Recycling of aluminum and plastic from laminated aluminum packaging films by metallurgy method

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Abstract

A hydrometallurgical method was applied for aluminum extraction from laminated aluminum packaging films (LAPFs) waste. The leaching of LAPFs using hydrochloric acid solutions was used to separate aluminum from polyethylene plastic. Leaching behavior were examined with the effects of acid concentration, liquid/solid ratio and leaching time under fixed condition. The aluminum content in the leached solution was observed to increase as each of the aforementioned factors increases. The content of aluminum was analyzed by UV-VIS spectrophotometer at 535 nm wavelength. The separated plastic was identified by Fourier transform infrared (FTIR) spectroscopy. At the optimal conditions; HCl concentration of 6 mol L⁻¹, liquid/solid ratio of 24:1, and leaching time of 8 hours, the experiment achieved 100% recovery of aluminum in the solution, which indicated that the complete separation of aluminum and polyethylene is achieved.

Keywords: Leaching, Separation, Aluminum, Laminated waste

1. Introduction

The increasing amount of plastic wastes has caused many problems in the world such as environmental pollution and is a waste of natural resources. The branch that uses the largest share of plastics is the packaging industry. General plastic packaging is discarded after a relatively short service life, hence packaging contributes to the majority of the plastic wastes (Dahlbo. H, 2018). The main options for treatment of plastic wastes involves reuse, recycling, and remanufacturing. Recycling is the reprocessing in a production of wastes for the original purpose or other purposes, which is considered cleaner and more sustainable than another options (Cui J, Zhang L, 2008) (Gente V, 2003). Some types of packaging plastic wastes are composed of metals and multiple layers of polymers, such as food and beverage packaging, which increases the difficulty of recycling.

Polymer laminates were manufactured particularly for the needs of the food and beverage packaging industry, which improved properties of individual polymers, such as printing, abrasion resistance, water resistance, and gas barrier properties (Niaounakis M., 2015). The main components of polymer laminates or laminated aluminum packaging films (LAPFs) consist of polyethylene film and aluminum foil (Xie M, 2016)
Various studies have investigated the separation of LAPFs into polyethylene and aluminum for recycling purposes. C. Wang et al. studied metallurgical separation of waste pharmaceutical blisters (WPBs), the hydrometallurgical method was demonstrated to improve the effectiveness of aluminum extraction from plastics (Wang, C, 2015) which led to the high recovery of aluminum and purified plastic. J. Xiao et al. research used acid leaching to extract free aluminum ions from coal gangue (Xiao, J, 2015). The aluminum minerals in coal gangue were extracted by hydrochloric acid (HCl) solution as shown in the following reaction:

\[ \text{Al}_2\text{O}_3 + 6\text{HCl} \rightarrow 2\text{AlCl}_3 + 3\text{H}_2\text{O} \]  

Leaching behavior of all valuable metals from waste printed circuit boards (PCBs) has been investigated using hydrometallurgical methods by E-y. Kim et al. (Kim E-y, 2011)

Recycling of WPBs, coal gangue, and PCBs is similar to LAPFs in the process of extracting metals from waste materials. Many recovery methods were investigated such as pyrometallurgical methods and hydrometallurgical processes. (Cui. J, 2008) The hydrometallurgical methods are considered to be the more efficient method compared to the pyrometallurgical methods, which have several drawbacks such as slow kinetics, significant generation of liquid wastes, and low efficiency in recovering all valuable metals from plastic wastes (Kim E-y, 2011)

In this study, a hydrometallurgical method was applied for aluminum extraction from LAPFs waste. The leaching of LAPFs using hydrochloric acid solution was conducted to separate aluminum from polyethylene dual layers while optimizing the condition parameters which include acid concentration, liquid/solid ratio and leaching time. The purpose is to recycle plastic waste for reuse, both for valuable metals and plastics, which operated on minimum energy in the leaching process.

2. Experimental

The LAPFs waste with the size range of 4.75-16 mm as shown in Fig. 1, which was used as the sample for the leaching tests. The samples of LAPFs were supplied from Confrere Expert Co., Ltd., Thailand, containing 20 wt% aluminum and 80 wt% plastics. Spectrophotometric analysis and Fourier transform infrared were employed for obtaining recovery rate of aluminum and analysis of separated plastic. In this research, all chemicals used were analytical grade reagents.
2.1 Leaching tests

Leaching LAPFs samples were conducted by hydrochloric acid (HCl). Acid leaching conditions were performed by treating 5 g of LAPFs sample in the beaker glass. The experiments were systematically studied by varying 2.5 to 10 mol L⁻¹-HCl acid concentration, 8:1 to 32:1 liquid/solid ratio and 2 to 12 hours of leaching time at room temperature. After the leaching tests, the residue plastic film was separated from the leached solution through filtration by using a filter paper, and the aluminum content in the leached solutions were analyzed using spectrophotometric analysis.

2.2 Determination of aluminum content

The leached solution was taken to determine aluminum content using Eriochrome Cyanine R method. 2 ml of the sample solution, containing 2-70 µg aluminum and free from interfering elements, was mixed with 5 ml of 5-volume hydrogen peroxide. pH of the solution was adjusted to 6.0 (using either 0.2 mol L⁻¹-sodium hydroxide or 0.2 mol L⁻¹-hydrochloric acid). Then 5 ml of Eriochrome Cyanine R solution was added into the sample. After that 50 ml of the dilute buffer solution was introduced, and immediately diluted with distilled water to 100 ml in a volumetric flask. After 30 minutes, absorbance of the solution was measured using a double beam UV-VIS spectrophotometer at 535 nm wavelength (UV-1800, Shimadzu Corporation, Japan) (Bassett J, 1985)
2.3 Fourier transform infrared analysis

The separated plastic was determined by Fourier transformation infrared (FTIR) analysis using a JASCO FTIR-6800 spectrometer (JASCO Corporation, US) and a ATR PRO ONE Single reflection accessory in the wave number region between 4000 to 400 cm\(^{-1}\) with the resolution of 4 cm\(^{-1}\).

3. Results and Discussion

3.1 Effect of acid concentration

The effect of acid concentration on extraction of aluminum was studied under room temperature without stirring, leaching time of 12 hours and liquid/solid ratio of 24:1 as shown in Fig. 2.

The recovery of aluminum as a function of HCl concentration shows similar trend at different concentration, and the recovery increases with increasing of HCl concentration. The recovery of aluminum is 67.86% when using 2.5 mol L\(^{-1}\) HCl solution and rises up to 100% when HCl concentration exceed 6 mol L\(^{-1}\). However, increasing HCl concentration from 8 to 10 mol L\(^{-1}\) does not yield higher aluminum recovery as it has already reached 100% recovery at 8 mol L\(^{-1}\), which is significantly higher compared to the C. Wang et al. research, which used 2.5 mol L\(^{-1}\) HCl to achieve 100% recovery of aluminum in WPBs. (Wang C, 2015)

The 6 mol L\(^{-1}\) HCl concentration was selected for next experiments.

3.2 Effect of liquid/solid ratio

The effect of liquid/solid ratio on the recovery of aluminum is displayed in Fig. 3.

The recovery of aluminum increased with increase in liquid/solid ratio. The recovery of aluminum is 43.95% at 8:1 liquid/solid ratio and up to 100% at 24:1 liquid/solid ratio. At 28:1 liquid/solid ratio, the percent recovery of aluminum decreased slightly due to experimental errors caused by the difference of aluminum content in the sample. Therefore, the liquid/solid ratio of 24:1 can be selected as the optimum condition for next experiments.
3.3 Effect of leaching time

The leaching of aluminum from the waste LAPFs was studied with different times and results are plotted in Fig. 4. The experiment conditions were fixed at 6 mol L\(^{-1}\) HCl concentration, liquid/solid ratio of 24:1 and without stirring. The recovery of aluminum is 93.24% at 2 hours leaching time, and up to 100% after leaching for 8 hours. At 12 hours leaching time, the percent recovery of aluminum slightly decreased due to experimental errors caused by the difference of aluminum content in the sample. The leaching time of 8 hours is sufficient to separate aluminum and polyethylene (PE) in LAPFs.

3.4 Separated PE plastic film

Aluminum and PE plastic film in LAPFs were separated completely with the optimum conditions at room temperature as follow; HCl concentration of 6 mol L\(^{-1}\), liquid/solid ratio of 24:1 and leaching time of 8 hours. The FTIR spectrum of PE plastic film was shown in Fig. 5. Peaks at 2916 and 2848 cm\(^{-1}\) are ascribed to the antisymmetric and symmetric stretching of -CH\(_2\) groups (Traboulsi A, 2012) -CH\(_2\)- deformation mode at 1464 cm\(^{-1}\) and -CH\(_3\)- deformation mode at 1377 cm\(^{-1}\) (Liu Z, 2011)

In the unsaturation zone, R\(_1\)-CH=CH-R\(_2\) trans vinylene groups at 965 cm\(^{-1}\), R-CH=CH\(_2\) vinyl end groups at 908 cm\(^{-1}\), R\(_1\)R\(_2\)C=CH\(_2\) vinylidene groups at 888 cm\(^{-1}\) (Tidjani A, 1995) and characteristic of long chains of -CH\(_2\)- in PE at 718 (peak) and 729 (shoulder) cm\(^{-1}\) (Gaston F, 2016)
Fig. 3 Effect of liquid/solid ratio on the recovery aluminum.

Fig. 4 Effect of leaching time on the recovery aluminum.
4. Conclusion

LAPFs is regarded as a potential recycling waste of aluminum and PE plastic with a hydrometallurgical method using hydrochloric acid. The effects of HCl concentration, liquid/solid ratio and leaching time on leaching of aluminum from LAPFs waste were investigated. The aluminum content in the leached solution was observed to increase as each of the aforementioned factors increases.

The optimal conditions for complete separation of aluminum and PE plastic in LAPFs, which were determined at room temperature, are HCl concentration of 6 mol L$^{-1}$, liquid/solid ratio of 24:1 and leaching time of 8 hours. The recovery of aluminum reached 100% at these conditions, and the purified PE plastic was identified by Fourier transform infrared spectroscopy. This study offers an efficient technique for the recycling of laminated plastic wastes, which is considered cleaner and more sustainable.

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