ARTICLE IN PRESS

Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Estimation on separation efficiency of aluminum from base-cap of spent fluorescent lamp in hammer crusher unit

Seung-Whee Rhee

Department of Environmental Engineering, Kyonggi University, Suwon, Republic of Korea

ARTICLE INFO

Article history:
Received 31 March 2017
Revised 29 May 2017
Accepted 1 June 2017
Available online xxxx

Keywords:
SFL
Base-cap
Aluminum
Separation efficiency
Hammer crusher unit

ABSTRACT

In order to separate aluminum from the base-cap of spent fluorescent lamp (SFL), the separation efficiency of hammer crusher unit is estimated by introducing a binary separation theory. The base-cap of SFL is composed by glass fragment, binder, ferrous metal, copper and aluminum. The hammer crusher unit to recover aluminum from the base-cap consists of 3 stages of hammer crusher, magnetic separator and vibrating screen. The optimal conditions of rotating speed and operating time in the hammer crusher unit are decided at each stage. At the optimal conditions, the aluminum yield and the separation efficiency of hammer crusher unit are estimated by applying a sequential binary separation theory at each stage. And the separation efficiency between hammer crusher unit and roll crush system is compared to show the performance of aluminum recovery from the base-cap of SFL. Since the separation efficiency can be increased to 99% at stage 3, from the experimental results, it is found that aluminum from the base-cap can be sufficiently recovered by the hammer crusher unit.

1. Introduction

With the Minamata Convention on Mercury coming into effect from 2013, mercury has been controlled in a serious manner throughout the world. According to the Minamata Convention, products containing mercury such as batteries, thermometers, electric switches, sphygmomanometers, cosmetics and fluorescent lamps will be prohibited to import and export by 2020 (UNEP, 2013). In addition, mercury usage is being regulated even in the electric/electronic products. But mercury usage is permitted in fluorescent lamp because fluorescent action in a fluorescent lamp is done by mercury (Battye et al., 1994; Kumar et al., 2017). Recently, the market of light emitting diode (LED) is expanding so that the market of fluorescent lamp containing mercury is likely to be reduced (Ardente et al., 2015; Yeh and Chung, 2009). However, it is estimated that about 114 million units of fluorescent lamp are sold every year in Korea, and that 70% or more spent fluorescent lamps (SFLs) are generated at business sites (Choi and Rhee, 2016; Park and Rhee, 2016; Rhee et al., 2013). According to the Korea lighting recycling corporation (KLRC), recycled amount of SFL selected as an item in the extended producer responsibility (EPR) has been improved from 33,125 thousand units in 2010 to 43,712 thousand units in 2014, which is a 10.5% increase during the last 5 year (KLRC, 2017). Based on the year 2014, SFLs have been recycled by 32.7%, but their recycling rate is insufficient yet comparing to the recycling rate of metal cans or glass bottles, which are about 80% (Ministry of Environment, 2015, 2016).

Recently, with the international recognition of its significance as a resource, nonferrous metal has been recognized for its significance of collection and made it as a resource. And many countries are showing their interest in collecting aluminum and copper from the SFL (Durao et al., 2008; Machacek et al., 2015; Wu et al., 2014). The price of aluminum has risen from approximately US $1400 per ton in 2009 to US $1700 per ton in 2015 (InfoMine Inc., 2017). It showing almost 20% price rise and the trend of price has increased. Demand on aluminum has increased throughout the world because it should remain supported by the building and apartment construction as well as the automotive and airway field (Sevigné-Itoiz et al., 2014). Since most concern for SFL has been focused on the control of mercury to prevent the contamination of environment and the toxicity of human health, the recycling of metals in SFL has not significantly considered (Huber et al., 2006; Jang et al., 2005; US EPA, 1997). In the United States, the environmental protection agency (US EPA) has classified SFL as a universal waste from 1999 but the majority of SFLs end up in the solid waste stream and only 23% have been recycled (Durao et al., 2008; US EPA, 2005, 2009). Canada has been recycled the combined metals from mercury-containing lamp but aluminum was not separately collected from the base-cap of SFL (Hilkene and Friesen, 2005). Hobohm et al. (2017) studied the efficiency of several acid

E-mail address: swrhee@kyonggi.ac.kr

http://dx.doi.org/10.1016/j.wasman.2017.06.003
0956-053X/

Please cite this article in press as: Rhee, S.-W. Estimation on separation efficiency of aluminum from base-cap of spent fluorescent lamp in hammer crusher unit. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.06.003

digestion methods for the determination of the elemental composition and elemental mass fraction including Al in SFLs. The recovery of another materials such as glass and plastics from compact fluorescent lamp was also studied by using the different specific gravity of materials in air separator unit (Rhee and Choi, 2016). Rabah (2004) has performed a study that collected aluminum and copper-nickel alloy from the SFL using a combined pyro-hydrometallurgical method. Rhee (2003) has crushed the base-cap by using a rolling machine in order to collect aluminum from spent fluorescent lamps. Aluminum from the rolling machine contained impurity materials as the aluminum is compressed, and it was evaluated that the separation efficiency of the aluminum collection in the rolling machine system was not very high. In order to collect aluminum and copper from the base-cap of SFLs, therefore, it was considered using more efficient device than the rolling machine. From the review on crushing methods and operations, the hammer crusher may be more favorable than the roll press to separate aluminum from the base-cap of SFL because the function of hammer crusher is an impaction on the base-cap.

In this study, aluminum, a valuable matter, was to be collected from the base-cap of SFL by using a hammer crusher unit. With this purpose, the characteristics and the mass of base-cap have been grasped preferentially to apply the binary separation theory through the hammer crusher unit. The optimal conditions for experimental factors in crushing and selective experiments were set based on the separation theory. Moreover, separation efficiency of aluminum was intended to be reviewed, checking recovery rate of aluminum and reject rate of other materials from the stream of the base-cap of SFL.

2. Theoretical background

In case of mechanical devices for crushing and separating spent fluorescent lamp (SFL), the definition of material recovery rate is not simple and may be more or less disparate according to each separation theory. This study has reviewed the yield of materials recovered such as aluminum from the base-cap of SFL by applying a sequential binary separation theory to the crushing process. In the binary separation theory, one inlet material such as the base-cap of SFL can be discharged through the crusher unit to 2 kinds of outlet, namely recovery material outlet and other material outlet (Vesilind et al., 2002). In recovery material outlet, aluminum was selected to be recovered material discharged from the crusher unit of the base-cap of SFL. The other materials except aluminum were selected to be rejected materials discharged from the crusher unit in other material outlet. However, the outlets in the binary separation theory may contain both recovery material and other materials. In the sequential binary separation theorem, the recovery rate of materials can be used as an indicator that shows the separation efficiency, and according to the proposal formula of Worrell, the recovery rate of aluminum can be expressed as follows (Worrell and Vesilind, 1979):

$$\text{Recovery rate of } X_i = \frac{X_i}{X_{i-1}} \quad (1)$$

where X_i is the net amount of X among the amounts recovered at stage i, and X_{i-1} is the total input amount of X at stage i. In addition, yield that shows the purity for a recovered good, aluminum, can be defined as follows, and it means that the higher the yield is, the better the purity is.

$$\text{Yield of } X_i(\%) = \frac{X_i}{X_i + Y_i} \times 100 \quad (2)$$

where Y_i is the net amount of Y in the recovery material outlet at stage i. The yield can be represented as the ratio of net amount of X from the amount recovered. In this study, it is significantly important to review the aluminum yield.

Besides, reject rate of the other material is used as another indicator that related the separation efficiency for the crusher unit. The reject rate of the other material can be defined as follows.

$$\text{Reject rate of } Y_i(\%) = \frac{Y'_i}{Y_{i-1}} \times 100 \quad (3)$$

where Y'_i is the net amount of Y in the other material outlet at stage i, and Y_{i-1} is the total amount of Y inserted at stage i. In order to separate and recover aluminum from the base-cap of SFL, it was tried to evaluate the aluminum yield based on the sequential binary separation theorem for 3 stages. The material flow in the binary separation system to recover aluminum from the base-cap of SFL for the sequential 3 stages can be shown in Fig. 1. In Fig. 1, the base-cap of SFL was the initial input material and discharged into aluminum and other materials. It was represented aluminum as X and other materials as Y in the recovery material outlet, while it was represented aluminum as X′ and other materials as Y′ in the other material outlet.

The separation efficiency for the hammer crusher unit can be described by Worrell's proposal formula as follows.

$$\text{Separation Efficiency } (\%) = \frac{(\text{Recovery rate of } X_i) \times (\text{Reject rate of } Y_i)}{100} = \frac{(X_i/X_{i-1}) \times (Y'_i/Y_{i-1})}{100} \quad (4)$$

If aluminum recovery can be decided to be 100%, in the binary separation theory, the separation efficiency should be the same as the reject rate of other materials. Since the mass of aluminum in the base-cap in inlet flow can't change the mass of aluminum in outlet flow, in the case of aluminum from the base-cap, the recovery rate of aluminum can be evaluated to be 100%. In order to evaluate the separation efficient of the hammer crusher unit, hence, that may be fully dependent of the reject rate of other material.

3. Materials and methods

3.1. The base-cap of SFL

The base-cap from the linear SFL (32 W) was used as an input material in the experiment and all experiments were carried out with the same type of base-caps from the linear SFL. In order to obtain base-cap, end-cutting system was introduced to recover it by thermal impact at the glass around the base-cap. The structure of the base-cap from the linear SFL was depicted in Fig. 2. Base-cap contains an insulation sieve plate with brass pins outside aluminum cap and the inside of aluminum cap is made up of tempered glass. 2 strands of copper/iron mixed wire through this glass cone are connected with the tungsten filament for flowing an electricity. In order to protect this filament, a circular plate consisted of iron was enclosed the filament. The size of aluminum cap is expressed by a diameter of 36.5 mm and a height of 14.3 mm.

3.2. Experimental apparatus and method

An experimental apparatus based on an impact crushing technique consists of hammer crusher, screen separator and magnetic separator as shown in Fig. 3. The reason why it used a hammer crusher is to have an advantage for the separation of aluminum from the base-cap without impurities. In this experiments, the recovery of aluminum from the base-cap was performed by using hammer crusher through 3 stages. Ferrous material was collected by using a magnetic separator. Aluminum was separated from

Please cite this article in press as: Rhee, S.-W. Estimation on separation efficiency of aluminum from base-cap of spent fluorescent lamp in hammer crusher unit. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.06.003