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Environmental recycling of compact disc using industrial wastewater

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ABSTRACT

We performed an environmental method to recycle compact discs using tannery industrial wastewater effluent. This study includes thermogravimetric analysis (TGA), mechanical properties and wastewater characterization before and after treatment. The final recycled compact disc was completely free of ink, and its mechanical properties were slightly enhanced after ink removal. The crystallization behavior of the compact disc remains the same after the de-inking process. After the de-inking procedure, the study was continued to the treatment of tannery effluent by conventional coagulation-flocculation followed by Fenton's treatment process. The coagulation-precipitation process removed 42%, 77%, 86%, 99%, 84%, 85% and 98% of BOD, COD, TSS, H_2S, TKN, P and (O&G), respectively. Unfortunately, due to its solubility in water, the coagulation process did not affect the concentration of phenols. Therefore, Fenton's oxidation process was able to remove 100% of phenols, hydrogen sulfide and phosphorus. The removal of BOD, COD, TSS, TKN, and (O&G) were 84%, 92%, 91%, 80% and 90%, respectively.

Keywords: De-inking, polycarbonate, recycling, wastewater treatment, coagulation, packaging materials.

INTRODUCTION

Polycarbonate is one of the most widely used polymers as electronic product enclosures. Its high heat resistance, toughness, strength and color stability make it a natural for use in office product covers and enclosure applications[1].Annually, immense amounts of compact discs are discarded; more than billionsof optical discs were manufactured and distributed worldwide. The non-biodegradable polycarbonate, heavy metals and harmful dyes of the discs lead to great pollution problems. A few countries have started to recycle compact discs,but the current process is not efficient, has many drawbacks, includes the use of poisonous chemicals and pays no attention to the treatment of dyes. Here, modified and more environmentally friendly processes to recycle compact discs were studied[2-4].

Compact disc (CD) and Digital Video Discs (DVDs) are made up of a polycarbonate disc body (95% by volume) with dye and reflective layers on their surfaces. The dye layer contains organic dyes such as cyanine and metalazo to store data; the reflective layer is made up of metals, largely aluminum, to reflect the laser. All of these materials, if buried in landfills, not only become 'lost' resources but may cause significant environmental impacts because they take a long time to break down.

Recycling has environmental and economic significance[5-7]. Recycling reduces the need for raw materials; using recycled products often requires less energy in the process of manufacturing[8]. Plastics, for instance, are derived from crude oil, a limited fossil fuel. Therefore, recycling discs and their cases can contribute to reducing oil consumption, thereby preserving oil supplies for longer periods of time.

The discs themselves go through a special process, to recycle polymer that removes paint, aluminum and data. The recovered aluminum can be reused in insulation purposes. The cleaned discs are then granulated, blended and compounded to polycarbonate of a high-quality for further use in injection-molded applications such as burglar alarm covers and other applications [9-12].

Given the growing waste stream of optical discs from households around the world, it is critically important to recycle polymers without chemicals in a completely closed environment.

Tannery effluents represent a serious environmental and technological problem due to the presence of many chemicals characterized by a low biodegradability. Several studies have been carried out related to the treatment of industrial effluents through flocculation and coagulation processes [13-16].

There are many important targets to improve environmental sustainability such as reduced water consumption, reusing water, improved uptake of chemicals, and reduced content of toxic compounds (e.g., heavy metals and electrolytes) in industrial applications. The wastewater used in this research was pre-treated tannery wastewater; the pretreatment method included the separation of chromium ions from wastewater by raising the pH near 12.5 [17].

Flocculation describes bridges between flocks and bind particles to large agglomerates that formed by the action of polymeric materials. The formed agglomerated particles are fragile and can be broken apart by shear forces during the mixing process. Care must also be taken not to overdose the polymer since doing so will cause settling and clarification problems.

In addition to conventional coagulation treatments, many studies have discussed advanced oxidation processes (AOPs), particularly the Fenton process.Fenton treatment is used mainly in the removal of phenols and soluble recalcitrant organics [18-20].

The Fenton reaction [21] can be formulated as follows:

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + OH^- + OH^{\cdot} \tag{1}$$

Equation (2) shows an $OH^{\cdot}$radical is generated and Fe^{2+} is consumed.

Fe^{2+} regeneration is suggested by[22] Eqs. (2,3), [23] Eqs (4,5) and by [24] Eqs. (6,7) in these suggestions a formation of superoxide radical anion ($O\text{-}O^{\cdot-}$), hydroperoxyl radical ($HOO^{\cdot}$) and Fe^{3+} is reduced by an iron-III-hydroperoxide in the reaction mixture which reduces Fe^{3+}:

$$OH^{\cdot} + H_2O_2 \rightarrow H^+ + H_2O + OO^{\cdot-} \tag{2}$$
$$Fe^{3+} + OO^{\cdot-} \rightarrow Fe^{2+} + O_2\uparrow \tag{3}$$

$$OH^{\cdot} + H_2O_2 \rightarrow HOO^{\cdot} + H_2O \tag{4}$$
$$Fe^{3+} + HOO^{\cdot} \rightarrow Fe^{2+} + H^+ + O_2\uparrow \tag{5}$$

$$Fe^{3+} + H_2O_2 \rightarrow [Fe^{III}(OOH)]^{2+} + H^+ \tag{6}$$
$$[Fe^{III}(OOH)]^{2+} \rightarrow HOO^{\cdot} + Fe^{2+} \tag{7}$$

The current study has two goals. First, we aim to recycle polymers without chemicals that generate industrial harmful waste. Our second goal is to evaluate the coagulation efficiency of tannery wastewaters as well as the efficiency of the Fenton process for the degradation and removal of recalcitrant materials from wastewater.

MATERIALS AND METHODS

2.1 Wastewater treatment processes

Tannery pre-treated wastewater (chromium separated at the industrial plant by elevating the pH) was collected in one batch for all experiments. The used wastewater of de-inking CDs was strongly contaminated with pollutants, as shown in Table 3. In the coagulation/flocculation process, freshly prepared aluminum sulphate ($Al_2(SO_4)_3 \cdot 18H_2O$), produced by ADWIC (Egypt), anionic polymer Sulzer 611950053, acted as a coagulant aid or as a flocculent that enhanced the impact of coagulation produced by Aquanile (Egypt). 50% sodium hydroxide and 30% sulphuric acid produced by ADWIC was freshly prepared for the pH adjustment.

Coagulation tests were performed in duplicate according to the jar-test method [25]. Six jars of tannery wastewater and coagulant reagents were flash mixed (200 rpm) for 2 minutes; the flocculation step was conducted for 10 minutes, at 30 rpm, followed by a settling time of 30 minutes at room temperature (25±1°C). To determine the optimal pH, coagulant dose, polymer dose and reaction time, we worked to achieve maximal removal of the chemical oxygen demand (COD), and the reaction was carried out and performed according to the jar test. For the process of Fenton treatment, hydrogen peroxides (30% H_2O_2) and ferrous sulphate hepta hydrate ($FeSO_4 \cdot 7H_2O$) were used as Fenton reagents; these substances were produced by ADWIC. Optimal operating conditions were achieved for doses of $FeSO_4 \cdot 7H_2O$ and H_2O_2 and the reaction time using the jar test as a mixing unit (120 rpm). The excess of H_2O_2 is removed by increasing the pH near to 11, and the complete removal of $H_2O_2$was pursued by using Quantofix Peroxide 25 test strips. All of the measured parameters, the biochemical oxygen demand (BOD), the COD, the total suspended solids (TSS), sulfides (H_2S), oil and grease and all extractable materials by chloroform (O&G), the total Kjeldahl nitrogen (TKN), phosphorus (P), of the raw and treated wastewaters were analyzed according to standard procedures for examining water and wastewater, American Public Health Association, APHA [26].

2.2 Instruments and methods

The CD samples were cleaned using wastewater in an ultrasonic cleaning bath from Spectrolab (United States).

We determined the thermal behavior of the CDs via thermogravimetric analysis (TGA) performed on a SDTQ 600 machine (TA instrument) in a nitrogen atmosphere at a scan rate of 10°C/minute from 50°C to 800°C. The mechanical properties (tensile strength, elongation at break and modulus strength) were determined using a tensile testing machine, Zwick 1425 (Germany).

Fig. 1 compact disc before and after deinking using tannery industrial wastewater effluent

For the de-inking process, the printed CDs were immersed in a solution of industrial waste. These solutions were collected directly from the factory (our study used wastewater from a tanning factory) before disposing of them into a drainage system. The CDs were cleaned by shaking them in wastewater using an ultrasonic cleaning bath at 75°C for 90 minutes.

RESULTS AND DISCUSSION

3.1 Ink removal by wastewater:

As can be seen in Fig. 1, the CD was clear and free of ink. Therefore, it is ready to be added to another virgin polymer as a reusable polymer. Also, CDs can be used as a body shape for packaging materials that can be used in different applications.

3.2 Mechanical properties

Based on the data in Table 1, the thicknesses of the deinked CDs (CD1, CD2 and CD3) were less than those of the inked CD (CD0) by 0.3 mm, which corresponds to the removed ink layer. We found that the thickness of the sample had no significant effect on the tensile properties or the elongation at break properties of any of the orientations tested [27]. Moreover, the changes to the tensile strength were similar to those of the tensile modulus. CD0 had the highest tensile strength and tensile modulus; CD3 had the lowest tensile strength and tensile modulus. The decreased tensile strength and tensile modulus for CD1, CD2 and CD3 is attributed to the effect of the solvent (factory waste as a de-inking solution) that decreased the rigidity of the polymer.

The elongation at the break of the de-inked CD was greater than the blank sample (i.e., the CD with ink). This result is due to solvent penetrating through the polymer chains, which increased the efficacy of the solvent de-inking process. Therefore, the recycled CD as a packaging material became more valuable and profitable.

Table (1) Mechanical properties of compact disc before and after De-inking process

Sample	Thickness, mm	Tensile strength(MPa)	Tensile Modulus (Mpa)	Elongation at break(%)
CD0	1.42	32.7	972.5	120
CD1	1.10	24.2	698.8	160
CD2	1.12	26.3	778.4	130
CD3	1.11	23.6	687.1	140

3.3 Thermal behavior

The onset temperature of the main degradation of de-inking of CDs was determined. In the TGA spectrum, for the deinked CD sample, degradation was observed only in one stage, and it commenced at approximately 435°C and finished at 525°C (Fig. 2). The increased mass loss due to the pyrolysis, which was much higher for the deinked PC sample, differed from the decreased loss within the prolonged treatment time, which indicates more polymer on the sample surface. Furthermore, these results also demonstrate that the formation of char potentially decreases with selective etching of the polymer.

It is known that CDs contain a dye layer that includes metal oxides. These metal oxides and dye formulations possess their own characteristics that may interfere with our results (the necessary part is the body of the CD without ink). Therefore, for safety reasons we avoided measuring the thermal transition of the blank CD (the CD with ink prior to de-inking), and we obtained results of virgin polycarbonate without ink for our comparison from the literature [28].

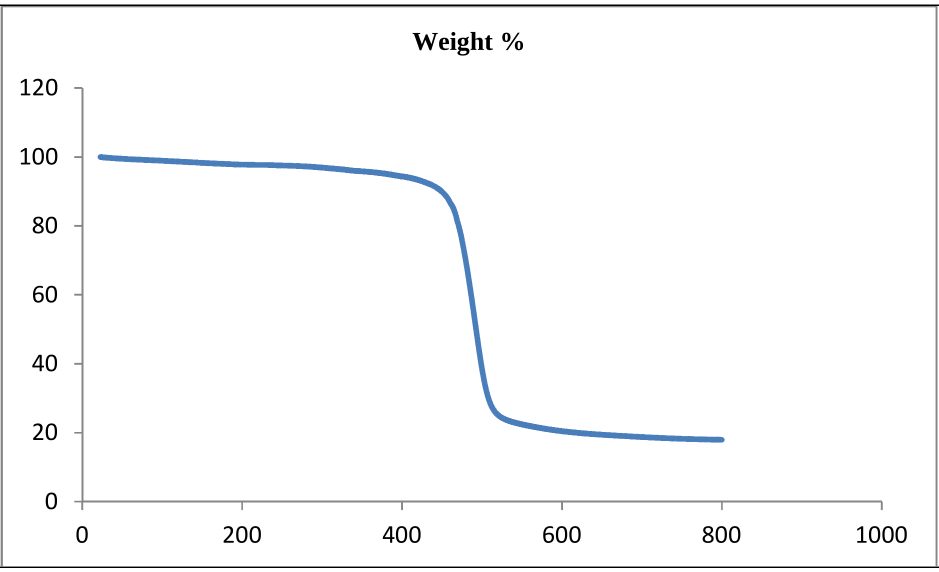

Fig. 2 TGA results of de-inked compact disc

Table (2)Thermal transition results of compact disc after De-inking process

Sample	T_g (°C)	T_m(°C)
CD0	145	154
CD1	145	156
CD2	147	153
CD3	149	155

Based on the data in Table 2 that the glass transition temperature of deinked CDs ranged from 145-149°C with an average of 147°C. This average is slightly higher than that of inked CDs (prior to the de-inking process) as a result of recycling. This shift can be attributed to the shortening of polymer chains: The segment movement of the shorter chains starts at low temperature. Additionally, all of the crystalline melting temperatures (Tm) of the CD samples were higher than the glass transition temperature (Tg); this coincidence with the crystalline domains of the polymer which have crystalline melting temperatures higher than the glass transition temperature of amorphous domains. Moreover, the presence of both a glass transition temperature and a crystalline melting temperature in the same polymer implies that the polymer is semicrystalline, i.e., the polymer exhibits both amorphous (where Tg is present) and crystalline (where Tm is present) regions. Furthermore, the presence of Tm and Tg for the CD after de-inking means that the polymer rheology remains semicrystalline like it was before and after the recycling process. This finding in turn demonstrates that the polymer (polycarbonate, CD) still retains the same characteristics as a semicrystalline polymer (e.g., anisotropic in flow and solid until a given quantity of heat is absorbed, at which point it rapidly changes into a low- viscosity liquid). This increases the value of the recycled CD as a recyclable polymer.

3.4 Coagulation-flocculation process

We conducted a secondary treatment process using the coagulation-flocculation process for chromium-free wastewater effluent. We optimized the aluminum sulphate dose, pH and polymer dose using the jar test as explained in the experimental section.

We adopted an aluminum sulphate dose of 1.5 g/L, an anionic polymer dose of 40 mg/L and a pH of 8. Table 3 lists data corresponding to the characterization of the raw tannery wastewater and the treated effluent using the coagulation-flocculation process. Fig. 3 shows removals of 42%, 77%, 86%, 99%, 98%, 84%, and 85% of BOD, COD, TSS, sulfides, O&G, TKN, and P, respectively; the aluminum released from the CDs was completely precipitated as aluminum hydroxide, which can be recycled. Due to the soluble nature of phenolic compounds, the efficiency of coagulation-flocculation procedure for phenols removal was not calculated.

Table (3) Chemical characterization of the raw and treated wastewater effluents

Parameter	Unit	Raw wastewater	Coagulation-flocculation Treatment	Fenton Treatment
pH	---	12.5	9	7
BOD	mg/L	4300	2500	400
COD	mg/L	40800	9500	800
TDS	mg/L	62920	68000	68230
TSS	mg/L	2300	320	30
TRS	mg/L	65215	68320	68260
SS	mg/L	---	---	---
H_2S	mg/L	2680	10	---
O&G	mg/L	470	50	5
TKN	mg/L	3200	500	100
P	mg/L	20	3	---
Phenol	mg/L	2	2	---
Al	mg/L	11250	0	0
Cr	mg/L	---	----	---

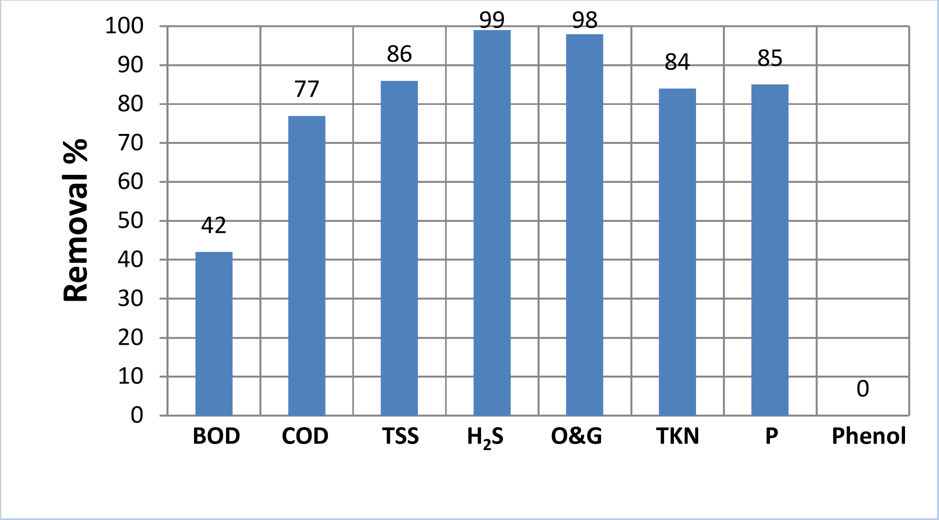

Figure.3 Efficiency of the coagulation-flocculation process for removal of pollutants in primary treated tannery wastewater

3.5Fenton process

A tertiary treatment process by AOPs – in particular, the Fenton process – was used with the treated effluent from the coagulation-flocculation process. Optimization of the ferrous sulphate dose, hydrogen peroxide dose and the duration of the reaction were achieved using the jar test at a pH of 3, The H_2O_2/Fe^{2+} molar ratio is 16; a ferrous sulphate dose of 1.2 g/L, an H_2O_2 (30%) dose of 2 ml/L and 10 minutes of stirring (120 rpm).

Table 3 lists the data of the treated effluent using the Fenton process, and Fig. 4 shows the removal of 84%, 92%, 91%, 100%, 90%, 80%, 100%, and 100% of BOD, COD, TSS, sulfides, O&G, TKN, P, and phenolic compounds, respectively. In this research the efficiency of COD removal (92%) is improved, it is more than the removal that conducted by [29, 19-20] and slightly less than what conducted by [30].

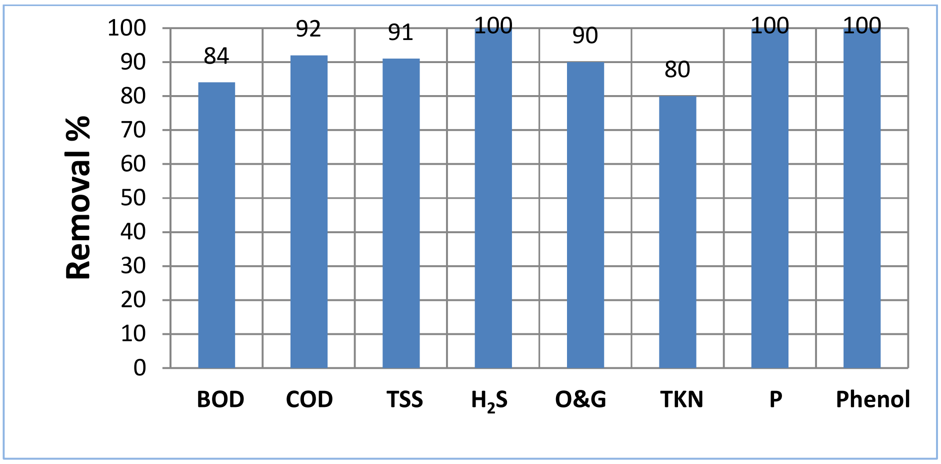

Figure.4 Efficiency of the Fenton process for removal of pollutants in secondary treated tannery wastewater

CONCLUSION

CDs (polycarbonate) were successfully de-inked using a tannery solution. The mechanical behavior indicates that the tensile modulus and tensile strength were generally decreased after the de-inking process; elongation at break was increased by de-inking. This finding may favor the use the solvent de-inking method rather than other de-inking methods.

The thermal behavior results indicate that the crystallization of CDs did not change via with the ink removal method. Moreover, the de-inking process was successfully achieved using wastewater from factories; this process has been a complicated problem that is apt to destroy drainage lines by corroding iron and concrete. Meanwhile, this de-inking process represented an environmentally friendly process for polymer (polycarbonate) recycling. Moreover, It can be concluded that this conjunction of treatments are effective for removal of BOD, COD, TSS, sulfides, O&G, TKN, and P and phenolic compounds by 84%, 92%, 91%, 100%, 90%, 80%, 100%, and 100%, respectively.

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