Separation and Purification Technology 144 (2015) 123–132

Contents lists available at ScienceDirect

Separation and Purification Technology

journal homepage: www.elsevier.com/locate/seppur

Rebound and attachment involving single bubble and particle in the separation of plastics by froth flotation

Yue Zhao [a], Yan-Peng Li [a,b,*], Jia Huang [a], Jun Liu [a], Wen-Ke Wang [a,b]

[a] Key Laboratory of Subsurface Hydrology and Ecology in Arid Areas, Chang'an University, Xi'an 710054, China
[b] School of Environmental Science and Engineering, Chang'an University, Xi'an 710054, China

ARTICLE INFO

Article history:
Received 17 November 2014
Received in revised form 11 February 2015
Accepted 13 February 2015
Available online 26 February 2015

Keywords:
High-speed photography
Plastic flotation
Spherical surface
Rebound
Attachment

ABSTRACT

Bubble–particle interaction is critical to the separation of particles by flotation which can be used in plastic recycling. The two particular processes of the interaction (rebound and attachment) are examined visually using high-speed photography in a laboratory scale flotation column. The effects of surfactant (concentration and type) and plastic material on these two stages are also studied quantitatively. The considered surfactants are Tea Saponin, SDBS and CTMAB, while the plastic materials are polyethylene, polypropylene and Teflon. A simple model of bubble attachment time is developed to analyse and interpret the experimental data. The results show that the presence of surfactant significantly affects the rebound process of a gas bubble, while the type of surfactant and plastic material seem to have slight effect. The bubble attachment process is a strong function of the surfactant and plastic material, which can be associated with the changing of bubble size and its hydrodynamic fluid resistance, contact angle on solid surface, as well as surface tension and viscosity of the solution. Such results are helpful for evaluation and analysis of the plastic flotation process, especially for the selection of reagents and objects at an early stage of design.

1. Introduction

In today's world, plastic has become a widely used material in many applications (e.g., packaging, municipal, automotive, electronic and information engineering, etc.) due to its cheap, lightweight and versatility [1]. Statistics show that the global production of plastic has increased by an average of almost 10% each year since 1950 and reaches to 270 million tons today [2]. The rapid rate of plastic consumption throughout the world has inevitably led to the generation of increasing amounts of plastic wastes, which in turn bring serious environmental influences because of their non-biodegradability and high visibility in the waste stream. Therefore, disposal and treatment of plastic wastes have attracted more and more attention and there are several methods developed over recent years, i.e. land filling, and incineration and recycling [3]. Compared with landfill and incineration, recycling of plastics has been demonstrated to be the most effective way to manage the plastic wastes because it poses several benefits such as reducing energy consumption, saving the land resources and reducing the emissions of CO_2, SO_2 and NO_x [4,5].

As one of four activities encircled in recycling of plastic wastes, an effective separation of mixed plastics is necessary because only clean, homogeneous resins can produce recycled plastics products of high quality [6]. Froth flotation, originally applied in the mineral separation process, has been indicated to be an effective separation technique for plastic wastes recently. For example, Pongstabodee et al. [7] reported the use of a three-stage sink–float method and selective flotation to separate six mixed-plastic wastes. Burat et al. [8] developed a treatment of PET and PVC particles with alkaline solutions followed by selective froth flotation using plasticizer reagents. More recently, Wang et al. [9] separated ABS from PS using selective wetting agents by dissolved air flotation in a self-designed apparatus.

Although some studies have been conducted on separation of plastic by froth flotation, these works provide mostly experimental results on the flotation yield as a function of various parameters (e.g., the kind and the concentration of reagents, plastic material, etc.). The fundamentals of rebound and attachment of bubbles with plastic surfaces are still scarce. While the mechanism of bubble–particle attachment in the case of mineral flotation is understood [10,11], the mechanism in plastic flotation is not completely clear. This is because there are two significant differences

* Corresponding author at: School of Environmental Science and Engineering, Chang'an University, Yanta Road #126, Yanta District, Xi'an 710054, China. Tel.: +86 029 82339982; fax: +86 029 85585485.

E-mail address: liyanp01@chd.edu.cn (Y.-P. Li).

http://dx.doi.org/10.1016/j.seppur.2015.02.016
1383-5866/

Nomenclature

C_{AM}	added mass coefficient
$C_{AM,t}$	added mass coefficient for terminal instant
$C_{AM,im}$	added mass coefficient for impact instant
$C_{AM,re}$	added mass coefficient for rebound instant
C_d	drag coefficient
D_{eq}	bubble equivalent diameter
d_h	bubble short axes
d_v	bubble long axes
E	aspect ratio
E_0	Eötvös number
E_k	bubble kinetic energy
$E_{k,t}$	bubble kinetic energy under terminal velocity
$E_{k,im}$	bubble kinetic energy under impact velocity
$E_{k,re}$	bubble kinetic energy under rebound velocity
F	net driving force
F°	average net driving force
F_z	hydrodynamic fluid resistance on bubble surface
g	acceleration of gravity
H	liquid film thickness between bubble and spherical surface
h	initial distance between bubble and spherical surface
h_{cr}	critical thickness of liquid film
O	origin of 2-dimensional coordinate system
P	pressure distribution inside of liquid film
R	reduced radius
R_b	bubble radius
R_s	spherical surface radius
Re	Reynolds number
r	horizontal direction in 2-dimensional coordinate system
S_{max}	bubble maximum rebound distance
t	time
t_{att}	bubble attachment time
U	bubble local velocity
U_t	bubble terminal velocity
U_{im}	bubble impact velocity
U_{re}	bubble rebound velocity
V_h	bubble instantaneous rising velocity
z	vertical direction in 2-dimensional coordinate system
z_1	bubble surface
z_2	spherical surface

Greek symbols

θ_a	contact angle
μ	liquid viscosity
ρ	liquid density
$\Delta\rho$	difference in fluid (liquid and gas) densities
σ	surface tension
χ	bubble deformation ratio
γ	surface free energy
γ^{LW}	dispersive (Lifshitz–Van der Waals) force
γ^{AB}	polar force
γ^{+}	Lewis acid component of polar force
γ^{-}	base component of polar force

between mineral and plastic flotation [12]: surface characteristics and size proportion of bubbles and particles. In the plastics flotation, surfaces of plastics are hydrophobic in natural conditions. Therefore, selective flotation for separation of mixed plastics is necessary, in which reagents (surfactants) need to be used to modify surface characteristics [13–15]. Additionally, small bubbles attach to the large plastic particles in the plastic flotation process, instead of attachment of small mineral particles to the large bubble surface in the mineral flotation process. The inverted size proportion changes the mechanics of bubble–particle interaction. Obviously, the detailed description of small bubble–large particle interaction is required to gain a deep insight on the attachment mechanism for achieving high efficiency in flotation separation of plastic wastes.

The bubble–particle interaction generally can be divided into three processes: collision–rebound, attachment and detachment [16]. With approach of bubbles and particles to the contact distance, collision–rebound can occur, but the outcome of collision–rebound may not lead to attachment. For a stable bubble–particle attachment, a liquid film formed between the bubble and particle surface needs to be ruptured, and a liquid/gas/solid three-phase contact (TPC) line must be formed [17–19]. So far, bubble–particle collision has been well studied and many models have been well established [20,21]. However, attachment process has not been fully explored yet due to its fast period and complex physicochemical mechanism. Recently, some studies appear on the attachment of a rising air bubble to solid surfaces [22–24]. However, most of those studies focused on interaction of bubble–flat solid surfaces, where the flat surface arrangement may lead to different behaviours in the interaction process (e.g. the bubble may slide away from the spherical surface instead of staying below the surface). In addition, several studies observed directly the collision and attachment, how to quantitatively characterize rebound and attachment of the bubble are still questionable.

The aim of the present work is to better understand the interaction between smaller bubble and larger plastic particle occurring in flotation separation of plastic wastes. Therefore, the study is focused on two particular interaction processes: the rebound and attachment. The normalized maximum rebound distance and kinetic energy of a single bubble are employed to quantify the first process. The attachment process is characterized by the bubble–particle attachment time. The effects of surfactant (concentration and type) and plastic material on these quantities are also examined. A simple model for attachment time is also developed to explore the attachment mechanism in plastic flotation.

2. Materials and methods

2.1. Materials

Three types of spherical ball with 38 mm in diameter were chosen as a stationary particle with which rising bubble interacted in the present study. These balls were composed of different types of commercial plastic materials: polyethylene (PE), polypropylene (PP), and Teflon. They were microscopically smooth. Before each measurement, these balls were cleaned and degreased with cyclohexane followed by ethanol and then carefully washed-out with deionised water.

Three types of surfactants employed as flotation reagents in this study were Tea Saponin (CAS No. 8047-15-2, nonionic, $C_{57}H_{90}O_{26}$, molecular weight 1191.3 g/mol), SDBS (CAS No. 25155-30-0, anionic, $C_{18}H_{29}NaO_3S$, molecular weight 348.48 g/mol) and CTMAB (CAS No. 57-09-0, cationic, $C_{19}H_{42}BrN$, molecular weight