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Environmental Compact Disc Recycling using Cationic and Anionic Surfactants

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ABSTRACT

The use of polycarbonates in industry has increased sharply in recent decades. Various methods are used to remove inks from the polycarbonate surface of printed Compact Discs (CDs). Surfactants were used for de-inking as an effective method for polymer recycling. In this study, the effect of using cationic and anionic surfactants with different concentrations at Critical Micelle Concentrations (CMC) was studied for de-inking of compact discs. The cationic surfactant Cetyltrimethylammonium Bromide (CTAB) removed significantly more ink from CD surfaces than the anionic surfactant Sodium Dodecyl Sulfate (SDS). Scanning Electron Microscope (SEM) was used to investigate the topography of CD surfaces before and after treatment with different surfactants. The de-inking power, which is represented by the area of ink-free pixels in the CD image, was increased with increasing surfactant concentration. The most significant de-inking using CTAB was achieved at 8x CMC, while that for SDS was achieved at 9x CMC.

Keywords: Compact disc, De-inking, Recycling, Surfactant, Polycarbonate

INTRODUCTION

Petroleum-based plastic products are generally nonrenewable and non-degradable. Recycling is therefore necessary to decrease the rate of plastic waste and the consumption of petroleum products, thereby reducing environmental damage. Compact Discs (CDs) are optical storage media, in which large amounts of information can be kept. CDs are made of mainly polycarbonate, dyes and reflective layers on the surface [1]. The dye layer is sandwiched between the polycarbonate substrate and the metalized reflective layer of the media and contains organic dyes such as cyanine and metal azo (to store data), while the reflective layer is made up of aluminum to reflect the laser light (allowing the data to be read). As CDs are mainly composed of polycarbonate, they are often referred to as polycarbonates.

The uses of polycarbonates has recently rapidly expanded, with variable applications in the automotive industry, electronics, rail services, devices, batteries, office equipment, glazing, data recording media and medical equipment [1]. Recycled polymers (or polymers prepared from recycled materials) are less valuable than virgin polymers. This is can be explained by the effect of the remaining ink and the change of the physical and mechanical properties of the polymer [2]. These problems can be easily avoided by removing ink from the plastic surface just before the recycling process. In last decades, recycling has withdrawn the attention of scientists for its unlimited importance [3-7]. The use of organic solvents or surfactants are promising possible alternatives for plastic de-inking. However, because surfactants are environmentally friendly (Biodegradable, non-toxicity and non-volatile as aqueous solutions) they are considered advantageous as de-inking tools. Many studies have addressed the surfactant-based de-inking processes on various surfaces and films [8-12].

De-inking of polymeric products is basically a laundering process. The adhesion of ink to the plastic materials is the result of various forces (e.g., Electrostatic, Van der Waals and chemical bonding). Laundering is a two-step process similar to de-inking: (i) Isolation of soil (ink) from the substrate (polymer surface) and (ii) Dispersion of soil in a solvent by a mechanical action [13]. As in any laundering process, the effect of surfactant adsorption, surface tension, dispersion, wetting and solubilization are all significant in the de-inking process. Ink removal from the polymer surfaces using aqueous solutions of surfactant is assisted by the surfactants adsorption onto the polymer and ink surfaces, thus, the interfacial tension of both polymer-water and ink–water is significantly decreased [14,15]. Moreover, numerous researchers have evaluated the removal of ink from various surfaces (e.g., paper surfaces) [16,17].

Here we focus on the removal of printed layers on surfaces of polycarbonate, a polymer of extensive use, using various surfactants. These surfactants are alternative types of opposite charge behavior, cationic and anionic surfactants were applied as de-inking agents with various concentrations up to 60 minutes to recycle printed CDs.

MATERIALS AND METHODS

CDs were mainly composed of polycarbonates. These CDs were randomly collected. The cationic surfactant Cetyltrimethylammonium Bromide (CTAB) and the anionic surfactant, Sodium Dodecyl Sulfate (SDS) were supplied by Sigma Aldrich Company with purity greater than 99%. These surfactants were used as received without further purification. Sonication bath was used to enhance the De-inking process of CDs in presence of different types of surfactants. Ultrasonic with frequency 80 kHz for tough or gentle mixing was adjusted at room temperature with different working periods.

Characterizations

Optical scanner: Samsung Scanner (SCX-4321) is a superior high resolution scanning performance instrument with high definition quality up to 4800 dpi and 64 bit.

Scanning Electron Microscopy (SEM): SEM was conducted for rubber blends with the aid of scanning electron microscope "probe micro-analyzer", Model JXA-840A, JOEL, Technics Co. Ltd., Tokyo, Japan.

De-inking process: Solutions of SDS and CTAB were prepared using distilled water at room temperature and stirred with a magnetic stirrer to prepare a homogeneous solution. The surfactant solutions were then stirred again at 40°C in order to accelerate the dissolution. Each CD sample was placed in a surfactant solution and then allowed to soak for different time intervals at room temperature in a sonication bath. After soaking, the CD samples were removed from the surfactant solution, washed several times using distilled water and air-dried.

Analysis of the De-inking process

The amount of the ink that has been removed was simply determined using an optical scanning method [18]. In this method, each CD sample was positioned carefully on a scanner and scanned under optimum conditions using a Samsung SCX-4321 scanner. A black board was placed behind the CD sample during the scanning process to avoid reflection from the white surface of the scanner cover. After the scanning process, the image file was transferred to Adobe Photoshop in order to compute the amount of ink (in pixels) remaining on the CD surface. Finally, the amount of removed ink (%) was simply determined according to the following relationship:

$$\text{Ink removed (\%)} = \frac{(\text{Pixels before Deinking} - \text{Pixels after Deinking})}{\text{Pixels before Deinking}} \times 100$$

RESULTS AND DISCUSSION

Important characteristics of the surfactants used (SDS and CTAB) are given in Table 1.

Table 1: Properties of the surfactants used (SDS and CTAB) for De-inking of CD

Surfactant	Structure	CMC (mM)
SDS	$C_{12}H_{25}SO_4^{-}Na^{+}$	8.21 [19]
CTAB	$C_{13}H_{33}N^{+}(CH_3)_3Br^{-}$	0.92 [19]

De-inking with different surfactants at various concentrations

To remove ink from a CD sample, we investigated the addition effect of cationic and anionic surfactants on to CDs. The cationic surfactant was CTAB, while the anionic surfactant was SDS. The concentrations of the surfactants were above the critical micelle concentration since it was expected that the ink removal would require higher surfactant concentration to decrease the surface tension between the ink and the CD surface (polycarbonate). This is mainly related to the fact that a liquid that is wetting a substrate has a higher critical surface tension than that of the non-wetted (free) liquid [19-21].

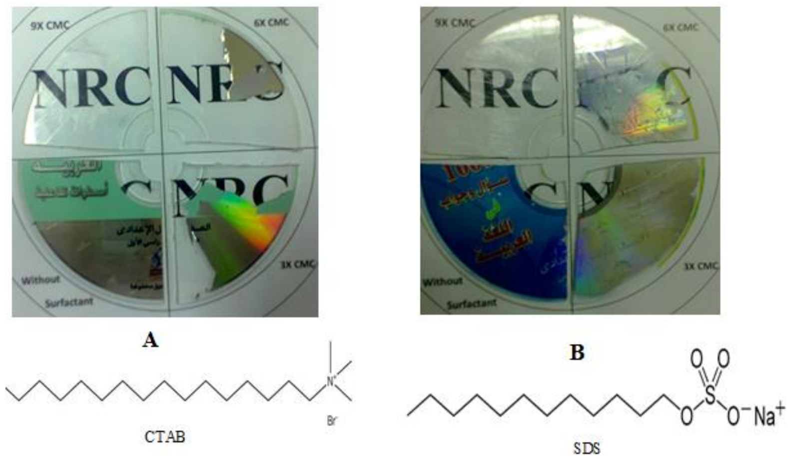


Figure 1: De-inked CD surfaces which were treated with (A) cationic surfactant, CTAB and (B) anionic surfactants, SDS at different surfactant concentrations

Figure 1A shows the four classes examined. The first one (top right side) involves the addition CTAB at 6x CMC, while the second (lower right side) includes CTAB at 3x CMC. The third class (lower left side) involves no surfactant, while the fourth one (top left side) involves the addition of 9x CMC.

In the Figure 1A, the first part of the CD is almost clear (but not completely de-inked). Some areas have remaining ink that was not been removed with the surfactant concentration used (6x CMC of CTAB). The second section of the CD has a relatively small area that is free of ink as a result of using a lower surfactant concentration (3x CMC of CTAB) than in the previous part. The third section of the CD has no evidence of ink removal, which is attributed to the absence of surfactant. In contrast, the best section that is absolutely free of ink was the fourth one, which was treated with CTAB at 9x CMC.

Figure 1B shows four different sections of another sample. For the first section (top right side), SDS at 6x CMC was added, while for the second one (lower right side), 3x CMC of SDS was added. For the third section (lower left side), no surfactant was added at all, while for the final section of this figure (top left side), the highest concentration of surfactant was added (9x CMC of SDS).

The Figure 1B shows that in the first section of the CD, a little ink is removed when using this surfactant concentration (6x CMC of SDS). For the second portion of the CD (3x CMC of SDS), much less ink is removed than in the first part, and the ink appeared as it was before de-inking. In the third section, the ink completely remained as it was before de-inking with water (no SDS surfactant). However, the fourth section of the CD (9x CMC of SDS), had the least remaining ink (the best ink removal).

Generally, the cationic surfactant CTAB had a significant effect on ink removal compared to the anionic surfactant SDS. The rate of ink removal was dramatically enhanced when using CTAB and was better than using SDS, which has a slow rate of ink removal. The optimum concentration of CTAB was 9x CMC. For all concentrations, the ink removal by CTAB was much better than that by SDS.

De-inking with different surfactants (9x CMC) at different soaking time

Figures 1 and 2 show that the best surfactant concentration for the de-inking process is 9x CMC for each surfactant. These figures show that the ink removal efficiency using CTAB and SDS was sharply increased by increasing the CTAB concentration, while it increased gradually with increasing SDS concentration. The difference of de-inking efficiency between CTAB and SDS was higher (between 1x CMC and 8x CMC of surfactant). However, at higher surfactant concentration (9x CMC of surfactant), the ink removal efficiency of both surfactants was actually identical. Therefore, it is important to study the removal of ink from CD samples using the SDS and CTAB at 9x CMC for different soaking times.

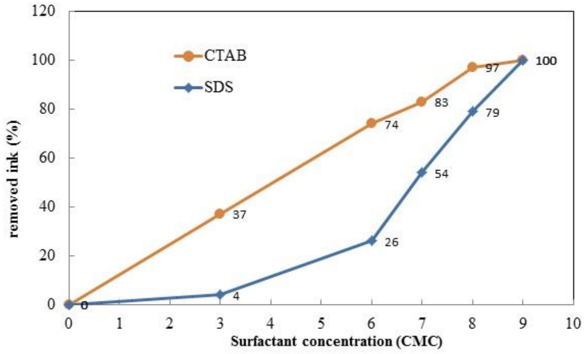


Figure 2: Amount of removed ink from printed CD surfaces using cationic and anionic surfactants at different concentrations

As shown in Figure 3, the rate of ink removal was increased by increasing the soaking time for both surfactants. Additionally, the rate was increased dramatically by increasing the soaking time for CTAB, while it increased steadily when increasing the soaking time of SDS. The best soaking time for completely removing ink from the CD substrate was 60 min. Also, CTAB was more effective than SDS for ink removal for all examined soaking intervals. This finding supports those in Figures 1 and 2.

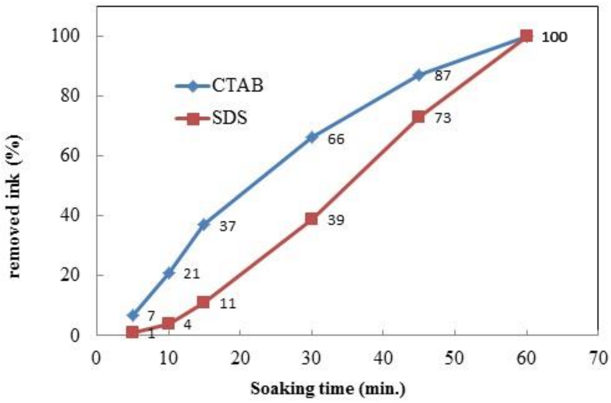
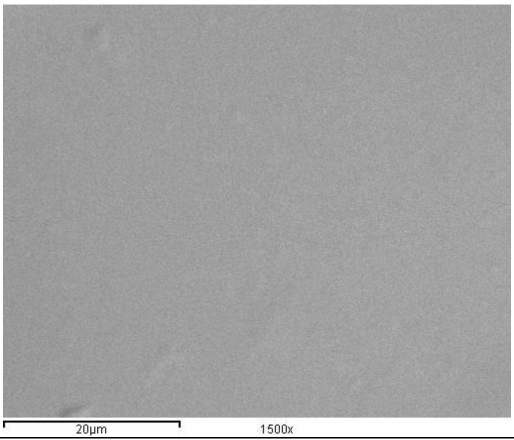


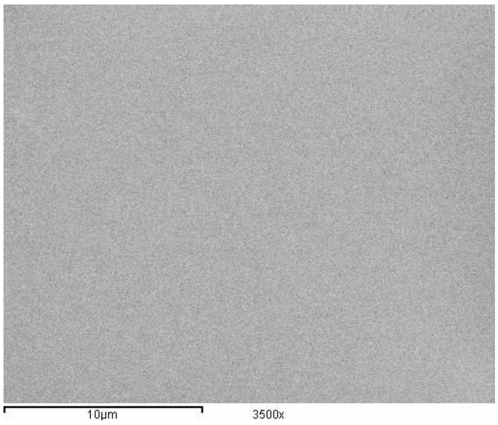
Figure 3: Amount of removed ink from printed CD surfaces using cationic, anionic and nonionic surfactant (at 9x CMC) as a function of soaking time

Scanning electron microscope

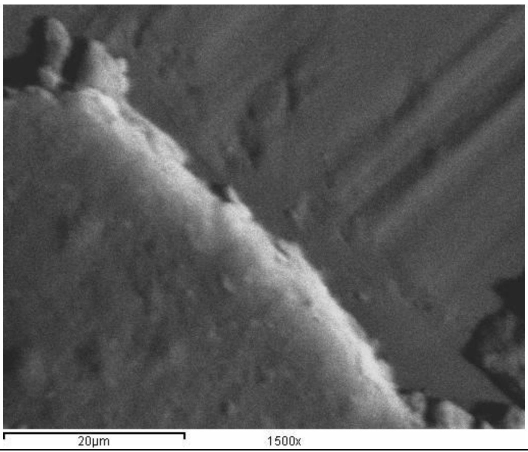
The topographic behavior of treated and non-treated CDs is exhibited in Figure 4. Smooth and clear surfaces were presented in micrographs of unprinted and treated CDs with 9x CMC of CTAB, as shown in Figures 4A and 4B. Additionally, a uniform surface appeared in Figure 4D as a result of the treatment process with 9x CMC of SDS. However, a layer of printing ink can be seen in Figure 4C on the upper surface of the CD treated with SDS (6x CMC), which was partially de-inked.



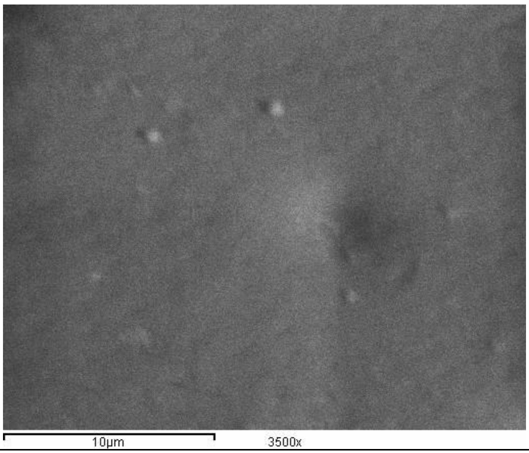
(a) SEM micrographs of unprinted CD



(b) SEM micrographs of de-inked CD with CTAB at 9x CMC for 60 min



(c) SEM micrographs of partially de-inked CD with SDS at 6x CMC for 60 min



(d) SEM micrographs of de-inked CD with SDS at 9x CMC for 60 min

Figure 4: Micrographs of unprinted and de-inked CD treated with CTAB or SDS

Figures 4A, 4B, and 4D show that CTAB has more significant de-inking power than SDS at 9x CMC for 60 min. It is important to study the scanning electron microscope images of de-inked CDs with CTAB only in addition to unprinted CDs to compare the morphological structure of CD surfaces before and after treatment. The surface of CDs treated with CTAB is more similar to that of an unprinted CD surface than CDs treated with SDS. Generally, CTAB has an efficient effect for removing printing ink from the surface of CDs and is an effective de-inking agent.

CONCLUSIONS

The cationic surfactant CTAB was more effective for ink removal from CD surfaces than the anionic surfactant SDS. The efficiency of ink removal was significantly increased by increasing the surfactant concentration CMC and soaking time. The printed layer on the polycarbonate CD surface is more complicated than other printed plastic films, but the cationic surfactant CTAB was better than the anionic surfactant SDS as with any printed plastic substrates.

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