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Comparative studies on bentonite clay and peanut shell carbon recovering heavy metals from printed circuit boards

Murugesan Manikkampatty Palanisamy[a,*] and Kannan Kandasamy[b]
[a]*Department of Chemical Engineering, Erode Sengunthar Engineering College, Erode, Tamil Nadu 638057, India*
[b]*Department of Chemical Engineering, Kongu Engineering College, Perundurai, Erode, Tamil Nadu 638060, India*

The quantity of electronic waste subjected to disposal annually is increasing alarmingly and is of major environmental concern due to the existence of heavy metals and other toxic substances. In this present study, by combining leaching and adsorption the recovery of heavy metals from Printed circuit boards (PCBs) has been performed. The two stage aqua-regia leaching extracts Copper (Cu), Tin (Sn), Lead (Pb), and Zinc (Zn) from PCB. Bentonite Clay (Bent) and Peanut Shell Carbon (PSC) in their pristine, thermally and chemically activated forms were employed as adsorbents to remove the heavy metals from leached solution. Effect of parameters (contact time, temperature, adsorbent dosage and size) on % adsorption was studied. Chemically activated bent (C-A Bent) has proven to be an effective among all adsorbents studies with % adsorption for Cu 97%, Sn 98%, Zn 96%, and Pb 96%. Leaching and adsorption combination can become a promising methodology for handing electronic waste.

Keywords: Leaching, Adsorption, Bentonite clay, Peanut shell carbon, Printed Circuit Board (PCBs).

Introduction

Nowadays, electronic devices are rapidly growing due to human population and industrialization. E-waste has been increased every year around 18.5 lakh metric tons [1]. Electronic waste like television (TV), personal computer (PC), Mobile phone, DVD Player, Printed circuit boards (PCBs), and Printed wiring board scraps contain heavy metals. PCBs are one of the major important Electronic wastes. The PCB scraps have 50% of iron and steel elements, 21% plastics, 13% non-ferrous metals and others 16% [2]. In addition to that metals contain 10-30% of copper and further metals such as Zn 2%, Pb 4%, etc., based on the source and category of the circuit board [3]. Skin damage, headache, cardiovascular diseases, hair losses, brain effects are the impact of heavy metals on human [4-8]. Due to these problems, heavy metals should be disposed of properly. At first, incineration method was used to dispose of the circuit boards [9-11]. Since it affects the environment by CO and CO_2 emissions, solidification and landfill methods were implemented to dispose of the circuit boards [12, 13]. Later, these practices were identified to be polluting the nature of soil by reducing the interface mass transfer rate of soil. Cu_2O and CuO were found from the oxidation method of the toxic metals from PCBs by use of NaOH-supercritical water [14]. The preheating method (Pyrolysis) recommended recovering the metals from electronic waste [15]. PCBs were dissolved in aqueous solution (HNO_3, H_2SO_4, and HCL), the Electro-deposition techniques achieved more than 90% of Cu recovered [16]. Sodium cyanide solution was used as a leaching agent in leaching column technique and the result obtained was recovery of Au 46%, Cu 62% and Ag 51% [17]. Leaching agents Cyanide, Thiosulphate, Thiourea, and Halide were used to separate the precious metals like Ni, Zn, Sn, Au, Cu, Pb and other elements [18-20]. Several inorganic Chemicals were tested as leaching agents such as HCL [21], H_2SO_4 [22, 23], Aqua Regia [24], HNO_3 [25]. 85.4% of copper was leached from waste PCBs by the principle of leaching methodology. It was analyzed based on the concentration and agitation time. The study emphasized that as the concentration increases, the leaching of metal ions increased [25, 26].

There are different conventional methodologies like Incineration, landfilling, gasification, pyrolysis, hydro-metallurgical and chemical leaching techniques have their own merits and demerits in various aspects like cost, environmental effects and metal recovery. However, there are more difficulties to recover the heavy metals in various processes like Electro-winning, Electro-deposition, Acids leaching and others. Therefore, heavy metals like Cu, Sn, Zn, Pb, As, Zi and Cr are recovered by adsorption techniques by Bent adsorbent [27, 28]. Natural clay adsorbed Cu and Zn based on various parameters like temperature (25 ^oC), Agitation speed (200 rpm) and pHfrom aqueous solution [6, 29]. The

*Corresponding author:
Tel : +9566604416
E-mail: engineermurugesh@gmail.com

result reveals that copper is recovered from phosphoric acid solution by A-Bent. It summarizes that the effect of concentration decides the rate of recovery by adsorbent [30]. The ability of the Bent was investigated by adsorption of Cu and Ni. The characterization of bent is based on concentration (5 ppm-30 ppm) and temperature (20-80 ^{o}C) [28]. The activated carbon (AC) was prepared by using chemical reagent (HCL). The adsorption capacity of A-Bent to recover the heavy metals like Pb, Cadmium (Cd), and Cu was analyzed. The results showed maximum adsorption capacities in natural and A-Bent and were found to be Pb 83 mg g^{-1} and 92 mg g^{-1} [31]. Natural clay (Sepiolite) can be used to adsorb the Cu and Zi from aqueous solution [32]. The result gave the metal ions (Cu^{2+} and Zn^{+}) adsorption efficiency with the respective parameter from aqueous solution and it concluded that the Natural clay is effective one for recovery of heavy metals and minerals [33-36]. Till now many studies were done focusing on extraction of heavy metals from PCBs but have not focused on handling the extracted solution and it is applicable to recover the metals from LCD monitors boards, LED, LCD Boards, mobile phone boards. On the other hand several researchers used adsorption technique for recovery of heavy metal from aqueous solutions. Here in this present study, it is focused on the extraction and recovery of heavy metals from crushed and sieved printed circuit boards using two stage leaching combined with adsorption.

Material and Methods

Materials

Raw Printed Circuit Boards (PCBs)

The waste (PCBs) raw materials were obtained from Global E-Waste management services, a waste collection unit in Tamil Nadu, India. For experimental purpose, 5 kg scraps of PCBs were utilized. The sample initially cleaned manually to remove dust particles by Air Blower. Later other elements such as capacitors, resister, integrated circuits, diodes, transistor etc., were detached with the help of mechanical tools (saw metal cutter, sheet metal cutter, metal lathe cutting tool, cutting pliers and materials separation toolkit. The sample PCBs and disassembled samples were taken out and shredded using scissors to a 15 mm × 15 mm size [22, 37, 38]. Raw boards were crushed with the help of jaw crusher having capacity 80 kg hr^{-1} with a clearance of 10 and 5 mm. PCBs of 5-10 mm sizes samples were obtained. Then the samples were further subjected to Ball mill having a ball weight 500 gm at a speed of 60-120 rpm with a mill diameter 200 mm driven by 0.25 HP, 3 phase motor. Then the samples were further subjected to Ball mill having a ball weight 500 gm at a speed of 60-120 rpm with a mill diameter 200 mm driven by 0.25 HP, 3 phase motor. Since, the samples obtained 5 mm sizes to 3 mm from ball mill were it is not meeting the specified size requirements; these PCBs are then subjected to heating operation at 700-900 ^{o}C using muffle furnace to enhance the flexibility and crushing properties of PCBs [16] followed by continues size reduction operations of Drop-weight crusher, Pulverizer and ball mill for two hrs. The crushed sample thus obtained were converted into powdered form using pulverizer having disc diameter 175 mm driven by 3 phase motor at 1,400 rpm in 225-445 V supply. The resultant powdered samples were screened under various mesh size and weight fraction of bottom products (sieves from 52 B.S.S to pan) becomes higher but not sufficient for expected recovery. The pulverized PCB powders were milled in a ball mill which results high size reduction and highest weight fractions were obtained at lowest sieves. The weight fractions obtained at each sieves were separately collected and subjected for leaching operation. Results obtained were in the range of 4 mm-0.05 mm particle sizes [26, 39]. Therefore, Fig. 1 showed that, Primary Raw PCBs; in to stepwise size reduction under the various mechanical operations (Jaw crusher, Roll crusher, thermal heater and pulverized mills produced small sizes between 4mm-0.05mm).

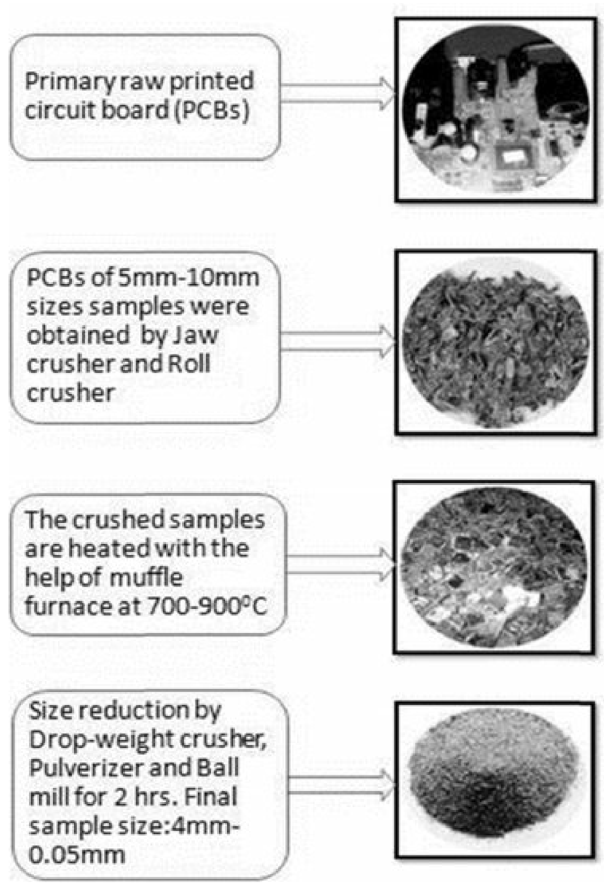

Fig. 1. Image of Primary Raw PCBs; in to stepwise size reduction under the various mechanical operations (Jaw crusher, Roll crusher, thermal heater and pulverized mills produced small sizes between 4 mm-0.05 mm).

Methods

Aqua Regia preparation and Metals leaching

The leaching media is an important factor that should be considered while extracting heavy metals such as Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+} etc from PCBs. Different sort of leaching agents given various leaching rates with respect to the type of metal were deliberated in previous studies [25]. The Previous studies have resulted in significant metal recovery; the copper (Cu) recovered by 3N HNO_3 and 3N HCL^+ in HNO_3 from PCB shows a recovery of 86.9% & 92.7% respectively [40]. It also possesses demerits such as targeted extraction of specific metal leads to loss of several other valuable metals (Table 1). By using aqua regia as leaching reagent by two stages (first stage HCL and HNO_3 and second stage HCL and H_2SO_4) heavy metals can be extracted from PCBs with various operating conditions and samples were analyzed by Energy-dispersive X-ray Spectroscopy EDXs [41, 42]. The dissolution of metal ions having PCBs takes place according to the following reaction mechanisms:

Reaction of copper with Nitric acid

$$2HNO_3^- \rightarrow H_2 + 2NO_{3^-} \tag{1}$$

$$Cu + 2NO_3^- \rightarrow Cu(NO_3)_2 + 2e^- \tag{2}$$

Reaction of Lead with Nitric acid

$$Pb + 2NO_3^- \rightarrow Pb(NO_3)_2 + 2e^- \tag{3}$$

Reaction of Tin with Nitric acid

$$2Sn + 2HNO_3 \rightarrow 2SnO_2 + NO_2 + H_2 \tag{4}$$

Reaction of Tin with Hydrochloric acid

$$Sn + 4HCl \rightarrow SnCl_4 + 2H_2 \tag{5}$$

Reaction of with Hydrochloric acid

$$Cu + 2HCl \rightarrow CuCl_2 + H_2 \tag{6}$$

Reaction of Tin with Sulphuric acid

$$Sn + H_2SO_4 \rightarrow SnSO_4 + H_2 \tag{7}$$

Reaction of Zinc with Sulphuric acid

$$Zn + H_2SO_4 \rightarrow ZnSO_4 + H_2 \tag{8}$$

Adsorbentactivation

Bent clay carbon and peanut shell carbon were used as adsorbents. Chemical and physical treatments are given to the adsorbents initially. 250 g of both adsorbents were taken in the thermal crucible and were dried for about five hrs for thermal activation at 900 °C. Therefore, the samples obtained are of 1 µm to 5 µm. The higher specific surface area was obtained due to the removal of unwanted gaseous molecules from the Non-activated adsorbents (NAC). The C-A Bent & C-A PSC was prepared by using concentrated HCL and HNO_3. Then, it was shaken at 200 rpm for 5 hrs. The acid-activated adsorbent was recovered and washed with deionized water. After drying, both samples were grinded and sieved. The preparedsamples were tested by the help of Scanning Electron Microscope (SEM-FEI-Quanta FEG 200F) [41, 43].

Adsorption studies

The adsorption of heavy metals on PSC & Bent was carried out in a batch system in both activated and NAC. 2 g of adsorbent was added to 20 ml of leached solution in a conical flask. The mixture was shaken at 200 rpm for 5 hrs at 80 °C temperature. After complete adsorption, the samples were filtered and metals concentration was analyzed by using EDXs. It is performing elemental analysis characterization of a sample in conjunction with SEM. The energy of the beam current is typically in the range of 100 Na, Schottky emitter ranges between (-200 v – 30 kv), magnifications ranges 12X-10^5 X and resolution as 2 nm (Gold Nano-particles suspended on carbon substrate). Then, adsorption efficiency of an adsorbent (PSC & Bent) was determined by the following the equation.

$$\text{Removal efficiency (\%)} = (C_o - C_e)/C_o \times 100 \tag{9}$$

C_o is initial concentration of metal ions from leached samples. C_e is the metal ions concentration at the completion of adsorption operation [30].

Influence of various parameters on recovery

The studies carried out on recovering of metal ions from leached solution with specified metals ions recovered by PSC & Bent. Experiments were conducted with pristine, thermally activated, chemically activated adsorbents to recover Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+} ions by varying the operating parameters like adsorbent dosage (0-10 g), concentration (0-40 ml), sizes of adsorbent

Table 1. Recovery rate of metals with different leaching agents

Leaching Media	Recovery rate	Reference
Ammonium thiosulfate and copper sulphate	The resultant product consists of 78.8% & 56.7% of Au simultaneously.	15
Sodium cyanide	Leached product contains 47.9% 0f Au,51.6% Ag,48.1% & 77.7% Cu.	17
H_2SO4 +H_2O_2	The acid leaching enhanced by ultrasonic power results a recovery of 96.72% of Cu, 97.77% of Ni, 98% of Zn, 53.03% of Cr and 0.44% of Fe.	36
3N HNO_3 and 3NHCl + in HNO_3	The copper (Cu) recovered from PCB shows a recovery of 86.9% & 92.7% respectively.	39

(10-0.5 μm) contact time (0-4 hrs) and temperature (0-120 °C) [25, 34, 35, 43]. Optimization studies were carried out to find the maximum recovery.

Results and Discussion

Analysis of printed circuit board

The primary samplefollowed three size reduction operations namely crushing, pulverizing and milling and the weight fractions were collected. The graphical representation (Fig. 2) of size analysis shows that the fraction of the sample obtained in the sieves with larger mesh size has been decreasing when subjected to a sequence of size reduction operations. From the sieve analysis data of each operation, the sample obtained from ball mill has many fractions of weight in the pan which is less than 0.05 mm [22]. The sample sizes are most important for dilution of metal ions from leaching agent. Here the minimum sizes of samples were used to recover the metals ions for better dilution. Therefore, the results showed in graphical representation of various size reduction operations (sizes up to 4-0.05 mm). The SEM images of crushed samples were shown in (Fig. 3). Few studies were carried out based on the effect of particle size to recover the metal ions from waste PCBs under bioleaching and chemical leaching techniques. Present research comprises of leaching used particle size 0.05 mm that is the sample retained just above the pan.

Leaching

The optimization of leaching experiments carried out by keeping optimized variable parameters based on previous studies. The electro deposition method recovered 98% of hazardous metals (Cu, Pb, Zinc (Zn), Tin (Sn), Nickel (Ni), Silver (Ag) and Gold (Au) etc.) from PCBs. It was done by using leaching (acetic aqueous chloride) and electrodeposition method [44, 45] in specific conditions of 80 °C of temperature, 0.05 mm of thickness, 3 hrs of contacting time, 80 rpm shaking speed and pulp density of PCB sample 20 g mL^{-1}, in bothstages having 3:1 ratio of HCL and HNO_3 prepared as a leaching agent. The experimental results were obtained under the above mentioned conditions and have been shown in (Table 2) and (Fig. 4). Results found the optimum recovery rate for Cu 97.06%, Sn 94.66%, Zn 96.64% and Pb 96.89% respectively.

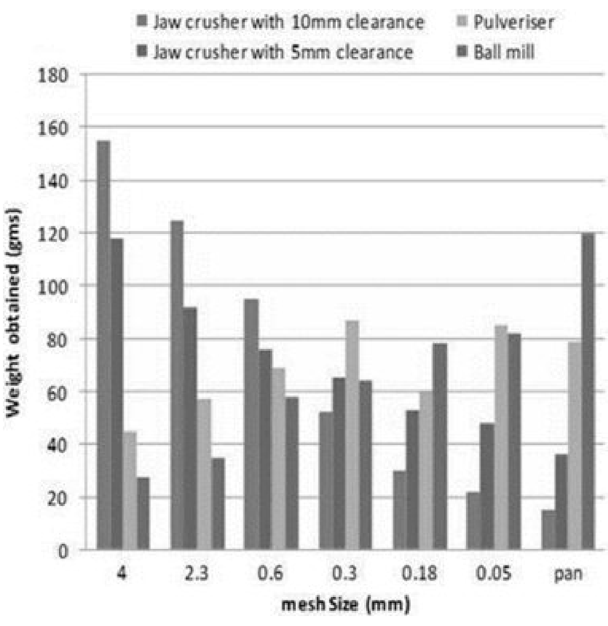

Fig. 2. Graphical representation of size reduction and analysis in various operations (jaw crusher, pulverize and Ball mill) sizes obtained 0.05 to 4 mm.

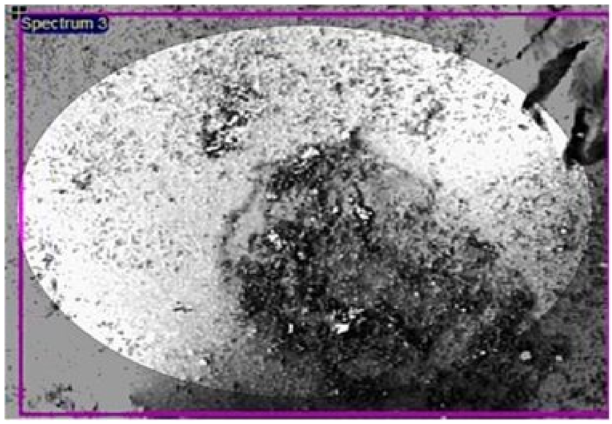

Fig. 3. SEM images of metals present in powdered PCBs.

Adsorbent characterization and studies

The SEM images of crushed and pulverized samples of Bent and PSC subjected to thermal treatment and chemical treatment as shown in Fig. 5 and it seems the C-A Bent particles were slightly smaller compared with C-A PSC particles. It has been found by the image of SEM. It reports the removal of moisturized contents and unwanted ions from the adsorbents. In this regard, adsorbents improve the pore sizes and enhance the recoverability rate. The adsorbent activation test were realized in a experimental work, where the C-A bent and PSC are given maximum numbers of pores like 2 μm of PSC and 0.5 μm of bent it should be comparatively more rate of pores are created. The thermally activated

Table 2. Metallic composition of leached PCBs at optimum conditions by stage-I & II.

Metals	CO	Stage-I & II Weight Fraction		% Recovery	
		C_e-I	C_e-II	Stage-I	Stage-II
Cu	3.1	0.03	3.12	89.5%	99.0%
Sn	42.4	0.32	42.8	64.4%	96.8%
Pb	27.8	0.8	27.1	80.9%	98.3%
Zn	1.1	0.08	1.08	63.4%	93.1%
Others	25.4	1.16	24.3	52.6%	95.4%

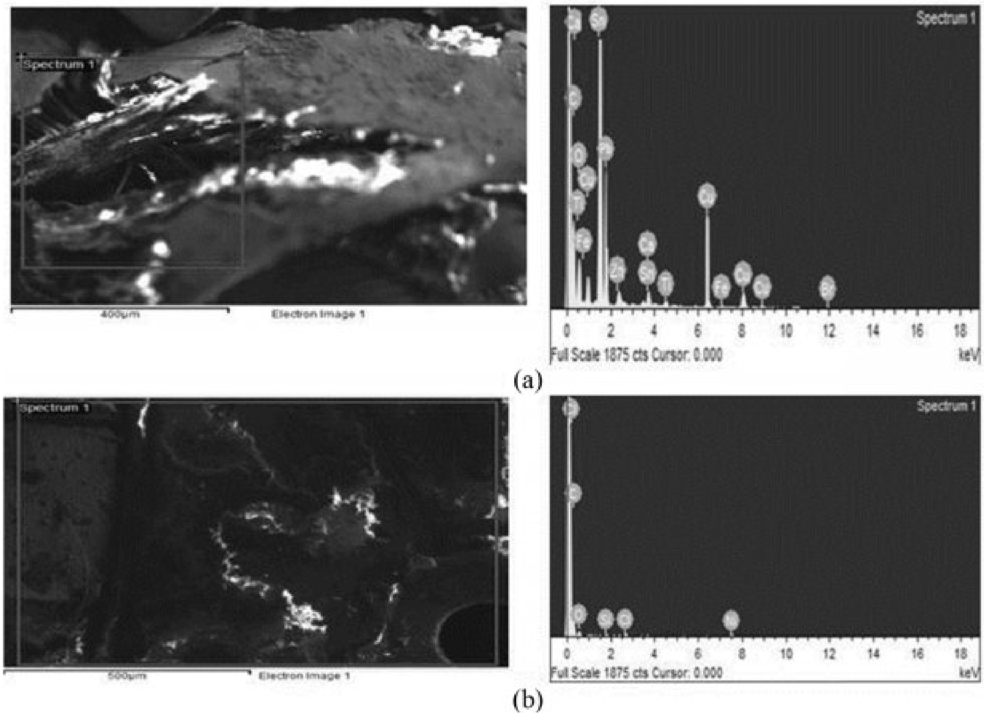

Fig. 4. EDXs spectrum analysis for metal ions obtained before (a) Metals composition in before treatment of (PCBs) and after (b) Metals composition in after treatment of (PCBs) PCBs by Leaching.

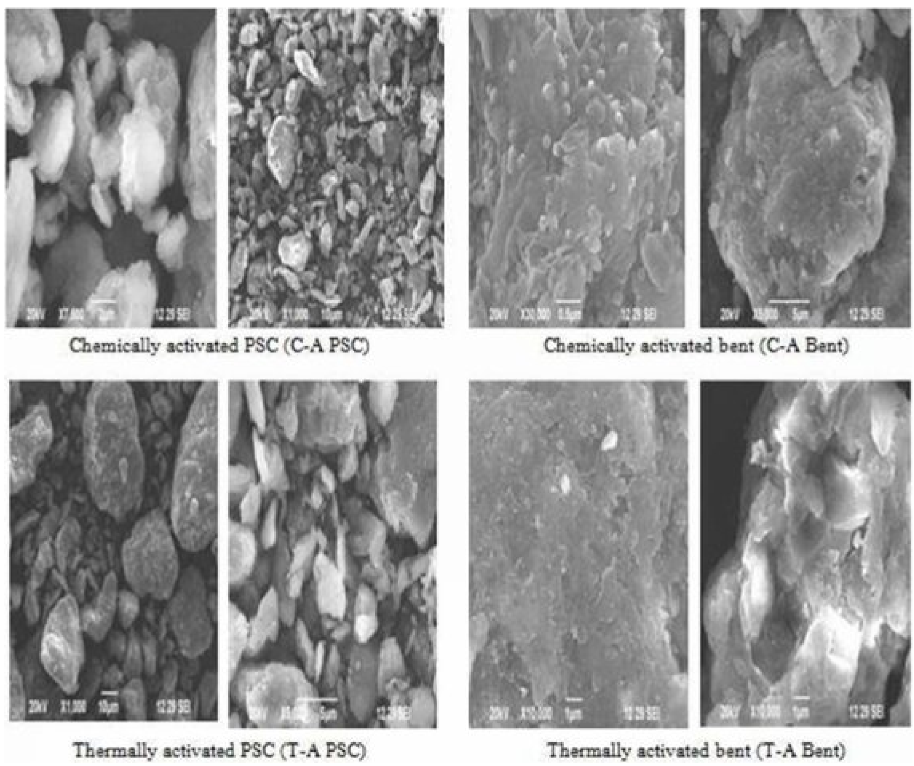

Fig. 5. SEM Microphotograph Surface images analysis of adsorbents (C-A Bent & C-A PSC and T-A Bent & T-A PSC).

adsorbents gave minimum pore rates like 5 µm of PSC (T-A PSC) and 1 µm of bent (T-A Bent) due to the recovery rate of unwanted minerals. Acid activation was more effective due to the dissociation of both adsorbents by concentrated HCL and HNO_3. From the result shown in (Fig. 5), we observed that HCL and HNO_3 are strong acid to be able to improve the surface area of both adsorbents. Therefore, many studies carried on the adsorption to recover of Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+} from various samples using bent and PSC. During our tests, specified parameters were deliberate to see their effects on the adsorbent performance in to the adsorbate (leached solution) adsorption.

Effect of contact time in the removal of metals

The contact time is an important factor affecting the adsorption efficiency by agitation. To determine the effective time ofadsorption, the sampleswere allowed to be leached for different interval of time based on previous studies. The persistent condition was maintained at 5 g sample adsorbents, size 0.05 mm shaken with 0.5 litter of aqua regia in a conical flask and shaking speed of 200 rpm while temperature maintained at 34 ºC for all category of adsorbents (C-A Bent & C-A PSC and T-A Bent & T-A PSC). It is followed to be leached for 1, 2, 3, 4 and 5 hrs respectively. The test reported 1 to 4 hrs, for adsorbent NAPC and NABC are adsorbed Zn 20-40%, Sn 35-65%, Cu 70% and Pb 40-60%, T-A PSC & T-A Bent are adsorbed Zn 83%, Sn 70-85%, Cu 70-80% and Pb 80-85%, C-A Bent & C-A PSC are adsorbed more recovery rate due to higher surface area of adsorbents were the results as a both adsorbents are recovered the metal ions at1 to 4 hrs more than 83% of Zn, 88% of Sn, 89% of Cu and Pb 80-85% respectively. Therefore, the tests are identified 1 to 3 hrs are gradually increased adsorption rate and then linearly attain equilibrium.The optimum values for removal of metal ions were determined at 2 to 4 hrs. Therefore, (Fig. 6) shows that higher efficiency for Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+} ions adsorption can be obtained at the time intervals between 2 to 4 hrs. All remaining experiments were carried out at 4 hrs contact time. The result shows at 3 hrs the maximum recovery of metals as 91.46%, 90.56%, 86.56% and 89.91% of Cu, Sn, Zn and Pb respectively.

Effect of adsorbent dosage in the removal of metals

The experimental studies were carried out in the ratios 1:2, 1:4, 1:6, 1:8. 1:10 of leached solution and adsorbent. The adsorption rate increased linearly with dosage and attained equilibrium. In order to determine the optimum value of adsorbent dosage during the adsorption process, parameters like contact time, concentration and temperature were kept constant. The increased adsorbent dosage increased the surface area of adsorbent. This can be attributed to the increase in the adsorption efficiency of adsorbent [42, 46, 47]. The experimental results were found with the dosage of

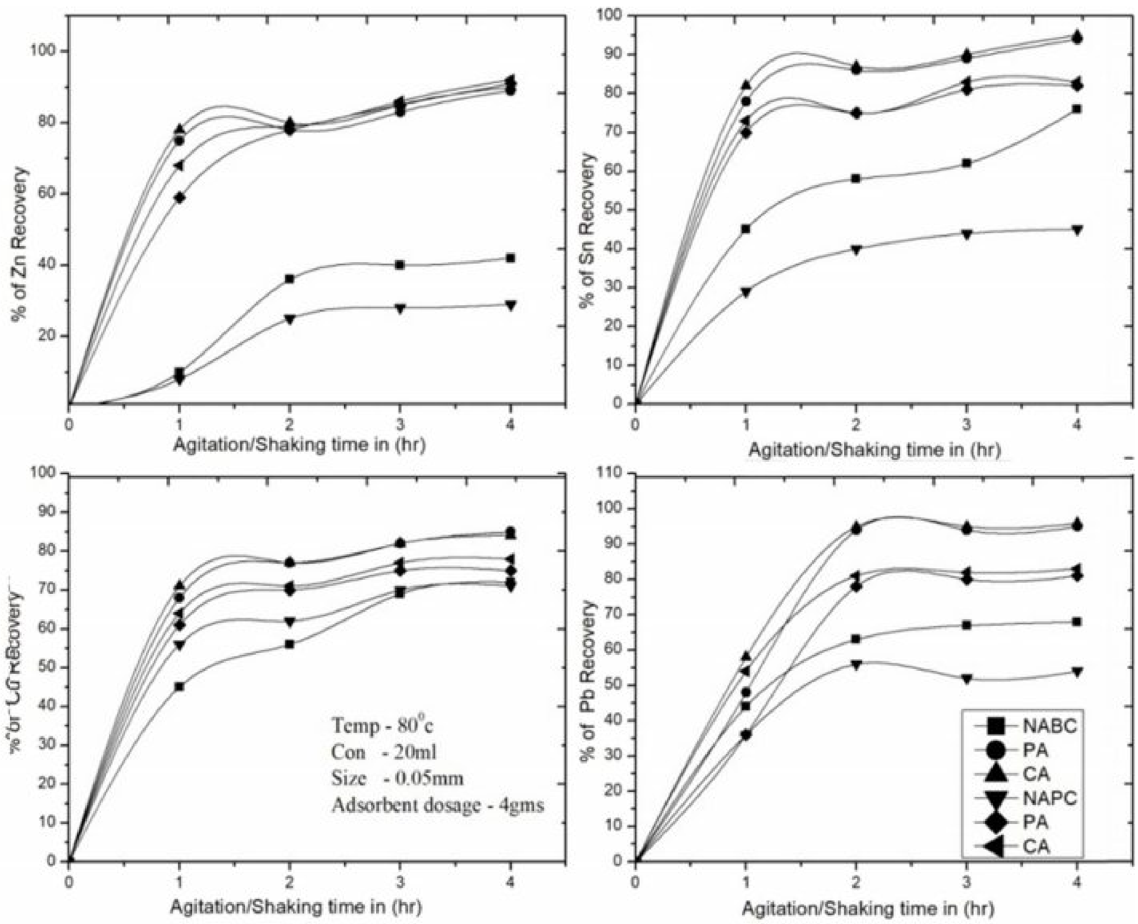

Fig. 6. Effect of contact time in various operating conditions for removal of Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+}.

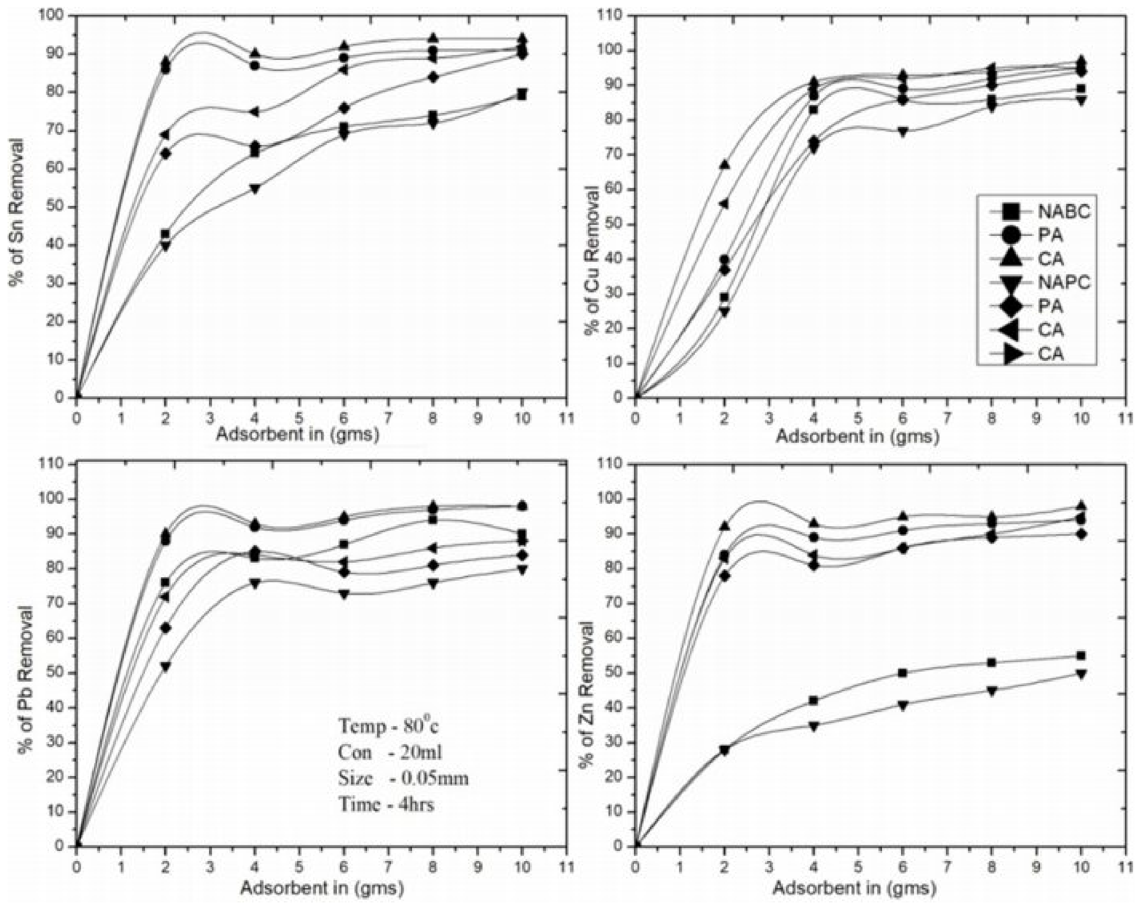

Fig. 7. Effect of adsorbent dosage on the removal of Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+}.

both adsorbents at the ranges from 0-10 g, NAPC and NABC are adsorbed linearly up to 5 g, after that attain equilibrium, and finally 75% of Sn, 80-85% of Cu, 75-80% of Pb and 30-42% of Zn, T-A PSC & T-A Bent are studied and the results as 82-25% of Sn, 85-92% of Cu, 85-88% of Pb, 80-89% of Zn and C-A Bent & C-A PSC are much effective at 1-5 g of both adsorbent were found maximum recovery rate of valuable metals like 93-95% of Sn, 96% of Cu, 94% of Pb, and 91-95% of Zn. The present tests were analyzed linearly increased adsorbent dosage rate as well as increased Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+} ions recovering media it was increased adsorption rate. Therefore, (Fig. 7) shows the adsorption efficiency of activated and NAC adsorbents and optimum values are found to be at 4 g per 20 ml of PCBs leached solution. CA-Bent adsorbents were found maximum recovery of metallic composition as 95.06% of Cu, 97.87% of Sn, 92.39% of Zn and 96.60% of Pb.

Effect of leached solution concentration

The effect of concentration on the adsorption of Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+} ions was carried out with the concentrations of 10, 20, 30, 40 and 50 ml under the operating temperature of 80 °C, agitating speed of 200 rpm and 0.5 µm of particle sizes within the equilibrium contact time of 4hrs and adsorbent dosage of 4grams. As shown in (Fig. 8), the removal quantity was increased with increasing themetal ions concentration until the equilibrium at the adsorption. After that, leached solution metal ions will not be adsorbed due to many more metal ions fully covered in the adsorbent surface. The previous studies [27, 43] reported, the leached solutions 0 to 40 ml were used in adsorption for heavy metals adsorption as aresult provides linearly increase in the adsorption rate and attain saturation condition. The initial metal concentration providesthe essential driving force to get over the resistance tothe mass transfer between the aqueousand the solid phases. At lower initial metal concentration, more sorption sites were available for metal adsorption. Higher initial metal ion concentrations are enhances the interaction among the adsorbate and adsorbent, hence the result was found higher adsorption efficiency. Our results indicated that 10-20 ml were the optimal concentrations for Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+} ions removal, respectively. All the studies carried out with the optimal concentration at 20 ml/4 g of adsorbent. Bent (C-A sample) showed the maximum removal rate due to higher pores and surface area. After the saturation time of 4 hrs, the removal of Sn decreased from more than 96% to 85% at 20 ml of leached sample because of metal recover ability reduction from both adsorbent. The same behavior

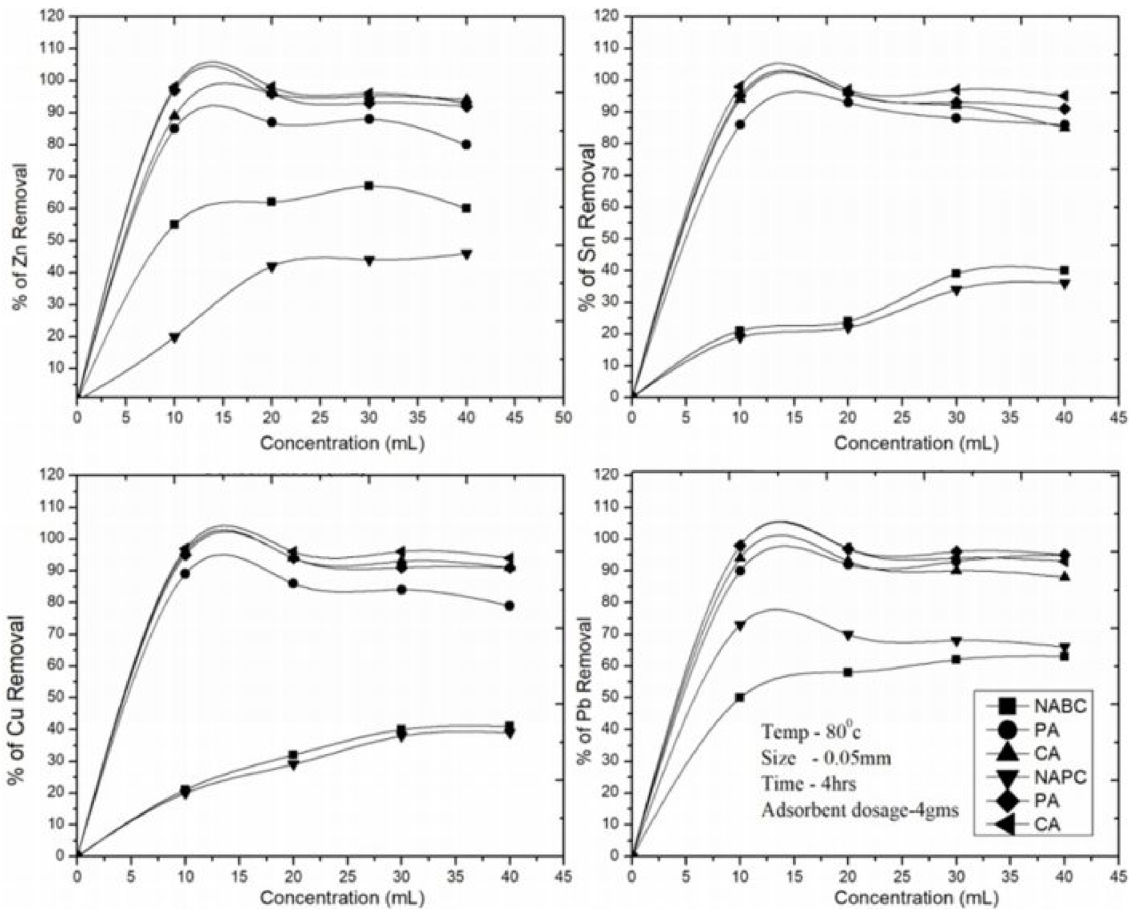

Fig. 8. Effect of concentrations in various operating conditions for removal of Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+}.

was observed with other metals ions removal Zn^{2+} (96-94%), Cu^{2+} (94-91%) and Pb^{2+} (98-93%), respectively. In comparison with PSC (C-A sample) samples, the Bent (C-A sample) samples removed maximum amount of metal ions but the treated PSC (C-A) and untreated samples are showed much lower removal efficiency (Fig. 8). Thus, it was clearly observed that the removal of metal ions was strongly influenced by the concentration and adsorbent surface recover ability rate.

Effect of temperature on the adsorption

The study was carried out for the effect of temperature on the adsorption of Cu^{2+}, Zn^{2+}, Sn^{2+} and Pb^{2+} ions on to Bent and PSC samples at 20, 40, 60, 80 and 100 °C with other parameters kept constant with respective equilibrium conditioned level. The adsorption capacity of metal ions by the both adsorbents increased as temperature increases from 20 to 60 °C and then attained equilibrium for endothermic sorption process**.** After attain the equilibrium/saturation, adsorption rate decreased continuously and stopped (temperature suggested an exothermic sorption process) it were reported [29, 48]. The (Fig. 9) shows the removal quantities of heavy metal ions by the activated and non activated adsorbent samples at highest removal efficiency with respective temperature. In this study shows that, the removal rate of C-A PSC adsorbent has presence of results as Cu^{2+} (91%), Zn^{2+} (94%), Sn^{2+} (93%), Pb^{2+} (95%) and C-A Bent presence of result as Cu^{2+} (88%), Zn^{2+} (82%), Sn^{2+} (86%), Pb^{2+} (94%) respectively. These results demonstrate that the Bent is not effective for removal of metals byendothermic temperature at 60 °C. 20-40 °C temperature range was used to get a good removal efficiency of about 90% for Pb removal. As a result of increased adhesiveness in C-A Bent & C-A PSC adsorbents, both adsorbents are showed higher adsorption rate at higher temperatures compare to T-A Bent & T-A PSC adsorbents.

Effect of particle size of the adsorbent

Effects of various sizes of adsorbents for both adsorbents were studied. The different particle sizes of adsorbents such as 10 μm, 5 μm, 2 μm, 1 μm, and 0.5 μm were performed for metal ions adsorption and keeping same operating procedure with studied parameters like agitation contact time 4 hrs, adsorbent dosage 4 g, leached solution metal ion concentration 20 ml and temperature 60 °C [49-51]. This study analyzed adsorption rate with respect to various particle sizes for both adsorbents. The small particle size of adsorbent gives maximum surface area so that metal ions easily adsorbed. Fig. 10 shows 0.5 μm particle size adsorbent's

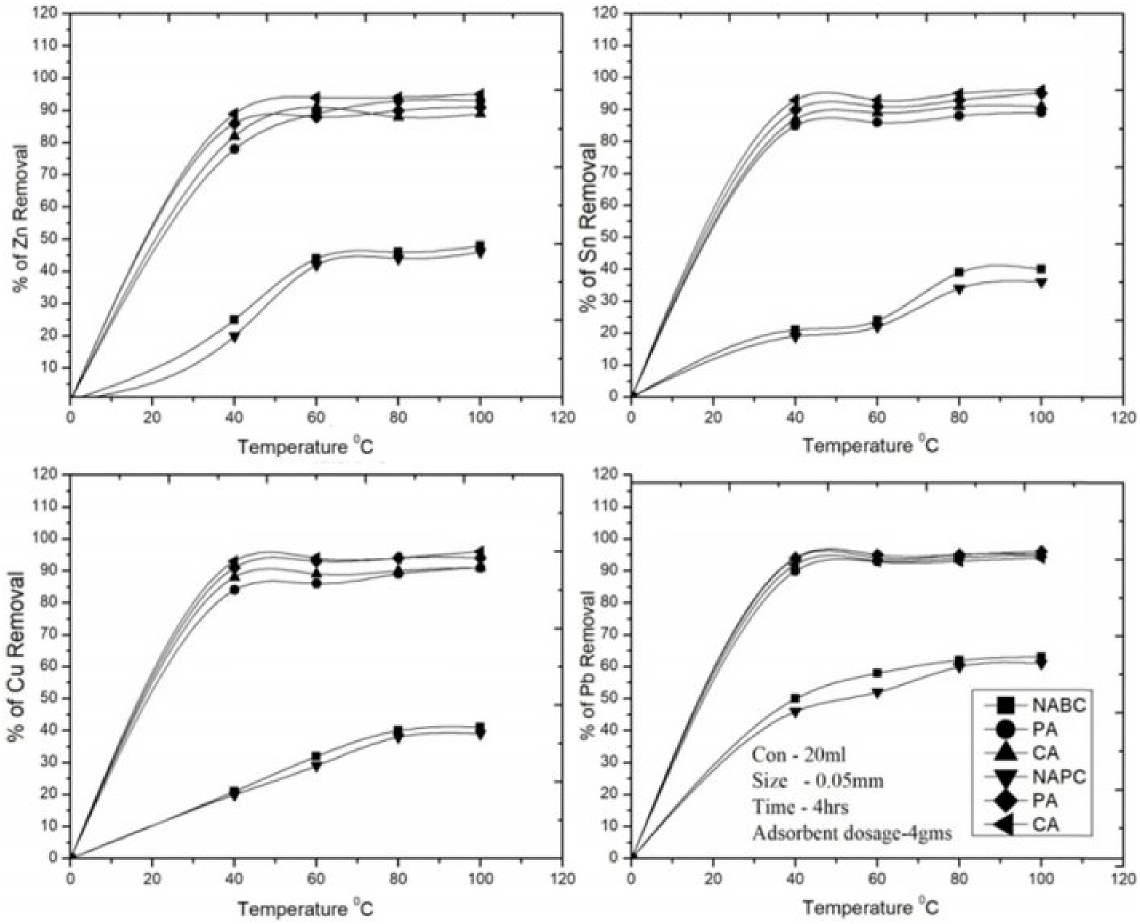

Fig. 9. Effect of temperature various operating conditions for removal of Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+}.

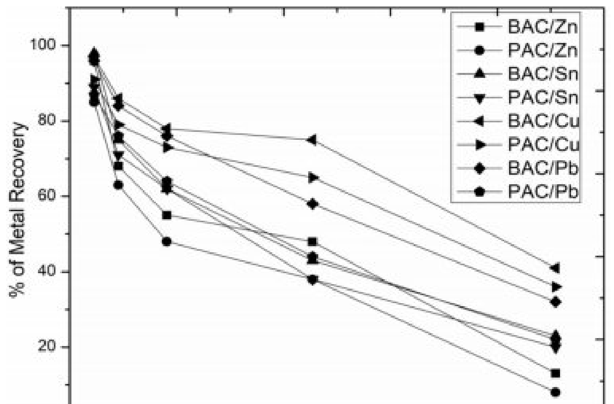

Fig. 10. Effect of sample sizes in various operating conditions for removal of Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+}.

removal rate of BAC. It gives Zn 96%, Sn 98%, Cu 97%, Pb 96% and PAC gives Zn 85%, Sn 89%, Cu 91%, Pb 87%. Therefore, particle size is more important to recover the heavy metals through adsorption.The previousresult also indicatesthat C-A Bent samples gave the better removal efficiency [53-55]. The study revived the recovery of heavy metal ions like Pb and Cu by different clay minerals. Therefore, in this experimental work also confirm their beneficial use for the removal of copper, tin, lead and zinc from heavy metals having leached solution.

Conclusions

Heavy metals in waste PCBs were leached into corresponding reagents during the two-stage leaching operations. The effectiveness of two leaching media (HCL; HNO_3, H_2SO_4; HCL) for recovery of heavy metals during the treatment of PCBs was evaluated. The recovery rate was nearly obtained for Cu - 99.04%, Sn - 96.88%, Pb - 98.34%, Zn - 93.1%, others - 95.44% (Ni, Mn, and Mg…) by aqua regia leaching. Hence the leached metal ions were treated by adsorption. Activated and NAC adsorbent (Bent & Peanut shell) were utilized to recover the heavy metal ions (Zn^{2+}, Sn^{2+}, Cu^{2+} and Pb^{2+}) from PCBs and investigated by different significant parameters. The experimental results showed that adsorption rate was linearly increasing and later itbecomes stable due to changes in operating conditions. From the result of this study, C-A Bent adsorbentsassist in effective separation of heavy metal ions. Hence, it was concluded that the combination of aqua regia leaching and bent adsorption is a more effective and economic way for the elimination of heavy metals from PCBs.

Nomenclature

PCBs	: Printed circuit boards
Bent	: Bentonite Clay
AC	: Activated carbon
NAC	: Non-activated Carbon
NABC	: Non-activated Bentonite Clay
PSC	: Peanut Shell Carbon
C-A Bent	: Chemically activated bent
C-A PSC	: Chemically activated Peanut shell carbon
C_o	: Initial concentration of metal ions from leached samples
C_e	: Metal ions concentration at the completion of adsorption operation
T-A Bent	: Thermally activated bent
T-A PSC	: Thermally activated Peanut shell carbon
C_e-I&C_e-II	: Metal ions concentration at the completion of adsorption in stage I & II

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