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Cleaning of lubricant-oil-contaminated plastic using liquid carbon dioxide

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ABSTRACT

The feasibility of using liquid carbon dioxide for cleaning contaminated plastics was evaluated. Flow sheets for the CO_2 cleaning processes have been conceptualized and the material and energy balances were conducted using ASPEN Plus. The average % lubricant oil in waste plastics was found to be 2.49%. Although the CO_2 cleaning process with hexane as a co-solvent resulted in a higher cleaning efficiency than the process without co-solvent, it consumed 2.2 times more energy. Based on cleaning 30 kg of plastics, the operating cost of the process with hexane was 5.7 times higher than that of the process without hexane.

Introduction

Plastics are used in a wide range of products due to their various beneficial properties such as versatility, durability and relatively inexpensive to produce. However, an increase in plastics waste generation, especially lubricating-oil containers, is unavoidable due to the rapid growth in industrial development and automobile industries. Since plastics are not biodegradable, they are not suitable for land filling. Their destruction via an incineration process can also cause serious air pollution problem due to the release of airborne particles and carbon dioxide into the atmosphere [1–3]. In addition, due to the high disposal amount of lubricating-oil containers each year, it is a challenge to minimize the disposal quantity. Recycling of these lubricating-oil containers seems to be an appropriate solution because it avoids accumulation in landfills, and clean plastics can be reused in the recycling process for making new containers.

In the recycling of lubricating-oil containers, the post-consumer plastics are inspected for quality and washed to remove any residual impurities. Then, they are ground into pieces, dried and processed into pellets or flakes. Finally, the processed materials, in either flake or pelletized form, become feedstock in the manufacture of new products. It is important to note that thermal, mechanical and impact properties of the recycled plastics should be close to the virgin material to ensure the quality of the final products [4,5]. In general, these lubricating-oil containers are washed by using either detergents or organic solvents. However, there are many drawbacks to this conventional cleaning technique. These include the production of large quantities of contaminated wash solution which must be handled as hazardous waste, low cleaning efficiency and the use of non environment-friendly organic solvents.

A supercritical fluid (SCF) has been established as a good alternative solvent. The use of supercritical fluids in the area of extraction has been well documented over the last few decades [6–11]. The adjustable solvent strength and gas-like transport properties make supercritical fluids efficient solvents for the extraction process. In addition, the increased scrutiny of industrial solvents by governments and awareness of pollution control have motivated the use of supercritical fluid as a cleaning solvent [12]. Recently, many researchers have used supercritical carbon dioxide for precision cleaning application, for examples, removing lubricating oil from metallic contacts [13], removing contaminants for remanufacturing industry [14,15], cleaning of rollers for

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printing industry [16] and degreasing process in the leather industry [17]. Low critical point fluids are typically preferred since they can be used in the processing of heat sensitive compounds such as pharmaceuticals, and the inherent expense of high pressure equipment is not significant. Carbon dioxide is the most common fluid employed in supercritical fluid applications since it is non-flammable, non-toxic, non corrosive, readily available and inexpensive and has a relatively low critical point (T_c = 31.8 °C and P_c = 7.3 MPa) [18].

Although the supercritical fluid cleaning has proved to be efficient and can be considered as a green sustainable process, the main drawback of this technology for up-scaling is the high operating pressure. A high pressure pump and high pressure resistant piping are mandatory in the cleaning process, resulting in an unavoidable high capital cost. In addition, operating under high pressure contributes to a higher risk and thus more safety precaution is needed. In order to compensate the drawback of supercritical fluid cleaning but still maintain its advantages, the use of liquid carbon dioxide for lubricating-oil removal was investigated in this study.

The objective of this work was to study the feasibility of lubricating-oil removal from plastic containers using liquid carbon dioxide. The effects of operating temperature, pressure, co-solvent and time of contact between oil and plastic on the removal efficiency were investigated. The original and the processed plastics were then analyzed using a Melt Flow Index Tester in order to monitor the quality of the extruded or injection-molded thermoplastics. Furthermore, flow sheets for the cleaning process of 30 kg/day of contaminated plastics (with and without hexane as a co-solvent), along with the material and energy balances, were simulated using the software ASPEN Plus version 7.1.

Materials and methods

Materials

Used lubricating-oil containers were purchased from a local market. The lubricating oil used in this research was Performa semi-synthetic SAE10W-40 API SM/CF from PTT Thailand (a mixture of long-chain hydrocarbons with a viscosity of 14.9 cSt at 100 °C and a flash point of 232 °C [19]). The material for the contaminated plastic and unprocessed plastic was high density poly ethylene (HDPE). Carbon dioxide (high purity grade, TIG) was used as an extracting or cleaning solvent. Hexane (commercial grade) was used as a co-solvent.

Methods

Determination of %lubricating oil in the waste plastics

Prior to performing the lubricating-oil removal using liquid CO_2, it is necessary to determine the amount of oil left in the waste plastics. The obtained % lubricating oil in the waste plastic is important data that is required for determining the % cleaning efficiency and for scaling up the process. Twenty lubricating-oil containers from various places were used as representative samples for determining the amount of lubricating oil left in the contaminated plastics. The labels on the containers were removed and the containers were cut into three different sections, namely the top, middle and bottom, and then cut again into small pieces. Two different techniques were used to determine the % lubricating oil in the plastics in this study. The first method was to find the % lubricating oil in different sections and then calculate the average value. Note that for each section, five specimens were selected based on systematic random sampling. The second method was to randomly select 5 specimens from all three sections and determine the overall % lubricating oil. Each specimen was weighed and washed with hexane. In order to ensure the complete removal of the lubricating oil, the specimen was immersed in hexane, in which the ratio of hexane to contaminated plastics was 5:1. The system was shaken for 1 min and the specimen was soaked in hexane for 3 h. The cleaning process was repeated three times with the use of new hexane. After completing the cleaning process, the specimen was air-dried to remove hexane and the final constant weight of clean plastic was then recorded. The %lubricating oil in the contaminated plastic was calculated based on the average of five selected specimens for each section.

Plastic cleaning process

Using new plastics contacted with lubricating oil

In order to control the amount of lubricating oil in the plastic sample, a brand new HDPE plastic container was used as a starting material. The container was cut into 15 cm × 10 cm pieces and then was placed to contact with the lubricating oil only on one side for 7, 15 and 30 days. After a certain period of contacting time, the piece of plastic was removed and the excess oil was drained out. The contaminated plastic was then cut into 0.5 cm × 0.5 cm pieces and used as samples for the cleaning process. Cleaning plastics with liquid CO_2 was carried out using the experimental setup as shown in Fig. 1. Approximately 5.6 g of contaminated plastics was packed in a 500 cm^3 cylindrical extractor. The system temperature was controlled to within 0.1 °C using a recirculation heater (Thermoline Unistat 130). Liquid CO_2 was directed from a dip tube cylinder to the extractor using a high pressure CO_2 cylinder. The system was maintained at the desired pressure and temperature for at least 30 min prior to commencing the cleaning process. The cleaning was initiated by opening valve V-6 and controlling the flow rate of liquid CO_2 at 4 mL/min. The cleaning process was fixed for 3 h. After the cleaning process was complete, the system was depressurized and the CO_2 was released to the atmosphere. All cleaned plastics were then removed from the sample cylinder for further analysis. The % cleaning efficiency was determined by the gravimetric method as follows:

$$\%\text{cleaning efficiency} = \frac{\text{mass of plastics before washing} - \text{mass of plastics after washing}}{\text{mass of plastics before washing} - \text{mass of dried plastics}} \quad (1)$$

Apart from the continuous cleaning process as mentioned earlier, batch cleaning processes with or without adding hexane as a co-solvent were also conducted in order to compare the cleaning efficiency. In the batch process, the extractor loaded with the contaminated plastics was filled with liquid CO_2 at 6.5 MPa and 5 °C. The system was maintained at the desired pressure and temperature for 3 h. After that, the liquid CO_2 was separated from the plastics. The system was then depressurized and the CO_2 was released to atmospheric pressure. In the case of adding hexane as a co-solvent, the contaminated plastics were loaded into the extractor, followed by adding hexane. The ratio of hexane to liquid CO_2 feed was set at 1:10 by volume.