QUALITATIVE ANALYSIS OF CADMIUM METAL FORM E-WASTE

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Abstract

As we are well acquainted with the world continue to sprint down the path of digital marketing which consists of business processes, exchange of information, and consumer interaction. Similarly, in the name of prison reforms almost all the prisons of India had persisted in earlier traditional means and methods for reformation and rehabilitation of prisoners behind the bar, whereas in the 20th century, digital marketing drastically came to the pinnacle as a matter of irrefutable empirical evidence, specifically in the era of globalization, industrialization, and privatization. Now we have various resources which underpin advertisements of the product manufactured by the prison manufacturing units through the help of digital marketing, wherein the various skilled prisoners had been working continuously to produce multipronged goods which have great economic significance in the market.

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I. Introduction

Today with the progression in the way of life and current innovation the requirement for hardware and electrical apparatuses are expanding step by step. These machines have infiltrated each part of our life's, and we never believe that what occur with the misuse of these apparatuses, on the grounds that, other than their beneficial outcomes they have negative ones too. The hindering venomous metals of these apparatuses are not poisonous up to people, yet additionally to conditions subsequently prompting genuine contemplations. E-waste is a rising issue given the volumes of e-waste being produced and the substance of both harmful and important materials in them [1]. "Solving the E-waste Problem (StEP)" Initiative gauges that the world will create 33% more e-waste, or 72 million tons by 2017. As a main maker, China produces about 12.2 million tons of e-waste, trailed by the U.S. with around 11 million tons [2]. A new report by The Associated Chambers of Commerce of India (ASSOCHAM) shown that the e-waste stores of India is developing at an accumulated yearly development pace of around 25% and is probably going to create 15 Lakh metric tons (MT) of e-waste by 2015 from the current degrees of 12.5 Lakh MT per annum. In India, Mumbai best the rundown in producing e-waste at 96,000, trailed by Delhi-NCR (67,000), Bangalore (57,000), Chennai (47,000), Kolkata (35,000), Ahmedabad (26,000), Hyderabad (25,000) and Pune (19,000) [3]. Unavoidably, the quantity of electrical machines will keep on expanding for an enormous scope and use of microchips are expanding in everyday objects. The electronic market is the present one of the rapidly extending market. Quick-money related development, along with urbanization and a developing revenue in shopper merchandise, has expanded both the usage and the assembling of electrical and electronic hardware (EEE) [4]. This new sort of waste raised the genuine concerns with respect to their mien and reusing everywhere on the world. The attitude of e-waste into India from other metropolitan nations have driven e-waste the board is an issue of natural and wellbeing concerns. Having unsafe parts in TV and PC screens (lead, mercury, and cadmium) and in circuit sheets (nickel, beryllium, and zinc), the reusing and disposing of e-waste turns into a key concern [5]. The United Nations Environmental Program (UNEP) had detailed 20-50 million tons of e-waste is produced each year universally causing a few human wellbeing and the climate chances that is additionally because of the 4 million (PCs) in China itself [6]. Safe administration of e-waste is these days a critical test to governments and public just as exchange opening since it comprises of both deadly and costly metals [7]. Be that as it may, the flighty acts of extricating these significant metals from the e-waste have coordinated to natural issues and wellbeing perils.

1.1 Electronic Waste

As per definition given in e-waste the board rules (2011) given by Government of India: "E-waste involves wastes produced from utilized electronic gadgets and families' apparatuses which are not good for their unique expected use and are bound for recuperation, reusing or removal. Such wastes envelop wide scope of electrical electronic gadgets like PCs, handheld phones, individual sound systems, including enormous home devices like fridges, forced air systems and so on" Whereas Electrical and electronic gear has been characterized as "hardware which is reliant upon electrical flows or electro-attractive fields to be completely practical" (MoEF, 2011). Globally, the most acknowledged meaning of e-waste is the definition according to the WEEE Directive which characterizes electronic waste, "e-waste" or "Waste Electrical and Electronic Equipment" ("WEEE") as the "waste material comprising of any messed up or undesirable electrical or electronic apparatuses including all segments,

subassemblies and consumables which are important for the item at the hour of disposing off". Electronic waste normally known as e-waste is the name given to all electronic and electrical apparatuses which are toward a mind-blowing finish. E-waste in short is a term nestles different types of electric and electronic device that have stopped to be of any worth to their proprietors. E-waste is an expansive and developing scope of electronic gadgets goes from enormous family types of gear (coolers, cools, PDAs, individual sound systems) and shopper hardware to PCs that have been disposed of by the clients [8]. There are 10 unique classes of e-waste based on European waste electrical and hardware gear (WEEE) Directives 2002/96/European Commission (EC) and 2012/19/European Union (EU) and is each organized in Table 1 by giving point by point extent of every classification [9]. As indicated by the Association of Plastics Manufacturers in Europe (APME) e-waste is a diverse blend made out of ferrous, nonferrous, plastic and artistic materials [7]. E-waste constituents vary as indicated by the made products and contain in excess of 1000 different substances, which fall under 'risky' and 'non-dangerous' classes. Comprehensively, it incorporates ferrous and non-ferrous metals alongside the plastics, glass, wood and compressed wood, printed circuit board (PCB), cement and pottery, elastic and different things. E-waste involves about half of iron and steel followed by plastics (21%), non-ferrous metals (13%) and different constituents. Non-ferrous metals comprise of exact metals like copper (Cu), aluminum (Al) and valuable metals, for example silver (Ag), gold (Au), platinum, palladium, and so on [10]. Past skirt amounts of components like lead, mercury, arsenic, cadmium, selenium

and hexavalent chromium and fire retardants of e-waste groups as perilous waste [11]. In orders e-waste into four unique classifications for example halogenated compounds, weighty metals, radioactive substances and some different substances alongside their quality in the electronic gadgets. An examination by Grant et al. [12] revealed the connection between the e-waste openness and its connected wellbeing results. The wellbeing results are principally actual wellbeing results like thyroid capacity, conceptive wellbeing, lung capacity, development, and changes in cell working. The brominated fire retardants present in the plastic piece of e-waste affects the sensory system and meddle with ripeness in warm blooded creatures. Lead part, generally present in Cathode Ray Tube (CRT) of old TV, lead–corrosive batteries, link sheathing and bind of printed circuit board is answerable for indications like heaving, loose bowels, seizures, trance state or even passing. Presenting to cadmium can cause intense and constant harmfulness and causes influenza like indications [12].

1.2 Classification of E-waste

Creation of e-waste is assorted and varies in items across various classifications. It contains in excess of 1000 unique substances, which fall under "perilous" and "non-unsafe" classifications. The presence of components like lead, mercury, arsenic, cadmium, selenium, and hexavalent chromium and fire retardants past edge amounts in e-waste groups them as perilous waste. The Directive of the Parliament and European Union Council on waste electrical and electronic hardware partitions WEEE into ten unique classifications (EU, 2002).

Table 1: Ten different categories of e-waste

S. No.	Category of Waste	Equipment	Label
1.	Major Household Gadgets	Air conditioner, dish washer, refrigerator, washing machines, microwave oven and induction cooker etc.	Large HH
2.	Minor Household Gadgets	CD and DVD players, video game consolers, alarm clock, television, grinder–juicer–mixer, electrical kettles and electric chimneys	Small HH
3.	IT and Telecommunication Gadgets	LAN, modems, mobile phones, landline phones, teleprinters and communication satellite	ICT
4.	User Gadgets	radio receivers, television sets, MP3 players, video recorders, DVD players, digital cameras, camcorders, personal computers	CE
5.	Illumination Gadgets	Ballast lamp, halogen, neon, LED and compact fluorescent lamps	Lighting
6.	Electrical and Electronics Apparatus	vacuum tubes, transistors, diodes, integrated circuits, wires, motors, generators, batteries, switches, relays, transformers, and resistors	E and E tools
7.	Toys, Leisure and Sports Gadgets	Batteries in cars, trains, buses, and airplanes etc.	Toys
8.	Medical Devices	Medical thermometer and biomedical engineering instruments	Medical equipment
9.	Monitoring and Control Instruments	Relays, thermostat, and b microcontrollers	M and C
10.	Automatic Dispenser	Automatic soap dispenser, automatic water dispenser, automatic spray dispenser etc.	Dispensers
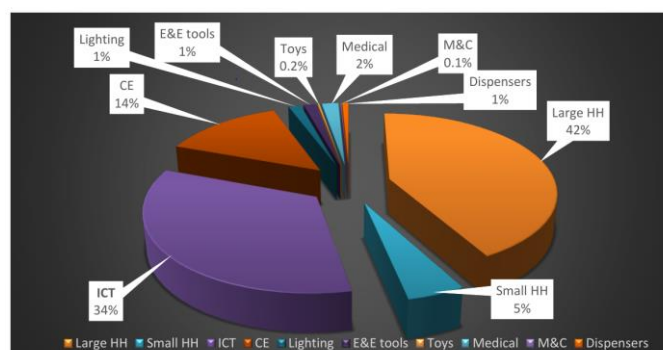
Fig. 1: E-waste Distribution (Widmer et al., 2005)

Of the ten classifications recorded above, Categories 1-4 record for practically 95% of the WEEE produced as demonstrated in figure 1.

1.3 Building Blocks of E-waste

Electrical and electronic equipment is made up of a number of different building components. Each piece of e-waste has been categorized according to the twenty-six common components that can be found in it. These components serve as the item's "Building Blocks," making them easily "identifiable" and "removable." Metal, motor/compressor, cooling, plastic, insulation, glass, LCD, rubber, wiring/electrical, concrete, transformer, magnetron, textile, circuit board, fluorescent lamp, incandescent lamp, heating element, thermostat, BFR-containing plastic, batteries, CFC/HCFC/HFC/HC, external electric cables, refractory ceramic fibers, electrolyte capacitors, and radioactive substances are some of the components.
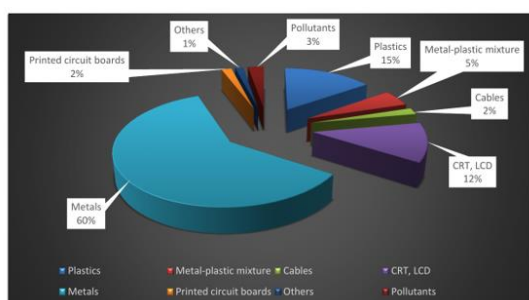

Fig. 2: Typical Composition of E-waste

Some of the specified building blocks are [25]:

- Printed Circuit Boards/Assemblies
- Plastic Containing Flame Retardants
- Cables, cords, wires, and connectors
- Mercury switches and breakers
- Display equipment such as cathode ray tubes and liquid crystal display (LCD)
- Sensors and accumulators
- Data storage media
- Light generating device.
- Capacitors, resistors, and relays
- Batteries

E-waste in developing and developed countries: - According to new research, developing countries will produce twice as much e-waste as developed ones in the next 6-8 years. By 2030, the developing and developed nations are expected to destroy 400-700 million and 200-300 million old computers, respectively [14]. According to the computer model, developing countries will discard more computers than developed countries by 2016 [15]. Furthermore, developed nations are exporting their electronic garbage to underdeveloped countries for disposal, raising severe issues. Much of the e-waste is shipped to Africa or Asia under questionable circumstances, even with permission to export the useless goods to needy countries for reuse or refurbishment. Non-functional products are incorrectly classified as "used items" in this case. Because of its handling in unfavorable places, a major portion of e-waste exports is directed outside of Europe, notably to West African countries, producing major environmental damage and health hazards for the local population. Failure to recover rare-earth minerals is also posing challenges in the development of future generations of electronic devices [16]. E-waste handling, disposal, and environmental and health concerns Because of its composition, e-waste management is extremely difficult. Electronic trash contains a variety of chemicals that harm the environment and pose health hazards to humans. Various pollutants and toxic metals such as lead, mercury, and hexavalent chromium are found in e-waste from cathode ray tubes (CRTs), printed circuit board assemblies, capacitors, mercury switches, batteries, liquid crystal displays (LCDs), photocopier cartridges, selenium drums (copier), and electrolytes [17]. Mercury and polychlorinated biphenyls (PCBs) are harmful compounds found in e-waste from switches, flat screen monitors, and computer cadmium batteries. Toxic compounds such as dioxins and furans are released when brominated flame

retardants are burned in printed circuit boards, plastic casings, and PVC insulted cables. Lead, brominated flame retardants (usually 5-10 percent by weight), and antimony oxide are other harmful elements found in e-waste [18].

1.4 The influence of temperature on the leaching process

The effect that temperature has on the extraction of cadmium was studied at temperatures ranging from 25 to 75 degrees Celsius for a variety of reaction times using an acid concentration of 8% by volume for a sample with a particle size of 250 lm. The results showed that temperature has a significant impact on the extraction of cadmium. Throughout the whole of the experiment, the ratio of solids to liquids was maintained at a value of 0.10 g/mL. Figure 2 demonstrates that the temperatures of the reactions have no obvious effect on the quantity of cadmium that is extracted from the sample. When compared to the lower temperature, the higher temperature results in an increase not only in the reaction rate but also in the rate at which reactants diffuse slowly. Additionally, the higher temperature results in a modest rise in extraction.

More than 88% of the cadmium that was present in the sample was recovered after the extraction process had been carried out for fifteen minutes at a reaction temperature of twenty-five degrees Celsius; this percentage increased to ninety-seven percent when the temperature was raised to seventy-five degrees Celsius. Researchers came upon discoveries that were similar when they were processing zinc plant trash to remove cadmium. The researchers made the interesting discovery that increasing the temperature resulted in a greater quantity of cadmium being removed from the sample. However, according to the data that we obtained, decreasing the temperature at which the leaching process occurred helped to attenuate the detrimental effects of the procedure.

Figures 3 and 5 illustrate the outcomes of plotting the data relating to the extraction of cadmium at various temperatures. According to the processes of chemical reaction control and diffusion control, respectively. According to the findings of this particular piece of research, the rate at which cadmium dissolves is controlled not by the chemical reactions that take place on the surface, but rather by a process that goes by the name of the diffusion control process.

$$\left(\left[1 - \frac{2}{3}\alpha - (1-\alpha)^{2/3}\right] = k_d t\right)$$

was cited as the controlling mechanism in the research conducted by Safarzadeh et al., and our results agreed with the hypothesis that diffusion was the determining factor for the ash product layer. The figure is constructed by using the slopes of the straight lines that lead to the locations of the apparent rate constants (kd). Given that the process seems to be controlled by diffusion, based on the activation energy that was anticipated to be 7.20 kJ/mol, the given information suggests that this is the case.
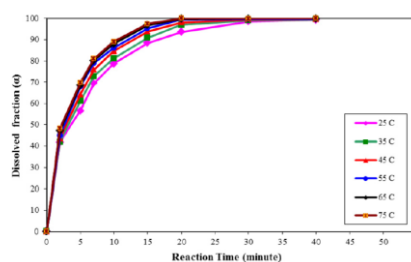

Fig. 3: Effect of reaction time on the cadmium extraction at varying temperature (8% (v/v) Acid, 500 rpm, S/L = 1/10, particle size: _250 lm).
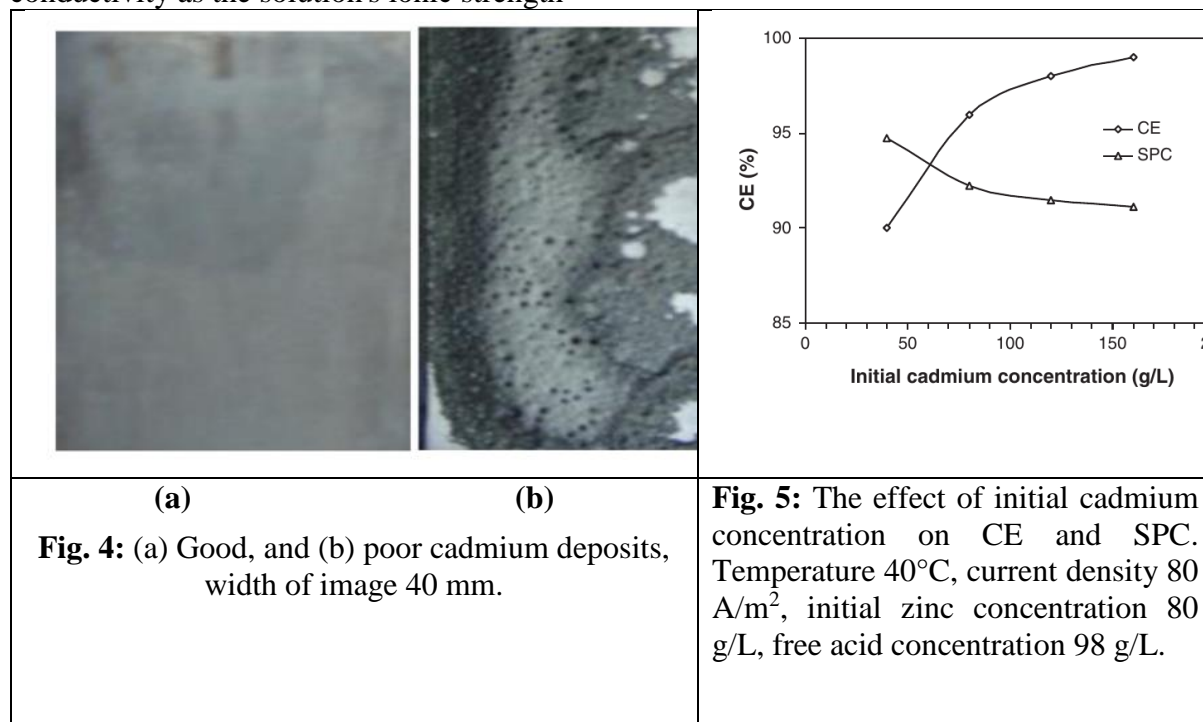
II.The electrowinning of cadmium in the presence of zinc

2.1 The effect of initial cadmium concentration

Depletion of electrolyte became an issue at the lowest cadmium dosage, with near-complete Cd depletion projected after 6 hours. The present efficiency is projected to decline with deposition time at this concentration; the value indicated is the average for the full 6 hours. The possibility of cadmium ions depositing on the cathode increases as the cadmium concentration rises, and the portion of current available for hydrogen evolution diminishes. Another effect of increased cadmium concentration seems to be a decrease in concentration polarization and, as a result, a decrease in the over potential for hydrogen development. The fall in SPC is mostly attributable to a drop in cell voltage caused by an increase in solution conductivity as the solution's ionic strength increased. The quality of the cadmium deposit was good up to a concentration of 120 g/L, and the formed sheets could be easily removed. Dendrite production and the deposition of coarse cadmium particles were seen when the concentration was increased over 120 g/L.

Reduced cadmium concentrations below 80 g/L resulted in greater hydrogen evolution and, as a result, a reduction in CE. Furthermore, higher hydrogen evolution would result in more acid mist above the cells. Due to a decrease in solution conductivity, the cell voltage was also raised, resulting in a rise in the SPC. As a result, the cadmium concentration in following trials was set to 120 g/L.

(a)   **(b)**
Fig. 4: (a) Good, and (b) poor cadmium deposits, width of image 40 mm.

Fig. 5: The effect of initial cadmium concentration on CE and SPC. Temperature 40°C, current density 80 A/m^2, initial zinc concentration 80 g/L, free acid concentration 98 g/L.

2.2 The effect of current density

The effect of current density on CE and SPC is shown in figure 6. CE is reduced from 99% to 90% by increasing current density from 50 to 150 A/m^2. The most likely reason for this is that hydrogen evolves faster at increasing current densities. Because this functions in an unstirred cell, the maximum current for cadmium plating is restricted by the diffusion of cadmium from the bulk solution to the electrode surface. In practice, the evolution of hydrogen results in an increase in cadmium mass transfer due to rising bubbles that enhance electrolyte circulation. As a result of the drop in CE, the SPC increased. Due to the accompanying rise (12.5 %) in cell voltage from 2.4 to 2.7 V required to produce the required 50 and 150 A/m^2, the increase in

SPC (23.8 %) was substantially greater than the decrease in CE (10 %). Greater anode and cathode overpotentials, as well as increased voltage loss inside the electrolyte, account for this rise. The cadmium deposits were of good grade up to 80 A/m^2. The efficiency of the cathode was reduced, and dendritic development was visible at current densities more than 80 A/m^2. As a result, in following experiments, 80 A/m 2 was chosen as the best current density value. It should be emphasized that at 50 A/m^2, the cathode quality was poor because the cadmium sheets became fragile and difficult to peel. There was no clear reason for this, and the same issue was visible during pilot operations.
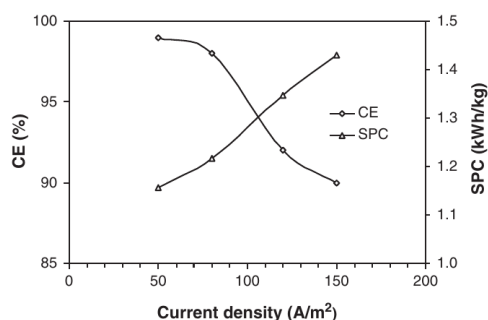

Fig. 6: The effect of current density on CE and SPC. Temperature 40°C, initial cadmium concentration 120 g/L, initial zinc concentration 80 g/L, free acid concentration 98 g/L.

2.3 The effect of free acid concentration

According to figure 7, increasing the free acid concentration up to 100 g/L increases CE, which then decreases at higher concentrations. With a decrease up to 100 g/L and an enhance beyond, the SPC is the opposite of the CE. The decrease in CE causes the increase in SPC at higher free acid levels. In N98 g/L acid, the grade of precipitated cadmium decreased as a result of enhanced hydrogen evolution at relatively high acid concentrations.
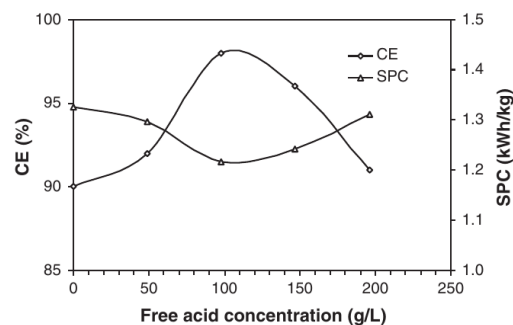

Fig. 7: The effect of free acid concentration on CE and SPC. Temperature 40°C, initial cadmium concentration 120 g/L, initial zinc concentration 80 g/L, current density 80 A/m^2.

2.4 The effect of initial zinc concentration

Experiments were carried out under ideal electrowinning circumstances to observe the influence of zinc concentration on CE and SPC. Variation in zinc content in the range of 20–120 g/L had no significant effect on CE and SPC, as demonstrated in Figure 8. At all zinc concentrations, CE remained about 98 %. However, raising the zinc content from 20 to 120 g/L reduced cathode purity from 99.97 % to 99.92 %. This has no effect on later cadmium sheet treatment since zinc creates a detachable slag during the smelting of cadmium plates in caustic soda. This is a significant benefit since it allows for the selective electro-winning of cadmium with zinc without the need to segregate the two metals first. More research is being conducted to find the optimal method of treating the cadmium-depleted solution in order to recover the residual cadmium and zinc. One option is to recirculate the solutions to the zinc calcine leaching phase, albeit this will boost zinc consumption because the flowing load of cadmium will have to be cemented. It might be possible to improve the proportion of Cd elimination from solution at higher CE and low SPC by reducing the influence of solution diffusion by utilizing a cell with high mass transfer.
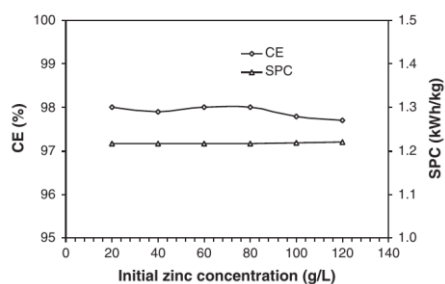
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Fig. 8: The effect of zinc concentration on CE and SPC. Temperature 40°C, initial cadmium concentration 120 g/L, current density 80 A/m^2, free acid concentration 98 g/L.

2.5 The effect of temperature

During the electrowinning of metals, temperature is a critical factor. Under the determined optimum electrowinning conditions, the effect of temperature was investigated over the range of 25–70°C. As the cell potential declined from 2.6 V to 2.4 V with raising the temperature up to a particular point, the SPC reduced from 1.49 kWh/kg to 1.30 kWh/kg. The cadmium electrodeposition over potential reduces more than hydrogen electrodeposition over potential as the temperature increases [23]. Changing the electrolyte temperature from 25 to 70°C improves the process current efficiency and, as a result, lowers the SPC. This is also due to a drop in electrolyte viscosity and, as a result, a rise in ionic diffusion coefficients, that decreases concentration polarization and, as a result, lowers cell voltage (lower energy demand). At temperatures above 50°C, the current efficiency declined dramatically due to a combination of a lower hydrogen production over potential [24] and greater relative diffusivity of proton comparing to cadmium ions, resulting in greater hydrogen evolution. The enhanced conductivity of the electrolyte also contributed to the observed drop in cell voltage. According to the findings, a temperature range of 40–50°C can be regarded for optimal performance. These findings reveal that an excellent cadmium deposition with a 99.97 % purity may be achieved by using 120 g/L Cd

concentration, 80 A/m^2 current density, and 98 g/L free acid concentration at 40 °C. The CE and SPC for this product are 98 % and 1.21 kWh/kg, respectively.

The subjective investigation of cadmium metal ion was obtained using the various methods described above. Because the cadmium salts were obtained in aqua regia, they appear slightly yellowish. It is a colourless salt when it is precipitated out (figure 9). A metal box with a fixing plate and a self-fixing security valve are typical of Ni-Cd batteries. The separator separates the positive and negative cathode plates, which are moved in a winding inside the casing. The jam roll design permits a Ni-Cd cell to convey a significantly more prominent greatest current than a soluble cell of equivalent size. The cell shell is loaded up with electrolyte and contains a graphite bar that goes about as the positive cathode in alkaline cells. The inner opposition of a comparable to measured basic cell is higher on the grounds that a moderately little district of the terminal is in touch with the electrolyte (instead of the jam roll plan), which confines the most extreme current that can be given. Nickel-Cadmium batteries contain various forms and compositions of the synthetic compounds Nickel (Ni) and Cadmium (Cd). The positive cathode is nickel hydroxide [Ni (OH)$_2$], while the negative anode is Cadmium hydroxide [Cd(OH)$_2$], with potassium hydroxide as the electrolyte (KOH). because the electrolyte part of the cell, specifically KOH creation, is higher in the battery than the other two components in their hydroxide structures, in particular Ni and Cd, the battery has a low content of Cd and Ni. The electrolyte had been filled to roughly two-thirds of the battery, resulting in a battery that was almost entirely made of KOH. This explains the Ni-Cd batteries low Cd content.

Fig. 9: Cadmium Salt

2.6 Analysis of Variance (ANOVA)

Along with factor coding, investigation of variance is utilized to define the noteworthy impact of progression variables on current efficacy (Table 2). Type III-partially generated from the ANOVA quadratic model is discovered to be the sum of squares. The model's F value of 4.43 indicates that it is important. Due to noise, the F value can have a minimum value of 3.12 %. Model terms with p values less than 0.0500 are significant. A and A^2 are important model terms in this scenario. The model phrases are not vital if the value is greater than 0.1000. Model reduction may additionally enhance the model if there are numerous inconsequential version terms (not which include those required to assist hierarchy). The F rating of 63.27 indicates that the design is not balanced. Variance inflation factors (VIFs) greater than 10 are reason for concern, while VIFs greater than 100 are the reason for panic, suggesting that constants are poorly assessed due to multicollinearity, with an ideal R_i^2 of 0.0. A high R_i^2 value indicates that words are highly connected, perhaps resulting in bad models. Multicollinearity will be more prevalent if the design contains multilinear restrictions. This causes the VIFs and R_i^2 to inflate, causing these statistics to perform poorly. As a result, FDS might be employed. When it comes to evaluating reaction surface designs, power is an ineffective tool. Use the %age of design space (FDS) data to calculate prediction-based metrics offered by this application.

Table 2: ANOVA quadratic model for cadmium.

Source	Sum of square	Degree of freedom (DOF)	Mean square value	F value	P value	
Model	2163.65	10	240.27	3.42	0.0214	Significant
A-CD	740.32	1	540.32	7.20	0.0150	
B-solvent	459.68	1	339.98	6.91	0.0124	
C-time	38.14	1	290.12	3.19	0.0603	
AB	8.12	1	5.10	0.0662	0.6471	
AC	0.2134	1	0.1235	0.0019	0.8605	
BC	210.23	1	210.53	2.73	0.1915	
A^2	1569.51	1	1349.50	19.57	0.0025	
B^2	13.68	1	15.56	0.1579	0.5111	
C^2	14.69	1	16.49	0.1678	0.6916	
Residual	568.01	8	80.03			
Lack of fit pure	621.54	5	190.34	63.27	0.0007	Significant
error	10.21	5	3.65			

2.7 Characterization of Reaction Products Obtained During High Temperature Pyrolysis of Ni-Cd batteries

Waste Ni-Cd batteries were subjected to extensive high-temperature pyrolysis tests across a wide temperature range. An in-depth characterization of reaction products created following various heat treatments is described in this chapter; these will be utilised to develop a full understanding of the behaviour of various constituents later on. A variety of analytical techniques were used to examine the products. Weight loss measurements, infrared (IR) analysis, thermo-gravimetric analysis (TGA) & derivative thermogravimetry (DTG), and Fourier transform infrared spectroscopy were used to investigate the gaseous component (FTIR). To obtain a chemical characterization of numerous metals included in these products, the metallic fractions were analysed using Inductively Coupled Plasma-Optical Emission Spectrometry (ICP-OES). In later chapters, SEM examinations of these products are provided. Due to the small sizes/amounts of metallic items, X-ray diffraction could not be used. LECO carbon analyzer, BET surface area analysis, and ICP-OES were used to examine the carbonaceous/slag phases.

Phase separation and characterization of reaction products

After heat treatment of waste Ni-Cd batteries at various temperatures, three different types of reaction products were obtained: a gaseous fraction, a metallic product, and a carbonaceous/slag residue, also known as non-metallic fraction (NMF). A variety of methodologies were used to examine these components. The results are described in detail below.

Gaseous products

During the heat treatment of waste Ni-Cd batteries in the horizontal tube furnace at temperatures ranging from 750°C to 1350°C, CO, CO_2, and CH_4 gases were produced and measured continuously using an IR gas analyser. The CO gas made up the majority of the gases produced, while a tiny amount of CO_2 was also formed during the heat treatment. Methane production was found to be low in most cases. The cumulative quantities of gases emitted at 1150°C for 10, 15, and 20 minutes of heat treatment are shown in Figures 10 to 12. As waste Ni-Cd batteries were placed directly into high temperatures, there was a rapid release of gases; this rapid first release of gases is ascribed to polymer degradation as waste Ni-Cd batteries are first subjected to high temperatures. In the temperature range of 300°C to 600°C, polymers are expected to breakdown. The amount of CO emitted was substantially higher than the amounts of CO_2 and CH_4. While CO was still being emitted during the heating process, the amount of CO_2 and CH_4 produced had decreased dramatically, as evidenced by the relatively flat cumulative volume figure.

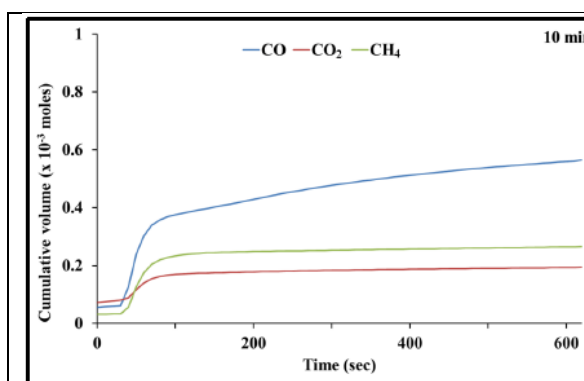*Eur. Chem. Bull.* **2023**, *12(Special Issue 9), 1871-1898*

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Fig. 10: Volumes of gases released after 10 minutes of heat treatment at 1150 °C.
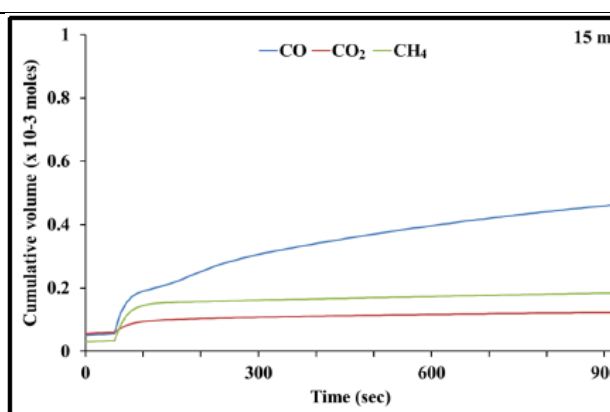
Fig. 11: Volumes of gases released after 15 minutes of heat treatment at 1150°C.
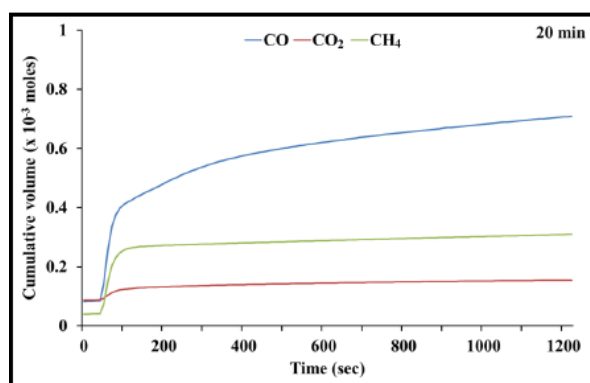

Fig. 12: Volumes of gases released after 20 minutes of heat treatment at 1150°C.

The gas generation at 1250 °C for 10, 15, and 20 minutes of heat treatment is shown in Figures 13 to 14. The volumes released were quite similar to those reported at 1150°C. However, CO production increased progressively, while CO_2 and CH_4 remained almost constant, with similar volumes released.
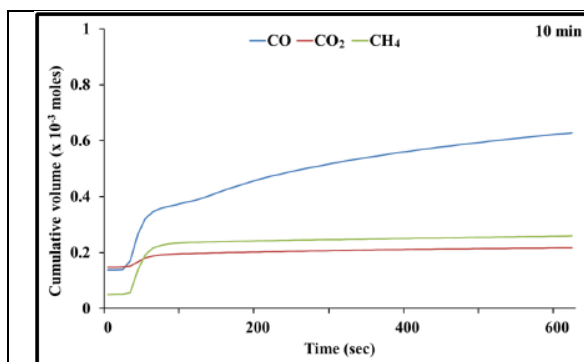

Fig. 13: Volumes of gases released after 10 minutes of heat treatment at 1250 °C.
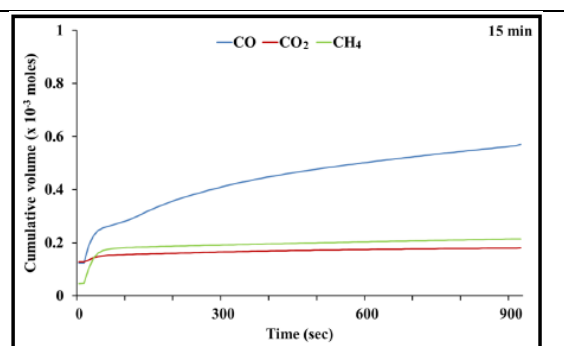
Fig. 14: Volumes of gases released after 15 minutes of heat treatment at 1250°C.
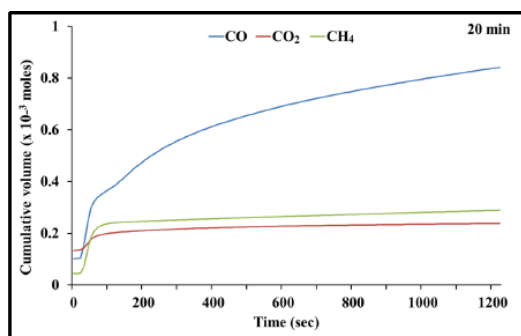
Fig. 15: Volumes of gases released after 20 minutes of heat treatment at 1250°C.

Off-gases produced at 1350 °C and similar processing periods are shown in Figures 13 to 15. CO_2 and CH_4 volumes were found to be nearly same, whereas CO levels continued to rise with time. The abrupt first CO release at 1150°C was replaced by a steadier CO release at 1350°C.

III. Current Efficiency of CD

Cadmium is a chemical element that is identified by the number 48 and the letter Cd in its atomic formula. Electroplating is one of the most common applications for this pliable and bluish-white metal, although it is also employed in the manufacturing of batteries, pigments, and plastics. The measurement of cadmium's current efficiency is an important step in the process of employing it. Current efficiency refers to the quantity of work that may be harvested from a current-carrying device or system. In this research work, we explore the numerous approaches that may be used to evaluate the present efficacy of cadmium, as well as how those methods are utilized in a variety of settings. Cadmium has been shown to be effective in a number of different situations. In addition, we investigate potential downsides of cadmium's current effectiveness as well as prospective solutions. It is essential to understand right away because the behavior of cadmium during electrodeposition is usually used to evaluate the effectiveness of its current, and this is something that must be recognized straight away.

Electrodeposition is the process of applying a very thin layer of metal to a surface by using an electric current as the deposition tool. This method can be utilized in a variety of contexts, such as in the production of ornamental finishes, functional layers, and coatings for a variety of different goods. When it comes to electrodeposition, the current efficiency of cadmium can be measured using a variety of different approaches. One of the most common approaches, known as the Faraday efficiency, determines the amount of cadmium that is deposited in a system based on the amount of electric charge that is transferred through it. This method, which is generally considered to be dependable and accurate, takes into account the entirety of the electrodeposition process. This method takes into account the dissolution of the cadmium in the electrolyte solution, the transport of the ions to the cathode surface, and the reduction of the ions to produce the metal. The Coulomb efficiency is an additional approach that is extensively used to measure the current efficiency of cadmium. This method is based on the quantity of cadmium that is deposited per unit of electric charge going through the system, and it is one of the most common methods. The efficiency of this method is comparable to that of the Faraday efficiency in that it only considers the movement of ions to the surface of the cathode and the reduction of ions into metal. Many people assume that the Coulomb efficiency is less accurate than the Faraday efficiency because it does not take into account the fact that cadmium is soluble in the electrolyte solution. However, the Faraday efficiency does take this into account.

There are a number of different measures that can be used to evaluate the present efficiency of cadmium. These metrics include the instantaneous, average, and relative efficiencies. The instantaneous efficiency is determined by the amount of cadmium deposited at a particular point in time, whereas the average efficiency is

determined by the amount of cadmium deposited on an ongoing basis on an average basis over a period of time. The ratio of the actual quantity of cadmium deposited to the theoretical maximum amount that might be deposited under ideal conditions is used to calculate the relative efficiency of the process. This ratio is expressed as a percentage. In addition to the factors that were discussed previously, there are a great deal of additional factors that can have an impact on the current efficiency of cadmium when it is being electrodeposited. These components include the temperature of the electrolyte solution, its pH level, and the surface characteristics of the cathode. The chemical composition of the electrolyte solution is also a factor.

Utilizing an electrolyte solution that is well-suited to the activity at hand is one strategy that can be utilized to mitigate the effect that these various parameters have on the effectiveness of the cadmium current. Applications that call for a high rate of deposition may make use of an electrolyte solution that contains a high concentration of cadmium ions; on the other hand, applications that call for a low rate of deposition may make use of a solution that contains a lower concentration. It is also possible to alter the temperature and pH of the solution in order to make cadmium work as effectively as possible at the present time.

3.1 Electrochemistry measurements and analysis

An electrochemical method has been established in order to rapidly evaluate the current efficacy of cadmium plating in both mediocre and stellar cadmium-cyanide plating baths. Researchers were able to evaluate the efficacy of the method by contrasting the outcomes of weight loss and gain measurements with those collected through electrochemical measurements. These measurements formed the basis for the cyclic voltammetry investigations that formed the basis for the method. The

method was utilized in research on total hydrogen analysis as well as the efficiency of current for cadmium plating at a variety of current densities that were applied. This method can serve as a sensor to monitor in real time the influence that factors such as impurities, the composition of the bath, and the shape of the component have on the performance of the cadmium plating process. Additionally, it can be put to use as a research instrument to quickly and accurately examine the impact of different plating settings or bath additives on the efficiency of Cd plating in its current form. According to the data, there was a direct correlation between a 2% decrease in the current efficiency of CD plating and a 50% increase in hydrogen uptake. The influence that different benzyl alcohols and electron-bridging anions have on the amount of cadmium that can be deposited per unit of current

The effectiveness of the currently used method for cadmium deposition can be enhanced by the incorporation of particular substituted benzyl alcohols into the plating baths containing cadmium sulphate and chloride. Alcohols have the ability to obstruct the development of hydrogen, and in millimolar levels, they can combine with cadmium ions to form complexes. Sulfate baths often exhibit a linear correlation between the concentration of the cadmium-alcohol combination and the amount of current that can be drawn from the bath. Due to the fact that hydrogen evolution is being inhibited, alcohol is unable to sub in for chloride in the cadmium-chloride system and produce a complex at this point in time. Alcohols have no influence on the mechanism by which electron-bridging anions catalyse the deposition of cadmium; this mechanism is unaffected by alcohols. The fact that the catalysis is always decreasing despite the increasing size of the bridging anion demonstrates that the electron bridging takes place in the holes that are present in the alcohol layer. Millimolar strong non-bridging complexing agents, on the other hand,

reduce the efficiency of the current and prevent metal deposition. On the other hand, millimolar surfactants are known to improve current efficiency by inhibiting the development of hydrogen.

Using electrochemical impedance spectroscopy, an investigation into the effects of benzyl alcohol (BA) and thiourea (TU) on the electrodeposited cadmium from an acid sulphate bath was carried out (EIS). According to the authors, the form that resembles a hexagon and may be seen in SEM photographs is obscured by Cd-TU complexes. Electrodeposited cadmium presents a possibility for application in the production of the radioactive isotope 111 In. Cadmium is poisonous and induces the embrittlement of hydrogen molecules. Electrochemical impedance spectroscopy, or EIS for short, is a method of analysis that can be used to identify likely reaction events and the influence that additives have on the formation of electrodeposition crystals. The charge transfer resistance appears to diminish when PEG adsorbs on the zinc surface in the event of copper deposition; however, this finding does not hold true for copper. When there is a higher concentration of PEG, there is an expansion of the third capacitive loop. In the case of cadmium acid sulphate plating, an increase in the time constant (TU) is most likely caused by the adsorption of [Cd (TU)] with increasing additive concentrations. This is the most likely explanation for this phenomenon (BA). The following equation was used to determine the level of adsorption that had occurred: The increase in additive concentration is accompanied by an increase in the value of R. Cadmium bioxide (BA) has a cathode surface that has the ability to spontaneously absorb additives. The presence of BA and TU results in an increase in the charge-transfer resistance on the surface of the metal. Adsorption of the additive molecules on the surface of the metal occurs as a result of surface diffusion of ions carrying cations. There have been observations of various deposit morphologies due to the fact that

every new component possesses its own unique qualities.

For a very long time, a significant number of people have taken an interest in non-stationary electrolysis that makes use of alternating current. The research presents a number of methods for determining the cathodic current efficiency of metal deposition procedures that use either alternating current (AC) or pulse current (PC). Additionally, it examines other industrial processes, such as the electrolysis of water and the refinement of metals. It is not possible to determine in a uniform manner both the total amount of electricity (charge) that is used and the amount of charge that is consumed by faradaic processes that use changing currents in a variety of regimes. In order to determine the level of a metal or alloy's current efficiency, it is common practice to compare the mass of a sample before and after the procedure while keeping track of the total charge that was used.

The current efficiency gives an indication of the total amount of current (or charge) that is utilized in the electrode process that is being discussed here. A particular electrode reaction is inextricably linked to the effectiveness of the current (CE i). The total that should be reached after tallying up all of the available efficiencies is one hundred percent (1). The value of the charging current of EDL is affected by a variety of factors, including the condition of the electrode surface, the thickness of the solution layer located close to the electrodes, and the power regime of the electrochemical system. If rectangular pulses are employed instead of sinusoidally alternating current, the potential change brought on by the sharp leading edge will result in a greater increase in magnitude over the course of time.

When the current is turned on, the processes are working toward reaching a condition that is either stationary or nearly stationary. At some point in time, in comparison to the amount of time that has passed since

attaining this condition, the proportion of the charge that has been absorbed by hydrogen evolution, metal deposition, and other processes that are occurring concurrently will shift. An acid tartrate electrolyte is used in the electrodeposition of indium, and quasi-sinusoidal asymmetric current (a) and rectangular potential pulses are utilized in the process (b). In order to calculate the total amount of charge that has been transferred throughout the electrochemical system, one can make use of a variety of different analytical methods (Q total). The total charge values of the modes that were displayed after being exposed to the galvanic bath for ten minutes (with a total of 30,000 exposures).

When utilizing pulse currents in a rectangular shape, it is possible to achieve a number of different modes (galvanostatic pulses). With the help of a double-beam oscilloscope, we will be able to monitor the voltage drop on the cell both with and without the addition of an extra resistor. By applying Ohm's law, we are able to calculate the amplitude of the pulse current. In order to calculate Q total when using the reverse mode of pulse electrolysis, the formula that is provided below should be applied. A mathematical formula known as Q total is used to represent the total amount of charge that has been carried by a current across an electrical circuit.

In order to properly evaluate the recommended expression, the values of the current during the direct and reverse pulses need to be treated as absolutes (i.e., without regard to polarity). The collection of electrical methods for calculating current that produce the pulse value with a period of less than a second is the most exciting. This set of methods has a shorter duration than a second. In order to use the alternating current and reverse modes, it is essential to make use of specialised integrators that have high working speeds and the capacity to store instantaneous current values. It is possible to calculate the amount of current flowing through a circuit by first measuring

the amount of potential drop that occurs across a reference resistor. The only charge that can be approximated is the charge that is employed for Faraday processes, which enables the calculation of the total CE.

Non-faradaic processes should only be addressed at high frequencies because the amount of time necessary for EDL recharge is only a few hundredths of a millisecond (above 1000 Hz). In spite of this, evidence from experiments suggest that increasing the frequency of the current from 10 to 100 Hz resulted in a reduction of 25% in the amount of current that is consumed by far-ADAic processes. A digital coulometer could be utilized in order to make an estimate of the amounts of gases that are released. It is recommended to utilize acid solutions rather than alkali solutions since an acidic environment significantly accelerates the discharge of hydrogen ions. Alkali solutions on the other hand, are known to neutralize hydrogen ions. Experimentation was used to determine the values for the E 1 and E 2 parameters, which helped guarantee that they are accurate. When zinc is electrodeposited from an acid electrolyte in the presence of lactic acid, it illustrates the relationship between the total charge, which is denoted by Q total, and the charge that is utilized in faradaic processes, which is denoted by Q F.

3.2 The Efficiency of the Current Formulation

The current efficiency of the electrolytic process refers to the percentage of the total amount of electricity that is consumed that is actually put to use in the electrolytic reaction that is being targeted. For the purpose of depositing metal, for instance, the temperature and current density of the bath are adjusted in such a way as to maximize the efficiency of the current while simultaneously preserving the desirable characteristics of the deposit. Every cathodic and anodic process have to have as their primary objective the maximization of current efficiency because

this is the only way to guarantee that the reaction in question proceed in a continuous manner.

Voltammetry on rotating disc electrodes was used to evaluate the oxidation of acetic, glycolic, glyoxylic, oxalic, and formic acid on boron-doped diamond electrodes. According to the findings of the study, there are significant distinctions between the carboxylic acids (formic, oxalic, glyoxylic, and glycolic acid), which are capable of being oxidized via direct electron transfer, and acetic acid, which can only be oxidized by hydroxyl radicals that are produced in close proximity to the site where water oxidation takes place. Glyoxylic acid was not discovered to be an intermediary in the oxidation of glycolic acid, despite the fact that glycolic acid was shown to be the primary intermediate produced in the oxidation of both glycolic and glyoxylic acid. Experiments using chronoamperometry suggest that all molecules, with the exception of acetic acid, are subject to extra oxidation, which results in carbon dioxide. It has been established that it is possible to selectively oxidize formic, oxalic, glyoxylic, and glycolic acids at 2.3 V vs. Ag/AgCl with high current efficiencies, at or close to mass transfer-limiting rates. There is a potential for decreased current efficiencies and conversion rates to take place when water is electrolyzed simultaneously at higher potentials (2.4 and 2.5 V). There is a possibility that this is connected to water oxidation-related activities such as the production of O2 and hydroxyl radicals.

3.3 The Most Fundamental Units of Measurement:

It is possible to measure the concentration of various chemical elements by employing a technique known as atomic absorption spectroscopy (AAS). This technique involves analyzing the light that is absorbed by free atoms when they are in a gaseous form. Quantifying the number of metals contained in a sample is one of its many applications, which also includes clinical and food analysis, the pharmaceutical business, and the mining industry. It is also commonly employed in medicine. The AAS is recognized for its great sensitivity and absence of interference, and it is capable of detecting more than 70 different elements in liquid as well as solid form. The current form of AAS was developed in the 1950s by an Australian chemist by the name of Sir Alan Walsh. When a flame is exposed to a metal salt solution (M+X-), it is possible for a gaseous byproduct to be produced that is composed of individual metal atoms. Several of these atoms, when they are in their ground state, have the potential to absorb light of a certain wavelength. A portion of the light will be taken in if a beam of light with the resonance wavelength is made to pass through a flame that contains the target atoms. In the flame, the ratio of atoms in their ground states to the quantity of absorption will be in the other direction. Shining light of a certain wavelength on gaseous metal atoms causes the ground state atoms of those atoms to transition into an excited state. Beer's law and Lambert's law both state that absorbance is equal to the logarithmic ratio of incident light intensity to absorbed light intensity. These laws state that the quantity of absorption is dictated by the ratio of these two quantities.

Measurement elements

Atomizers: Prior to analyzing the atomic structure of an element, the element first needs to be atomized. Flame atomizers and electrothermal atomizers (which use graphite tubes) are currently the two most widely used types of atomizers. The two different kinds of AAS that can be used are flame-based and electrothermal or graphite furnace-based, respectively. Atomization in flame-based AAS is achieved using a process known as nebulization, which involves spraying a sample solution into a flame atomizer while simultaneously utilizing a gaseous mixture consisting of an oxidant and a fuel. The furnace for the graphite Atomization in an open-ended

graphite tube is required for the AAS process, which is also referred to in some contexts as an electrothermal or graphite furnace atomizer. The process of atomization of the chemical begins when the temperature of the tube begins to rise. The analytes are excited by radiation that is introduced into the tube from one end. The absorbed fraction is determined by the detector located at the other end.

One of the most common kinds of radiation sources is a lamp with a hollow cathode. The metal cathode of such a lamp is shaped like a cylinder, and it is filled with a low-pressure gas, like argon or neon, that contains both the necessary element and an anode. Ionization of the filled gas occurs when a high voltage is applied to the cathode as well as the anode. The material of the cathode is energized so that it can release the radiation that is associated with the target element while the gas ions are being steered toward the cathode during the glow discharge. Electron-free discharge lamps, often known as EDLs, and deuterium lamps are two more common sources of radiation (DL). A monochromator is then used to separate the radiation that is accurately focused at each element from the other radiation that is produced by the radiation source. This is done by sending the radiation through the monochromator. The method employs either a prism monochromator or a diffracting grating to get the desired results.

Detector: When it comes to the detector, a photomultiplier tube is usually utilized. This is the component that the monochromator focuses the necessary light upon. The light signal is converted into an electrical signal by the detector in a manner that is inversely proportional to the intensity of the light.

3.4 Cadmium: a brief introduction

Cadmium (Cd), which is one of the many different metals that can be explored using AAS, is of special interest due to the fact that it is so widely used and has the potential to be harmful. The detection of

cadmium in biological and environmental samples is necessary for the monitoring of exposure and the evaluation of possible dangers to health. In this essay, we shall discuss the utility of AAS at the present time for quantifying Cd. The absorption of electromagnetic light by atoms in their ground state provides the foundation for AAS. The process involves atomizing the vaporized species, vaporizing the sample, and determining the amount of a particular light wavelength that is absorbed. AAS is ideally suited for the detection of cadmium in tiny sample sizes due to its exceptionally high sensitivity as well as its capacity to identify metal ions in extremely trace levels.

The excellent selectivity of the AAS makes it a particularly useful tool for determining the presence of cadmium. Even when other metal ions are present, it is still possible to identify cadmium because it possesses a singular set of absorption lines that are only able to be brought into play by the application of a particular wavelength of radiation. This is essential for analysis in complicated samples, such as those derived from biological or environmental components, in which Cd is typically present in very low concentrations.

Due to the versatility of the AAS, it is possible to use it to detect cadmium in a variety of sample matrices, which is another one of the benefits of using this method. AAS is capable of performing analyses on samples that are either solid, liquid, or even gaseous in consistency. Because of its adaptability, cadmium can be found in a wide variety of samples, including those derived from living organisms, soil, and water.

Although AAS offers a number of benefits, it is essential to keep in mind that the method also has a few drawbacks, which should not be overlooked. The considerable sample preparation that is required for AAS, which may include sample digestion and clean-up, is one of the primary hurdles that must be overcome. This preparation

can be both labor- and time-intensive. Because the AAS is susceptible to interferences from other species, which could lead to the production of erroneous findings, it is vital to carefully regulate the experimental conditions, include a sufficient set of standards, and utilize the appropriate calibration method.

As a result, AAS is a method that can effectively detect cadmium in a wide variety of materials while maintaining a high level of efficiency and adaptability. It is the method of choice for the study of complex materials containing cadmium because of its exceptional selectivity, sensitivity, and adaptability in sample matrices. However, interferences and the constraints of sample preparation should be taken into consideration. By overcoming these constraints, AAS can be used to detect cadmium in a wide variety of materials with a high degree of precision and accuracy.

Inductively coupled plasma mass spectrometry is yet another well-liked technique for determining the presence of cadmium as well as its concentration (ICP-MS). ICP-MS is a very sensitive method that can detect Cd at levels as low as 0.1 ng/L. It is one of the most widely used analytical methods. Ionization of the sample is the first step in the process, which is then followed by mass separation and detection. Even in complicated matrices like those seen in biological samples, ICP-MS is able to identify cadmium.

Inductively coupled plasma-optical emission spectroscopy is a further technique that is utilised in the search for and measurement of Cd (ICP-OES). This technique is not only sensitive and selective, but it is also able to detect Cd at levels as low as ng/L. This method, which involves taking a reading of the amount of light that an atomized sample produces, can be utilized to identify and assess the presence of cadmium in a wide variety of materials, such as biological, soil, and water samples, among others.

In addition to x-ray fluorescence spectroscopy, graphite furnace atomic absorption spectroscopy and inductively coupled plasma atomic emission spectroscopy (ICP-AES) are both well-known methods for determining the presence of cadmium as well as for quantifying its concentration (XRF). Each of these techniques is extremely sensitive and selective, and they are all able to detect cadmium at concentrations as low as 0.1 ng/L.

It is essential to keep in mind that, despite the great effectiveness of these methods for detecting and quantifying Cd, sample preparation can occasionally be an issue, and sample interferences can occur to a certain degree. Despite this, it is important to remember that these approaches. It is also vital to carefully manage the experimental parameters and employ the appropriate calibration procedure to achieve precise and accurate results. This can be done by following the steps outlined in the next paragraph.

XRF, AAS, ICP-MS, ICP-OES, ICP-AES, GF-AAS, and ICP-AES are only few of the analytical methods that may detect and quantify cadmium. These techniques have a high degree of sensitivity and selectivity, and they are able to identify Cd even at concentrations as low as ng/L. When choosing a method, it is vital to keep in mind that sample preparation and interferences may create restrictions, and these should be taken into account. These restrictions are able to be effectively circumvented, which paves the way for the accurate detection and quantification of cadmium in a variety of samples.

3.5 The Faraday Law

The amount of material that is actually produced during an electrolytic reaction is compared to the amount that is predicted by Faraday's Law in order to determine how effective an electrochemical process is. When evaluating the efficiency of a method, such as the electrodeposition procedure, this statistic is one of the

measures that is taken into consideration. In addition to these phrases, which all refer to the same concept, "current efficiency" is sometimes referred to as "coulombic efficiency," "faradaic efficiency," and "faradaic yield." All of these terms are synonymous with one another.

The connection between the total applied current density and the electrochemical equivalent current density for a certain reaction is what constitutes current efficiency. This is a measure of how well a particular reaction works. The term "current efficiency" refers to how effectively a system transfers charge (or electrons) in order to maintain an electrochemical reaction. This phenomenon was first understood because to the work of Michael Faraday, who later detailed it in his laws of electrolysis. Initially, this understanding came about because of his work.

During a typical electroplating process, it is feasible to assess how much metal is deposited on the cathode or dissolved at the anode by measuring the current efficiency. Efficiency at the cathode refers to how well the cathodic reaction is carried out, whereas efficiency at the anode refers to how well the anodic reaction is carried out. Cathode current efficiency is another term for this efficiency, and it refers to the ratio of the weight of metal that was actually deposited to the weight of metal that would have been deposited if the entire current had been used for deposition. This efficiency refers to the ratio of the weight of metal that was actually deposited to the weight of metal that would have been deposited. Faraday proposed two principles that should be followed in order to control the electrolysis process. According to the first law of electrolysis, the amount of a substance that is released during electrolysis has a relationship that is inversely proportional to the amount of electricity that is flowing through the electrolyte. In mathematics, this is represented by the letter M. It (where M represents the mass that was deposited, I

represents the current, and t is the time) (Where M is the mass deposited, I is the current and t is the time). According to the second law, when a constant amount of power is passed through a variety of electrolytes, the mass of the various elements that are released will be proportionate to the chemical equivalents of the ions that are involved in the process. This relationship was discovered by Hans Christian Oersted.

Efficacy of the Faraday Current

The electrolysis laws developed by Faraday describe the relationship that exists between the amount of electricity that is passed through an electrolyte and the mass of an element that is released. In order to comprehend a variety of electrochemical processes, such as electroplating, charging batteries, and operating fuel cells, it is vital to have an understanding of these rules. The Faraday Efficiency is one of the most essential notions that describes the effectiveness of an electrolytic process, and among these laws, it is one of the most important concepts. The Faraday Efficiency is the ratio of the actual mass of an element freed during electrolysis to the theoretical mass that is suggested by Faraday's first law. This ratio can be found by dividing the actual mass by the theoretical mass. A mathematical definition of faraday efficiency is as follows:

The Faraday efficiency is the ratio of the actual mass of an element discharged to the theoretical mass of an element predicted by Faraday's first rule. This ratio is referred to as the "actual mass of an element discharged." There is a range of 0% to 100% for the Faraday efficiency. A score of 100% shows that the process is running at an optimal level of efficiency, whereas a score of less than 100% indicates that some of the current that is flowing through the electrolyte is not being used to liberate the element. In many different electrochemical processes, including electroplating, Faraday efficiency is an extremely essential factor. The quantity of metal that is

deposited on the cathode surface is directly proportional to the degree to which the electroplating process is successful. If nickel is being electroplated, for example, a high Faraday efficiency means that a significant amount of nickel is being deposited for each unit of power that is transmitted through the electrolyte. As a direct consequence of this, the deposit is of a higher quality, contains fewer faults, and maintains its thickness more consistently.

Another essential use of the Faraday effect is in the industrial production of fuel cells and batteries. The effectiveness of the electrochemical reactions that are going place inside of these devices is directly proportional to the effectiveness of the devices themselves. The performance of batteries and fuel cells can be enhanced by increasing their Faraday efficiencies. This can lead to a longer battery life, faster charging times, and greater power production from the batteries. In spite of the significance of Faraday efficiency, the idea is plagued by a great deal of ambiguity and inaccuracy. One of its primary shortcomings is that it does not adequately account for the influence of side effects, which may result in a reduction in effectiveness. When the composition of the electrolyte or other parameters change, it is possible that Faraday efficiency will no longer be a relevant gauge of efficiency. Regular evaluation of the process is required, and it is probable that more efficiency indicators will need to be taken into consideration if the goal is to create a picture of efficiency that is more accurate to the real world.

The concept of Faraday efficiency is important in the field of electrochemistry because it describes the relationship between the volume of an element that is liberated and the amount of electricity that travels through an electrolyte. This relationship is described as "the amount of electricity that passes through an electrolyte." The efficiency of the Faraday circuit is essential for a variety of electrochemical processes, such as electroplating, the charging of batteries, and the operation of fuel cells. Even though the concept of Faraday efficiency has a number of drawbacks, it can nevertheless be a helpful tool for comprehending and enhancing the effectiveness of a wide variety of electrochemical procedures if these drawbacks are taken into consideration.
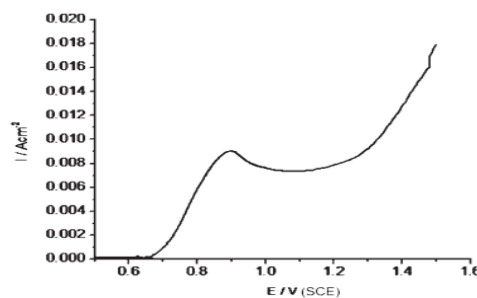

Fig. 16: Cathodic Polarisation of Cadmium deposition in Acid sulphate medium (Scan Rate 10mVS^{-1})
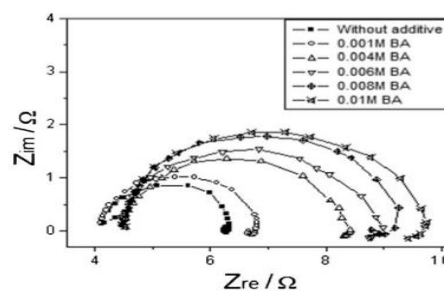

Fig. 17: Nyquist Plot for Cadium Deposition with and without different concentration of BA

IV. Recovery of Cadmium Metal from Printed Circuit Board Waste by Electrowinning Process

Electronic waste, also known as e-waste, trash electrical and electronic equipment, or end-of-life electronics, refers to electronic and electrical equipment that has been deemed outmoded or unwanted by the user. It includes all components, sub-assemblies, and consumables. However, the term can be deceptive because it categorises used electronics as garbage, even when part of the equipment will be repurposed through secondary markets. Information and communication technology (ICT) is fast

evolving in terms of functionality, and there are demonstrable societal benefits to ICT's technological progress that contribute to its long-term viability. People are buying more electronic equipment (such as computers, entertainment electronics, mobile phones, and other devices) as technology progresses, even if they are not necessary. Meanwhile, the considerable increase in e-waste has not been matched by a rise in the methods for collecting, recycling, and reusing this electronic equipment, resulting in challenges in disposing of this garbage and a loss of numerous natural resources [1].

E-waste recycling is an essential topic not only in terms of trash treatment, but also in terms of recovering valuable resources [2, 3]. Metals account for more than 95% of the market value of the components in e-waste. As a result, the intrinsic purpose in e-waste disposal is the recovery of valuable metals. Many techniques for recovering valuable metals from e-waste have been developed over the last few decades, including gravity separation, magnetic separation, and electrostatic separation [4], synthesis of CuCl with e-waste, separation of PCBs with organic solvent method [5, 3], cyanide and noncyanide lixiviants leaching methods, ammonium persulfate leaching bioleaching methods [6–8], or a combination of these techniques. Hydrometallurgical methods are the most accurate, predictable, and controllable of these methods. In the last two decades, hydrometallurgical techniques have been the most active in the development of valuable metal recovery from electronic waste.

Traditional hydrometallurgical procedures, on the other hand, are acid-dependent, time-consuming, and ineffective for simultaneous precious metal recovery. Surprisingly, corrosive or toxic reagents such as aqua regia, nitric acid, cyanide, and halide are used in high quantities, resulting

in poisonous and corrosive vapours or solutions [8, 9]. As a result, a more environmentally friendly process for recovering valuable metals from e-waste is required. In the upgrading and refining stages of the recycling process, hydrometallurgical processes are applied [10–12].

Batteries- Ni-Cd batteries: Cadmium was used in batteries for 86 % of the time in 2009, mostly in rechargeable nickel-cadmium batteries. The nominal cell potential of nickel-cadmium cells is 1.2 V. An alkaline electrolyte separates a positive nickel hydroxide electrode and a negative cadmium electrode plate in the cell (potassium hydroxide). With a few exceptions, the European Union limited the use of cadmium in electronics to 0.01 % in 2004 but reduced the permissible quantity of cadmium in batteries to 0.002 %. Electroplating- A photo of a colloidal Cd-Se quantum dot with a representative spectrum of photoluminescence. Cadmium electroplating is used in the aircraft sector because of its ability to resist corrosion when applied to steel components, accounting for 6% of world output. The use of chromate salts is used to passivate this coating. The electroplating process causes hydrogen embrittlement of high-strength steels, which is a restriction of cadmium plating. As a result, steel items with tensile strengths greater than 1300 MPa (200 ksi) should be coated using a different procedure (such as special low-embrittlement cadmium electroplating processes or physical vapour deposition). Titanium embrittlement induced by cadmium-plated tool residues also led to the removal of these tools (together with routine tool testing programmes to detect any cadmium contamination) from the A-12/SR-71 and U-2 programmes, as well as following titanium-based aircraft programmes.

Nuclear fission- Cadmium is employed in nuclear fission as a neutron control barrier. The alloy used in the pressurised water reactor created by Westinghouse Electric Company is composed of 80% silver, 15% indium, and 5% cadmium.

Laboratory uses- A helium cadmium metal vapour laser emits violet light. The cadmium transition line of 441.563 nm is responsible for the highly monochromatic colour. Blue ultraviolet laser light is commonly produced by helium–cadmium lasers. They are employed in fluorescence microscopes and numerous scientific investigations and operate at 325 or 422 nm. Under UV stimulation, cadmium selenide quantum dots exhibit a brilliant glow (He-Cd laser, for example). Depending on the particle size, the luminescence can be green, yellow, or red. A fluorescent microscope is used to image biological tissues and solutions using colloidal solutions of such particles. Cadmium is a component of various compound semiconductors that can be used for light detection or solar cells, such as cadmium sulphide, cadmium selenide, and cadmium telluride [1].

In this research article, the recovery of cadmium metal from e-waste is widely investigated. The PCBs were converted into fine ash powder and subjected to electrowinning process for the recovery of cadmium metal. The experimental results were determined by AAS. Furthermore, the experimental results are validated through RSM software at different parameters like acid-base concentration, electrode combination, and leaching time [20-22].

V. Materials and Methods

5.1 Materials

For the recovery of metals, computer PCBs were acquired from several sources. PCBs were collected and crushed in a roll crusher before being powdered in a hammer mill. Pyrolysis was used to reincarnate crushed PCBs in order to avoid side reactions with the electrolyte solution during the leaching procedure. The pyrolysis reactor worked best at 600°C in air pressure for 45 min, with the epoxy resins and polymers volatility at temperatures lower than 600°C. The contents of the volatized liquids were condensed and collected separately. A magnetic separator was used to extract ferrous elements from the resulting ash.

5.2 Electrowinning Process

In the incineration chamber, fine ash powder was treated with aqua regia solution (3:1 ratio of HCl and HNO_3) to prevent hazardous gases from escaping. Bath arrangement and amplifier make up the electrowinning setup. The electrode is connected to the amplifier, and the current density was changed through the amplifier. The bath has two slots for the anode and cathode fixing, and the electrode is connected to the amplifier.

5.3 Extraction process of Cadmium

The batteries of the varying compositions are carefully opened. The inner contents are dissolved in aquaregia (HNO_3+3HCl) and is kept undisturbed for few minutes in a fume chamber until it stops fuming and all the contents are completely dissolved except the graphite content and the other undissolved constituents. The concoction after the complete dissolution is taken and poured into a 50ml burette which is previously fitted with a piece of non-adsorbent cotton and then lined with a layer of amberlite so as to filter off the undissolved graphite effectively. The remaining filterate is treated with a few drops of 3mol/L HCl.H_2S gas is passed in acidic medium. A yellow precipitate is present as Cadmium in its sulphide form.

VI. Results and Discussion

The qualitative analysis of cadmium metal ion was obtained using the various methods described above. Because the cadmium salts were obtained in aqua regia, they appear slightly yellowish. It's a colourless salt when it's precipitated out. A metal box with a sealing plate and a self-sealing safety valve are typical of Ni-Cd batteries. The separator separates the positive and negative electrode plates, which are rolled in a spiral inside the casing. The jelly-roll architecture allows a Ni-Cd cell to deliver a substantially greater maximum current than an alkaline cell of equal size. The cell shell is filled with electrolyte and contains a graphite rod that acts as the positive electrode in alkaline cells. The internal resistance of an analogous sized alkaline cell is higher because a relatively small region of the electrode is in contact with the electrolyte (as opposed to the jelly-roll design), which restricts the maximum current that can be provided. Nickel-Cadmium batteries contain various forms and compositions of the chemicals Nickel (Ni) and Cadmium (Cd). The positive electrode is nickel hydroxide [Ni $(OH)_2$], whereas the negative electrode is Cadmium hydroxide [Cd $(OH)_2$], with potassium hydroxide as the electrolyte (KOH). Because the electrolyte part of the cell, namely KOH composition, is higher in the cell than the other two elements in their hydroxide forms, namely Ni and Cd, the battery has a low content of Cd and Ni. The electrolyte had been filled to roughly two-thirds of the battery, resulting in a battery that was almost entirely made of KOH. This explains the Ni-Cd battery's low Cd content.

Fig. 18: Cadmium Salt

6.1 RSM for cadmium

Response surface methodology (RSM) is a statistical modelling technique used in multiple regression analysis to solve multivariable equations utilizing quantitative data gathered from designed experiments. Reaction surfaces are three-dimensional charts that show the response as a function of two variables while holding the other variables constant. The red zone corresponds to an extract %age of more than 85%, the yellow zone to 60 to 70%, and the blue zone to less than 40% cadmium extraction. For the RSM data plots for the cadmium, the regression equation is within the provided limit, a model as a function of coded factor might be used to anticipate the reaction of each parameter. The maximum limit of process parameters (factors) is referred to as +1, whereas the minimum limit is referred to as -1. Table 3 shows Box-Behnken experimental design table for recovery of cadmium. By linking the coefficient of factors, a modified equation or coded equation may be used to find the comparative effect of process parameters. In terms of actual factors, the final equation is:

$$
\begin{aligned}
Extract = {}& 66.36 + 9.0175 \times A \\
& + 7.37375 \times B + 6.42375 \\
& \times C \\
& +1.235 \times AB + 0.17 \times AC \\
& + (-7.1525 \times BC) \\
& +(-18.6187 \times A^2) + (-1.67125 \times B^2) \\
& +(-1.81625 \times \\
& C^2)\dots\dots\dots\dots\dots\dots (1)
\end{aligned}
$$

The model as a function of coded factor could be utilized to predict the response of each parameter within the given limit. Here, the maximum limit of process parameters (factors) is termed (coded) as +1 and minimum limit is terms (coded) as −1. The modified equation or coded equation is very much useful in order to find the

comparative effect of the process parameters by relating the coefficient of factors. The final equation in terms of actual factors is:

$$Extract = -70.2662 + 5.06454 \times CD + 0.201188 \times solvent$$

$$+25.6766 \times time + 0.000914815 \times CD \times solvent$$

$$+0.0125926 \times CD \times time$$

$$+(-0.0317889 \times solvent \times time)$$

$$+(-0.229861 \times CD^2)$$

$$+ (-7.42778e - 05 \times solvent^2)$$

$$+(-0.807222 \times time^2)\dots\dots\dots\dots\dots\dots\dots\dots (2)$$

Equation (2) could be used to predict the response for the given levels of each parameter in terms of process parameters. The original units of each parameter should be considered for each level in this equation. The preceding equation should not be used to examine the comparative effect of each element because the coefficients are balanced to encompass the units of each parameter.

Table 3: Box-Behnken experimental design table for recovery of cadmium.

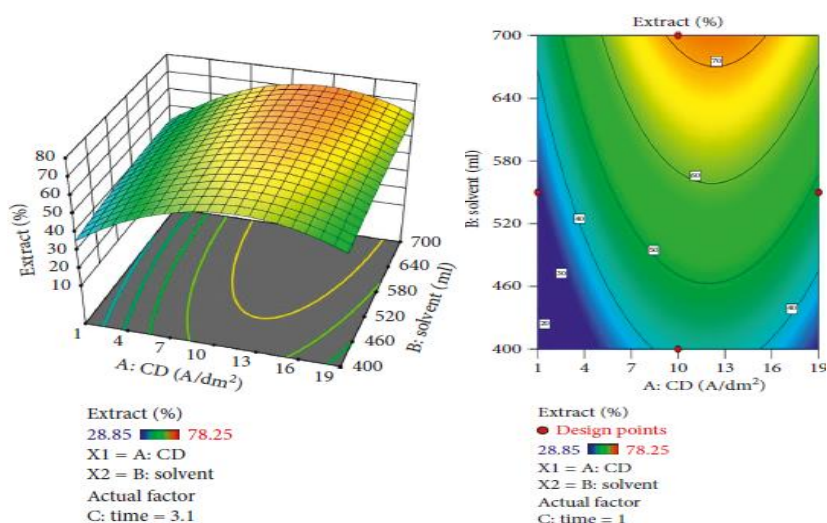| Standard	Run	Factor 1 A:CD A/dm^2	Factor 2 B: solvent (ml)	Factor 3 C: time (hrs)
1	9	2	600	3
2	10	20	600	3
3	18	3	900	3
4	13	21	900	3
5	2	3	400	1.5
6	15	22	450	1.5
7	8	12	600	2
8	7	15	600	2.5
9	6	12	600	2.5

Fig. 19: Contour plot for recovery of cadmium.

6.2 Analysis of Variance (ANOVA)

Along with factor coding, analysis of variance is utilized to determine the significant impact of process variables on current efficiency. Type III—partially generated from the ANOVA quadratic model is discovered to be the sum of squares. The model's F value of 4.43 indicates that it is important. Due to noise, the F value can have a minimum value of 3.12 %. Model terms with p values less than 0.0500 are significant. The model terms are not important if the value is bigger than 0.1000. Model reduction may improve the model if there are many inconsequential model terms (not including those required to support hierarchy). The F rating of 63.27

indicates that the design is not balanced. VIFs greater than 10 are cause for concern, while VIFs greater than 100 are the reason for panic, suggesting that coefficients are poorly estimated due to multicollinearity, with an ideal R_i^2 of 0.0. A high R_i^2 value indicates that words are highly connected, perhaps resulting in bad models. Multicollinearity be more prevalent if the design contains multilinear restrictions. This causes the VIFs and R_i^2 to inflate, causing these statistics to perform poorly. As a result, FDS might be employed. When it comes to evaluating reaction surface designs, power is an ineffective tool. Use the %age of design space (FDS) data to calculate prediction-based metrics offered by this application.

Table 4: ANOVA quadratic model for cadmium.

Source	Sum of square	Degree of freedom (DOF)	Mean square	F value	P value	
Model	2163.65	10	240.27	3.42	0.0214	Significant
A-CD	740.32	1	540.32	7.20	0.0150	
B-solvent	459.68	1	339.98	6.91	0.0124	
C-time	38.14	1	290.12	3.19	0.0603	
AB	8.12	1	5.10	0.0662	0.6471	
AC	0.2134	1	0.1235	0.0019	0.8605	
BC	210.23	1	210.53	2.73	0.1915	
A^2	1569.51	1	1349.50	19.57	0.0025	
B^2	13.68	1	15.56	0.1579	0.5111	
C^2	14.69	1	16.49	0.1678	0.6916	
Residual	568.01	8	80.03			
Lack of fit pure	621.54	5	190.34	63.27	0.0007	Significant
error	10.21	5	3.65			

VII. Conclusion

For the recovery of lead and copper from scraped printed circuit board wastes, the cadmium sulphide systems have been used as leaching agents. The scrap board was leached with 0.1M cadmium sulphide, which resulted in the selective dissolving of cadmium leaching rates, with other metals discovered in smaller levels, respectively. Undissolved residue including nickel, tin,

and silica from the leaching stage was leached off in the appropriate procedures. With increasing contact duration in an acid bath, current efficiency was observed to rise with the current density and concentration ratio. As a result, the electrowinning method was successful in recovering 73.29% cadmium. According to RSM Software, lead and cadmium recovery rates are 78.25%. ANOVA, model terms,

and fit statistics were all assessed for the experimental conditions in addition to the quadratic model equation.

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