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Characterization of Mixed Plastic Wastes as a Potential Renewable Energy Resource

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Abstract

The management of waste materials is a problem worldwide. Incineration technology to burn all kind of wastes and reduce them to much smaller volume i.e. ashes and gas emission is not accepted in Malaysia due to public concern on dioxin and furan emission to the environment. In this study, the characteristics of flue gas emission from various kinds of plastic wastes as well as the calorific value were investigated. HDPE, LDPE, PS, PVC, PP and PET were incinerated in a furnace at temperature 850-900°C to imitate the thermal incineration process, and the emission from the burning process was found to contain CO_2, CO, SO_2, NO, NO_2, NO_x and Cl_2. Then, each plastic wastes were combusted in a bomb calorimeter to analyze the calorific value. However, when the plastic wastes were mixed with the ratio of 1:1:1:1:1:1 and combusted in the bomb calorimeter, the calorific value was found to be 45.54 MJ/kg, much higher than biomass fuels with the range of 14.0 - 18.4 MJ/kg and similar range with LPG, gasoline and fuel oil. Therefore, a new technology should be invented to recover this waste and convert them into value-added energy.

Keywords: *waste management, plastic waste, calorific value, energy.*

1. Introduction

Waste management is troublesome, not only in Malaysia, but everywhere in the world. In Asia, waste management requires immediate attention especially in countries such as China, South Korea and Malaysia. Malaysia, like most of the developing countries, is facing an increase of the waste generation which leads to problems related to managing and disposing these wastes generated [Lau, 2004]. An average Malaysian household produces 0.8 kg of waste a day, while Klang Valley residents themselves produce 1.5 kg daily. With 25 million Malaysian populations in 2005, the total waste generated in excess of 7.3 million tons of garbage [Bhattacharjee, 2006] and by year 2020 with the targeted 70 million Malaysian populations, the total wastes generated possibly reach to 20 millions tons.

To manage the waste, characteristics and properties should be taken care off. Three different waste categories with respect to disposal are solid, medical and hazardous, yet medical wastes are only handled by proper company liaising with the government such as Redicare Sdn. Bhd. and hazardous waste in Malaysia on the other hand is handled by Kualiti Alam Sdn. Bhd., the only company and a private waste management company to handle hazardous waste in Malaysia.

Solid waste in Malaysia on the other hand is still under the responsibility of the public sector even though part of the management services has been contracted to the private company. A study shows that 70% from the total wastes come from five states namely Kuala Lumpur, Selangor, Pahang, Terengganu and Kelantan, and 64% from the total wastes are from domestic waste [Anderson, 1998] which comprises any waste generated from housing areas. One type of solid wastes is plastic materials which now is apart of everyday life and contribute immensely to the benefit of humanity. Plastic materials are widely accepted as raw materials for a wide range of industries and are converted into an even wider range of articles for domestic and industrial purposes. It has been reported that the world's annual consumption of plastic materials were increased from 5 million tonnes in 1950's to nearly 100 million tonnes today [APME, 2002; APME, 2008]. Plastic consumption keeps growing each year and it makes up around 7% of the average household dustbin [APME, 2002; APME, 2008]. But, the main challenge now is the accumulation and the disposal of enormous amount of plastic wastes contributes significantly to the environmental impact. When the plastics are landfilled, they take a long time to break down, possibly up to hundreds of years, and more and more plastics are being disposed every year which leads to the landfill space required for the plastic wastes that need to be concerned.

A RM 1.5 billion largest incinerator in Asia was planned to be built at Broga, 50 km south of Kuala Lumpur, using Japan technology. This incinerator with a capacity of 1500 tonnes per day using a fluidized bed gasification technology is proposed to incinerate all kind of wastes and reduce them to much smaller volume i.e. ashes and gas emission yet the technology has not been accepted by the public due to emission to the environment. On Friday July 6^{th} 2007, the counsels representing the government pulled off the project to build the incinerator after several files suit by the Broga residents to protest on the project due to safety and health issues [Yee and Cheah, 2007]. Plastics materials and other wastes containing chlorine-based chemicals will produce dioxin and furan when burning, and exposure to dioxin damages the immune system, causes birth defects and is a class one cancer-causing agent [Morgan, 2003]. Since landfill disposal of the plastics in municipal solid waste is no longer in line with increasing environmental consideration and stricter regulations and incineration project was already terminated, the possibility of using waste plastics as a source of secondary fuel in a furnace via combustion has been of recent interest to convert the waste to energy. Plastics materials contain carbon which classifies them as organic materials, thus, using appropriate but safe method, energy from plastics waste materials can be recovered. Energy recovery is the process of recovering the thermal energy produced when fuels are converted to gases and residues through the combustion process and the high heating value of plastics makes them a valuable source of energy that can be readily recovered in modern waste-to-energy plants [Tchobanoglous *et al.*, 1977].

The present study will conduct investigation on various kinds of plastics wastes in a furnace at temperature 850 - 900°C. The objectives are to investigate the gas emission appears from the incineration process and detect the amount of calorific value obtained from the combustion process. Results from single plastic waste will be compared to mixed plastic wastes to be used as possible renewable energy.

2. Experimental

This project was carried out using six different types of plastic wastes namely high-density polyethylene (HDPE), low density polyethylene (LDPE), polyethylene terephthalate (PET), polypropylene (PP), polystyrene (PS) and polyvinyl chloride (PVC). The plastic wastes were shredded into smaller pieces. To detect the emission of gases, the sample was combusted in a furnace (1100°C Chamber Furnaces ELF model) at a uniform mass or ratio for single plastic, three mixtures and all six mixtures of plastics. The sample was introduced inside the furnace through an opening of the furnace when temperature achieves 850-900°C and the emission of gases from the combustion process would be read using gas analyzer (Madur DA60 (Austria)). To detect the calorific value, an exact amount of sample, single and mixtures of plastics, was placed inside a bomb calorimeter (Parr 1341 Plain Jacket Oxygen Bomb Calorimeter). The difference weight of sample and length of fuse wire were used to calculate the calorific value of the material. The below equation is used to calculate a heating value (HV) of the plastic waste material.

$$HV = \frac{\Delta U_{water}}{m_{sample}} = \frac{(mC_v \Delta T)_{water} - (2.3C_3)_{fusewire}}{m_{sample}} \quad (1)$$

where is mass of sample of water (kg), is heat capacity of water (kJ/kgK), is temperature change (K), is centimetres of fuse wire consumed in firing (cm), and is heating value of sample (MJ/kg).

3. Results and discussion

3.1 Emissions of Gases

This project was done on six different types of plastic wastes namely HDPE, LDPE, PET, PS, PP and PVC. These plastic materials were chose due to common plastic material found in the municipal solid waste [APME, 2002]. The study on the emission of gases from the incineration process was conducted on single type of plastics waste, mixture of three HDPE + PVC + PS and LDPE + PP + PET with the ratio of 1:1:1, and mixture of six plastic materials HDPE + LDPE + PET + PVC + PP + PS with the ratio of 1:1:1:1:1:1. ***Table 1*** shows the CO_2 gas emission from all plastic wastes, single and mixtures, burnt in the furnace at 850-900°C using gas analyzer. The CO_6 pt emission is one of the important parameters in determining whether the wastes are suitable or not for the combustion process. As shown in ***Table 1***, LDPE and PS generate high CO_2 emission with the emission of 17-20 wt%, and as compared to mixtures of HDPE+PVC+PS and LDPE+PP+PET, the emissions are in the similar range which validates that LDPE and PS contribute high amount of CO_2 emission in their respected mixtures. These results can also be seen in ***Figure 1*** which shows the trend of CO_2 gas emission from single plastic wastes obtained from the furnace at 850-900°C using gas analyzer and ***Figures 2*** and ***3*** which portray the CO_2 emission trends for single plastic waste as compared to the mixtures. ***Figure 4*** shows the CO_2 trends for all three types of the plastic waste mixtures. This graph shows that the mixtures of HDPE + PVC + PS with the ratio of 1:1:1 gave higher CO_2 gas emission trend as compared to the mixtures of LDPE+PP+PET of ratio 1:1:1 which also validates the previous discussion. However, when all the plastic wastes were mixed together with the ratio of 1:1:1:1:1:1, the emission was increased which shows that the more carbon content in the mixtures, the branches in the polymer structures might crosslink with each other and due to different angle of bonding and different steric hindrance among the structures, the higher amount of CO_2 emission.

Figure 5 shows CO emission for all six plastic wastes and from this figure, LDPE gave the highest trend as compared to the others. This is because LDPE is a highly branched polymer with leads to inefficient alignment of chains leading to 50-60%

crystallinity [Rodriguez *et al.*, 2003; Sperling, 2001] which is hard for the C-bonding to vibrate and release all the C-bonding when heating, and thus, when this plastic was incinerated, apart was partially combusted which shows highest trend of CO emission (more than 12000 ppm). ***Figures 6 - 9*** show similar trends of NO_2, NO_x, NO and SO_2 emissions for almost all plastic wastes except LDPE, which also might due to the higher degree of branched chains as well as the additives contained in the polymer structure to strengthen the bonding and differentiate the colour and structures for various use. ***Figure 10*** portrays Cl_2 emission and as expected, PVC shows a Cl_2 trend. However, LDPE and PS also show Cl_2 trends which might due to the additives in the polymer matrices to hold the bonding as well as structures. ***Figure 11*** shows all gas emissions other than that CO_2 for mixed plastic wastes with the ratio of 1:1:1:1:1:1 and this figure shows that mixed plastic wastes also generated high CO emission, which concludes that a group of different structures and matrices of polymer when they are combined together, might lead to a possible partial combustion reaction leading to releasing partial combustion gases i.e. CO and some traces of NO_x, NO and possible SO_3.

From the above results, the most critical gas emissions detected is carbon monoxide (CO) gas from the burning of LDPE, PS and the mixtures, which shows that LDPE and PS are kinds of polymer that hard to be burnt off due to different highly branches and steric hindrance [Rodriguez *et al.*, 2003; Sperling, 2001]. The mixture of plastics also hard to be burnt off which means that apart might undergone partial combustion reaction and gives CO gas and traces of other partial reaction gases as their by-product from the combustion reaction. Even after 90 s of burning in the furnace, the CO emissions are still high for the above polymers and the mixtures. The CO gas is poisonous and not only adversely affects to human health, but it also affect the property [Morgan, 2003]. Even though the other gas emissions are rather low as compared to CO emission, they still take part in contaminating and generating air pollutants which lead to health and environmental impact. Thus, the safety measures are to be taken care off when dealing with incomplete combustion process.

TABLE 1. CO_2 Emission from plastic wastes, %

CO_2, %	0 s	10 s	20 s	30 s	40 s	50 s	60 s	70 s	80 s	90 s
HDPE	0	5.04	5.00	5.03	5.18	5.12	5.10	5.12		
LDPE	0	8.10	8.22	8.35	8.56	11.01	11.01	13.75	17.23	16.86
PET	0	3.43	3.43	3.43	3.46	3.56	3.62	3.60		
PVC	0	6.67	6.73	6.70	6.55	6.13	5.22			
PS	0	6.84	6.78	6.84	7.33	8.01	12.34	15.68	19.74	20.19
PP	0	2.51	2.48	2.53	2.52	2.51	2.54	2.58		
HDPE+PVC+PS	0	8.90	8.89	8.89	8.73	9.71	11.10	18.68	22.15	25.61
LDPE+PP+PET	0	9.05	8.95	8.95	8.96	8.60	9.91	11.80	11.80	19.72
HDPE+LDPE+ PET+PVC+PP+PS	0	10.23	10.36	10.20	10.30	10.30	12.42	23.81	26.31	40.75

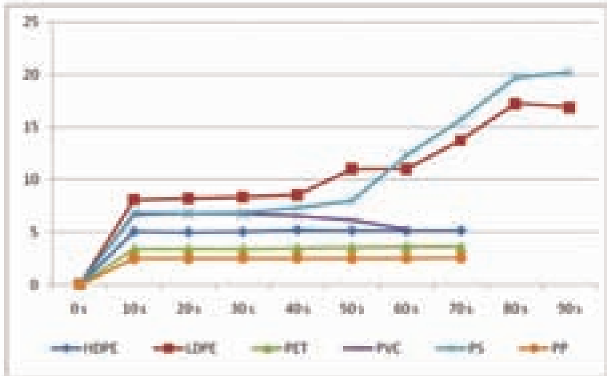

Figure 1. *CO_2 emission (%) vs time for each plastic waste.*

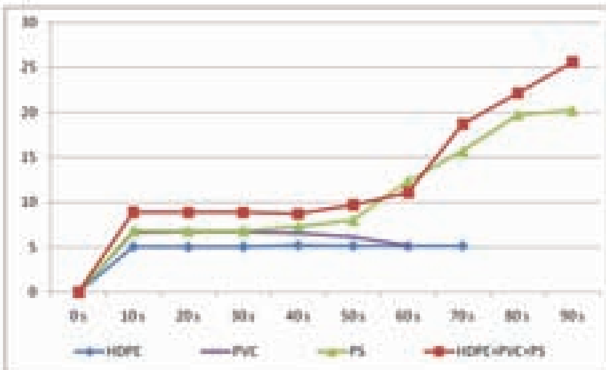

Figure 2. *CO_2 emission (%) vs time for HDPE, PVC, PS and their mixtures.*

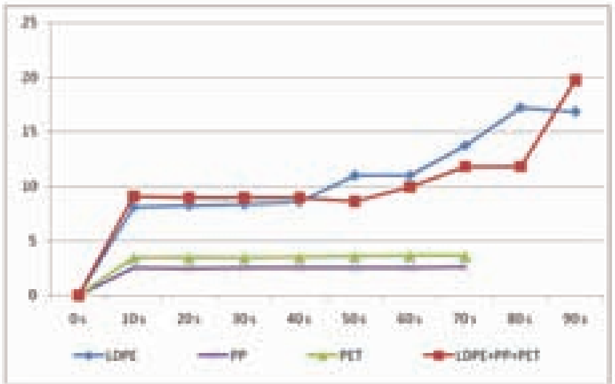

Figure 3. *CO_2 emission (%) vs time for LDPE, PP, PET and their mixtures.*

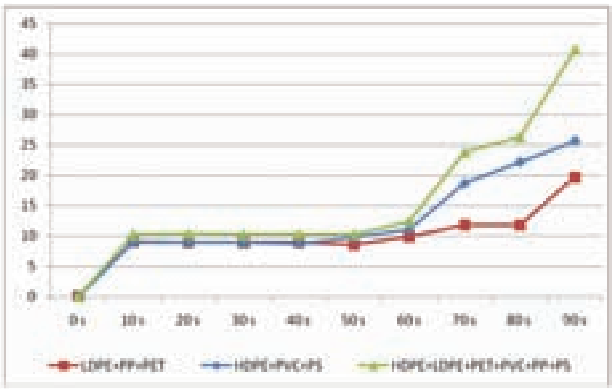

Figure 4. *CO_2 emission (%) vs time for mixed plastic waste.*

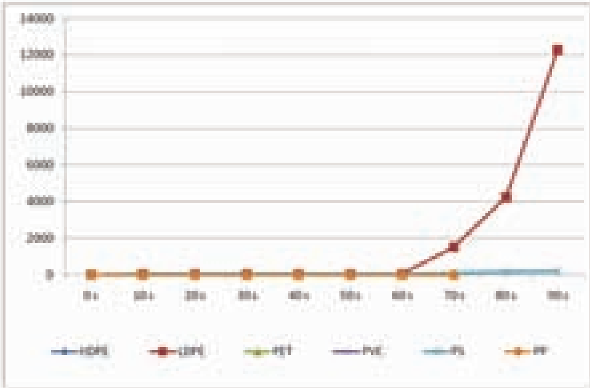

Figure 5. *CO emission (mg/m[3]) vs time for single plastic waste.*

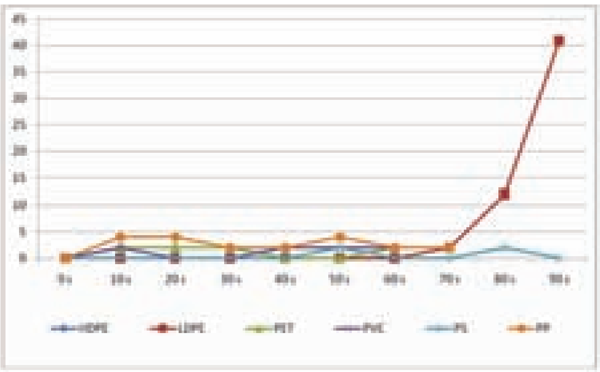

Figure 6. *NO_2 emission (mg/m[3]) vs time for single plastic waste.*

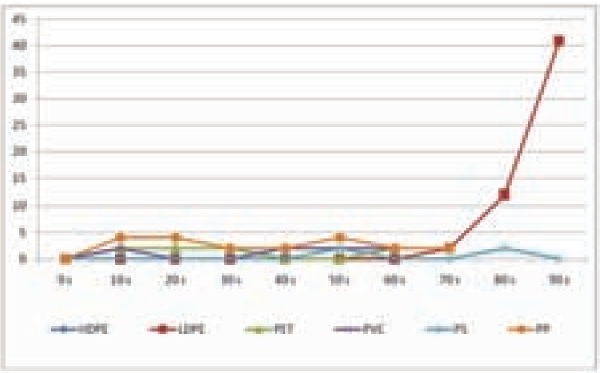

Figure 7. *NO_x emission (mg/m[3]) vs time for single plastic waste.*

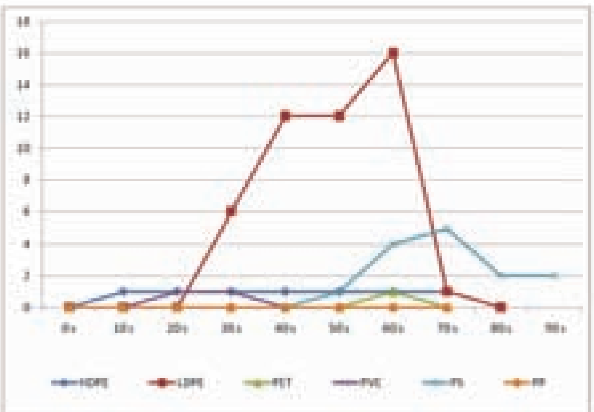

Figure 8. *NO emission (mg/m[3]) vs time for single plastic waste.*

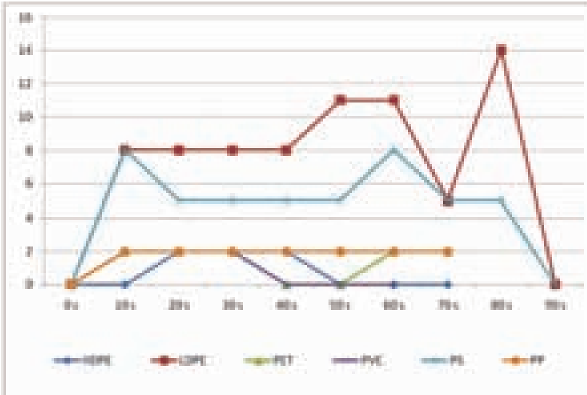

Figure 9. *SO_2 emission (mg/m[3]) vs time for single plastic waste.*

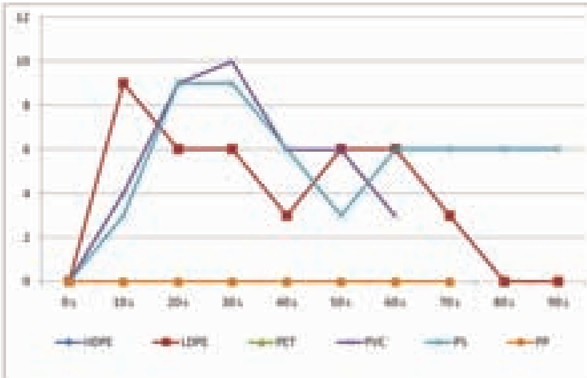

Figure 10. *CL_2 emission (mg/m[3]) vs time for single plastic waste, mg/m[3].*

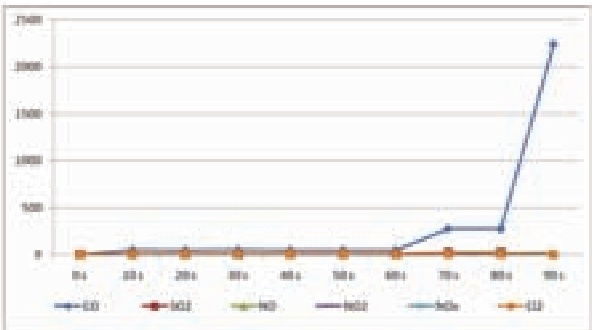

Figure 11. *Gas emission emission (mg/m[3]) vs time for mixed plastic waste.*

3.2 Calorific Value

The sensible way to evaluate a fuel's heating value (HV) is in terms of the energy it will produce per unit mass of fuel. Using formula (E.1), the heating values for each plastic material together with the mixtures are tabled in ***Table 2***.

The highest heating value obtained from six different plastic waste materials came from LDPE which gave about 42 MJ/kg, whereas PVC gave the lowest value of 14 MJ/kg. Based on the calorific value of the plastic wastes mixture, the six plastic wastes mixture with the ratio of 1:1:1:1:1:1 yielded 45 MJ/kg, which is in the same range with gasoline and LPG.

The mixture contains higher heating value because of different polymer structure in the mixture which representing different type of plastics. When all of these types of plastics are combined and being combusted, the polymer undergone a chemical reaction and the molecular chain for each polymer will combine and the plastics will have or contain more carbon and hydrogen atoms. When these mixtures of plastics undergone a combustion process, it will release more energy and that is why the mixture gave the highest heating value as compared to the other types of plastic wastes. The higher the relative content of carbon, the higher the calorific value of the material. Besides, these plastics material come from petroleum-based feedstock as their raw material, thus, the similar range of the heating value can be expected. In addition, the value from this mixture is much higher as compared to biomass fuel. This means that instead of burning the plastic waste to reduce the size of the volume, the plastic wastes can be collected and burnt to convert them into energy for other purposes such as electricity supply or generator operations. Also, as being performed by Recycle Energy Sdn. Bhd., the first private company in Malaysia established in 2000, selected domestic wastes from Kajang area has been converted into refuse derived fuel (RDF) which they plan to be used as feedstock for boiler to generate steam for their plant [Recycle Energy, 2000]. However, the wastes must be sorted manually prior to RDF conversion processing in order to maintain the characteristics and composition of the wastes. The wastes required must be within 30-40 % moisture content and with the ratio of 70 wt% polyethylene bag and 30 wt% textile and paper. Thus, instead of manually sorted, all six common plastic wastes can be mixed and combusted to convert into value-added energy.

TABLE 1. CO_2 Emission from plastic wastes, %

	Heating Value, HV, MJ/kg
HDPE	30.95
LDPE	41.74
PET	15.88
PVC	14.22
PS	33.44
PP	31.98
HDPE+PVC+PS	43.69
LDPE+PP+PET	42.25
HDPE+LDPE+PET+PVC+PP+PS	45.54
Biomass Fuel [Chuah *et al.*, 2006]	14.0 - 18.4
Coal (premium) [Chuah *et al.*, 2006]	23 - 28
Natural Gas [Chuah *et al.*, 2006]	54
Gasoline [Chuah *et al.*, 2006]	45
LPG [Chuah *et al.*, 2006]	48

Conclusions

In conclusion, a new integrated technology comprises air pollutant control (APC) and energy converter should be invented to recover the plastics wastes and convert them into value-added energy as well as monitoring and controlling gas emission from the burning process.

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