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INSTITUTE OF GRADUATE STUDIES
ENVIRONMENTAL ENGINEERING DEPARTMENT

FLOTATION AND SORPTIVE-FLOTATION TECHNIQUES FOR HEAVY METAL REMOVAL FROM AQUEOUS SOLUTION UTILIZING BANANA PEELS AS ADSORBENT

Master's Thesis

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Supervisor

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ACCEPTANCE AND APPROVAL OF THE THESIS

The study entitled **"FLOTATION AND SORPTIVE-FLOTATION TECHNIQUES FOR HEAVY METAL REMOVAL FROM AQUEOUS SOLUTION UTILIZING BANANA PEELS AS ADSORBENT . "** prepared by **Ali Hussein Mohammed ALBAAJ**, and supervised by **Prof. Dr. Emre Burcu ÖZKARAOVA**, was found successful and unanimouslyunanimously accepted by committee members as MasterMaster thesis, following the examination on the date 12.9.2023 .

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ÖZET

FLOTASYON VE SORPTIF-FLOTASYON TEKNİKLERİ İLE SULU ÇÖZELTİLERDEN AĞIR METAL GİDERİMİNDE MUZ KABUKLARININ ADSORBAN OLARAK KULLANILMASI

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Yüzey aktif madde olarak Sodyum Dodesil Sülfat (SDS) ve düşük maliyetli emici malzemeler olarak muz kabukları kullanılarak iyon yüzdürme ve sorptif yüzdürme teknikleri kullanılarak kadmiyum iyonu, bakır iyonu, kurşun iyonu sentetik atık sularından rekabetçi koşullarda giderimi incelenmiştir. Hava kabarcıklı kolonda, başlangıç metal konsantrasyonları, pH, sorbent dozajı, sürfaktan konsantrasyonu, hava akış hızı ve söz konusu metallerin konsantrasyonları dahil olmak üzere farklı etkileşim parametrelerin metallerin tekli ve çoklu varlığındaki giderimlerini incelemek için yüzdürme ve sorptif yüzdürme testleri yapılmıştır.

Kesikli çalışma bulgularına göre, muz kabukları için optimum pH değeri 5-6 arasında olduğu ve dengeye 60 dakikada ulaşıldığı tespit edilmiştir. Kuru muz kabuğuna emilen metalik iyonların miktarı kurşun için 24.74 mg/g , bakır için 18.3 mg/g ve kadmiyum için 21.2 mg/g ulaştığı görülmüştür. Tek bir sistem için adsorpsiyon izotermlerini açıklamak için üç model, ayrıca ikili sistem ve üçlü sistem için iki model kullanılmıştır. Denge bilgisinin, Langmuir izoterm modeli ve genişletilmiş Langmuir modelinin yanı sıra A varsayımsal ikinci dereceden kinematik model tarafından iyi uyduğu görülmüştür. Zeta potansiyel testleriyle incelendiğinde muz kabuklarının negatiflik konumları, pH 5'te en yüksek zeta potansiyel değerlerine sahip olduğu belirlenmiştir. Fourier Transformation Infrared (FTIR), metal iyonu emiliminden önce ve sonra muz kabuklarının yüzeyini analiz etmek için kullanılmıştır. Bulgular, hidroksil grupları, karboksilik asit, amin ve aromatiklerin varlığını göstermektedir.

Yüzdürme ve sorptif yüzdürme deneysel testlerinin sonuçları, ağır metallerin en etkili gideriminin, 200 mg/L'lik bir SDS konsantrasyonu ve yüzdürme için 500 cm3/dak ve sorptif yüzdürme için 100 mg/L ve 1000 cm3/dak koşulları için

gerçekleştiğini ortaya koymuştur. Sonuçlar, flotasyon verisinin birinci dereceden kinetik formüle çok yakın olduğunu ve sodyum dodesil sülfat konsantrasyonu arttıkça ve başlangıçtaki metal konsantrasyonu düştükçe ortalama sabit (k) değerlerinin arttığını göstermiştir.

Muz kabuğu yüzdürme için tekil sistemdeki en yüksek kurşun (Pb (II)) iyonu giderme verimlerine %99,9'a ulaşmıştır. Bakır (Cu(II)) iyonları için bu değer %89,8 olarak belirlenirken, kadmiyum (Cd(II)) iyonları için %98,5 olarak belirlenmiştir. Sorpsiyon, flotasyon ve sorptif-flotasyon proseslerinde ikili ve üçlü sistemlerde tüm metallerin giderim verimleri tekli sisteme göre daha düşük olduğu saptanmıştır. Tüm bulgular, sorptif flotasyon yaklaşımının, tek başına flotasyona kıyasla metalik iyonların uzaklaştırma yüzdesini artırdığını ortaya koymuştur. Kurşun (Pb(II)) iyonları, tüm metaller arasında en yüksek uzaklaştırma etkinliğine sahip olduğu anlaşılmıştır.

Anahtar Sözcükler: Muz kabukları, adsorpsiyon, tekli, ikili ve üçlü sistemde yüzdürme, sorptif yüzdürme.

ABSTRACT

FLOTATION AND SORPTIVE-FLOTATION TECHNIQUES FOR HEAVY METAL REMOVAL FROM AQUEOUS SOLUTIONS UTILIZING BANANA PEELS AS ADSORBENT.

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A competitive removal of cadmium ion, copper ion, and lead ion from simulated wastewater has been studied using ion floatation and sorptive-flotation techniques utilizing Sodium Dodecyl Sulphat (SDS) as the surface active agent and banana peels as the low-cost sorbent material. In a bubble column, floatation and sorptive-flotation tests were conducted to examine the removal of heavy metals at different influencing parameters, including initial metal concentrations, pH, sorbent dosage, surfactant concentration, air flow rate, as well as selective removal of metals in binary and ternary systems.

According to the findings of batch testing, the optimal pH value for banana peels was between 5-6 and equilibrium has been reached within 60 minutes. The quantity of sorbed metallic ions reached 24.74 mg/g of dry banana peels for lead (II), 18.3 mg/g of banana peels for copper (II), as well as 21.2 mg/g of banana peels for cadmium (II). Three models were utilized to explain the adsorption isotherms for a single system, plus two models have been used for ternary system and binary system. The equilibrium information were shown to be well-fitted by the Langmuir isotherm model and the extended Langmuir model, as well as the A hypothetical second-order kinematic model. The negativity locations of banana peels had the highest zeta potential potential values at pH, according to zeta potential tests. Fourier Transformation Infrared (FTIR) has been utilized to analyze the surface of banana peels prior to and after metal ion sorption; the findings indicate the presence of hydroxyl groups, carboxylic acid, amine, and aromatic materials.

The outcomes of flotation and sorptive flotation experimental tests showed that the most effective removal of heavy metals was achieved in a short amount of period at an acidic pH value of 5 to 6 with an SDS concentration of 200 mg/L and an air

flow rate of 500 cm^3/min for flotation and 100 mg/L and 1000 cm^3/min for sorptive flotation. The outcomes showed that the flotation information fit closely with the first-order kinetic formula and that the values of the average constant (k) go up as the sodium dodecyl sulfate concentration goes up and as the initially concentration of metals goes down.

Peak lead-II ion removal efficiencies in a singular system reached 99.9% for banana peel flotation. For copper (II) ions, it must have been 89.8 %, while it was 98.5 % for cadmium (II) ions. In sorption, flotation, and sorptive-flotation processes, the removal efficiencies of all metals are lower for binary and ternary systems as compared to a single system. All findings revealed that the sorptive-flotation approach increased the removal percentage of metallic ions in comparison to flotation alone; lead(II) ions had the highest removal effectiveness among all metals.

Keywords: Banana peels, adsorption, single, binary and ternary system, flotation, sorptive-flotation.

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Ali Hussein Mohammed ALBAAJ

CONTENTS

SYMBOLS AND ABBREVIATIONS

Å	: Angstrom.
B	: The constant is related to the heat of adsorption.
At.wt	: Atomic weight of metal ion.
a	: Order of kinetic flotation equation.
bi	: The single component Langmuir parameter for component i.
bT	: Temkin isotherm constant.
b	: The constant related to the affinity of the binding site.
Ce	: Equilibrium concentration of metal in solution.
C	: Final concentration of metal.
Co	: Initial metal concentration.
Ce,i	: The equilibrium concentration of the component i in the multi-component solution.
k	: The flotation rate constant.
Kf	: Freundlich equilibrium constan.,
KT	: Timken isotherm equilibrium binding constant.
k1	: The equilibrium rate constant of pseudo first sorption.
k2	: Pseudo-second order rate constant.
Ki	: Derived from the corresponding individual Freundlich isotherm equation for the component i.
M.wt	: Molecular weight of metal salt.
n	: Freundlich constant.
m	: The mass of sorbent materials.
ni	: Derived from the corresponding individual Freundlich isotherm equation for the component i.
Q	: Air flow rate.
q_{eq}	: The amount of metal sorbed at equilibrium.
qm	: maximum sorption capacity for monolayer coverage.
qi	: The equilibrium uptake of the component i.
qm,i	: The single component Langmuir parameter for component i.
qt	: The amount of metal sorbed at any time, t.
R^2	: Coefficient of determination.

Re	: Removal efficiency.
R	: Gas constant.
Rs	: Separation factor or equilibrium parameter.
t	:Time.
T	: The absolute temperature.
W	: Weight of heavy metal salt.
v	: Volume of wastewater solution.

FIGURES LEGENDS

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1. INTRODUCTION

1.1. Background

Environmental contamination is presently one of humanity's most pressing problems. In terms of its impact on living organisms, it has reached frightening proportions during the last several years, having risen dramatically (Renge et al., 2012; Ogidi and Akpan, 2022). Environmental engineers have paid greater attention to heavy metals than to other pollutants because they belong to a distinct category of toxic metals that can't be converted into non-toxic forms. Consequently, streams contaminated with heavy metals pose significant environmental and health risks (Farraji et al., 2014; Singh et al., 2022).

Due to their non-degradable and persistent nature, the increased utilization of chemicals and metals in industrial processes has led to the generation of enormous volumes of liquid waste containing a high concentration of potentially harmful heavy metal ions, which causes environmental disposal issues (Ahluwalia and Goyal, 2005; Yang et al., 2019). In general, metals with a density more than 5 g/cm^3 are regarded to be heavy metals (Mohammed and Mohammed, 2014; Roxana et al., 2020). Nickel, cadmium, chromium, copper, zinc, iron, mercury, and lead are the metals of most concern according to the World Health Organization (WHO) (WHO, 1984; Shelar et al., 2021).

Both natural and manmade sources may introduce heavy metals. Wastes from mining activities, landfill leachate, municipal effluents and effluents from electroplating and oil refining industries, especially from a electroplating, and oil refining industries, are the main sources of pollution. As a result of the escalating production of metals as a result of technological endeavors, the disposal of trash has assumed a position of preeminence (Sahmoune et al., 2009; Zhou et al., 2020).

When discharged directly into the municipal wastewater collection system, wastewater containing heavy metals will cause damage to the biological treatment units, resulting in the production of active sludge polluted with heavy metals that can destroy agricultural products when used as fertilizers or for improvement of soil structure (Chamanchi et al., 2012; Singh et al., 2022; Razzak et al., 2022). Since heavy metals are not biodegradable, they are stored or bio-accumulated in the living tissues and enter the food chain of living species, which disrupts the normal

biochemical processes and causes the majority of health illnesses. Due to the multiple negative effects of heavy metal, their elimination from industrial effluents is an essential environmental concern (Issabayeva et al., 2010; Kumar et al., 2022).

The impacts of Pb(II), Cu(II), and Cd(II) ions on human health are listed in Table 1.1, whereas the Iraqi standards for these ions in various water sources are included in Table 1.2.

In recent years, the complete separation, pre-concentration of heavy metals in the eco system have attracted increasing attention. Various techniques, such as chemical precipitation, electro-coagulation, solvent extraction, ion exchange, membrane filtration, adsorption, and flotation isolation, can be utilized to reduce/remove these hazardous substances. Among these, adsorption has proven to be an effective method, which is based on the use of various types of abundantly available natural materials or specific waste substances from agricultural sector or industrial processes that have the possibility to serve as cheap sorbent materials and can be utilized in their natural or modified state (Qin et al., 2020). Due to the difficulty of extracting the sorbent from the suspension in order to renew it, this procedure may have economic limits. Therefore, efforts to create separation methods have been attempted (Shrestha et al., 2021).

Flotation has recently gotten a lot of attention as a way to separate solids from liquids or liquids from liquids (or both). This is because it is easy to use, quick, cheap, has impart clear yields (recovery process more than 95% for tiny defect agent concentration levels (10-2-10-6 mole/L). It can be used for a wide range of species with different natures and structures, has flexible supplies and instruments and treatment for recovery, and makes more concentrated sludge. Flotation as (Nafi and Taseidifar, 2022) is the ion flotation includes adding surfactants that serve as collectors to remove ions at the surface that are inactive or molecules from aquatic solutions. Following the passage of gas bubbles through the solution, the surface active ion are subsequently transported to a top of the flotation column (Gahlan et al., 2023). This method is probable to be used soon as a clean way for the treatment of both water and waste water. Due to the reasons above, combining adsorption and flotation into such a single process called sportive-flotation could be seen as a very important thing to do (Ghazy et al., 2010; Mohammed et al., 2013; Gahlan et al., 2023). The sorptive-flotation technique is a simplistic and efficient method for

removing metallic ions from wastewaters by employing particles as sorbing material. It is a version of the adsorbing colloid flotation process, which removes metals ions through adsorption on to the carrier floes like $Fe(OH)_3$ and $Al(OH)_3$ (Samra et al., 2014).

Table 1.1. Principal sources of Pb(II), Cu(II), and Cd(II) ions and their impact on human health (Nandal et al., 2014)

Heavy Metals	Human Health Effects	Major Sources
Cadmium	Renal failure, lung illness, lung cancer, , hypertension, renal damage, bronchitis, gastrointestinal issue, and bone marrow cancer,bone defects.	insecticide,, electroplating,Welding , nuclear reactor , Ni and Cd batteries.
Copper	damage to the liver and kidneys, intestinal and stomach inflamma tion, and Anemia.	the manufacture of pesticides, the chemical industry, metal pipes, and Mining
Lead	kidney, sensor neutral deafness, developmental delay, fatal newborn encephalopathy, congenital paralysis, acute or chronic nervous system damage, liver and gastrointestinal disease are among the conditions that affect childrene, pilepsy.	smoking,mining,Paint, pesticides, car emissions, and coal burning.

Table 1.2. Permissible limits of Pb, Cu, and Cd ions in drinking water (COSQC, 2009)

Heavy metals	Permissible limits (mg/L)
Cadmium	0.0030
Copper	1.01
Lead	0.010

1.2. Problem Statement and Aims of the Work

Adsorption, flotation and sorptive flotation systems employing low cost sorbent banana pells and SDS as surfactant were investigated for the removal of the heavy metals cadmium, copper and lead from synthetic wastewater. Flotation and sorptive flotation processes was explored using batch systems and induced air flotation (IAF). The following methods were used to accomplish this:

- Investigation of the viability of employing banana pells as adsorbents for the single, binary, and ternary removal of several metals ions such as cadmium, copper and lead ions from wastewater, as well as a flotation column system using metal-loaded sorbents to achieve the authorized levels.
- Exploration about the variables such as the solution pH, contact time, amount of sorbent, initial concentrations of (cadmium, copper and lead ions), surfactants (SDS) concentrations, and rate of air flow that influence the removal efficiency of copper, cadmium, and lead ions in sorption, flotation, and sorptive-flotation systems.
- Research about the applicability of sorption isotherm models and kinetic models.

2. THEORETICAL AND LITERARY SURVEY

2.1. The Introduction

As a result of the rise in the globally populated and the expansion of industrial applications, there is a growing need for fresh water, as well as an increase in the quantity of wastewater produced, which makes its recycling an urgent problem. Limits on the recyclability of these fluids are imposed due to the existence of heavy metals with higher and prolonged toxicities. In the absence of adequate treatment, especially large quantities of heavy metals in industrial wastewater represent a hazard to both the environment and human health (Maja and Ayano, 2021).

Heavy metals may be removed from wastewater and water utilizing a variety of treatment methods that have been improved over time. The kind of treatments process needed for a particular industry is dependent on the nature, composition, and flow rate of the effluent, in addition to the required degree of removal efficiency. Adopting any one of the strategies or a suitable mix of two or more techniques will maximize the treatment plant's efficiency (Anderson et al., 2022).

Table 2.1. Several the physico-chemical treatment techniques that utilised to get rid of heavy metals.

Treatment	Process details	Advantages	Disadvantages
Chemical precipitation	After the pH is modified to a basic level (pH is eleven), the dissolved metallic ions have been turned into insoluble solids through a chemical reaction when precipitants like lime, iron salts, alum, and other organic polymers are added.	Simple operation, Low capital cost	Large quantities of sludge generated throughout a process will present removal challenges.
Ion exchange	Metal ions from dilute solutions are exchanged with ions held by electrostatic forces on the exchange resin.	Metal recovery that is efficient	Certain ions are costly and only partially removed.
Reverse osmosis	At a pressure higher than the osmotic pressure triggered by dissolved solids, a semi-permeable membrane separates metal ions.	Pure effluent	Costly due to membrane contamination

Electro - dialysis	A semipermeable ion selective membrane is used to separate the metal ions. A difference in electrical potential between the two electrodes makes the cations and anions separate. This makes cells of concentrated and weak salts.	Superior separation efficiency	High operational costs due to fouling and high energy consumption and clogging of membranes.
Adsorption	Transfer of metal ions from the liquid phase to the solid surface, where they are bound by physical and/or chemical interactions.	Economical and efficient metal disposal	Separation of the adsorbent from the suspension is hard.
Flotation	Surface active agents are used to attach bubbles to heavy metals and solids that are in a liquid phase (collector). The bubble rise separates the heavy metal particles that are stuck together from the heavy metal that is in suspension.	Inexpensive and less hydraulic retention period	Heavy metal removal needs to be improved with supplemental treatments.

2.2 Adsorption

Recently, the adsorption process has been seen as a better long-term method to removal heavy metals from wastewater as it is more economical and effective. The adsorption process gives design and operating flexibility and, in many instances, produces high quality treatment effluent (Fu and Wanng, 2011; Arora, 2019; Chakraborty et al., 2022).

The term adsorption refers to a process of mass transfer in which chemicals that are already present in liquid or gaseous form (referred to as "adsorbate") are adsorption or collected on a solids (referred to as "adsorbent"), then removed from the gas or liquid phase (Joseph et al., 2020; Soliman and Moustafa, 2020). The molecular size, polarity, and nature of the contaminant, as well as the kind of adsorbent utilized, significantly impact the efficiency of the adsorption process. Another source of adsorption is the attractive connections between a surface and various adsorbing species at the molecular levels (Amalina et al., 2022). When comparing sorbent materials, cost should be taken into account. But the total cost of different sorbents depends on how much processing is needed and where they are available. Overall, if the adsorbent is cheap and doesn't require much processing, is easy to find in its natural state, or get from any type of industry (Pourhakkak et al.,

2021; Oladoye, 2022).

2.2.1 Adsorption Forms

The process of adsorption resembles molecules leaving solution and going to stick to a solid surface through chemical or physical bonds (Jainn and Neeha, 2013). The type and nature of the bonds relies on the properties of the sorbent concerned. However, the adsorption processes could be characterized generically as follows (Fiyadh et al., 2019; Gao et al., 2020).

• Electrostatic adsorption (Ion Exchange): This phrase refers to the attractive coulombic interactions between ions and charged function units. This force generates both ion interactions, such as ionic exchange, and bipolar-ion interactions. The sorption of Cu (II) on the surface of clay is an example of electrostatic sorption. Typically, the electrostatic adsorption process is fast and may be reversed.

- Physical adsorption: Adsorption occurs when molecules of the adsorbent and the adsorbate are attracted to one another by intermolecular interactions. The term "Vander Walls forces" is used to describe interactions between molecules that do not rely on their electronic characteristics. This phenomenon is easily reverseable. Only at temperatures under 150 °C is the adsorbate stable, and its adsorption heat is only 40 kj/mol °C (Aljamali et al., 2021).

- Chemical adsorption: A chemistry interactions between certain surface locations and dissolved molecules leads to the creation of a chemical bond that becomes more stable with high temperatures. The heat of adsorption ranges from 40 to 400 kj/mol and is much more than the heat on physical adsorption. It solely includes monolayer covering and occurs at certain functional group positions (Aljamali et al., 2021).

2.2.2 Adsorbents with a low Cost

In past few years, the hunt for inexpensive adsorbents with metal-binding capabilities is intensifying. As inexpensive adsorbents, locally accessible materials in large numbers may be exploited (Abas et al., 2013; S. Wang et al., 2021; Sadeghalvad et al., 2021; Sardar et al., 2021). Various sources of low-cost adsorbents are including agriculture sector waste (orange peels, rice hulls, peanut husk, coconut husk, and wheat bran); industry sector by-products (ash, waste iron & slag from steel plants); inorganic materials (clay and zeolite); and various inexpensive adsorbents like coal, sludge, and peat moss). The majority of all these materials may be utilized in their natural state or even after undergoing certain chemical or physical treatment. Additionally, several of these materials may well be turned into activated carbon, which can be utilized for an adsorbent in purifying water, thus enhancing their economic value, reducing waste disposal costs for companies, and offering a viable alternate to costly activated carbon (Kwikima et al., 2021).

Table 2.2. Summary of inexpensive adsorbent to remove heavy metal ions.

References	**Adsorbent**	**Synthesis solutions**	**Variable studied**
Feng et al., (2011)	Orange peels	Pb(II), Cd(II), Ni(II)	Individual component: contact time as well as pH
Thakur and Semil, (2013)	Coconut husk	Cd(II), Cr(VI), Pb(II)	Individual component: sorbent dosage, pH, temp., contact period as well as metal concentrations
Hikmat et al., (2014)	Petiole and fiber of the date palm	Pb(II)	Sorbent dosage,pH,Contact period and metal concentrations
Sulaymon et al.,(2014)	Garden grass	Cd(II),Cr(III)	Individual component: metal concentrations, pH, temp., and agitation speed.

Hamadi, (2014)	Phosphate rock, Porcelanit ,Granite and GAC	Pb(II), Cu(II), Cd(II)	Single, binary and ternary component: duration, pH, sorbent dosage, temp, agitation speed as well as metal concentrations
Kamar et al., (2015)	Walnut shells	Pb(II),Cu(II), Cd(II)	Single and ternary component: pH, duration, metal concentrations and sorbent dosage
Bozecka et al., (2016)	Sunflower hulls, walnut shells and plum stones	Pb(II) ,Cd(II)	Single component: sorbent dosage, pH as well as temp
(Oliveira et al., 2019)	Zeolites	Cu	Temperature and calcination time
(Kyobe, 2022)	Banana peel	Cu (II)	Adsorbent Dosage, pH, Temperature, Agitation time, and the İnitial Concentrations of the Cu (II)
(Naik et al., 2023)	Rice Husk and Orange Peel	Mg, Pb, Zn, Cu, Ni, Cd, and Cr	Dosage, Contact time, pH and Mixing Speed

2.3. The Flotation Process

Flotation utilizes bubble attachment for separating dispersed liquids or solids that are spread out in a liquid phase. A surfactant-based separation technique in which air is pushed through an aqueous solution and a surfactant is linked to the solution. The air functions as a separator (Saleh et al., 2022; Pawlik, 2022).

Foam may transport dissolving ions or molecules, solid particle, or droplet to the surface of a flotation cell by attaching to air bubbles. Consequently, the flotation approach requires the establishment of sustained bubble-particle aggregation to

maximize separation efficiency (Pooja et al., 2022).

Ion flotation involves the injection of surfactants and the concurrent transit of gas bubbles through aqueous solutions in order to remove surface-deactivated ions. Ion flotation is the process of removing surface non-active ions in aqueous solutions by first adding a surfactant, and then allowing gas bubbles to pass through the solution. The molecules of the surfactant automatically place themselves at the surface of the bubbles, with all their other polar functional groups facing of the bulk of the solution. Certain other surface-inactive anti ions (metal ions or colligends) in the solution may also attach to the surfaces of the bubbles through electrostatically or chemically interactions, mostly with the functional chemicals of a surfactant. When bubbles leave a solution, they must form a stabilized foam stage. The bubbles with the collectors and colligends on them inform the foam, which could be actually physically detached than of the solution. Figure 2.1 depicts a standard ion flotation procedure (Pooja et al., 2022).

Precipitate flotation seems to be an intriguing alternate flotation approach, meeting within the foam extraction strategies recommended to correctly manage the removal from a contained minimal contaminant concentration solution, with the added benefit of requiring a smaller quantity of collectors (Kyzas and Matis, 2018). This method entails the precipitate of ionized types before the flotation with the inclusion of suitable collectors. Through a bubble swarm, the gas phase may be introduced in to solution; therefore, the interactions between of collector and the metal precipitate produce a hydrophobic type that is capable of adsorbing on to gaseous phases. The precipitation is then collected as a dry foam at the upper edge of the floatation cell (Chang et al., 2019).

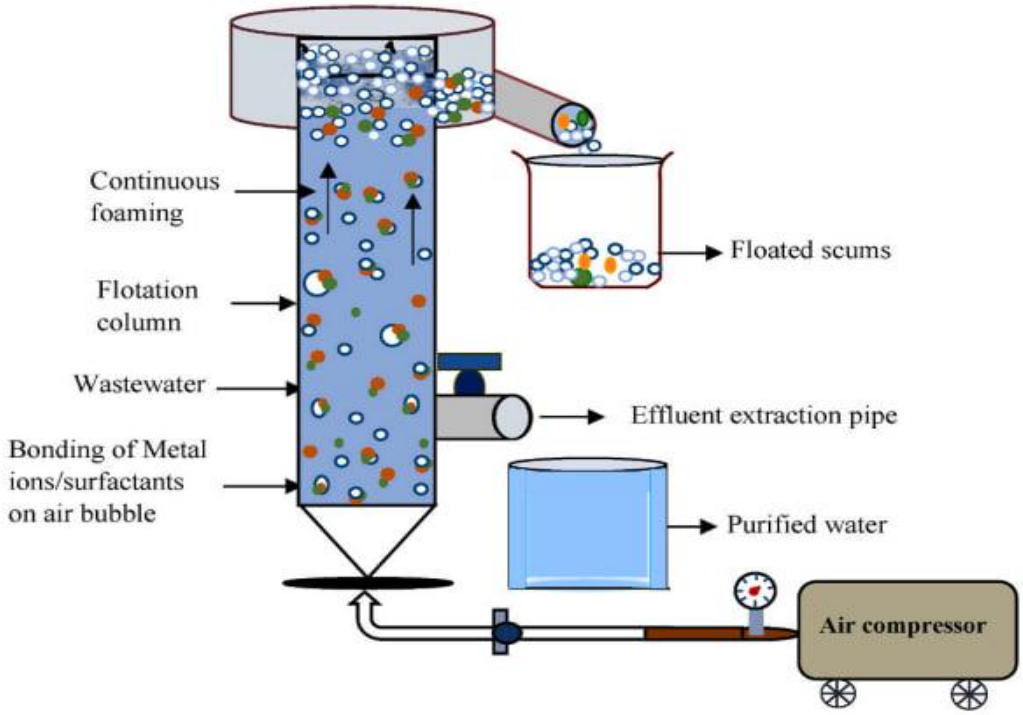


Figure 2.1. Typical ion flotation process (Pooja et al., 2022)

The two most common commercial kinds of normal gas flotation system presently used in industry today are dispersion or induced gas (typically air) floatation (IAF), a process in which air bubbles (of about 1000 m in diameter) are mechanically injected into a waste flow using some type of disperser: porous media, perforated tubes (spargers), high-speed impeller, etc., and (DAF), in which air is forced into solution in the wastewater under the pressure before being pushed out from the solution when the pressure would be reduced. This pressurization-depressurization causes extremely tiny gas bubbles, measuring between 30 and 120 m, to develop and ascend to the top (Wang et al., 2010; Lawrence et al., 2010).

Retention periods for induced air flotation are shorter than those for dissolved air flotation (20-60 min). Thus, dissolved air flotation is ineffective when large quantities and high flow rates of effluents need treatment (Pooja et al., 2022).

Generally, the DAF procedure can provide the greatest treatment capacity. Nevertheless, the DAF method has limits in term of investments costs, operational complexity, and equipment actual size (Ding et al., 2019; Pooja et al., 2022). Consequently, the IAF procedure was selected as an appealing choice in this research study.

Column flotation remains a topic of significant importance in metal treatment, and with a continually increasing amount of research investigations and industry applies; heavy metals recovery applications have been recently recorded (Chang et al., 2019; Sharma et al., 2021). Among the claimed benefits of flotation columns are enhanced separation efficiency, especially for finer material; inexpensive operational and capital costs; minimal facility floor area requirements and simple adaptation to robotic management (Pooja et al., 2022). It would be anticipated that such a technique will be used for clean technologies to start treating both wastewater and water in the near future. A method that combines flotation and adsorption into single operations called sorptive-flotation could have been deemed essential for the aforementioned reasons (Mohammed et al., 2013; Craioveanu et al., 2020).

2.4. Sorptive-Flotation Theory

In recent years, mass-transfer-based separation techniques using adsorptive bubbles have seen constant development. Sorptive-flotation seems to be just as adsorptive bubbles disconnection process that employs interface surface properties to separate ionic, molecule, and otherwise colloidal elements from an aqueous phase (Abdulhussein and Alwared, 2019; Shrestha et al., 2021).

Sorptive flotation have demonstrated their viability in metal disconnection of aqueous solutions. It has been a flotation mechanism involving liquid-state reactions between metal types and surfactants (collectors), after that co-precipitation and or adsorption on the surface of the solid propped material, etc., and disposal of hydrophobic compounds made through solution, mostly by gas mini-bubble employing a type of flotation method (dissolved air flotation or dispersed air flotation). The large efficiency of a separator, the capability to control minimal residual metal concentrations, the flexibility in applying to different metals of different scales, the limited power requirements, the minimum need for surfactant, the need for less space, the quick operation, the output of limited volumes from sludge extremely greatly infused with pollutants, and the modest costs are just a few of the advantages of sorptive-flotation (Stoica et al., 2004; Alwared and Sadiq, 2019).

2.5 Factors Influencing the Removal of Heavy Metals in Adsorption and Flotation Systems

2.5.1. pH of Solution

pH of solutions does have an important effect on this adsorption for metal ions from wastewater. The pH may have an impact on the surfaces charged for the adsorbents, the rate of ionization, and the adsorbate type. In a certain pH domain, the majorities of metals sorption are boosted when pH climbs into a definite value and then decreases as pH increases further. The pH dependency of metal absorption may be attributed to both the surfaces functionality units upon this adsorptive location of the adsorbent and the solution's metals chemistry (Wu et al., 2019).

With the ion flotation method, pH represents one of the main influencers on metal species separation. The productivity of flotation is determined by the pH affects a number of factors, including disintegration of collectors, ionic compositions and otherwise ionic charges in a solution, the kind and solubility for goal ion-collectors complexes, the immutability of froth, and even the selective of the processes. So, controlling the acidity of the aqueous solution thoroughly is a key part of making flotation work better (Kyzas and Matis, 2019).

So all flotation methods are vulnerable to pH fluctuations, although a acidity or basicity of a metal and collector would modify a pH's impact (Hladíková and Šulc, 2021) cites a number of explanations for this impact, among which the following seem to be the most major causes:

• At every system, the ionic competitiveness for the solution would vary with initial pH, i.e. the surfaces charges of the ions that would be removed may change owing to hydrolysis or the creation of multiple complex, the value of pH must be that kind of the surfactant in the appropriate condition of ionization.

• Changes in pH alter the nature of the process; for instance, the ion may precipitate as hydroxide, transforming ion flotation into precipitate flotation.

• The process may be inhibited by the increased ionic strength and species that are favored in these solutions resulting from severe pH shifts.

Rubin did a study in 1972 to find out how pH affected the disconnection of lead from foam, utilizing an anionic surfactant sodium lauryl sulfate (NaLS), as collectors. The better flotation outcomes were observed at a pH asset of 8.2; however, there have been major differences between removalist effectiveness

determined from theory solubility information and testing outcomes information, which could be attributed to H^+ contest at small pH and less stability of its lead lauryl sulfate complicated. Lead (II) would be known to produce a stabilizing aqueous complex with OH, as seen in Figure 2.2. Lead is mostly found as Pb^{2+} ions below a pH of around 7 in pure water. "$Pb(OH)^+$, $Pb(OH)_2$ and $Pb(OH)_3$ types predominate over Pb^{2+} ions as pH increases (EPA, 2007).

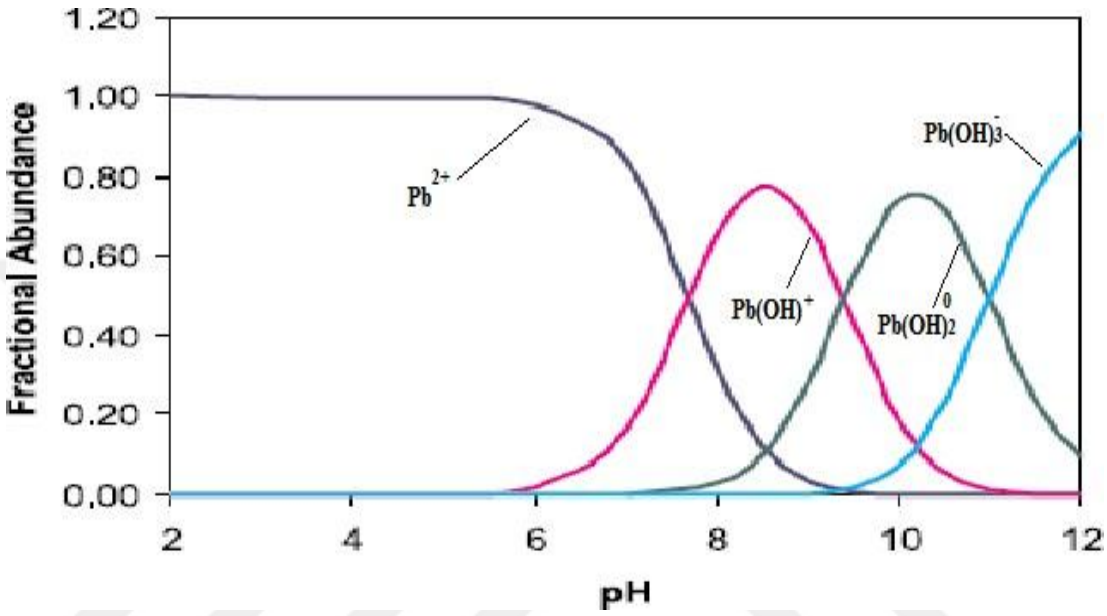


Figure 2.2. The distribution of lead (II) types in purified water at a temperature of 25 °C (EPA, 2007).

In 2007, Erdogan and Polat looked at how pH affects the thermodynamic distribution of copper ions and other elements in aqueous solutions. Then they realized that the positive ions Cu^{+2}, $CuOH^+$ and the negativity charged Cu(OH)-3 and Cu(OH)-4 are the most common forms of copper in pH levels lower than 10. According to Figure 2.3, neutral $Cu(OH)_2$ precipitates at or around pH 10.

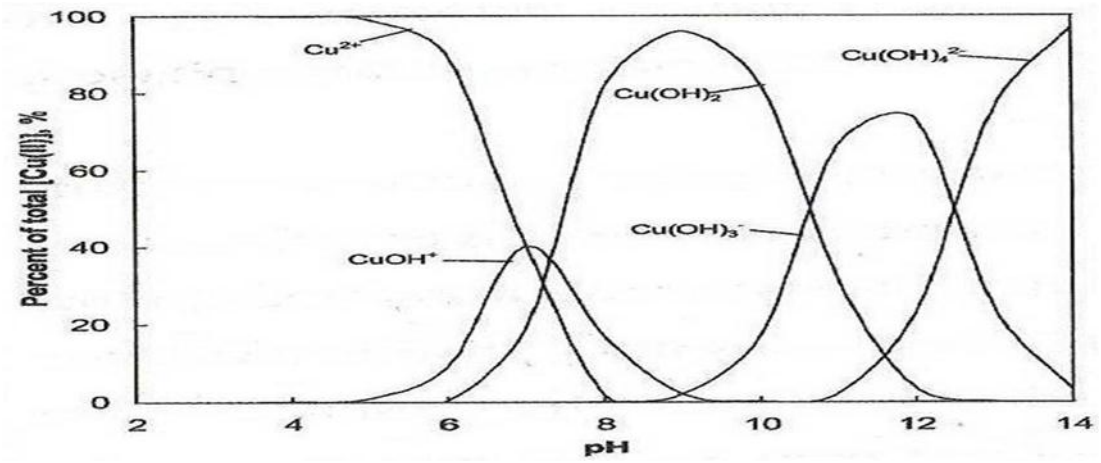


Figure 2.3. The Cu (II)–H2O system is speciation diagrams (Liu and Doyle, 2003).

Figure 2.4 depect the fractional exuberance for Cd-OH types in the water as the factor of pH. According to the distribution map for cadmium hydroxy complexes, the predominant types are $Cd(OH)^{+}$, Cd^{2+}, and $Cd(OH)_2$, which are found below pH 12. In freshwaters with a pH below 7, free cadmium ions represent the prominent portion of inorganic types (EPA, 2007; Davis et al., 2018)

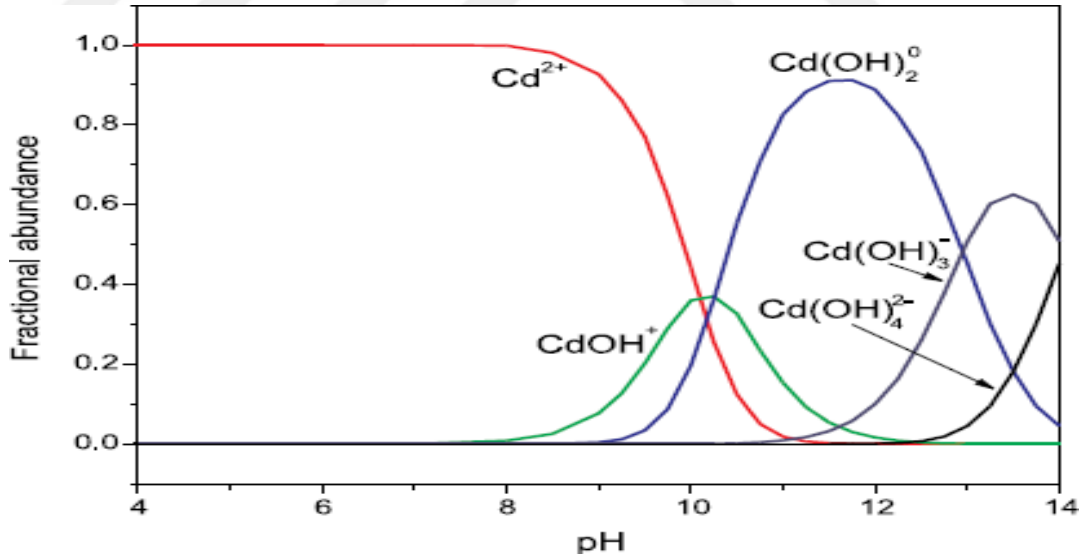


Figure 2.4.The types of distribution of Cd(II) in purified water at 25 °C as a function of pH (Davis et al., 2018)

It would be evident that its solution's pH plays a crucial role for flotation because it determines the kind and the charge of the types existent in the solution, etc and, thus, a structural of a surfactant (cationic collector or anionic) to use (Z. Wu et al., 2016; Peleka et al., 2018).

2.5.2 Collectors

A significant group of organic chemical compounds with a variety of chemical structures and functionalities make up the collectors. In the flotation process, the collectors' primary job is to create a hydrophobic coating on the exterior of a particular material. As a result, hydrophobic particles can adhere to air bubbles and end up in the froth product. Based on their capacity to distinguish between each other in water, collectors can be divided into two kinds (Liu et al., 2017):

1. Ionizing collectors: They are made up of organic molecules that have heteropolar charges. The collector takes on the characteristics for either the cation or the anion, determined by the charge that is produced. Depending upon the composition of a solidophilic collection, an anionic collector may be further split into oxhydryl collectors. In an anionic collector, the polar collection is an anion. When the solidophilic collection be composed of bivalent sulfur and when a solidophilic collection is dependent on organic and sulfo-acid ions, as well as a sulfhydryl collector. Cationic collectors are a class of chemical compounds that have a polar group that is a cation and a hydrocarbon radical that has been protonized. Such reagents have been amines, and the initial amines are a more significant flotation collector (Cui and Chen, 2021).

2. Non-ionizing collectors: Usually aqueous, “non-polar”, moisture hydrocarbon with a variety of structural types. Additionally, it was split into two groups. The first category consists of chemicals containing bivalent sulfur. The second category consists of hydrocarbon oils that are non-polar.

Hydrophobicity is the key to chemical species' floatability. The addition of the appropriate collector renders substances hydrophobic; iIt involves the elimination of polar groups by interaction with having left non-polar collections uncovered to the solution. These non-polar collections could be adsorbed onto the liquid/gas interface (Cui and Chen, 2021).

The group of collectors known as anionics is the one that sees the greatest application in flotation. The negatively charged portion of these surfactants adsorbs onto the ions, and the hydrocarbon chain accentuates the hydrophobic nature of the metal species. Due of this association, the particles were successfully detached from the liquid phase and the exudation that were moving thru the solution were capable of attaching themselves to the hydrophobic core quite securely. Figure 2.5A shows that when SDS surfactant is absent, a metal ion does not connect to the air bubble, bu

Figure 2.5B shows that same attachment occurs when SDS surface-active sites is included (Taşdemir and Başaran, 2021).

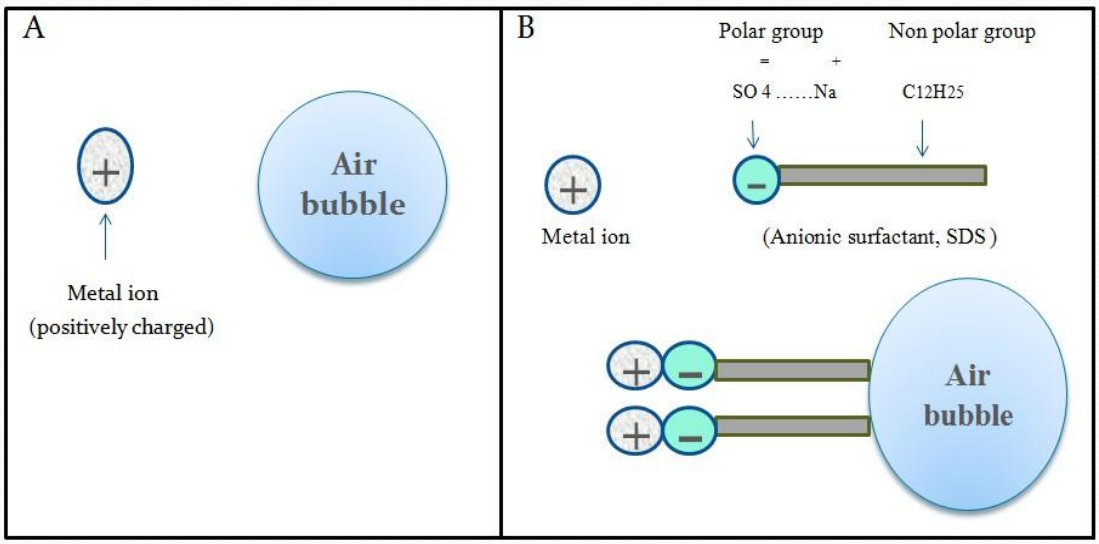


Figure 2.5.A) metal ions and air bubbles don't stick together when there is no surfactant. B) metal ions and air bubbles stick together when there is surfactant (Erdogan, 2005)

Due to the force of repulsion between adsorbed surfactant stratumes of the air bubbles, the existence of a surfactant may slow a coalescence of air bubbles. As a result, the bubble size reduces as the surfactant dose rises. This is due to the fact that surfactant adsorption upon air bubbles surfaces lowers tension of surfaces in air-water interfaces, hence decreasing the holding forces during bubble formation and the coalescence average of air bubbles (Xia et al., 2019).

The amount a collectors utilized in ion flotation is also crucial. Typically, a little excess of collector is introduced to remove as many metallic ions as possible from a solution. Not only should excessive surfactant be avoided because of its greater cost, but also due to its additional impacts, which include substantial foam loss and the possible toxicity from residual collectors quantities at the effluent (Xia et al., 2019). In the case of foam flotation, various anionic surfactants with C12 alkyl chains have shown to be effective, which brings our attention to the surfactants that are most likely to be accepted (Amani et al., 2021).

2.5.3 Metal Concentration, Sorbent Dose, and Competition

The quantity of sorbent is an essential metric because it defines the sorbent's capability for a certain starting sorbate concentration under operational

circumstances. A rise in sorbent dosage could be ascribed to a growth in a sorbent surface area, therefore, the amount of binding locations accessible to metal ions (Ghazi and Gaad, 2014; Alwared and Sadiq, 2019). But if the amount of sorbent is increased, the rate of sorption can slow down because there will be more active sites taken up. When a concentration gradation of the solute stays a same, there isn't enough solute to fill all of the accessible binding locations upon the sorbent, which usually means low the solute absorption (Abas et al., 2013; Pooja et al., 2022).

In addition, initial metal concentration in the aqueous medium is an additional component that should be considered throughout the sorption processes. Concerning the total metal removed, The percentage for adsorption has been noticed to be unrelated to the start concentration when a solution with a concentration level of less than 10 mg/L was utilized; This is due to the lower ratio of its initial moles for metals to attainable surface area. Nevertheless, at greater concentrations of metals, there are fewer sites accessible for sorption as compared to the moles of metal existing. Thus, metal removal is highly reliant on its starting metal concentrations (Abedin, 2014; Taseidifar et al., 2019; Pooja et al., 2022).

According to the findings of several studies conducted on the flotation process, there is not a discernible difference in the rate of removal between different beginning metal concentrations despite the increasing concentration of metal ions. The higher surfactant-to-metal ratio, which generates rivalry for particles surface among metallic materials and loose collector ions, however, decreased the removal rate because when levels of heavy metals was small (less than 25 mg/L) and the pH condition was basic (Mohamed et al., 2013).

The majority of industrial effluents include several metal components at varying concentrations. Therefore, competitive adsorption is very significant for treating wastewater (Sheth et al., 2021). In the existence of the combination of such metal ions, the ions of metals vie for the adsorption locations of the adsorbent This rivalry influences the diffusion characteristics of the metal ions and, as a result, reduces their adsorption capability. Therefore, a metal ion which reaches the adsorption location quicker relies on the aforementioned factors (like metal concentrations and sorbent dosage) as well as the metal ions' hydrated radius. It is obvious that the ability to adsorb was impacted by metal ions vying for adsorption sites. These hydration radii of various metal cations are visible in Table (2.3**)** (Kouotou et al., 2021). Based on these findings, the sorbent's relatively small

hydrated radius is what gives it its high Pb selectivity (II). Ions whose hydrated radius is lower than the channel size of the sorbent structure may readily travel inside the canal (Giri and Cordeiro, 2021).

Table 2.3. Hydrated radius for various cations (Kouotou et al., 2021)

Metal Cations	Hydrated ionic radius
Cu	4.19 Å
Pb	4.01 Å
Cd	4.26 Å

In ion flotation, it is also important to have selectivity for jumbled-metal solutions to get back valuable parts from waste remediation and process solutions. For instance, the intended metal mayn't be remove from the solution if there is an excessive amount of other metal ions in the solution. These additional metallic ions compete with the desired metal for available surfactant bind sites through electrical attraction. This problem might be solved by the selection intricacy between a certain surfactant and the desired metal, which is based on the various effective ionic radii and stability constants of such complexes. The complex would then be able to serve as a surfactant. This might also give a hint to the recovery of the metal's (Boddagh et al., 2013; Saneie et al., 2022).

Overall, when two ions have opposite charges but the relatively similar sign, the greater the valence of one kinds, the more selective it would seem to be over numerous different kinds with lesser valence. On the other hand, we don't recognize much about how to choose among ions with a similar valence (Doylee and Liiu, 2003).

2.5.4. Frothes

Frothers seem to be heteropolar surface-active substances with a polar term and a hydrocarbons radicals that could also have the capability to adsorb upon that air bubbles-water interfaces and reduce the water's surface tension. Their existence in the liquid stage enhances the air bubbles' film strength, enabling more hydrophobic particles to adhere to the bubbles. Based on how well they work at different pH levels (the pH at which they work best), frothers can be put into the following groups (Ceylan and Bulut, 2021; Khoshdast et al., 2023)

• Acidic: Those frothers are mainly effective under acidic conditions. In an alkaline environment, its frothing characteristics decrease. Alkyl sulfates and phenols

are idealistic types of such reagents.

• Basic: These frothers, which are exemplified via pyridine and homologs, have been employed in the floatation of base-metal ores.

• Neutral: the action of all these frothers is independent of the pH level. This is the most significant category of frothers. These frothers have been separated into the major categories: alkoxy paraffins, aliphatic alcohols, glycols, and cyclic alcohols.

The polarity groups, or hydrophilic, were guided into the two liquids and the non-polar hydrocarbons sequences due to the organization of the molecules of the frother at the air-water interface or hydrophobic, were in the air phases. In actuality, the frother induces froth production as well as reduces the surface tension of the water. A frothers concentrate on an interface air and water bubbles, generating an circumstance around the bubble to avoid them either touching or colliding (Khoshdast and Sam, 2011; Schomäcker et al., n.d.).

2.5.5 Features of Air Bubbles

Because solids, liquid, and gas phases have been implicated in a flotation operation, which is controlled via the existence of an increasing stream of bubbles, the interfacial region of a bubble existing in the gasliquid diffusion is crucial to the process's efficiency. That interfacial region, in turn, has been controlled by the flow rate of the gas diffusion and is connected to how much gas has been held up in it. The aeration rate is thus a key variable in dispersed-air flotation that may be crucial (Boddagh et al., 2013; Sun et al., 2019). An effectiveness of flotation, as well as types for floated material, are determined by the bubble sizes of the air gases, that are established via gas flow rate across the porous plates or sparger, and the plate hole diameters. These bubbles floated to the solution's surface by forming an interface between the solution's bulk and surface-activated complexes (Ghadi et al., 2010; Ksenofontov, 2019; Dyagelev et al., 2020).

The kind of gas sparger may vary the features of bubbles, which in turn influences gas detention values as well as numerous other factors defining bubble columns. The sparger is utilized to definitively assess the observable bubble sizes in the columns. Plates with a narrow opening diameter permit the generation of smaller-sized bubbles. Common kinds of gas spargers include perforated plates, membranes, ring-style distributors, the porous plate, as well as arm spargers (Shen et al., 2022; Nallakukkala et al., 2022). Tiny gases bubbles in ions flotation not only offer big gases/liquids interfaces but also avoid the creation of tumultuous liquid flows at the a

solution, which are most likely to disturb the attached species when big gas bubbles are used (Lu et al., 2005).

In a standard flotation cell, the size of the bubbles varies between 0.5 and 1 mm. While bubble volume was lowered, the sum of bubbles in a system would rise for the same kind of volumetric air flow rate, resulting in an increased flotation average (Erdogan, 2005).

2.6 Absorbent in the Current Study

Banana peels were the most affordable organic adsorbent because they are readily obtainable and have a higher capacity for adsorption than other natural adsorbents. banana peels biomass is an excellent and affordable alternative to traditional carbon-based adsorbents (Afolabi et al., 2021a; Afolabi et al., 2021b; Arifiyana and Devianti, 2021; Nurain et al., 2021; Hussain et al., 2022; Nadhirah et al., 2022; Lavanya et al., 2022; Gahlan et al., 2023). Banana peels that have been consumed are discarded as trash. Lignin, hemicelluloses, condensed tannins, cellulose, and structural proteins are all essential components of banana peels (Bakar et al., 2021; Aguilar-Zuniga et al., 2021). It has been noted that these naturally polymers have a superb ability to bind metals. So heavy metals may be removed from aqueous solutions utilizing banana peels as the adsorbent (Khairiah et al., 2021; Negroiu et al., 2021). The reality that individual hazardous metallic kinds are uncommon in wastewaters can't be overlooked. In actuality, the existence of numerous metal ions frequently results in an interaction impact, despite the seeming lack of attention paid to this issue (Arifiyana and Devianti, 2021). Although several metals with competing interactions in solutions involving the sorbent particles were among the fundamental elements controlling the percentage of metal ions removed by biosorption, very few investigations on various metal systems were published (Anwar et al., 2010).

2.7. Models of Adsorption Isotherms

Normally, adsorption is expressed using an isotherm, which refers to the relation among adsorbate concentrations in liquid phases as well as adsorbate concentrations in the adsorbent particles at a specific temp. This relates to the proportions of the amount of adsorbate to the equilibrium quantities of the adsorbed species present in solution (quantity of adsorbate to weight of adsorbent, or qe) (Ce). In order to make comparisons between different compounds easier, the amount is almost always standardised by the density of the adsorbent (Barros et al., 2013).

Generally, the quantity of materials absorbed per unit of weight of adsorbent increases with rising concentrations, although not in a straight proportion. As seen in Figure 2.6, certain common isotherm forms are depicted as arithmetic graphs (Olawale, 2021).

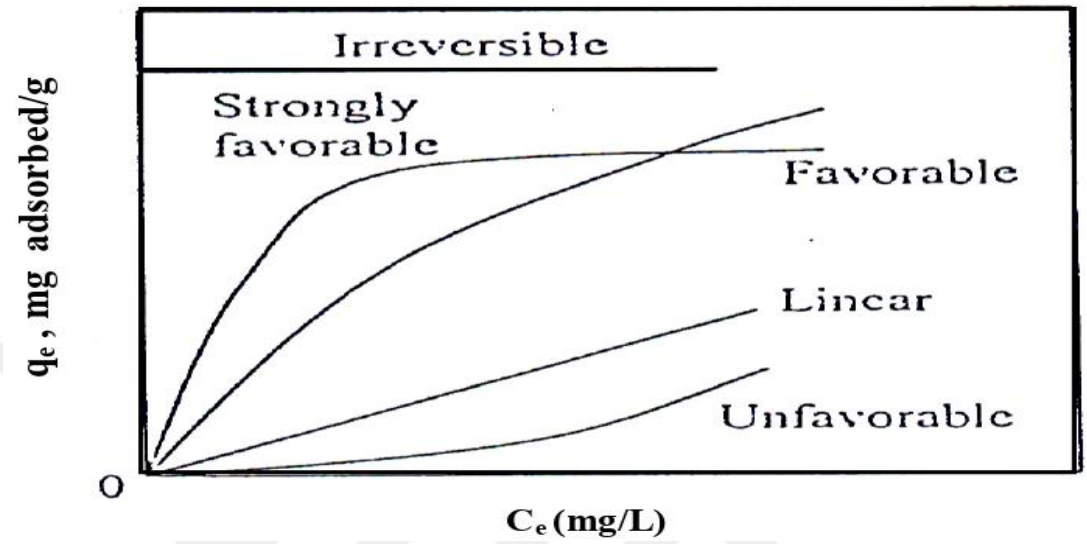


Figure 2.6. Illustrates the kinds of adsorption balance isotherms linkage (Olawale, 2021)

Except for the irreversible isotherm, all isotherms pass via the origin, and the convex upward isotherms is seen favorable since a reasonably large solid loading may be produced at a low fluid concentration. A concave upward isotherm is considered unfavorable because comparatively little solid loading is achieved. According to the linear isotherm, the quantity adsorbed was proportionate to the fluid concentration. The limiting state of an extremely favorable isotherm was irreversible adsorption, in which the quantity adsorbed is independently of concentrations at very small levels. The adsorption isotherms were a very effective way of analyzing the adsorption processes (Nandiyanto et al., 2020). Several among the most prevalent models are mentioned in the below:

2.7.1. Models of Single-Component Isotherms

2.7.1.1. Model of the Langmuir Isotherm

With respect to single-layer adsorption, the Langmuir is a useful model. In this model, we assume that the adsorption energy is constant, that the adsorbate does not undergo transmigration in the plane of the surface, and that the solute molecules form a saturated monolayer on the adsorbent surface for maximal adsorption to take place (Ghazi and Gadd, 2014; Guo and Wang, 2019; Wang and Guo, 2020). The

Langmuir isotherm equation is:

$$qe = \frac{qmbce}{(1+bCe} \quad \text{(Nonlinear form)} \qquad 2.1$$

$$\frac{1}{qe} = \frac{1}{qm} + \frac{1}{(qm*b)} * \frac{1}{ce} \quad \text{(Linear form)} \qquad 2.2$$

Where:

qe = metal ions sorbed on the sorbent (mg/g).

qm = the highest monolayer coverage sorption capacity (mg/g).

b = a constant related to the binding site's affinity (L/mg).

Ce = concentration of metal ions in the equilibrium solution (mg/L).

The Langmuir isotherm, which has limitations due to the presumption that adsorption energy on the the adsorbent's surface is uniform, is frequently used to refer to the adsorption isotherm.

- All adsorption sites are equal, since the surface of the adsorbents is uniform.
- There are no interactions between molecules adsorbing on adjacent sites.
- At certain places on the surface of an adsorbent, molecules are adsorbed.
- The same mechanism governs all adsorption processes.

According to Weber and Chakravorti in 1974, the non-dimensional constant separating factor as well as the equilibrium parameter, Rs, given via the following equations, may be used to explain the fundamental properties of a Langmuir isotherm equation.

$$R_s = \frac{1}{1+bC_O} \qquad 2.3$$

The above-described separation factor was determined utilizing the Langmuir model constant. This separating factor generates the isotherm kind seen in Table 2.4.

Table 2.4. Values for the separating factor as well as isotherm kinds (Al-Ghouti and Da'ana, 2020)

kind of isotherm	**Value of Rs**
Unfavorable	"R s > 1"
Linear	"R s = 0"
Favorable	"0 < R s < 1"
Irreversible	"R s < 0"

2.7.1.2. Freundlich Isotherm Model

The Freundlich formula is designed for modeling both multilayered absorption and the absorption of heterogeneous surfaces. The Freundlich isotherm theory states that over a variety of concentrations, the ratio of the amount of solute adsorbed on to a particular mass of sorbent to the concentration in the solution is not constant (Khayyun and Mseer, 2019). The calculation looks like this:

$q_e = k_f c_e^{1/n}$ (Nonlinear form) 2.4

$$\ln q_e = \ln k_f + \frac{1}{n} \ln c_e \quad \text{(linear form)} \quad 2.5$$

Where :

K_f is a constant that represents an adsorbent's proportional adsorption capability in (mg/g) * (l/ mg) * (1/n) units.

n = constant which represents the adsorption's strength.

The constants K_f and n were both chosen to represent an amount for whole adsorption as well as the degrees of nonlinearity among solutions and concentrations, respectively. When you plot lnqe against lnCe, you get a linear Freundlich plot, from which you can figure out the adsorption coefficients, as shown in Figure 2.7 (Yu et al., 2009).

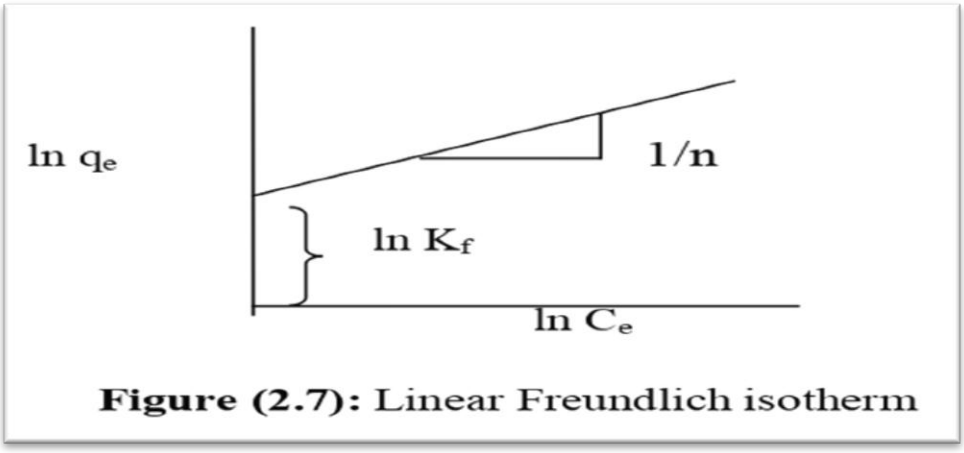


Figure (2.7): Linear Freundlich isotherm

2.7.1.3. Temkin Isotherm

Adsorbent-adsorbate interactions are expressly taken into consideration by a component in the Temkin isotherm. This isotherm assumes (i) that all molecules in the layer's heat of adsorption decrease with coverage due to the interaction of the adsorbate with the adsorbate, and (ii) a comparability of binding affinity up to a maximum anticipated binding energy distinguishes adsorptions; The process of

understanding models the Temkin isotherm:

$$q_e = \frac{RT}{b_T} \ln(K_T * C_e) \quad \text{(Nonlinear form)} \quad 2.6$$

It is possible to linearize equation (2.6) using equation (2.7).

$$q_e = B \times \ln k_T + \ln c_e \quad \text{(Linear- form)} \quad 2.7$$

In which B = RT/bT

The determination of isotherm constants kT and B is made possible by regression of qe against lnCe. (kt) is a Temkin isotherms balance binding constant (l/g) corresponds to a maximal energy bands, B stands for the temperature constant for adsorption heat (j/mole), bT for the Temkin isotherms constant, R for the gas constant (8.314 (j/mol) k), and T for the absolute temperature (k) (Musah et al., 2022).

2.7.2. Models of Multi-component Isotherms

Due to the many variables involved, experimentally measuring the multi-component adsorption/biosorption isotherm takes a long time. So, the question of how to predict sum-component adsorption isotherms from information about single-component adsorption has gotten a lot of attention. The number of isotherm models has been presented to characterize competitive adsorption. A majority of all these isotherm models were predicated upon a single component isotherm parameters as well as a correcting factor determined from competing experiment data (Musah et al., 2022). Several major models are including:

- Extended Langmuir Model
- Extended Empirical Freundlich Model

2.7.2.1 Extended Langmuir Model

For multi-component systems, the Langmuir isotherm may be expanded to provide the following formulation (Alafnan et al., 2021):

$$q_i = \frac{b_i q_{m,i} c_{e.i}}{(1+\sum_{j=1}^{n} b_j c_{e,j})} \quad 2.8$$

In which Ce,i represents the balance concentration of component I in a sum-component solution. The balance absorption of a component i is represented by qi and the individual component Langmuir parameters for component I are represented by q_m, I and bi respectively. This model works if each single component in a single-component system follows the Langmuir model. The expanded Langmuir formula is

a frequently used model for sum-component adsorption information (Alafnan et al., 2021).

2.7.2.2 Extended Empirical Freundlich Model

According to Pagnanelli et al. (2001), the empirical extension version of the Freundlich models confined for multi-mixtures may been expressed as follows:

$$q_{ei} = \frac{k_i c_{e,i}^{ni+n1}}{c_{e,i}^{n1} + \sum_{j=1}^{n} k_j c_{e,j}^{nj}} \quad 2.9$$

Which in , K_i and n_i (i = 1, 2) can be obtained from the single Freundlich isotherm formula corresponding to a component i.

2.8 Kinetics of Sorption

The kinetics represents the rate of solute absorption, which governs resident time for sorbate absorption in a solid solution interface. It is essential to be able to predict the pace that these sorbates are extracted from the liquid suspension in order to create effective sorption treatment methods. Thus, sorption kinetics is the crucial factor for determining an importance of the sorption processes (Wang and Guo, 2020).

2.8.1 Model for Pseudo-First Order Kinetics

The Lagergren rates formula became the first rate formula founded on solid capability for an adsorption of a liquid/solid combination. One of the most popular sorption rates formulas for adsorption of a solute from the fluid is the Lagergren rate formula. It might be demonstrated as (Wang and Guo, 2020):

$$\frac{d_q}{d_t} = K_1(qe - qt) \quad 2.10$$

The result of integrating formula (2.10) as well as employing the boundaries circumstances “qt = 0 at t = 0 & qt = qe when t = t” is:

$$\ln(q_e - q_t) = \ln q_e - K_1 t \quad 2.11$$

Where of the following is an integrated average rule for a pseudo first order interaction. in which qe would be the quantity of metals sorbed at balance (mg/g), qt represents the quantity of metals sorbed at duration t (mg/g), as well as k_1 represents the balance average constant of pseudo - first - order sorption (1/min)?

In general, formula applied for experimental findings is different from the genuine first-order formula throughout 2 directions. :

1. A value $k_1(q_e-q_t)$ doesn't accurately indicate the number of accessible sites.

2. The value ln (q_e) can be changed. It is frequently observed that ln (q_e) does not equal the intercept of the ln (q_e-q_t) plot against t, despite the fact that in a true first order operation, ln (q_e) must equal the intercept of the ln (q_e-q_t) plot against t.

2.8.2 Pseudo Kinetic Model of Second Order

This kinetic model's definition contains some assumptions (Wang and Guo, 2020):

1. On the surface of the adsorbent, a monolayer of adsorbate is present.

2. The adsorption energy of every adsorbent was the same as well as independently by surface covering.

3. Adsorption happens solely at localised places, and there are no interactions between the contaminants that are adsorbed. When compared to an initial rate for adsorption, the average rate of adsorption is virtually insignificant. The expression for the kinetic average may be expressed as shown in:

$$\frac{d_q}{q_t} = k_2(q_e - q_t)^2 \qquad 2.12$$

Where K_2 represents an average constant of sorption (g/mg min), qeq represents a quantity of divalent metallic ions sorbed when balance (mg/g), and q_t represents a quantity of divalent metallic ions throughout any moment upon that surface of a sorbent (mg/g).

Regarding a boundaries circumstances q_t = qe when t = t & q_t = 0 in t = 0 , the integral form of formula (2.12), as presented by (Hoo et al., 2006), is as follows:

$$\frac{1}{(q_e-q_t)} = \frac{1}{q_e} + k_2 t \qquad 2.13$$

A pseudo-second order reaction's integrated rate law is represented by this. You may rearrange Equation (2.13) to get:

$$q_t = \frac{t}{(\frac{1}{k_2 q_e^2}+\frac{t}{q_e})} \qquad 2.14$$

the linear form of which is:

$$\frac{t}{q_t} = (\frac{1}{k_2 q_e^2} + \frac{t}{q_e}) \qquad 2.15$$

Constants may be empirically calculated by charting t/q_t versus t. Based on a primary sorption rates:

$$h = K_2 q_e^2 \quad 2.16$$

2.9. The Flotation Kinetics

Flotation kinetics is a study of the variations of floating concentrations with time Studying flotation kinetics may be helpful for elucidating the mechanism of a process and for implementing flotation technologies (Hernainz and Calero, 2001). The quantity of float-able material still present in a cell has a direct correlation with the rate of flotation, and this connection is as follows:

$$\text{Flotation rate} = (\text{concentration in the cell})^{\alpha} * K \quad 2.17$$

The flotation average was equals to the average variation in floatable material concentrations in a cell, thus Equation (2.17) could be rewritten as differential: This is a basic average formula where k is the flotation average constant and (a) is the order of the formula. The result of integrating Equation (2.18), with a = 1 (first - order) is:

$$C = C_{\circ} e^{-kt} \quad 2.19$$

In which Co repsrents the concentrations of precious material in t = 0 and C represents the ultimate concentrations of beneficial material left in time t.

Using ln of Equation (2.19):

$$\ln \frac{c}{c_{\circ}} = -kt \quad 2.20$$

Furthermore, when ln (C/C_o) experimental data is plotted vs t, the resulting graph must be a direct line with a slope of k if a = 1.

This equation's average constant, k, describes how quickly a type floats. A type that floats quickly has a large average constant, while a type that floats slowly has a small average constant (Gupta and Yan, 2006).

2.10. Previous Studies

Doyle and Liu (2003) was utilized as the collector reported the impact of the neutral chelating ligand, Trien, upon this capability to separate calcium (II) ions and copper (II) ions. They also tried to compare an ion flotation actions of Ni (II) & Cu (II) aquo-ions with those of Ni-Trien and Cu-Trien complexes. They came to the conclusion that copper was taken out preferentially. During ion flotation with SDS, trien was shown to significantly improve the clearance rates of "Ni (II) and Copper (II)" and decrease the stable-state concentrations attained. Surface tensions experiments showed that all Trien improved the surface reactivity as well as adsorption densities for solutions containing SDS-Ni (II) and SDS-Cu (II).

Polat and Erdogan (2007) explored the removal of copper (II)ion , Cr(III) ion , zinc (II) ion, and silver (I) ion through waste fluids by flotation,. Several variables, including frother, pH, and collectors concentrations, as well as air flow rates, have been examined to ascertain the optimal flotation circumstances. Researchers utilized hexadecyltrimethyl ammonium bromide and SDS as collectors, as well as MIBC and ethanol as frothers. Under optimal circumstances at a low pH, metal removal achieved 74%; at a basic pH, it reached 90%, most likely because of the involvement of metal precipitation flotation.

Bodagh et al (2013) analyzed the possibility of Cd(II) ion removal of aqueous solutions using foam floatation with some rhamnolipid bio-surfactant. Researchers studied the impacts of several primary operational variables, including cadmium concentrations, frother kind and concentrations, aeration rate, rhamnolipid and, solutions pH, on Cd(II) removal. Researchers discovered that, in a presence of rhamnolipid, the selectivity coefficients retained the following distinct orders: Cd (II) is superior to Zn (II), whereas Cd (II) is superior to copper (II), and zinc (II) was superior to Cu (II). A coefficient of selectivity of Cd (II) over Cu (II) was the greatest. At pH 6, the maximal Cd (II) removal from uncontaminated, Zn (II), and Cu (II)-polluted solutions was about 57%, 36%, and 48%, in both. According to kinetic investigations, the ion floatation of Cd (II) is governed by a kinetic formula with a kinetic average of 0.0071 min^{-1}.

Kadhem and Mohamed (2013) investigated the floatation technique of extracting lead, zinc of simulated wastewater. The study was employing 100 mg*l of SDS like a collector as well as 1% ethanol like a frother, it was possible to remove lead with an efficiency of approximately 95% at pH 8 and zinc with an efficiency of

about 93% at pH 10. They demonstrated that raising beginning metal concentrations in alkaline circumstances boosted removal efficiency while decreasing starting metal concentrations in acidic situations. They also demonstrated that raising air flow rates upward to 1,000 ml/min improved separating effectiveness. Additionally, they investigated selective flotation tests with metal ion mixture solutions, and under optimal conditions, lead and zinc removal rates were 84% and 81%, respectively.

Mohammed and Mohammed (2014) expert Sorptive floatation process to remove the ions Ni (II) and Cd (II) from wastewater. utilizing Amberlite IR120 as a resins and flotation columns. As anionic and cationic surfactants, they employ (SLS) and (HTAB), respectively. At pH 7, the investigation revealed that the sorption mechanism removed the most metal ions. Both the Freundlich isotherm and the Langmuir expressions have been found to suit the experimental information well. kinetic results agreed well with Lagergren's 2nd-order kinetic models, as well as the flotation stage increased the percentage removal of cadmium and nickel from wastewater by around 75 % to 94 % and reduced turbidity, allowing the elimination of the costly filtering procedure.

Mohamed and colleagues (2016) studied the potential of SBTL for biosorptive-flotation-based lead ion removal from aqueous solutions. The maximum biosorption capacity was found to be 19.70 mg/g at pH 5 and over a contact time of 180 minutes. The Freundlich isotherm model's applicability was shown through investigations of isotherms. The pseudo-first-order model provides the best fit, according to kinetic study. According to FTIR analysis, the biosorbent's surface sulfonic, carboxyl, and amino clusters were the main groups in charge of lead ion binding. The flotation approach increased the removal effectiveness from 91% to 99 % utilizing sodium dodecyl sulfate as a surfactant.

Ezzat et al., (2017) study the removal of Eu(III) from aqueous solutions by sorptive flotation process. This process involves adsorption of Eu(III) onto bentonite and kaolinite. The effect of adsorption parameters (pH, contact time, clay weight, Eu(III) concentration, ionic strength) as well as flotation parameters (collector and frother concentrations, bubbling time, concentrations of foreign cations and anions) on the removal efficiency of Eu(III) were studied. The obtained results show that Eu(III) ions are removed efficiently (R% ~ 95%) at pH=4 after 1 h shaking with clay and 15 min floatation. The adsorption kinetics of Eu(III) onto the employed clays followed the pseudo-second-order model and the equilibrium data fitted well to the

Freundlich isotherm model.

Abdulhussein and Alwared, (2019) predict the removal of copper ions from simulated wastewater by flotation and sorptive flotation systems using Sodium Dodecyl Sulfate (SDS) as surface active agent and sunflower seed husk as low-cost locally available adsorbent based on experimental data. The effect of initial copper ion concentration, flow rate, sunflower seed husk dosage and surfactant concentration at 40 min contact time, pH of 5 and at room temperature, were investigated. The best value of these parameters that achieved maximum removal efficiency of Cu(II) ion were 30 g/l initial Cu(II) ion concentration, 500 cm3/min flow rate for both systems and 7 g/l sunflower seed husk for sorptive flotation while the SDS concentration was 60 mg/L for flotation and 30 mg/L for sorptive flotation. Sensitivity analysis shows that the time and pH was found to be most significant parameters.

Youssef, (2020) synthesized the silica nanoparticles functionalized with folic acid (Nano-SiO2-FA) as a sustainable and promising sorbent for preconcentration of Al(III) from natural water samples by sorptive-flotation (SF) separation technique. A several trials were made in lab, to determine the feasibility of using Nano-SiO2-FA as a sorbent and oleic acid as a surfactant. The influence of: solution pH, temperature, shaking time, surfactant, sorbent and Al(III) concentration and the presence of foreign ions that affect the sorptive-flotation process were investigated. Good results attained under optimum circumstances, at pH 3.5 and ~25°C, according to which nearly 100% of aluminum was separated.

Pooja et al., (2021) concentrates on the removal of heavy metal from wastewater which was produced from an electroplating industry. the Dissolved Air Flotation (DAF) treatment process is carried out to remove toxic metals such as chromium, cadmium, nickel, lead, and copper using Sodium Dodecyl Sulfate (SDS) as a collector. The best-optimized conditions for the maximum removal of all the metal ions about 97.39% was achieved at pH 8, contact time of 60 min, surfactant dosage of 0.2 g, and the pressure of 137.89 kPa. At optimized conditions, the treated water consists of 2.71 mg/L of chromium, 1.13 mg/L of cadmium, 10.24 mg/L of nickel, 0.06 mg/L of lead, and 1.14 mg/L of copper. The used surfactant SDS was found as an environmentally friendly compound as prescribed by the Environmental Protection Agency.

Schlebusch et al., (2023) studed the flotation of metal ions (Cu^{2+}, Ni^{2+}, and Co^{2+}). Surfactin, at a molar ratio of 1:3, has been shown to float 75.2%, 94.7%, and 98.2% of initial 100 μM solutions of copper nickel and cobalt, respectively. Increasing the gas flow rate modifies the float by increasing the carryover of water into the overflow. A pH of 5 was found to be ineffective (due to surfactin precipitation), while a pH of 10 was less effective than pH 7, likely due to the ionic speciation of the metals in solution tending to hydroxyl precipitates at a high pH.

The goal of the current study is to further investigate the marketable withdrawal of copper, lead, and cadmium ions from simulated wastewater using banana peels as an inexpensive sorbent material. This was done using batch sorption and sorptive flotation methods, which were compared to the ion procedure for metals separation using SDS surfactant.

3. EXPERIMENTAL WORK AND PROCEDURES

3.1. Materials

3.1.1. Adsorbate

Pb $(NO_3)_2$, $CuSO_4.5H_2O$, and $Cd(NO_2.4H_2O)$ were dissolved in distilled water to produce synthetic wastewater with the appropriate concentration (10, 30, 50, 100, 200 mg/L).mg/l of lead, copper, and cadmium ions for this experiment. The solution's pH was adjusted to the correct level by adding NaOH or HCl (0.1 M) as necessary. Table 3.1 displays the principal physicochemical features of the examined metals. The mass of the metals necessary to attain the desired concentrations has been calculated using Equation (3.1) under the assumption of total dissolution:

$$\boldsymbol{w = v \times c_o \times \frac{m.wt}{At.wt}} \qquad 3.1$$

in which :

w= the weight of salt in heavy metals (mg)

V = volume of solution (L).

C_o = the initial (mg/L) concentration of metal ions in solution.

m.wt = molecular weight of metal salt (g/mole).

At.wt = the atomic weight of a metal ion (g/mole).

Table 3.1.Principal physico-chemical characteristics of a tested metals (Christophiand Axe, 2000; Doyle and Liu, 2003; Ehrampoush et al., 2011).

Property	Copper sulfate pentahydrate	Cadmium nitrate tetrahydrate	Lead nitrate
Appearance	Blue crystals	White colorless crystals	white crystals
Chemical formula of metal salts	$CuSO_4.5H_2O$	$Cd(NO_3)_2.4H_2O$	$Pb(NO_3)_2$
Atomic weight of metal ions(g/mole)	63.546	112.7	207.2
Density (g/cm^3)	2.284	2.45	4.53
Molecular weight of metal salts (g/mole)	249.70	308.7	331.2
Hydrated ionic radius, Å	4.19	4.26	4.01

Solubility of metal ions in water g/100 mL at 20 °C	32	136	54.3
Ionic radii, Å	0.72	0.95	1.19
Company	RIEDEL DE HAEN Germany	BDH England	BDH England

3.1.2. Reagents

•For flotation and sorptive flotation, Fisher Scientific's sodium dodecyl sulphate (SDS) surfactant was utilized as an anionic collector. Chemical formula ($C_{12}H_{25}OSO_3Na$), trade name (Na-Dodecyl Sulfate), molecular weight (288.38 g/mole), and molecular mass density (8.025 X 10^{-3} moles/L) all describe this white powder substance.

• The pH has been modified by utilizing NaOH, which has a molecular weight of 40 grams/mole and is 100% pure, and HCl, which has a molecular weight of 98.08 g/mole and is also % pure."

• As a frother, ethanol (C_2H_5OH) from Lancaster Synthesis was utilized.

3.1.3. Sorbent

The collection of banana peels as an organic sorbent from solid waste. It has been cleaned with distilled water to eliminate surface contaminants and then sun-dried for two days. The dried leaves were pulverized as well as sieved through 2 sieves (No. 30 and No. 35) to produce 500-600 μm-diameter grains, which were then kept in polyethylene bags awaiting usage. Figure (3.1) demonstrates the prepared banana peels.

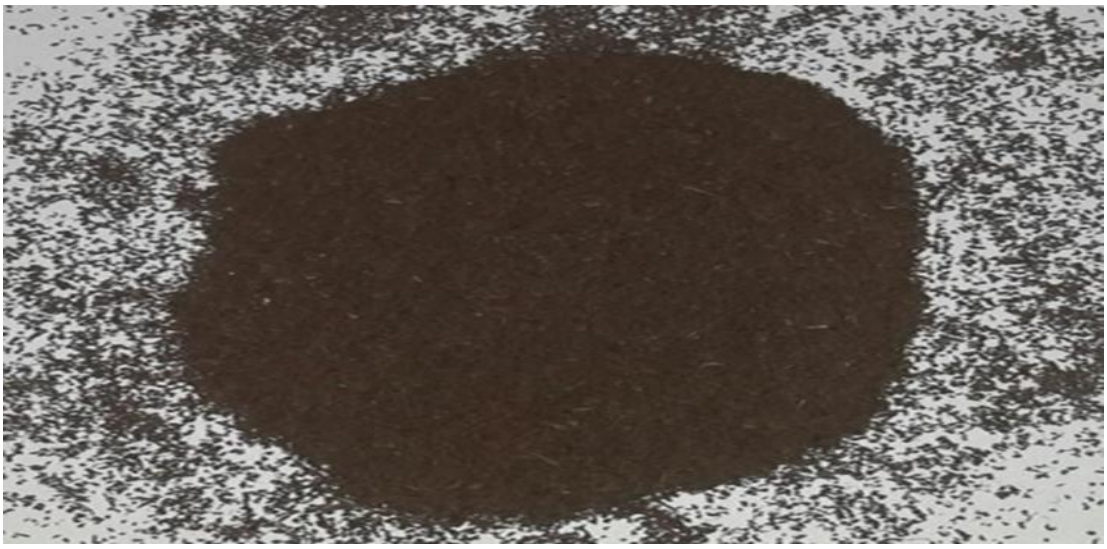


Figure 3.1. The prepared Banana Peels

Physical characteristics of banana peels have been evaluated in the labs of the Ibn Sina Center-Baghdad/Iraq , as stated in Table 3.2.

Table 3.2. Physical characteristics for banana peels

Property	Banana peels	Test method
Real density (g/cm^3)	2.0798	ASTM D-4892
Bulk density (g/cm^3)	0.2713	ASTM D-4164
Surface area (m^2/g)	9.9934	ISO-9277-2010

3.2 Measurement Instruments and Equipment

1. Atomic Absorption Spectrometer: utilized to determine the amounts of soluble copper, lead, and Cadmium ions (GBC 933 plus, Australia)."

2. pH Meter: A pH bench meter has been utilized to determine the pH of the solution (wtw. Sr. Nr. 08490207).

3. The objects used in this investigation were weighed using an electronic balance (species: Sartorius) with a capacity of 210 g.

4. The Shaker Incubator "model: LIS-3016A, No.B110416002, Korea".

5. Zeta Meter 4.0: instrument for measuring the electrical potential of a particle's surface (microscopic module, USA).

6. An air compressor (type: SAMTONG).

7. Rotameter air flow meter with 200-12,000 cm^3/min range.

3.3. Experimental Procedures

3.3.1 Experiments in Batch Sorption System

In order to determine the optimal working conditions and sorption isotherm for banana peels in removing lead ion (Pb), copper ion (Cu) and cadmium ion (Cd) from aqueous solutions, 100 mL of heavy metal solutions with defined concentrations were put into 250 mL conical flasks. Using HCl or NaOH, each flask's aqueous solutions' pH was adjusted to the proper level (3, 5, 6, 7, and 8). Each flask was filled with a specific amount of sorbent (0.5-8 g/L), and after that, the flasks were put on a mechanical shaker and constantly swirled for the required length of time (10, 15, 30, 60, 90, 120, 150, and 180 min) with 100 ml of solution volume at ambient temperature (~30 C). After every test, the samples have been taken dragged by 10ml pippete, filtered utilizing Whatman 70 micrometer filter papers, and afterwards analyses with an Atomic Absorption Spectrometer (AAS) for heavy metal concentration remaining.

Each pollutant's clearance efficiency was determined using the following relationship:

$$Re\% = \frac{(c_o - c_e)}{c_o} \times 1oo \qquad 3.2$$

Where C_o and C_e represent the starting and final metal doses (mg/L), correspondingly.

For the following studies in which were carried out to determine whether banana pells were effective at sorbing ions containing heavy metals from simulated wastewater:

3.3.1.1 The pH Effect

Experiments on the impact of the pH on absorption have been conducted at various pH levels (3, 5, 6, 7, and 8) via adding 0.10 M of NaOH or HCl to obtain the appropriate pH value utilizing the pH meter. For banana peels, the contact duration, sorbent dose, agitation speed, initially concentrations of metals, as well as temperatures, have been set at 120 min, 2 g/L, 175 revolutions per minute, 50 ppm, as well as 30^{o}C.

3.3.1.2 The Effect of the Speed of Agitation

The impact of agitation velocity on the sorption of lead ion (Pb), copper ion (Cu) and cadmium ion (Cd) was tested at various speeds (125, 175 as well as 250 revolutions per minute (rpm) utilizing a shaker incubator with optimal pH data, whereas sorbent dose, beginning metal concentration, contact duration, as well as temperature have been held constant at 2 g/L for banana peels, 50 mg/L, 120 min, as well as room temprture (30^{o}C) .

3.3.1.3 Impact of Sorbent Dosage (Equilibrium Isotherm Experiment)

During the experiments, the initially ions concentrations of 50 mg/L of the every heavy metals has been matched with sorbent dose (0.5-8 g/L) for banana peels, 120 min of contact time, 175 rpm of agitation speed, as well as room temprture. A pH has been adjusted to the optimal levels previously determined. The quantity adsorbed is then measured utilizing Equation (3.3):

$$qe = \frac{v(c_o - c_e)}{M} \qquad 3.3$$

In which V represents the volumes of wastewater samples in the beaker (L) and m represents the mass of sorbent material (g).

In order to determine the sorption isotherm for a single solution, a binary solution, as well as a ternary solution, the amount of solute that is absorbed per unit of sorptive weight (q_e, mg/g) was plotted versus the last balance concentrations of the solution's solutes (C_e, mg/L) (Yaqub et al., 2022).

3.3.1.4. Time's Impact (Kinetic Experiment)

Using the same method as described in Section 3.3.1.1, the removal of metallic ions also had been investigated as a function of contact time at the optimal pH with the optimal sorbent dose. These samples were collected and examined over time intervals of (10, 15, 30, 60, 90, 120, 150, and 180 min) in order to identify the kinetic modeling that best fit the experimental information as well as calculate the quantity of adsorbed ions per adsorbent mass (q_t) at duration (t).

3.3.1.5 Effect of Concentration of Metal

While the sorbent dosage, time, agitation speed, fitted adsorbent dose for banana pells as 4 g/l, 120 min, 175 rpm, and room temperature (~30C), a solution was prepared for each metal ion with a various starting concentrations (10, 30, 50, 100, 200 mg/L). Using the optimal pH values from the prior laboratory activity, this solution was prepared.

3.3.2 Experiments Involving Flotation and Sorptive-Flotation

The experimental methods for the flotation system involve the manufacture of 1.5 L of aqueous solution with the necessary concentrations of lead ion, copper ion, and cadmium ion; the pH of the solution has been modified to the desired value utilizing NaOH or HCl. After adding ethanol (0.1 which equivalent to a drop) and SDS surfactant to the aqueous solution, the solution has been carefully added at the top of the flotation column. AAS was used to measure the concentration of each solute in collected samples.

During the sorptive-flotation experiments, a synthetically contaminated solution had a known weight of sorbent materials (banana peels) added to it, and the mixture was then put in the flotation column. In Table 3.4, a summary of all of the experimental conditions for the flotation and sorptive-flotation phases can be found.

The ion flotation studies were conducted in a cylinder-shaped Perspex glass flotation column (120 cm in height and five cm inner diameter). This column has six (0.2 cm) inner diameter taps spaced 15 cm apart; samples were collected from the tap in the center of the column (at height 45 cm from the bottom of column). In a semi-batch mode, the column was operated (batch wastewater, continuous air). Figures (3.2) and (3.3) provide a schematic and photographic representation of experimental flotation equipment, respectively. Through a rotameter that had been previously calibrated, the column was supplied with 1 bar to 7 bar-compressed air from the compressor. The air that entered the column was spread into the liquid as bubbles. A plate with 25 holes with a diameter of 0.05 cm was utilized as a distributor of air. Inside of the column is a region that has holes drilled into it at regular intervals in an equilateral triangle pattern. Samples of the foam were collected at predetermined time intervals of three, ten, twenty, thirty, and forty minutes respectively. About 3 mL of solution were drained from the port to analyis it using AAS to detect the removal efficincy. The samples were then removed very gently in order to prevent the introduction of air bubbles. In between each set of studies, the column was first washed with HCl, and then it was rewashed with distilled water three times.

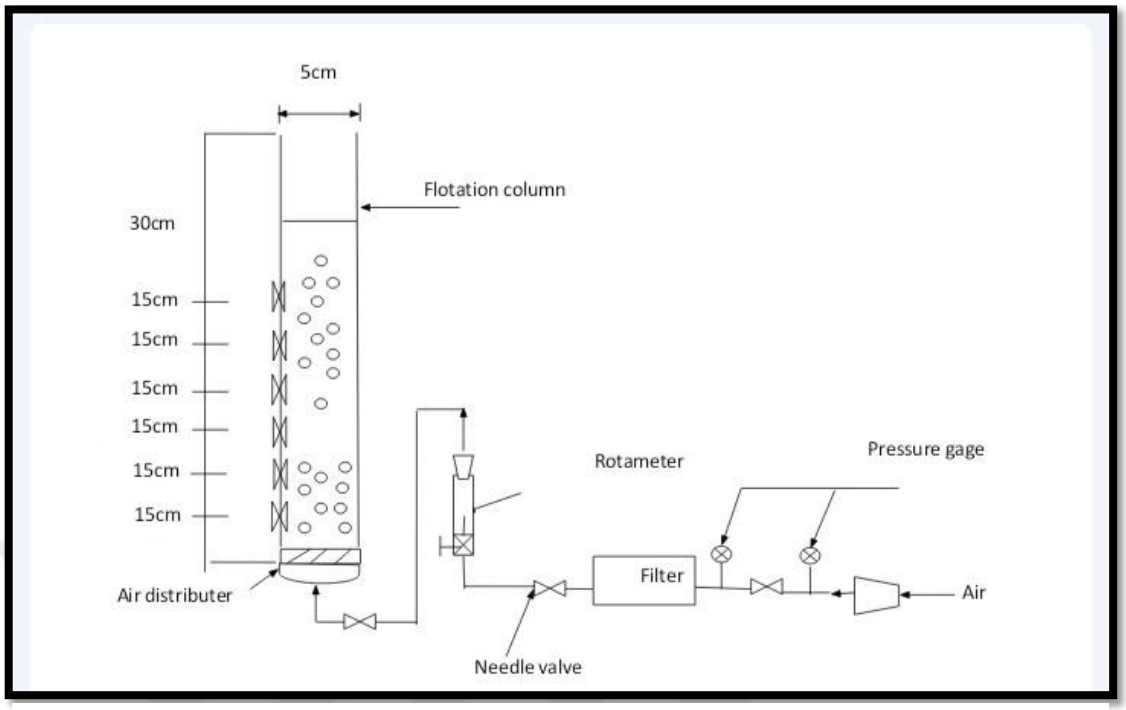


Figure 3.2. Diagrammatic representation of the unconventional flotation device

Table 3.4 Presents the experimental settings for flotation and sorptive-flotation systems.

Conditions	Sorptive-Flotation	Flotation
pH	5 and 6	3, 4, 5, 6, 7 and 8
Metal concentrations	30, 50 and 100 mg/L	30, 50 and 100 mg/L
Sorbent dosages	(1, 2 and 4 (g/L)) for Banana Peels	
SDS concentrations	50, 100 and 200 mg/L	50, 100 and 200 mg/L
Air flow rates	250, 500 and 1000 cm^3/min	250, 500 and 1000 cm^3/min
Temp.	~30 Cº	~30 Cº

Figure 3.3. Schematic diagram of the flotation equipment used in the experiment

3.4 Infrared Fourier-Transform Analysis (FTIR)

Comparing the "Fourier-Transform Infrared Analysis" (FTIR) spectra of the sorbents, Lead(ii) ions-loaded biosorbent, Copper(ii) ions-loaded biosorbent, Cd(II) ions-loaded biosorbent, and others enables one to identify the most important binding affinity and heteroatoms (carbonyl, carboxylic, hydroxyl, and others) existent on the biofuels of banana pells. The investigation of biosorbent utilized (SHIMADZO FTIR, 800 series spectra- photometer).

The subjecting of 0.4 g of banana peels to containar of 100 mL with 50 mg/L of heavy metals. The samples were shaken for 2 hours at 175 rpm at ambient temperature. Samples of adsorbent were filtered, after which they were allowed to dry. İn turn, the dried gathering was collected for the assessment.

3.5 Zeta Potential Measurement

Zeta potential is the surface electrical potential of a particle. It may be calculated by measuring the velocity of particles in an electric field. Measurements of the zeta potential may provide information on the net effective charge on the wall surface of biosorbents. By accurately measuring 0.2 g of the banana pells biosorbent into 250-mLr conical erlenmeyer flasks 100 mL of distilled water. The aciditiy of the original solutions was raised from 3 to 8 by Adding of 0.1 M sodium hydroxide or 0.1 M hydrogen chloride to each flask. The samples were stirred at 175 rpm for 2 hours to make sure they were all the same, and then the zeta potential was measured. A Zeta-Meter 4.0, USA was used to take the measurements. The samples were injected, and for each sample, the zeta potential was measured three times to get an average. Between samples, distilled water was run through the cell to clean it.

4. RESULTS AND DISCUSSION

4.1 System for Sorption

4.1.1 pH Effect

The parameter that seems to be most crucial for regulating the sorption process is pH. It influences the metal's physico-chemistry, hydrolysis, and solution chemistry as well as the network of charges on the sorbent's surface (Corpuz et al., 2019).

Experiments were conducted in a pH range of 3 to 8 for lead, copper and cadmium ions in 2 g/L for banana peels with a beginning metals concentration of 50 mg/l for single systems. The outcomes of these experiments can be found in Annex (A), as well as in Figure (4.1). These tests were conducted to find out how pH affects the way metal ions are adsorbed. The results show that the removal rates of (Pb), (Cu), and (Cd) increase with increasing pH, peaking between 5 and 6. As the pH is raised after reaching this optimum, the removal efficiencies start to decline.

The least amount of adsorption has been seen at low pH levels. Hydrogen ions stay competitive with those M(II) ions for an active surface locations of banana peels at low pH; and the complicated between M(II) ions as well as acidic functional clusters is predicted to break down, releasing an adsorbed M(II) in to solution (Arifiyana and Devianti, 2021).

Further increasing the pH to about 7, produces precipitate of metallic ions upon that adsorbent. Insoluble metals hydroxides $M(OH)_2$ begin precipitation in solution at larger levels of pH, also making it hard to conduct accurate sorption tests. According to some researches, the inability of negative metals $M(OH)_3^-$ and $M(OH)_4^{-2}$ (i.e., compounds contain OH ion), to react with negative surfaces for sorbents may be the cause of the drop in removal efficiency at higher pH (Ghazi et al., 2008a; Ghazi and Gadd, 2014; Hamadi, 2014; Muhaisn, 2014; Arifiyana and Devianti, 2021).

To obtain a great removal effectiveness without the precipitation of metal hydroxides, 5 is the best pH values for Pb(II) and Cd(II) ions, while 6 for Cu(II). However, 5.5 chosed for the binary and ternary system for both kinds of sorbent materials for a following experiments.

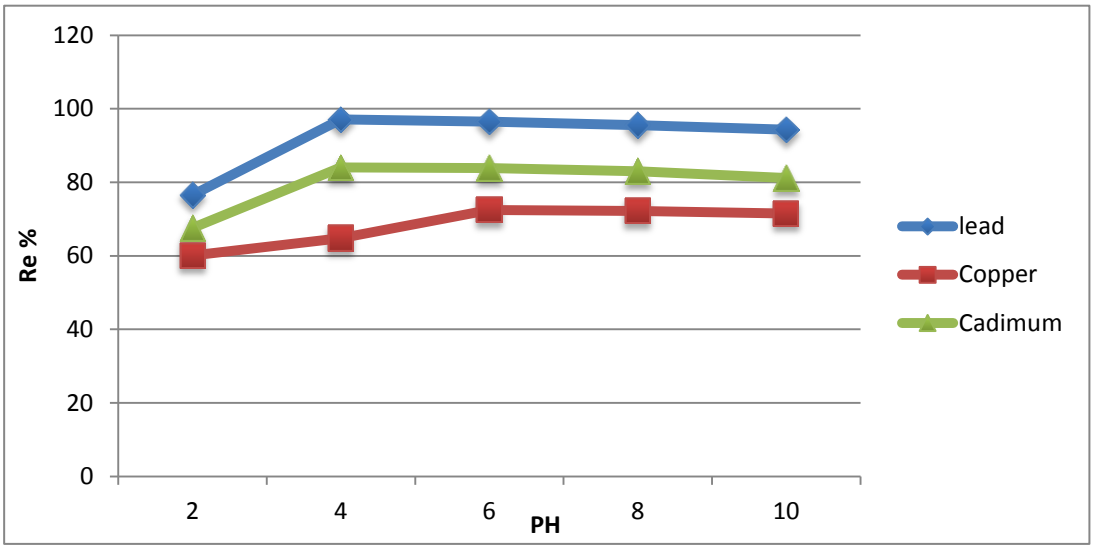


Figure 4.1. The impact of pH upon the removal of Pb, Cu and Cd ions via banana peels in (banana peels dose = 2 g/L, agitation speed = 175 rpm; duration = 120 min; room temprture = ~30; C_o = 50 mg/L).

4.1.2. Impact of gitation speed

The feasibility of eliminating triple metallic ions from the sorbent at 3 distinct agitation speeds (125, 175 and 250 rpm) has been investigated utilizing 2 g/L of the each sorbent, a contact duration of 120 minutes, a pH about 5–6, , as well as metals concentrations of 50 mg/L The outcomes are shown in Annex (A) and charts (4.2). As agitation speed increases from 125 to 250 rpm for sorbent, the removal efficiency for metal ions increases. Increasing turbulence and the resulting reduction in membrane resistance to mass transport around the adsorbent particulates are responsible for the improvement in removal efficiency (Nurain et al., 2021; Cheah et al., 2021).

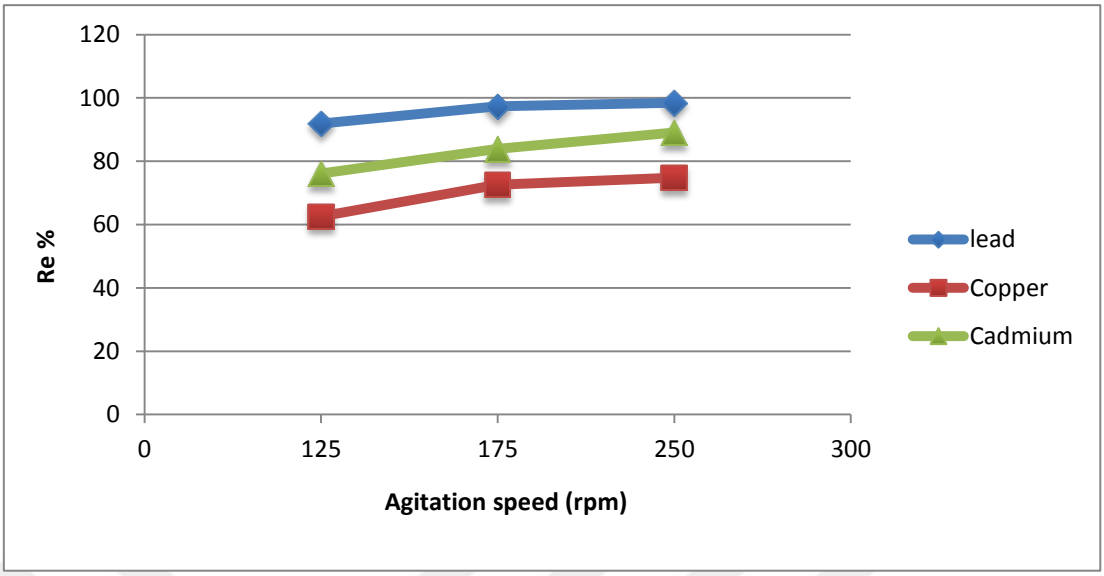


Figure 4.2. The impact of agitation speed upon removing Pb, Cu, and Cd ions by banana peels in an individual system (Banana Pells dose=2 g/L; pH=5-6; C_o=50 mg/L; time=120 min; room temperature= ~30 C).

4.1.3. Impact of the Contact Time

At initial metal levels of 50 mg/L, the removal of (Pb), (Cu) , and (Cd) from an aqueous medium has been studied as a mechanism across contact times between 0 and 180 min, pH 5 – 6 , 2 g/L of sorbent in a individual system, agitation velocity of 175 rpm, as well as at room temprture.

The effect of contact time on the separation of minerals from banana peels in an unified system is depicted in Figure (4.3). The outcomes are provided in Appendix (A). According to these figures, the proportion of metal ions absorbed by banana peels rose with time and reached equilibrium for all heavy metals after approximately 60 min. Additional increases in contact duration showed no appreciable impact on metal removal, and the sorption rate became nearly negligible. The discrepancy in sorption degree could be due to a greater number of sorbent patches being accessible for the absorbing of metallic ions. Due to the formation of repulsive contacts between both the elements in the liquid phase and on the flat substrate within the first 30 min, the sorption removal dropped. Similar phenomena have been seen through other researchers (Mohamed and Mohamed, 2014; Muhaisn, 2014; Badessa et al., 2020)

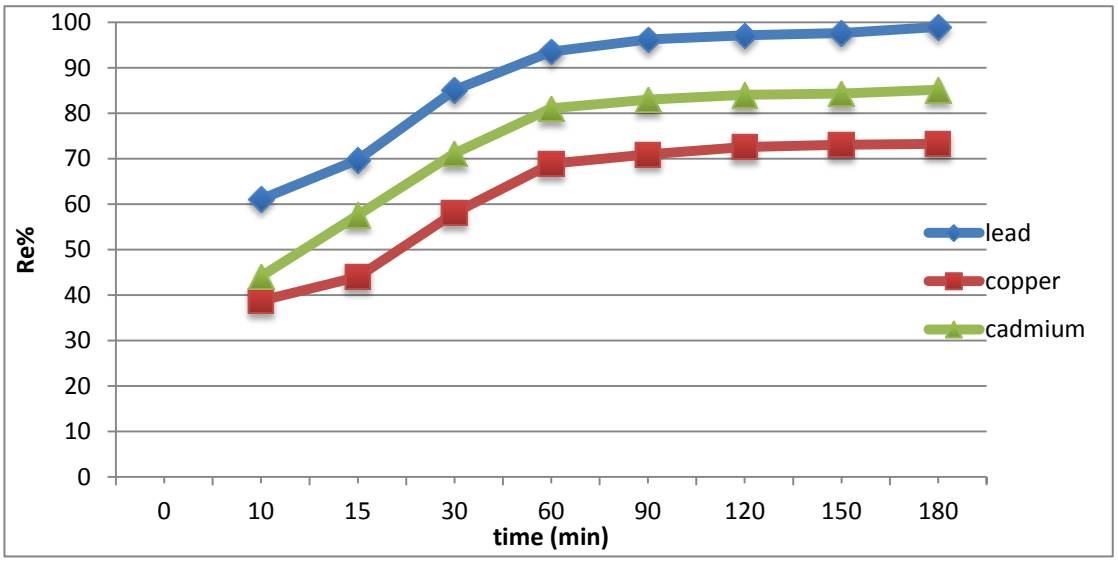


Figure.4.3. The impact of contact time on removing lead, copper, and cadmium ions by banana peels in an individual system (Banana Peels dose=2 g/L; pH=5-6; C_o=50 mg/L; rpm =175; room temperature=~30 Cº).

4.1.4. Effects of Sorbent Dose

Using agitation at 175 revolutions per minute and sorbent doses ranging from 0.5 to 8 g/L of different adsorbents, the impact of dose of adsorbent on the elimination of metallic ions has been examined, 50 g/L bottle of the each metal ions concentration, a contact time of 2 hours, and a pH range of 5 to 6 for individual based, binary system, and ternary system. Figure (4.4) displays the results, and Appedix contains a report (A).

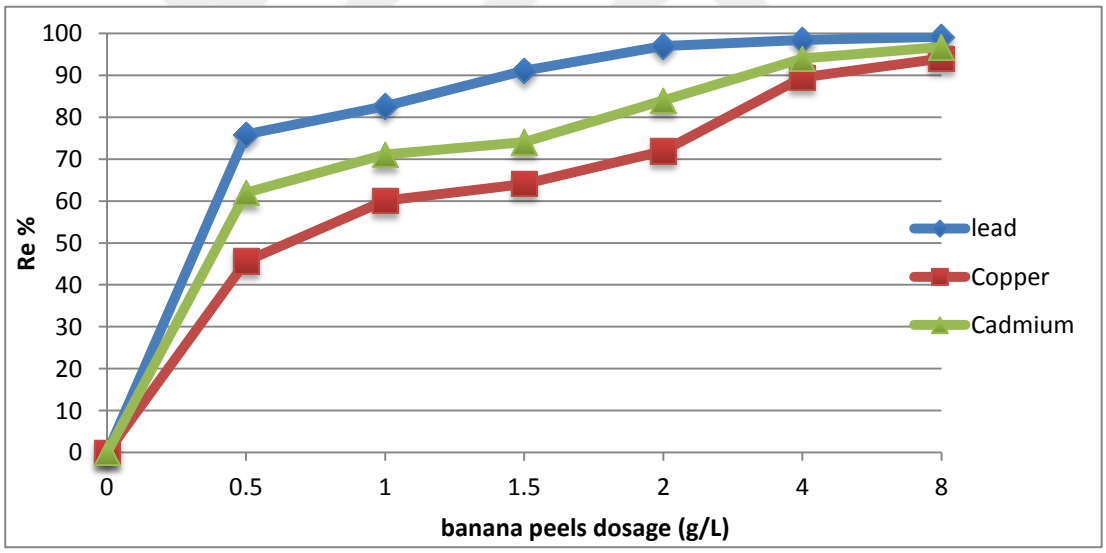
Results showed that in a single system, the removal of metals increased as the amount of sorbents increased up to 4 g/L. By raising the sorbent dose, the removal efficiency is slightly or slightly improved.

Increasing the quantity of sorbent increases the amount of metal ions removed from solutions. When the adsorbent amount rises the sum of active sorbent particulates increased; thus, these particulates bind so many ions to its surfaces. The rise in removal effectiveness with sorbent dosage may be ascribed to an increase in sorbent surface area as well as, therefore, the sum of metal ion binding locations accessible. (Wasewar, 2010; Ghazy and Gad, 2014; Badessa et al., 2020).

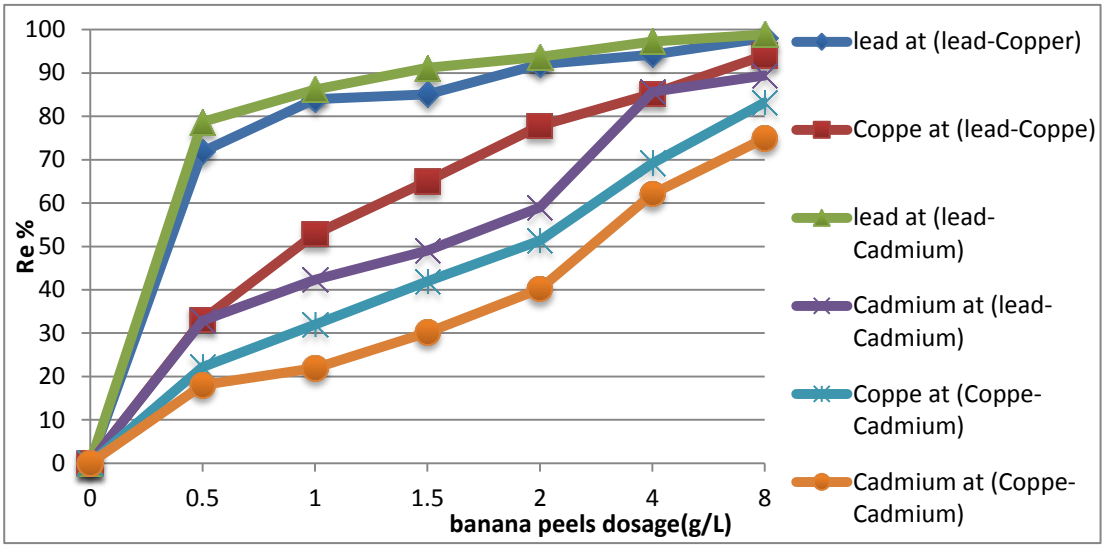
Figre 4.4 demonstrates that a removing effectiveness of “lead , copper and cadmium ions” by a banana peels dose of 4 g/L is around 98.4%, 89.54%, and 93.9% for a single systems, but reduces to 90.94%, 81.16%, as well as 51.3% for a ternary systems. Whereas for binary systems, the efficiency reduced to 94.18% for

lead, 85.23 % for copper (lead, copper system), 97.27 % for lead as well as 85.6% for cadmium (lead, cadmium system), as well as 69.18% for copper and 62.09% for Cd, respectively (copper, cadmium system).

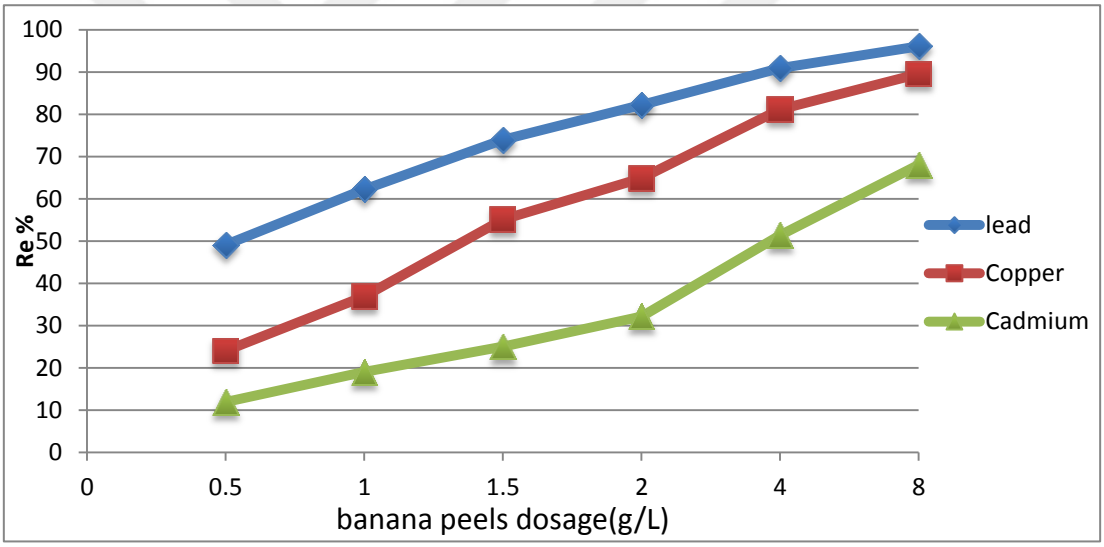
In binary system and ternary system, sorbent displayed the best adsorption efficacy for lead ions and the smallest for cadmium ion and copper ion among the three metal ions. This could be because the chemical and physical characteristics of Pb(II) ions make them more susceptible to sorption than Cd (II) ion and Cu (II) ion. This propensity may be related to the hydration state of hydrated ions, which affects how easily metallic ions may access the surface of pores. Because of this, ionic species with hydrated radii less than the pore width may freely flow through pores due to the competitiveness amongst metal ions. A hydrated ionic radii as already shown in Table 3.1 is as follows: cadmium (4.26 Å) lead (4.01 Å) copper (4.19 Å) (Morali, 2006). Consequently, in Single systm the order of metal elimination became lead > copper > cadmium.



(a)Single system



(b)Binary System



(c)Ternary system

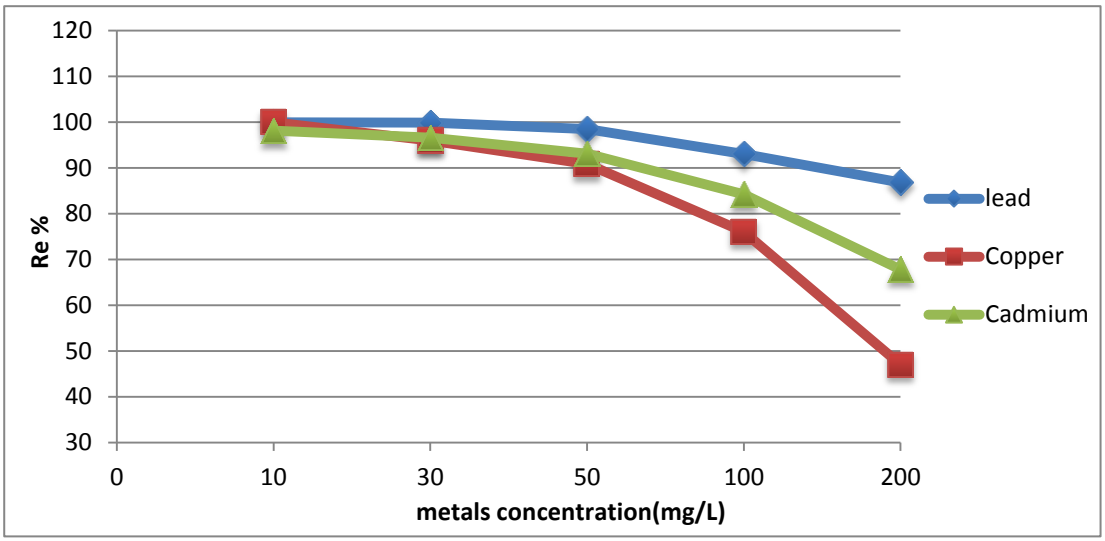
Figure 4.4. The impact of sorbent dosage banana peels on removal lead , copper and cadmium ions (time = 120 min; rpm = 175 ;pH = 5–6; C_o = 50 mg/L; at room temperature for (a)single system, (b)binary system, as well as (c)ternary system).

4.1.5. Impacts for Initial Metal Concentrations

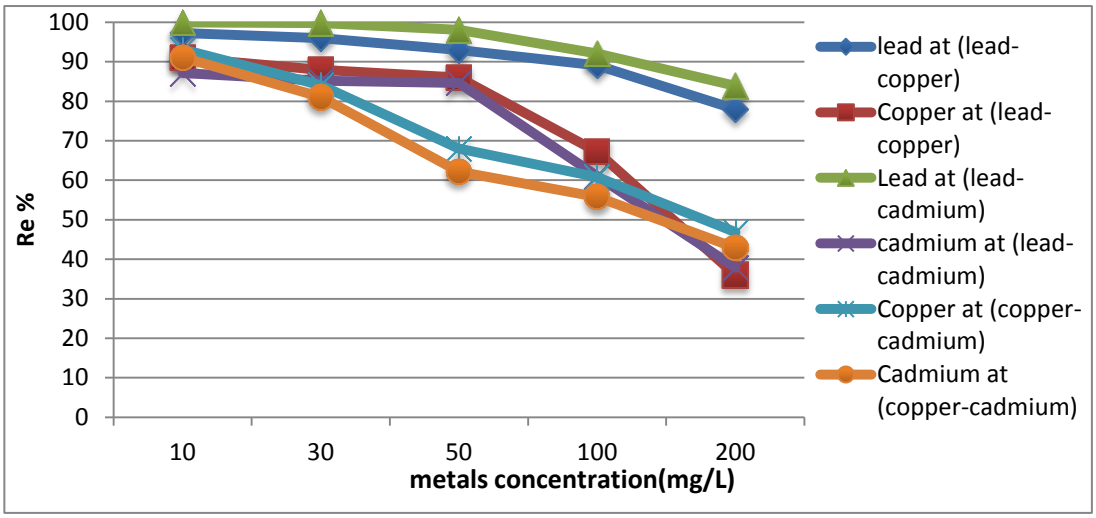
Experiments have been conducted at various starting Cd(II) ion, Cu(II) ion, and Pb(II) ion concentrations that ranged from 10 to 200 mg/L with a dose of 4 g/L for sorbent in single, binary, and ternary systems, while holding all remaining parameters constant Figure (4.5) .

According to the findings, when the starting metals concentration was increased from 10 to 50 mg/L for sorbent in a single system, the percent removal of metals declined marginally, however between 50 and 200 mg/L, the percentage removal reduced quickly. This tendency may be explained by a decrease in sorption sites that are available on the sorbent's surface area when the concentration of metal ions is around 50 and 100 mg/L. A lower sorption percentage resulted from an increase in the initial percentage of metallic ion equivalents to the available sorption places at higher metal ion concentrations. Similar actions were observed in previous studies of (Ghazi et al., 2008; Anwarr et al. 2010; Mohammed et al., 2016; Badessa et al., 2020).

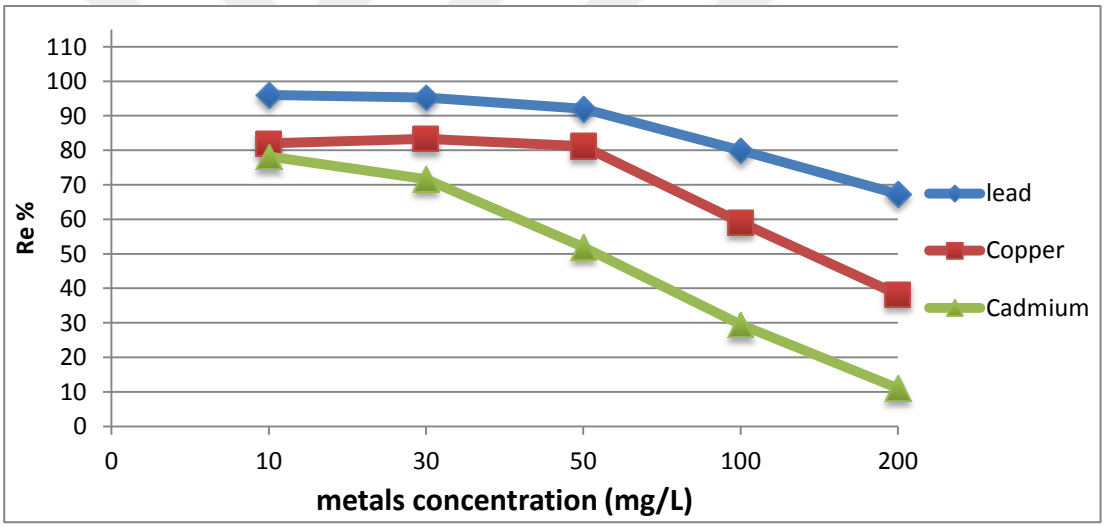
Comparing the individual, binary, as well as ternary systems reveals that the removal percentage drops as the concentration of competitive metal ions with each other rises, as well as that the elimination percent for each metal drops in the binary as well as ternary systems compared to the individual system. When using the same beginning metal ion concentration, adsorbent dosage, as well as contact duration, various heavy metals are removed at different rates. This is due to metal competition, which develops as a result of differences in the metals chemical affinities and exchange capabilities for the complex formation and amount of chemicals groups found on the outer layer of a sorbent (Parmmar and Thakurr, 2013).



(a) Single syestem



(b) Binary Systems



© Ternary systems

Figure 4.5. The impact of the metal concentration peels remove lead, copper and cadmium ions via banana peels (time = 120 min; rpm = 175; pH = 5-6; C_o= 50 mg/L; with room temperature for each (a)single system,(b)binary system, as well as (c)ternary system).

4.1.6. Models of Sorption Isotherms

Isotherms of sorption are highly significant instruments for the investigation of the sorption processes because they determine a relation between both the equilibria concentrations and a quantity of adsorbate that is absorbed by the adsorbent's unit mass at a constant temperature (Oladipo et al., 2019; Çatlıoğlu et al., 2021; Bayuo et al., 2023)

The results in Annex (B) for individual, ternary, as well as binary system components were associated with the models described in Section (2.8). By fitting the formulae to the experimental data, each model's parameters have been determined. The correlation coefficients for all parameters are shown in Tables 4.1 through 4.3. The adsorption isotherms of (Pb) lead ion, (Cu) copper ion, and (Cd) cadmium ion are displayed on banana peels in Figure (4.6).

Table 4.1. Parameters for the individual solute isotherm for of (Pb), (Cu) and (Cd) onto banana peels.

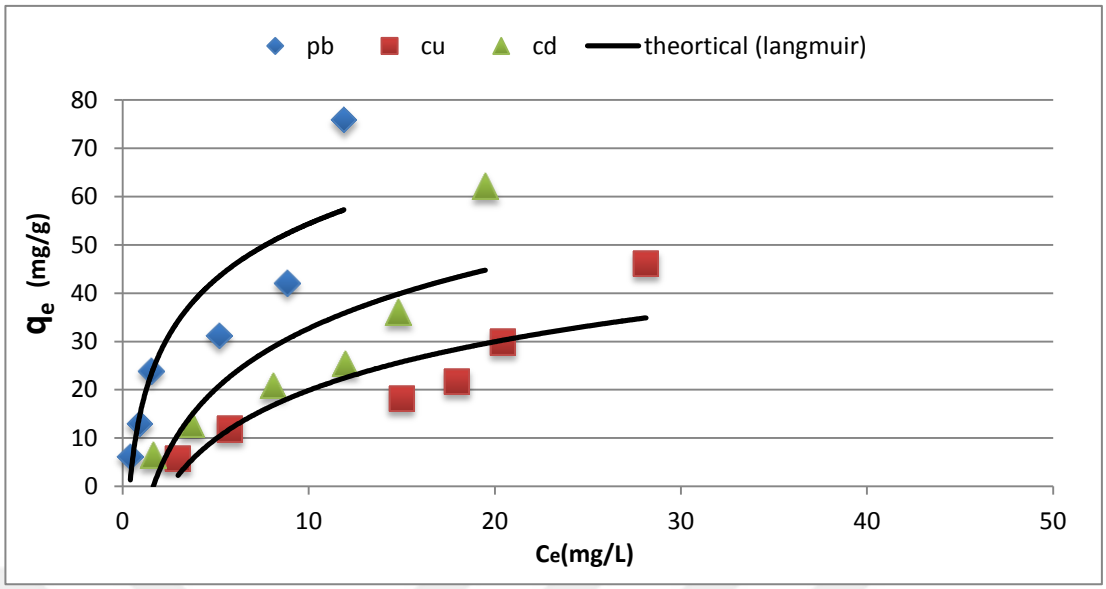
Models	Parameters	Banana peels		
		Lead	Copper	Cadmium
Langmuir Eq. (2.1, 2.3)	"b (L/mg)"	0.19	0.029	0.052
	q_m (mg /g)	86.71	74.09	77.16
	R_S	0.094	0.40	0.277
	R^2	0.98	0.97	0.98
Freundlich Eq. (2.4, 2.5)	K_f, (mg/g) (L/ mg)$^{1/n}$	13.32	2.48	3.814
	N	1.57	1.22	1.17
	R^2	0.92	0.94	0.960
Temkin Eq. (2.6, 2.7)	"K_t "(L/mg) "	2.72	0.40	0.603
	"$B=RT/b_T$ "	16.60	14.38	17.98
	"R^2"	0.80	0.774	0.733

Table 4.2. Specifications for the "ternary solute isotherm of the metal ions" (Pb, Cu, and Cd) on banana peels.

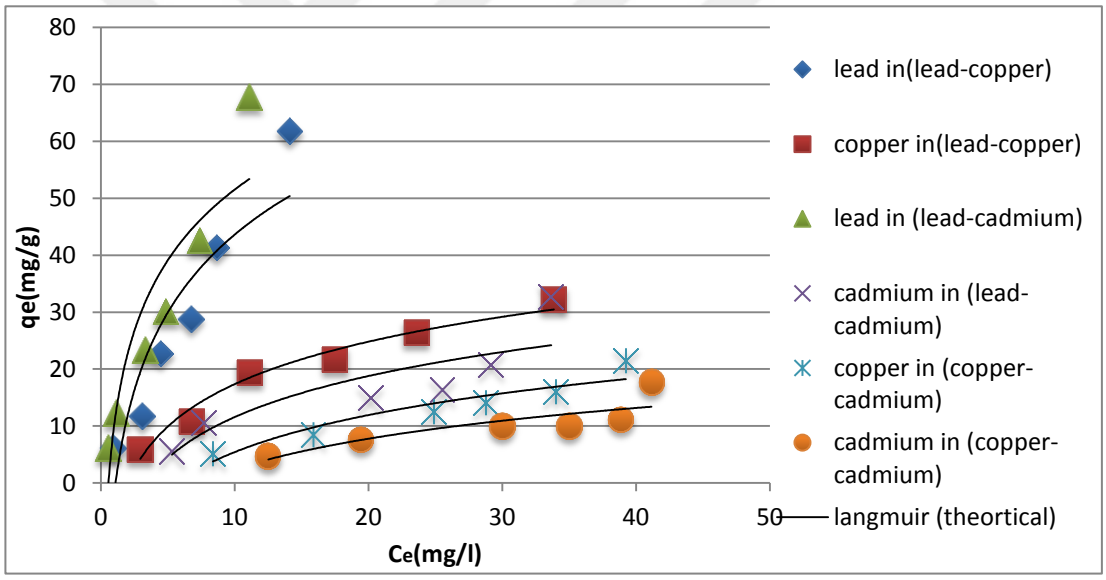
Models	Parameters	Banana peels		
		Lead	Copper	Cadmium
Extended Langmuir Eq.(2.8)	"b (L/ mg)"	0.049	0.024	0.006
	"q_m (mg /g)"	66.72	50.34	48.32
	"R^2"	0.99	0.98	0.994
Extended Freundlih Eq.(2.9)	"K_f,(mg /g)(L/ mg)$^{1/n}$"	3.57	1.98	0.383
	"N"	1.29	1.449	1.150
	"R^2"	0.99	0.951	0.99

Table 4.3. Parameters for the binary solute isotherm for of (Pb), (Cu) and (Cd) onto banana peels

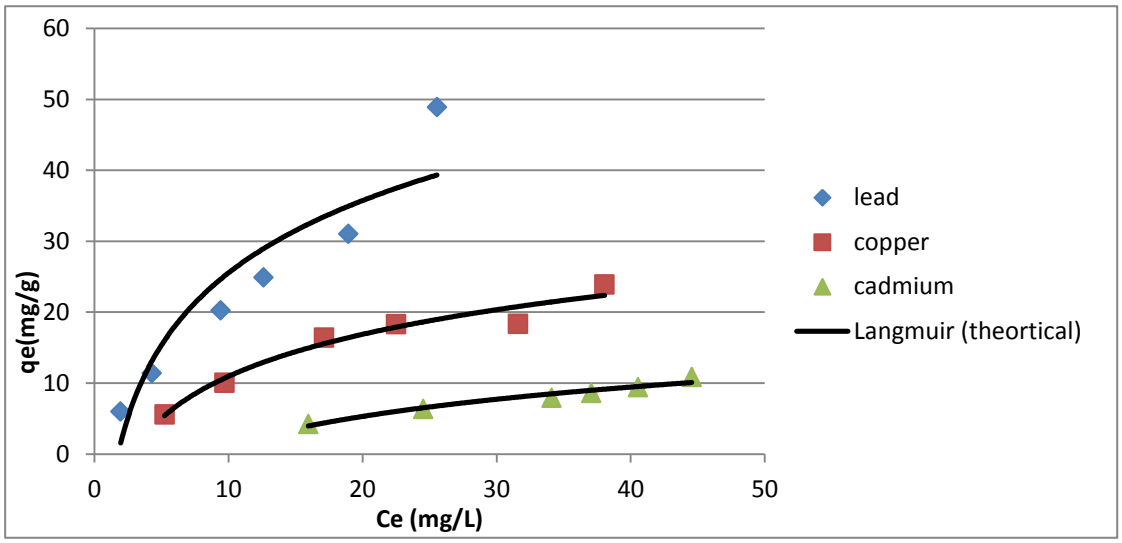
		Lead +Copper System"		lead + Cadmium System		Copper+Cadmium System	
Models	Parameters	Lead	Copper	lead	Cadmium	Copper	Cadmium
Extended Langmuir Eq. (2.8)	"b (L/mg)	0.08	0.04	0.15	0.02	0.01	0.00
	q_m (mg/g)	76.22	54.03	79.4	51.4	58.3	56.54
	"R^2"	0.95	0.99	0.99	0.91	0.99	0.94
Extended Freundlih Eq.(2.9)	"K_f,(mg/g)* (L/mg)$^{1/n}$"	5.46	2.91	9.87	1.83	0.791	0.52
	"N"	1.08	1.42	1.28	1.35	1.15	1.14
	"R^2"	0.96	0.97	0.98	0.88	0.98	0.86



(a)Single system



(b)Binary system



(c)Ternary system

Figure 4.6. Lead, copper, and cadmium ion sorption isotherms on banana peels in (a) single, (b) binary, and (c) ternary component systems.

The following conclusions were derived from prior studies and obtained data:

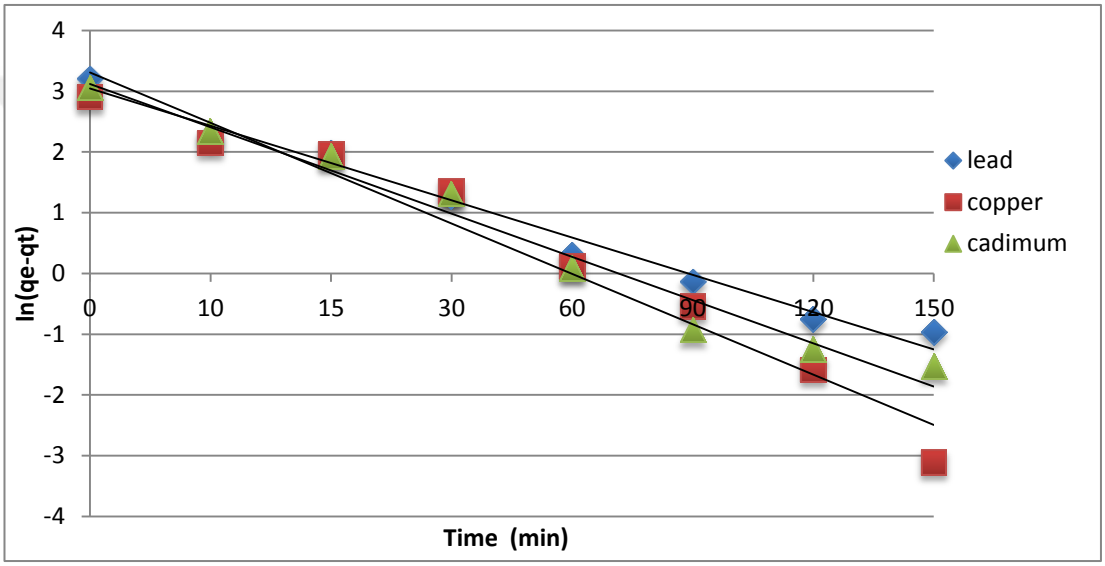
• The absorption capacities qe and heavy metals removal efficiency have been dependent to the quantity of sorbent added; according to their equations, the removal efficacy increase with sorbent dosage increasing and the larger absorption capacities has been obtained with a large sorbent dosage.

• The value of (qe) is at its highest when the component in the solution is the only solute. As more than one or two components are added to a single solute, the (q_e) value goes down in a clear way. All metals behave in the same way.

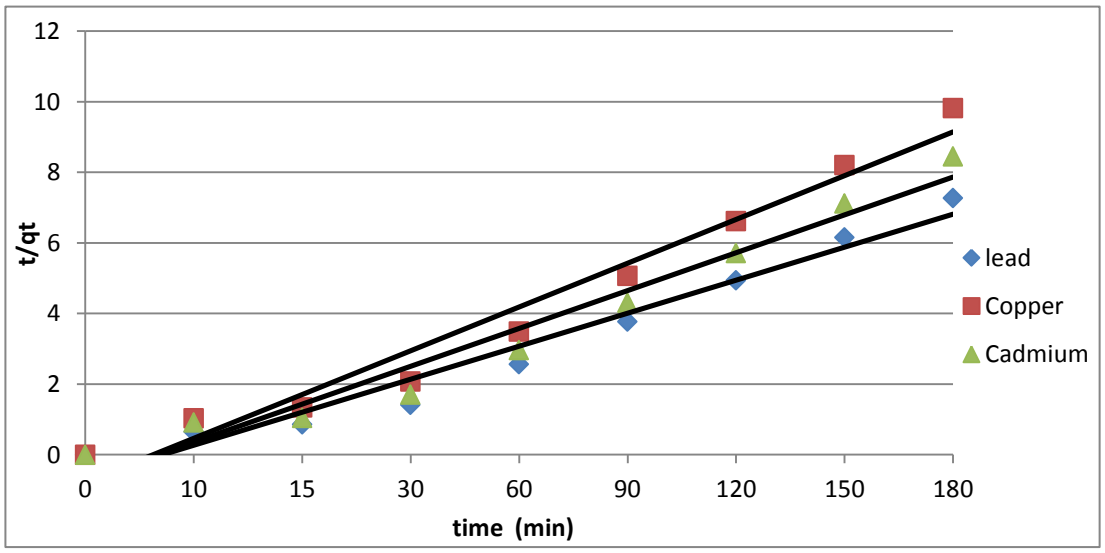
The Langmuir equation provides the finest match to experimental information for individual, binary, and ternary components adsorption systems for "lead, copper and cadmium ions, as determined by the largest value of the determining coefficient" (R^2).The equilibria isotherm for every individual component of sorbent is of the favourable kind $0 < RS < 1$.

4.1.7 Models of Sorption Kinetics

The kinematics of the absorption of (Pb), (Cu), and (Cd) onto banana peels in an unified system have been studied using pseudo-first-order and pseudo-second-order models, as shown in Figure (4.7) and Table 4.4 Appendix (C). In accordance with the values of the determination coefficient, the pseudo-second-order model for sorbent seems to fit the experimental data more accurately than the pseudo-first-order model (R^2). With determination coefficients exceeding 0.980, the experimental data and the predicted values of qe from the 2nd order equilibrium data coincided quite well. The second-order model can be utilized to comprehend the sorption procedures of Cd(II), Cu(II), and Pb (II) .



"Pseudo- first- order model"



"Pseudo- second- order model"

Figure 4.7. Kinetic models for the sorption of (Pb), (Cu), and (Cd) on banana peels in a single system (pH=–5-6; rpm = 175; Banana Peels dose= 2 g/L; Co=50 mg/L; room temperature=~30 C for pseudo-first-order model and pseudo-second-order model)

Table 4.4. The sorption rates characteristics, observed and calculated q_e values for pseudo-first- and -second-order reaction kinetics for the sorbent in separate system components.

Sorbent	Metal	q_e experimental mg/g	Pseudo-first-order			Pseudo-second-order		
			k_1 1/min	q_e calculated mg /g	R^2	k_2 g/mg. min	q_e calculated mg /g	R^2
Banana peels	lead	24.74	0.026	11.54	0.91	0.0066	25.46	0.99
	Copper	18.31	0.037	13.55	0.98	0.0614	19.28	0.991
	Cadmium	21.29	0.030	11.60	0.93	0.0071	22.07	0.999

4.1.8. Zeta Potential Measurements for banana peels

The zeta potential of a particle refers to the electrical potential that exists at the particle's surface. It is possible to ascertain by determining the speed of particles while they are moving through an electric field (Kaliannan et al., 2019). The zeta potentials of banana peels were -3.070, -4.240, -4.20, and -4.19, respectively, as shown in Figure (4.8), when the pH was three, four, five, six, seven, and eight, respectively.

The samples exhibited a negatively charged value that would be conducive to the attractions of active locations as well as a positively charged metal ion, leading to electrostatic interaction. Banana peels with a pH of 5.0 had the highest zeta-potential values.

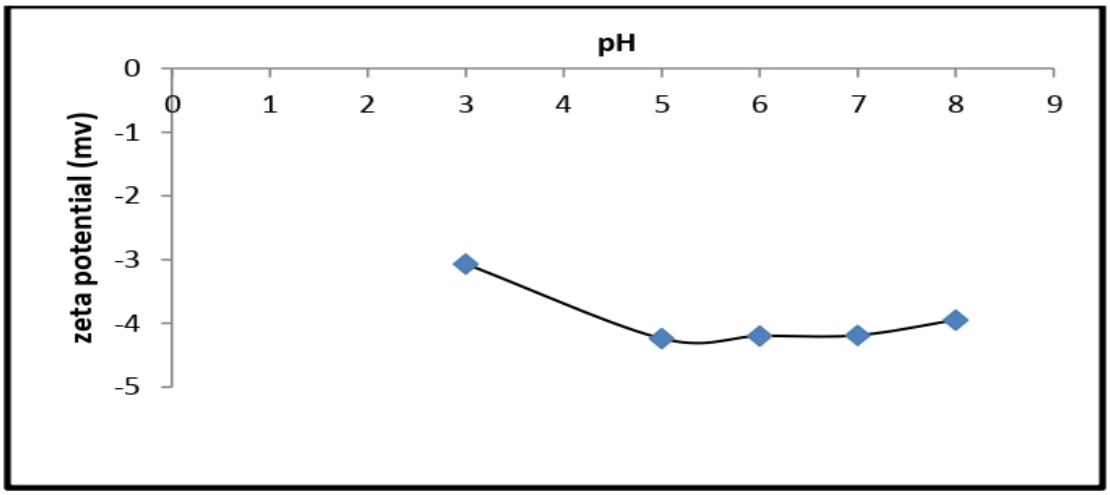


Figure 4.8. Zeta-potential for banana peels in different solutions pH (rpm=175, banana peels dose =2 g/L, room temprture =~30 C, time = 120 min)

4.1.9 Banana peel FTIR analysis

Banana peels have been analyzed using (FTIR) to determine the “functional groups present”. Not only do “functional groups of adsorbents” influence adsorption behavior, but they also govern the adsorption process. According to their respective wave numbers, distinct functional groups were given to the peaks in the FTIR spectrum.

The FTIR spectrum of banana peels is shown in Figure (4.9) both” before and after adsorption of heavy metals”. The observed peaks and their corresponding descriptions were included in Table 4.5. Heavy metal ion adsorption is hypothesized to be mediated via "amine, aromatic, carboxylic acid, and hydroxyl functional groups" on the cell surfaces of adsorbents (Negroiu et al., 2021). As cellulose compounds, which constitute a majority of plant components, may major constraint metal cations in an aqueous solution, sorption may also occur. The number of places, how accessible and chemically stable they are, as well as their affinities for the metal, all play a role in how important they are for metal absorption (Dramann et al., 2015; Afolabi et al., 2021). According to the results of FTIR spectra, lead ions have the largest variations in the maxima of bands when compared to copper ions and cadmium ions, and banana peels may be used as a biosorbent. The absorption bands of banana peel biomass can be deduced to favour leading ion over other metals”.

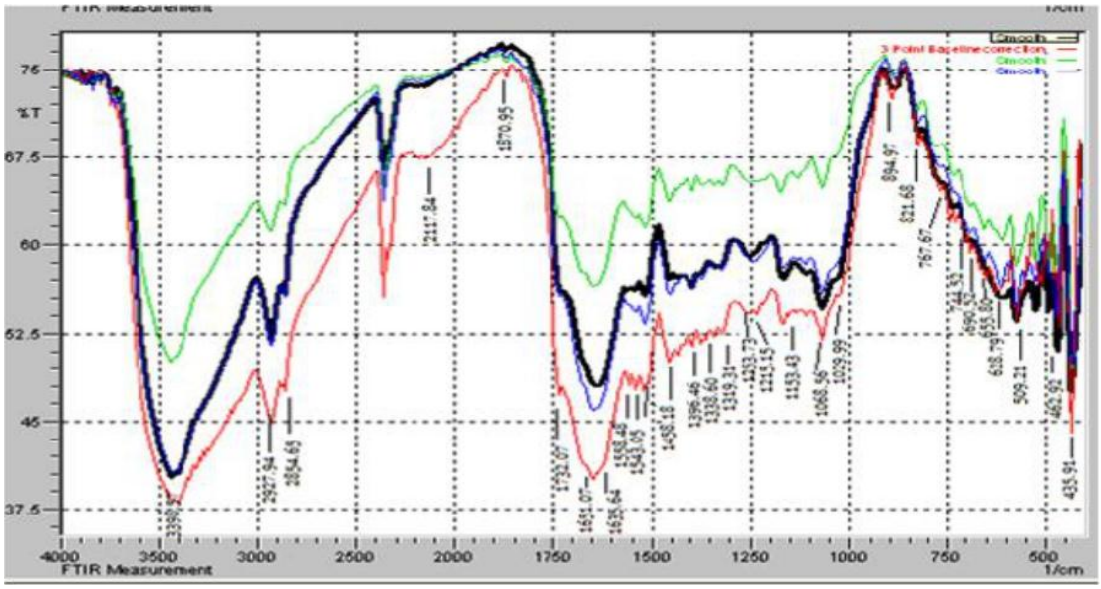


Figure 4.9. (Green path) is Pb (II)-loaded banana, (blue path) is Cu (II)-loaded banana, (black path) is Cd (II)-loaded banana, and (red line) is unloaded banana.

Table 4.5. Functional groups list, after and before lead, copper and cadmium ions were added to the banana peels biomass.

Assignment Functional Groups	Wave number (cm^{-1})			
	Before Adsorption	After Adsorption of cadmium cm^{-1}	After adsorption of lead cm^{-1}	After adsorption of copper cm^{-1}
Carboxyl (C-H aldehyde stretch)	2927.94	2924.09	2927.94	2924.09
Hydroxyl group (-OH), amides (N-H stretch)	3398.57	3429.43	3437.15	3398.57
Carboxyl (C-C ketone stretch), alcohol (C-O stretch)	1253.73	1249.87	1234.44	1246.02
Alkyl halides (C-I)	509.21	524.64	524.64	528.50
Amides (C=O stretch)	1635.64	1631.78	1629.21	1647.21
Aromatic (C-H bend), alkyl halides (C-Cl stretch)	767.67	763.81	779.24	767.67
Aromatic (C-H bend), sulfonate (S-O stretch)	821.68	825.53	829.39	823.35
Aromatic (C-H bend), sulfonate (S-O stretch)	894.97	879.54	883.40	887.26
Alcohol (C-O stretch), carboxyl (C-C ketone stretch)	1153.43	1168.86	1172.72	1168.86
Nitro aliphatic group (-NO2)	1365.60	1377.17	1369.46	1373.32

4.2 System for Floatation

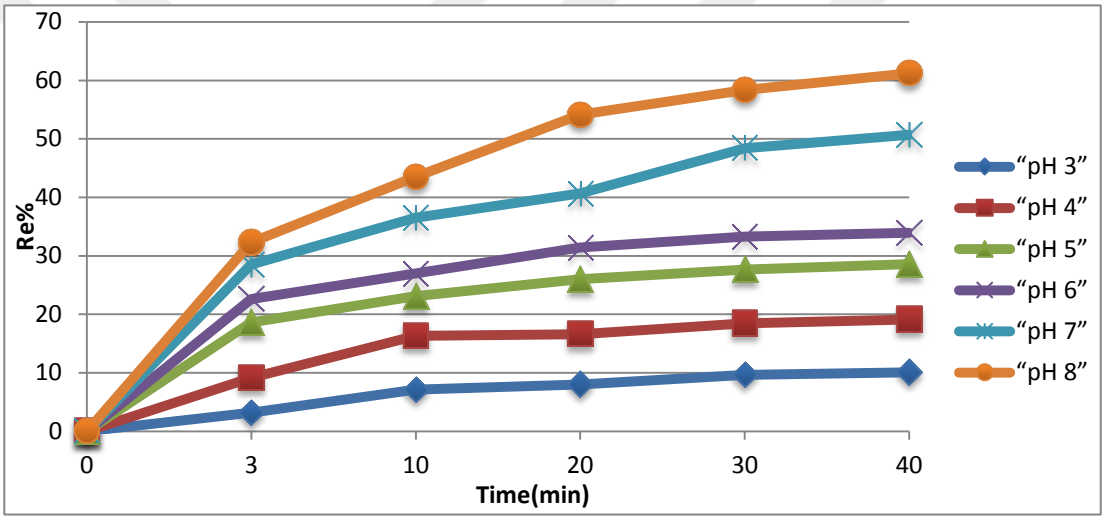
4.2.1 Effects of pH

Solution pH is one of the most influential parameters on ion separation by flotation. Due to the fact that pH influences the shape and charge of the metal present in solution, various interfacial characteristics and reaction pathways may be seen based on pH. **(**Erdogan,et al 2005; Kyzas and Matis, 2019). In order to examine the behavior of the cadmium, copper, and lead ions toward the collector, a first flotation experiments were undertaken as a function of pH. Experiments using an anion collector (SDS, 50 mg/L) have been conducted at ph levels of 3, 4, 5, 6, 7, and 8 with a starting metal "concentration of 50 mg/L and an air flow rate of 500 cm^3/min". The data are summarized in Appendix (D) and shown in Figure (4.10). This chart demonstrates that removal efficiency rises abruptly during the first three minutes of the experiment, and thereafter increases more gradually owing to surfactant consumption.

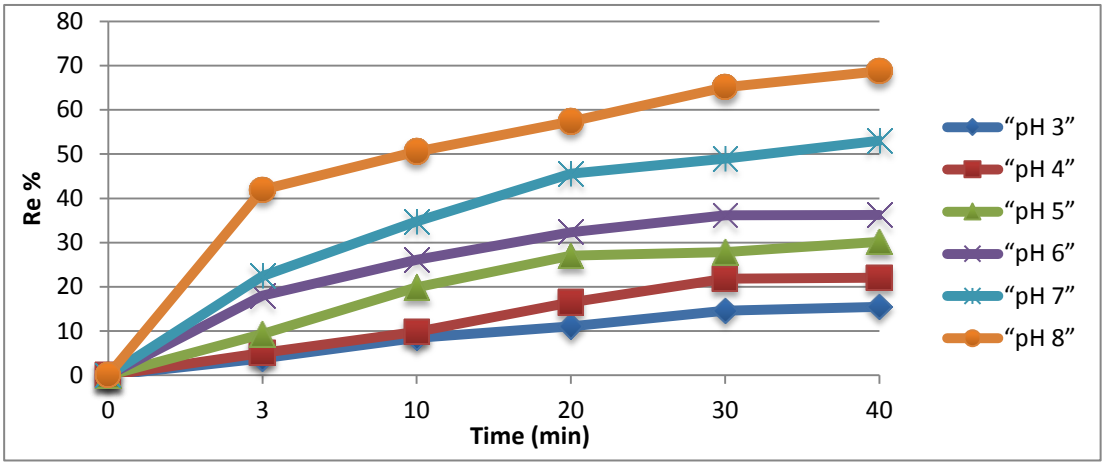
It became discovered that removal effectiveness rose as the pH rose, with the

maximum removal occurring at pH 8, that corresponds to a precipitation of metallic ions. Higher removal efficiency at pH 8 were 61.18 % for lead ion, 68.73 % for copper ion, and 49.51 % for cadmium ion, whereas pH values below 5, removals reduced as pH declined owing to competion between metal ions and H^+ ions for collectors, the similar trend has been seen research of (Mohammed and Abed, 2011; Mohammed and Kadheem, 2013; Wang et al., 2021).

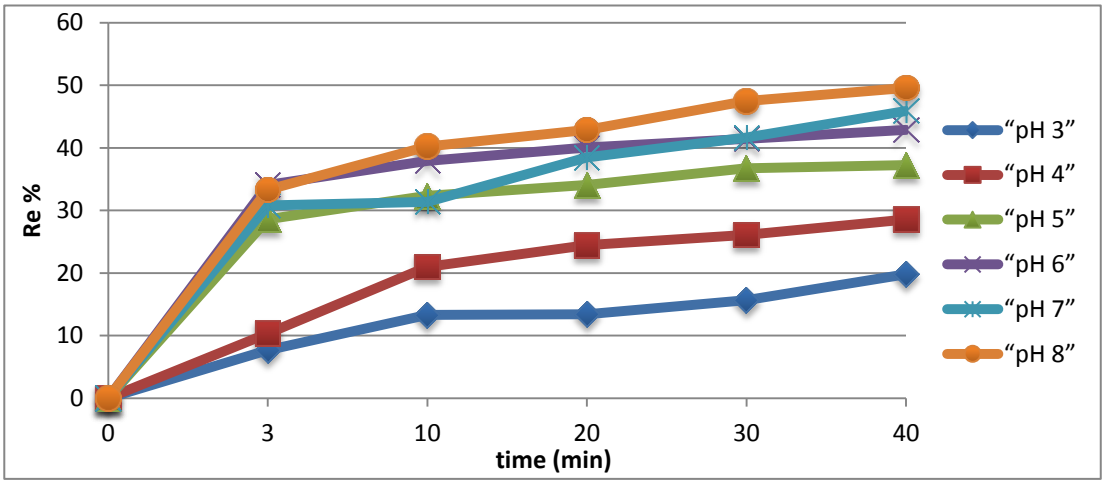
When pH rises between 5.0 and 7.0, metal removal increases somewhat due to the electrostatic interaction between positive charged species (M^{2+}, $M(OH)^+$) as well as the negative charged SDS collector within that pH range. This pH values indicated that metallic ions in this instance are eliminated via an ion flotation procedure rather than a precipitated flotation mechanism (Wang et al., 2021).



(a)Pb



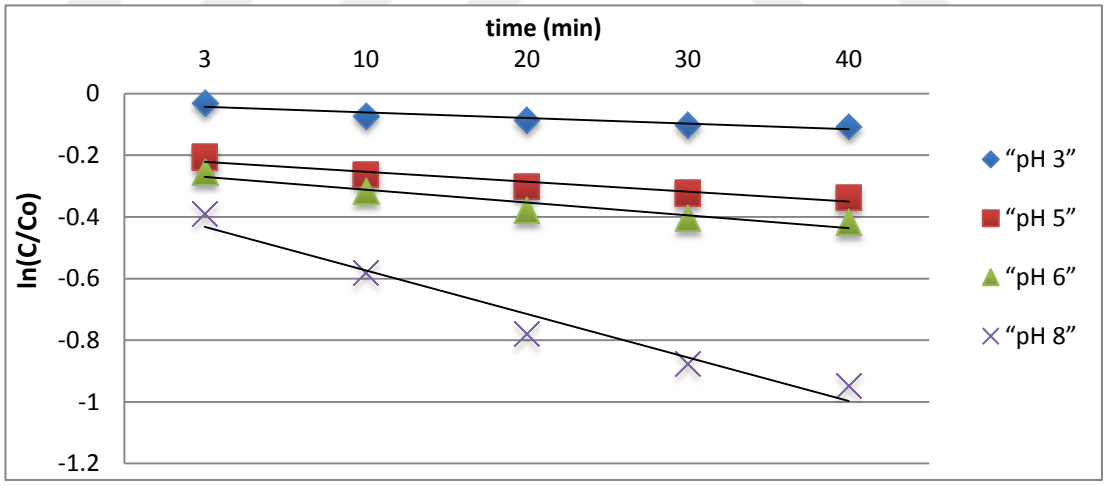
(b) Cu



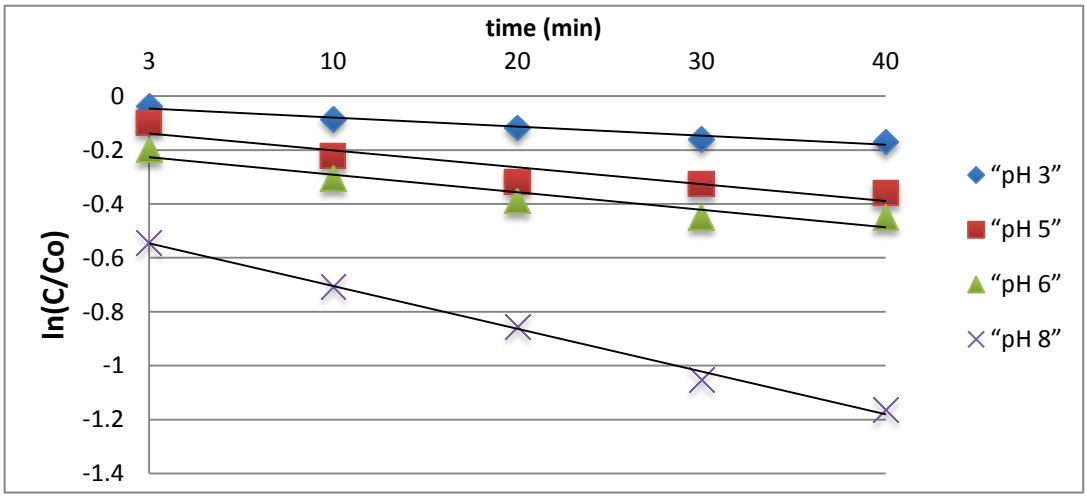
(c) Cd

Figure 4.10. The impact of pH on the flotation removal of (Pb), (Cu) and (Cd) (SDS=50 mg/L, Co=50 mg/L, Q=500 cm^3/min, and 0.1 % ethanol)

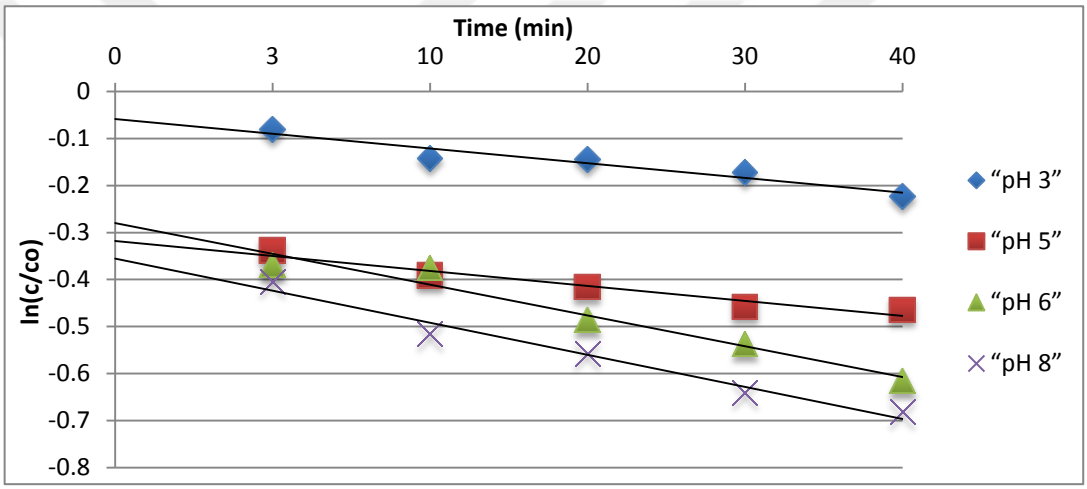
The elimination rate constant (k) at different pH levels (3, 5, 6 and 8) was determined via graphing ln (C/C_o) with duration using Equation (2.20). Figure 4.11 displays the average constants calculated from the slant of the line, and Table 4.6 lists their values. It could be noticed that this average constant rose as the pH rose.



(a) Pb



(b) Cu



(C) Cd

Figure 4.11. Ln(C/Co) vs. time for Pb, Cu, and Cd (SDS=50 mg/L, Co=50 mg/L, flow rate=500 cm^3/min).

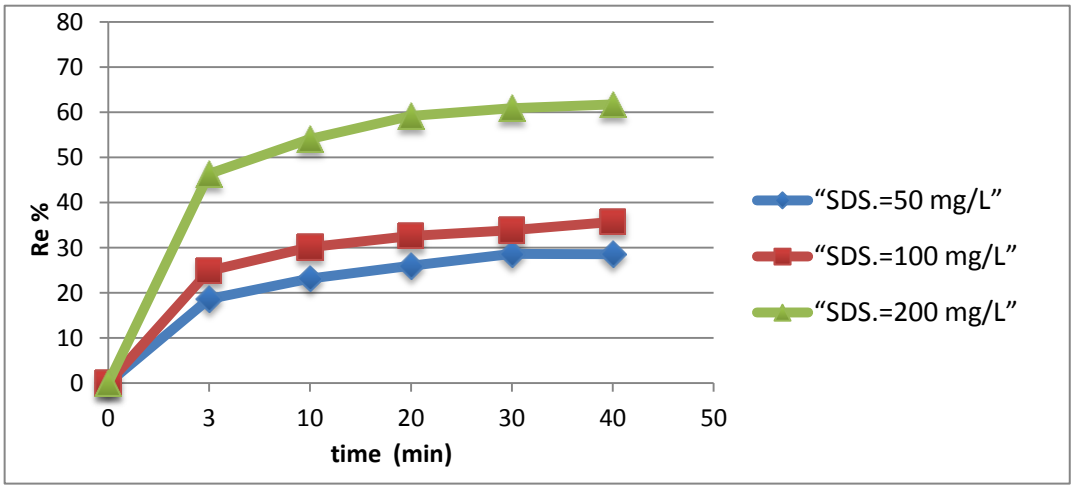
Table 4.6. Constant rate at different pH

Metals	$k \times 10^2$ (min^{-1})			
	pH3	pH 5	pH 6	pH=8
Cadmium	0.31	0. 32	0.65	0.68
Lead	0.18	0.32	0.41	1.41
Copper	0.33	0.62	0.64	1.58

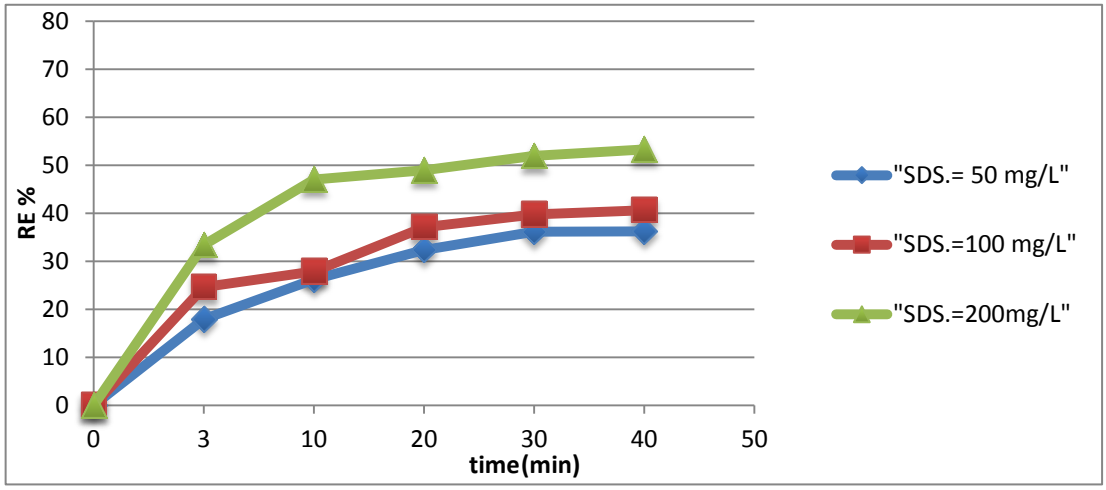
For the following experimentations and the following system, pH values have been chosen to be identical to those of the sorptive system in order to avoid the creation of metals precipitate and also to enable comparison of the findings for every metal during all systems examined using the relatively similar pH levels (i.e., pH 5 for cadmium and lead ions and pH 6 for copper ion).

4.2.2. The Impact of Concentration of surfactant

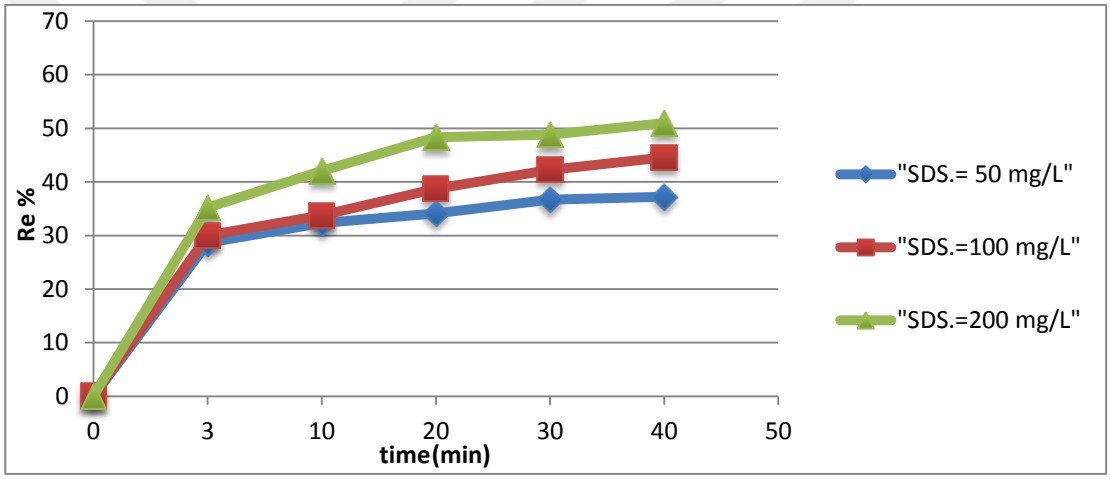
Upon that elimination effectiveness of cadmium, lead, and copper ions, various sodium dodecyl sulfate (SDS) concentrations of 50, 100, and 200 mg/L have been examined at pH 5-6 , 500 cm^3/min air flow rate , and 50 mg/L metal concentration, 0.1% ethanol . Figure (4.12) and a table of the findings were included in the Appendix (D). Based on these findings, it was shown that the removal efficiency rose as collector concentration increased from 50 to 200 mg/L, increasing the elimination percent for Cd , Cu(II), and Pb ion from 44.56% to 50.9%, 40.6% to 53.2%, and 35.6% to 61.7% respectively . It could be because metal ions seem to be fully soluble at small pH and removal average are highly dependents on collector dosage. For complete removal, higher concentrations of collectors are needed, and lower concentrations may not be enough to give all the particles hydrophobic properties. The same thing was seen by (Polate and Erdogan 2007; Mohammed and Abed, 2011; Mohammed and Kadhem, 2013; Alwared and Sadiq, 2019). Higher collector usage should be avoided not only because it costs more, but as well due it can cause problems like foam damage, competition strongly "between free collector ions and the metal-collector" complex for the bubble's surface location, and the possibility that small quantities of collector left in an effluent could be toxic (Mohammed et al., 2016; Alwared and Sadiq, 2019) . Values of the removal average constants at different SDS concentration levels have been found as well as put in Table 4.7. You can see that the average constant went up as the SDS amount went up. The outcome is in line with the (Farraj, 2014).



(a)Pb



(b)Cu



(c) Cd

Figure 4.12. The impact of concentrations of surfactant upon that flotation elimination of Pb, Cu, and Cd (Co = 50 mg/L, pH 5-6, Q = 500 cm^3/min, as well as ethanol equal 0.1%)

Table 4.7. Rate constant at various SDS concentrations

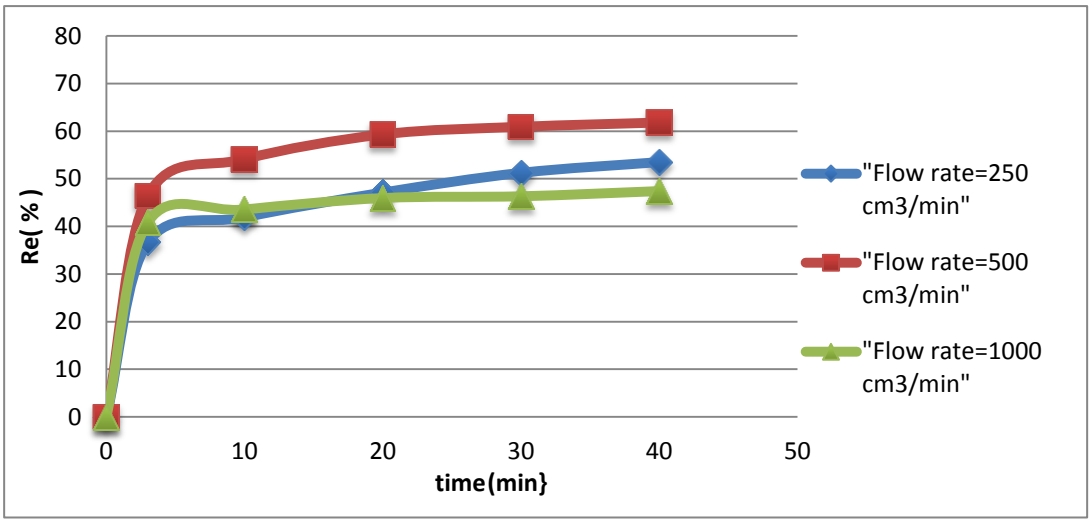
Metals	$k \times 10^2$ (min^{-1})		
	SDS=50 mg/L	SDS=100 mg/L	SDS=200 mg/L
Cadmium	0. 34	0.64	0.71
lead	0.35	0.38	0.87
Copper	0.65	0.69	0.83

4.2.3 The impact of Air Flow Rate

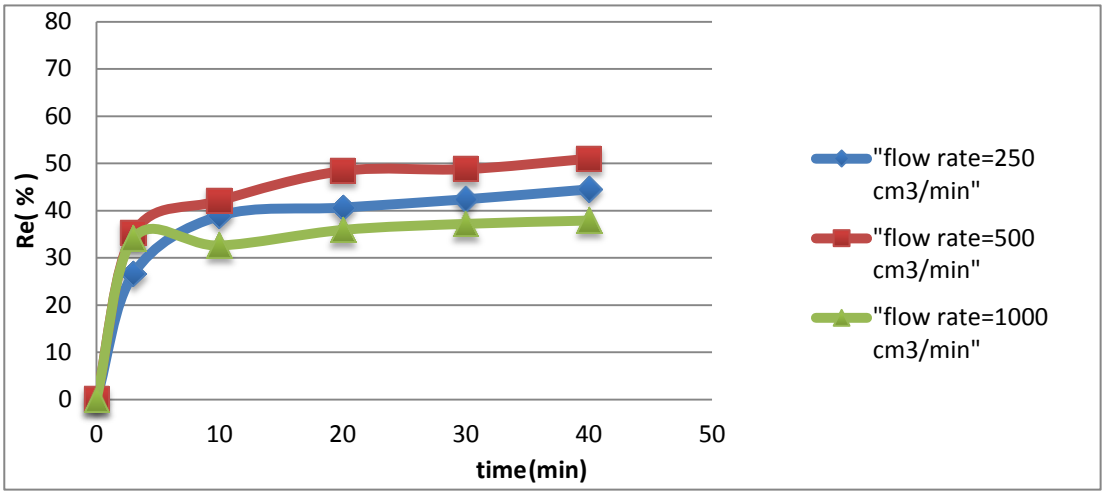
At pH 5–6, 50 mg/L metal ions, and 200 mg/L SDS, the effects of the airflow rate (250, 500, and 1000 cm^3/min) on removal efficiencies of copper, cadmium, and lead ions in its bubble column have been investigated. The results are presented in Figure (4.13) and timetable in Appendix (D) .

The statistics shown in this chart suggest that removal effectiveness rose as the airflow rate rose from (250 to 500) cm^3/min. This is due to the gas flow rate increaseing cause a premature bubble separation, suitable fluid activity, and bubble coalescence (largely) (Mohamed and Sulayman, 2010; Mohamed et al., 2016). It outcomes in a big number of tiny bubbles, that increases the metal-accessible collector's surface area for adsorption. When the gas flow rate is increased to 1000 cm^3/minute, the removal efficiency is reduced from its ideal value by the redispersion of a portion of a metallic collector-attached product back into the bulk solution, which is brought on by the hard conditions created by the stream of bubbles climbing up the column. As a result, it is likely that a limit was reached at a particular aeration average where these two averages, those of connections as well as removal, and backentrainent and drainage, became equal and no further influence of air flow ratio could be noticed (Kadhem and Mohamed, 2013; Bodagh, 2013).

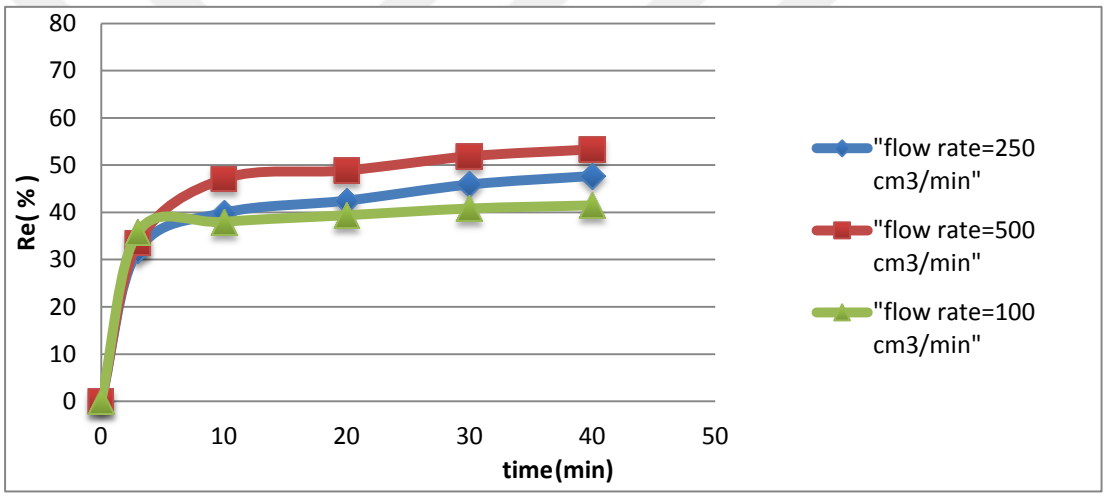
The results have been compiled in Table (4.8) after finding the removal ratio constants for a variety of different air flow rates. The flow rate of gas improved from 250 to 500 cm^3/min, which caused the rate constant to rise. The rate constant, however, decreased when the typical gas flow was raised to 1000 cm^3/min.



(a)Pb



(b)Cu



(C)Cd

Figure 4.13. The impact of the air flow rates on the floatation removing of Pb, Cu, and Cd ions (pH 5-6, C_o = 50 mg/L ; SDS = 200 mg/L ; 0.1% ethanol)

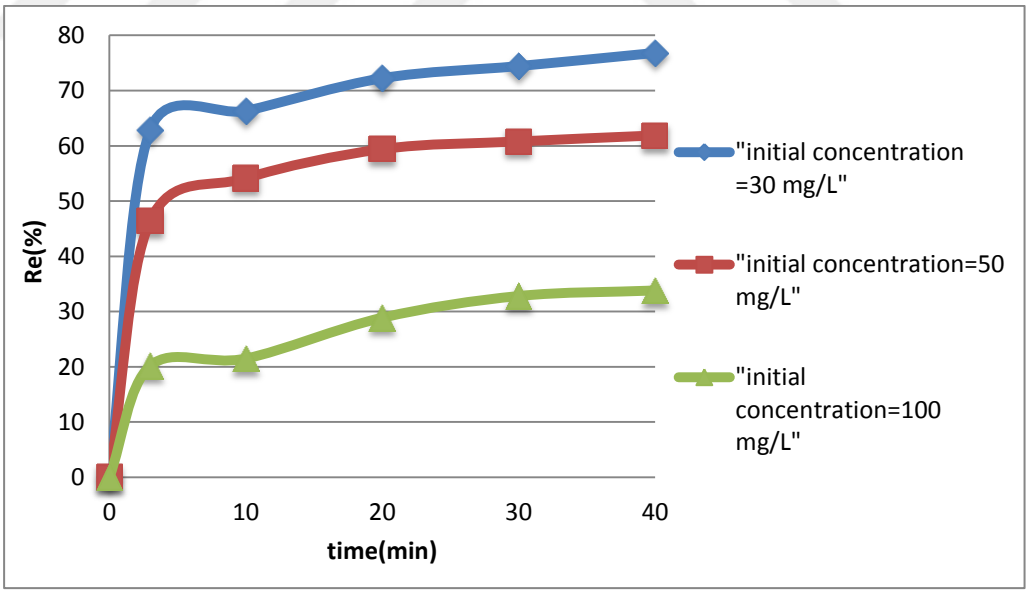
Table 4.8. Rate constant at various air flow rates

	"$k \times 10^2$ (min^{-1})"		
Metals	Flowrate=250 cm^3/min	Flow rate=500 cm^3/min	Flow rate=1000 cm^3/min
cadmium	0. 63	0.71	0.21
lead	0.84	0.87	0. 30
copper	0.66	0.83	0.24

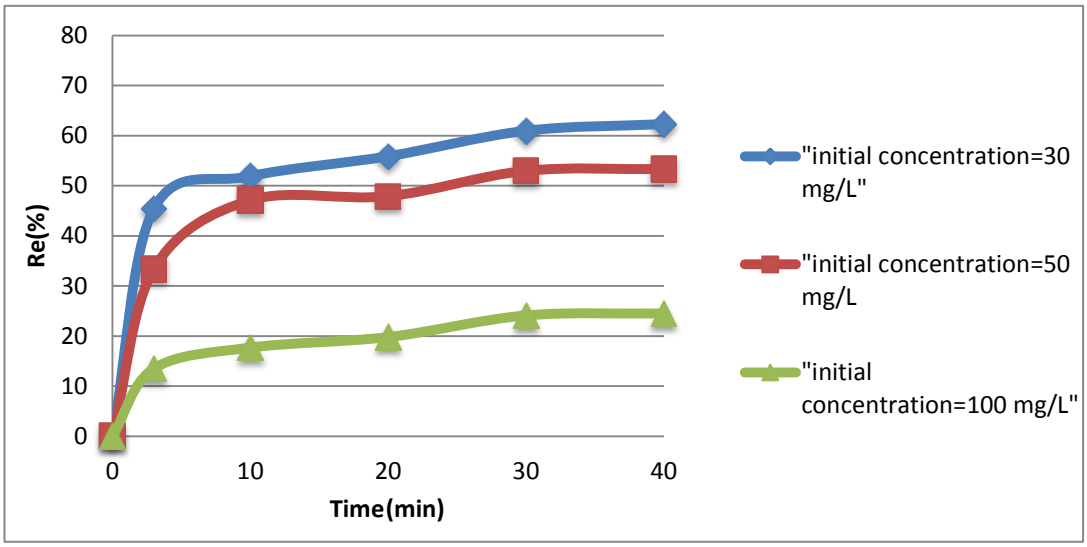
4.2.4 The Effects of the Concentration for Initial Metal Ions

The elimination effectiveness of cadmium, lead, and copper ions at different beginning metal concentration (30, 50, as well as 100 mg/L) at pH 5-6, 200 mg/L SDS concentration, and 500 cm^3/min air flow average is illustrated in the chart (4.14) by plotting removal percentage versus time at pH 5-6, 200 mg/L SDS concentration, as well as 500 cm^3/min air flow average. The data are shown in Table (4.9). By raising the starting concentration of metallic ions from 30 to 100 mg/L, the elimination effectiveness decreased from 76.8% to 33.8% for Pb(II), 62.350% to 24.5% for Cu(II), and 60.88% to 22.96 for Cd(II). This trend was comparable to the other two metal ions (Abed and Mohammed, 2011; Bodgah et al., 2013; Pooja et al., 2021). Researchers implied that at decreased pH, a rise in metallic ion concentration raised the amount of collector necessary for a similar removal percentage. Consequently, the removal percentage falls as metallic concentrations increase.

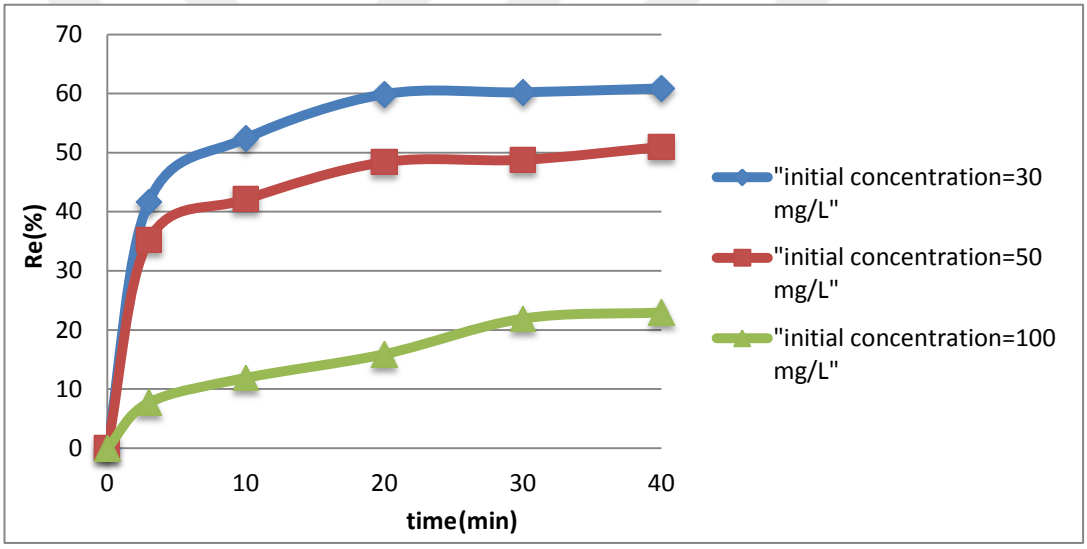
Table (4.9) lists the values of the removal rate constants (k) for various concentrations of "lead, copper, and cadmium". Each metal ion was shown to be eliminated most quickly at its lowest initial concentration.



(a)Pb



(b) Cu



(C) Cd

Figure 4.14. Impact of initially metal ion concentrations on its elimination of Pb, Cu, and Cd ions via floatation (SDS =200 mg/L, pH 5-6 , Q =500 cm^3/min, 0.1% ethanol)

Table 4.9: Rate constant at various initial metals concentration

Metals	"$k\times10^2$ (min^{-1})"		
	initial concentration =30 mg/L	initial concentration = 50 mg/L	initial concentration =100 mg/L
Lead	1.29	0.87	0.56
Copper	1	0.85	0.37
Cadmium	1.01	0.71	0.51

4.2.5 Competitive Metal Ion Removal through Flotation

The elimination of "lead , copper and cadmium ions" by flotation in binary, as well as ternary component systems, is demonstrated in the chart (4.15)" using pH 5.50, 50 mg/L metallic dosage, 200 mg/L of SDS, and 500 cm^3/min air flow ratios. Due to the competion between metal ion species and SDS molecules, the elimination percentage of metallic ions was demonstrated to be lower in binary and ternary component systems than in single component systems. The findings are presented in appendex (D).

The values of the removal rate constants for lead , copper and cadmium ions, which correlate to their selectivity, were summarized in table 4.10.

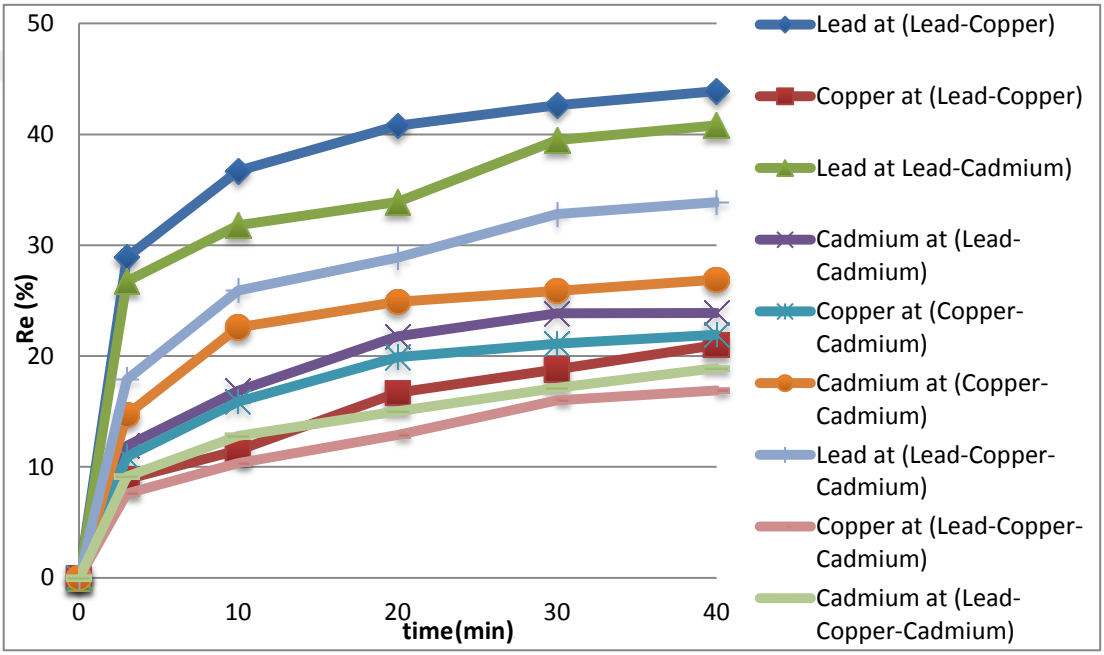


Table 4.15. The competitive floatation of Lead, Copper, and Cadmium ions in binary as well as ternary component systems (SDS =200 mg/L , C_o =50 mg/ L , Q =500 cm^3 / min , pH =5.5 , and 0.1% ethanol).

Table 4.10.Rate constant for binary and ternary metal component system

parameter	Metal								
	Cadmium			Lead			copper		
	Pb, Cd	Cu, Cd	Pb,Cu, Cd	Pb, Cu	Pb, Cd	Pb,Cu, Cd	Pb, Cu	Cu,Cd	Pb,Cu,Cd
$k\times10^2$ (Min^{-1})	0.4	0.36	0.3	0.59	0.58	0.55	0.39	0.34	0.29

The only conclusion to be drawn from these results is that SDS has a much larger affinity for accessible lead species than for cadmium and copper species.

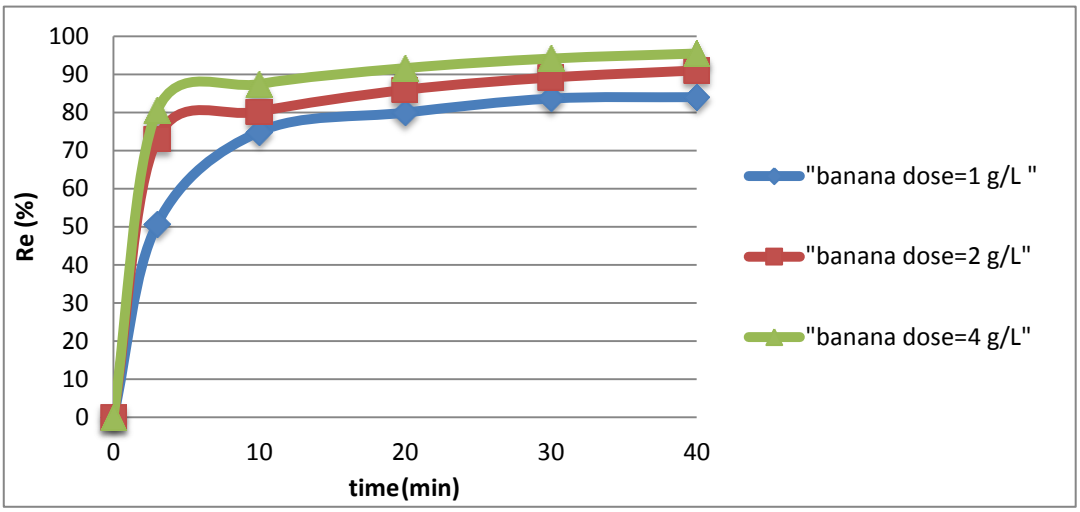
Pb > Cd > Cu was discovered to be the order of selectivity for the examined metallic ions in binary and ternary systems. Pb (1.19) > Cd (0.95) > Cu (0.72) Aº are the order of magnitudes for the ionic radii of metal ions (Joseph et al., 2020; Xiao et al., 2020). Then, ions with greater ionic amount have a tendency to interact more with surfactant during flotation. Also, the constants kPb > kCd > kCu for the metals under investigation's flotation rates match up with their selectivity. The following can be used to explain this outcome: The most highly selective ion comes first. The following can be used to explain this outcome: The ion with the highest selectivity makes initial contact with the SDS collector and moves more quickly than some other metallic SDS compounds to the froth zone. They noticed a pattern of conduct that was fairly consistent (Bodgah et al., 2013; Xiao et al., 2020).

4.3 System for Sorptive-Flotation

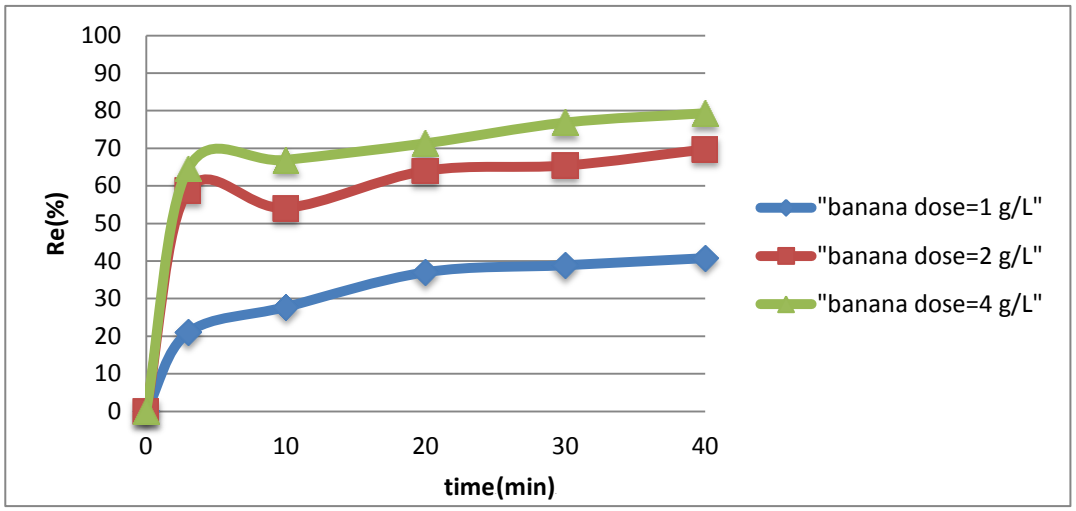
During this system, the disposal of heavy metals ions was brought out similarly as in a flotation system, "the removal of metal ions was improved in single binary and ternary systems with the inclusion of banana peels" as a sorbent material at a variety of experimental conditions, such as a pH range of 5 to 6, a concentration of ethanol of 0.1%, and an ambient temperature of 30 Cº. The effects of these traits are described in more depth below.

4.3.1 Impact of Sorbent Dose

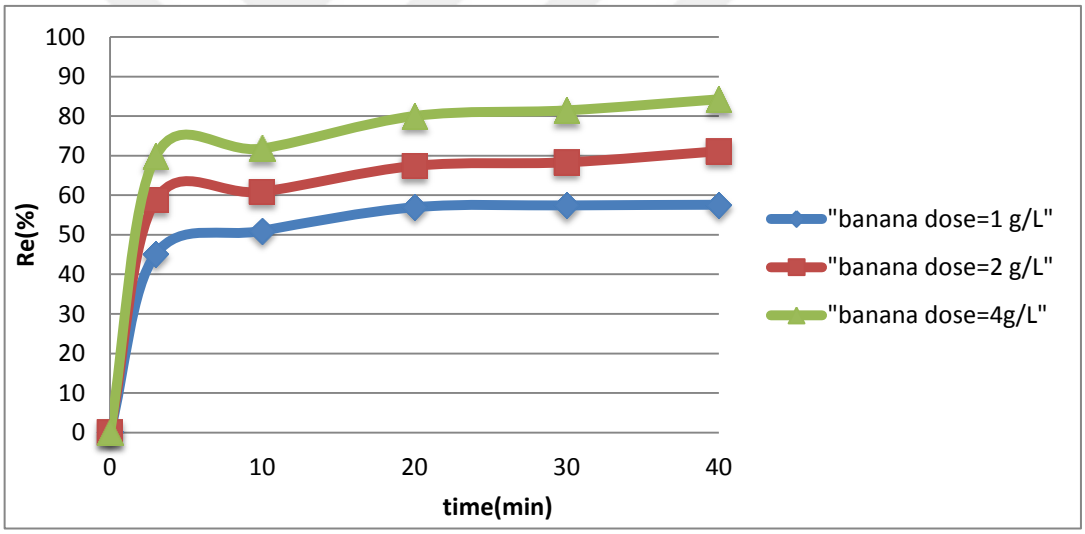
Figures illustrate the effect of sorbent dosage on the elimination" of 50 mg/L of copper, cadmium, and lead ions by a high sorption (bubble) column for a single component of the system as shown in the Figure (4.16) for banana peels, by plotting the disposal effectiveness versus period at different sorbent dose values (1, 2, and 4 g/L) for banana peels, 500 cm^3/min air flow rates and 50 mg/L SDS concentration. From these Chart, it's clear that the removal rate went up quickly at the start of a run as well as then slowed down after about twenty minutes. Furthermore, the percent of metal ions that were removed went up as the sorbent dosage went up. This may be because there were more binding locations on a sorbent for M(II) ions to use. Relatively similar behavior was already noticed in (Alwared and Sadiq, 2019; Constantin et al., 2022). All of the outcomes have been demonstrated in the Appendix (E).



(a) Pb



(b) Cu



(C) Cd

Figure 4.16. The Impact of the banana dose on the removing of (Pb), (Cu) and (Cd) via sorptive flotation (Q=500cm^3/min,pH = 5–6, C_o = 50 mg/L; SDS = 50 mg/L ; 0.1% ethanol).

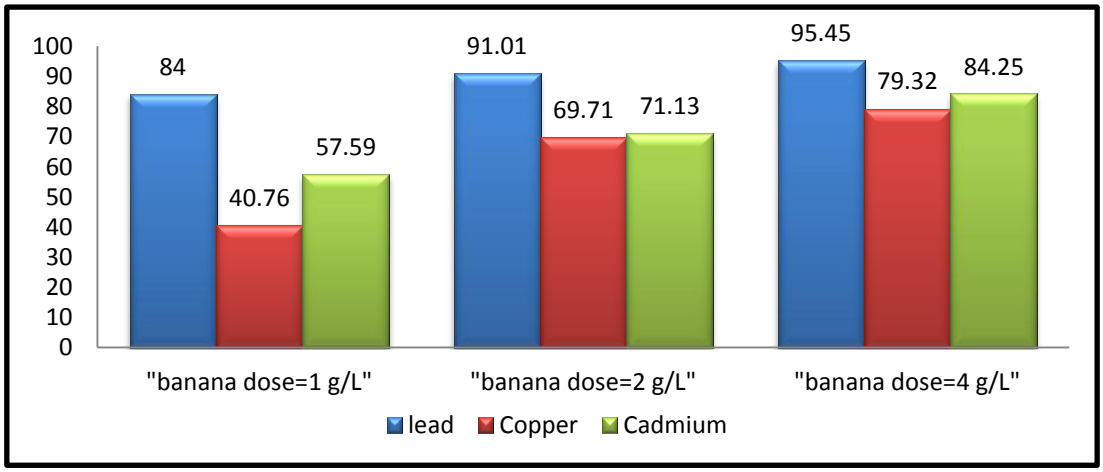
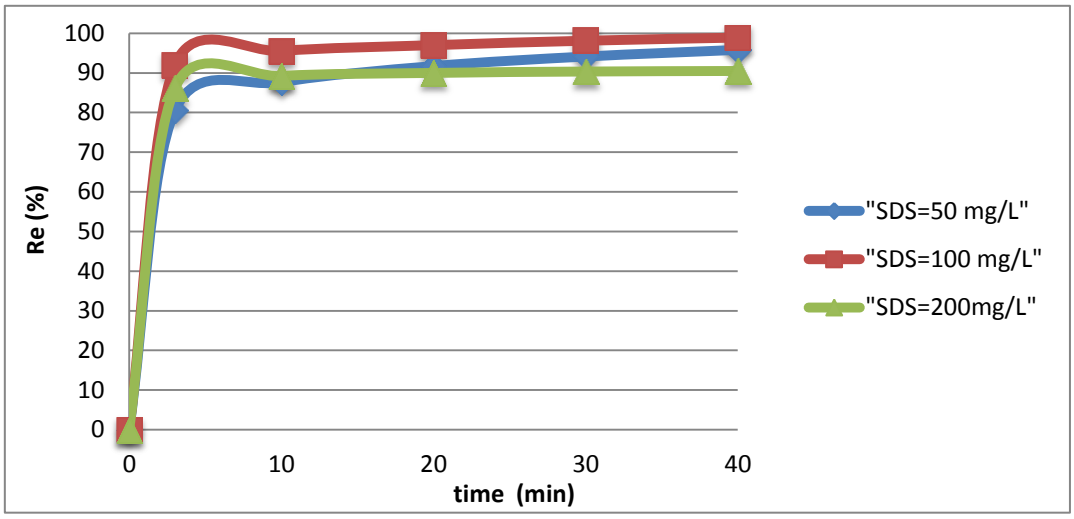


Figure 4.17. The Peak removal of Cu ion, Pb ion and cd ion via sorptive -flotation at various doses of banana peels.

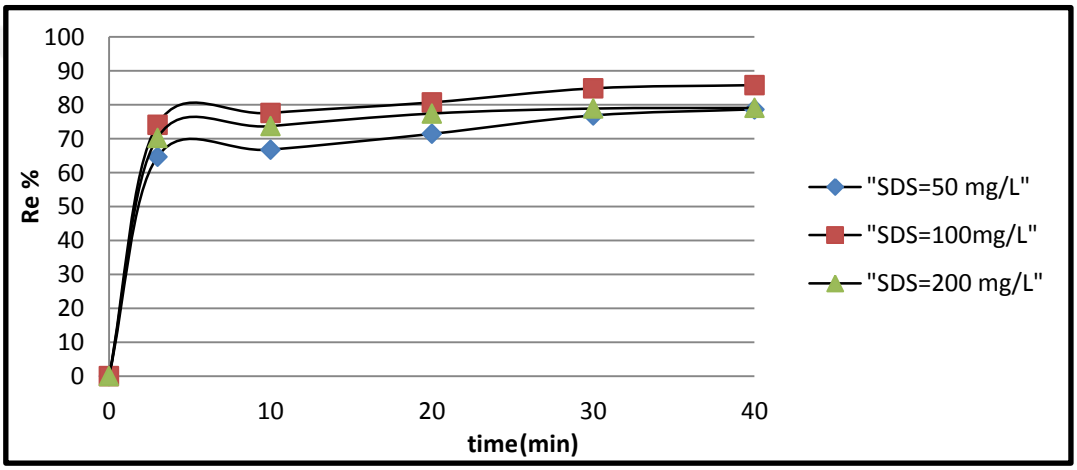
The maximal removal of metallic ions via sorptive flotation with varying doses of the sorbent is demonstrated in the Figure (4.17). The highest lead, copper, and cadmium removal occurs at around 4 g/L of banana peels. The greatest removal efficiencies for lead, copper and cadmium ions at a dose of 4 g/L banana peels were 95.45, 79.32, and 84.25%, respectively. Consequently, these doses were chosen for the subsequent trials.

4.3.2 The Effect of Surfactant Concentration

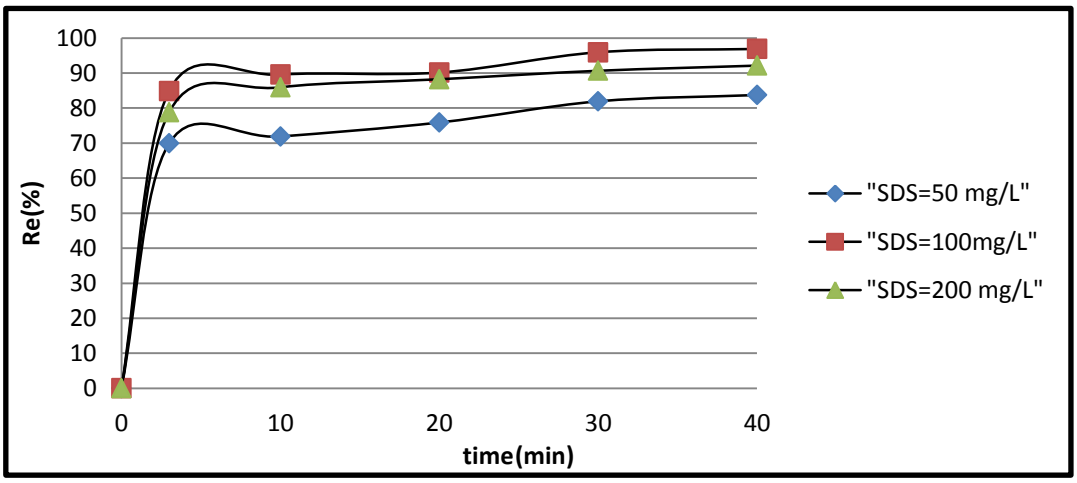
The illustrations show the experiments to float lead, copper, and heavy metal ions from alkaline solutions with a pH range of 5-6, an average air flow of 500 cm^3/min, and the use of banana peels as an adsorbent. Several SDS dosages were utilized in these tests with single, binary, and ternary component systems (4.18 to 4.20). The amount of metal ions removed was found to be negligible at a surfactant concentration of 50 mg/L. This can be due to insufficient surfactant levels to support full floating (Ghazy et al., 2008). The separation efficiency rises as surfactant concentrations rise up to 100 mg/L. A decrease in the removal of metal ions and poor flotation are brought on by raising the surfactant level above 200 mg/L. In response to a higher surfactant concentration, (I) air bubbles, (II) the surfactant's hydrated wrapper, or (III) a layer of hydration microemulsion on the surface of a solid all developed. The resulting hydrophobic surface was therefore unflotation-friendly. The same behaviors were seen by (Mohamed et al., 2016;.Alwared and Sadiq, 2019) An appendix contains information on each result (E) .



(a) Pb

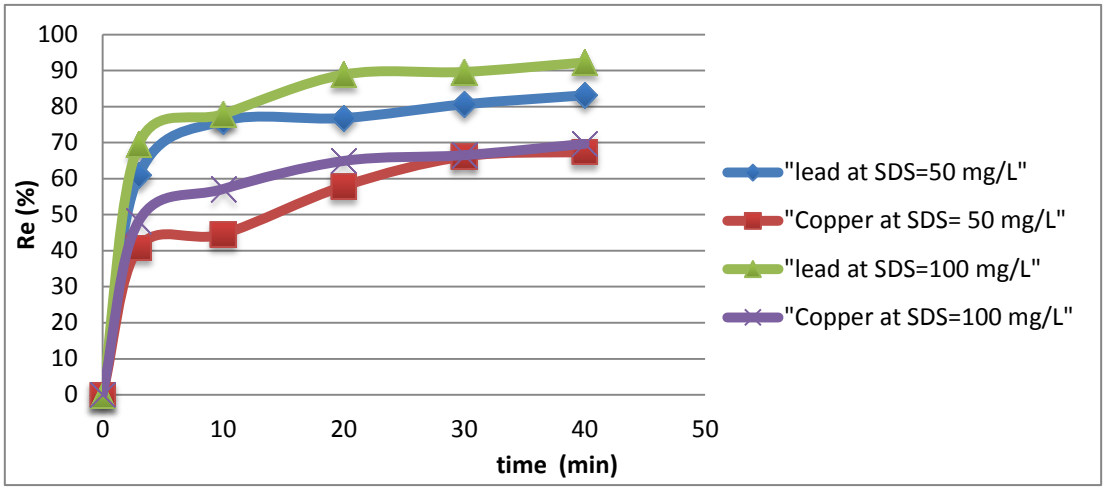


(b)Cu

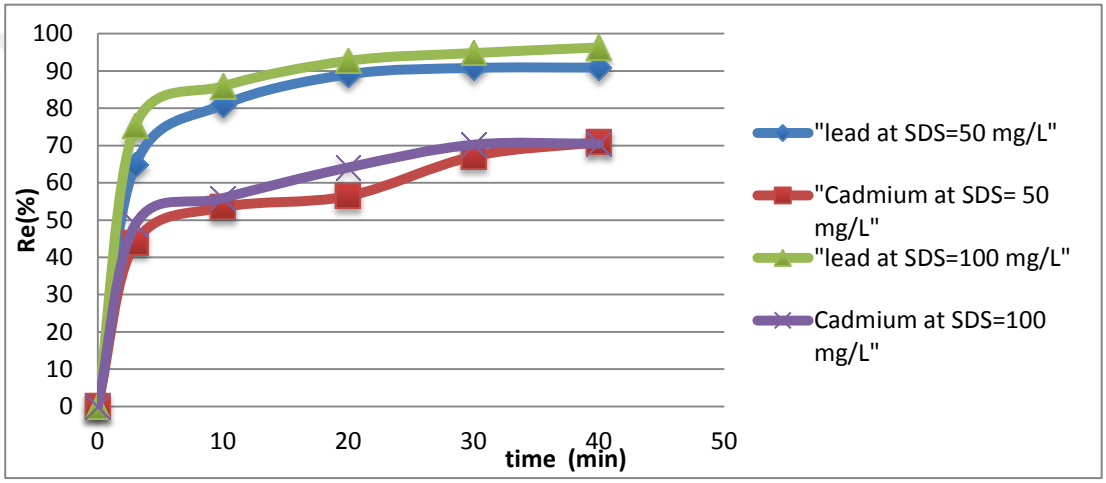


(C)Cd

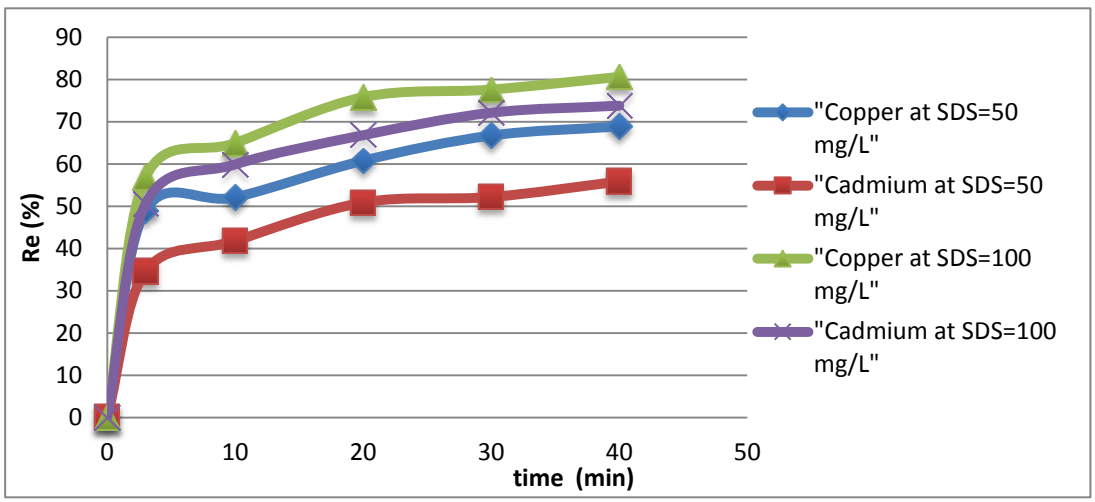
Figure 4.18. The impact of the surfactant concentration on the removing of (Pb), (Cu) and (Cd) via sorptive flotation in individual system utilizing banana peels (Q=500cm^3/min,pH = 5–6,Co = 50 mg/L ; banana peels dose= 4 g/L; 0.1% ethanol) .



(a)Pb-Cu



(b) Pb-Cd



(c) Cd-Cu

Figure 4.19. The impact of the surfactant concentration on the removing of (Pb), (Cu) and (Cd) via sorptive flotation in binary system utillizing banana peels (Q=500cm^3/min,pH = 5.5 ,C_o = 50 mg/L ; banana peels dose= 4 g/L ; 0.1% ethanol).

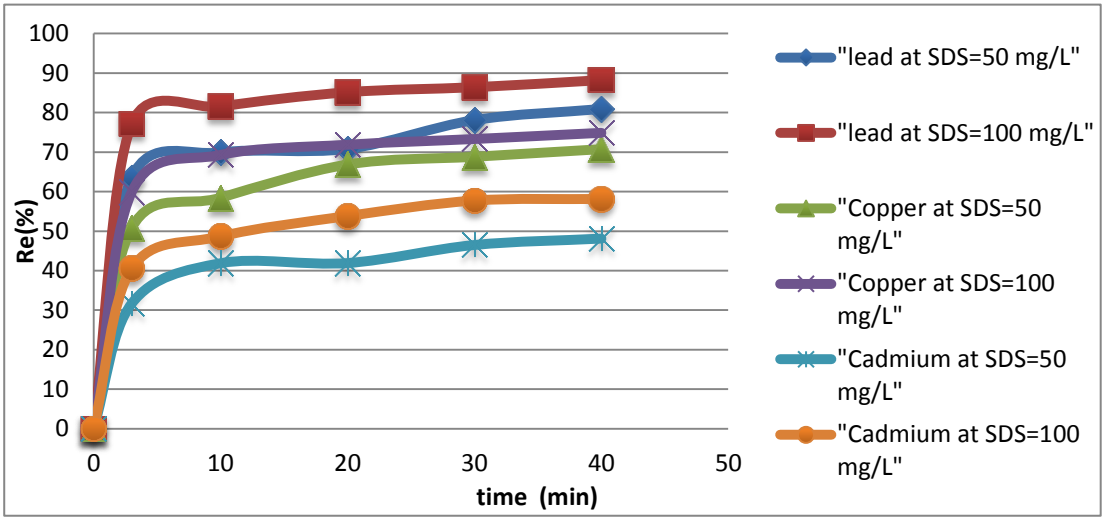


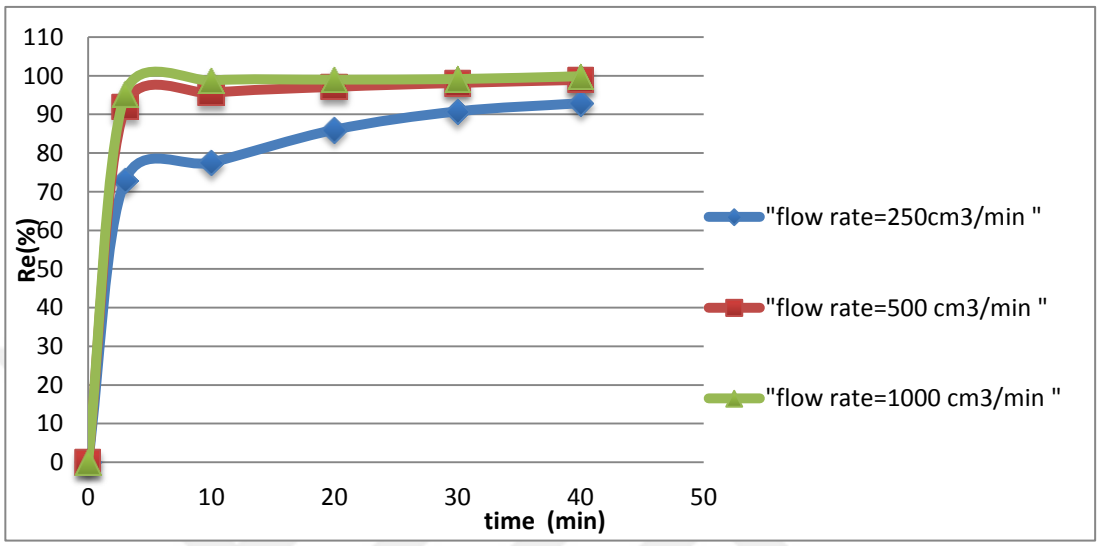
Figure 4.20. The impact of the surfactant concentration on the removing of (Pb), (Cu) and (Cd) via sorptive flotation in ternary system utillizing banana peels (Q=500cm^3/min, "pH = 5–6,C_o = 50 mg /L ; banana peels dose= 4g/L ; 0.1% ethanol)

Furthermore, the rivalry among the studied metals for binding positions on the bubble surface and sorbent material was observed to diminish the removal rates in binary and ternary systems when compared to a single system.

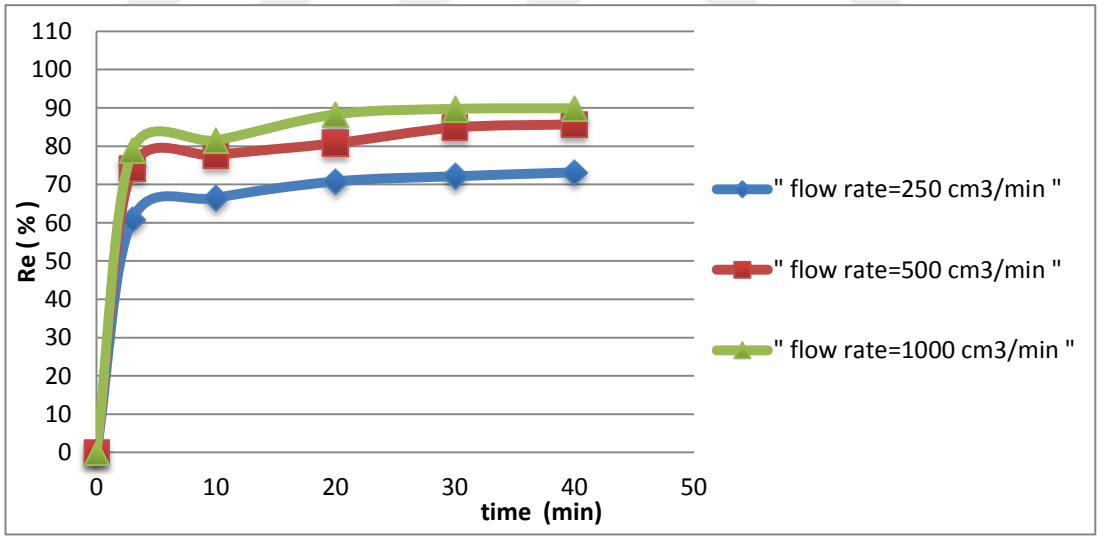
4.3.3. Impact of the Rate of Air Flow

All other parameters were held constant while the effects of airflow rates (250, 500, and 1000 cm^3/min) for an individual directly, (500, and 1000 cm^3/min) for a binary system, and (500, and 1000 cm^3/min) for a ternary system were investigated. Tables and charts (4.21 to 4.23) in Appendix present the findings (E). These plots allowed us to demonstrate that the elimination% rose as the average gas flow grew from 250 cm^3/min to 1000 cm^3/min. This is because a higher gas flow average causes bubbles to burst earlier, fluid activity to increase at the bottom, and bubbles to unite and (most frequently) burst. The bottom is moving fluidly, and bubbles constantly combine and split. This produces a huge amount of tiny bubbles, increasing the surface area of the collector that is accessible to metal (Mohammed and Suleiman, 2010; Alwared et al., 2019). Similar outcomes were found by Mohamed et al. (2016), who found that the gas flow rate had a significant impact on the biosorptive-flotation process for the removal of Pb(II) ions with banana peels and that raising the air flow rate above 500 cm/minute was necessary to achieve the highest metal removal (99.8%).They contend that a greater gas flow rate (more than a thousand centimeters

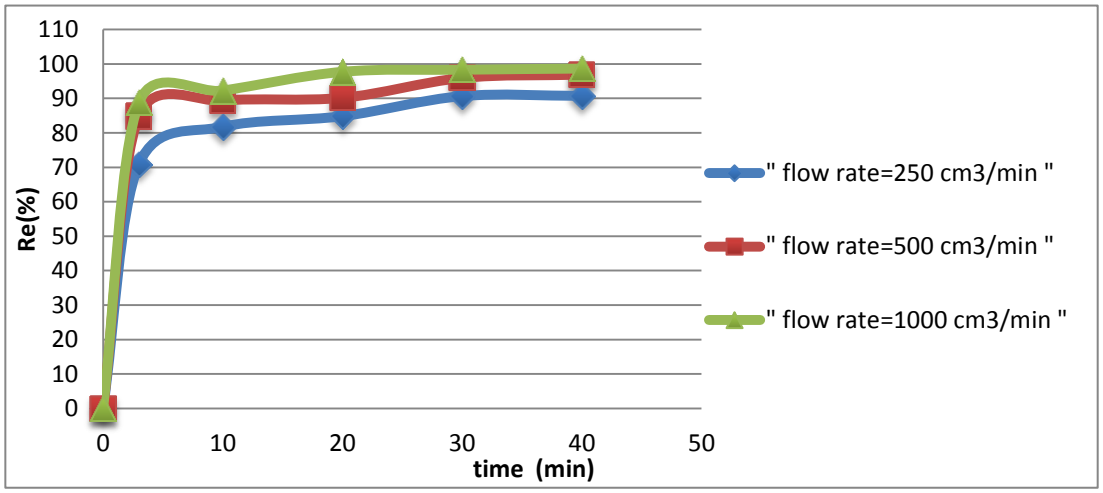
per minute) caused the removal rate to fall below its maximum as a result of the dispersion of some metal collector and the precipitation of product back into the bulk solution. The same behavior was seen by (Mohamed and Mohamed, 2014; Faraj, 2014; Hoseinian et al., 2019).



(a)Pb

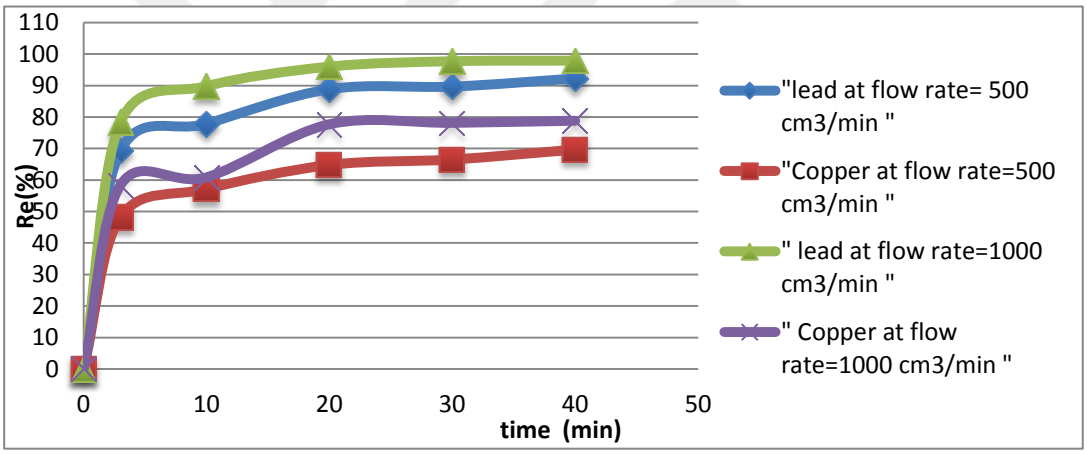


(b)Cu

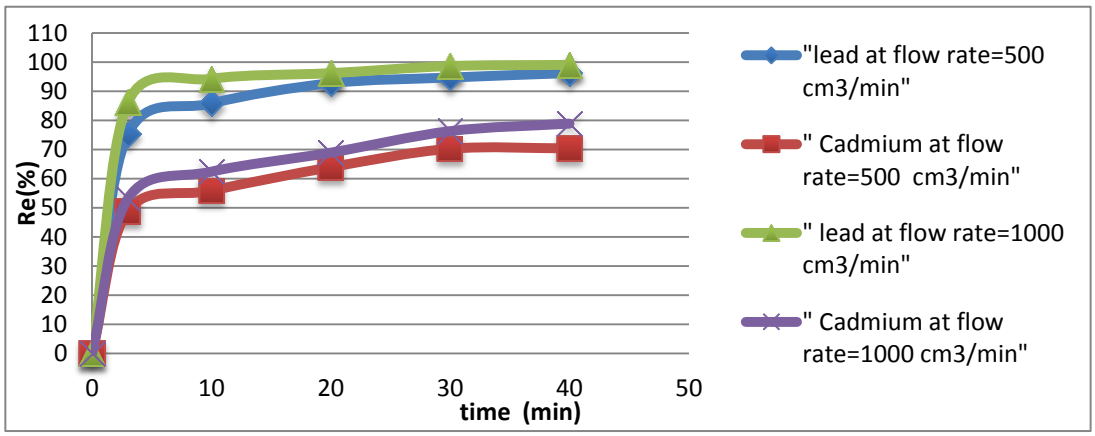


(C) Cd

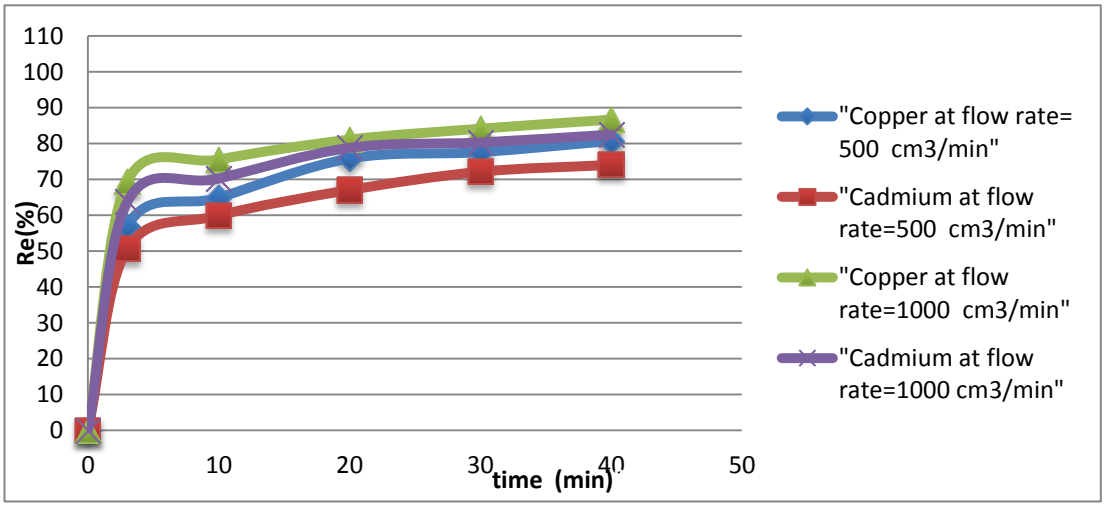
Figure 4.21. The impact of air flow rates on the removal of Pb, Cu, and Cd ions by sorptive-floatation in a single system with banana peels (banana peels dose =“4 g/L , pH= 5-“6 ,Co=50 mg/L , SDS=100 mg/L) .



(a) Pb-Cu



(b) Pb-Cd



(C) Cu-Cd

Figure 4.22. The impact of air flow rates on the removal of (a) Pb-Cu, (b) Pb-Cd, as well as (c) Cu-Cd by sorptive-flotation in a binary system with banana peels (banana peels dose=4 g/L; C_o=50 mg/l ,pH=5.50 ; SDS=100 mg/l ; 0.1% ethanol) .

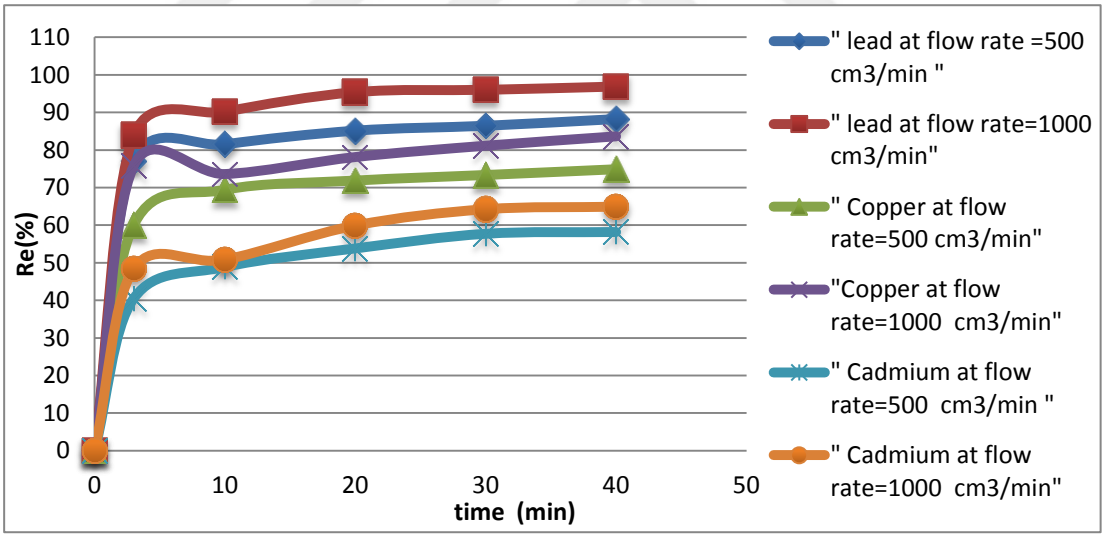
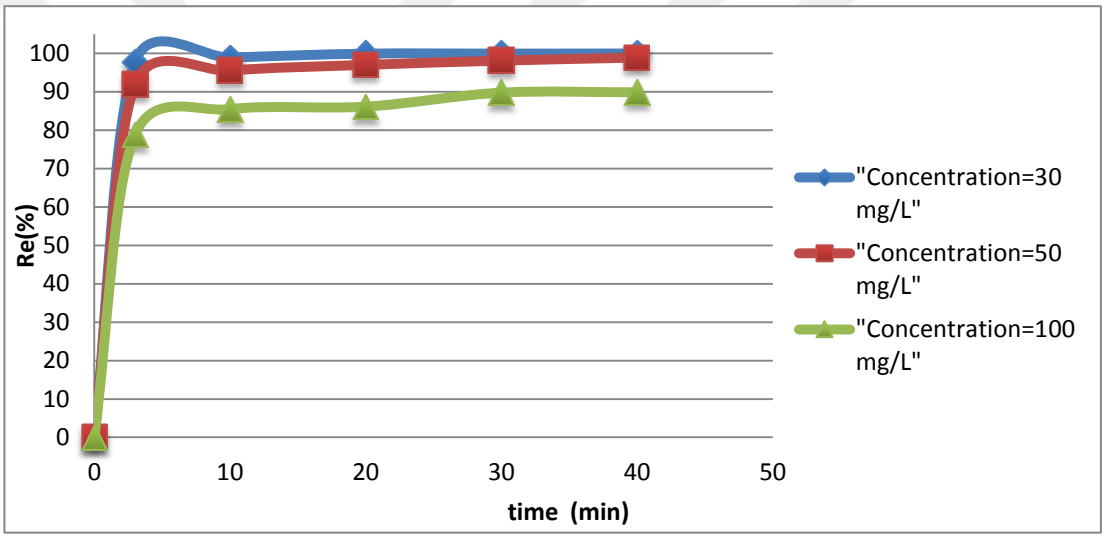


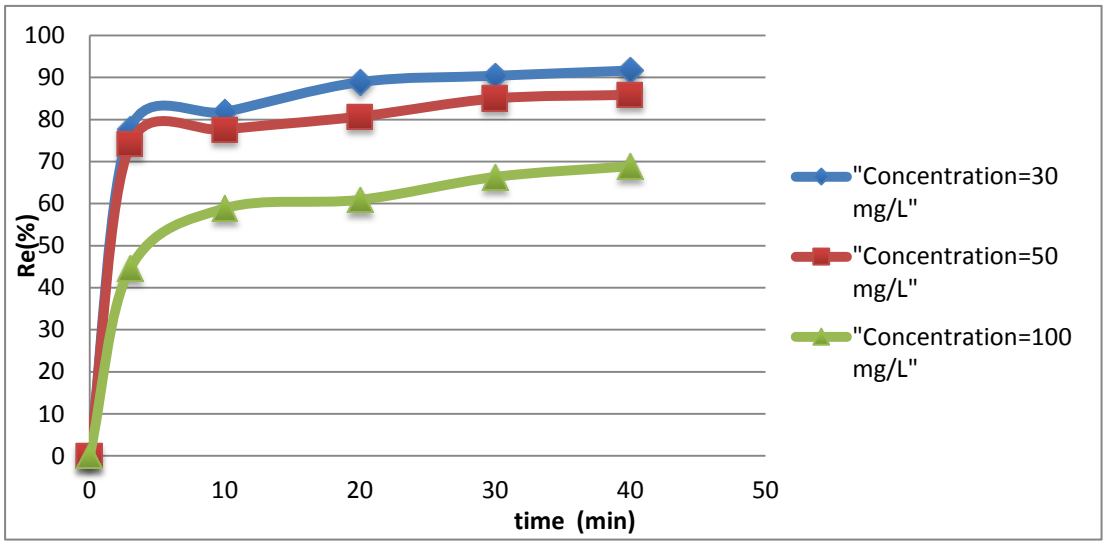
Figure 4.23. The impact of air flow rates on the removal of Pb,Cu,and Cd by sorptive-flotation in a ternary system with banana peels (banana peels dose=4 g/L; C_o=50 mg/l ,pH=5.50 ; SDS=100 mg/l ; 0.1% ethanol) .

4.3.4 The Effect of the Initial Concentrations of Metals

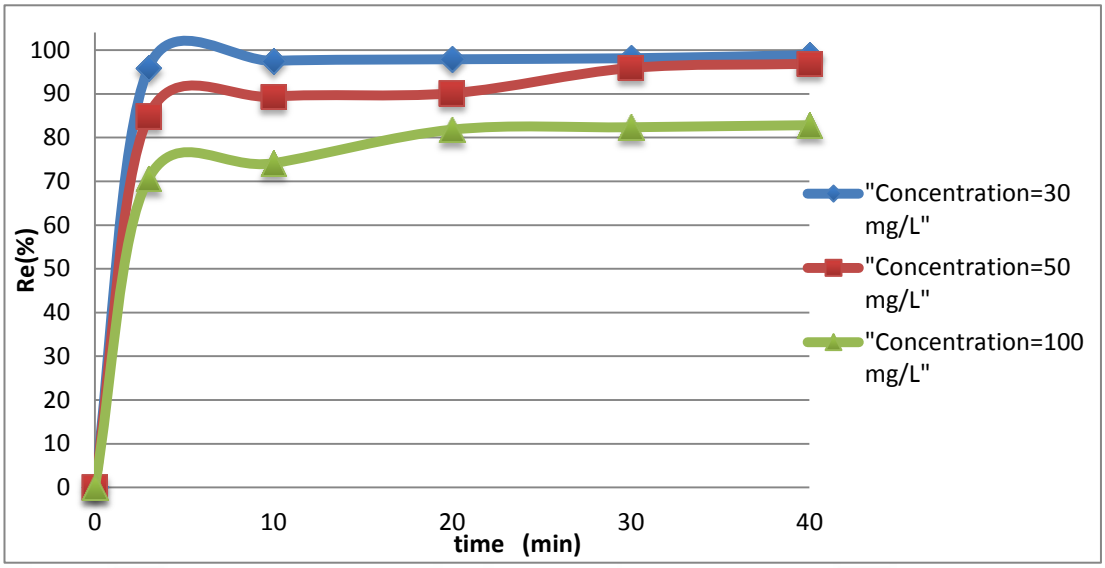
Figure 4.24, at 500 cm^3/min air flow rate and 100 mg/L of SDS, shows the average amount of metallic ions removed by sorptive flotation using banana peels at varied beginning dosages (30, 50, and 100 mg/L). The results are presented in Annex (D). These plots show that at pH 5-6, lowering metal ion concentrations increase removal efficiency. They claimed that at acidic pH levels, a larger quantity of metal ions would increase the number of collector needed for a similar percentage of removal. These results were equivalent to (Alwared et al., 2019; Kyzas et al., 2021). Reducing levels at basic pH levels reduces removal efficiency, though, so because free collector ions and the metal-collector product compete for the surface of the bubbles because there is a high surfactant-to-metal ion ratio (Mohamed et al., 2013).



(a)Pb



(b)Cu



(C)Cd

Figure 4.24. The impact of beginning metal concentration on the removal of (a) Pb, (b) Cd, as well as (c) Cu by sorptive-flotation in a indivdual system with banana peels (banana peels dose=4 g/L; Q = 500 cm3/min, pH=five - six ; SDS=100 mg/l; 0.1% etha

5. CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The major findings that could be derived from this study's experimental research regarding sorption include the following:

1.The findings indicated banana peels are inexpensive advantage sorbent for the elimination of Pb, Cd, and Cu ions from wastewater.

2.The optimal pH as well as agitation rate for metallic ions on banana peels were found to be 5-6 and 175 rpm , as well as Equilibrium conditions were achieved in 60 minutes for banana peels.

3. In single, binary, and ternary component systems, the removing effectiveness of banana peels increases with rising dose and decreases with increasing initially concentrations of metals.

4. Compared to the Temkin isotherm and Freundlich models, the Langmuir sorption isotherms best fit sorption information with factors of determine (R^2) values larger than 0.90. Alternatively, the enlarged Langmuir models were a good match for the binary and ternary sorption isotherm information.

5.The mono-layer adsorption capability of Pb, Cd, and Cu determined for banana peels using the Langmuir theory was found to be around (86.7, 74 and 77.16 mg/g) in individual component system, for Pb ion, Cu ion, as well as Cd ion, and in binary component system these percentages were reduced to 76.2 mg/g for lead and 54.03 mg/g for copper (lead, copper system); 79.4 mg/g for lead and 51.4 mg/g for cadimum (lead, cadmium system); and about 58.312 mg/g for copper and 56.5 mg/g for cadimum, (copper, cadmium system) while in ternary system these uptake were reduced to (66.7, 50.3 and 48.32 mg/g).

6. The sorption data for three metals matches closely to the pseudo second order kinetic theory, with R^2 values greater than 0.980.

7. Because of the competing effect of three metal mixes to occupy a accessible locations of banana peels, Pb ions give the best removal percentage as well as Cd the lower removal rates, with the exception of banana peels in singular system where Cadimum (II) removal is larger than Copper (II) removal . 0.98.

8. The findings of Zeta potential for banana peels suggested that it carried negatively charged value, which ought to be favourable to the attractions among actives locations as well as positively charged metallic ions, leading to electrostatic

interactions.

9. The FTIR analyses /examination showed that lead (II) ions altered the functional clusters of banana peel biomass more than Copper(II) and Cadimum(II) ions. This showed that banana peels have a large affinity for lead (ii). The wave numbers of the, aromatic, carboxylic acid , amine, as well as hydroxyl clusters on the biosorbent altered that after biosorption of Lead(II),Copper(II) , as well as Cadimum(II) ions.

The major findings that could be derived from this study's experimental research regarding flotation and sorptive flotation include the following:

1. The outcomes demonstrate that the method of metal ion flotation with sodium dodecyl surfactant (SDS) was indeed very delicate to pH, and as such, the pH for flotation as well as sorptive flotation systems has been chosen to be between five and six.

2. Experimental data for the flotation stages demonstrate that the order of kinetic metal ion floatation has been almost first order as well as the percentage removal constants (k) increased with increasing concentrations of surfactant (SDS) as well as lowering initially concentrations of metals.

3. The sorptive flotation system is greatly influenced with sorbent dose; the highest removal efficiency of metallic ions at 50 mg/L SDS and 50 milligrams/L metal concentrations, as well as 500 cm3/minute air flow average, was around 95.45 % for Pb, 79.32 % for Cu , and 84.25 % for Cd at 4 g/L banana peel dose.

4. Raising the SDS concentrations up to 200 mg/L increases the removal ratios of metallic ions throughout the floatation phase, whereas raising the SDS concentrations up to 100 mg/L increases the removal ratios after forty minutes of operations in the sorptive-flotation system. Increasing the SDS concentrations further decreases the disposal levels.

5.According to the findings, removal rates rose with raising air flow rates up to 500 cm^3/min for the floatation system as well as up to 1000 cm^3/min for the sorptive- floatation system, but afterwards dropped.

6. The findings indicate that the removal effectiveness for floatation as well as sorptive-floatation systems decreases as the concentrations of metals increase from 30 mg/L to 100 mg/L.

7.According to all data, the removal effectiveness of metallic ions is greater in

the sorptive-flotation system than in the flotation-only system, as well as Lead(ii) ions get the highest elimination efficacy when comparing with the other elements in every system.

5.2 Recommendations

1. Using several sorbent particle sizes, to study the capacity of banana peels to absorb heavy metallic ions.

2. Investigating the sorptive as well as competitive flotation of much more than 3 chosen wastewater heavy metals or utilizing real industrial wastewaters.

3.Utilizing higher active surfactant, as suggested by previous researchers.

4. Using a high-speed cam to investigate the impact of bubble size diameter, and speed of bubble rise on the floatation bubble column.

5.Utilizing a mathematical model to determine how well sorption,floatation, as well as sorptive-floatation will work to remove metals from aqueous solutions.

6.Researching the viability of employing banana peels to remove organic contaminants from wastewater.

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APPENDIXES

Appendix(A) Batch Experiments Data

Table A.1. The effect of Alkalinity and acidity on lead, copper, and cadmium ions removal using banana peels in a single component system.

pH	Removal Efficiency %		
	Banana peels		
	Lead(II)	Copper(II)	Cadmium(II)
3	76.52	60.08	67.61
5	97.1	64.82	84.02
6	96.53	72.45	83.89
7	95.5	72.18	83.03
8	94.29	71.5	81.16

Table A.2. The influence of agitation speed on lead, copper, and cadmium ions elimination for banana peels in a single component system.

Agitation speed (rpm)	Removal Efficiency %		
	Banana peels		
	Lead(II)	Copper(II)	Cadmium(II)
125	91.88	62.545	76.11
175	97.4	72.544	83.92
250	98.49	74.834	89.03

Table A.3. Effect of contact time on banana peels' ability to remove lead, copper, and cadmium ions in a single component system.

Time (min)	Removal Efficiency %		
	Banana peels		
	Lead(II)	Copper(II)	Cadmium(II)
0	0	0	0
10	61.099	38.78	44.089
15	69.732	43.99	57.588
30	85.066	58.08	71.125
60	93.534	68.87	81.08
90	96.198	70.96	82.95
120	97.15	72.546	84.02
150	97.659	73.089	84.315
180	98.99	73.27	85.17

Table A.4. The elimination of lead, copper, and cadmium ions in a single component system is affected by the dosage of banana peels.

Dosage (g/L)	Removal Efficiency %		
	Banana peels		
	Lead(II)	Copper(II)	Cadmium(II)
0.5	75.94	45.63	62.02
1	82.63	60.12	71.06
1.5	91.12	64.04	74.06
2	96.98	71.95	84.01
4	98.41	89.54	93.98
8	99.2	94.044	96.785

Table A.5. The elimination of lead, copper, and cadmium ions in binary and ternary component systems is affected by the dosage of banana peels.

banana Dose (g/L)	Removal Efficiency %								
	"Lead+Copper"		"Lead+Cadmium"		"Copper+Cadmium"		"Lead+Copper+Cadmium"		
	Lead(II)	Copper(II)	Lead(II)	Cadmium(II)	Copper(II)	Cadmium(II)	Lead(II)	Copper(II)	Cadmium(II)
0.5	71.87	33.12	78.7	32.87	22.15	18.07	49.08	24.05	11.9
1	83.98	52.89	86.2	42.31	32.01	21.98	62.23	36.89	19.06
1.5	85.056	65.03	91.19	49.05	41.97	30.13	73.976	55.09	24.98
2	92.02	77.84	93.72	58.98	51.31	40.22	82.21	64.88	32.14
4	94.18	85.23	97.27	85.62	69.18	62.09	90.94	81.16	51.36
8	98.09	94.1	98.90	89.39	83.24	74.97	96.08	89.54	68.08

Table A.7. The elimination of lead, copper, and cadmium ions in a single component system is affected by the starting metal concentration.

C_o (milligrams /L)	Removal Efficiency %		
	Banana peels		
	Lead(II)	Copper(II)	Cadmium(II)
10	99.97	99.95	98.17
30	99.92	95.98	96.58
50	98.46	90.84	93.07
100	93.03	76.02	84.19
200	86.83	47.021	67.79

Table A.8. The removal of lead, copper, and cadmium ions from banana peels in binary and ternary component systems is affected by the initial metal concentration.

C_o (mg/L)	Removal Efficiency %								
	Lead+Copper		Lead+Cadmium		Copper+Cadmium		Lead+Copper+Cadmium		
	Lead (II)	Copper (II)	Lead (II)	Cadmium (II)	Copper (II)	Cadmium (II)	Lead (II)	Copper (II)	Cadmium (II)
10	97.3	91.02	99.94	87.14	93.16	91.1	96.03	82.03	78.25
30	95.96	87.94	99.8	85.22	84.079	81.04	95.24	83.31	71.63
50	92.98	85.97	98.07	84.65	67.98	62.21	92.04	81.18	51.94
100	89.11	67.19	92.06	61.07	60.83	55.77	79.99	59.12	29.53
200	77.980	35.98	83.9	37.89	46.9	42.86	67.35	38.24	11.09

Appendix (B)

Experimental and Theoretical Data for Sorption Isotherms

1.Single Component System:

Table B.1. Equilibrium isotherm for single component system of Lead(II), Copper(II), and Cadmium(II) at Co=50 mg/L for each solute onto Banana peels.

Banana dosage (g/L)	"Lead(II)"		"Copper(II)"		"Cadmium(II)"	
	C_e (mg/L)	q_e (mg/g)	C_e (mg/L)	q_e (mg/g)	C_e (mg/L)	q_e (mg/g)
0.5	11.89	75.94	28.13	46.136	19.49	62.22
1	8.85	42.15	20.45	29.85	14.82	36.13
1.5	5.19	31.24	17.98	21.68	11.97	25.42
2	1.53	23.87	14.99	18.14	8.09	20.95
4	0.925	13.03	5.75	11.81	3.72	12.97
8	0.411	6.19	2.97	5.78	1.64	6.48

Table B.2. Langmuir isotherms onto banana peels as sorbent in a single component system: experimental and theoretical data.

"Lead(II)"		"Copper(II)"		"Cadmium(II)"	
"$1/C_e$"	"$1/q_e$"	"$1/C_e$"	"$1/q_e$"	"$1/C_e$"	"$1/q_e$"
0.0834	0.01315	0.0366	0.0220	0.0518	0.0162
0.1138	0.0242	0.0493	0.0336	0.0688	0.0281
0.2227	0.0329	0.0552	0.047	0.0821	0.0396
0.6896	0.0412	0.0726	0.0552	0.1251	0.0476
1.2121	0.0813	0.1895	0.0894	0.277	0.0862
2.439	0.1613	0.3355	0.1701	0.6211	0.1653

Table B.3. For Frendlich isotherms onto banana peel sorbent in a single component system, experimental and theoretical data are presented.

"Lead(II)"		"Copper(II)"		"Cadmium(II)"	
$Ln(C_e)$	$Ln(q_e)$	$Ln(C_e)$	$Ln(q_e)$	$Ln(C_e)$	$Ln(q_e)$
2.4832	4.3312	3.3076	3.8146	2.9595	4.1177
2.173	3.7188	3.0081	3.3928	2.6755	3.5689
1.5018	3.4124	2.8958	3.0572	2.4989	3.2276
0.3716	3.1894	2.6227	2.8966	2.0781	3.0447
-0.1924	2.5091	1.6629	2.4142	1.2837	2.4507
-0.8916	1.8243	1.0919	1.7711	0.4762	1.7998

Table B.4. Experimental and theoretical data for Temkin isotherms onto Banana peels sorbent in single component system.

"Lead(II)"		"Copper(II)"		"Cadmium(II)"	
"$Ln(C_e)$"	"q_e"	"$Ln(C_e)$"	"q_e"	"$Ln(C_e)$"	"q_e"
2.4832	76.04	3.3076	45.36	2.9596	61.42
2.1731	41.215	3.0082	29.75	2.6755	35.48
1.5018	30.34	2.8958	21.268	2.4989	25.22
0.3715	24.275	2.6227	18.1135	2.0782	21.005
-0.1924	12.2937	1.6629	11.181	1.2837	11.597
-0.8916	6.1987	1.0919	5.8775	0.4762	6.0487

2.Binary Component System:

Table B.5. Equilibrium isotherm for the binary component system of "Lead(II), Copper(II), and Cadmium(II)" onto banana peels at a concentration of Co=50 mg/l for each solute.

Lead+Copper				Lead+Cadmium				Copper+Cadmium			
"Lead(II)"		"Copper(II)"		"Lead(II)"		"Cadmium(II)"		"Copper(II)"		"Cadmium(II)"	
C_e (mg/L)	q_e (mg/g)	C_e (mg/L)	q_e (mg/g)	C_e (mg/L)	q_e (mg/g)	C_e (mg/L)	q_e (mg/g)	C_e (mg/L)	q_e (mg/g)	C_e (mg/L)	q_e (mg/g)
14.11	61.78	33.87	32.25	11.1	67.8	33.66	32.68	39.25	21.5	41.16	17.67
8.655	41.345	23.61	26.39	7.4	42.6	29.191	20.808	34.021	15.979	38.89	11.1
6.772	28.819	17.51	21.66	4.85	30.097	25.523	16.318	28.77	14.153	35.03	9.98
4.486	22.756	11.13	19.43	3.33	23.335	20.16	14.92	24.87	12.565	30.02	9.99
3.087	11.728	6.835	10.79	1.15	12.213	7.705	10.574	15.88	8.53	19.46	7.63
0.955	6.131	2.947	5.882	0.55	6.181	5.305	5.587	8.38	5.203	12.51	4.69

Table B.6. Langmuir isotherms onto banana peels as sorbent in a binary component system: experimental and theoretical data.

Lead+Copper				Lead+Cadmium				Copper+Cadmium			
"Lead(II)"		"Copper(II)"		"Lead(II)"		"Cadmium(II)"		"Copper(II)"		"Cadmium(II)"	
$1/C_e$	$1/q_e$	$1/C_e$	$1/q_e$	$1/C_e$	$1/q_e$	$1/C_e$	$1/q_e$	$1/C_e$	$1/q_e$	$1/C_e$	$1/q_e$
0.071	0.0139	0.0295	0.031	0.0901	0.0128	0.0297	0.031	0.0254	0.046	0.024	0.0565
0.1155	0.0241	0.0423	0.037	0.1351	0.0235	0.0342	0.048	0.0294	0.0625	0.0257	0.0901
0.1476	0.0347	0.0571	0.046	0.2059	0.0332	0.0391	0.061	0.0347	0.0706	0.0285	0.1002
0.2228	0.0439	0.0898	0.051	0.301	0.0428	0.049	0.067	0.0402	0.0795	0.0333	0.1001
0.3239	0.0852	0.1463	0.092	0.869	0.0818	0.1297	0.095	0.0629	0.1172	0.0513	0.1309
1.0471	0.1631	0.3392	0.17	1.8181	0.1617	0.1885	0.1789	0.1193	0.1922	0.0799	0.2134

Table B.7. Experimental and theoretical data for Frendlich isotherms on banana peels sorbent in binary component system

Lead+Copper				Lead+Cadmium				Copper+Cadmium			
"Lead(II)"		"Copper(II)"		"Lead(II)"		"Cadmium(II)"		"Copper(II)"		"Cadmium(II)"	
$Ln(C_e)$	$Ln(q_e)$	$Ln(C_e)$	$Ln(q_e)$	$Ln(C_e)$	$Ln(q_e)$	$Ln(C_e)$	$Ln(q_e)$	$Ln(C_e)$	$Ln(q_e)$	$Ln(C_e)$	$Ln(q_e)$
2.6468	4.274	3.5226	3.4735	2.4069	4.3541	3.5163	3.4867	3.6699	2.068	3.717	2.871
2.1582	3.7219	3.161	3.2729	2.0014	3.7518	3.3738	3.0353	3.5269	2.7713	3.66	2.407
1.9128	3.361	2.8627	3.0754	1.58	3.4044	3.2395	2.7922	3.3593	2.649	3.5562	2.3

1.5011	3.1248	2.4098	2.967	1.2029	3.1499	3.0037	2.7027	3.2136	2.5309	3.4018	2.301
1.1272	2.462	1.9221	2.379	0.1397	2.5024	2.0418	2.3584	2.765	2.1435	2.9686	2.032
-0.046	1.8133	1.0809	1.772	-0.598	1.8215	1.6686	1.7204	2.1258	1.6491	2.5265	1.545

3.Ternary Component System:

Table B.8. On banana peels, the equilibrium isotherm for the ternary component system of "Lead(II), Copper(II), and Cadmium(II)" was measured at Co=50 mg/l for each solute.

banana Dosage (g/L)	"Lead(II)"		"Copper(II)"		"Cadmium(II)	
	C_e (mg/L)	q_e (mg/g)	C_e (mg/L)	q_e (mg/g)	C_e (mg/L)	q_e (mg/g)
0.5	25.55	48.9	38.05	23.9	44.55	10.9
1	18.95	31.05	31.61	18.39	40.544	9.456
1.5	12.62	24.92	22.51	18.326	37.055	8.63
2	9.425	20.287	17.125	16.437	34.095	7.953
4	4.3	11.425	9.7	10.075	24.535	6.366
8	1.96	6.005	5.235	5.595	15.96	4.255

Table B.9. Data from experiments and theory for the Langmuir isotherms onto the sorbent of banana peels in a ternary component system.

Lead(II)		Copper(II)		Cadmium(II)	
$1/C_e$	$1/q_e$	$1/C_e$	$1/q_e$	$1/C_e$	$1/q_e$
0.0391	0.0204	0.0262	0.0418	0.0224	0.0917
0.0527	0.0322	0.0316	0.0543	0.0246	0.1057
0.0792	0.0401	0.0444	0.0545	0.0269	0.1158
0.1061	0.0492	0.0583	0.0608	0.0293	0.1257
0.2325	0.0875	0.1031	0.0992	0.0407	0.157
0.5102	0.1665	0.191	0.1787	0.0626	0.235

Table B.10. Data from experiments and theory for Frendlich isotherms on a sorbent made of banana peels in a ternary component system.

Lead(II)		Copper(II)		Cadmium(II)	
"Ln(C_e)"	"Ln(q_e)"	"Ln(C_e)"	"Ln(q_e)"	"Ln(C_e)"	"Ln(q_e)"
3.2406	3.8897	3.6389	3.1738	3.7966	2.3887
2.9418	3.4355	3.4534	2.9118	3.7039	2.2466
2.5352	3.2156	3.1139	2.9083	3.6124	2.1552
2.2433	3.0101	2.8405	2.7995	3.5291	2.0735
1.4586	2.435	2.2721	2.3101	3.2001	1.851
0.6729	1.7925	1.6553	1.7219	2.77	1.4489

Appendix (C)

Experimental and Theoretical Data for Sorption Kinetics Models

Table C.1: Data on the sorption kinetics of Lead(II), Copper(II), and Cadmium(II) on banana peels, both experimental and theoretical.

Time (min)	Lead(II)		Copper(II)		Cadmium(II)	
	C_e (mg/L)	q_t (mg/g)	C_e (mg/L)	q_t (mg/g)	C_e (mg/L)	q_t (mg/g)
0	50	0	50	0	50	0
10	19.501	15.249	30.565	9.717	28.095	10.952
15	15.084	17.458	27.705	11.147	21.251	14.374
30	7.67	21.165	21.1	14.45	14.875	17.562
60	3.23	23.385	15.615	17.192	9.6	20.2
90	2.251	23.875	14.527	17.736	8.205	20.897
120	1.45	24.275	13.772	18.113	7.99	21.005
150	1.27	24.364	13.451	18.274	7.847	21.076
180	0.505	24.747	13.362	18.319	7.412	21.294

Table C.2. In banana peels, lead (II), copper (II), and cadmium (II) exhibited pseudo-first order kinetics, according to experimental and theoretical evidence.

Time (min)	$Ln(q_e-q_t)$		
	banana peels		
	Lead(II)	Copper(II)	Cadmium(II)
0	3.208	2.907	3.058
10	2.251	2.152	2.336
15	1.986	1.970	1.934
30	1.276	1.352	1.316
60	0.309	0.119	0.089
90	-0.135	-0.54	-0.925
120	-0.749	-1.583	-1.241
150	-0.96	-3.112	-1.524

Table C.3: For Lead(II), Copper(II), and Cadmium(II), experimental and theoretical data on pseudo second order kinetics were collected on banana peels.

Time (min)	t/q_t (min g/mg)		
	banana peels		
	Lead(II)	Copper(II)	Cadmium(II)
10	0.655	1.0291	0.913
15	0.859	1.345	1.0435
30	1.417	2.076	1.708
60	2.565	3.489	2.970
90	3.769	5.074	4.306
120	4.943	6.624	5.7129
150	6.156	8.208	7.117
180	7.273	9.825	8.453

Appendix (D)

Data from experiments and theory for a flotation system

Table D.1. Impact of pH on flotation's ability to remove 50 mg/L of "Lead(II)

Time (min)	pH3		pH4		pH5		pH6		pH7		pH8	
	"Re(%)"	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0	0	0	0	0	0	0
3	3.19	-0.032	9.17	-0.096	18.62	-0.206	22.6	-0.256	28.5	-0.335	32.30	-0.390
10	6.99	-0.072	16.32	-0.178	23.13	-0.263	27.01	-0.314	36.5	-0.454	43.5	-0.570
20	8.01	-0.083	16.61	-0.181	25.99	-0.300	31.44	-0.377	40.7	-0.522	54.16	-0.780
30	9.67	-0.101	18.46	-0.204	27.63	-0.323	33.28	-0.404	48.39	-0.661	58.35	-0.875
40	10.1	-0.106	19.12	-0.212	28.6	-0.336	33.92	-0.414	50.7	-0.707	61.19	-0.946

Table D.2: Consequence of pH on the elimination of 50 mg/L of Copper(II) by flotation

Time (min)	pH3		pH4		pH5		pH6		pH7		pH8	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0	0	0	0	0	0	0
3	3.82	-0.038	5.05	-0.051	9.29	-0.097	17.98	-0.198	22.42	-0.253	41.96	-0.544
10	8.43	-0.088	9.801	-0.103	19.87	-0.221	26.07	-0.302	34.81	-0.427	50.58	-0.704
20	11.04	-0.116	16.47	-0.179	27.03	-0.315	32.32	-0.390	45.58	-0.608	57.36	-0.852
30	14.59	-0.157	21.81	-0.246	27.82	-0.326	36.13	-0.448	48.95	-0.672	65.1	-1.052
40	15.48	-0.168	22.08	-0.249	30.17	-0.359	36.23	-0.449	53.06	-0.756	68.74	-1.162

Table D.3. Consequence of pH on the elimination of 50 mg/L of Cadmium(II) by flotation

Time (min)	pH3		pH4		pH5		pH6		pH7		pH8	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0	0	0	0	0	0	0
3	7.71	-0.08	10.33	-0.109	28.62	-0.337	34.07	-0.416	30.81	-0.368	33.34	-0.405
10	13.3	-0.142	20.97	-0.235	32.33	-0.390	37.9	-0.476	31.4	-0.376	40.22	-0.514
20	13.41	-0.143	24.47	-0.28	34.11	-0.417	40.09	-0.512	38.48	-0.485	42.86	-0.559
30	15.67	-0.170	26.11	-0.302	36.73	-0.457	41.44	-0.535	41.68	-0.539	47.47	-0.643
40	19.82	-0.220	28.56	-0.336	37.24	-0.465	42.89	-0.560	45.92	-0.614	49.59	-0.684

Table D.4. Impact of SDS concentration on ion flotation's ability to remove 50 mg/L of Lead(II)

Time (min)	SDS=50mg/L		SDS=100mg/L		SDS=200mg/L	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	18.62	-0.206	24.87	-0.285	46.32	-0.622
10	23.15	-0.263	30.12	-0.358	54.06	-0.77
20	25.98	-0.300	32.63	-0.394	59.22	-0.896
30	28.66	-0.337	33.89	-0.413	60.88	-0.938
40	28.55	-0.336	35.69	-0.441	61.739	-0.960

Table D.5. Impact of SDS concentration on ion flotation's ability to remove 50 mg/L of Copper(II)

Time (min)	SDS=50mg/L		SDS=100mg/L		SDS=200mg/L	
	"Re(%)"	"$\ln(c/c_o)$"	"Re(%)"	"$\ln(c/c_o)$"	"Re(%)"	"$\ln(c/c_o)$"
0	0	0	0	0	0	0
3	17.98	-0.198	24.621	-0.282	33.42	-0.406
10	26.19	-0.303	27.911	-0.327	47.05	-0.635
20	32.32	-0.39	37.104	-0.463	48.921	-0.671
30	36.13	-0.448	39.742	-0.506	51.97	-0.733
40	36.24	-0.450	40.609	-0.521	53.27	-0.76

Table D.6. Impact of SDS concentration on ion flotation's absorption of 50 mg/L of cadmium(II)

Time (min)	SDS=50mg/L		SDS=100mg/L		SDS=200mg/L	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	28.632	-0.337	30.01	-0.356	35.191	-0.433
10	32.321	-0.390	33.781	-0.412	42.059	-0.545
20	34.149	-0.417	38.701	-0.486	48.368	-0.661
30	36.719	-0.457	42.271	-0.549	48.819	-0.669
40	37.219	-0.465	44.569	-0.590	50.959	-0.712

Table D.7. Impact of air flow rate on ion flotation's removal of 50 mg/L of Lead(II)

Time (min)	Q=250 cm^3/min		Q=500 cm^3/min		Q=1000 cm^3/min	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	36.63	-0.456	46.44	-0.624	40.89	-0.525
10	41.89	-0.542	54.11	-0.778	43.54	-0.571
20	47.102	-0.636	59.32	-0.899	45.95	-0.615
30	51.24	-0.718	60.91	-0.939	46.32	-0.622
40	53.499	-0.765	61.81	-0.962	47.41	-0.642

Table D.8. mpact of air flow rate on ion flotation's elimination of 50 mg/L of Copper(II)

Time (min)	Q=250 cm^3/min		Q=500 cm^3/min		Q=1000 cm^3/min	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	31.92	-0.384	33.51	-0.408	35.81	-0.443
10	39.91	-0.509	47.12	-0.637	38	-0.478
20	42.5	-0.553	48.89	-0.671	39.399	-0.500
30	45.9	-0.614	51.88	-0.732	40.82	-0.524
40	47.71	-0.648	53.34	-0.762	41.49	-0.535

Table D.9. Impact of air flow rate on ion flotation's clearance of 50 mg/L of cadmium(II)

Time (min)	Q=250 cm^3/min		Q=500 cm^3/min		Q=1000 cm^3/min	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	26.62	-0.309	35.21	-0.434	0	-0.417
10	38.91	-0.492	42.101	-0.546	34.13	-0.394
20	40.66	-0.521	48.41	-0.661	32.62	-0.445
30	42.41	-0.551	48.79	-0.669	35.92	-0.465
40	44.51	-0.588	51	-0.713	37.21	-0.476

Table D.10. Ion flotation's ability to remove Lead(II) depends on the initial metal concentration.

Time (min)	C_o=30mg/L		C_o=50mg/L		C_o=100mg/L	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	62.91	-0.991	46.44	-0.624	20.16	-0.225
10	66.32	-1.088	54.13	-0.779	21.49	-0.241
20	72.24	-1.281	59.41	-0.901	28.88	-0.34
30	74.43	-1.363	60.79	-0.936	32.81	-0.397
40	76.812	-1.461	61.88	-0.964	33.812	-0.412

Table D.11. Ion flotation's ability to remove Copper(II) depends on the initial metal concentration.

Time (min)	C_o=30mg/L		C_o=50mg/L		C_o=100mg/L	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	45.41	-0.605	33.39	-0.406	13.51	-0.145
10	51.88	-0.731	47.101	-0.636	17.69	-0.194
20	55.87	-0.818	47.89	-0.651	19.79	-0.220
30	60.96	-0.940	52.97	-0.754	24.101	-0.275
40	62.3	-0.975	53.31	-0.761	24.5	-0.281

Table D.12. Cadmium(II) removal via ion flotation and initial metal concentration

Time (min)	C_o=30mg/L		C_o=50mg/L		C_o=100mg/L	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	41.7	-0.53	35.21	-0.43	7.7	-0.07
10	52.41	-0.74	42.101	-0.54	11.89	-0.12
20	59.89	-0.91	48.402	-0.66	15.91	-0.17
30	60.21	-0.92	48.79	-0.66	21.92	0-.24
40	60.871	-0.93	50.959	-0.71	22.969	-0.26

Table D.13. Impact of selectivity on ion flotation's ability to remove 50 mg/L Lead(II) in binary and ternary component systems.

Time (min)	Lead at (Lead-Copper)		Lead at (Lead-Cadmium)		Lead at (Lead-Copper-Cadmium)	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	28.91	-0.34	26.74	-0.30	17.88	-0.19
10	36.72	-0.45	31.81	-0.38	25.91	-0.29
20	40.79	-0.52	33.9	-0.41	28.89	-0.34
30	42.63	-0.55	39.49	-0.50	32.81	-0.39
40	43.89	-0.57	40.82	-0.52	33.87	-0.41

Table D.14. Impact of selectivity on ion flotation's ability to remove 50 mg/L Copper(II) in binary and ternary component systems.

Time (min)	Copper at (Lead-Copper)		Copper at (Copper-Cadmium)		Copper at (Lead-Copper-Cadmium)	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	8.89	-0.094	10.91	-0.115	7.61	-0.078
10	11.49	-0.122	15.88	-0.174	10.33	-0.108
20	16.69	-0.183	19.91	-0.22`	12.89	-0.138
30	18.81	-0.207	21.13	-0.237	16.01	-0.174

40	21	-0.235	21.92	-0.246	16.89	-0.186

Table D.15. Effect of selectivity on the removal of 50 mg/L Cadmium(II) by ion flotation in binary and ternary component system

Time (min)	Cadmium at (Lead-Cadmium)		Cadmium at (Copper-Cadmium)		Cadmium at (Lead-Copper-Cadmium)	
	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$	Re(%)	$\ln(c/c_o)$
0	0	0	0	0	0	0
3	11.91	-0.126	14.71	-0.158	9.12	-0.095
10	16.86	-0.186	22.59	-0.256	12.81	-0.1362
20	21.77	-0.244	24.89	-0.286	15.01	-0.162
30	23.85	-0.271	25.88	-0.3009	17.14	-0.1866
40	23.88	-0.274	26.89	-0.314	18.92	-0.209

Appendix (E)

Experimental Data for Sorptive-Flotation System

Table E. Impact of sorbent dosage on the elimination of 50 mg/L of Lead(II) by sorptive-flotation in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	Dosage=1g/L	Dosage=2g/L	Dosage=4g/L
0	0	0	0
3	50.71	73.12	80.501
10	74.91	80.21	87.42
20	79.93	85.91	91.61
30	83.62	89.14	94.12
40	84	91.01	95.45

Table E.2: Impact of sorbent dosage on sorptive-ability flotation's to remove 50 mg/L of Copper(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	Dosage=1g/L	Dosage=2g/L	Dosage=4g/L
0	0	0	0
3	20.93	58.77	64.55
10	27.77	54.13	66.91

20	37.01	64.01	71.32
30	38.88	65.42	76.84
40	40.76	69.71	79.32

Table E.3. Impact of sorbent dosage on sorptive-ability flotation's to remove 50 mg/L of cadmium(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	Dosage=1g/L	Dosage=2g/L	Dosage=4g/L
0	0	0	0
3	45.12	58.82	69.92
10	51.01	60.89	71.81
20	56.96	67.42	80.02
30	57.42	68.32	81.45
40	57.59	71.13	84.25

Table E.4. Impact of SDS content on sorptive flotation's ability to remove 50 mg/L of Lead(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	SDS =50mg/L	SDS =100mg/L	SDS =200mg/L
0	0	0	0
3	80.51	91.91	86.12
10	87.65	95.53	89.23
20	91.72	97	90
30	94.13	98.12	90.35
40	95.82	98.91	90.49

Table E.5.Impact of SDS content on sorptive flotation's ability to remove 50 mg/L of Copper(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	SDS =50mg/L	SDS =100mg/L	SDS =200mg/L
0	0	0	0
3	64.71	74.18	70.31
10	66.79	77.61	73.72
20	71.45	80.72	77.44
30	76.88	84.87	78.91
40	78.69	85.82	79.1

Table E.6. Impact of SDS content on sorptive flotation's ability to remove 50 mg/L of cadmium(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	SDS =50mg/L	SDS =100mg/L	SDS =200mg/L
0	0	0	0
3	69.91	84.87	78.81
10	71.89	89.55	85.91
20	75.88	90.14	88.22
30	81.92	95.93	90.64
40	83.73	96.87	92.12

Table E.7. Impact of SDS concentration on sorptive flotation's ability to remove Lead II and Copper II at 50 mg/L in a binary system

Time (min)	Removal Efficiency %			
	Flotation with banana peels			
	SDS=50mg/L		SDS=100mg/L	
	Lead(II)	Copper(II)	Lead(II)	Copper(II)
0	0	0	0	0
3	60.91	40.87	69.55	48.21
10	76.01	44.61	77.88	57.12

20	76.81	57.92	88.87	64.91
30	80.62	66.15	89.61	66.52
40	83.13	67.41	92.23	69.66

Table E.8. Impact of SDS concentration on sorptive flotation's ability to remove Lead II and Cadmium II at 50 mg/L in a binary system

Time (min)	Removal Efficiency %			
	Flotation with banana peels			
	SDS=50mg/L		SDS=100mg/L	
	Lead(II)	Cadmium(II)	Lead(II)	Cadmium(II)
0	0	0	0	0
3	64.81	43.92	75.22	48.81
10	80.92	53.41	85.91	55.88
20	89.1	56.44	92.73	64.11
30	90.82	67.12	94.81	70.23
40	90.91	70.91	96.31	70.51

Table E.9. Impact of SDS content on sorptive flotation's ability to remove Copper II and Cadmium II at a rate of 50 mg/L in a binary system

Time (min)	Removal Efficiency %			
	Flotation with banana peels			
	SDS=50mg/L		SDS=100mg/L	
	Copper(II)	Cadmium(II)	Copper(II)	Cadmium(II)
0	0	0	0	0
3	49.01	34.61	56.88	50.61
10	52.13	41.82	64.98	59.93
20	60.81	50.91	75.85	66.85
30	66.77	52.21	77.65	72.16
40	68.92	55.88	80.66	73.84

Table E.10. Impact of SDS content on sorptive flotation's ability to remove 50 mg/L of Lead(II) in a ternary system

Time (min)	Removal Efficiency %	
	Flotation with banana peels	
	SDS =50mg/L	SDS =100mg/L
0	0	0
3	63.55	77.13
10	69.91	81.53
20	70.81	85.15
30	78.1	86.42
40	80.91	88.22

Table E.11. Impact of SDS concentration on sorptive flotation's ability to remove 50 mg/L of Copper(II) in a ternary system

Time (min)	Removal Efficiency %	
	Flotation with banana peels	
	SDS =50mg/L	SDS =100mg/L
0	0	0
3	50.82	59.88
10	58.44	69.29
20	66.85	71.87
30	68.82	73.31
40	70.74	74.87

Table E.12. Effect of SDS concentration on the removal of 50 mg/L of Cadmium(II) by sorptive- flotation in ternary system

Time (min)	Removal Efficiency %	
	Flotation with banana peels	
	SDS =50mg/L	SDS =100mg/L
0	0	0
3	31.67	40.55
10	41.88	48.66
20	41.92	53.81
30	46.49	57.73
40	48.11	58.14

Table E.13. Impact of air flow rate on sorptive-ability flotation's to remove 50 mg/L of Lead(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	Q=250 cm^3/min	Q=500 cm^3/min	Q=1000 cm^3/min
0	0	0	0
3	72.87	91.94	95.33
10	77.54	95.55	98.76
20	86.01	97.12	98.99
30	90.77	98.13	99.14
40	92.88	98.93	99.87

Table E.14. Impact of air flow rate on sorptive-ability flotation's to remove 50 mg/L of Copper(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	Q=250 cm^3/min	Q=500 cm^3/min	Q=1000 cm^3/min
0	0	0	0
3	60.86	74.18	78.85
10	66.49	77.68	81.53
20	70.79	80.78	88.31
30	72.14	84.88	89.74
40	73.17	85.69	89.91

Table E.15. Impact of air flow rate on sorptive-ability flotation's to remove 50 mg/L of cadmium(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	Q=250 cm^3/min	Q=500 cm^3/min	Q=1000 cm^3/min
0	0	0	0
3	70.87	84.88	88.76
10	81.74	89.36	92.23
20	84.83	90.15	97.71
30	90.66	95.92	98.31
40	90.73	96.88	98.66

Table E.16. Impact of air flow rate on sorptive flotation's ability to remove Lead(II) and Copper2+ at 50 mg/L in a binary system

Time (min)	Removal Efficiency %			
	Flotation with banana peels			
	Q=500 cm^3/min		Q=1000 cm^3/min	
	Lead(II)	Copper(II)	Lead(II)	Copper(II)
0	0	0	0	0
3	69.33	48.22	78.39	58.41
10	77.86	57.16	89.79	60.87
20	88.84	64.79	96.01	77.72
30	89.66	66.52	97.72	78.15
40	92.24	69.67	97.91	78.82

Table E.17. Impact of air flow rate on sorptive-ability flotation's to remove Lead(II) and Cadmium2+ at 50 mg/L in a binary system

Time (min)	Removal Efficiency %			
	Flotation with banana peels			
	Q=500 cm^3/min		Q=1000 cm^3/min	
	Lead(II)	Cadmium(II)	Lead(II)	Cadmium(II)
0	0	0	0	0
3	75.23	48.86	86.14	53.14
10	85.79	55.87	94.24	62.39
20	92.73	63.91	96.19	68.91
30	94.69	70.24	98.63	76.29
40	96.22	70.39	99.03	78.88

Table E.18. Impact of air flow rate on sorptive flotation's ability to remove 50 mg/L of Copper(II) and Cadmium2+ in a binary system

Time (min)	Removal Efficiency %			
	Flotation with banana peels			
	Q=500 cm^3/min		Q=1000 cm^3/min	
	Copper(II)	Cadmium(II)	Copper(II)	Cadmium(II)
0	0	0	0	0
3	56.88	50.61	69.41	63.71
10	64.91	59.91	75.55	70.24

20	75.84	67.05	81.12	78.82
30	77.62	72.14	84.16	80.32
40	80.73	74.06	86.68	82.51

Table E.19. Impact of air flow rate on sorptive flotation's ability to remove 50 mg/L of lead(II) in a ternary system

Time (min)	Removal Efficiency %	
	Flotation with banana peels	
	Q=500 cm^3/min	Q=1000 cm^3/min
0	0	0
3	77.12	83.91
10	81.51	90.16
20	85.14	95.39
30	86.45	96.01
40	88.23	96.88

Table E.20: Impact of air flow rate on sorptive flotation's ability to remove 50 mg/L of copper(II) in a ternary system

Time (min)	Removal Efficiency %	
	Flotation with banana peels	
	Q=500 cm^3/min	Q=1000 cm^3/min
0	0	0
3	60.1	75.83
10	69.42	73.61
20	71.87	78.13
30	73.35	81.14
40	74.88	83.63

Table E.21. Impact of air flow rate on sorptive flotation's ability to remove 50 mg/L of cadmium(II) in a ternary system

Time (min)	Removal Efficiency %	
	Flotation with banana peels	
	Q=500 cm^3/min	Q=1000 cm^3/min
0	0	0
3	40.52	48.39
10	48.88	50.82
20	53.81	59.91
30	57.71	64.24
40	58.18	64.91

Table E.22. Impact of initial metal concentration on the sorptive-flotation process for removing Lead(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	C_o=30 mg/L	C_o=50 mg/L	C_o=100 mg/L
0	0	0	0
3	97.72	91.91	78.79
10	98.91	95.53	85.49
20	99.95	97.02	86.14
30	99.96	98.13	89.79
40	99.99	98.92	89.88

Table E.23. Impact of initial metal concentration on the sorptive flotation process' ability to remove Copper(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	C_o=30 mg/L	C_o=50 mg/L	C_o=100 mg/L
0	0	0	0
3	77.71	74.14	44.62
10	81.81	77.61	58.88
20	88.91	80.72	60.92
30	90.41	85.01	66.35
40	91.66	85.89	68.91

Table E.24. Impact of initial metal concentration on sorptive flotation's ability to remove Cadmium(II) in a single system

Time (min)	Removal Efficiency %		
	Flotation with banana peels		
	C_o=30 mg/L	C_o=50 mg/L	C_o=100 mg/L
0	0	0	0
3	95.88	84.87	70.61
10	97.55	89.35	74.14
20	97.91	90.14	81.813
30	98.14	95.91	82.36
40	98.87	96.86	82.84

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