Jurnal Kejuruteraan 33(2) 2021: 175-181
https://doi.org/10.17576/jkukm-2021-33(2)-02

Plant and Non-plant based Polymeric Coagulants for Wastewater Treatment: A Review

Faheem Akhter[a*], Suhail Ahmed Soomro[b], Mohammad Siddique[c] & Mansoor Ahmed[b]

[a]*Department of Chemical Engineering, Quaid-e-Awam University of Engineering, Science & Technology, Nawabshah, Pakistan*

[b]*Department of Chemical Engineering, Mehran University of Engineering & Technology, Jamshoro, Pakistan*

[c]*Department of Chemical Engineering, Balochistan University of Information Technology, Engineering and Management Sciences*

**Corresponding author: faheemakhtar86@quest.edu.pk*

Received 22 June 2020, Received in revised form 26 July 2020
Accepted 15 September 2020, Available online 30 May 2021

ABSTRACT

The major source of fresh water is rain, which ultimately streams down into oceans and rivers. This water is consumed by the human beings for various purposes. All the consuming channels of this water, such as domestic, industrial, agricultural etc. generate the wastewater. Furthermore, urbanization and population growth are also the prime contributors. The reason why this water is called wastewater is due to the presence of contaminants such as organic material, biological components and toxic compounds, hence they have adverse effect on human health. Conventionally, many of the inorganic materials have been used as coagulants to treat the wastewater as these compounds have the ability to alter the physico-chemical properties. The present paper reviews the polymeric coagulants used for wastewater treatment that are green, sustainable and efficient. Moreover, these natural polymeric coagulants are biodegradable, eco-friendly and without any adverse effects on human health.

Keywords: Polymeric coagulants; wastewater; plant based; non-plant based

INTRODUCTION

Water is the most important natural substance without which neither of the living beings, including humans, can survive. Hydrological cycle, which inculcates water reservoirs such as lakes, rivers and oceans, is one of the main contributing factors to balance the ecosystem of earth (“Coagulants and natural polymers: perspectives for the treatment of water” n.d.). Every kind of life is dependent on water in one way or the other. Fresh and clean water sources are declining with the inclination in number of human population, industries and urbanization (Ambiental & 2008 n.d.). Due to this rapid industrial and population growth, the demand for the fresh water is on the rise with availability on the fall. Industries have directly impacted the water by contaminating it with augmented levels of numerous pollutants such as heavy metals, thereby adversely affecting the overall ecosystem. One of the major contributors of heavy metals have been the battery manufacturing industries (Othman, Asharuddin & Pahat n.d.). Unfortunately, in many developing countries, this wastewater is used for drinking purposes untreated, hence resulting in water borne diseases (Sowmeyan et al. n.d.). Cleaning the wastewater of the pollutants through different treatments have been the focus of the researchers worldwide for decades. The contaminated water can contain the impurities in 2 major forms; Dissolved and Suspended. Such impurities can alter the physico-chemical properties of the water itself, i.e. increasing the turbidity, changing the taste, odor or color, creating toxicity (McConnachie et al. n.d.; Tawakkoly et al. n.d.). Recently, the biomass derived substances have been trialed as coagulants by many researchers to treat the wastewater of these impurities such as Iranian oak (Jamshidi et al. 2020), tamarind seeds, banana peels and fly ash (Chitra & Muruganandam 2020).

The effluents of the untreated water consequently end up being consumed by humans, animals and aquatic life, thereafter severely affecting the health and ecosystem. In humans, the contaminated water can cause infections, skin diseases and respiratory/urinary system disorder. The only possible solution is to remove these water impurities/contaminants via physical/chemical treatment methods (Nath, Mishra & Pande 2020). The method of treatment is carefully chosen as it depends upon the type of impurities present. For example, the suspended solids and turbidity is usually treated via coagulation/flocculation process. Similarly, other conventional methods include solvent extraction, reverse osmosis and ion exchange (Sarode et al. 2019). In any colloidal mixture, there exist a repulsive force between the particles. Hence the principle behind coagulation/flocculation process is to reduce this repulsion by charging the particles resulting in formation of flocs (Oladoja et al. 2017). These colloidal particles accumulate and grow into bigger sized flocs, thereby settling in the bottom from where they can be segregated easily. Table 1 shows the factors that influence the coagulation/flocculation process.

There exists a variety of natural coagulants. Some of them possess cationic properties hence binding the water impurities with negative charge into precipitates (Rajendran et al. 2015). Selectivity of coagulants depends highly upon the nature of impurities present in wastewater. Moreover, it is pivotal to take into consideration the pH of the solution and inject the coagulant doses accordingly to remove turbidity. After the coagulation/flocculation process, the charged particles are neutralized via charge destabilization/neutralization method.

Several biocoagulants have been used to treat wastewater such as starch, derivatives of cellulose, glues, chitosin, galactomannas and aliginate. These coagulants have their natural roots and, unlike other coagulants like alumunium salts, do not pose any adverse effects for human health (Rajendran et al. 2015). To increase their efficiency, the natural coagulants are coupled with synthetic coagulants, called grafted coagulants. But the development of natural coagulants is still in its infancy stage. The coagulation/flocculation process includes its sub step processes involving bridging, adsorption and charge dispassionate mechanism, as shown in Figures 1 and 2.

The present review, following a green and sustainable route, gives a significant insight into the possibility of natural coagulants for treating wastewater along with their effectiveness and drawbacks, keeping in consideration the associated disadvantages with using synthetic/inorganic coagulants. Furthermore, the study encourages the future research towards using natural coagulants for wastewater treatment by providing a comprehensive review that can be used as a basis for the relevant research in the time to come.

NON-PLANT BASED COAGULANTS

The coagulants that are derived from substances other than plants and microbes are termed as non-plant based coagulants. These polymer based coagulants can be anionic, cationic or non-ionic but they can possess dual ionic nature as well called polyelectrolytes (Al-Sahari, Al-Gheethi & Maya Saphira Radin Mohamed 2020). In order to treat the wastewater, polysaccharides and proteins are segregated from natural sources and used subsequently for the treatment (Zemmouri et al. 2013). A small amount of charge interaction is seen when the polymer chain has a partial charge and solvent with hydroxyl group (-OH) (Al-Sakkari et al. n.d.). Chitosan is one such example of naturally occurring hydrophilic polysaccharide that can be used to absorb numerous metal ions and remove the turbidity from the wastewater (Figures 3 and 4). Moreover, besides having cellulosic structure, it is biodegradable and eco-friendly (Nyström et al. n.d.).

Chitosan is the acetyl derivative of chitin found in some kinds of fungi and arthropods. These cationic linear chained polymers are non-poisonous and environmental friendly. The eco system is not affected by the separation of chitosan from chitin (Renault et al. 2009).

Similarly, another example of naturally occurring polymers are sodium aliginates. These are the sodium salts of aliginic acids that exist in capsular or structural forms with natural polysaccharides of carboxylic and other groups (Al-Sakkari et al. n.d.).

These are shown to possess significant potential in removing metal ions form wastewater as shown in Figure 5. Among the microbes, the *actinobacteria* is shown to produce novel bioactive compound (Law et al. 2020). Cellulomonas and Stretptomyces spp. have shown a promising and effective flocculating behavior. The experimental results have confirmed that potential of such flocculating agents can be improved by protiens, natural sugar, amino sugar and uric acid among others (Nath, Mishra & Pande 2020).

PLANT-BASED COAGULANTS

Even though plant based coagulants are effective in water treatment yet their cost compared to synthetic coagulants hinders them from being used on industrial scale. These natural coagulants are effective for the wastewater with medium turbidity (50-500 NTU). Besides they are biodegradable and eco-friendly (Patchaiyappan et al. 2020). The primary sources of plant based coagulants are Morinaga oleifera, Nirmali seeds, tannin and cactus. One of the major sources of anionic polyelectrolytes are Nirmali seeds. Their extract is known to increase the efficiency of coagulation due to the presence of carboxylic and hydroxyl groups (Vijayaraghavan et al. 2011). Another approach is to use the mixture of polysaccharides, such as mixture of galactomannan and galactanii obtained from the seeds of *Strychnospotatorum* successfully reduced the turbidity of wastewater by up to 80%. The hydroxyl (-OH) groups in the mentioned mixture enable it to adsorb on contaminant particles and consequently increase the bridging among the pollutants (Yin 2010). Furthermore, a type of stifling plant called *Moringo oleifera* has the potential as a promising precursor for natural plant based coagulant. Figure 7 shows the removal efficiency of this coagulant for turbidity, COD and BOD. It is not hazardous at low concentrations and contains water soluble substances. Its seeds are a source of eatable oil (Taiwo et al. n.d.).

Generally, dimeric cationic proteins are employed for coagulation as these have the mass of 12-14 Da their iso-electric point is within 10-11. The polymeric coagulants mainly need to fulfill 2 purposes: first to neutralize the charge and secondly to form a bridge between the contaminant particles so that they may form flocs to settle down for consequent segregation (Oladoja 2015).

Likewise, the natural polyelectrolytes adsorb onto the surface of contaminant particles and neutralizing them of

TABLE 1. Factors Affecting Coagulation Process. Adapted from (Nath et al. n.d.)

Coagulant property	Characteristics	Properties of wastewater
	Resolving time	pH
Solubility of coagulants	Instability	Alkalinity
Dosage of coagulants	1.Quick assimilation	Accessibility of Bacteria's
Charge on coagulants	2. Deliberate assimilation	Elements present (Cl, Na, Mn, Si, Al, Fe etc.)
Coagulant's basicity	Amount of coagulant added	are present
	Particles variety	TDS SS (Suspended Solid) Temperature Turbidity DO (Dissolved Oxygen)

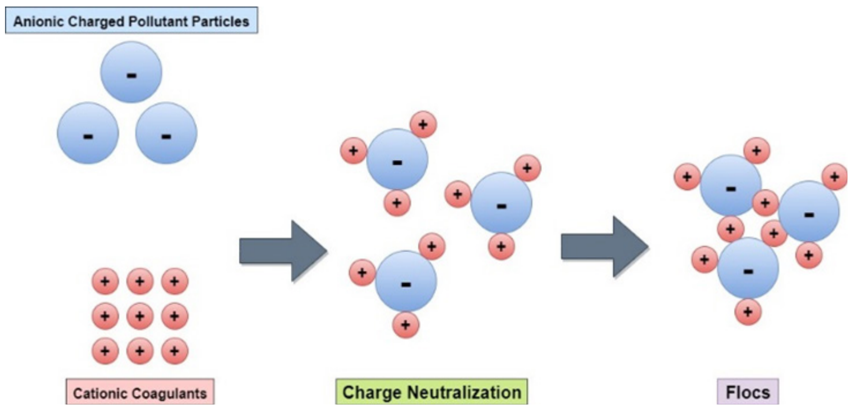

FIGURE 1. Charge Neutralization Mechanism

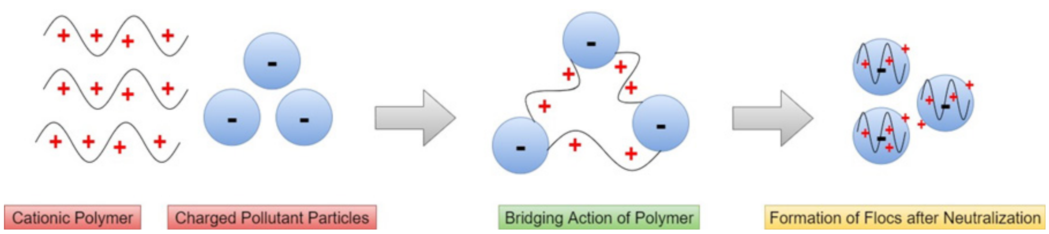

FIGURE 2. Bridge Mechanism

TABLE 2. Advantages and Disadvantages of Synthetic/Inorganic Coagulants. Adapted from (Nath et al. n.d.)

Coagulants	Effectiveness	Drawback
Al(III)sulphate (Alum)	Simple handling convenient to use; less volume of sludge generated;	Put in water as dissolved solids (salts);
$Al_2(SO_4)_3 18H_2O$ Sodium aluminium salt Na2Al2O4	Optimum pH 6.5–7.5. Can be used in hard water; small doses required;	Effective in a limited pH range. Normally used with alum; high cost; not effective for soft water
Polyaluminiumchloride (PAC)	Formation of flocs is denser and more rapidly settling.	Not convenient in use; as compare with derivatives of aluminium.
Fe(III)sulphate	Suitable pH ranges 4–6 and 8.8–9.2.	Put in water as dissolved solids (salts); maintained alkaline medium.
Fe(III)chloride	Optimum pH range 4–11	Put in water as dissolved solids (salts); maintained high alkaline medium.
Fe(II)sulphate	No pH sensitivity	Put in water as dissolved solids (salts); maintained alkaline medium.
Lime $Ca(OH)_2$	Commonly used; effective, sufficient for coagulation	pH sensitive; large volume of sludge produce; required high doses.

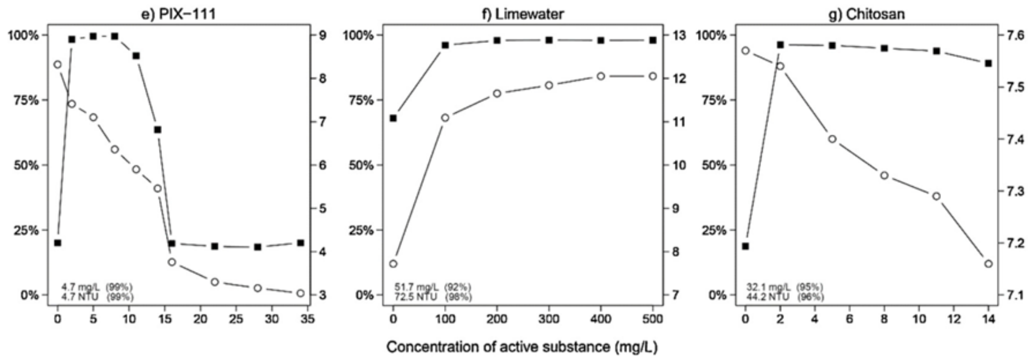

FIGURE 3. Treatment effect in terms of turbidity reduction on the primary y-axis, plotted against the concentration of the active substance with the effect on the pH on. Open Access Ref. (Nyström et al. n.d.)

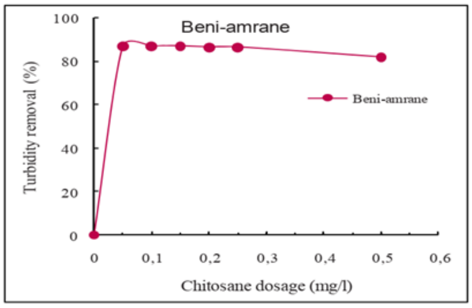

FIGURE 4. Effects of chitosan addition on removal percentage of turbidity (%) at pH 7.8. Open Access Ref. (Zemmouri et al. 2013)

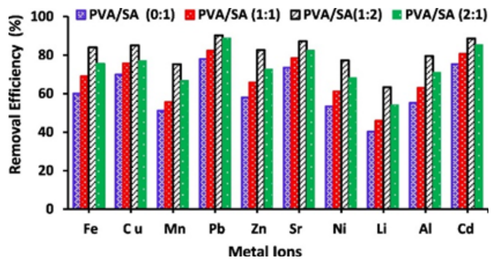

FIGURE 5. The effect of PVA/Sodium Alginate binary comonomer concentration on the removal efficiency of the selected metal ions (Al3+, Li2+, Fe3+, Ni2+, Sr2+, Cd2+, Cu2+, Zn2+, Mn2+and Pb2+). Open Access Ref. (Isawi 2020)

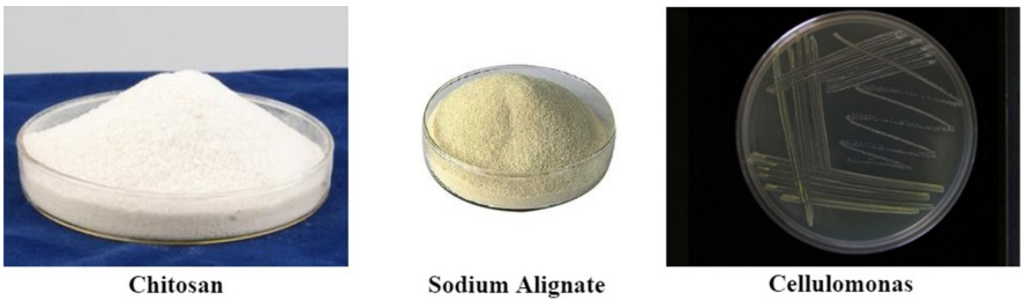

FIGURE 6. Images of Some of the Non-Plant based Coagulants

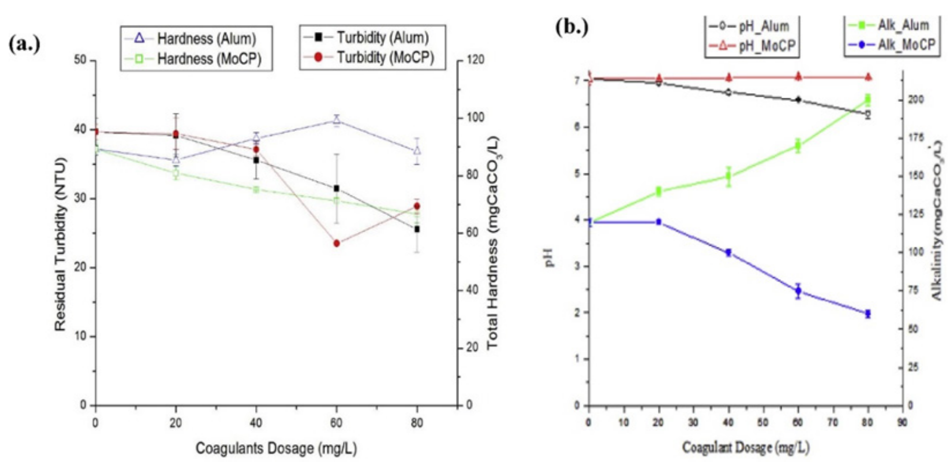

FIGURE 7. Removal Efficiency of Moringo oleifera Protein (MoCP) for Turbidity, Electrical Conductivity, COD and BOD from Opa Reserviour Water. Open Access Ref. (Taiwo et al. n.d.)

the charge (Vijayaraghavan et al. 2011; Yin 2010). The natural polymers that are cationic in nature have shown a better efficiency in coagulation/flocculation process. For example, tannin is a material extracted from plants such as *Accacia, Castenea or Schinopis barks* that can be suitable for wastewater treatment as it contains nitrogen and carboxylic acid groups (Hameed et al. 2020).

In the countries like Maxico and North America, numerous species of cactus have shown efficient and promising results as coagulants for wastewater treatment, such as *Opentia latifaria*, nopal and pricly pear (Vijayaraghavan, … & 2011 n.d.). The reason behind cactus coagulation efficiency is the presence of bridging compounds like I-arabinose, I-rhamanosei, d-galactose, d-xyloose and galacturonic acid. Galacturonic acid is known to remove almost 50% percent of the wastewater turbidity (Sáenz et al. n.d.). Figure 8 shows the images of some plant based coagulants discussed in the present section of the review.

MECHANISM

Coagulation capacity in the natural polymers comes in with the presence of functional group and charges embedded in their structure. Due to such groups, these coagulants are able to neutralize the charge and bridge the pollutant particles together (Nath, Mishra & Pande 2020). Usually, the bio-coagulants are composed of carbohydrates, lipids and proteins, whereas the polymers mainly constitute of polysaccharides and amino acids (Othmani, Rasteiro & Khadhraoui 2020). Figures 2 and 3 show some of the mechanism involved in coagulation/flocculation process.

When there are pollutant particles with anionic nature, the cationic polyelectrolytes can be used to effectively remove them. This is done when the particles get adsorbed by anionic polymer and subsequently neutralized via generation of electrostatic attraction between them. Consequently, after being neutralized, the pollutant particles come in contact with each other to form flocs and settle down to be removed later (Bolto & Gregory 2007).

The flocculation capacity also depends upon the charge density carried by the polyelectrolytes. Higher charge density enhances the flocculation capacity of a coagulant (Sun et al. n.d.). Polyelectrolytes possessed with higher cationic charge density are shown to interact in a unique mechanism with the particles called "electrostatic patch mechanism" (Cheng et al. 2010).

When the coagulants are used in large amount to treat the wastewater, they form precipitates of hydroxide which trap the dissolved impurities and sweep them, the phenomenon called as sweep coagulation. This process can effectively remove the particles that are neutralized by destabilization (Abiola 2019). The example of this process is when chitosan is used against the turbid water.

FIGURE 8. Images of Some Plant based Coagulants

TABLE 3. Plant and Non-plant based coagulants given in the present review

Plant based Coagulants	Ref.	Non-plant based Coagulants	Ref.
Morinaga oleifera	(Taiwo et al. n.d.)	Chitosin	(Nyström et al. n.d.) (Renault et al. 2009)
Nirmali Seeds	(Vijayaraghavan, … & 2011 n.d.)	Sodium alginates	(Al-Sakkari et al. n.d.) (Isawi 2020)
Tannin	(Hameed et al. 2020)a natural tannin-based coagulant and flocculant, was used in this study as a pre-treatment agent for a biofilm unit that was used to treat municipal wastewater. The point of interest in this study was the effect of the extended use of Tanfloc (around 2 months	*Actinobacteria*	(Law et al. 2020)
Cactus	(Vijayaraghavan, … & 2011 n.d.)	Cellulomonas	(Nath et al. n.d.)
Strychnospotatorum seeds	(Yin 2010)processes, effectiveness and relevant coagulating mechanisms for treatment of water and wastewater is presented. These coagulants are, in general, used as point-of-use technology in less-developed communities since they are relatively cost-effective compared to chemical coagulants, can be easily processed in usable form and biodegradable. These natural coagulants, when used for treatment of waters with low-to-medium turbidity range (50-500 NTU	Streptomyces spp.	(Nath et al. n.d.)

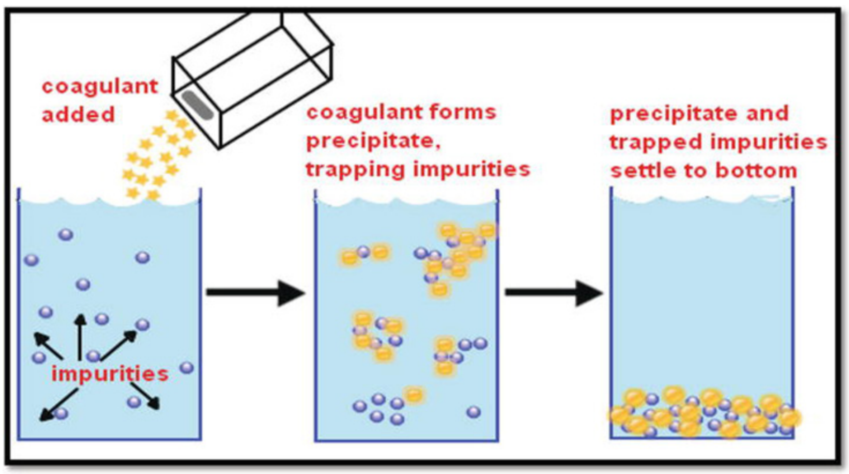

FIGURE 9. Process of Coagulation, Flocculation and Sedimentation

CONCLUSION

Having natural lineage, the biocoagulants are becoming a safe, cheap and eco-friendly option to treat the wastewater of pollutants. As mentioned earlier, these coagulants have 2 major natural sources: plant based and non-plant based sources. They can either be used as primary or auxiliary inputs in the coagulation/flocculation process, hence improving various parameters of wastewater. The major highlighting preferences of natural coagulants are their good efficiency, biodegradable nature and eco-system/ environment friendly. Novel methods are being proposed to enhance the coagulation potential where these natural coagulants are used to produce polymer composites. The present paper has reviewed the natural coagulants extracted from plants, animals and biomass of their effectiveness against wastewater treatment.

DECLARATION OF COMPETING INTEREST

None.

REFERENCES

Abiola, O.N. 2019. *Polymers for Coagulation and Flocculation in Water Treatment*. Springer, Cham.

Al-Sahari, M., Al-Gheethi, A. & Maya Saphira Radin Mohamed, R. 2020. Natural Coagulates for Wastewater Treatment; A Review for Application and Mechanism The investigation of microalgae biodiversity of temporary water habitats in Johor National Park as source of renewable novel bioactive compounds View project BioNanotechnology View project. Springer.

Al-Sakkari, E., Abdeldayem, O., … E.G.-I.J. of & 2020, undefined. (n.d.). New alginate-based interpenetrating polymer networks for water treatment: A response surface methodology based optimization study. *Elsevier*.

Ambiental, A.B.-E.S. e & 2008, undefined. (n.d.). Water reuse: issues, technologies, and applications. *SciELO Brasil*.

Bolto, B. & Gregory, J. 2007. Organic polyelectrolytes in water treatment. Elsevier Ltd.:

Cheng, Y.L., Wong, R.J., Lin, J.C. Te, Huang, C., Lee, D.J. & Mujumdar, A.S. 2010. Water coagulation using electrostatic patch coagulation (EPC) mechanism. *Drying Technology* 28(7): 850–857.

Chitra, D. & Muruganandam, L. 2020. Performance of natural coagulants on greywater treatment. *Recent Innovations in Chemical Engineering (Formerly Recent Patents on Chemical Engineering)* 13(1): 81–92.

Coagulants and natural polymers: perspectives for the treatment of water. (n.d.). . *academia.edu*.

Hameed, Y.T., Idris, A., Hussain, S.A., Abdullah, N. & Che Man, H. 2020. Effect of pre-treatment with a tannin-based coagulant and flocculant on a biofilm bacterial community and the nitrification process in a municipal wastewater biofilm treatment unit. *Journal of Environmental Chemical Engineering* 8(2): 103679.

Isawi, H. 2020. Using Zeolite/Polyvinyl alcohol/sodium alginate nanocomposite beads for removal of some heavy metals from wastewater. *Arabian Journal of Chemistry* 13(6): 5691–5716.

Jamshidi, A., Rezaei, S., Hassani, G., Firoozi, Z., Ghaffari, H.R. & Sadeghi, H. 2020. Coagulating potential of Iranian oak (Quercus Branti) extract as a natural coagulant in turbidity removal from water. *Journal of Environmental Health Science and Engineering* 18(1): 163–175.

Law, J.W.-F., Letchumanan, V., Tan, L.T.-H., Ser, H.-L., Goh, B.-H. & Lee, L.-H. 2020. The Rising of "Modern Actinobacteria" Era. *Progress In Microbes & Molecular Biology* 3(1).

McConnachie, G., Folkard, G., research, M.M.-W. & 1999, undefined. (n.d.). Field trials of appropriate hydraulic flocculation processes. *Elsevier*.

Nath, A., Mishra, A. & Pande, P.P. 2020. A review natural polymeric coagulants in wastewater treatment. *Materials Today: Proceedings*.

Nath, A., Mishra, A., Proceedings, P.P.-M.T. & 2020, undefined. (n.d.). A review natural polymeric coagulants in wastewater treatment. *Elsevier*.

Nyström, F., Nordqvist, K., Herrmann, I., … A.H.-J. of W. & 2020, undefined. (n.d.). Laboratory scale evaluation of coagulants for treatment of stormwater. *Elsevier*.

Nyström, F., Nordqvist, K., Herrmann, I., … A.H.-J. of W. & 2020, undefined. (n.d.). Laboratory scale evaluation of coagulants for treatment of stormwater. *Elsevier*.

Oladoja, N.A. 2015. Headway on natural polymeric coagulants in water and wastewater treatment operations. Elsevier Ltd.:

Oladoja, N.A., Unuabonah, E.I., Amuda, O.S. & Kolawole, O.M. 2017. Operational Principles and Material Requirements for Coagulation/Flocculation and Adsorption-based Water Treatment Operations. hlm. 1–11. Springer, Cham.:

Othman, N., Asharuddin, S.M. & Pahat, B. (n.d.). Cucumis Melo Rind as Biosorbent to Remove Fe(II) and Mn(II) From Synthetic Groundwater Solution. *Trans Tech Publ*.

Othmani, B., Rasteiro, M.G. & Khadhraoui, M. 2020. Toward green technology: a review on some efficient model plant-based coagulants/flocculants for freshwater and wastewater remediation. Springer.:

Patchaiyappan, A., Sarangapany, S., Saksakom, Y.A. & Devipriya, S.P. 2020. Feasibility study of a point of use technique for water treatment using plant-based coagulant and isolation of a bioactive compound with bactericidal properties. *Separation Science and Technology (Philadelphia)* 55(1): 112–122.

Rajendran, R., Abirami, M., Prabhavathi, P., Premasudha, P., Kanimozhi, B. & Manikandan, A. 2015. African Journal of Biotechnology Biological treatment of drinking water by chitosan based nanocomposites. *ajol.info* 14(11): 930–936.

Renault, F., Sancey, B., Badot, P.M. & Crini, G. 2009. Chitosan for coagulation/flocculation processes - An eco-friendly approach. Pergamon.:

Sáenz, C., Sepúlveda, E., environments, B.M.-J. of arid & 2004, undefined. (n.d.). Opuntia spp mucilage's: a functional component with industrial perspectives. *Elsevier*.

Sarode, S., Upadhyay, P., Khosa, M.A., Mak, T., Shakir, A., Song, S. & Ullah, A. 2019. Overview of wastewater treatment methods with special focus on biopolymer chitin-chitosan. Elsevier B.V.:

Sowmeyan, R., Santhosh, J., Biochemistry, R.L.-I.R.J. of & 2011, undefined. (n.d.). Effectiveness of herbs in community water treatment.

Sun, Q., Zhao, S., Yan, Y., Jia, W., Supply, W.Y.-W. & 2020, undefined. (n.d.). Parameter optimization and mechanism research of enhanced coagulation treatment for Yuquan River water. *iwaponline.com*.

Taiwo, A., Adenike, K., Heliyon, O.A.- & 2020, undefined. (n.d.). Efficacy of a natural coagulant protein from Moringa oleifera (Lam) seeds in treatment of Opa reservoir water, Ile-Ife, Nigeria. *Elsevier*.

Tawakkoly, B., Alizadehdakhel, A., Products, F.D.-I.C. and & 2019, undefined. (n.d.). Evaluation of COD and turbidity removal from compost leachate wastewater using Salvia hispanica as a natural coagulant. *Elsevier*.

Vijayaraghavan, G., … T.S.-… J. of A. & 2011, undefined. (n.d.). Application of plant based coagulants for waste water treatment. *technicaljournalsonline.com*.

Yin, C.Y. 2010. Emerging usage of plant-based coagulants for water and wastewater treatment. Elsevier.:

Zemmouri, H., Drouiche, M., Sayeh, A., Lounici, H. & Mameri, N. 2013. Chitosan application for treatment of Beni-Amrane's water dam. *Energy Procedia*, hlm. 558–564. Elsevier Ltd.: