Asian Journal of Water, Environment and Pollution, Vol. 18, No. 3 (2021), pp. 109–115.
DOI 10.3233/AJW210035

Polyelectrolytes as a Material of Value in Water Treatment: A Review

Shagufta Jabin, Priti Gupta* and Mukta Sharma
Department of Chemistry, Manav Rachna Educational Institutions, Faridabad, India
✉ me.pritigupta@gmail.com

Received August 31, 2020; revised and accepted January 29, 2021

Abstract: The use of polyelectrolytes in the treatment of water/wastewater has been studied with special emphasis on the characteristic impurities, which should be removed and the types of polyelectrolytes commonly available. Much attention is being on using polyelectrolyte as primary coagulation, their application as a coagulant aid, including the use of dual polyelectrolytes in the treatment of complex industrial wastewater. The optimum dosage of polyelectrolytes in all kinds of water and wastewater is very low when they are used as coagulant aids in conjunction with inorganic polyelectrolytes. Hence, the quantification of remaining polyelectrolytes in the water after their treatment is ruled out in this case. Polymer toxicity in aquatic animals has been assessed and the presence of residual polyelectrolytes in the treated water has been discussed. Keeping in view the applicability of these polyelectrolytes for the removal of contaminants, it is expected that this technique can be applied for further investigation in various types of water from different origins.

Key words*:* Polyelectrolytes, charge neutralization, polymer bridging, toxicity, coagulation, coagulant aid.

Introduction

The well-being of mankind mainly depends upon the environment and ecological factors. However, environmental and ecological factors depend upon the quality of water available to be used for different purposes.

The literature data reveals that impurities in water are associated with suspension and dissolution (de Nardi et al., 2007; Vaughan et al., 2000). So, it is necessary to perform detailed analyses of impurities present in water and wastewater. Water has complex chemistry and contains different types of impurities ranging from suspended matter to dissolved matter. In conventional chemical treatment, inorganic coagulants like aluminum or iron salts are utilised majorly (Wei et al., 2016). However, handling a large volume of sludge produced from the use of metal coagulants is a difficult task (Chang et al., 2005). With the establishment of different industries, organic polyelectrolytes were introduced for the treatment of different kinds of water and wastewater (Iakovides et al., 2014). Since then polyelectrolytes are being used in water treatment (Lourenço et al., 2017).

According to their ionic charge, polyelectrolytes are classified into different categories. Polyelectrolytes with a positive charge are cationic and the ones with negatively charged are anionic (Radoiu et al., 2004; Sarika et al., 2005). Different types of polyelectrolytes are available commercially. Most of them have been reviewed by Bolto and Gregory, (2007). They are available in synthetic and natural forms (Bing-hui et al., 2005; Choi et al., 2001; Selvapathy et al., 1992). Synthetic polyelectrolytes include polyamines, polyacrylamides, polyalkyleneimine, polyacrylonitrile, polydiallyl dimethyl ammonium chloride (PDADMAC), epichlorohydrine polymers and poly-acrilamides

*Corresponding Author

(Razali et al., 2011; Yap et al., 2014). The natural polyelectrolytes used in wastewater treatments include chitosan, glue, starch, gelatin galactomannans, cellulose derivatives and tannin (Elhakeem et al., 2014; Jabin and Kapoor, 2020).

The natural polyelectrolytes being biodegradable in nature are always preferred. An advantage of natural polyelectrolytes is that they are virtually toxicity-free (Ishak et al., 2020). So, natural polyelectrolytes and their derivatives can work as potential substitute in place of synthetic polyelectrolytes for minimising water pollution. Polyelectrolytes are used as primary as well as secondary coagulants in conjunction with inorganic coagulants

Polyelectrolytes as a Primary Coagulant

The selection of coagulant is one of the most challenging task in the treatment of water and wastewater. There are many cases where polyelectrolytes have been used as a primary coagulant (Wilts et al., 2018), effectively replacing the use of inorganic coagulants; in many cases, they are used to reduce or remove suspended particles from water and wastewater (Blanco et al., 2002; Wu et al., 2018). Cationic polyelectrolytes with high charge density and low to medium molecular weight are more successfully applied as primary coagulants (Jabin and Kapoor, 2020). The most common examples of cationic polyelectrolytes used as primary coagulants are polydiallyl dimethyl ammonium chloride (PDADMAC) and poly methacrylate (Bharti and Mishra, 2016; Zhou and Franks, 2006). The literature also shows that polyelectrolytes, as primary coagulants, are also capable of removing dyes (Ahmad et al., 2008). It was also studied that the polyelectrolytes have the ability to remove colour from wastewater (Szyguła et al., 2009). As per literature, polyelectrolytes have been proven to be effective in the removal of microorganisms (Bolto and Xie, 2019) but it is more successfully applied in the removal of suspension present in different kinds of water.

Several types of research have been reported on the coagulation–flocculation technique for the treatment of industrial effluent (Cao et al., 2011; Qin et al., 2006). The process of coagulation involves different steps which have been shown in Figure 1. After the collection of water/wastewater, different parameters are assessed. After optimisation of pH, destabilisation of coagulated flocs occurs by the addition of polyelectrolyte (Crittenden et al., 2005). Mixing of coagulant is done in two steps viz.: (i) rapid and (ii) slow mixing. It requires proper turbulence to form homogenous mixing. The mixing is done slowly to encourage the formation of the homogenous mixture, and this process is known as "coagulation". The final step involves the removal of the impurities with the process of sedimentation. A high dosage of polyelectrolyte is required when it is used as a primary coagulant (Lee et al., 1998). The coagulant dosage added also depends upon the types of wastewater and pH.

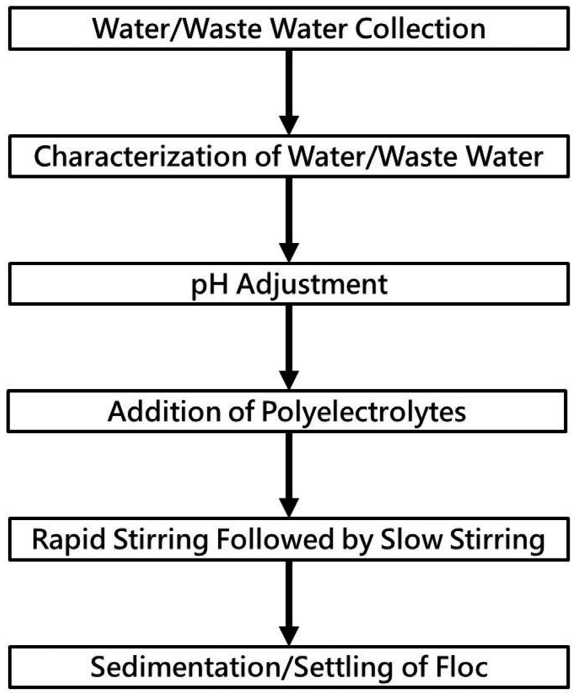

Figure 1: Flow chart showing the process of removal of impurities by polyelectrolyte as a primary coagulant.

Polyelectrolytes as a Coagulant Aid

Polyelectrolytes are majorly used as coagulant aids in water treatment in conjunction with inorganic coagulants, which are used as primary coagulants in this situation. The use of inorganic coagulants alone has its own limitations, such as a large amount of coagulant is required and as a result, a large volume of sludge is generated. In contrast, proper use of polyelectrolytes as a coagulant aid can successfully remove pollutants from different kinds of wastewater (de Sena et al., 2008). A low dosage of polyelectrolyte is required when it is used as a coagulant aid. Synthetic polyelectrolytes are more widely used as they are more effective as coagulant aids. Their efficiency depends upon the properties they possess such as the type of charge units, charge density and molecular weight. The charge density of a particular polyelectrolyte influences the destabilisation mechanism and leads to floc formation (Theodoro et al., 2013). Kam and Gregory (2001) have demonstrated that the charge density instead of the molecular weight is more important in selecting the polyelectrolytes as a coagulant aid. Synthetic polyelectrolytes, especially cationic polyelectrolytes are more effective in the removal of turbidity and suspension as compared to anionic and non-ionic polyelectrolytes (Kapoor et al., 2015). However, anionic polyelectrolytes are more effective in the removal of dissolved impurities (Clark and Stephenson, 1999). As per Bolto, the efficiency of cationic polyacrylamide with low molecular weight is better than a high molecular weight polyacrylamide. In general, the best results are found when polyelectrolyte is added after primary coagulant addition (Choong et al., 2007). In some cases, where polyelectrolyte and impurities are of opposite sign, then the addition of polyelectrolyte before metal coagulant could reduce the surface charge of particles on adsorption, thereby subsequently reducing the quantity of metal coagulant required to effect charge reduction.

A combination of inorganic coagulants and polyelectrolytes as a coagulant aid can be useful for minimising pathogens in water. Judicious choice of appropriate polyelectrolytes may go a long way to enhance the effectiveness of coagulation-flocculation. The schematic diagram of coagulation is presented in Figure 2.

In summary, each process has its positive and negative aspects. Overview on the usage of polyelectrolytes as a primary coagulant and as a coagulant aid is presented in Table 1.

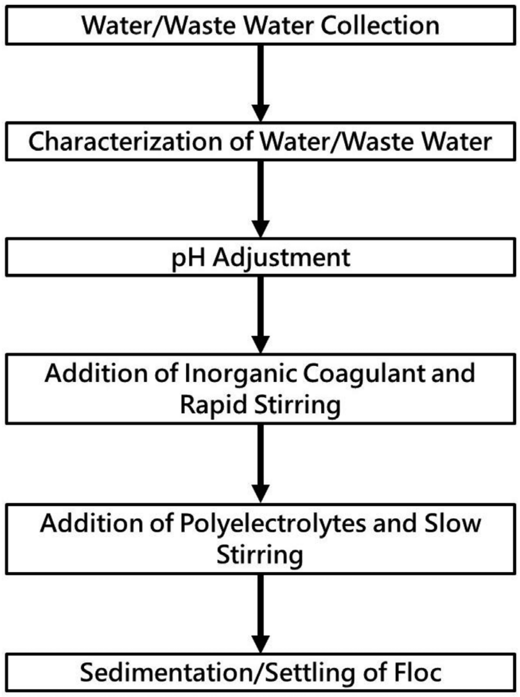

Figure 2: Flow chart showing the process of removal of impurities by polyelectrolytes as a coagulant aid.

Use of Dual Polyelectrolytes in Single Wastewater Treatment

Nowadays many chemical treatment methods are available, but none is efficient enough to remove all kinds of impurities from different sources. A single polyelectrolyte cannot do it, so focussing on environmental sustainability can be done by applying dual polyelectrolytes in water and wastewater treatment. The use of dual polyelectrolytes for the treatment of industry effluent especially for the removal of suspended solids, oil and grease and organic matter is well established (Lee and Liu, 2000). Dual polyelectrolytes can enhance efficiency without adding to the solids load that occurs with inorganic coagulants. A combination of "low molecular weight with high charge density cationic" and "low-charge density with high molecular weight anionic" polyelectrolytes yield effective results (Petzold et al., 2001). Suspended particles are mostly negatively charged that's why cationic polyelectrolytes are successfully attached with suspended particles by charge neutralisation. However, anionic polyelectrolytes work through an electrostatic patch mechanism. Vaughan et al. (2000) exploited dual polyelectrolytes

Table 1: Comparative study of the usage of polyelectrolyte as a primary coagulant and as a coagulant aid

S. No	*Parameters*	*Polyelectrolyte as a coagulant aid*	*Polyelectrolyte as primary coagulant*
1	Treatment efficiency	Suspended/dissolved pollutants both	Suspended pollutants only
2	Types of coagulants	Inorganic coagulants and polyelectrolytes	Polyelectrolytes only
3	Overall chemical requirement	More	Less
4	pH adjustment	More pH adjustment is required	Less pH adjustment is required
5	Cost	More expensive	Less expensive

in oil industry effluent, they also explored the use of cationic and then anionic polyelectrolytes. Dual polyelectrolytes in the form of cationic hemicellulose and anionic tannin have shown better performance in the removal of oil and surfactant residues in biodiesel effluent. A deep understanding of dual polymers mechanism is important before utilising them for the treatment of any kind of wastewater.

Better results could be obtained if both polyelectrolytes are used one after another. Different steps of coagulation based on dual polyelectrolytes have been shown in Figure 3.

Interaction of Suspended Impurities with Polyelectrolytes

Coagulation-flocculation is an important physicochemical operation used for the removal of suspension with the help of polyelectrolytes. It is used in the treatment of different kinds of water. Considering that this is a complex mechanism, a thorough understanding of suspended particles is important. Their surface is generally negatively charged and they repel each other to form a stable dispersed suspension. The concentration of polyelectrolytes required for coagulation is proportional to the concentration of impurities present in water. Nozaic et al. studied that optimisation of polyelectrolytes dosages is the most important parameter in the water industry's ability to meet the goal of suspension removal (Kapoor et al., 2011). They stressed the significance of adopting a treatment process and highlighted the necessity of adjustment of two important parameters: pH and polyelectrolytes dosage. The polyelectrolytes dosage depends upon the types of wastewater and pH.

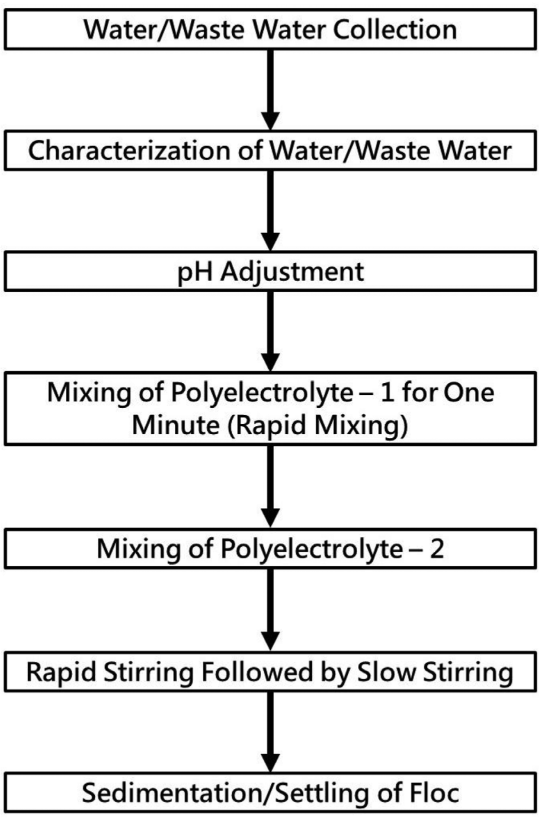

Figure 3: Flow chart showing the process of removal of impurities by dual polyelectrolytes as a coagulant aid.

Removal of suspension requires less amount of coagulant-flocculant. In the presence of suspended solids, low molecular mass polyelectrolytes preferentially react with dissolved organic matter and high molecular mass polyelectrolytes at low dosage with suspended solids. At higher dosage, the surface of the suspended solids is completely covered by polymer and then additional polyelectrolytes start interacting with humic substances. The presence of suspended solids increases the degree of humic substance removal. For removal of suspension, polyelectrolytes can be used as primary coagulants or as coagulants-aids in conjunction with inorganic coagulants.

Proper mixing of polyelectrolytes is an essential parameter for the removal of suspension. This is the first process wherein polyelectrolyte is distributed evenly throughout the suspension. Mixing is generally carried out swiftly, else extra concentration may cause uneven adsorption and some particles may re-establish as a result of adsorbing excess amount of polyelectrolyte. Improper mixing generally results in residual haze in water after polymer flocculation and sedimentation. It is desirable to have a considerable amount of turbulence for proper mixing, this is because polyelectrolyte chains may encounter some scission in this condition.

Interaction of Dissolved Impurities with Polyelectrolytes

Dissolved organic matter (DOM) is generally divided into two categories: humic substances and non-humic substances. Humic substances are generally hydrophobic macromolecules and bound together by a hydrogen bond. It shows yellowish-brown colour in water. Non-humic materials are colourless, less hydrophobic and more easily defined such as polysaccharides, protein, nucleic acids and small molecules such as sugar and amino acids. The non-humic substances consist of biodegradable organic carbon which serves as the substrate for bacterial growth in water distribution systems.

Research on the removal of DOM with polyelectrolytes has also been done (Lurie and Rebhun, 1997). In natural water, dissolved organic matters (both humic and non-humic) are generally anionic in nature. They are generally removed by the mechanism of charge neutralisation. There is stoichiometric relation between cationic polyelectrolyte and dissolved organic matter (Lee and Westerhoff et al., 2006). As per literature, cationic polyelectrolytes having high charge density are more effective in the removal of dissolved organic matter. It has been observed that the molecular weight of polyelectrolytes is not an important criterion for the removal of dissolved organic matter. It has also been observed from the literature that more hydrophobic DOM is easily removed as compared to low hydrophobic DOM. Inorganic coagulants showed poor results in the removal of DOM. They also reduce alkalinity leading to a decrease in the pH of effluent.

The technology for suspended and dissolved impurities so far has shown a great degree of variation in terms of their respective removal efficiencies. Variation in impurities in various types of water makes it difficult to handle. The impurities are both organic and inorganic in nature. The fine fraction of suspended solids carries a significantly high pollutants load compared to dissolved water pollutants.

Toxicity of Polyelectrolytes

The issue of toxicity in polyelectrolytes cannot be ignored. If polyelectrolyte is used as a coagulant aid in conjunction with an inorganic coagulant, then a very low dosage of polyelectrolyte is required. So, this fact ruled out the possibility of toxicity in the treated water. As a primary coagulant, polyelectrolytes are considered more toxic (Goodrich et al., 1991).

If polyelectrolytes are used as primary coagulants to treat drinking water ,then the quantification of polyelectrolytes in treated water is an important factor. The toxicity of the remaining polyelectrolytes depends upon the amount of monomers units present in treated water (Ghimire and Bhattarai, 2020). Quantification of epichlorohydrin and polyacrylamide polyelectrolytes in treated water have more health hazards as compared to other polyelectrolytes (Letterman and Pero, 1990). So, it's always safe to use polyelectrolytes as a coagulant aid since quantification of polyelectrolytes is negligible in such cases.

As per literature, polyelectrolytes having a positive charge are considered to be more toxic as compared to anionic and non-ionic polyelectrolytes; hence, cationic polyelectrolytes are more harmful to aquatic organism especially fishes (Goodrich et al., 1991). However, the presence of clay and humic acid reduces the toxicity of polyelectrolytes in water (Weston et al., 2009) because humic acid and clay can adsorb the polyelectrolytes present in water.

As per Bolto, Japan and Switzerland do not permit the usage of polyelectrolyte in the treatment of drinking water. However, France and Germany also have stringent limits. As per Bolto, acrylamide polyelectrolytes are more toxic so their permissible limit is only 0.5mg/L. However, in USA, the limit for polydiallyl dimethyl ammonium chloride is <50mg/L, and for dimethyl amine, the limit is <20mg/L. Literature also reveals that polyelectrolytes with high charge density are more toxic than polyelectrolytes with low charge density (Bolto and Gregory, 2007).

Conclusion

The study tries to find out treatment techniques for all kinds of water pollution viz, suspended and dissolved impurities with the help of polyelectrolytes. The study shows that polyelectrolyte as a primary coagulant is more successful in the removal of suspension from water. However, polyelectrolyte as a coagulant aid is efficient to remove both suspended and dissolved impurities in conjunction with an inorganic coagulant. The optimum dosage of polyelectrolyte is low when the amount of pollutants is high. It was found that the efficiency of polyelectrolyte was affected by molecular weight, charge density, characteristics of flocculants, of polyelectrolyte and polyelectrolyte dosages. In a complex situation, dual polyelectrolytes can be used for the removal of oil and grease, colour and other pollutants. Dual polyelectrolytes are not added simultaneously. After homogenous mixing of one polyelectrolyte, another one is added. When polyelectrolyte is used as coagulant aids then the optimum dosage is kept low. So, the toxicity of polyelectrolyte in the aquatic medium is ruled out in this case.

Acknowledgement

The authors would like to acknowledge the researchers on this subject. This paper is an attempt to consolidate the findings by all of them.

References

Ahmad, A.L., Wong, S.S., Teng, T.T. and A. Zuhairi (2008). Improvement of alum and PACl coagulation by polyacrylamides (PAMs) for the treatment of pulp and paper mill wastewater. *Chemical Engineering Journal*, **137:** 510-517.

Bharti, S. and S. Mishra (2016). Synthesis, characterization and application of polymethyl methacrylate grafted oatmeal: A potential flocculant for wastewater treatment. *International Journal of Environmental Research*, **10(1):** 169-178.

Bhattarai, A. (2020). A review on polyelectrolytes (PES) and polyelectrolyte complexes (PECs). *International Journal of Engineering and Research*, **V9(8)**. doi: 10.17577/ijertv9is080112

Bing-hui, T., Bin, F., Xian-jia, P. and L. Zhao-kun (2005). A cleaner two-step synthesis of high purity diallyldimethylammonium chloride monomers for flocculant preparation. *Journal of Environmental Sciences*, **17:** 798-801. https://DOI 1000-0742(2005) 05-0798-04

Blanco, A., Fuente, E., Negro, C. and J. Tijero (2002). Flocculation monitoring: Focused beam reflectance measurement as a measurement tool. *The Canadian Journal of Chemical Engineering*, **80:** 1-7.

Bolto, B.J. (2007). Gregory, organic polyelectrolytes in water treatment. *Water Research*, **41(11):** 2301-2324. https://DOI.org/10.1016/j.watres.2007.03.012

Bolto, B. and Z. Xie (2019). The use of polymer in flotation treatment of wastewater. *Processes*, **7(6):** 374-385. DOI: 10.3390/pr7060374

Cao, B., Gao, B., Liu, X., Wang, M. and Z. Yang (2011). The impact of pH on floc structure characteristic of polyferric chloride in a low DOC and high alkalinity surface water treatment. *Water Research*, **45:** 6181-6188. DOI: 10.1016/j.watres.2011.09.019

Chang, E.E., Chiang, P.C., Tang, W.Y., Chao, S.H. and H.J. Hsing (2005). Effects of polyelectrolytes on reduction of model compounds via coagulation. *Chemosphere,* **58:** 1141-1150.

Choong, T., Chuah, T., Robiah, Y., Gregory, K. and I. Azni (2007). Arsenic toxicity, health hazards and removal techniques from water: An overview. *Desalination*, **217:** 139-166. Doi: 10.1016/j.desal.2007.01.015

Choi, J.H., Shin, W.S. and S.H. Lee (2001). Application of synthetic polyamine flocculants for dye wastewater treatment. *Seperation Science and Technology*, **36:** 2945-2968. https://doi.org/10/1081/SS-100107638

Clark, T. and T. Stephenson (1999). Development of a jar test protocol for chemical phosphorus removal in activated sludge using statistical experimental design. *Journal of Water Research*, **33(7):** 1730-1734.

Crittenden, J.C., Trussel, R.R., Hand, D.W., Howe, K.J. and G. Tchobanoglous (2005). Coagulation, mixing and flocculation. *In:* Water Treatment: Principles and Design. John Wiley and Sons, New Jersey, pp: 643-779.

Elhakeem, M.A. and T.A. Alkhulaqi (2014). Simple, rapid and efficient water purification by chitosan coated magnetite nanoparticles. *Journal of Environment and Nanotechnology*, **3(4):** 17-20.

Goodrich, M.S., Dulak, L.H., Friedman, M.A. and J.J. Lech (1991). Acute and long-term toxicity of water soluble cationic polymers to rainbow-trout (*Oncorhynchus mykiss*) and the modification of toxicity by humic-acid. *Environmental Toxicology and Chemistry*, **10(4):** 509-515.

Iakovides, I., Pantziaros, A., Zagklisa, A.D. and C. Paraskeva (2014). Effect of polyelectrolytes on the removal of solids and organics from olive mill wastewater. *Journal of Chemical Technology and Biotechnology*, **91:** 204-211. DOI: 10.1002/jctb.4563

Ishak, S.A., Murshed, M.F., Md Akil, H., Ismail, N., Md Rasib, S.Z. and A. A. S. Al-Gheethi (2020). "The application of modified natural polymers in toxicant dye compounds wastewater: A review." *Water*, **12(7):** 2032. doi: 10.3390/w12072032

Jabin, S. and J.K. Kapoor (2020). Role of polyelectrolytes in treatment of water and wastewater I.A. Asiri, "Sustainable Green Chemical Process and their Allied Applications", Springer Nature Switzerland, pp: 289-309. https://doi.org/10.1007/978-3-030-42284-4_10

Kam, S.K. and J. Gregory (2001). The interaction of humic substances with cationic polyelectrolytes. *Water Research*, **35(15):** 3557-3566.

Kapoor, J.K., Jabin, S. and H.S. Bhatia (2011). Evaluation of cationic and anionic polyelectrolytes as a coagulant aid for water quality improvement. *Journal of Chemistry and Chemical Sciences*, **1(4):** 267-275.

Kapoor, J.K., Jabin, S. and H.S. Bhatia (2015). Optimization of coagulation-flocculation process for food industry wastewater treatment using polyelectrolytes with inorganic coagulants. *Journal of Indian Chemical Society*, **92:** 1697-1703.

Lee, Ch. and J.C. Liu (2000). Enhanced sludge dewatering by dual polyelectrolytes conditioning. *Water Research*, **34(18):** 4430-4436. DOI: 10.1016/S0043-1354(00)00209-8

Lee, J.F., Liao, P.M., Tsen, D.H. and P.T. Wen (1998). Behavior of organic polymers in drinking water purification. *Chemosphere*, **37(6):** 1045-1061.

Lee, W. and P. Westerhoff (2006). Dissolved organic nitrogen removal during water treatment by aluminum sulfate and cationic polymer coagulation. *Water Research*, **40(20):** 3767-3774. DOI: 10.1016/j.watres.2006.08.008

Letterman, R.D. and R.W. Pero (1990). Contaminants in polyelectrolytes used in water treatment. *Journal of American Water Works Association*. doi: 10.1002/j.1551-8833.1990.tb07056.x

Lourenço, A., Arnold, J., Gamelasa, J.A.F., Cayrec, O.J. and M.G. Rasteiro (2017). Pre-treatment of industrial olive oil mill effluent using low dosage health friendly cationic polyelectrolytes. *Journal of Environmental and Chemical Engineering*, **5:** 6053-6060. DOI: 10.1016/j.jece.2017.11.029.

Lurie, M. and M. Rebhun (1997). Effect of properties of polyelectrolytes on their interaction with particulates and soluble organics. *Water Sciences Technology*, **36(4):** 93-101.

de Nardi, I.R., Fuzi, T.P. and V. del Nery (2007). Performance evaluation and operating strategies of dissolved-air flotation system treating poultry slaughterhouse wastewater. *Resources, Conservation and Recycling*, **52:** 533-544.

Petzold, G., Mende, M., Lunkwitz, K., Schwarz, S. and H.M. Buchhammer (2001). Higher efficiency in the flocculation of clay suspensions by using combinations of oppositely charged polyelectrolytes. *Colloids Surface A—Physicochemical Engineering Aspects*, **218 (1-3):** 47-57.

Radoiu, M.T., Martin, D.I., Calinescu, I. and H. Iovu (2004). Preparation of polyelectrolytes for wastewater treatment. *Journal of Hazardous Materials*, **106:** 27-37. DOI: 10.1016/j.jhazmat.2003.08.014

Razali, M.A.A., Ahmad, Z., Ahmad, M.S.B. and A. Ariffin (2011) Treatment of pulp and paper mill wastewater with various molecular weight of polyDADMAC induced flocculation. *Chemical Engineering Journal*, **166:** 529-535. DOI: 10.1016/j.cej.2010.11.011

Qin, J.J., Kekre, K.A., Knops, F. and P. Miller (2006). Impact of coagulation pH on enhanced removal of natural organic matter in treatment of reservoir water. *Separation and Purification Technology*, **49:** 295-298. DOI: 10.1016/j.seppur.2005.09.016

Sarika, R., Mantzavinos, D. and N. Kalogerakis (2005). Treatment of olive mill effluents. Part II: Complete removal of solids by direct flocculation with polyelectrolytes. *Environment International*, **31:** 297-304. DOI: 10.1016/j.envint.2004.10.006

Selvapathy, P. and M.J. Reddy (1992). Effect of polyelectrolytes on turbidity removal. *Water Supply*, **10(4):** 175-178.

de Sena, R.F., Moreira, R.F. and H.J. José (2008). Comparison of coagulants and coagulation aids for treatment of meat processing wastewater by column flotation. *Bioresources and Technology*, **99:** 8221-8225.

Szyguła, A., Guibal, E., Palacín, M.A. Ruiz, M. and A.M. Sastre (2009). Removal of an anionic dye (Acid Blue 92) by coagulation–flocculation using chitosan. *Journal of Environmental Management*, **90:** 2979-2986.

Theodoro, J.D.P., Lenz, G.F., Zara, R.F. and R. Bergamasco (2013). Coagulants and natural polymers: Perspectives for the treatment of water. *Plastic and Polymer Technology*, **2:** 55-62.

Vaughan, R.L., Reed, B.E., Roark, G.W. and D.A. Masciola (2000). Pilot-scale investigation of chemical addition-dissolved air flotation for the treatment of an oily wastewater. *Environmental Engineering and Sciences*, **17:** 267-277.

Yap, R.K.L., Whittaker, M., Diao, M., Stuetz, R.M., Jeerson, B., Bulmus, V., Peirson, W.L., Nguyen, A.V. and R.K. Henderson (2014). Hydrophobically-associated cationic polymers as micro-bubble surface modifiers in dissolved air flotation for cyanobacteria cell separation. *Water Research*, **61:** 253-262.

Wei, Y., Dong, X., Ding, A. and D. Xie (2016). Characterization and coagulation flocculation behavior of an inorganic polymer coagulant polyferric-zinc-sulfate. *Journal of Taiwan Institute of Chemical Engineers*, **58:** 351-356. DOI: 10.1016/j.jtice.2015.06.004

Weston, D.P., Lentz, R.D., Cahn, M.D., Scott Ogle, R., Rothert, A.K. and M.J. Lydy (2009). Toxicity of anionic polyacrylamide formulations when used for erosion control in agriculture. *Journal of Environmental Quality Abstract - Surface Water Quality*, **38(1):** 238-243. Doi:10.2134/jeq2008.0109

Wu, W., Palmarin, M.J. and S. Young (2018). Poly(dimethylamine-co-epichlorohydrin) as an alternative to alum for the demulsification of commercial dishwasher wastewater. *Seperation and Purification Technology*, **195:** 281-287. doi: 10.1016/j.seppur.2017.11.051

Wilts, E.M., Herzberger, J. and T.E. Long (2018). Addressing water scarcity: Cationic polyelectrolytes in water treatment and purification, *Polymer International*, doi: 10.1002/pi.5569

Zhou, Y. and G.V. Franks (2006). Flocculation mechanism induced by cationic polymers investigated by light scattering. *Langmuir*, **22:** 6775-6786.

CAPITAL PUBLISHING COMPANY

Recent and Forthcoming Publications on Climate Change and Environmental Sciences

Mohanty	Advanced Numerical Modeling and Data Assimilation Techniques for Tropical Cyclone Predictions
Goel	Advances in Soil and Hazardous Waste Management
Rakhecha	Applied Hydrometeorology
Behera	Bioenergy for Sustainability and Security
Nagarajan	Climate and Natural Resources
Subramanian	Coastal Environments — Focus on Asian Regions
Asthana	Dam Engineering
Nagarajan	Drought Assessment
Křeček	Ecosystem Services of Headwater Catchments
Sikdar	Environmental Management: Issues and Concerns in Developing Countries
Kónya	Environmental Sustainability Education for a Changing World
Talapatra	Geochemical Exploration and Modelling of Concealed Terrestrial and Offshore Mineral Deposits
Naqvi	Geology and Evolution of the Indian Plate (From Hadean to Holocene – 4 GA to 4 KA)
Basavaiah	Geomagnetism: Solid Earth and Upper Atmosphere Perspectives
Raju	Geostatistical and Geospatial Approaches for the Characterization of Natural Resources in the Environment: Challenges, Processes and Strategies
Mitra	Global Environmental Changes in South Asia: A Regional Perspective
Sikdar	Groundwater Development and Management: Issues and Challenges in South Asia
Thangarajan	Groundwater Flow and Mass Transport Modeling
Ghosh	Groundwater Governance
Ghosh	Groundwater Modelling and Management
Thangarajan	Groundwater: Resource Evaluation, Augmentation, Contamination, Restoration, Modeling and Management
Ray	High Impact Weather Events over the SAARC Region
Machiwal	Hydrologic Time Series: Theory and Practice
Beheim	Integrated Watershed Management
Chatterjee	Macro-Economics of Mineral and Water Resources—Important Issues
Ramanathan	Management and Sustainable Development of Coastal Zone Environments
Krecek	Management of Mountain Watersheds
Raju	Management of Natural Resources in a Changing Environment
Raju	Management of Water, Energy and Bio-Resources in the Era of Climate Change: Emerging Issues and Challenges
Das	Microbial Fuel Cell: A bioelectrochemical system that converts Waste to Watts
Kayal	Microearthquake Seismology and Seismotectonics of India
Tiwari	Modern Singular Special Based Denoising and Filtering Techniques for 2d and 3d Reflection Seismic Data
Mohanty	Monitoring and Prediction of Tropical Cyclones in the Indian Ocean and Climate Change
Jha	Natural and Anthropogenic Disasters: Vulnerability, Preparedness and Mitigation
Nagarajan	Natural and Mad-made Disasters: Assessment and Management
Subramanian	Rivers of South Asia
Ramanathan	Safe and Sustainable Use of Arsenic Contaminated Aquifers in the Gangetic Plain: A Multi-Disciplinary Approach
Behari	Sustainability, Green Energy and Climate Change: Revisited
Datta	Theory and Principles of Simulation Modelling in Soil-Plant System
Kurisu	Trends in Asian Water Environmental Science and Technology
Sengupta	Treatment and Disposal of Solid and Hazardous Wastes
Mohapatra	Tropical Cyclone Activity over the North Indian Ocean

For more detailed information on individual titles, please log on to our website www.capital-publishing.com