



Combating oil spill problem using plastic waste



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ABSTRACT

Thermoplastic polymers (such as polypropylene, polyethylene, polyethylene terephthalate (PET) and high density polyethylene (HDPE)) constitute 5–15% of municipal solid waste produced across the world. A huge quantity of plastic waste is disposed of each year and is mostly either discarded in landfills or incinerated. On the other hand, the usage of synthetic polymers as oil sorbents, in particular, polyolefins, including polypropylene (PP), and polyethylene (PE) are the most commonly used oil sorbent materials mainly due to their low cost. However, they possess relatively low oil absorption capacities. In this work, we provide an innovative way to produce a value-added product such as oil-sorbent film with high practical oil uptake values in terms of g/g from waste HDPE bottles for rapid oil spill remedy.

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1. Introduction

Plastic products open up a new epoch in industrial history ever since synthetic polymers were first introduced into industrial scale production in the 1940s (Al-Salem et al., 2009). The utilization of plastic products has considerably and profoundly changed the structure of material research. Some of the advantages of using plastics include high resistance to corrosion, high flexibility to process and low manufacturing cost. In addition, they are pervasively used in medical delivery systems, artificial organs and other medical applications (Subramanian, 2000).

With the unprecedented development of industrial society, the production of plastic waste has been an overwhelmingly growing domain and accordingly, it is reasonable to find that the increasing research focus has been drawn to post-consumer plastic products including thermoplastics (such as polypropylene, polyethylene, polyethylene terephthalate (PET) and high density polyethylene (HDPE)). In essence, plastics form a considerable portion 5–15% of municipal solid waste by weight, which equals to 20–30% volumetric proportion (Bazargan et al., 2013). It was reported that in 2011, total MSW (municipal solid waste) generation was 250 million tons in the United States thus it can be estimated that the PSW (plastic solid waste) disposed is around 25 million in weight (Gug et al., 2015). Meanwhile, the proportion of plastic waste in total MSW significantly expanded from 0.5% to 12.5% between 1960

and 2010. These statistics reveal that beneath the convenience due to wide use of plastic products, people should be alarmed about the challenges of white pollution and accompanying environmental issues created by plastic waste.

Traditionally, due to the acceptable rate of PSW generation, landfill or incineration is the optimum approach for post-consumer plastic treatment (Merrild et al., 2012; Zhou et al., 2014). However, the steadily increasing rate of PSW generation and the emission of hydrogen chloride as well as dioxin from MSW thermal treatment plants, have raised environmental concerns due to the incomplete combustion of plastic (Assamoi and Lawryshyn, 2012). Thus, plastic recycling has grown appreciably since the 1980s. Such research was also driven by changes in regulatory and environmental issues, therefore promoting more than 1700 companies engaged in collecting and reclaiming plastic waste in 2000 (National Policy Statement Freshwater Management 2011, 2011). Among industrial utilization of plastic waste, Pyrolysis is one of the favorable approaches. Conesa et al. studied the production of alkane gases from the pyrolysis of HDPE using a fluidized bed reactor (Conesa et al., 1994). The thermal degradation of HDPE in a reactive extruder to obtain oily products with future potential to refine fuels was also examined (Wallis and Bhatia, 2006). Application of plastic waste to produce porous carbon is another option for reclaiming of PSW since porous carbon investigated in research performs considerably more impressively than commercially available activated carbon (Bernardo et al., 2012). Nonetheless, the low yield (less than 10%) due to large volatilization and burn-off effect under vacuum condition accompanied

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with the high energy intensive process restrict the widespread application of plastic waste pyrolysis (Bazargan et al., 2013).

Another alternative is to directly use plastic waste to produce value-added products such as oil sorbents. Polypropylene and polyethylene waste powders and sheets were used for adsorption of spilled oil from water (Aboul-Gheit, 2006), but the main focus was on oil–water separation efficiency and the oil uptake capacity was not presented. Polyurethane foams based on post consumed polyurethane foam (Tanobe, 2009), and based on recycled polyethylene terephthalate (Atta et al., 2013) were used as oil sorbents but the uptake capacity of these sorbents was limited with practical oil pick up values after prolonged dripping were either not presented or were pretty low. As far as author is aware, only a little research has been focused on reusing plastic waste as oil sorbent films that give high practical uptake capacity. Most of the research on plastic waste has been focused on its elimination in a low-cost approach rather than its beneficial, value-added reuse. Hence, the aim of this study is to explore the viability of converting waste material into an innovative oil-sorbent.

In this research, we have produced oil sorbent films from high density polyethylene bottles supplied by Nestle Hong Kong limited. These films were systematically characterized to give a better insight of the oil uptake mechanism.

2. Experimental

2.1. Materials

HDPE bottles were supplied by Nestle Hong Kong Limited. Ultra high molecular weight polyethylene UHMWPE (GUR 4022N) 3.5 million molar mass was supplied by Ticona. Kaydol White Mineral oil and White Protopot 1S Petrolatum were provided by Sonneborn. Irganox 1010 was supplied by BASF and used as an antioxidant. RMG380 Marine diesel oil was provided by Gulf Marine Company. Vegetable (corn) oil was purchased from the local market. The properties of solvents are presented in Table 1.

2.2. Development of polymer film

The polymer–solvent wt. ratio of 10:90 was used in which HDPE and UHMWPE constitute 7.5 and 2.5 wt% respectively. The HDPE bottle was cut into small pieces and then washed with detergent. It was further washed with acetone and then dried in an oven for several hours to remove traces of solvent. The blends were prepared via melt mixing in a static-mixer (Haake Rheomix 600) which is equipped with roller rotors. HDPE pellets were first charged into the chamber at 180 °C and a mixing speed of 25 rpm. A mixture of dispersed UHMWPE in solvent (mineral oil and petrolatum wax with equal wt%) was slowly added to the chamber. The mixture was allowed to mix for 30 min at a mixing speed of 25 rpm at 180 °C. The partial gel obtained from the chamber was cut into fine pieces and was put back into the static-mixer for round 2 under the same operating conditions in order to achieve uniform mixing. Then, it was hot-pressed at 180 °C in order to achieve a flat sheet followed by solvent extraction in a

hexane bath for 20 min at room temperature to remove around 50–60% of the solvent. The sheet was later stretched by using successive biaxial stretching technique at a stretching ratio of 12×12 using a crosshead speed of 400 mm/min at 121 °C. The thus stretched film was placed in boiling hexane to extract and remove the residual solvent and then dried to obtain the porous film and was named as HD-75. A similar procedure for material preparation was used in our previous works (Saleem et al., 2013, 2014, 2015). Our initial target was to prepare sorbent films using only HDPE bottles; however HDPE, with relatively smaller molecular weight and molecular chains, could not be swollen significantly with the solvent and could not be converted into a pseudo-gel state; hence most of the solvent did not mix well with HDPE and remained unmixed resulting in an inhomogeneous gel sheet. From the literature (Young-Keun et al., 2007; Zachariades and Shukla, 1995; Zhang and Rumierz, 2011), it was found out that in order to meet this criteria, the polymer's molecular weight should be sufficiently higher with values ranging from 300,000 to 6,000,000 g/mol. Hence, it is in this context, we added 25 wt% of higher molecular weight polymer UHMWPE to help the blend undergo swelling by the solvent to get a pseudo gel state followed by extraction of solvent to create pores. As there are other methods (dry-stretch process and particle stretch process (Zhang and Rumierz, 2011)) available to create porous polymer films, the reason of using solvent extraction method was to achieve a thin film with uniform thickness and good physical properties (Young-Keun et al., 2007; Zhang and Rumierz, 2011).

3. Characterization

BET surface area, pore size and pore volume of HD-75 were determined by N₂ adsorption using Autosorb1-Quantachrome analyzer. Prior to the measurements, the samples were placed under vacuum overnight and then outgassed at 45 °C for 2 h in order to remove moisture completely. Nitrogen adsorption was carried out using a liquid nitrogen bath maintained at 77 K.

Differential Scanning Calorimetry (DSC) with model number TA Q1000 was used to determine the melting temperatures of HDPE bottle, HD-75, and pure UHMWPE.

JEOL 6700F Scanning Electron Microscopy (SEM) with energy dispersive analysis by X-ray was used to observe the surface of the porous sheets.

The hydrophobicity of the absorbent was determined by measuring the water contact angle using digidrop model number “N° SERIE 2850902D”, a product from GBX.

The swelling test was also performed to measure the extent of swelling. In this experiment corn oil was used as a solvent. Sorbent film ($3 \times 3 \text{ cm}^2$) was placed vertically in the oil bath in such a way that only the edge was in contact with the oil surface. The thickness of the sorbent before and after the swelling was measured to calculate % swelling.

3.1. Oil uptake test

A specimen of size ($3 \text{ cm} \times 3 \text{ cm}$) was initially weighed dry (m_s grams) and was then placed on the surface of a liquid bath containing oil. The sorbent was allowed to float on the liquid for 5 min. The specimen was then removed by one of the four corners with the help of forceps and allowed to hang for a specific duration of 60 min in order to achieve equilibrium, then weighed to give the combined weight of uptaken oil and the sorbent sheet, ($m_o + m_s$) g. Then, the oil uptake capacity, which is amount of oil taken up by the dry sorbent, was measured.

Table 1
Properties of the solvents at 23 °C.

Solvent	Viscosity ^a Pa s	Density g/cm ³
Vegetable corn oil	0.09	0.853
Mineral oil	0.21	0.831
RMG380 Marine diesel oil	7.13	0.991

^a At shear rate of 1 per second.

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