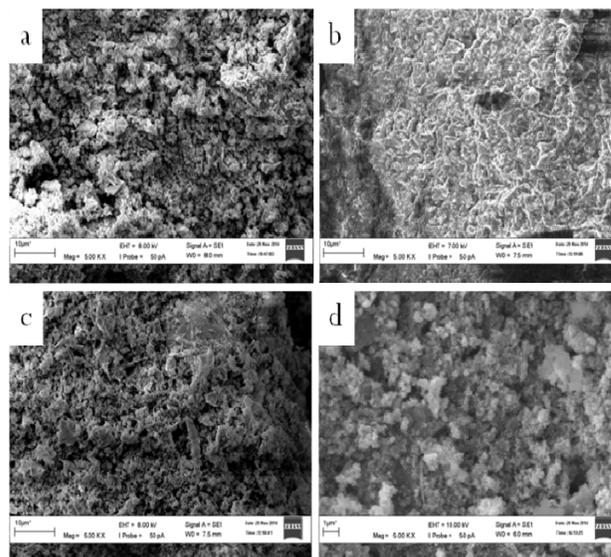


Figure-4. Electron microscope photo of; (a) fresh nickel alumina (b) spent nickel alumina (c) fresh nickel ash (d) spent nickel ash.

Fresh nickel oil palm biomass ash catalyst (Figure-4(c)) has better nickel dispersed compared to fresh nickel alumina catalyst (Figure-4(a)). This indicates that nickel oil palm biomass ash has higher catalytic activity and lead to higher product yield i.e. of liquid fuel and gas fuel.

The presence of cerium as the promoter in the catalyst can reduce the formation of coke, due to its high redox property. Ibrahim *et al.*, (2011) also reported that the catalyst performance improved when CeO_2 was used as a promoter in nickel alumina catalyst. (Isha *et al.*, (2015)) reported that nickel oil palm biomass ash contain oxide compound such as high amount of silicon dioxide (SiO_2), potassium oxide (K_2O), calcium oxide (CaO), iron oxide (Fe_2O_3), magnesium oxide (MgO), alumina and other compounds. Oxide elements in both nickel alumina and nickel oil palm biomass ash could help in cracking and aromatization reaction. (Kimberly *et al.*, (2003)) and (Veeranuch *et al.*, (2014)) also found the same finding in which oxide element such as K_2O , MgO , and SiO_2 can promote cracking process. The multi oxide elements in oil palm biomass ash including MgO enhanced the performance of the catalyst. In conclusion, nickel biomass ash has higher catalytic activity and able to lower carbon coking formation during the pyrolysis reaction.

Catalyst thermal characterization via thermogravimetric analyser (TGA)

Figure-5 represents the coke decomposition on the spent nickel alumina catalyst and spent nickel oil palm biomass ash catalyst using TGA. The coke on the spent nickel oil palm biomass ash was completely degraded at 700°C , while nickel alumina was degraded at 650°C . The weight percentage for nickel alumina started to reduce



gradually at 100°C and drastically decreased at 450°C. It was completely degraded at 650°C. The nickel biomass ash, on the other hands, decreased gradually at 200°C and drastically reduced at 650°C, and completely degraded at 700°C.

There are two type of carbons which are filamentous carbon and encapsulated carbon. Filamentous carbons start to degrade at high temperature (600°C), while encapsulated carbon degraded at low temperature (400°C). It clearly indicates that encapsulated carbon deposited on the spent nickel alumina; while filamentous carbon deposited on the spent nickel biomass ash. Wu *et al.*,(2009) reported that filamentous carbon does not mainly contribute to the deactivation of the catalyst compared to encapsulated carbons. That might be the reason why nickel oil palm biomass ash has better catalyst reactivity than nickel alumina in plastic pyrolysis.

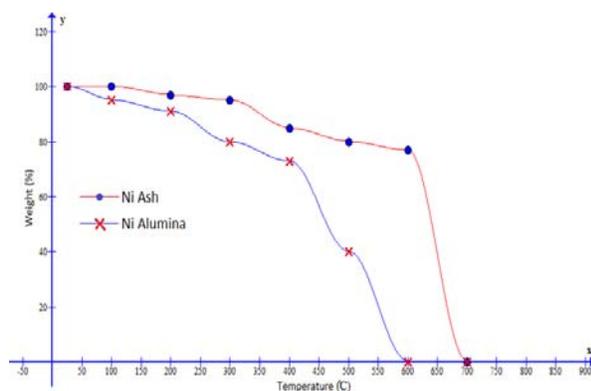


Figure-5. The decomposition of spent catalyst at various temperatures.

Characterization of liquid fuel via gas chromatography (GC/MS)

A summary of results obtained in the GC-MS of both liquid fuels and diesel are presented in Table 4. All the compounds that identified by GC-MS have been grouped in three categories according to their number of carbons: C₅ to C₉, C₁₀ to C₁₂ and higher than C₁₃.

There are not much different in the % area for each fraction in nickel alumina and nickel oil palm biomass ash. Nickel alumina produced 30.04% and nickel oil palm biomass ash produced 33.52 wt% of C₅ to C₉ hydrocarbons. About, 15.83% and 16.29% of C₁₀ to C₁₂ hydrocarbon are produced for nickel alumina catalyst and nickel oil palm biomass ash catalyst, respectively. Furthermore, 54.12% and 50.19% of >C₁₃ hydrocarbons are produced for nickel alumina catalyst and nickel biomass ash catalyst, respectively. Both nickel alumina and nickel oil palm biomass ash are able to crack higher carbon chain effectively in synthetic plastic mixture pyrolysis. ((Adrados *et al.*,(2012)) claimed that a simulated plastic sample produced 69.2 % of light hydrocarbon (C₅ to C₉) by using red mud as a catalyst. Red mud is rich in alumina, CaO and TiO₂. Thus, oxide elements has high capability to crack the carbon chain.

Table-4. GC-MS analysis of the diesel and pyrolysis liquids fuels (% area).

Fraction	Diesel	Fuel _{MAI2O3}	Fuel _{MAsh}
C5 – C9	1.98	30.04	33.52
C10 – C12	11.61	15.83	16.29
>C13	86.43	54.12	50.19
Total	100.02	100.00	100.00

Characterization of liquid fuel via fourier transformed infrared spectroscopy (FTIR) result

A FTIR spectrum analysis of the liquid oil is shown in Figure-6 and Table-5. Germanium cell is used for analysis with 4 cm⁻¹ resolution and spectrum ranging from 4000 to 500 cm⁻¹. The FTIR spectra of all liquid fuels; by using nickel alumina, nickel oil palm biomass ash, and diesel fuel, share same trend. The C-CH₃ compound is detected at vibration in a range of 2800 to 3000 cm⁻¹. Meanwhile, the bending stretching between 1440 to 1550 cm⁻¹ and 1350 to 1400 cm⁻¹ provides the evidence of CH₂ and CH₃ existence. The -CH=CH₂ and -CH=CH- (cis) stretching absorption cause the bands between 900 to 1000 cm⁻¹ and 650 to 730 cm⁻¹, in the spectrum. This also indicates that the oil contains mostly alkanes, alkenes, and also some oxygenated hydrocarbons. Similar finding was also reported by Miskolczi *et al.*,(2011), Elizabeth *et al.*,(1997), and Moinuddin *et al.*,(2012).

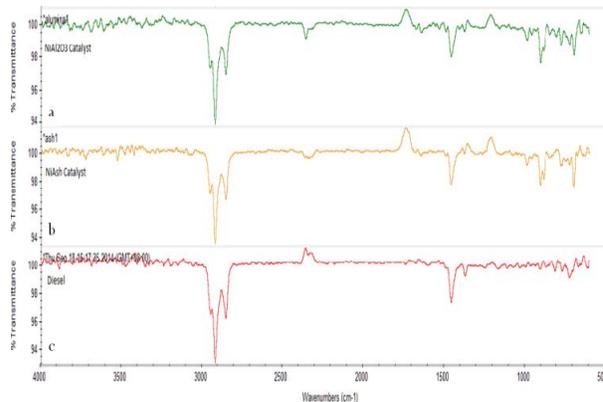


Figure-6. FTIR spectra of liquid fuel; (a) cracking with nickel alumina catalyst (b) cracking with nickel oil palm biomass ash catalyst (c) diesel.

Table-5. FTIR spectra functional group of plastic to liquid fuel.

Wave number	Functional Group
3500-3650	Free OH
2800-3000	C-CH ₃
1440-1500	CH ₂
1350-1400	CH ₃
900-1000	-CH=CH ₂
650-730	-CH=CH- (cis)



Characterization of gas fuel

The percentage of the gases produced during the pyrolysis is presented in Table-6. It shows that both catalytic pyrolysis either using nickel alumina or nickel oil palm biomass ash generated high percentage of methane (CH₄) and hydrogen (H₂) along with a small quantities of carbon dioxide (CO₂) but no trace of carbon monoxide (CO). It seems that, the presence of nickel oil palm biomass ash promotes more methane gases production than nickel alumina. Moreover, nickel alumina produced higher percentage of hydrogen gas than nickel biomass ash.

Adrados *et al.*, (2012) reported that about 10.9 vol% of H₂ was produced via simulated plastic sample pyrolysis by using red mud. It clearly indicates that the nickel is significantly influence the hydrogen production.

Table-6. GC-TCD analysis.

Compound Concentration (vol %)	NiAl ₂ O ₃ catalyst	Ni Ash catalyst
H ₂	87.80	65.90
CO	0	0
CO ₂	2.30	0.01
CH ₄	9.90	34.10

CONCLUSIONS

Catalytic pyrolysis is one of attractive alternative for plastic waste recycling. The product produced from the pyrolysis contain significant amount of hydrocarbon fuel and can be used as a source of chemicals. Apart from liquid fuel production, this process also produced pyrolysis gases that useful as alternative fuel for power generation. The effect of nickel catalyst that supported by either alumina or oil palm biomass ash was investigated in catalytic plastic pyrolysis. Although both of nickel catalysts are able to produce high liquid fuel and gases during the pyrolysis, nickel oil palm biomass ash produced higher liquid fuel than nickel alumina. The filamentous carbon was formed on the nickel oil palm biomass ash while encapsulated carbon was formed on the spent nickel alumina catalyst. The nickel oil palm biomass ash catalyst has better coke resistant than nickel alumina catalyst. The various oxide elements in nickel oil palm biomass ash promotes higher cracking of hydrocarbon and produces more liquids yield. The fuel generated from plastic pyrolysis has similar compound as commercial diesel.

REFERENCES

- [1] Adrados, A., Marco, I. D., Caballero, B. M., Lopez, A., Laresgoiti, M. F and Torres, A. (2012). Pyrolysis of Plastic Packaging Waste: A comparison of Plastic Residuals from Material Recovery Facilities with Simulated Plastic Waste. *Waste Management*, 32, pp. 826-832.
- [2] Elizabeth, A. W. and Williams, P. T. (1997). Analysis of products derived from the fast pyrolysis of plastic waste.
- [3] Ibrahim, F. E., Wu, C. and Williams, P. T. (2011). Hydrogen production from the pyrolysis gasification of waste tyres with nickel/cerium catalyst. *International Journal of Hydrogen Energy*, 36, pp. 6628-6637.
- [4] Isha R. and Abd Majid N. H. (2015). A Potential Hybrid TiO₂ in Photocatalytic Seawater Desalination. *Advanced Materials Research*, 1113, pp. 3-8.
- [5] Kimberly, A. M. B., Stefan, C., Rick, F. and Esteban, C. (2013). Fluidizable Catalysts for Hydrogen Production from Biomass Pyrolysis/Steam Reforming. *Hydrogen, Fuel Cells, and Infrastructure Technologies*.
- [6] Laresgoiti, M. F., Caballero, B. M., Marco, I. D., Torres, A., Cabrero, M. A. and Chomon, M. J. (2014). Characterization of the liquid products obtained in tyre pyrolysis. *Journal of Analytical and Applied Pyrolysis*, 71, pp. 917-934.
- [7] Lee, K. H. and Shin, D. H. (2007). Characteristics of liquid product from the pyrolysis of waste plastic mixture at low and high temperatures: Influence of lapse time of reaction. *Journal of Waste Management*, 27, pp. 168-176.
- [8] Lopez, A., Marco, I. D., Caballero, B. M., Laresgoiti, M. F. and Adrados, A. (2010). Pyrolysis of municipal plastic wastes: influence of raw material composition. *Waste Management*, 30, pp. 620-627.
- [9] Marco, I. D., Caballero, B. M., Lopez, A., Laresgoiti, M. F., Torres, A. and Chomon, M. J. (2009). Pyrolysis of the rejects of waste packaging separation and classification plant. *Journal of Analytical and Applied Pyrolysis*, 72, pp. 97-102.
- [10] Miskolczi, N., Bartha I., Deák, G. and Jover, B. (2004). Thermal degradation of municipal plastic waste for production of fuel-like hydrocarbons. *Polymer Degradation and Stability*, 86, pp. 357-366.
- [11] Miskolczi, N., Borsodi, N., Angyal, A., Buyong, F. and Williams, P. T. (2011). Converting of Municipal Solid Wastes into Valuable Hydrocarbons by Pyrolysis. The effect of Paper/Plastic Ratio and Reaction Time. *Journal of Energy and Power Engineering*, 5, pp. 291-299.
- [12] Moinuddin, S., Mohamma, M. R. and Muhammad, S. R. (2012). Transforming Fuel From Municipal Waste Plastic using Nickel Silica Catalyst.



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- [13] Veeranuch, S., Siriporn, Y. and Unalome, W. (2014). Catalytic pyrolysis of LDPE plastic wastes over mortar cement catalyst. *Advance Materials Research*, Vols. 931-932, pp. 47-51
- [14] Wu, C. and Williams, P. T. (2009). Hydrogen production by steam gasification of polypropylene with various nickel catalysts. *Applied Catalysis B: Environmental*, 87. pp. 152-161.
- [15] Wu, C. and Williams, P. T. (2010). Pyrolysis gasification of plastics, mixed plastics and real world plastic waste with and without Ni-Mg-Al catalyst. *Fuel*, 89, pp. 3022-3032.
- [16] Jabatan Pengurusan Sisa Pepejal Nasional (JPSPN). (2011), A study on plastic waste management in Peninsular Malaysia, pp. 25.