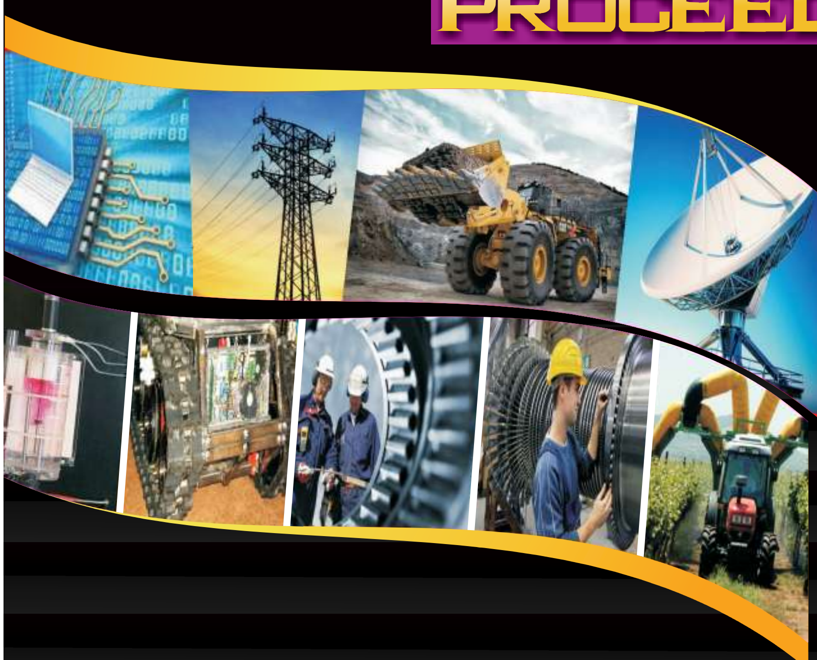
FEDERAL UNIVERSITY OF TECHNOLOGY, MINNA

SCHOOL OF ELECTRICAL ENGINEERING AND TECHNOLOGY &
SCHOOL OF INFRASTRUCTURE, PROCESS ENGINEERING AND TECHNOLOGY

3rd INTERNATIONAL ENGINEERING CONFERENCE IEC 2019

THEME THE ROLE OF ENGINEERING AND TECHNOLOGY IN SUSTAINABLE DEVELOPMENT

BOOK of PROCEEDINGS



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CONTENTS

Content **Page**

FORWARD

The School of Engineering and Engineering Technology, Federal University of Technology, Minna, organized the 1st and 2nd International Engineering Conference in 2015 and 2017 respectively. With the emergence of the new School of Electrical Engineering and Technology and the School of Infrastructure, Process Engineering and Technology, the two schools came together to organize this 3rd International Engineering Conference (IEC 2019) with the theme: “The Role of Engineering and Technology in Sustainable Development” considering the remarkable attendance and successes recorded at the previous conferences. The conference is aimed at offering opportunities for researchers, engineers, captains of industries, scientists, academics, security personnel and others who are interested in sustainable solutions to socio-economic challenges in developing countries; to participate and brainstorm on ideas and come out with a communiqué, that will give the way forward. In this regard, the following sub-themes were carefully selected to guide the authors’ submissions to come up with this communiqué.

1. Engineering Entrepreneurship for Rapid Economic Growth.
2. Regulation, Standardization and Quality Assurance in Engineering Education and Practice for Sustainable Development.
3. Solutions to the Challenges in Emerging Renewable Energy Technologies for Sustainable Development.
4. Electrical Power System and Electronic as a Panacea for Rapid Sustainable Development
5. Promoting Green Engineering in Information and Communication Technology
6. Reducing Carbon Emission with Green and Sustainable Built Environment
7. Artificial Intelligence and Robotics as a Panacea for Rapid Sustainable Development in Biomedical Engineering
8. Petrochemicals, Petroleum Refining and Biochemical Technology for Sustainable Economic Development.
9. Advances and Emerging Applications in Embedded Computing.
10. Traditional and Additive Manufacturing for Sustainable Industrial Development.
11. Emerging and Smart Materials for Sustainable Development.
12. Big Data Analytics and Opportunity for Development.
13. Building Information Modeling (BIM) for Sustainable Development in Engineering Infrastructure and Highway Engineering.
14. Autonomous Systems for Agricultural and Bioresources Technology.

The conference editorial and Technical Board have members from the United Kingdom, Saudi Arabia, South Africa, Malaysia, Australia and Nigeria. The conference received submissions from 4 countries namely: Malaysia, South Africa, the Gambia and Nigeria. It is with great joy to mention that 123 papers were received in total, with 0.9 acceptable rate as a result of the high quality of articles received. Each of the paper was reviewed by two personalities who have in-depth knowledge of the subject discussed on the paper. At the end of the review process, the accepted papers were recommended for presentation and publication in the conference proceedings. The conference proceedings will be indexed in Scopus.

On behalf of the conference organizing committee, we would like to seize this opportunity to thank you all for participating in the conference. To our dedicated reviewers, we sincerely appreciate you for finding time to do a thorough review. Thank you all and we hope to see you in the 4th International Engineering Conference (IEC 2021).

Engr. Dr. S. M. Dauda
Chairman, Conference Organizing Committee

ACKNOWLEGEMENT

The Chairman and members of the Conference Organizing Committee (COC) of the 3rd International Engineering Conference (IEC 2019) wish to express our gratitude to the Vice Chancellor and the management of the Federal University of Technology, Minna, the Deans and all staff of the School of Electrical Engineering and Technology (SEET) and the School of Infrastructure, Process Engineering and Technology (SIPET) for the support towards the successful hosting of this conference. We also thank the entire staff of the university who contributed in one way or the other. We are sincerely grateful to you all.

A Comprehensive Review on Use of Poly Electrolyte Complex PEC as an Adsorbent for the Removal of Heavy Metals From Aqueous Solution.

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ABSTRACT

Water pollution has become a 21st century problem because of industrialization. Adsorption is one of the most cost effective ways of removing noxious heavy metals from the solvent phase. This paper presents a detailed information and review on the adsorption of noxious heavy metal ions from wastewater effluents using polyelectrolyte complex PEC formed by Natural-Natural , natural-synthetic, synthetic-synthetic interaction of polyelectrolyte as adsorbents. In addition to this, the mode of preparation, efficiency of developed PEC for adsorption of the heavy metals ions is discussed in detail along with the comparison of their maximum adsorption capacity in tabular form. The results of searches show that PECs, which have low or almost no economic value because most are derived from waste, can be used as adsorbents for the adsorption of heavy metal ions from the solution.

Keywords: *Adsorption, Heavy metals, Metal ions, Polyelectrolyte complex PEC, Wastewater.*

INTRODUCTION

Nowadays researchers are looking for novel ways to remove metals from wastewater; this environmental pollution is caused by rapid industrialization. The using of various metallic materials have a negative impact on the environment, namely the emergence of cases of environmental pollution caused by waste containing heavy metals (Hastuti, et al 2017) . This pollution can cause harm to the people around the industry producing the metallic waste. Refining metal factory, metal plating, painting and manufacturers of battery are a source of heavy metal contaminants. Waste containing the remains of these heavy metals is dangerous if not properly treated. Many methods are being used to remove heavy metal ions include chemical precipitation, ion-exchange, adsorption, membrane filtration, electrochemical treatment technologies etc. According to Hastuti et al Adsorption is one of the physicochemical treatment processes which have been found to be effective in removing heavy metals from aqueous solutions. adsorption has gained much attention because of its ease of operation, effectiveness, low cost etc. different adsorbents have been used in the adsorption of metals, however poly electrolyte complex PEC, have recently received a great deal of attention because of the fact that they represent renewable resources and are more environmentally friendly, nontoxic, than traditional materials. Poly electrolyte complex PEC is formed through combined electrostatic interactions, which are predominate, between poly cations and poly anions upon mixing of aqueous solutions of oppositely charged poly electrolyte PE leading to the formation of a dense phase that is separated from the solvent, and the formation of multitudinous charges and functional groups such as -OH, -NH, -SH and –COOH on the surface of the PEC. (Meka, et al. 2017). PECs have a three-dimensional network structure, which was used in medical treatment when it was first discovered. Due to its ability to absorb water, it is used in agriculture, health care and so on. In recent years, it has been found that the PECs have a polyfunctional structure so that it also exhibits excellent performance as an adsorbent for heavy metal ion treatment (Yin, et al, 2018). Taking into account the importance of water quality and emerging benefits of polyelectrolyte complex, attempts have been made to discuss various issues of water treatment using low cost adsorbents. Critical analysis of various PEC used in the removal of various heavy metals, their performance, selectiveness and the optimum conditions in which they were operated. Furthermore, knowledge gaps, uncertainties, and future challenges involved in the fabrication and regeneration of PEC are also identified.

2.1 Polyelectrolyte complex PEC

Poly electrolyte complex results from electrostatic interactions between poly cations and poly anions, there are other bonds which can be formed between poly cations and poly anions such as hydrogen bonds, Vander Waals forces and covalent bond which results from crosslinking macro molecules (Chan, et al, 2010). PEC are formed from poly electrolyte PE, these PEs are divided into natural, chemically modified/semi-synthetic and synthetic PE (Meka, et al, 2017). PECs has the ability to attract water molecules, the super-hydrophilicity characteristics and porous structure networks; they can swell quickly in the aqueous solution, which is necessary for shortening the time to reach the adsorption equilibrium (Abd El-Mohdy, et al, 2013). The functionalization of PEC can improve its water uptake capacity and also act as a support for molecular species and metal ions. As hydrogels these hydrogels possess functional groups it increases their metal uptake capacity.

Table 1: polyelectrolytes (PEs) and their ionic nature

polyelectrolytes (PEs) and their ionic nature

PE type	Polyanion	Polycation	Reference
Natural	Galactorunic acid, Nucleic acids, poly(L-glutamic acid), carrageenan, sodium alginate, hyaluronic acid, chondroitin sulfate, gellan gum, gum kondagogu, gum karaya, Cieba pentandra gum, Termianlia catappa gum,	Poly(L-lysine), lysozyme, gelatin, chitosan, dextran, starch	Meka, et al, 2017
Chemically modified/ semi-synthetic	N-carboxymethyl chitosan, cellulose-based (sodium carboxymethyl cellulose), carboxymethyl konjac glucomannan, pectin, sodium dextran sulfate, xanthan gum	Chitosan (deacetylation of chitin), N-trimethyl chitosan, chitosan-g-poly(ethylene glycol) monomethyl ether	Meka, et al,2017
Synthethic	Poly(acrylic acid)/carbopol, poly(methacrylic acid), Eudragit1 (Eudragit1 L 100, Eudragit1 S 100, Eudragit1 FS 30 D), poly(acrylamide-2-methyl-propane sulfonate), poly(3-sulfopropyl methacrylate), dextran sulfate, poly (sodium styrene sulfonate), poly(vinyl sulfate), poly (acrylic acid-co-maleic acid), poly(p-styrenesulfonic acid), poly(p-styrenecarboxylic acid), poly(metaphosphoric acid), poly(4-	Poly(ethyleneimine), poly(allylamine hydrochloride), Eudragit1 E polymer (Eudragit1 E PO, Eudragit1 E 100), poly(N,N,N-trimethyl-2-methacryloyl ethyl ammonium) bromide, poly(diallyldimethyl ammonium chloride), poly (4-vinyl-N-methylpyridinium iodide), poly (acrylamide-co-dimethyldiallylammonium chloride), poly(vinylbenzyl trialkyl ammonium), poly(acryloyl-oxyalkyl-trialkyl ammonium), poly(acrylamidoalkyl-trialkyl ammonium), poly(2-vinylpyridine), poly(aminoethyl	Meka, et al, 2017

	methacryloyl oxyethyl trimelliate), poly (itaconic acid), poly(vinyloxy -4-butyric acid), poly(sodium 4-vinylbenzoate), poly(sodium acrylate)	methacrylate), poly(2-ethyloxazoline), poly[4-(N,N-dimethylamino methylstyrene)], poly(b-amino ester), poly(sulfoneamine) hydrochlorate, poly(methacryloxyethyl trimethylammonium chloride)	

2.1.1 TYPES OF PECs ON THE BASIS OF INTERACTION (Shailesh *et al*, 2016)

1. Polyelectrolyte complex between natural polyelectrolyte

2. Polyelectrolyte complex between synthetic polyelectrolyte

3. Polyelectrolyte complex between natural and synthetic polyelectrolyte

4 Protein – polyelectrolyte complexation

2.1.2 PROCESS FOR THE FORMATION OF PECS

The process involved in the formation of PECs can be subdivided into three classes (Meka, et al., 2017):

Primary complex: Primary complex can form immediately after mixing of the two oppositely charged PE solutions owing to the binding forces. This process is fast.

Intra complexes. This is an intermediate complex formation usually taking 1–2 h from the time of mixing. It is at this process, new electrostatic bonds can form and/or alterations in the polymeric chains can occur.

Inter complex/aggregation. This process involves the aggregation of intermediate complexes through hydrophobic interactions. Such an aggregation is caused by some factors, for example the structure of the polymer components and the complexation conditions

2.1.3 Factors influencing PECs Formation

The nature, structure, quantity and application of PECs depend on the method by which it was prepared. This method depends on some factors, such as degree of ionization and charge distribution on the PEs, density of the PEs as well as their charges, PE chain stiffness, concentration, strength of the ionic sites, mixing ratio, order, duration and intensity, ionic group nature, chain flexibility, molecular weight, polymer structure, hydrophobicity, temperature conditions during process, degree of complexation, pH and ionic strength (Meka, et al, 2017).

2.1.3.1 EFFECT OF PH

pH is a very important factor in the formation of PECs because it determines the yield of PEC formed. At a very low pH polyanions will not dissociate and will not form complexes owing to the lack of dissociated carboxylate anions. As the pH is increased or upon dilution, polyanions can form a stable complex with oppositely charged polycations because the quantity of dissociated carboxylate anionic sites exceeds the critical value. At this stage, the complex is formed in the form of a curdy precipitate (Meka et al, 2017). At a pH higher than 7 (pH >7) an equimolar electrolyte complex aggregate is formed because of a complete dissociation of the poly anions.

2.1.3.1 EFFECT OF CONCENTRATION

The size of PEC formed depends greatly on the ratio of the poly cation and poly anion mixed, at a higher concentration of PEs, the PEC formed has large size.

2.2 Poly electrolytes complex used as Pb^{2+} adsorbent

Lead is a byproduct of industrial activities; these industries include battery and fuel industry, foundry and refinery industries. The presence of lead in the environment can wreak havoc in the lives of humans. These damages include kidney failure, brain damage, liver damage etc. Hastuti, et al, 2016 used carboxymethyl chitosan CMC and pectin to remove lead from aqueous solution. Chitosan is a copolymer of glucosamine and N-acetylglucosamine with reactive groups of amine and hydroxyl groups. Pectin is a polysaccharide derived from plant walls especially orange peel and apple pomace, it is a galacturonic acid with carboxylate group as its functional group (Zhang et al, 2017). CMC-pectin complex formed was characterized by using IR the active groups of the PEC was hydroxyl (OH) and carboxylate (-COOH) groups. The optimum mass ratio CMC: pectin to form the polyelectrolyte complex was 70%: 30%. The optimum conditions for Pb (II) ion adsorption was 10 mg of the adsorbent mass, 75 min of contact time, and pH 5. The material was effectively used to adsorb Pb (II) ions, where up 91% Pb (II) metal ions was adsorbed from aqueous solution and the adsorption capacity of the adsorbent was 41.63 mg/g.

Cellulose is the most abundant biopolymer in plant, it is nontoxic, biodegradable. Due to the multiple hydroxyl groups in its molecular chain, cellulose can be an ideal carrier for tannin immobilization via epichlorohydrin activation (Ying, et al, 2019). Tannin/cellulose microspheres (T/C) were used in the removal of Pb2+ by Ying, et al, 2019. The microsphere had a maximum adsorption capacity of 23.75 mg/g from the Langmuir isotherm evaluation at 308K with an initial pH of 5, the optimum conditions for Pb (II) in their experiment was 2 mg of the adsorbent mass, 60 min of contact time, adsorbate initial concentration 100mg/L and pH 5. Ying 2019 reported that lead adsorption by Tannin/cellulose microspheres was driven by pH as seen from ZETA potential. The removal efficiency of the PEC was 95%. The results suggested that tannin/cellulose microspheres could be a low-cost and effective adsorbent for removing Pb (II) ions from aqueous solution. The mechanism of adsorption for lead from wastewater was via ionic interaction and chelation (Ying et al., 2019).

PEC was synthesized between N, N-dimethylacrylamide (DMAa) and 2-hydroxyethyl methacrylate (HEMA) for the adsorption of lead by free-radical type bulk copolymerization of equal volumes of each monomer (Ramos-Jacques et al, 2018). The PEC was formed between synthetic poly electrolytes, the uptake of water of the adsorbent was 3.5 times its weight at a period of 6 hrs which is necessary for shortening the time to reach the adsorption equilibrium (Abd El-Mohdy, et al, 2013), and their optimum condition for the uptake of Pb^{2+} was 5hrs of contact time, optimum temperature of 270C. As the Pb (II) initial concentration was increased gradually from 10 to 200 ppm, the amount of sorbed Pb(II) at equilibrium increased. As a result, different Qe values were obtained when higher initial concentration solutions (Ci) were used. This continued until a critical point QC was reached were there was no change in Qe (Ramos-Jacques et al, 2018). The final concentration Ce remained unchanged after equilibrium was reached. The Pb(II) adsorption on the p(HEMA-co-DMAa) copolymer followed the Langmuir model than the Freundlich model. Therefore, the p(HEMA-co-DMAa) copolymer behaves preferably as an energetically homogeneous surface during the Pb(II) sorption process. The adsorption capacity was 61.41mg/g and the removal efficiency was 60%.

2.1.3.2 POLY ELECTROLYTE COMPLEX USED AS PB2+ AND CD2+ ADSORBENT

The composite formed between polyaniline and chitosan is between a natural and a synthetic poly electrolyte (Shailesh et al, 2016). Polyaniline grafted chitosan PGC was prepared by grafting polyaniline into the matrices of chitosan, the reactive group in PGC is hydroxyl and carboxylate group (Karthik, 2014). Karthik 2014 reported that the adsorption of Cd (II) and Pb (II) reached equilibrium at pH 6, beyond pH 6, the experiments were not carried out due to the formation of lead hydroxide and cadmium hydroxide. The percentage removal increased as the dosage increased from 0.05 to 0.15 g/L due to an increase in the available adsorption sites and that the removal efficiency for Pb (II) was 100% while that of Cd(II) was 96.95%. PGC showed a greater affinity towards Pb(II) than Cd(II) because the binding energy that is constant b from langmuir isotherm, of Pb(II) was greater than that of Cd(II). Karthik 2014 revealed that the adsorption process using PGC was spontaneous, endothermic and freundlich isotherm was the suitable model for the adsorption process. The sorption capacity of PGC will increase with increase capacity. The adsorption capacity for Pb(II) and Cd(II) was 13.23mg/g and 12.87mg/g respectively.

TABLE 2: SHOWING PEC FOR REMOVAL OF PB

PEC(adsorbent)	Type of Interaction	Optimum conditions				Qe (mg/g)	Removal %	Reference
		pH	Dosage	Temp	Time			
CMC-pectin complex	Natural-Natural	5	10	-	75	41.63	91	Hastuti et al, 2017
Tannin/cellulose microspheres (T/C)	Natural-Natural	5	2	-	60		95	Ying et al., 2019
(HEMA-co-DMAa)	Synthetic-Synthetic	<8	-	27	300	61.41	60	Ramos-Jacques et al, 2018
Polyaniline grafted chitosan PGC	Natural	6	0.15	-	60	13.23	100	Karthik, 2014

2.3 POLY ELECTROLYTES COMPLEX USED AS CU^{2+} ADSORBENT

Cellulose is the most abundant biopolymer in plant, it is nontoxic, biodegradable. Due to the multiple hydroxyl groups in its molecular chain (Ying et al., 2019). Gelatin is an ionic hydrophilic linear polymer which exhibits properties of water solubility, non-toxicity, and biodegradability (Wang 2013). It has proven to be able to improve the strength, hydrophilicity, and functional properties of hydrogel. Cellulose and gelatin was used to form composite for the removal of Cu2+, the performance of the adsorbent was evaluated and from the characterization of the PEC, Teow et al, 2018 reported that the functional group is the O-H and N-H group. from Zeta potential, it was also reported that PEC had Higher negative charge of cellulose/gelatin hydrogels at higher weight percent of gelatin was due to the presence of dipolar polarization effect inherent by N-H functional group attributed to the addition of gelatin. The optimum pH for the adsorption of Cu^{2+} was 4.7, because at pH 4.7, Cu^{2+} is at its Natural pH. At this pH H+ ions concentration was lowest and the O─H and N─H groups were existed in neutral forms. Hence, the competition between H^{+} ions and Cu2+ ions on adsorption sites of hydrogel was less significant and the electrostatic repulsion between the active sites and Cu^{2+} ions was weaker. As a result, more Cu^{2+} ions could be adsorbed onto the hydrogel (Teow et al, 2018). An increase in the concentration of Cu^{2+} ions in aqueous solution , caused the concentration gradient between the adsorbent (hydrogel) and adsorbate solution (Cu^{2+} ions aqueous solution) to induced a stronger driving force to transport the large number of Cu^{2+} ions from the bulk solution to the active sites on the surface of hydrogel (Wang et al, 2013). The optimum time was observed to be 6hrs, the adsorbent dosage was 20 mg and the adsorption capacity was found to be 52.3mg/g. It was concluded from the success of the research study that cellulose/gelatin composite hydrogel and is a sustainable and environmental-friendly adsorbent for the removal of heavy metal from wastewater.

Chitosan/polyvinyl alcohol (CTN/PVA-$Fe^{3}O^{4}$) was investigated by Karaer et al, 2017 for the removal of copper. Poly (vinyl alcohol) (PVA) is a water-soluble matter containing large amounts of -OH groups and it has a lot of advantages such as low price,chemically stable, biocompatibility, high durability and non-toxic. The effect pH was not conduct in a basic medium due to precipitation in a pH>6(Karaer et al, 2017). The ractive group of the PEC determined from FTIR was OH and NH_2 group. The PEC swelled up to 93%, the water absorbency of the composite was found very high. From the experiment the initial concentration increased from 25 to 400 mg/L with increase in time and reached equilibrium at 200 mins. kinetic experimental data of this work be fit better pseudo second-order adsorption indicating that adsorption process was dependent on ion concentration, and chemical sorption was the rate-controlling step. The optimum pH was observed to be 5, the adsorption was fitted for Langmuir isotherm and the thermodynamics parameters showed it was spontaneous and endothermic. The adsorption capacity was found to be 62-143 mg g-1.

2.4 Poly Electrolytes Complex Used in Removal of Multi Metal

Lessa et al, 2017, investigated the adsorption capacity of pectin/cellulose microfibers (Pec-CF) beads towards the removal of multi-metals ions from water. For this, a series of experiments were performed and rationalized to establish the optimum conditions for the adsorption of copper (Cu), cadmium (Cd) and iron (Fe) on Pec-CF beads. The composite was prepared by factorial design approach. The optimized analytical conditions set for the further experiments were: adsorbent dosage – 150 mg; pH of the medium – 4; and content of CF – 5.5 wt%. This pH (pH 4) was chosen because it is an intermediate value between the optimum pHs verified for the removal of Cd (II), Cu(II), and Fe(II) ion (Lessa et al, 2011). The result from batch experiment carried out by Lessa et al, showed that amount of metal adsorbed on beads increased with increasing initial metal concentration in the medium. It also showed that above 20 min, the adsorption capacity values tend to level off and they showed slight variation up to the end of the experiment. The removal efficiencies were slightly affected by the initial metals concentration. The maximum removal of Cd(II), Cu(II), and Fe(II) ions was ca. 58%, 77%, and 94% when the initial concentration of such metals falls in the range of 50–150 mg/L. the adsorption capacity for this study was 192.3, 88.4 and 98.0 mg/g. the adsorption capacities and removal efficiencies followed the order Fe(II) > Cu(II) > Cd(II). The Pec-CF beads can be utilized as an efficient and reusable adsorbent material for removing of multi-contaminants from wastewater (Lessa et al, 2011).

Jiang. C, et al, 2019 reported the performance of Glucan/chitosan (GL/CS) in the removal of Cu^{2+}, Co^{2+}, Ni^{2+},Pb^{2+} and Cd^{2+}. Glucan is homologous polysaccharide composed of glucose monosaccharide it is linked by glycoside bonds. The glycosidic bond can be divided into alpha-glucan and beta-glucan. Alpha-glucan, is also known as glucan, it is found in the mucus secreted by certain microorganisms during their growth (Jiang. C, et al, 2019). GL/CS PEC was synthesized by ultrasonic assisted method using glucan and chitosan as the main raw materials. The swelling capacity of the adsorbent was observed and it was reported that the absorption rate increased rapidly within 40mins and reached a saturation point at 60 mins. Adsorption increases when the absorption rate is fast but decreases with a decrease in adsorption rate (Jiang. C, et al, 2019). qe increases with an increase in pH value and the minimum value of qe is at pH=1 for all the ions. The reactive group in the PEC is (-COO-, -NH-, -O-), the optimum adsorbent dosage was 0.02mg, beyond this, the adsorption capacity of the adsorbent decreased. This was true for all the ions. The adsorption capacity of Cu^{2+} is 365 mg g-1, Co^{2+} is 251 mg g-1, Ni^{2+} is 207 mg g-1, Pb^{2+} is 424 mg g-1, and Cd^{2+} is 356 mg g-1. The thermodynamic parameter of the adsorption process is a spontaneous endothermic chemical monolayer adsorption. The adsorbent was selective towards $Pb^{2+} > Cu^{2+} > Cd^{2+} > Co^{2+} > Ni^{2+}$.

Carboxymethyl cellulose/polyacrylami CMC/PAM composite hydrogel was prepared via free-radical polymerization for the removal of Cu^{2+}, Pb^{2+} and Cd^{2+} (Godiya et al, 2018). For multiple metal-ion adsorption, the qe values are much lower than those for the single metal-ion adsorption, this result reveals that the adsorption of metal ions (Cu^{2+}, Pb^{2+} or Cd^{2+}) is negatively affected by the existence of the other two metal ions (Godiya et al, 2018), this is because the metal ions will compete for the binding site (Burakov, et al,2018). The CMC/PAM composite hydrogel showed a preference of $Cu^{2+} > Pb^{2+} > Cd^{2+}$. The adsorption follows the Langmuir model and exhibits a pseudo second-order kinetics. The adsorption capacities for the metal ions were observed to be 151.5, 185.2 and 144.9 mg/g. The adsorption of the three ions followed the Langmuir model rather than the Freundlich model, indicating a monolayer adsorption manner of the investigated metal ions in the CMC/PAM hydrogels. The optimum time for this work was 7hrs.

He, et al, 2017 investigated the use of β-cyclodextrin (β-CD) polymer, for the removal of lead (Pb), copper (Cu) and cadmium (Cd). The adsorption took place in the chelating sites and ion exchange sites of the PEC. β-cyclodextrin (β-CD) is inexpensive, sustainable produced macro cycle of glucose, But it has low surface areas and poor removal performance compared to conventional adsorbents like activated carbons, it was crossed linked with tetrafluoroterephthalonitrile to improve the surface area. The adsorption of Pb, Cu and Cd on β-CD polymer was fit better with Freundlich model, indicating that the adsorption process of Pb, Cu and Cd took place on heterogeneous surfaces that varied with surface coverage (He, et al, 2017). The adsorption capacities Was found to 215.2, 192.8 and 163.2 mg/g. the optimum pH beyond which no adsorption will take place was pH 5, temperature was 45^{0}C, and the optimum time was 5mins. The PEC was preferential towards Pb > Cu > Cd.

Cellulose-graft-poly (acrylic acid (AA)- co-acrylamide (AM)) was used as a biosorbent in the removal of Cu (II), Pb (II) and Cd (II) from aqueous solutions (Zhao et al, 2019). The effect on pH on MCC-g-(AA-co-AM), above pH 6, the metal hydroxides would be precipitated from the solution, the adsorption reached equilibrium at a pH 3. The optimum time at which equilibrium was reached was 15 mins. The adsorption capacity of the PEC increased with increase in initial concentration of the metal ions, the increased rate of mass transfer resulted from increased driving force of ions, which led to a high adsorption capacity (Garg et al., 2008). the adsorption capacity was 177.02, 556.69 and 306.22 mg/g for Cu (II), Pb (II) and Cd (II), respectively. The adsorption kinetics parameters showed the adsorption was a pseudo-second-order kinetic equation better described metal adsorption by the PEC, which meant chemisorption dominates the adsorption process (Chen et al., 2004; Li et al., 2017). Langmuir was the best fit for describing the adsorption process, which illustrated monolayer adsorption dominant. The PEC was preferential towards $Pb^{2+} > Cd^{2+} > Cu^{2+}$. the adsorption capacity from this experiment showed that it was good for metal removal.

Table 3: Showing Optimum Conditions for Adsorption

PEC (adsorbents)	Types of interaction	Optimum conditions					References
		pH	Dosage (mg)	Temperature (^{0}C)	Initial concentration(mg/L)	Time (Mins)	
Pec-CF	Natural-Natural	4	150		50-100	20	Lessa *et al.*, (2011)
GL/CS	Natural-Natural		0.02	-	-	60	Jiang *et al.*, (2019)
CMC/PAM	Natural-	-	-	-	-	-	Godiya *et al.*, 2018
(β-CD)	Natural-synthetic	5	-	25	-		He, *et al.*, 2017
MCC-g-(AA-co AM)		3	-		-	15	Zhao *et al.*, 2019

`Table 4: Showing Adsorption Capacities of the PEC

PEC (adsorbents)	Metal Ion						References
	Cu^{2+}	Pb^{2+}	Co^{2+}	Cd^{2+}	Ni^{2+}	Fe^{2+}	
Pec-CF	88.4	-	-	98.4	-	192.3	Lessa, *et al.*, 2011
GL/CS	365	424	251	366	207	-	Jiang, *et al.*, 2019
CMC/PAM	185.2	151.5	-	185.2	-	-	Godiya, *et al.*, 2018).
β-CD)	192.8	215.2	-	163.2	-	-	He, *et al.*, 2017
MCC-g-(AA-co AM)	177.02	556.69	-	306.22	-	-	Zhao *et al.*, 2019

2.6 Future directions in the development of PECs for adsorption

Heavy metal ions varies in complex matrixes, such as groundwater, stream waters, oceans, lake, and impoundment water which contain amount of alkaline metal ions (He, et al, 2017). So, it's necessary to do researches in the presence of impurities such as Na^+, Mg^{2+} and Ca^{2+}. To investigate practical applications, of the effects of Na^+, Mg^{2+} and Ca^{2+} on the adsorption. The use of PEC in the removal of heavy metals has not been applied in real life scenario because exhaustive work has not been carried out on it, to show its viability. There are little of no comparative studies amongst the PECS, because the mode of preparation of the PECS differs. Further studies should be carried out to determine the mechanism behind the preferences of metal ions by PECs.

Conclusion

Large amounts of industrial, agricultural, and domestic wastewater need to be treated before being discharged into the environments. Polyelectrolyte complex showed great potential compared to other adsorbent because of renewability, low cost, nontoxicity, environmental compatibility and high adsorption capacity. PEC remains a superior alternative for the removal of heavy metal ions, dyes, and antibiotics. PECs for pollutants mainly depends on the corresponding adsorption mechanism, which in turn is determined by the modification method employed. Ion exchange, electrostatic attraction, hydrogen bonding, and pore-filling are the predominant mechanisms controlling the adsorption of heavy metal ions.

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