



## Phase Transfer-Mediated Removal of Copper (II) and Zinc (II) Ions from Aqueous Solution

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### Abstract

Metal ions in aqueous solutions can be removed by phase transfer-mediation. The aim of this work was to use palm kernel oil (PKO) as an extractant in the presence of a chelating agent [ethylenediaminetetraacetic acid (EDTA)] for the removal of copper (II) and zinc (II) ions from an aqueous solution. The phase transfer of the metal ions was carried out by the addition of aqueous phases to different concentrations of organic phases using standard methods. The effect of the concentration of metal ions on the distribution coefficient and % removal efficiency was studied. The fatty acid composition of PKO was also determined. The results obtained revealed that the distribution coefficients and % removal efficiency of the metal ions increased with an increase in the initial concentrations of the copper (II) and zinc (II) ions. The zinc (II) ions were slightly increased after modification with EDTA.

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The concentrations of copper (II) and zinc (II) ions increased with an increase in the initial concentration of the aqueous phases and an increase in the volume of PKO, but showed a greater increase with the addition of EDTA. It was also observed that the most abundant fatty acid found in PKO was hexadecenoic acid (palmitic acid-C16:0). The results obtained revealed that PKO modified with EDTA can be an excellent organic solvent for the removal of metal ions from aqueous solutions.

**Keywords:** Phase transfer; Copper (II) ions; Zinc (II) ions; Palm kernel oil; Aqueous Solution

### 1.0 Introduction

Pollution with heavy metals is regarded as more harmful than other types of water pollution because of its high degree of toxicity (Li & Trost, 2008; Nordberg & Nordberg, 2009; Tian *et al.*, 2019; Khan & Mondal, 2021). Heavy metal-contaminated wastewater has been released into significant water bodies as a result of the rapid expansion of human industrial

activity in areas like agriculture, mining, and manufacturing (Reza & Singh, 2010; Barakat, 2011). Toxic heavy metals' inability to biodegrade results in their bioaccumulation in aquatic plants and animals (Heikens *et al.*, 2001; Chi *et al.*, 2007). As such, there is need to develop efficient and cost-effective techniques for the removal of heavy metal contaminants from industrial wastewaters. Traditional methods for removing heavy metals from industrial aqueous effluents include electrolysis, ion exchange, chemical precipitation, solvent extraction, membrane separation, coagulation, and adsorption (Blais *et al.*, 1999; Fu *et al.*, 2006; Fu & Wang, 2011). Among these technologies, liquid-liquid extraction (LLE) is one of the most effective and straightforward methods for separating and concentrating metal ions from aqueous solutions (Singh & Savoy, 2020). The use of ionic liquids as an extracting agent to remove heavy metals from wastewaters could be an excellent advancement over currently used methods (Faur-Brasquet *et al.*, 2002; Pacheco-Fernández & Pino, 2019). Various methods such as ion exchange (Dabrowski *et al.*, 2004), adsorption (Ali *et al.*, 2016), membrane filtration (Camarillo *et al.*, 2010), chemical precipitation, and LLE have been used to extract Cu (II) ion and other heavy metal ions from the aqueous phase (Halim *et al.*, 2019). Among the different techniques available, LLE is one of the most efficient methods for removing copper (II) ions from the aqueous phase (Ghanadzadeh & Abbasnejad, 2011).

However, a simple approach for removing heavy metal ions using spontaneous and selective phase transfer into an oil phase has been reported by Chang *et al.* (2017). Interfacial complexation and diffusion are known to induce phase transfer. The metal ion removal method makes use of spontaneous and selective phase transfer into an oil phase. Long-chain carboxylic acids are known to form stable complexes with a wide range of metal ions and

can thus be utilised as an effective oil phase for metal ion removal in aqueous solutions (Bunting & Thong, 1970; Kalhapure & Akamanchi, 2013; Chang *et al.*, 2017). Compared to chemical precipitation and adsorption, this approach, which does not necessitate the use of a specially developed adsorbent or precipitant, has significant advantages. For example, oleic acid is one of the long chain carboxylic acids that is known to be biocompatible and can capture metal ions in aqueous solutions, making it easy for the separation of such metal ions by exploiting its density difference with water (Abdel Salam *et al.*, 2011; Kalhapure & Akamanchi, 2013). Therefore, the method does not require additional filtration to remove insoluble precipitates or fine solid adsorbents. PKO is an edible plant oil derived from the kernel of the oil palm tree (*Elaeisguineensis*), which is cultivated in large quantities in the South-South geopolitical zones of Nigeria, including Akwa Ibom, Cross River States, and South-Western parts of the country (Poku, 2002). The composition of PKO is comparable to that of coconut oil, and both are the only sources of lauric oil. PKO and coconut oil are derived from the oil palm and coconut palm, respectively. The palm oil is produced from the fruit, whereas the PKO is extracted from the kernel. Palm kernel and coconut oils are classed as lauric oils due to their high quantities of lauric acid (C12:0) (Pantzaris & Basiron, 2002; Amri, 2011; Bhattacharya, 2019). No other commercial plant oil contains more than 1% lauric acid, making them special. Because PKO contains a lot of lauric acid (C12:0), it is categorised as a lauric oil (Amri, 2011; Bhattacharya, 2019). While the PKO is used to make soap, vegetable oil, and margarine, the cake residue left over after oil extraction is fed to animals. It is also used locally in body creams, cooking oils, and medicinally as antidotes for poisoning and as surface protectants for minor wounds. Due to its

stability, it is a great alternative oil for the food sector, including bakery, confectionery, ice cream, etc.

The copper (II) and zinc (II) ions are extremely toxic and non-biodegradable. Since they cannot undergo microbial or chemical degradation, they enter the food chain once they are released into the environment and they tend to accumulate at low concentrations in living organisms. Despite the trend of globalization in recent years, environmental pollution by heavy metals is increasingly becoming a problem due to its associated adverse effects on humans. Additionally, they are ingested directly by drinking contaminated water or inadvertently via the food chain (Ali *et al.*, 2019). However, various methods such as ion exchange (Dabrowski *et al.*, 2004), adsorption (Ali *et al.*, 2016), membrane filtration (Camarillo *et al.*, 2010), chemical precipitation and LLE have been used for the removal of Cu (II) ion and other heavy metal ions from the aqueous phase (Halim *et al.*, 2019). Among the different techniques used to remove copper ions and other heavy metal ions from the aqueous phase, LLE is one of the most effective methods to remove copper ions from the aqueous phase (Ghanadzadeh & Abbasnejad, 2011). Due to a difference in solubility, the LLE, also known as solvent extraction, is a conventional method for distributing one or more species (solutes) between two immiscible liquids in contact with one another. Their relative solubility in two immiscible liquids, often water and an organic solvent, serves as the basis for its mechanism (Hu *et al.*, 2019).

The major aim of this paper is the removal of copper (II) and zinc (II) ions from aqueous solution using PKO as an organic extractant.

## 2.0 Materials and Methods

### 2.1 Chemicals and Reagents

All the chemicals and reagents, namely copper (II) chloride ( $\text{CuCl}_2$ ), zinc sulphate

( $\text{ZnSO}_4 \cdot 6\text{H}_2\text{O}$ ), sodium hydroxide (NaOH), tetraoxosulphate (VI) acid ( $\text{H}_2\text{SO}_4$ ), oleic acid, dichloromethane, ethylenediamine (disodium salt) and deionized (DI) water were used throughout the experiments. AccuStandard Fame Reference Standard (catalogue Number: FAMQ005) containing 37 FAMES components was purchased from AccuStandard (US). Three-point serial dilution calibration standards (5.0, 10.0, 20 ppm) was prepared from the stock and used to calibrate the Gas chromatography-mass spectrometry (GC-MS).

### 2.2 Preparation of Stock Solution and Ethylenediaminetetraacetic Acid (EDTA)

The Stock solutions were prepared using 1000 ppm of copper (II) chloride and zinc (II) sulphate respectively. The copper (II) chloride and zinc (II) sulphate solutions were prepared by dissolving 2.68 g of copper chloride and 2.06 g of zinc sulphate in 500ml of deionized water. The copper solutions of different concentrations were prepared by adequate dilution of the stock solutions with 500ml of deionized water. The range of initial concentrations of copper chloride prepared from stock solutions varied between 10 ppm, 30 ppm and 50 ppm respectively.

0.05M EDTA was prepared by dissolving 9.31g of the disodium salt in 500 ml of deionized water and used as a chelating agent during the experiment.

### 2.3 Phase Transfer of Copper (II) Ions from Aqueous Solution into Organic Phase

The phase transfer of copper (II) and zinc (II) ions was carried out using PKO of different volumes (2, 4, 6, 8, 10ml) for organic phase respectively. The initial concentrations of Cu (II) and Zn (II) ions in the aqueous phase used in the experiment were 10, 30, and 50 ppm. The solutions were mixed in a beaker. A hot plate with a magnetic stirrer was used for stirring at 7 rpm for 10 minutes. After stirring, the solution was allowed to stand for two minutes before

separation. The temperature was maintained at 30 °C. A syringe with a small needle was used to separate the aqueous phase from the organic phase and the extraction efficiency for both aqueous and organic phases was determined using the Atomic Absorption Spectrophotometer (AAS) Model 225/23x series. The percentage efficiency of the removal of metal ions was then calculated using the formula in equation 1 below:

$$\% E = \frac{C_o - C_f}{C_o} \times 100 \dots\dots\dots 1$$

where:  $C_o$  is the initial concentration of the metal ions in aqueous phase and  $C_f$  is the final concentration of the metal ions in aqueous phase after extraction. In addition, the distribution coefficient of metal ions was calculated using the formula in equation 2 below:

$$\text{Distribution Coefficient} = \frac{\text{Concentration of metals ions in extract} - \text{initial concentration of metals}}{\text{Final concentration of metal ions in aqueous phase}} \dots\dots\dots 2$$

#### 2.4 Determination of Chemical Composition of Palm Kernel Oil (PKO)

The chemical composition of PKO was determined using an 8860 A gas chromatograph coupled to a 5977 inert mass spectrometer with electron impact source (Agilent Technologies). The stationary phase for the separation of the compounds was carried out on HP-5 capillary column coated with 5% phenyl methyl siloxane (30 m length  $\times$  0.32 mm diameter  $\times$  0.25  $\mu$ m film thickness). The carrier gas (hydrogen) was used at a constant flow rate of 1.48ml/min, an initial nominal pressure of 1.49 psi and at an average velocity of 44.22 m/second. One microliter of the samples was injected in a split less mode at an injection temperature of 300°C. The purge flow to split vent was 15.0 ml/min at 0.75 minutes with a total gas flow rate of 16.67 ml/min and the gas saver mode was switched off. The oven was initially programmed at 80°C for 2 min and then ramped at 30 °C/min to 320 °C (2 min). The run time was 15 minutes with a 3 minutes solvent delay. The mass spectrometer was operated in electron-impact ionization mode at 70 eV with ion source temperature of 230 °C, quadrupole temperature of 150 °C and transfer line temperature of 300 °C. After calibration, the samples were analysed and the corresponding fatty acids concentrations, (% composition) and mass spectral data were obtained. The percentage composition of the fatty acid in PKO was calculated as shown in Table 9.

#### 2.5 Removal of Aqueous Phase Using PKO with Addition of EDTA

The removal of  $\text{Cu}^{2+}$  ions with using PKO was carried out using different concentrations of copper (II) and zinc (II) ions (10, 30, 50 ppm) and various volumes of PKO (2,4,6,8,10 ml).

In addition, the removal of  $\text{Cu}^{2+}$  and  $\text{Zn}^{2+}$  ions using different volumes of PKO (2, 4, 6, 8, 10 ml) and 2ml of EDTA was added.

### 3.0 Results and Discussions

The various results obtained are discussed in details here. Emphasis is placed on the distribution coefficients and percentage removal efficiencies of the metal ions between the aqueous and the organic phases. Equally, the discussion on the fatty acid composition of PKO is presented herein.

#### 3.1 Removal of Copper (II) Ions from Aqueous Solution using Palm Kernel Oil (PKO)

Palm kernel oil (PKO) was used as organic phase for the removal of copper (II) ions from the aqueous solution. The results obtained from this sets of experiments are discussed below.

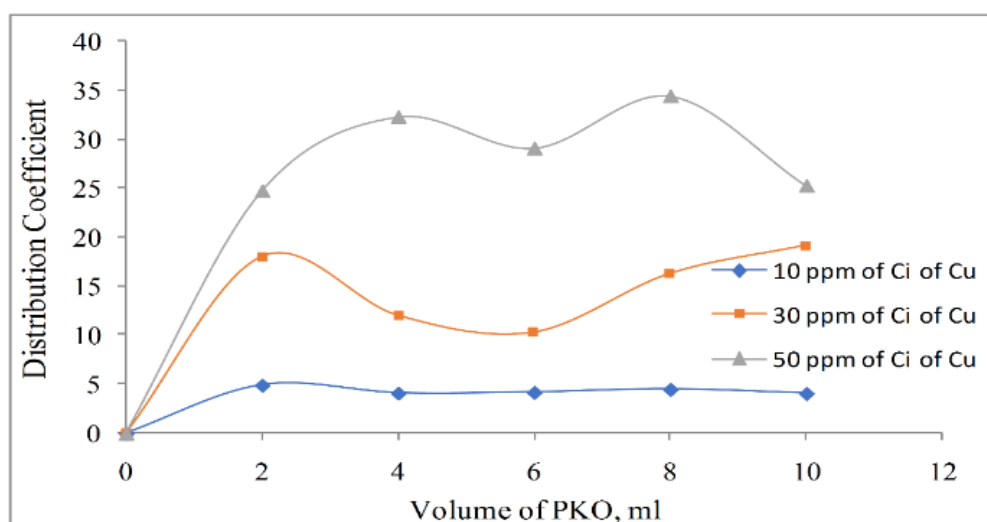
##### 3.1.1 Distribution Coefficient of Copper (II) Ions between Aqueous and Palm Kernel Oil (PKO) Phases

The distribution coefficients are shown in Table 1 for the various volume of PKO used as the

organic phase. It has been observed that the distribution coefficient increased with increase in the initial concentrations of copper (II) ions and decreased with the increased in the volume of PKO used in the process which is in agreement with the results reported by (Papandreou *et al.*, 2007).

**Table 1:** The distribution coefficient for  $\text{Cu}^{2+}$  using PKO. Initial concentrations of Cu (II) ions = 10 ppm, 30 ppm and 50 ppm

S/N	Volume of PKO (ml)	Distribution Coefficient		
		10 ppm	30 ppm	50 ppm
1	2	4.91	17.98	24.77
2	4	4.10	11.98	32.33
3	6	4.18	10.27	29.12
4	8	4.49	16.24	34.46
5	10	4.07	19.13	25.31



**Figure 1:** The variation of the distribution coefficient for Copper (II) ions with various volume of PKO

### 3.1.2 Distribution Coefficient of Copper (II) Ions between the Aqueous and Palm Kernel Oil with EDTA

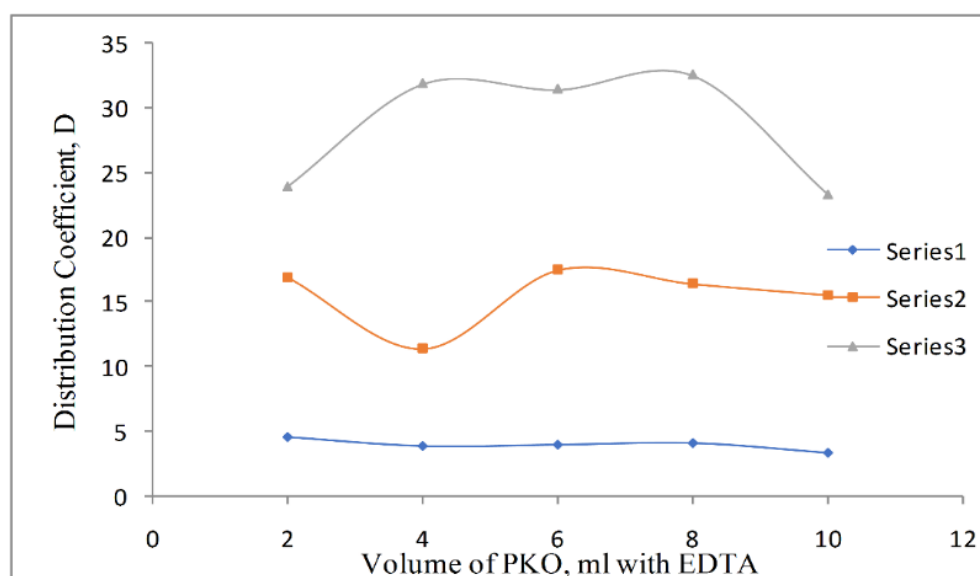
The distribution coefficients of phase mediated transfer of the copper (II) ions from the aqueous phase into PKO which was used as the organic

phase were slightly higher than that of the comparable cases where EDTA was not present. (2014). This is presented in Table 2 and Figure 2. which is in consistent with the results obtained by Jaishankar *et al.* (2014).

**Table 2:** The distribution coefficient for  $\text{Cu}^{2+}$  using PKO in the presence of EDTA. Initial concentrations of Cu (II) ions = 10 ppm, 30 ppm and 50 ppm

S/N	Volume of PKO (ml)	Distribution Coefficient		
		10 ppm	30 ppm	50 ppm
1	2	4.61	16.96	24.00
2	4	3.92	11.39	31.89
3	6	4.02	17.51	31.46
4	8	4.15	16.44	32.55
5	10	3.40	15.57	23.39





**Figure 2:** The variation of the distribution coefficient for Copper (II) ions with various volume of PKO in the presence of EDTA

### 3.1.3 Removal Efficiency of Copper (II) Ions by Palm Kernel Oil (PKO)

The experimental data show that the percentage efficiency increased with an increase in the concentration of the copper ions and the volume of PKO respectively. This is presented in Table 3 and Figure 3. It was evident that as the initial concentrations of the copper ions and the volume of PKO used as the organic phase increased, more ions were removed from the aqueous phase

into the organic phase. This could be explained based on the basis that from the chemical analysis of the PKO, its constituents were mostly long chain fatty acid so as the volume of the PKO used increased, more of the carboxyl function groups were available for the coordination of the copper ions which is in agreement with the finding reported by Wu et al. (2016).

**Table 3:** Percentage efficiency removal for  $\text{Cu}^{2+}$  using PKO. Initial concentrations of Cu (II) ions = 10 ppm, 30 ppm and 50 ppm

S/N	Volume of PKO (ml)	Percent Efficiency		
		10 ppm	30 ppm	50 ppm
1	2	98.12	99.41	99.57
2	4	97.83	99.14	99.66
3	6	97.86	99.38	99.63
4	8	97.98	99.35	99.68
5	10	97.82	99.44	99.57

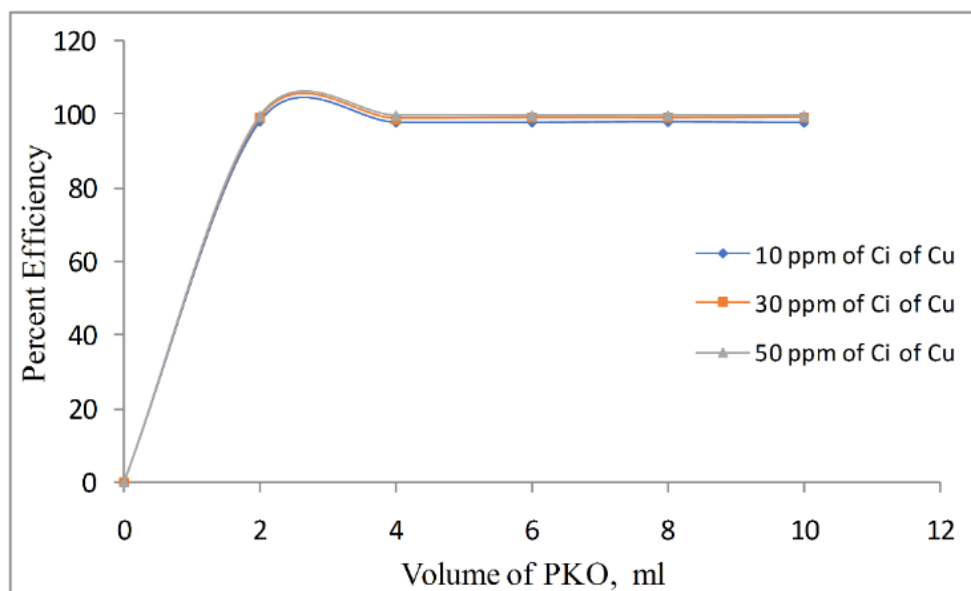
### 3.1.4 Percentage Efficiency of the Removal of Copper Ions from Aqueous Solution Using PKO In The Presence Of EDTA

The percentage efficiencies for the removal of the phase mediated transfer of the copper (II) ions from the aqueous phase into the PKO phase were all nearly the same as cases when EDTA

was not added. It was observed that EDTA did not have a significant effect in the extraction of the metal ions from the aqueous phase when PKO was used as the organic phase. The reason adduced for this behaviour is that there is a competitive chelating within the organic phase and between the aqueous and organic phases by EDTA. The EDTA complexes with the metal

carboxylates formed by the various fatty acids present in the PKO within the organic phase and the metal ions within the aqueous phase. The competitive complex forming reactions neutralize the impact of EDTA in the phase transfer mediated process shown in Figure 1.

This is presented in Table 4 and Figure 4. The results obtained are in agreement with the results reported by Gunstone (2011). This explanation follows from the behaviour of the distribution coefficients presented in Table 5 and Figure 5, respectively.



**Figure 3:** The variation of the percent Efficiency removal for Copper (II) ions with various volume of PKO

**Table 4:** The values of the percent efficiency removal for  $\text{Cu}^{2+}$  using PKO in the presence of EDTA. Initial concentrations of Cu (II) ions = 10 ppm, 30 ppm and 50 ppm

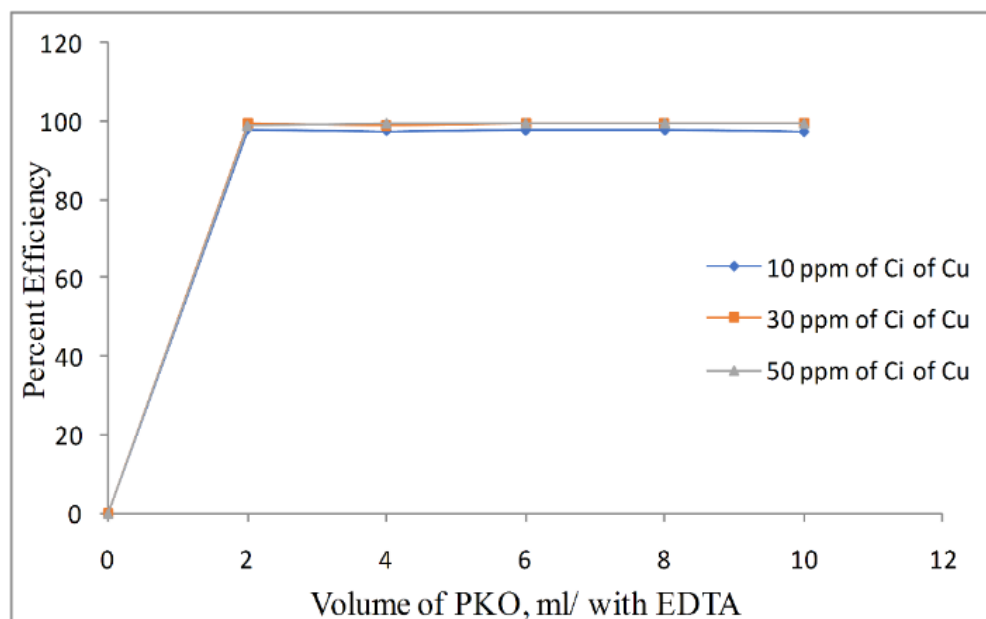
S/N	Volume of PKO (ml)	Percent Efficiency		
		10 ppm	30 ppm	50 ppm
1	2	98.03	99.38	95.05
2	4	97.75	99.10	99.66
3	6	97.79	99.40	99.65
4	8	97.85	99.36	99.67
5	10	97.48	99.33	99.56

### 3.2 Removal of Zinc (II) Ions from Aqueous Solution using Palm Kernel Oil (PKO)

PKO was used as organic phase to remove zinc (II) ions from the aqueous solution. The result from this sets of experiments are discussed below.

#### 3.2.1 Distribution Coefficient for Zinc (II) Ions between Aqueous and Palm Kernel Oil (PKO) Phases

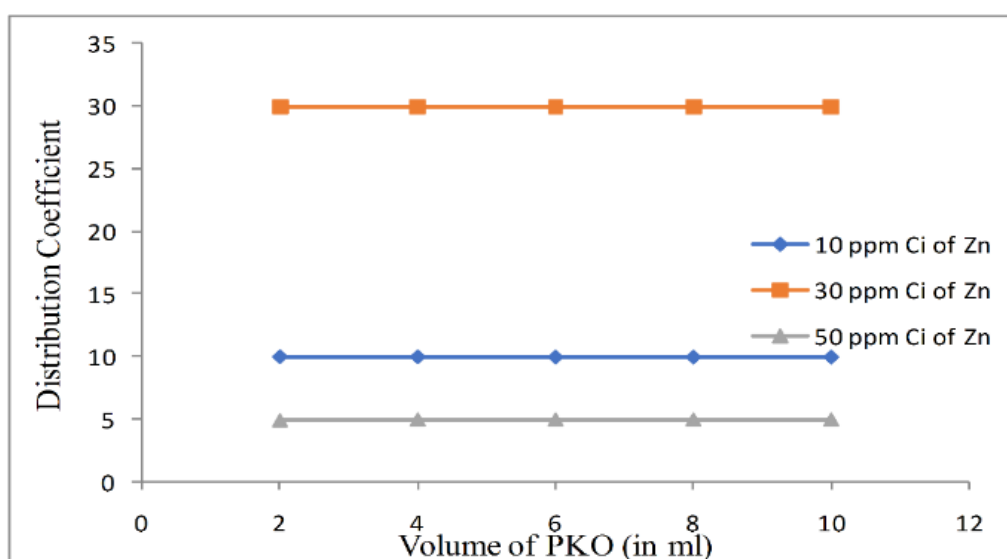
Table 5 and Figure 5 for the various volume of PKO used as the organic phase. The results obtained revealed that the distribution coefficient decreased in the increased volume of PKO used in the experiment. This finding is in agreement with the results reported by Jaishanker *et al.* (2014).



**Figure 4:** The variation of the percent Efficiency removal for Copper (II) ions with various volume of PKO in the presence of EDTA

**Table 5:** The values of the distribution coefficient for  $zn^{2+}$  using PKO. Initial concentrations of Zn (II) ions = 10 ppm, 30 ppm and 50 ppm

S/N	Volume of PKO (ml)	Distribution Coefficient		
		10 ppm	30 ppm	50 ppm
1	2	9.94	29.87	49.91
2	4	9.94	29.91	49.90
3	6	9.96	29.90	49.90
4	8	9.96	29.94	49.89
5	10	9.97	29.94	49.89



**Figure 5:** The variation of the distribution coefficient for Zinc (II) ions with various volume of PKO



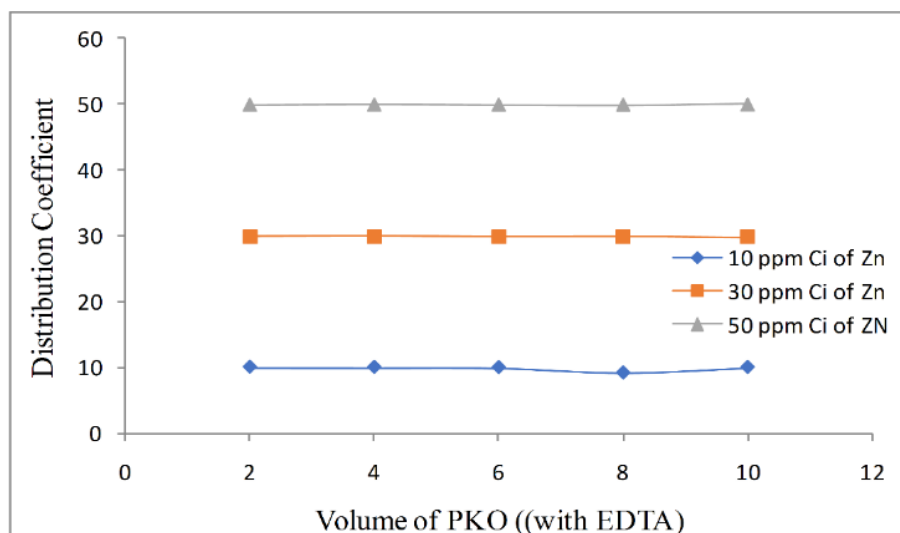
### 3.2.2 Distribution Coefficient of Zinc (II) Ions between Aqueous and Palm Kernel Oil (PKO) in the Presence of EDTA

The distribution coefficients of the phase mediated transfer of zinc (II) ions from the aqueous phase into the palm kernel oil were

slightly lower than those of the comparable cases where EDTA was not added. This finding is in agreement with the results reported by Al-Othman *et al.* (2012). This is shown in Table 6 and illustrated in Figure 6.

**Table 6:** The values of the distribution coefficient for  $Zn^{2+}$  using PKO in the presence of EDTA. Initial concentration of Zn (II) ions = 10 ppm, 30 ppm and 50 ppm

S/N	Volume of PKO (ml)	Distribution Coefficient		
		10 ppm	30 ppm	50 ppm
1	2	9.96	29.92	49.88
2	4	9.94	29.94	49.89
3	6	9.90	29.89	49.88
4	8	9.10	29.90	49.87
5	10	9.93	29.82	49.91



**Figure 6:** The variation of the distribution coefficient for zinc (II) ions with various volume of PKO in the presence of EDTA

### 3.2.3 Percentage Efficiency for the Removal of Zinc (II) Ions from Aqueous Solution by Palm Kernel Oil (PKO)

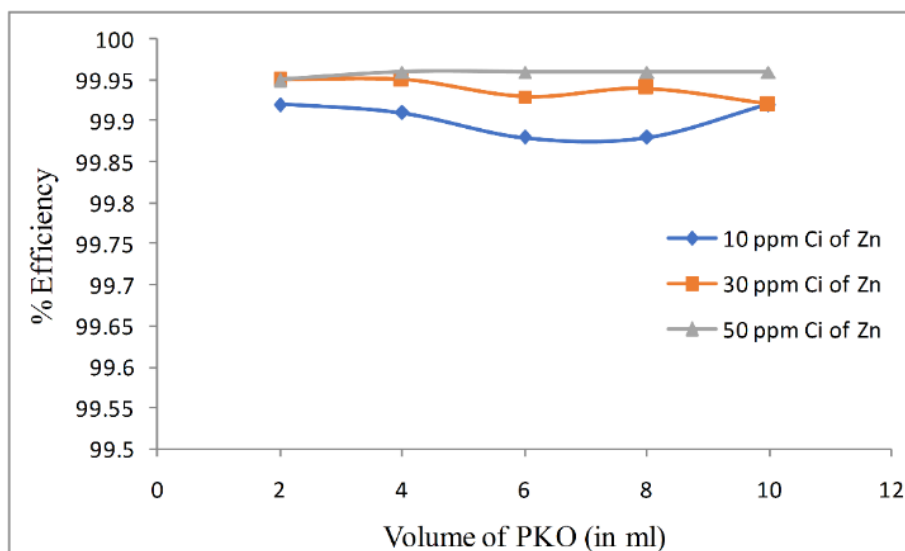
The experimental data obtained indicated that the percentage efficiency for the removal of zinc (II) ions increases with decreased initial concentration of the zinc ions and the volume of PKO respectively. This can be seen in Table 7 and Figure 7. It was noted that an increase in the concentration of zinc ions resulted in greater metal removal from the solution (Al-Asheh & Banat, 2001).

### 3.2.4 Percentage Efficiency for the Removal of Zinc (II) Ions from Aqueous Solution by PKO in the Presence of EDTA

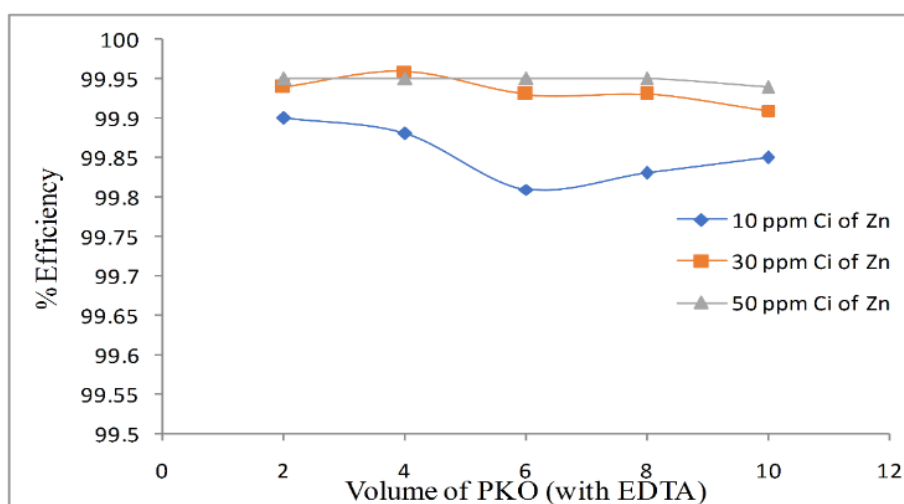
The % efficiency of the phase moderated transfer of the zinc (II) ions from the aqueous phase into the PKO phase was slightly higher than that of the comparable cases when EDTA was not added. It was also observed that a reasonably good amount of zinc ions was obtained with EDTA. This is depicted in Table 8 and Figure 8.

**Table 7:** The percent removal efficiency for Zn<sup>2+</sup> using PKO. Initial concentration of Zn (II) ions = 10 ppm, 30 ppm and 50 ppm

S/N	Volume of PKO (ml)	Percent Efficiency		
		10 ppm	30 ppm	50 ppm
1	2	99.92	99.95	99.95
2	4	99.91	99.95	99.80
3	6	99.88	99.93	99.80
4	8	99.88	99.94	99.79
5	10	99.92	99.92	99.79

**Figure 7:** The variation of the percent removal of zinc (II) ions with various volume of PKO**Table 8:** The percent removal efficiency for Zn<sup>2+</sup> using PKO in the presence of EDTA. Initial concentration of zinc (II) ions = 10 ppm, 30 ppm and 50 ppm

S/N	Volume of PKO (ml)	Percent Efficiency		
		10 ppm	30 ppm	50 ppm
1	2	99.90	99.94	99.76
2	4	99.88	99.96	99.77
3	6	99.81	99.93	99.76
4	8	99.83	99.93	99.76
5	10	99.85	99.91	99.66



**Figure 8:** The variation of the percent removal efficiency for zinc (II) ions with PKO

### 3.3 Percentage (%) Composition of Fatty Acid in Palm Kernel Oil in Fatty Acid

The percentage % composition of fatty acid in PKO is shown in Table 9. The GC-MS analysis results revealed that the greatest percentages of fatty acid in the PKO sample were tridecanoic acid 32.16 %, pentadecanoic 18.02%, Dodecanoic (16.13 %) and Hexadecanoic acid 12.4% were reported. The most abundant fatty acid found in PKO was hexadecenoic acid (palmitic acid-C16:0). Pentadecanoic (C15:0) acid was the second most abundant fatty acid determined in the PKO. The results of this research are in consonance with those of some researchers (Edem, 2002; Gibon, 2012). Palmitic acid, a saturated fatty acid, is the principal constituent of PKO (Mancini et al., 2015). Approximately 82% of PKO is saturated fat with the main contributors being 48% lauric acid, 16% myristic acid, and 8% palmitic acid (Gibon, 2012). PKO has a high content of lauric and shorter-chain fatty acids and a low content of unsaturated acids (Berger, 2003). In a study, Habibi et al. (2022) observed that drying also significantly affected the composition of some fatty acids in PKO such as capric acid, lauric acid, myristic acid, palmitic acid and oleic acid.

In a related study, Nainggolan and Sinaga (2021) reported that lauric acid (C: 12-0) and myristic acid (C: 14-0) have been found to be greatest in PKO, 45.61% and 16.25%, respectively. The confectionery business, where its high solid fat content and precise melting qualities are critical, is where PKO products are most often used (Berger, 2003). Unfortunately, some applications cannot use PKO because it melts at too low temperatures.

The presence of palmitic acid in PKO indicates its suitability for the manufacture of soaps, detergents, cosmetics, shaving cream and shampoos (Diezel et al., 1993). Historically, palm oil has been utilized in food and about 85 to 90% of palm oil is utilized in food products including margarine, shortening, cooking oil, confectionery fats, etc. (Gold et al., 2012; Yeong et al., 2012; May & Nesaretnam, 2014). It is known that only 10-15% of palm oil is used for purposes other than food and about 70% of this is used as a surfactant in applications for food or other products (Yeong et al., 2012). Due to the growth of the oleochemical industry globally, PKO is a significant source of lauric oil, which is in high demand for the production of lauric acid (Jalani et al., 2003; Yeong et al., 2012).

**Table 9:** The Fatty Acid Concentration and % Composition in Palm Kernel Oil (PKO)

Fatty acid	Concentration (mg/l)	% Composition	Molecular formula
Capric acid	207.39	5.28	C <sub>10</sub> H <sub>20</sub> O <sub>2</sub>
Undecanoic acid	10.22	0.26	C <sub>11</sub> H <sub>22</sub> O <sub>2</sub>
Dodecanoic acid	633.30	16.13	C <sub>12</sub> H <sub>24</sub> O <sub>2</sub>
Tridecanoic acid	1262.66	32.16	C <sub>13</sub> H <sub>26</sub> O <sub>2</sub>
Cis-10-pentadecenoic acid	47.16	1.20	C <sub>15</sub> H <sub>28</sub> O <sub>2</sub>
Pentadecanoic acid	707.64	18.02	C <sub>15</sub> H <sub>30</sub> O <sub>2</sub>
9-Hexadecenoic acid	160.80	4.10	C <sub>16</sub> H <sub>30</sub> O <sub>2</sub>
Hexadecanoic acid	6.66	0.17	C <sub>16</sub> H <sub>32</sub> O <sub>2</sub>
Cis-10-Heptadecanoic acid	52.09	1.33	C <sub>17</sub> H <sub>32</sub> O <sub>2</sub>
Heptadecanoic acid	479..30	12.21	C <sub>17</sub> H <sub>34</sub> O <sub>2</sub>
Gamma-linolenic acid	8.94	0.23	C <sub>18</sub> H <sub>30</sub> O <sub>2</sub>
Oleic acid	171.06	4.36	C <sub>18</sub> H <sub>34</sub> O <sub>2</sub>
Arachidonic acid	8.00	0.20	C <sub>20</sub> H <sub>32</sub> O <sub>2</sub>
5,8,11,14,17-Eicosapenoic acid	6.96	0.18	C <sub>20</sub> H <sub>30</sub> O <sub>2</sub>
Cis-11,14- Eicosadienoic acid	19.88	0.51	C <sub>20</sub> H <sub>36</sub> O <sub>2</sub>
Cis-11-Eicosenoic acid	20.98	0.53	C <sub>20</sub> H <sub>38</sub> O <sub>2</sub>
Eicosanoic acid	18.69	0.48	C <sub>20</sub> H <sub>40</sub> O <sub>2</sub>
Heneicosanoic acid	30.50	0.78	C <sub>21</sub> H <sub>42</sub> O <sub>2</sub>
4,7,10,13,16,19-Docosanoic acid	9.67	0.25	C <sub>22</sub> H <sub>32</sub> O <sub>2</sub>
13-Docosenoic acid	7.17	0.18	C <sub>22</sub> H <sub>42</sub> O <sub>2</sub>
Docosanoic acid	9.34	0.24	C <sub>22</sub> H <sub>44</sub> O <sub>2</sub>
Tricosanoic acid	3.08	0.08	C <sub>23</sub> H <sub>46</sub> O <sub>2</sub>
15- Tetracosenoic acid	37.26	0.95	C <sub>24</sub> H <sub>46</sub> O <sub>2</sub>
Tetracosanoic acid	7.65	0.19	C <sub>24</sub> H <sub>48</sub> O <sub>2</sub>
Total	3926.4	100.02	

#### 4.0 Conclusions and Recommendations

The phase transfer-mediation removal of copper (II) and zinc (II) ions from aqueous solutions using PKO as an organic phase in the presence of chelating agents has been carried out. The distribution coefficient increased with an increase in the concentration of copper (II) ions and the % E removal with EDTA showed a slight increase compared to that of comparable cases in the absence of EDTA. However, for zinc (II) ions, the distribution coefficient decreased with an increase in the volume of PKO and the % E removal decreased with the initial concentration and the volume of PKO but was higher in the presence of EDTA. The best extraction capacity was obtained with PKO. The addition of EDTA enhanced the removal of

metal ions. The concentrations of PKO used as extraction agents were seen to strongly influence the distribution coefficient and percentage efficiency removal of zinc ions. The findings of this work suggest that PKO could be used as an excellent and cheap organic extractant for the removal of some metal ions from aqueous solutions.

The findings of this study or investigation have opened many new questions in need of further investigations. Some of these are as follows:

1. Development of new reagents that are resistant to degradation, more selective, highly reusable and less toxic and harmful substances which are compatible with the principles of green chemistry.

2. Boosting the extraction efficiency, organic and inorganic complexes, which shall aid in the formation of the quantitative extraction of metal ions.
3. Searching for ecologically safe, heterogenous systems with a high extraction capacity issue.
4. Further investigation on eco-friendly, cost-effective and sustainable materials and techniques for the removal of metal ions from aqueous solutions.

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