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Review

# Flotation separation of waste plastics for recycling—A review

Chong-qing Wang, Hui Wang *, Jian-gang Fu, You-nian Liu

*School of Chemistry and Chemical Engineering, Key Laboratory of Resource Chemistry of Nonferrous Metals, Ministry of Education, Central South University, Changsha, 410083 Hunan, China*

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ABSTRACT

The sharp increase of plastic wastes results in great social and environmental pressures, and recycling, as an effective way currently available to reduce the negative impacts of plastic wastes, represents one of the most dynamic areas in the plastics industry today. Froth flotation is a promising method to solve the key problem of recycling process, namely separation of plastic mixtures. This review surveys recent literature on plastics flotation, focusing on specific features compared to ores flotation, strategies, methods and principles, flotation equipments, and current challenges. In terms of separation methods, plastics flotation is divided into gamma flotation, adsorption of reagents, surface modification and physical regulation.



**Contents**



*Abbreviations:* ABS, acrylonitrile-butadiene-styrene; GRPP, glass reinforced polypropylene; HDPE, high-density polyethylene; HIPS, high impact polystyrene; PA, polyamide (nylon); PC, polycarbonate; PE, polyethylene; PET, poly (ethylene terephthalate); PMMA, poly (methyl methacrylate); POM, polyoxymethelene; PP, polypropylene; PPE, poly (phenylene ether); PS, polystyrene; PUR, polyurethane; PVC, polyvinyl chloride; PVDC, poly (vinylidene chloride).

* Corresponding author. Tel.: +86 731 88879616.
*E-mail addresses:* zilangwang@126.com (C.-q. Wang), huiwang1968@163.com (H. Wang), fu_jiangang@126.com (J.-g. Fu), liuyounian@csu.edu.cn (Y.-n. Liu).

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## 1. Introduction

The world's total consumption of plastics has an average growth rate of 5–6%, and will reach 297.5 million tons by 2015 (Madisonadmin, 2012). Plastic is an excellent and a very useful material to replace ceramic, wood and metals because it is very functional, cheap, hygienic, light and economic. The global production of plastic, therefore, has grown sharply over recent years. The increase in plastic consumption is largely responsible for the increase in solid wastes, and it has a great impact on their management (Derraik, 2002; Al-Salem et al., 2009).

Plastic wastes cause significant environmental problems. Up to now, a major portion of plastic wastes is either landfilled or incinerated with municipal solid wastes (Al-Salem et al., 2009; Subramanian, 2000; Patel et al., 2000; Hopewell et al., 2009). Landfill occupies a great number of lands since plastics need a very long time to be degraded, and it becomes more expensive and limited owing to the increasing volume of plastics and the decreasing landfill capacity for disposal. Incineration of plastic wastes generates hazardous emission including HCl gas and dioxins containing chlorine, and bottom ash which contains lead and cadmium (Hopewell et al., 2009; Zhang et al., 2010). There are several alternative methods for disposal of plastic wastes, e.g., pyrolysis and incineration with energy recovery (Achilias et al., 2007; Demirbas, 2004; Mølgaard, 1995). The pyrolysis process needs high energy consumption for operation and emits air pollution even though the output products from pyrolyzing plastic wastes have a high calorific value. Incineration with energy recovery requires a complicated device to eliminate hazardous products before discharging to the surrounding environment. In this regard, disposal of plastic wastes with clean technology has become an important issue due to environmental effects.

An important characteristic of plastic materials is that they can be melted and reprocessed without any serious change in their physico-chemical properties. With the attitude that plastic wastes can be considered as potential useful resources, the emphasis for disposal of plastics has now changed. Plastic recycling receives increasing attention due to economic, social and environmental reasons (Al-Salem et al., 2009; Subramanian, 2000; Patel et al., 2000; Hopewell et al., 2009; Zhang et al., 2010).

Because of their chemical structure, different types of plastics should not be mixed together for recycling process (Hopewell et al., 2009; Garcia et al., 2007; Andričić et al., 2008). Contamination of the main product with other polymers of different melting points or thermal stabilities can limit the quality of recycled plastics. For example, PET remains unmelted at PVC processing temperatures, and PVC contamination of PET leads to discoloration of the products (Braun, 2002; Paci and La Mantia, 1999). Diminished physical properties resulting from polymer–polymer incompatibility, discoloration, and degradation, cause a relatively low price for such mixed plastics compared with virgin polymers. In this regard, selective separation of waste plastics is the weakest link in the plastic-recycling industry. Recycling of plastics is limited by difficulties in the separation of plastics from one another.

Numerous methods were developed for plastic separation, such as manual separation, triboelectrostatic separation (Park et al., 2007; Hearn and Ballard, 2005), gravity separation (Pascoe, 2006; Malcolm Richard et al., 2011; Gent et al., 2009), selective flotation (Shent et al., 1999; Fraunholcz, 2004; Alter, 2005) and selective dissolution (Pappa et al., 2001). Manual separation is labor-intensive, low efficient and poor in working conditions (Edward, 2000). Due to similar properties of plastics, triboelectrostatic separation and gravity separation are significantly limited for separation of plastic wastes (Shent et al., 1999; Buchan and Yarar, 1996). In the case of selective dissolution, the toxic organic solvents associated with high costs makes alternative methods more attractive. Selective flotation, as a promising alternative, shows remarkable advantages, such as cost-effective and high efficiency (Jody et al., 2003).

The application of flotation to separation of plastic mixtures is relatively new. The earliest study dates back to 1970s and initiates from S. Izumi (Izumi and Saitoh, 1978; Izumi and Tanaka, 1975). Early studies on plastics flotation focused on testing depressants used in ore flotation or on optimizing the hydrodynamics of the flotation device used (Saitoh et al., 1976; Valdez and Wilson, 1979). Considering later studies, surface treatments by utilizing specific chemical and physico-chemical properties of plastics were developed, such as critical surface tension, chain degradation, absorption of reagents (Sisson, 1993; Buchan and Yarar, 1995; Kobler, 1993), which resulted in a number of different techniques for surface treatment of plastic particles to achieve selective bubble attachment in flotation.

In this paper, we discuss the specific features of plastics flotation compared to ores flotation, and review the technology of plastics flotation with respective to strategies for plastics flotation, methods and principles of plastics flotation, flotation equipments, and current challenges. We will focus on experimental studies on separation of plastics by flotation. The problems that hinder the application of plastics flotation are also presented.

## 2. The features of plastics flotation

Though application of flotation to plastic separation is a further step of ores flotation, plastics flotation exhibits a number of specific features, and these features are related to the distinct properties of plastics, such as low density and low surface energy. The features can provide some insights into plastics flotation, and a brief survey of the important features of plastics flotation is shown below.

### *2.1. Properties of plastics*

The hydrophobicity of plastic surface depends on the electrochemical property, which is related to the properties of plastics, involving chemical composition, plasticizers, degree of polymerization, crystallinity, surface structure, and the like (Izumi and Saitoh, 1978; Rossier et al., 1999; Erbil et al., 2003). The difference in these properties is considered to affect the hydrophobicity of plastic surfaces. In addition, the additives in plastics was found to influence the surface properties and the floatability of PVC plastics (Wang et al., 2014). Therefore, from the viewpoint of fundamental study, the effects of properties and additives of plastics should be examined in detail.

Unsimilar to minerals, the properties and additives of plastics can be easily obtained from manufacturers. This helps to conduct fundamental research on plastics flotation. However, the properties of plastics can be changed through mechanical action or contacting with other materials during the utilization of plastic products. Also, prerequisite steps usually employed before selective flotation, including washing, crushing, sink-float separation or surface treatment, cause changes in properties of plastics.

### *2.2. Size reduction of plastics*

The major application of plastics flotation is separation of shredded plastic particles since liberation and decontamination are prerequisite steps before separation. Size reduction involves creation of new surface, and thus the surface of shredded particles is composed of new surface and original surface. The ratio of new