Essential Characteristics of Plastics Waste for Pyrolysis Process: Comparison of Selected Packaging Plastics and PVC
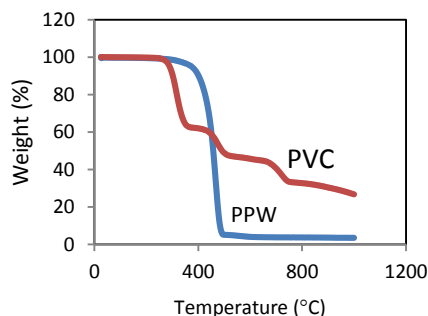
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Graphical abstract

Abstract

The poor degradability of plastics has led to huge plastics deposit in a landfill of which pyrolysis technology has been proposed to solve plastics waste problem. This paper reports the study on characteristics of two kinds of plastic wastes: selected packaging plastics and PVC. Characterizations have been performed for investigating water content, ash content, and decomposition temperature. The results revealed that the water content of packaging plastic waste was 0.69 ± 0.11%, while PVC was 1.22 ± 0.24%. The ash contents are 2.36 ± 1.03 % and 27.24±1.73 % for packaging plastics waste and PVC waste respectively. Plastic waste from packaging application and PVC waste decomposed at a temperature of 300-500°C and 200-800°C respectively. Decomposition of PVC waste took place in three stages: 200-370°C, 370-525°C and 600-800°C. It is recommended that the pyrolysis process should be conducted in the range of 300-500°C for packaging plastic waste and 200-800°C for PVC waste.

Keywords: Characteristics, decomposition, packaging plastic, PVC, pyrolysis

1.0 INTRODUCTION

It is almost impossible to live without plastic. People rely on plastics in everyday activities such as milk jugs, eyeglasses, telephones, nylons, automobiles, and other consumer goods. The steady growth of plastics sales reflects the ability of plastics products to fulfill an increasing number of consumer demands [1]. The world's annual production of polymer resins has experienced a steady growth since the beginning of the century, with growth predicted way into the 21st century close to 1.5 million tons per year in 2000 [2]. In 2010 together the big five plastics families (LDPE/LLDPE/HDPE, PP, PVC, PS, and PET) accounted for around 74% of all European plastics demands [3]

Plastics have also achieved an irreplaceable position in the packaging industry [4]. In the United States, packaging accounts for over one-third of the captive use of thermoplastics, whereas construction, accounts

for about half that number, and transportation account for only 4% of the total captive use of thermoplastics. On the other hand, 69% of the thermosets are used in building and construction, followed by used in transportation [2]. Whereas in Europe, packaging remains the biggest end-use of plastics (40%) followed by electrical and electronic (23%), household (15%), automotive (9%), construction (7%), agriculture (3%) and others (3%) [3].

Generally, most of packaging applications eventually end up as litter. Griffin [5] reported that over 50% of the annual tonnages of all manufactured synthetic polymers are applied as packaging materials and that some 90% of this flow finishes as a component of urban garbage. The other report showed that the municipal solid waste stream in the U.S. totals nearly 160 metric tons per year and consists of about 7-11% by weight of post-consumer plastics [6]. In 2001, plastics waste which mainly consists of PE (above 40 wt %), PVC,

PP, and poly-(ethylene terepthalate) had a total volume of 19.2 million tonnes, accounting for about 8.4% of total municipal solid waste in the United States [7].

The municipal solid waste stream in the United States totals nearly 160 metric tons per year and consists of about 7-11% by weight of post-consumer plastics [6]. The fact that plastics are hard to degrade in the natural environment to be the disadvantage of their application. Recycling, as an alternative to reduce plastic waste, only covers 25-30% of polymer waste. The other products eventually find their way to landfills or incinerators. Plastic waste has become serious an environmental concern. [1]. As such, pyrolysis process may be acceptable to overcome the pollution from plastics waste.

Pyrolysis is thermal degradation process of materials in the absence of oxygen or air. Pyrolysis of plastics may offer the way of plastics waste removal with recovery of useful compound of hydrocarbon. Plastics are heated at high temperature to crack down into smaller molecules that containing wide range hydrocarbon [8]. The heating in a pyrolysis process commonly takes place in the range of 400-700°C. Organic compounds decompose and result in liquid and gaseous products that are useful as fuels [9].

Thermogravimetric analysis has widely chosen as a useful technique to investigate the decomposition process of solid material. The information about this technique is useful to design a reactor, where thermal decomposition process can take place [10-12].

Many studies on pyrolysis of plastics have been conducted [13--20]. However, pyrolysis of packaging plastics waste has not been conducted, even though packaging plastics waste is biggest component of plastics waste. It is important to understand the characteristics of packaging plastics waste in order to determine the most favorable conditions of the pyrolysis process. This study also compares the characteristics of packaging plastics waste and PVC, since PVC also contribute much amount of plastics waste.

2.0 EXPERIMENTAL

2.1 Materials

Selected packaging plastic waste was collected and selected. It was washed to eliminate impurities and then dried. It was then cut into small slices. Packaging plastics waste that was laminated with aluminum foil was rejected during selection. PVC waste was also collected and treated in the same manner with packaging plastics waste.

2.2 Method

2.2.1 Water Content Test

Water content test was performed in the oven at 110 °C for 2 hours. Five grams of the sample were placed into the oven and heated. Periodic weighing was carried out, and it was finished after constant weight of sample reached.

2.2.2 Ash Content Test

Ash contents of the packaging plastic waste and PVC waste were analyzed by combustion in the furnace. Five grams of the sample were laid on the porcelain dish and place furnace. The operating temperature was set at 1000 °C. The ash obtained was weighed. Ash content was calculated as the ratio of weight of ash and sample.

2.2.3 Thermal Decomposition Test

Evaluation of decomposition temperatures was performed using thermogravimetric analyzer (TGA) (MODEL: Mettler). The applied heating rate was 20°C/min from room temperature up to 1000°C under nitrogen atmosphere. The flow rate nitrogen was 50 ml/minute. The tests were carried out using platinum pan. A sample of about several milligrams was tested in the chamber of TGA.

3.0 RESULTS AND DISCUSSION

3.1 Water Content

The results of the water content test are presented in Table 1. It was found that PVC waste has slightly higher water content than packaging plastics waste, i.e. the water content of packaging plastic waste was 0.69 ± 0.11%, while PVC was 1.22 ± 0.24%. Water content commonly affects the production of the pyrolysis. Higher water content of sample will result in higher water content in pyrolysis product. The water in pyrolysis products reduces its flammability.

Table 1 Water content of plastics waste

Material	Water content, %
Packaging plastics waste	0.69± 0.11
PVC waste	1.22± 0.24

3.2 Ash Content

The results of ash content test are listed in Table 2. Ash content of plastic waste is 2.36 ±1.03 %. It is quite low. It means that most of packaging plastics material decomposes during heating process. On the other hand, PVC waste has ash content of 27.24 ± 1.73 %. Ash content of PVC waste is much higher than its of packaging plastics waste. The ash content indicates the residue that obtained during pyrolysis process.

Ash content could depend on the content of additives added into plastic that commonly composed of inorganic compound. Plastics are usually mixed with additives to improve its properties. Additives are selected depending on the type of polymers to which

they will be added or the application for which they will be used. Appropriate selection of additives helps develop value-added plastics with improved durability as well as other advantages. However, high ash content during incineration or pyrolysis will be left. Higher ash content will result in a lower yield of liquid product of pyrolysis, and vice versa.

Table 2 Ash content of plastics waste

Material	Ash content, %
Packaging plastics waste	2.36 ± 1.03
PVC waste	27.24 ± 1.73

3.3 Decomposition Temperature

Decomposition temperature can be determined from the extreme decrease of weight during the heating process. It was shown by a steep slope of the curve in the TGA test result. The results of TGA tests of packaging plastic wastes and PVC are presented in Figures 1 and 2. The corresponding data are listed in Table 3.

Figure1 shows the thermogravimetry (TG) traces of packaging plastic waste and PVC waste. TG traces have revealed that packaging plastic waste decomposed at the temperature of 300-500°C. The decomposition took place in a single step as shown by single peak of derivative thermogravimetry (DTG) trace. PVC waste decomposed at the temperature of 200-800 °C, that consisted of three stages of decomposition. It was obviously shown by DTG trace of PVC. The three stages of decomposition lay in the range of 200-370°C (first stage), 370-525°C (second stage) and 600-800 °C (third stage).
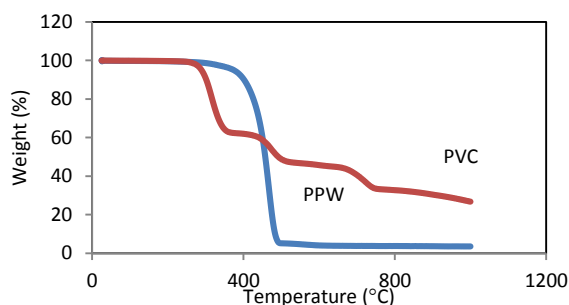

Figure 1 TG traces of packaging plastic waste (PPW) and PVC waste
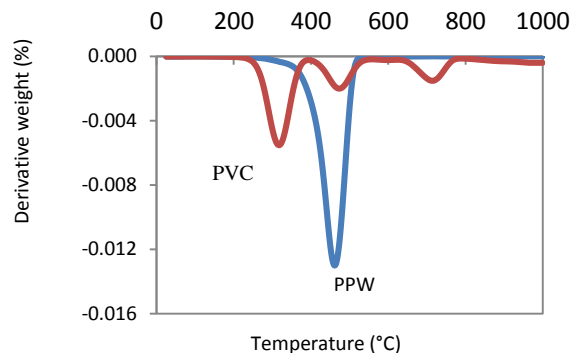

Figure 2 DTG traces of packaging plastic waste (PPW) and PVC waste

The decomposition temperature of packaging plastic waste is lower than PVC, as shown in Figures 1 and 2. It has revealed that the packaging plastic waste is easier to decompose than PVC.

Demirbas et al. [8] reported the decomposition temperature of three types of plastics i.e. PE, PP and PS. They decomposed at a temperature of about 500-800 K. The decomposition temperature of packaging plastic waste is similar to the three types of plastics (PE, PP, and PS). Adrados et al. [9] studied pyrolysis of real plastics waste that rejected from recovery unit. They reported that real plastics waste of packaging plastic consisted of PE (35 wt %), PP (40 wt %), and PS (19 wt %), PET (5 wt %) and PVC (1 wt %).

The TG curve also revealed that PVC contained material that did not decomposed until the end of the process of which the residue was much more (26.72 %) than that of packaging plastics waste (3.52%). However, the pyrolysis of packaging plastic will give more products amount than pyrolysis of PVC. In the view of products amount, packaging plastics waste is more favorable to be processed with pyrolysis rather than PVC.

The DTG curve describes that the peak of decomposition rate of packaging plastics waste takes place at temperature of 461.67°C. Meanwhile, PVC waste with three stages of decomposition has three peaks of decomposition rate i.e. 317.00 °C (stage 1), 473.33 °C (stage 2), and 714.32 °C (stage 3).

Table 3 Decomposition temperature of plastics waste [a]

Material	Decomposition temperature, °C	Peak temperature, °C	Activation Energy, kJ/mole
Packaging plastics waste	300-500	461.67	112.62
PVC waste	200-800		
	Stage 1 : 200-370	317.00	98.89
	Stage 2 : 370-525	473.33	15.33
	Stage 3 : 600-800	714.32	18.07

[a] Test was conducted at temperature of 25-1000 °C, under Nitrogen atmosphere at flow rate of 50 ml/minute.

Activation energy of decomposition process was calculated using Broido equation [18]:

$$\ln\left(\ln\frac{1}{y}\right) = -\frac{E_a}{RT} + \ln\left(\frac{RZ}{E_a\beta}T_{max}^{\;2}\right) \qquad (1)$$

where y is the fraction of non-volatilized material not yet decomposed, T_{max} is the temperature of maximum reaction rate, β is the heating rate, Z is the frequency factor, and Ea is the activation energy. Initially plots of ln(ln(1/y)) versus 1/T for various stages of decomposition were drawn, such as in Figures 3 and 4. The plot was found to be linear, suggesting a good agreement with the Broido equation. The activation energies, Ea, determined from the slopes of these plots.

Figures 3 and 4 show the graphical calculations of activation energy (Ea) of packaging plastic waste decomposition and PVC waste decomposition (stage 1), respectively. Slope of the curve indicate the value of Ea/R. The corresponding data are listed in Table 3.

It was found that the activation energy of decomposition of packaging plastic waste was 112.62 kJ/mole. PVC waste had an activation energy of 98.89 kJ/mole, 15.33 kJ/mole and 18.07 kJ/mole for the first stage, second stage, and third stage of decomposition, respectively. Generally, PVC had lower activation energy than packaging plastics waste. Nevertheless, PVC underwent decomposition process in a wide range of temperature (200-800 °C), compared with packaging plastics (300-500 °C). Packaging plastics waste will be more efficiently processed by pyrolysis than PVC.
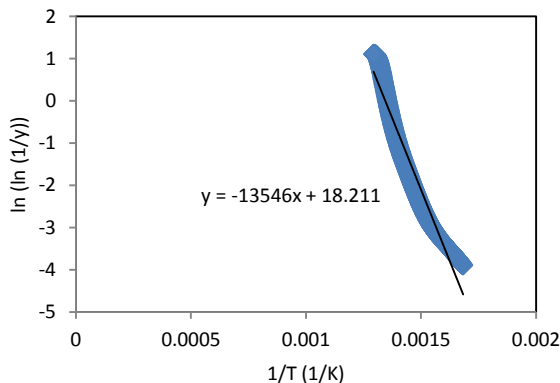

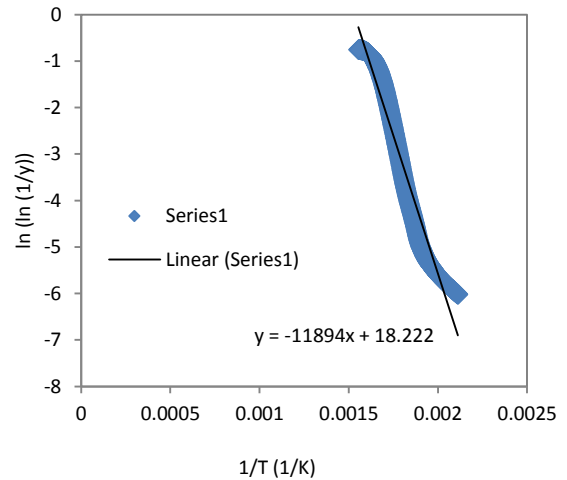**Figure 3** Graphical calculation of activation energy of PPW

Figure 4 Graphical calculation of activation energy of PVC (stage 1)

4.0 CONCLUSION

Packaging plastic waste has lower water content than PVC, and also lower ash content than PVC. Pyrolysis of packaging plastic will leave few amount of residue, while PVC will give much more. The decomposition temperature of packaging plastic waste is in the range of 300-500 °C in single stage decomposition, while PVC decomposes in the range of temperature of 200-800°C that consists of three stages of decomposition. Packaging plastics waste is more efficient to be processed with pyrolysis than PVC. Pyrolysis process should be conducted at temperature of decomposition, 300-500°C, based on TG trace. The optimal condition of pyrolysis should be explored in that range.

Acknowledgement

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