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Evaluation of Banana Peel as a Natural Adsorbent for the Removal of Heavy Metals from Industrial Wastewater

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ABSTRACT
This study examined the low-cost, easy, and eco-friendly adsorption of heavy metals from industrial effluent using activated carbon from banana peels.Results indicated that banana peels can remove lead, nickel, and cadmium. Heavy metal adsorption was impacted by pH, contact time, and adsorbent dosage. Nickel and cadmium adsorption rose with increased adsorbent dosage, peaking at 0.6 mg/g and 0.8 mg/g respectively. This means the adsorbent reached its maximum adsorption before desorption. Unfortunately, lead adsorption reduced at larger doses. This suggests that the binding sites were somewhat clustered, impeding lead adsorption. Overall, . Adsorption capabilities were detected at neutral pH, indicating that heavy metal ions and hydrogen ions compete for adsorption at pH 7.adsorption increased as contact time increased until an equilibrium time of 120 minutes was reached. The utilization of banana peel-derived activated carbon (BPAC) for the removal of heavy metals from industrial wastewater is effective, achieving high removal efficiencies typically ranging from 80% to more than 97 %.

Keywords: Heavy metals, Adsorption, Adsorbent, Wastewater, Activated Carbon

I. INTRODUCTION

Industrial wastewater pollution from hazardous heavy metals like lead (Pb), cadmium (Cd), chromium (Cr), and arsenic has become a major environmental issue. These non-biodegradable, poisonous metals can accumulate in living organisms and endanger humans and the environment. Chemical precipitation, ion exchange, and membrane filtering are expensive, energy-intensive, and may produce secondary contaminants.

Natural adsorbents for heavy metal removal have been investigated in recent years as cost-effective and environmentally benign alternatives. Agricultural waste, especially plant-based biomass, has excellent adsorption properties due to its abundance, low cost, and high surface area. Banana peels are of particular importance due to their high content of lignin, cellulose, hemicellulose, and metal-binding functional groups.

Banana peel is tested as a natural heavy metal adsorbent in industrial effluent. Banana peel adsorption relies on pH, contact time, adsorbent dosage, and initial metal concentration. This research will establish banana peel's heavy metal mitigation efficiency, adding to sustainable and cheap wastewater treatment methods.

Adsorption is a mass transfer mechanism that transfers an adsorbate from the liquid phase to the solid surface for physical and chemical binding (Siti, 2013).Adsorption can be batch, semi-batch or continuous. It can also be physical or chemical. Physical adsorption is dependent on Van der Waals forces of attraction between adsorbate and adsorbent, while chemical adsorption, sometimes referred to as activated adsorption involves a chemical reaction between adsorbent and adsorbate. Several studies have established that adsorption is the best method for the treatment of industrial effluent containing heavy metals and the most commonly used adsorbent was activated charcoal, although it was frequently used, it is very expensive. Engineers have been challenged with the need to find a relatively cheap, environmentally sustainable and eco-friendly adsorbent that is effective as activated charcoal.

Jahin et al., 2024 examined chemically activated banana peels for the removal of copper (Cu^{2+}) and zinc (Zn^{2+}) ions from wastewater. The research found that the optimal pH for adsorption was 6, with maximum adsorption capacities of 3.2 mg/g for Cu^{2+} and 2.8 mg/g for Zn^{2+} . The pseudo-second-order kinetic model and Langmuir

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isotherm showed monolayer metal ion coverage on the adsorbent surface. Thermodynamic study showed spontaneous, exothermic adsorption.

Additionally, the study demonstrated the effective implementation of the banana peel adsorbent in removing various metal ions from wastewater samples.

Bereket et al., 2024 concentrated on using banana peel-derived biochar to remove hexavalent chromium (Cr(VI)) from the tanning facility wastewater. The biochar was produced by activating banana peels at 450 °C for 2 hours. Under optimal conditions—pH 3, contact time of 92 minutes, and adsorbent dose of 1.5 g/L—the biochar achieved a 94% removal efficiency for Cr(VI). The adsorption process conformed to the Langmuir isotherm model, with a maximum adsorption capacity of 38 mg/g, and followed pseudo-first-order kinetics. The study also highlighted the reusability of the biochar, maintaining over 70% efficiency after six cycles.

Mkilima et al., 2024 also investigated the potential of banana peel-derived activated carbon (BPAC) and commercial activated carbon for heavy metal removal, addressing a pressing environmental concern. The analysis encompassed diverse pH levels, crucial for real-world applicability, offering valuable insights into adsorption capacities and kinetics. The results revealed competitive performance of both materials, with typical lead (Pb) removal ranging from 4 to 6 mg/g and cadmium (Cd) from 3 to 5 mg/g. Commercial activated carbon exhibited slightly superior adsorption kinetics and capacities, highlighting its efficacy in heavy metal removal. Throughout the study, optimizing dosage proved essential for maximizing removal efficiency, emphasizing the practical implications of this research. Furthermore, the time-dependent behaviour of adsorption kinetics underscored the importance of extended contact times for enhanced removal.

The removal of heavy metals using the adsorbent described above is found to be more encouraging in extended terms as there are several materials existing locally and profusely such as natural materials, agricultural wastes or industrial by- products which can be utilized as low-cost adsorbents (Siti, 2013). An adsorbent should have high selectivity, thermal and chemical stability, mechanical strength, high resistance to fouling, regeneration capacity and low solubility in the liquid in contact.

Banana peels contain potassium, calcium, sodium, iron, manganese, bromine, rubidium, strontium, zirconium, and niobium at concentrations of 78.10, 19.20, 24.30, 0.61, 76.20, 0.04, 0.21, 0.03, 0.02 and 0.02 mg/g (Anhwange et al., 2009). They also contain pectin (10-21%), lignin (6-12%), cellulose (7.6-9.6%), hemicelluloses (6.4-9.4%), and galactouroninc acid.Galactouroninc acid with the carboxyl functional group could make pectin substances a strong metal adsorbent in aqueous solutions (Saeed, 2005). Pectin extracted from banana peel contains glucose, galactose, rhamnose, xylose and arabinose (Emaga, 2008).When the carboxylic acids are charged, their negatively charged electron pairs are active and they can bind with the positively charged heavy metals in the wastewater. Banana peels treated with acid (HNO_3) and alkali (NaOH) can be used to adsorb divalent heavy metal ions (Cu^{2+}, Zn^{2+}, $CO_{2,}$ Ni^{2+} and Pb^{2+}), with adsorption capacity in this order of Pb2+ > Ni^{2+}> Zn^{2+}> Cu^{2+}> Co^{2+} (Annadurai, 2002).

Recently, a great deal of interest in the research for the removal of heavy metals from industrial effluent has been focused on the use of agricultural by-products as adsorbents (Barakat, 2011).

Adsorption of heavy metals from water using banana and orange peels was studied by Annadurai, et al., (2002). The effect of pH was experimented for both orange and banana peels on different metals. It was concluded that the maximum adsorption occurs at pH 6-8 for orange and banana peels. Arunakumara et al., 2013, revealed by laboratory investigations that banana peel contains pectin (10-21%), Lagnin (6-12%), cellulose (7.6-9.6%) and hemicelluloses (6.4-9.4 %), and also investigated that banana peel is capable of absorbing 5.71, 2.55, 2.800, 6.88, 7.97 and 5.80 mg/g of Ca^{2+}, $CO_{2,}$ Cu^{2+}, $Ni^{2+,}$ Pb^{2+} and Zn^{2+} respectively from aqueous solution. Absorption capacity depends on solution pH, absorbent dose, metal concentration, contact time, and shaking speed. At 40% of the fresh fruit's weight, banana peels are a cost-effective and environmentally friendly adsorbent for heavy metal removal from contaminated waters (UNCTAD, 2012).

Biosorption of cadmium (Cd), and lead (Pb) in textile effluent using banana peels was carried out by Okereke et al., (2016). The adsorption capacity of banana peels on the metal ions were of the order: Cd >Pb, with percentage removal of metal ions as 99.93% for Cd and 99.64% for Pb. A similar study carried out by Wanna and Pairat (2009), recorded that banana peels had the highest Cadmium ions removal of

73.15%. Generally, 1g and 2g of both ripe and unripe banana peels reduced the values of Cd and Pb in the textile effluent below World Health Organization standards, while 4g is the approved standard. Thuraiya et al. (2015) examined how pH, contact time, adsorbent dosage, and particle size affect diary wastewater pollutant removal using orange and banana peels by carbonisation and dehydration (biosorption). The tests found that orange peels remove dairy wastewater contaminants better than banana peels. The orange peel is more efficient in both carbonisation and de-hydration methods, with the highest percentage removal of 50.1% and 14.3%, respectively, compared to the banana peels' 44.1% and 8.2%. Both orange and banana peels work best at 6-8 pH. The optimal contact time for orange peel dehydration and banana peel carbonisation is 120 min and 150 min, respectively. For orange peel dehydration, 0.15 g of adsorbent is best and for banana peel, 0.25g. The ideal adsorbent dosage for carbonising orange and banana peels is 0.3g, with a particle size of 300μm. Hossain et al. (2013) found that some adsorption of Cu (II) ions onto banana peel is faster than others in the first 30 minutes, followed by a uniform removal rate until equilibrium was reached.

With the very large volume of literature showing the efficiency of banana peels used as a sole adsorbent or in combination with other adsorbents in the removal of heavy metals from industrial wastewater and aqueous solution, the effect of contact time, the effect of pH and adsorbent dosage on the adsorption capacity of the banana peels, the need for this study is justified.

The main objective of this work is to test the removal of heavy metals from industrial wastewater using banana peel as an adsorbent, which is cheap and readily available. The following parameters are to be considered: carbonization, activation of adsorbent, and adsorption of heavy metal. Atomic Absorption Spectrophotometer (AAS) is used to analyse the initial and final heavy metal concentration in the wastewater, also the effect of contact time, adsorbent dosage and pH on the adsorbent capacity of banana peel were also highlighted in this study.

II. METHODS

Banana peels were collected from houses and dumpsites and the industrial wastewater was obtained from Eleme Petrochemicals, Port Harcourt, Rivers state.

ADSORBENT PREPARATION

Banana peels used for the experiment was obtained from household waste and dumpsites. Activated carbon was prepared following these procedures.

The banana peels from household waste and dumpsites were collected and washed properly to remove dirt.

The peels were air dried in open air and intense sunlight for about 1 hour and then put in the tray drier for 14 hours at a temperature of $115^{O}C$ to remove all moisture.

The dried peels were made to undergo pyrolysis in a furnace at a carbonization temperature of $350^{O}C$ for 3 hours.

The pyrolyzed peels were cooled in the absence of moisture from the environment and then made to undergo chemical activation.

Chemical activation of the peels was carried out using HCL as the activating agent. This was done by preparing a sample of 10%w/w HCL and diluting with 500ml of distilled water, the mixture was then poured on the peels and stirred at intervals to ensure efficient mixing. Chemical activation was done for 2 hours.

Afterwards, the activated peels were filtered out using a sieve, and thoroughly rinsed with distilled water continuously with the pH checked at intervals until it became neutral.

Finally, the rinsed sample was dried for 1 hour at $105^{O}C$ and the dried peels were crushed to powder.

Crushed adsorbent was kept in an airtight container until it was ready for use.

Wastewater obtained from Eleme petrochemical industry is treated with activated charcoal by the following procedures in accordance with the batch experiments carried out by Al-Qahtani, 2016.

To study the effect of adsorbent dosage, weighed quantities of 0.2g,0.4g,0.6g,0.8g, 2g and 4g of the adsorbents were poured into 250ml conical flasks, 100ml of wastewater was added into the conical flask. The conical flask containing the adsorbent and the wastewater was placed on a magnetic stirrer at room temperature ($28^{o}C$) for a period of 60 min to ensure equilibrium. The solution was filtered through a filter paper, and the filtrate was taken for heavy metal concentration determination using AAS.

To study the effect of pH on adsorption, a constant mass of 0.8g is used, and the pH is varied from acid to alkaline. This is done by preparing different concentration solutions of HCL and NaOH for acid and alkali respectively. Adsorbent

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weight of 0.8g with pH 4, 7, 9 and 12 were poured into 250ml conical flasks, 100ml of wastewater was added into the conical flasks. The conical flask containing the adsorbent and the wastewater was placed on a magnetic stirrer at room temperature ($28^{O}C$) for a period of 60 min to ensure equilibrium. The solution was filtered through a filter paper, and the filtrate was taken for heavy metal concentration determination using Atomic Absorption Spectrometry AAS.

To study the effect of contact time, a constant mass of 0.2g is used for Pb, 0.6g for Ni and 0.8g for Cd. Respective adsorbent weights were poured into 250ml conical flasks and mixed with 100ml of wastewater. The conical flask containing the adsorbent and the wastewater was placed on a magnetic stirrer at room temperature ($28^{O}C$) for a period of 30 mins, 60 mins, 90 mins and 120 mins. The solution was filtered through a filter paper, and the filtrate was taken for heavy metal concentration determination using Atomic Absorption Spectrometry (AAS).

AAS PROCEDURE

The AAS was switched on and allowed to cool and run steadily for 18min, the cathode camp of the metal concentration to be determined was inserted into the equipment and the specific wave length of the metal was selected on the machine.

The equipment was cross-checked with zero blank deionized water. The presence of the metals in the sample was determined by spraying the sample solution into the flame.

III. RESULTS AND DISCUSSION

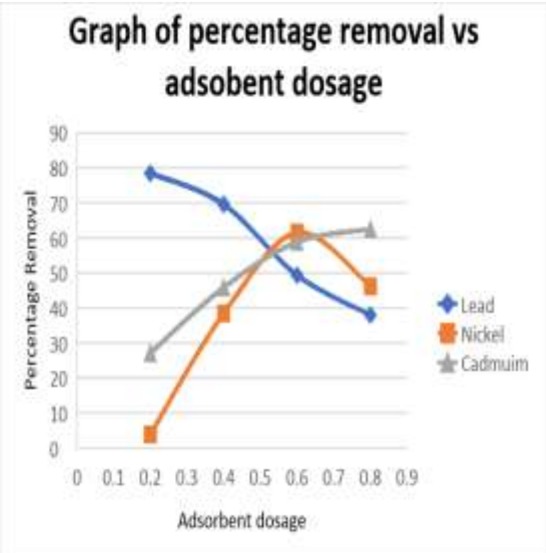

Figure 1: Effect of Adsorbent dosage on the adsorption of Pb (11), Cd (11) and Ni (11).

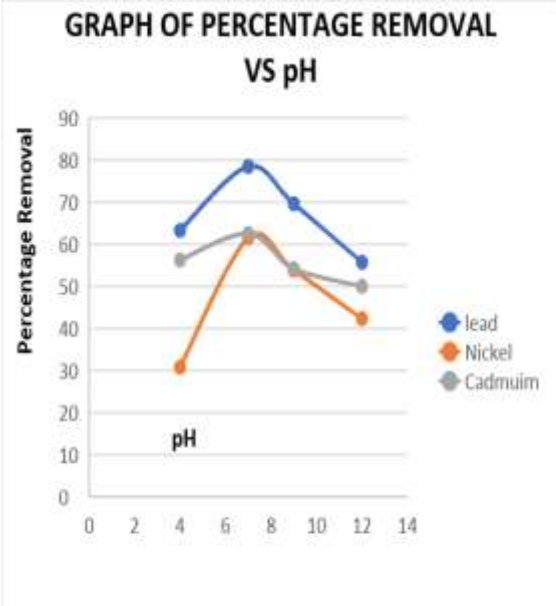

Figure 2: Effect of pH on the adsorption of Pb (11), Cd (11) and Ni (11)

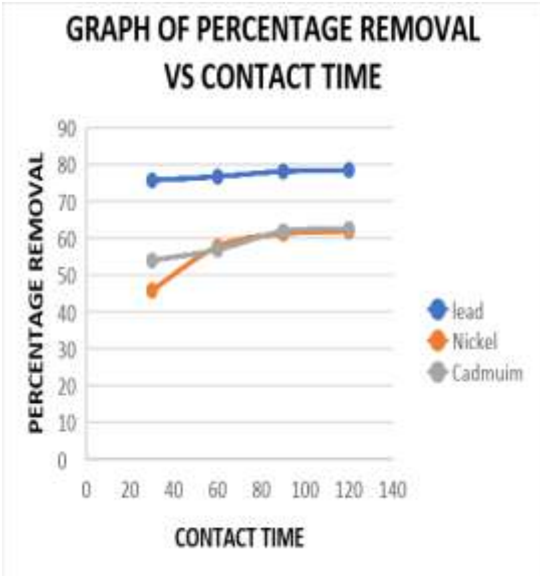

Figure 3: Effect of contact time on the adsorption of Pb (11), Cd (11) and Ni (11).

IV. DISCUSSION

From the data analysis above, the utilization of banana peel-derived activated carbon (BPAC) for the removal of lead, Nickel, and cadmium from industrial wastewater was found to be effective, achieving high removal efficiencies typically ranging from 80% to more than 97 %. This is in line with the result obtained by Rodriguez et al., 2024. It was observed that factors such as pH, contact time and adsorbent dosage affected the adsorption of these metals.

As seen in figure 1, figuring out the ideal adsorbent dosage is crucial to preserving materials and optimising both adsorption capacity and removal efficiency. It is observed that adsorption of nickel and cadmium increased as adsorbent dosage increased with optimum adsorption at 0.6mg/g and 0.8mg/g after which it began to decrease. This is in line with Wu et al., (2017). which posits that higher initial concentrations of adsorbates can enhance the adsorption capacity of adsorbents due to increased mass transfer driving forces and more efficient utilization of adsorption sites This is because more active adsorption sites are provided by a higher dose of adsorbent, which means that many sites stay unsaturated during the adsorption reaction. This clearly indicates that the adsorbent reaches its optimum adsorption before desorption occurs. However, this was not the case in the adsorption of lead as adsorption decreased at higher doses, the decrease was caused by unsaturated sites provided as the amount of Lead ions in solution remained constant, many of the sites remain unoccupied leading to a decrease in the adsorption capacity per unit mass. This indicates that there is a partial aggregation or clustering among the available binding sites, thereby preventing the adsorption of lead.

From Figure 2, it is seen that pH also played an essential role in the adsorption efficiency of these heavy metals. The adsorption of lead, nickel and cadmium were affected by pH, as adsorption increased from pH 4-7 after which it began to decrease. Increase in pH lead to increase in adsorption since at low pH, there is a high concentration of H^+ ions with high mobility due to metal ions, this causes a competitive interaction between the heavy metal ions and hydrogen (H^+) ions, increase in the competition between the ions causes a reduction in its adsorption. This result agrees with Inga et al., 2023. This indicates that at higher pH values adsorption is affected by alkalinisation. The optimum pH is found to be pH 7.

Finally, as shown in Figure 3, it was observed that percentage uptake increased with time and after some time it reached a constant value where no more metal ion could be removed from solution. The optimum time was discovered to be 120 mins, the rate of metal binding was more predominant during the initial stages because the active adsorption sites of the adsorbent get involved in metal complexation as soon as the adsorbent is introduced into the mixture.

V. CONCLUSIONS

The overall best condition concluded from the experiment was at pH 7 and contact time of 120 mins. However, the effect of adsorbent dosage varied for each metal, as adsorbent dosage was increased; the adsorption of lead reduced, the adsorption of cadmium increased, the adsorption of nickel increased and after which it decreased. The size of adsorbent was very small hence it helped in the efficiency of adsorption. Finally, banana peels are readily available for use, inexpensive and eco-friendly making it suitable for use.

VI. RECOMMENDATIONS

From this study, banana peels has been found to be very effective in the removal of heavy metals from wastewater with best results at optimum conditions. The following recommendations can be made for future study:

• Using banana peel as a sole biosorbents showed preference for certain metals, combination of banana peels with other biosorbents could be evaluated for removal of heavy metals from industrial wastewater.

• To maximize the adsorption of heavy metals using biosorbents, suitable modification method should be developed for the preparation of biosorbents to enhance its adsorption capacity.

REFERENCES

[1]. Al-Qahtani, K. M. (2016). Water purification using different waste fruit cortexes for the removal of heavy metals.Journal of Taibah University for Science, 700-708.

[2]. Anhwange, B., Ugye, J.,andNyiatagher ,T. D.(2009). Chemical Composition of the Musa sepientum (Banana) peels. Electronic Journal of Environment, Agriculture and Chemistry.Vol 8

[3]. Annadurai, G.J (2002). Adsorption of Heavy Metals from Water using banana and Orange peels. Water Science and Technology 185-190

[4]. Arunakumara, K., Walpola, BuddhiChathuranga., & Yoon, Min-Ho (2013). Banana Peel: A Green Solution for Metal Removal from Contaminated Waters. Journal of Environmental Science and Technology, 6(4), 203-213

[5]. Barakat, M. (2011).New trends in removing heavy metals from industrial wastewater.Arabian Journal of Chemistry, 361-377.

[6]. BereketAmeha,TalbachewTadesseNadew, TsegayeSissayTedla, Belay Getye, DestawAgumassMengiea and ShiferawAyalnehc (2024). The use of banana peel as a low-cost adsorption material for removing hexavalent chromium from tannery wastewater: optimization, kinetic and isotherm study, and regeneration aspects. Royal Society of Chemistry (RSC) 2024,14, 3675-3690

[7]. Emaga T.H.(2008). Dietary fibre components and Pectin Chemical features of peels during ripening in banana and Plantain Varieties.Bioresource Technology, 4346-4354

[8]. Hossain, M. A. (2013). Development of novel bio sorbents in removing heavy metals from aqueous solution.PhD Thesis, Sydney.

[9]. Inga Zinicovscaia, &Yushin, Nikita &Humelnicu, Doina&Grozdov, Dmitrii&Ignat, Maria &Humelnicu, Ionel. (2023). Adsorption Capacity of Silica SBA-15 and Titanosilicate ETS-10 toward Indium Ions.Materials (Basel, Switzerland). 16. 10.3390/ma16083201.

[10]. Jahin, H.S., Khedr, A.I. &Ghannam, H.E. Banana peels as a green bioadsorbent for removing metals ions from wastewater. Discov Water 4, 36 (2024).https://doi.org/10.1007/s43832-024-00080-2

[11]. Mkilima, T., Zharkenov, Y., Abduova, A., Sarypbekova, N., Kudaibergenov, N. N., Sakanov, K., Zhukenova, G., Omarov, Z., Sultanbekova, P., &Kenzhaliyeva, G. (2024). Utilization of banana peel-derived activated carbon for the removal of heavy metals from industrial wastewater. Case Studies in Chemical and Environmental Engineering, 10, 100791. https://doi.org/10.1016/j.cscee.2024.100791

[12]. Mohapatra, Mrutyunjay, S. Mishra, and N. Sutar(2010).Banana and its By-Product Utilization; an overview. Journal of Science Industrial Research, 323-329

[13]. Okereke, Chioma J, EkaEssien, Mathew Wegwu (2016). Human Risk Assessment of Heavy Metal Contamination for Population via Consumption of Selected Vegetables and Tubers grown in Farmlands in Rivers State. South-South Nigeria. Journal of Analytical and Pharmaceutical Research.Vol 3, issue 6.

[14]. Rodríguez.Hans Roger Portilla, TaboadaNeira, Martin.,PortillaJauregui,SteysiJamely., Vega González, Juan.Antonio., Castillo Chung Aldo Roger., & Perez Rodas, Katherine. (2024). Time and particle size of Musa Sapientum shell on the adsorption of Cu and Pb in mining effluent. RevistaCiencia y Tecnología, 20(4), 73–85. https://doi.org/10.17268/rev.cyt.2024.04.06

[15]. Saeed, A., WaheedAkther, and Igbal Muhammad.(2005). Removal and Recovery of Heavy Metals from Aqueous Solution Using Papaya as a new Bio sorbent.Separation and Purification Technology, vol 45.

[16]. SitiNur A.A, (2013). Adsorption Process of Heavy metals by low-cost adsorbent: A Review. World Applied Sciences Journal, 1518-1530.

[17]. ThuraiyaMahir Al Khusaibi., Joefel Jessica Dumaran., M. Geetha Devi., L. NageswaraRao., and S. Feroz (2015).Treatment of diary waste water using orange and Banana Peels. Journal of Chemistry and Pharmaceutical Research, 1385-1391.

[18]. UNCTAD, U.C (2012). Commodity Profile: Banana Uses. Retrieved from http://www.unctad.info/en/infocomm/AACP-Products/COMMODITY -PROFILE-Banana

[19]. WannaSaikaewandPairatKaewsarn (2009). Cadmium ion Removal using Biosorbents derived from fruit Peel Waste. Songklanakarin Journal of Science and Technology.

[20]. Wu, Hui& Wen, Qingbo& HU, Li-ming&Asce, A & Gong, Meng. (2017). Effect of Adsorbate Concentration to Adsorbent Dosage Ratio on the Sorption of Heavy Metals on Soils.Journal of Environmental Engineering. 144. 04017094. 10.1061/(ASCE)EE.1943-7870.0001306.