Global J. Environ. Sci. Manage. 6(4): 553-578, Autumn 2020

Global Journal of Environmental Science and Management
(GJESM)

Homepage: https://www.gjesm.net/

REVIEW PAPER

Use of natural coagulants for industrial wastewater treatment

S. Gautam and G. Saini*

Department of Civil Engineering, School of Engineering and Technology, Sharda University, Uttar Pradesh, India

ARTICLE INFO

Article History:
Received 02 February 2020
Revised 15 April 2020
Accepted 18 May 2020

Keywords:
Coagulation
Chemical coagulant
Environment-friendly
Industrial Wastewater
Natural coagulant

ABSTRACT

Industrial effluents are a menace to the environment and the fact that their characteristics vary from industry-to-industry only adds to the complex challenge they offer to the engineers and scientists. Resource-efficient and environment-friendly solutions to this hazard are a call of the hour. Coagulation, by synthetic chemicals, has been used as a cost-effective and efficient method for managing the effluents generated by a large number of industries. However, the synthetic chemicals themselves are a cause of concern due to their non-native nature, non-degradability, and health conditions associated with their left-over residues. Natural coagulants offer a cost-effective, environment-friendly, and sustainable alternative to the application of synthetic chemicals. Such natural coagulants, despite their demonstrated effectiveness in treating the industrial wastewaters, have their own limitations and are yet to be investigated for large-scale applications. The current work presents a state-of-the-art review of the natural coagulants' application in treating industrial wastewaters and their relative advantages and disadvantages as compared to the chemical coagulants. Future research areas have also been identified that may ultimately lead to the large-scale commercial application of natural coagulants and will result in an environment-friendly and sustainable solution to the problems created by industrial effluents and synthetic chemical coagulants.

DOI: 10.22034/gjesm.2020.04.10

NUMBER OF REFERENCES
190

NUMBER OF FIGURES
0

NUMBER OF TABLES
3

*Corresponding Author:
Email: *gaurav.saini@sharda.ac.in*
Phone: +91 828 705 1260
Fax: +91 828 705 1260

Note: Discussion period for this manuscript open until January 1, 2021 on GJESM website at the "Show Article.

INTRODUCTION

Rapid industrialization has posed many threats to the environment due to the wastewater generation through various industrial processes. Indiscriminate disposal of this wastewater (with or without an appropriate level of treatment) can cause water pollution and land pollution. This has a profound effect on the health of living beings apart from the impacts on the abiotic components such as soil (Chhonkar *et al*., 2000) and water (Pal *et al.,* 2010). Some key sources of industrial wastewater are palm oil mills (Bhatia *et al.,* 2007; Jagaba *et al.,* 2020), paper and pulp industry (Ashrafi *et al*., 2015; Wang *et al.*, 2011; Chaudhari *et al.,* 2010), brewery and winery (Brito *et al.,* 2004), cosmetic industry (Naumczyk *et al*., 2014), tannery industry (Rameshraja and Suresh, 2011), slaughterhouses (Bustillo-Lecompte *et al.*, 2015), paint industry (Aboulhassan *et al*., 2014), dairy industry (Triques *et al*., 2020), etc. A huge quantity of industrial wastewater is generated worldwide daily. Saha *et al.* (2005) claimed that a single unit of Indian distillery uses 1133.5 KLD of water, and, after processing, around 668 KLD of wastewater is generated. In another attempt to quantify the wastewater generation in India, Majumder *et al.* (2014) estimated that every day around 13,468 MLD of wastewater is generated, out of which, more than 50% is discharged into the environment untreated. The quantity and quality of industrial effluent are functions of the ongoing industrial process, raw material utilized, and products manufactured in each industrial unit, and therefore the composition and constitution of wastewater generated are different for different industries. For instance, the textile dyeing processes in the textile industry generate colored wastewater rich in chemical dyes (Ariffin *et al.,* 2009). On the other hand, the effluent from paper and pulp industry contains large quantities of sodium salts of organic acids, lignin, etc. (Wang *et al.,* 2011). Wastewater from the cosmetic industry has significant concentrations of COD, oils, detergents, fats, and suspended solids (Tobajas *et al.,* 2014). Muralimohan *et al.* (2014) studied the various processes contributing to the wastewater generation in the textile industry. The study revealed that processes like cleaning, de-sizing, etc. are responsible for toxic wastewater generation. The main high-risk constituents of this wastewater are chemicals, dyes, bleaching agents, oils, acids, bases, etc. Sometimes, wastewater contains heavy metals which are a potential cause of concern for the environment and human health (Ahemd *et al*., 2020). Prasad and Rao 2016 studied the impact of the cadmium pollution, caused due to the discharges from the mining activities. Elevated levels of cadmium can cause diseases like Itai-Itai; whereas, at low levels, it may cause problems like kidney damage, sterility among males, flu disorders, and high blood pressure. The characteristics of wastewater have been studied in terms of key parameters like BOD (Sehar *et al*., 2013), TDS, COD (Rathi and Puranik, 2002), and color. These parameters help in gauging the level of potential hazard the effluent can pose to the environment and human health. Due to the potential toxicity, industrial effluents may require prior treatment before their release into the environment. Improper disposal of the wastewater can cost liability in addition to their environmental impacts (Elsheikh and Al-Hemaidi, 2013). Sahu and Chaudhari 2013 suggested that industrial wastewater management is necessary to eliminate the health and socio-economic concerns. Wastewater treatment technologies can be physical, chemical, or biological (Elsheikh and Al-Hemaidi, 2013). Among the physicochemical processes, coagulation-flocculation has been frequently used. In this process, the charge of the colloidal particles is destabilized with the help of coagulants (typically aluminium or iron salts) which results in floc formation due to collision of destabilized particles and their aggregation, which ultimately gets separated from the liquid phase. An alternative to the conventional coagulation-flocculation is the electrocoagulation process. Here, coagulants are formed due to electro-dissolution of the anode which causes hydrolysis products that result in the destabilization of the particles (Verma and Kumar, 2018). Electrocoagulation has been successfully used for the treatment of textile wastewater using iron and aluminium electrodes (Kobya *et al.,* 2003), synthetic textile wastewater (Merzouk *et al.,* 2011), sewage (Carballa *et al.,* 2005), vegetable oil refinery wastewater (Tezcan *et al.,* 2009), paint industry wastewater (Akyol*,* 2012), olive oil mill wastewater (Salameh*,* 2015), petroleum refinery wastewater (El-Naas *et al.,* 2009), etc. This process has also been used to successfully remove harmful substances, such as Diclofenac (responsible for vulture population decline) (Oaks *et al.,* 2004; Green *et al.,* 2004), and a carcinogenic dye, acid red 14 (Ahangarnokolaei *et al.,* 2017). Electrocoagulation requires very small settling time due to the rapid settling of the flocs and results in lesser sludge production (Ahangarnokolaei *et al.,* 2017). However, complicated experimental setup with the electricity or current input is required for the treatment which limits its commercial application by increasing the operational cost of the treatment unit (Perren *et al.,* 2018). Therefore, electrocoagulation cannot be seen as an economical option for a large-scale industrial wastewater treatment. Coagulation, on the other hand, is an important chemical treatment method and is very effective for wastewater treatment (Carballa *et al*., 2005). Wastewater streams obtained from industries like tannery (Ariffin *et al.,* 2009), hospital (Wang *et al.,* 2011), paper and pulp mill (Wang *et al.,* 2011), etc. have been treated by coagulation using synthetic chemicals. The use of chemical coagulants for coagulation of wastewater has various implications such as their potential to cause diseases (WHO Guidelines, 2010), the possibility of groundwater contamination or surface runoff of treated water containing high residual aluminium concentration and therefore their use for the wastewater treatment is not an eco-friendly option. On the other hand, the use of natural substances for coagulation in place of chemicals is a promising alternative for the treatment of industrial wastewater. Natural coagulants are safe for consumption (owing to their plant-origins) and are biodegradable in the environment (Feria-Díaz *et al.,* 2016; Nath, *et al.,* 2020). Plant components, which are otherwise considered as waste are an economical option, as compared to the synthetic chemicals. Natural coagulation has been used for treating wastewater from various industries like textile (Muralimohan *et al.,* 2014; Shankar *et al.,* 2014; Dotto *et al.,* 2019; Prabhakaran *et al.,* 2020), dairy (Sivakumar *et al.,* 2014; Sivakumar, 2015; Sivakumar *et al.,* 2016; Triques *et al.,* 2020), tannery (Ahmed *et al*., 2020), etc. A compilation of the various chemical and natural coagulants used for the treatment of industrial wastewater, from literature studies, has been provided in Table 1.

In comparison, some of the synthetic coagulants used for the treatment of domestic sewage include alum (Sarparastzadeh *et al.,* 2007), ferric chloride (Sarparastzadeh *et al.,* 2007), poly-aluminium chloride (El Samrani *et al.,* 2008) and aluminium sulphate (Fabres *et al.,* 2017). Several research studies have shown the potential of natural coagulants in treating the wastewaters originating from different industries and have shown them to be equivalent to chemical coagulants in terms of treatment efficiencies for various parameters of interest. Coagulation using natural coagulants has also been effectively used for the water treatment. However, the current work is solely focused on industrial wastewater. A brief introduction of the coagulation-flocculation process and factors affecting this process is presented, followed by a review of the applications of chemical coagulants and their advantages and disadvantages. The need for reducing the residual aluminium in water is emphasized by a brief review of the relevant literature. Natural coagulants are discussed as an attractive and environment-friendly alternative to the chemical coagulants and some of the more commonly studied natural coagulants are

Table 1: Chemical and natural coagulants investigated for the coagulation of industrial wastewaters.

Chemical coagulants	Natural coagulants	
Potassium Aluminium Sulphate ($KAl(SO_4)_2{\cdot}12H_2O$)	Chitosan	*Opuntia mucilage*
Aluminium sulphate $Al_2(SO_4)_3$	*Moringa oleifera*	*Psyllium husk*
Ferric chloride ($FeCl_3$)	*Abelmoschus esculentus* (okra)	*Plantago major L.*
Iron(III) chloride hexahydrate	*Malva sylvestris* (mallow)	*Hibiscus Rosa sinensis*
Poly aluminum chloride (PAC)	*Ocimum Basilicum*	*Trigonella foenum-graecus*
Lime (CaO)	*Sechium edule* (Chayote)	*Dolichos lablab*
Magnesium chloride ($MgCl_3$)	*Plantago ovata*	*Cicer arietinum*
Ferric sulphate	*Zea mays* (maize)	Roselle seeds
Poly ferric acetate	Cactus	Banana juice
Poly ferric sulphate	*Tamarind Indica*	*Strychnos Potatorum*
Poly aluminium ferric chloride (PAFC)	Bitter gourd seed	Castor oil cake
Poly aluminium silicate chloride (PASic)	Cotton seed oil cake	Surjana seed powder
	Maize seed powder	

described in detail. The advantages offered by these plant-based substances and the issues impeding their commercial-scale application are also discussed. The authors have also identified several constraints that prevent the commercial adoption of the natural coagulants for wastewater treatment. To overcome these constraints, some areas of future research have been identified and are likely to promote the large-scale adoption of natural coagulants. Recommendations have also been made for usage of natural coagulants over the synthetic chemicals. Natural and environment-friendly options for managing industrial wastewaters are not only cost-effective and sustainable; but may also ensure that industrial effluents are treated (before disposal) in the far-flung areas in developing and the under-developed world, where the technical expertise is absent and chemical coagulants are not easily available or are too expensive to be considered a viable option. This study is aimed at providing state-of-the-art and comprehensive review of the application of natural coagulants for treating industrial wastewaters. This work was done in Greater Noida, Uttar Pradesh, India during 2018-20.

Chemical coagulation

Chemical coagulation is the process of destabilizing the colloidal impurities in water or wastewater by using chemically produced substances. The process of formation of flocs on charge neutralization is known as flocculation (Hamawand, 2015). Aluminum sulfate (Quintero-Jaramillo *et al*., 2016), potassium aluminium sulfate, Iron (III) chloride hexahydrate, ferric sulfate (Karamany*,* 2010), etc. can be used as coagulants for water and wastewater treatment. Alum is the most commonly used chemical coagulant. Alum contains potassium and aluminum, and is chemically represented as $KAl(SO_4)_2.12H_2O$. Alum or potassium aluminium sulfate is very frequently used for water and wastewater treatment. Alum is easily available and is an inexpensive alternative for the wastewater treatment. Madhavi *et al.* 2014 used alum for treating wastewater from the metal fabrication industry. Alum, at a concentration of 450mg/L, removed 99% of color from the wastewater at a pH of 8.0 (Madhavi *et al*., 2014). The effectiveness of alum can be increased by using it with other coagulants. In a study, alum, when used with polyacrylamide (PAA) and poly ferric sulfate (PFS), resulted in an increase in the efficiency of COD removal to 82% from 68% (Loloei *et al*., 2014). Jiang and Llyod 2002 reviewed the potential of ferrate salts for the treatment of wastewater and reported their potential application for wastewater treatment. Iron (III) chloride, also called as ferric chloride (represented as $FeCl_3$), can also be used as a coagulant for wastewater treatment. Bogacki *et al.* 2011 used ferric chloride for the treatment of cosmetic industry wastewater with the aim of COD reduction. Using ferric chloride, up to 63.9% reduction of COD was achieved at a pH of 6.0. Poly aluminum ferric chloride can also be used as a coagulant (Ebrahimi *et al.,* 2014). Liang *et al.* 2009 used ferric chloride for treating the molasses wastewater. At optimum conditions, 96% color and 86% COD could be removed from the wastewater (Liang *et al.,* 2009). Ebeling *et al.* (2003) used ferric chloride to remove 93% orthophosphate from aquaculture discharge. Iron (II) sulfate, also called ferrous sulfate (represented as $FeSO_4•xH_2O$), can act as coagulating agent for wastewater treatment. In a comparative study using coagulants: lime, alum, ferric chloride ($FeCl_3$), ferrous sulfate ($FeSO_4$), and magnesium chloride ($MgCl_3$) for the treatment of textile industry wastewater, Bidhendi *et al.* 2007 found that ferrous sulfate was the most effective and could remove color at low coagulant dose, had minimum settled sludge volume and maximum decolorization of wastewater. Loloei *et al.* 2014 did a comparative study of alum and ferric sulfate for treating the wastewater from the dairy industry. Ferric sulfate could remove up to 95% turbidity and 62% COD (Loloei *et al.,* 2014). Aluminium sulphate is an aluminium salt that can be used as a coagulant for wastewater treatment. Poly aluminium chloride (PAC) can be used as a coagulant for wastewater treatment. Fattah *et al.,* 2013 used poly aluminium chloride for automotive wastewater treatment and reported that it could remove 98% iron, 83% zinc and 63% nickel. Chemical coagulants, after immobilization, were found to be more effective in reduction of TDS, phenolphthalein, total phenolphthalein, COD, and chromium as compared to their native forms (Imran *et al.,* 2012 ; Aravind *et al.,* 2016). Immobilized ammonium aluminium sulphate was found to be more effective for the chromium removal from tannery industry wastewater (Imran *et al., 2012*). Gregory and Duan, 2001 discussed the charge neutralization by hydrolyzing metal coagulants and the effects associated with precipitated metal hydroxide. The study also reviewed the basic principles of colloid stability and metal ion hydrolysis. Some of the hydrolyzing salts that can be used as coagulants to aid coagulation and flocculation process are PAC (Pal *et al.,* 2010; Alavijeh *et al.,* 2017), Poly ferric sulphate, poly aluminium ferric chloride, and. They have superior color removal efficiency even at a small dosage and are effective for treating wastewater over a wide pH range (Muralimohan *et al.,* 2014). Wei *et al.*, 2017 used poly ferric acetate to remove phosphorus from synthetic wastewater prepared using 0.2 g/L kaolin solution. It was found that, under optimum pH range of 7.0-9.0, the removal percentage of phosphorus was 96.1 % using poly ferric acetate, proving it to be a promising alternative for phosphorus removal from wastewater. Irfan *et al.*, 2017 used chemical coagulants such as aluminium chloride, poly-aluminium chloride, and anionic PAM for treating black liquor wastewater. The combination could remove 88% color, 95% total suspended solids and 81% COD. Response surface methodology (RSM) is a new approach in the wastewater treatment. This technique uses a combination of mathematical and statistical models to determine the efficiency of the coagulants in the coagulation and flocculation process. Thirugnanasambandham *et al.,* 2014 used this technique for the bagasse wastewater treatment with the help of biopolymer. Wang *et al.,* 2011 used aluminium chloride as a chemical coagulant for paper mill wastewater treatment. In addition, a modified natural polymer was used as a flocculant. The models were developed to obtain the efficiency of chemical coagulants in terms of turbidity and lignin removals. For the experiments, the dose of coagulant used was 871 mg/L and to aid the process, a flocculant dose of 22.3 mg/L at pH 8.35 was selected. Experiments confirmed that combination of the Uniform Design and RSM is an efficient approach for the treatment of paper and pulp mill wastewater. Ghafari *et al.*, 2009 investigated the efficiency of poly aluminium chloride and alum for leachate treatment. Using Central composite design (CCD) and response surface method (RSM), quadratic models were developed. Using 2 g/L PAC (at a pH of 7.5) and 9.5 g/L alum, the efficiency of the coagulants was determined. The predicted efficiency of the coagulants matched with the experimental data. The COD, turbidity, color, and TSS removal efficiencies for PAC were reported to be 43.1%, 94.0%, 90.7%, and 92.2%, respectively. The comparable efficiencies for alum were found to be 62.8%, 88.4%, 86.4%, and 90.1%, respectively. Chemical coagulants have several advantages. The easy availability and cheap prices are some of the reasons which outweigh the issues and concerns associated with the large-scale application of these coagulants on the commercial level. The efficiency of chemical coagulants is not affected by the pH variation as they are effective over a wide pH range. The optimum conditions are obtained at very low dosages. The easy availability of chemicals, ease of storage, no efficiency loss with long-term storage, reliability of the system and better efficiency are some of the key advantages of the chemical coagulants (Semerjian and Ayoub, 2003). The efficiency of the chemical coagulant gets influenced by several different factors. Next section will comprehensively detail the factors affecting the efficiency of chemical coagulants.

Factors affecting the efficiency of chemical coagulants

The factors affecting the efficiency of coagulation process are characteristics of wastewater, the type and the quantity of coagulant used (Azhar *et al.*, 2016). Temperature also has a very significant effect on the flocculation process. Joudah 2014 studied the effect of temperature on the flocculation efficiency of coagulants. The study claimed that, at lower temperatures, the flocculation efficiency is reduced as the bigger flocs get broken (Joudah, 2014). Warmer temperatures are therefore, preferred to ensure better flocculation (Fitzpatrick *et al.*, 2004). The effectiveness of coagulants in the wastewater treatment depends on the wastewater pH. Altaher and Alghamdi 2011 comprehensively studied the effects of pH, temperature and stirring rate on the coagulation and flocculation efficiency of four coagulants: alum, ferrous sulfate, ferric chloride, and commercial synthetic cationic polymer. The study reported that the wastewater pH significantly affected the turbidity reduction. The highest removal efficiency was obtained at higher pH values. Variation in the stirring rate did not affect coagulation efficiency. The process of coagulation has been identified as an effective method for treatment of the wastewater having variations in temperature, dosage, and concentration. Zhang *et al.* 2018 used the combination of poly aluminium chloride and chitosan for the treatment of low temperature and low turbidity water. This coagulant combination yielded removal efficiencies of turbidity, DOC and UV254 of approximately 87%, 63%, and 82%, respectively. In another study, Dhivya *et al.* 2017 noted that the natural coagulant *Plantago ovata* (*P. ovata*) worked best at the room temperature and when tested for the varying turbidity values removal efficiencies in range 98.2% to 80.2% were obtained. However, PO-NaCl was found to be most effective in alkaline conditions. Saritha *et al.* 2020 used various combinations of natural and synthetic coagulants for water treatment and turbidity removal of 99.29 % was attained at all the pH variations and dosages. Thus, it is necessary to consider the effect of parameters such as temperature, dosage and concentration of the source water on the coagulant dosage and efficiency.

Addition of flocculants

The efficiency of the chemical coagulants can be further improved by the addition of flocculants. Flocculants are the substances which link destabilized particles thereby causing settling of the colloidal impurities in the form of flocs. De Godos *et al.* 2011 used $Fe_2(SO4)_3$, $FeCl_3$ and five commercial polymeric flocculants (Chitosan, Flocudex CS/5000, Drewfloc 447, Flocusol CM/78, and Chemifloc CV/300) to evaluate their efficiency of algal biomass removal from the piggery wastewater. Biomass removals of up to 98% were achieved using the combination of 150–250 mg/L ferric salts and 25–50 mg/L flocculants. Vanerkar *et al.* 2013 treated food industry wastewater using coagulation and flocculation process and discussed the behavior of coagulant supplemented with polyelectrolytes. Different coagulants and flocculants were tried to attain the best results and lime was selected as the optimum coagulant based on the cost factor. Lime was used for the coagulation and resulted in 53.59% COD and 57.19% BOD reductions respectively, at the dosage of 200 mg/L. Only, 25 mL/L of sludge was developed at this dose of the coagulant. Alum dosage was not very effective for the treatment. 0.3 mg/L of Magnafloc E-207 in combination with 200 mg/L of lime effectively reduced 67.61%, 71.01% and 81.53% of COD, BOD and SS, respectively (Vanerkar *et al.,* 2013). Wong *et al.* 2006 used anionic and cationic polyacrylamides to treat paper and pulp mill wastewater. Aguilar *et al.* 2005 also used anionic polyacrylamide for improving coagulation-flocculation process for treatment of slaughterhouse effluent. The use of anionic polyacrylamide helped in increasing the coagulation efficiency of the coagulants, ultimately reducing the cost of treatment. Chemical coagulants have also been used in conjunction with other processes to get zero discharge. El-Awady *et al.* 2019 studied the possibility of reusing treated water from a paper recycling mill industry to obtain zero discharge from the unit. The wastewater treatment was carried out using synthetic coagulants like alum, ferric chloride and cationic polymer. Removal efficiency up to 98.9% was obtained for TSS and up to 79.4% was obtained for COD. It was noted that the treated water was fit to be reused at the unit for the industrial activities. Mohammadtabar *et al.* 2019 tried five chemical membrane hybrid processes, in conjunction with coagulation, for the treatment of boiler blowdown water from oil and sand stream. This experimental study showed that the direct treatment of blowdown water by nano-filtration resulted in up to 97% of TDS removal. A flux recovery of 97% was obtained by simple hydraulic washing which necessitated the need of the pre-treatment with ion exchanger regeneration wastewater and soda ash solutions. These two processes combined can help attain Zero liquid discharge and calcium sulfate extracted from the sludge has direct applications in cement manufacturing, food factories, and water treatment, whereas the nano filter soda ash can be reused for generation of ion exchanger. Semblante *et al.* 2018 tried to find better management options for brine and suggested pre-treatment by coagulation and flocculation process followed by thermal treatment to obtain a Zero liquid discharge.

A summary of the various chemical coagulants, the industrial wastewaters studied, and key results is presented in Table 2. From this listing, it is clear that alum, poly aluminium chloride (PAC) and ferric chloride hexahydrate are the most efficient chemical coagulants and have been used to treat wastewaters generated by different industries such as tannery, paper and pulp, textile, beverage, etc.

Reducing the residual aluminium in the supernatant

The residual aluminium varies based on the type of the coagulant used for the treatment. There are a number of health effects associated with high levels of residual aluminium in the water (discussed in more detail in the following section) and hence it needs

Table 2: A summary of the various chemical coagulants and their effectiveness for the treatment of industrial wastewaters

S.N.	Coagulant	Industry	Form of coagulant	Optimum dosage	Parameters studied	Removal efficiency	Reference
1	Alum and cationic polymer (C-492)	Tannery wastewater	Dry	100 and 5 mg/L	Turbidity TSS Total COD Chromium	97% 93.50% 36.20% 98.40%	Haydar and Aziz, 2009
2	Alum and cationic polymer (Cytec)	Textile dyes wastewater	Dry	200 and 1.0 mg/L	Color COD	94.00% 44.00%	El-Gohary and Tawfik, 2009
3	Alum and Anionic polymer	Tannery wastewater	Dry	160 and 5 mg/L	Turbidity TSS Total COD Chromium	99.70% 96.30% 48.30% 99.70%	Haydar and Aziz, 2009
4	Alum+ organopol	Paper and pulp mill wastewater	Dry	1000 mg/L	Turbidity TSS COD	99.70% 99.50% 95.60%	Ahmad *et al.*, 2008
5	Alum	Tannery wastewater	Dry	240 mg/L	Turbidity TSS Total COD Chromium	99.70% 96.40% 53.30% 98.90%	Haydar and Aziz, 2009
6	Alum	Leachate treatment	Dry	11 g/L	COD Color TSS	58.00% 79.00% 78.00%	Al-Hamadani *et al.*, 2011
7	Alum	Paper and pulp mill wastewater	Dry	1000 mg/L	Turbidity TSS COD	99.80% 99.40% 91%	Ahmad *et al.*, 2008
8	Alum	Oil refinery wastewater	Powder	40 mg/L	COD Turbidity TSS	52% 92% 82%	Dehghani and Alizadeh, 2016.
9	PAC	Wastewater	powder	30 mg/L	Turbidity COD	96% 71%	Awad *et al.*, 2013
10	PAC and Shendi	Wastewater	powder	30 mg/L and 400mg/L	Turbidity COD	95% 63%	Awad *et al.*, 2013
11	PAC and Singa	Wastewater	powder	30 mg/L and 400 mg/L	Turbidity COD	96% 61%	Awad *et al.*, 2013
12	PAFS	sewage wastewater	aqueous solution	45 mg/L	COD	83%	Zhu *et al.*, 2012
13	Ferric chloride	Coal washery wastewater	solution	400 ppm	Turbidity	98%	Babarao and Verma, 2015
14	Ferric chloride	Tannery wastewater	powder	150 mg/L	Turbidity Cr TDS TSS Turbidity BOD	82% 93% 71% 95% 72% 81%	Ahmed *et al.*, 2016

Table 2: A summary of the various chemical coagulants and their effectiveness for the treatment of industrial wastewaters

S.N.	Coagulant	Industry	Form of coagulant	Optimum dosage	Parameters studied	Removal efficiency	Reference
15	Ferric Chloride and Aluminium Sulfate	Hospital wastewater	Dry		COD TSS Diclofeneac (DCF) Naproxen (NPX)	85% 92% 46% 42%	Suarez *at al.,* 2009
16	Ferric chloride and lime	Coal washery wastewater	Solution	400 ppm	Ibuprofen (IBP)	23%	Babarao and Verma, 2015
17	Iron III chloride Hexahydrate	Beverage industry wastewater	Dry	300 mg/L	Turbidity COD TP	100% 73% 95%	Amuda and Amoo, 2007
18	Iron III chloride Hexahydrate	Textile wastewater	Stock solution	0.37 mol/L	TSS Turbidity	97% 94%	Wang *et al.,* 2011
19	Iron III chloride Hexahydrate	Cosmetic industrial wastewater	Powder	500 mg/L	COD Turbidity O&G	50% 70% 87%	Carpinteyro *et al.,* 2012
20	Iron III chloride Hexahydrate and polyelectrolyte	Beverage industry treatment	Dry	100 and 25 mg/L	COD COD TP	48% 91% 99%	Amuda and Amoo, 2007
21	PAC	Paper and pulp mill wastewater	Dry	500 mg/L	TSS Turbidity TSS COD	97% 99.90% 99.50% 91.30%	Ahmad *et al.*, 2008
22	PAC	Leachate wastewater	Dry	7.5 g/L	COD Color TSS	55.00% 80.00% 95.00%	Al-Hamadani *et al.,* 2011
24	Lime	Textile dyes wastewater	Dry	600 mg/L	Color	100%	El-Gohary and Tawfik, 2009
25	Magnesium chloride	Textile dyes wastewater	Dry	120 mg/L	COD Color	50% 100%	El-Gohary and Tawfik, 2009
26	Lime+ Magnesium chloride	Textile dyes wastewater	Dry		COD Color COD	40% 97-100% 40-50%	El-Gohary and Tawfik, 2009
28	Ferrous sulfate with lime	Coal washery wastewater	solution	400 ppm	Turbidity	56.67%	Babarao and Verma, 2015
29	Ferric sulfate trihydrate	Beverage industry	Dry	500mg/L	Turbidity COD TSS TP	81.81% 78% 74% 75%	Amuda and Amoo, 2006
30	Ferric sulfate trihydrate and polyelectrolyte	Beverage industry	Dry	500 mg/L and 25 mg/L	COD TSS TP	93% 94% 96%	Amuda and Amoo, 2006

to be taken care of. Zouboulis and Tzoupanos 2009 realized the issues that may arise due to the high residual aluminum content in the treated water by the use of aluminum-based coagulant and therefore suggested the use of silica-based coagulants instead. Silica-based coagulants have low residual aluminium content in the treated water (Zouboulis and Tzoupanos, 2009). Presence of residual aluminium and its concentration in the supernatant is a function of the coagulant type. The use of the PASiC was suggested due to smaller residual aluminium content in the treated water. It was found that PASiC is resilient to pH variation as compared to the other coagulants (Zouboulis and Tzoupanos, 2009). A comparative study to see the flocs formation efficiency of silica-based and aluminium based coagulants showed that though silica-based coagulants form bigger flocs, if the results are compared to Poly aluminium chloride (PAC) and alum, there was not a very substantial difference in phosphate removal efficiencies of both types of coagulants (Zouboulis and Tzoupanos, 2009). Zouboulis and Traskas 2005 conducted a comparative study to understand the effect of basicity on the efficiency of poly aluminium chloride. The study reported that the PAC with intermediate basicity produced better coagulation results as compared to PAC with higher basicity and alum. The PAC has lesser residual aluminium concentration than alum. Poly aluminum chloride had better efficiency in removal of suspended particulates. Furthermore, the study concluded that the residual aluminium content in the treated water is also affected by the pH (Zouboulis and Traskas, 2005). Tolkou and Zouboulis 2014 tried different coagulants for water and wastewater treatment and suggest that PsiFAC (Poly-aluminum-ferric-silicate-chloride) is the most effective coagulant for water and wastewater treatment and has minimum residual aluminium concentration (140 µg Al/L). The coagulant could remove up to 99% turbidity using the coagulant dose of 100 mg/L.

Disadvantages of chemical coagulants: Health and environmental impacts

Chemical coagulation is carried out using synthetic chemical coagulants. This practice has the potential of leaving a bad impact on the environment and the public health. Chemical coagulants are non-biodegradable and remain in the water even after the coagulation process is completed. There is a possibility that the treated supernatant contains the traces of metals present in the chemical coagulants due to the presence of residual aluminium in the supernatant (Zouboulis and Tzoupanos, 2009). Use of chemical coagulants can cause neurological diseases like Alzheimer's disease (WHO Guidelines, 2010; Niquette *et al.,* 2004), Encephalopathy (Srinivasan *et al.,* 1999) leading to dementia, Down's syndrome and staining of Hippocampal neurons (Walton, 2006). The treated water containing the high concentration of residual aluminium may either get seeped into the groundwater or may have a surface runoff (WHO Guidelines, 2010). Chemical coagulants are non-biodegradable (Muralimohan *et al*., 2014) and remain in the water because of which, synthetic chemicals are said to generate a sludge that may not be amenable to safe environmental disposal and may result in contamination of our water and land. Parmar *et al.* 2012 in his study suggested that supernatant obtained from dairy industry using alum and ferrous sulfate was not suitable for discharge into the municipal drains due to the high values of various parameters like BOD and COD in the supernatant. Major issues with the use of aluminium-based coagulants are that they lead to increased concentration of residual aluminium in the supernatant (WHO Guidelines, 2010). This aluminum may either seep into the groundwater or may have a surface runoff (WHO Guidelines, 2010). Conventional, water and wastewater treatment plants do not remove aluminium and water with elevated aluminium content (Walton, 2006) is supplied to the end consumers (Srinivasan *et al.,* 1999). If aluminium entered the public distribution system, it could lead to precipitation of hydrous aluminium in the water, which is to be supplied to the consumers (Srinivasan *et al.,* 1999). Residual aluminium in the treated water is found to negatively impact the health of consumers. Exposure to aluminium is linked to Alzheimer's disease (WHO Guidelines, 2010; Niquette *et al*., 2004) as it stains the Hippocampal neurons (Watson, 2006). Aluminium is neurotoxic and is responsible for disorders like Parkinson's disease and Down's syndrome (Watson, 2006). Its accumulation in the bloodstream for the long term can result in severe Encephalopathy (Srinivasan *et al*., 1999), and consequently contributing to dementia (Oaks *et al.,* 2004).

Natural coagulants for wastewater treatment

The potential environmental and human health hazards associated with the use of chemical coagulants has necessitated the need for the use of natural coagulants for industrial wastewater treatment. Natural coagulants are gaining a lot of attention these days as they are an effective alternative to the chemical coagulants (Yin, 2010). Natural coagulants are a sustainable approach

(Folkard *et al.,* 1995). Plant-based materials have been investigated for treating industrial effluents from different industries. Plant-based substances like *Moringa Oleifera* (Chonde and Raut, 2017; Sivakumar, 2013), chitosan and chitin, *Abelmoschus esculentus*, *Opuntia ficus-indica*, *Synchorous Potatorum, Prosopis laevigata* Seed Gum, *Hibiscus rosa-sinensis* (Awang and Aziz, 2012), *Acacia mearnsii* (Beltrán-Heredia *et al.,* 2011), etc. can be used as coagulants. Generally, the natural coagulants are directly used as a powder or a stock solution. In some cases, the deoiled powder is also used, after extraction of oil from the coagulant. The plant-based products (such as seeds, etc.) are first extracted from the plant, cleaned to remove any impurities that may interfere with coagulation, and then dried. The powder is then formed (with or without the oil extraction, as per need) by grinding (Miller *et al*., 2008). This powder may be directly used, or a stock solution can be prepared from it. In some cases, proteins may be extracted from the specific plant parts and used as a coagulant. This may require extensive extraction and purification steps (Kansal and Kumari, 2014). Kumar *et al.* 2017 and Tariq et al., 2015 reported that the microbial polysaccharides, starches, gelatin galactomannans, cellulose derivatives, chitosan, glues, and alginate can be used for wastewater treatment. Natural coagulants can also be used with synthetic coagulants to assist the coagulation process for wastewater treatment. Mohamed *et al.* 2014 used *Moringa oleifera* and *Strychnos potatorum* seeds as a natural coagulant for car wash wastewater. The turbidity and COD reduction efficiency of coagulants was studied. Using *Moringa oleifera,* 94% turbidity, 60% COD, 81% phosphorus removal were obtained, whereas using *Strychnos potatorum*, 97% turbidity, 54% COD, and 82% phosphorus removal were obtained. These results were compared with synthetic coagulants, and natural coagulants were suggested for coagulation process as they provide better treatment, are cost-effective and are safe for environment. Sundaresan and Anu 2016 investigated the feasibility of natural coagulant for the treatment of dairy wastewater. *Artocarpus heterophylius* (jack fruit) and *Phaseolus vulgaris* (Common Beans) were used to remove turbidity from wastewater. *Artocarpus heterophylius* (jack fruit) seeds attained 94% turbidity removal efficiency and Phaseolus vulgaris (common beans) seeds gave up to 99% of turbidity removal (Sundaresan and Anu, 2016). Jeon *et al.* (2009) used the grape seed for removal of cationic dyes and confirmed that grape seed-derived coagulants induced decolorization of cationic dyes. Nharingo and Moyo 2016 used derivatives of *Opuntia ficus-indica* for treatment of the wastewater. The study demonstrated coagulant as a very promising alternative to remove dyes, metallic species, heavy metals, turbidity and COD. Gandhi *et al.* 2013 used plant-based polyelectrolytes as coagulants (derived from the fruits of *Opuntia ficus indica*, fruits of *Jatropha gossypifolia* and *Borassus flabellifier*) to remove chromium. It was concluded that there is a significant improvement in the physicochemical characteristics of wastewater and heavy metal chromium was successfully controlled by natural coagulants. These polyelectrolytes can be effectively used for removal of chromium as they destabilize and reduced the repulsive forces between the molecules. Prodanovic *et al.* 2015 used the common bean for distillery wastewater treatment and it was concluded that pH value of stillage influenced activity of the natural coagulant. The optimum pH for the treatment was reported to be 8.5. Saharudin and Nithyanandam 2014 assessed possibility of using natural coagulants as an alternative to the aluminium sulphate and to optimize the parameters related to the working for treatment of synthetic wastewater samples. It was concluded that roselle seeds are a viable commercial alternative to aluminium sulfate. The highest removal efficiency with roselle seeds powder was within the range 81.2% to 93.13% for synthetic wastewater at a pH 4.0. However, the highest removal efficiency for industrial wastewater was within 76.8% to 87.18% at a pH value of 10.0. Kani *et al*. 2016 used banana pith juice for textile wastewater treatment. At pH 4, 97.5% turbidity and 50.1% total solids were removed from the wastewater. There was a significant improvement in the electrical conductivity. The results confirmed that banana stem juice has an enormous potential for turbidity removal from the textile wastewater. Wu *et al.* 2005 used white-rot fungi for degradation of lignin from the paper mill wastewater. The lignin and COD removal efficiencies were reported to be 71% and 48%, respectively. Optimum pH range for lignin removal by *Chrysosporium, Pleurotus ostreatus* and s22 was observed to be 9.0-11.0. Gaurang and Punita 2012 used fruit mucilages of *Coccinia indica* and *Abelmoschus esculentus*, and the dry seed powder of Moringa for treatment of dairy wastewater. Using *Abelmoschus esculentus*, 60.33% of turbidity could be removed whereas *C. indica* gave highest turbidity removal of 77.67%. Nicholas *et al.* 2018 used *Hibiscus sabdariffa* seeds for removing dyes from the synthetic wastewater. The study involved preparation of models and ANOVA (analysis of variance). Response surface methodology showed 98.68% dyes removal from the wastewater. Oyster mushroom has been tested for the reduction of parameters like turbidity and TSS (total suspended solids) from domestic wastewater. The basic coagulation mechanism of natural coagulants differs from that of the synthetic coagulants due to their inability in forming the hydroxide precipitates in the water. Synthetic coagulants generally work on the mechanism of charge destabilization and sweep flocculation. In comparison, the polymeric nature of plant-based coagulants and presence of functional groups suggest that polymer bridging, and charge neutralization are the dominant mechanism for the natural coagulants (Ang and Mohammad, 2020; Saleem and Bachmann, 2019). For some of the natural coagulants, adsorption in conjunction with either charge neutralization or polymer bridging has been cited as the dominant coagulation mechanism (Kansal and Kumari, 2014; Daverey *et al.,* 2019).

Commonly studied natural coagulants

A large number of natural coagulants, mostly plant-based, have been studied for their potential in treating industrial effluents. A brief description of some of the more commonly studied coagulants is provided here.

Moringa Oleifera is a small or medium-sized tree grown in northwest India, several parts of Asia, Africa, and South America. It is a multipurpose plant (Muthuraman and Sasikala*.,* 2014) and is cultivated in tropical, sub-tropical or semi-arid regions at an altitude between 0-2000 m. Cultivation of *Moringa* requires an annual rainfall between 250-3000 mm. It belongs to the *Moringaceae* family (Okuda *et al.,* 2001). Moringa can grow on the low altitude tropical belt on the less humid soil. *Moringa Oleifera* is an organic polymer. Moringa grows rapidly from the seed or cutting and does well even in poor soils (Adebayo *et al.,* 2017). *Moringa oleifera* is one of the most effective and certainly the most investigated natural coagulant for wastewater treatment (Bhuptawat *et al.,* 2007). Typically, the grounded seed powder of *Moringa oleifera* is used as a coagulant. Sulaiman *et al.* 2017 studied the potential of *Moringa* and reported excellent results for wastewater treatment. The seeds of moringa do not further deteriorate the environment and are amenable to biodegradation and thus are environment friendly. Hemapriya *et al.* 2015 used *Moringa* for treating the textile mill effluent. *Moringa oleifera* was reported to cause significant COD reduction for textile mill wastewater (Dotto *et al.,* 2019). Parmar *et al.* 2012 used grounded seed powder of *Moringa Oleifera* for dairy wastewater treatment. The *Moringa oleifera* seeds left the water clear and reduced the turbidity by almost 100 percent and 99.50-100 percent removal of fecal coliforms was observed. Ashmawy *et al.* 2012 used *Moringa Oleifera* for treating the laundry wastewater and obtained up to 83.63% of turbidity removal.

Abelmoschus Esculentus belongs to *A. esculentus* species of plants and *Malvaceae* family (Kumar *et al.,* 2010). It is commonly known as ladyfinger or Gumbo Okra. Okra is a vegetable crop cultivated in Asia and Africa (Kumar *et al.,* 2010). Ameena *et al.* 2010 studied the binding effects of the *Hibiscus rosasinensis Linn* and Okra (*Abelmoschus esculentus* Linn) mucilages, both of which were found to be amorphous (after drying). It was reported that instead of starch, lower concentrations levels of okra can be used. Anastasakis *et al.* 2009 suggested that Okra has better efficiency than *Malva sylvestris* (mallow) in removing turbidity, even at much lower doses.

Opuntia ficus indica, a species of cactus, is grown in different parts of the world with different habitats with different climates. *Opuntia ficus* mucilage has enormous potential to treat industrial wastewater and is safe for the environment. It can serve as a potential replacement of aluminium and iron salts (Bogacki *et al.,* 2011). Different species of cactus have been tried to ascertain the potential of cactus in coagulation and flocculation process. Cactus is used in different forms such as powder, mucilage for wastewater treatment. De Souza *et al.* 2014 used *Opuntia ficus-indica (OFI)* for textile effluents treatment and reported 95% turbidity removal. The coagulant was stored for 4 days which did not affect the efficiency of the coagulation mechanism. Rebah and Siddeeg 2017 reviewed the potential of cactus for wastewater treatment. Renewability, abundance, adaptability, and biodegradability of cactus plants make them a suitable alternative to the chemical coagulants. It has a potential to be used as coagulant/ flocculant, as biosorbent and as packed material for bio-filter. The presence of cactus enzymatic system can transform toxic textile dyes when used for textile wastewater treatment. However, limitation of using cactus is that there is variation in the efficiency on basis of wastewater characteristics.

Chitosan is a cellulose-like biopolymer and is widely distributed in nature. It is yellow colored in powder form and completely biodegradable (Renault *et al.,* 2009). The major sources of chitin and chitosan in the environment are shells of crabs, shrimp (Feria-Diaz *et al.,* 2018), lobsters (Kumar *et al.*, 2010), fungi, mollusks, diatoms, and marine and freshwater sponges (Malerba and Cerana*,* 2018). Chitosan can be used for the process of coagulation (Rao, 2015). Renault *et al.* 2009 reviewed the potential of chitosan for coagulation, and flocculation process and confirmed that chitosan has potential for the wastewater treatment. Kumar *et al.* 2000 suggested the different applications of chitin and chitosan for use in a variety of industries due to the minimum toxicity, which makes them safe for discharge into the environment. Wan Ngah *et al.* 2011 suggested using chitosan and its derivatives for dyes and heavy metals removal from the wastewater. Anteneh and Sahu 2014 used chitosan for treating soap and detergent wastewater. Chitosan reduced 83% of COD as well as 90 % of color from wastewater. The authors concluded that easy availability and unique properties of chitosan as a coagulant make it a promising alternative to chemical coagulants. Sarkar *et al*. 2006 investigated the possibility of treating dairy wastewater using chitosan. They found that chitosan worked efficiently even at very low dosages (10 mg/L). The study suggested that PAC treatment of supernatant following chitosan treatment completely removed color and odor from wastewater before membrane processing (Sarkar *et al.,* 2006). Savant and Torres 2000 used chitosan complexes for treating cheddar cheese whey. Turbidity reductions of 40-43% and 65-72% were obtained and up to 70% protein recovery from cheese whey was obtained. Feria-Diaz *et al.* 2018 used chitosan for turbidity removal from slaughterhouse wastewater. The study claimed that as much as 90% of turbidity could be removed from the wastewater using chitosan as a coagulant.

Tannins are aromatic compounds and have polycyclic structures (Thakur and Choubey, 2014). Beltran-Heredia 2011 showed that tannin–derived coagulant is a novel product for dye (azo, anthraquinonic, indigoid, and triphenylmethane ones) removal.

Cicer arietinum is grown in arid and semi-arid zones (Hiremath *et al.,* 2014). It is grown in areas experiencing good rainfall where the soil has good moisture content. Jaseela and Chadaga 2015 used *cicer arietinum* for COD and turbidity removal from the dairy industry wastewater. Using the coagulant in the powder form, 86.29% of turbidity removal was achieved.

Ocimum basilicum, commonly known as basil, is traditionally used in medicines and studies have indicated that it can be used as a coagulant. With 1.6 mg/L of coagulant in 50 mg/L solution of pigment, up to 61.6% of BOD, and 68.5% of color removal was attained from textile wastewater. With a dosage of 9.6 mg/L *Ocimum basilicum* solution, 50.9% color, and 56.6% COD removal efficiencies can be achieved (Shamsnejati *et al.,* 2015). Mosaddeghi *et al.* 2020 reported 85% color removal and 82% total suspended solids removal with *O. basilicum* for paper recycling wastewater.

Cassia seed gums-based coagulants like *Cassia javahikai*, *Cassia angustifolia*, *Cassia fistula*, *Cassia obtusifolia*, and *Cassia tora* can be used for textile wastewater treatment (Karoliny *et al.,* 2018). Ngan *et al.* 2017 used *Cassia fistula* seed gum with PAC for the treatment of fish processing wastewater.

Table 3 shows the details of the natural coagulants used for the effluents obtained from various industries. The details of the effective doses and treatment efficiencies are also listed. From this listing, it can be seen that *Moringa oleifera* and chitosan are the most efficient natural coagulants and have shown potency for wastewaters generated from different industries.

Advantages of natural coagulants

Wastewater treatment using natural coagulants is an eco-friendly option. Natural coagulants are non-toxic, biodegradable, and environment friendly (Verma *et al.,* 2012; Muralimohan *et al.,* 2014). Unlike synthetic coagulants, treated water contains no residual aluminium. Prodanović *et al.* 2013 used common bean extract for the treatment of distillery wastewater treatment. The study claimed that anaerobic sludge contained no aluminium salts. This ensures that aluminium-related health issues (such as Parkinson's disease, Alzheimer's disease, and other neurological diseases), as stated earlier, would be absent when natural coagulants are used for the coagulation-flocculation of the wastewater. The supernatant and sludge produced on treatment using natural coagulants can be used for other purposes, unlike those obtained from chemical coagulation.

Table 3: Summary of the key literature findings of industrial wastewater treatment by using natural coagulants

S.N.	Coagulant	Wastewater source	Original form of coagulant prepared	Form of coagulant used	Optimum dosage	Parameters	Removal efficiency	Reference
1	*Moringa oleifera*	Palm oil mill effluent	Deoiled powder		6000 mg/L	Suspended Solids	95%	Thirugnanasambandham *et al.*, 2014
2	*Moringa* (425 µm)	Dairy wastewater	Deoiled	direct powder	300 mg/L	Turbidity	90%	Pallavi and Mahesh, 2013
3	*Moringa* (212 µm)	Dairy wastewater	Deoiled	direct powder	500 mg/L	Turbidity	93.50%	Pallavi and Mahesh, 2013
4	*Moringa* (150 µm)	Dairy wastewater	Deoiled	direct powder	500 mg/L	Turbidity	96.80%	Pallavi and Mahesh, 2013
5	*Moringa oleifera*	Secondary oxidation pond effluent	Powder	stock solution	100mg/L	COD Alkalinity BOD(5-day) Turbidity	60% 99% 75% 99%	Katayon *et al.*, 2007
6	*Moringa oleifera*	Dairy wastewater	Powder	solution	1g/L	turbidity COLOUR COD	98% 95% 55%	Vieira *et al.*, 2010
7	*Moringa oleifera*	Domestic wastewater	Powder	solution	250 mg/L	color turbidity total coliform *Escherichia coli*	71% 85% 96% 83%	Silva *et al.*, 2013
8	*Moringa oleifera*	Dairy waste water	Powder	powder	0.2 g/L	turbidity COD	61.60% 65.00%	Patil and Hugar, 2015
9	*Moringa oleifera*	Tannery wastewater	Powder	powder	0.6 g/L	turbidity COD	82% 83%	Kazi *et al.*, 2013
10	*Moringa oleifera*	Dairy waste water	Powder	suspension	60 mg/L	BOD (5-day) COD	55% 60%	Bhutada *et al.*, 2006
11	*Moringa oleifera*	Dairy wastewater	Powder	powder	0.3 mg/L	turbidity BOD(3-day) COD TDS TSS	78% 80% 86% 9% 95%	Neethu *et al.*, 2017
12	*Moringa oleifera*	Leachate treatment	Deoiled seed powder	stock solution	-	turbidity Cu and Cd Pb	85%-94% 98% 78%	Shan *et al.*, 2017
13	*Moringa oleifera*	Batik effluent	Powder	powder	4000 mg/L 5000 mg/L	Turbidity TSS	96% 88%	Effendi *et al.*, 2015
14	*Moringa oleifera*	Oil refinerry wastewater	Solution	powder	70 mg/L	TSS Turbidity	62% 64%	Dehghani and Alizadeh, 2016
15	*Moringa oleifera*	Textile effluent	Powder	stock solution	40 mL	TDS BOD COD	71% 72% 79%	Muralimohan *et al.*, 2014
16	*Moringa oleifera*+NALCO 7751	Palm oil mill effluent	Deoiled powder	-	4000+7000 mg/L	Suspended solids COD	99.30% 52.50%	Bhatia *et al.*, 2007
17	*Moringa Oleifera* and fuller earth	Dairy wastewater	Powder	suspension solution	60 mg/L+ 15mg/L	BOD(5-day) COD	60.00% 66.00%	Bhutada *et al.*, 2006

Table 3: Summary of the key literature findings of industrial wastewater treatment by using natural coagulants

S.N.	Coagulant	Wastewater source	Original form of coagulant prepared	Form of coagulant used	Optimum dosage	Parameters	Removal efficiency	Reference
18	*Moringa* and Alum	Oil refinery wastewater	Powder	solution	70 and 80 mg/L	COD turbidity TSS	50.41% 86.14% 81.52%	Dehghani and Alizadeh, 2016
20	*Moringa* and Alum	Textile industry effluent	Powder	stock solution	50:50:00	turbidity BOD COD	61.60% 80.67% 66.73%	Muralimohan *et al.*, 2014
21	Chitosan	Olive mill wastewater	Powder	solution 5g/L	400 mg/L	TSS	81%	Rizzo *et al.*, 2008
22	Chitosan	Paper and pulp wastewater	Powder	-	1.8 g/L	turbidity BOD COD	84% 90% 93%	Thirugnanasambandham *et al.*, 2014
23	Chitosan	Brewery wastewater	-	stock solution	120 mg/L	Turbidity COD	95% 50%	Maya *et al.*, 2014
24	Chitosan	Textile wastewater	Powder	stock solution	30 mg/L	COD Turbidity	73% 95%	Ariffin *et al.*, 2009
25	Chitosan	Textile wastewater	Powder	powder	30 g/L 25 g/L and 30 g/L	COD Color	65% 43%	Patel and Vashi, 2013
26	*Okra mucilage*	Textile wastewater	Mucilage	-	3.20 mg/L	Color Turbidity COD	93.57% 97.24% 85.69%	Wang et al., 2011
27	*Okra*	Coal washery wastewater treatment	Powder	stock solution	400 ppm	Turbidity	61.03%	Babarao and Verma, 2015
28	*Okra* + Iron (III) chloride Hexahydrate	Textile wastewater	-	stock solution	3.20 mg/L + 88 mg/L	turbidity COD color	97.24% 85.69% 93.57%	Wang *et al.*, 2011
29	*M. sylvestris* (mallow) + aluminium Sulfate	Synthetic wastewater Biologically treated effluent	-	stock solution	12 mg/L 62.5 mg/L	turbidity turbidity	97.40% 66%	Anastasakis *et al.*, 2009
30	*Okra mucilage* + aluminium sulphate	Synthetic wastewater Biologically treated effluent	-	stock solution	5 mg/L 2.5 mg/L	turbidity turbidity	97.70% 74%	
31	*Psyllium husk* + PAC	Leachate treatment	Powder	-	0.4 g/L + 7.2 g/L	COD Color TSS	64% 90% 96%	Al-Hamadani *et al.*, 2011
32	Guar	Cosmetic wastewater	Powder	-	300mg/L	turbidity	67.82%	Carpinteyro *et al.*, 2012
33	Locust bean gum	Cosmetic wastewater	Powder	-	300mg/L	turbidity	67.82%	Carpinteyro *et al.*, 2012
34	*Opuntia mucilage*	Cosmetic wastewater	Powder	-	150mg/L	turbidity	49.56%	Carpinteyro *et al.*, 2012
35	*Ocimum basilicum*	Textile wastewater	Powder	stock solution	1.6 mg/L	color COD	68.50% 61.60%	Shamsnejati *et al.*, 2015

Table 3: Summary of the key literature findings of industrial wastewater treatment by using natural coagulants

S.N.	Coagulant	Wastewater source	Original form of coagulant prepared	Form of coagulant used	Optimum dosage	Parameters	Removal efficiency	Reference
36	*Plantago major L.*	Dye wastewater	Powder	stock solution	297.6 mg/L	color COD	92.40% 81.60%	Chaibakhsh *et al.*, 2014
37	*Plantago psyllium*	Textile wastewater	Mucilage solution	-	10 mg/L	Golden dye reactive black	71.40% 35%	Mishra and Bajpai, 2014
38	*Chyote* + Iron trichloride	Textile wastewater	Powder	-	15 mg/L + 47.40 mg/L	turbidity COD	97.95% 83.84%	Almeida *et al.*, 2017
39	*Hibiscus Rosa sinensis* + Alum	Leachate wastewater	Powder	-	500 mg/L + 4000 mg/L	Suspended solids turbidity Iron (III)	72% 60% 100%	Awang and Aziz, 2012
40	*Trigonella foenum-graecus*	Dairy wastewater	Powder	powder	0.1 g/L	turbidity COD	58% 63%	Patil and Hugar, 2015
41	*Dolicus lablab*	Dairy wastewater	Powder	powder	0.2 g/L	turbidity COD	71.74% 75%	Patil and Hugar, 2015
42	*Cicer arietinum*	Dairy wastewater	Powder	powder	0.1 g/L	turbidity COD	78.33% 83%	Patil and Hugar, 2015
43	*Cicer arietinum*	Tannery wastewater	-	powder	0.2 g/L	turbidity COD	81% 90%	Kazi *et al.*, 2013
44	*Cicer arietinum*	Slaughter house wastewater	Powder	powder	0.5 g 2 g 2 g 1.5 g	Turbidity TDS BOD COD	68% 82% 83% 84%	Sheikh *et al.*, 2016
45	Roselle seeds	Glove manufacturing	Powder	powder	60 mg/L	Turbidity	87.18%	Saharudin and Nithyanandam, 2014
46	Cactus	Tannery wastewater	Powder	powder	0.4 g/L	Turbidity COD	78.54% 75%	Kazi *et al.*, 2013
47	Tanfloc SG	Dairy wastewater	Powder	stock solution	20 mg / L	turbidity COD Total solids Total coliform	71.20% 77.28% 0.48% 100.00%	Wolf *et al.*, 2015
48	Tanfloc SH	Dairy wastewater	Powder	stock solution	20 mg/L	Turbidity COD Total solids Total coliform	65.60% 44.14% 0.43% 69.00%	Ayangunna *et al.*, 2016
49	Tamarind seed powder	Detergent wastewater	Powder		400 mg/L	Turbidity	97.72%	Ayangunna *et al.*, 2016
50	Tamarind Indica	Textile effluent	Powder	stock solution	60 mL	TDS	41.50%	Babarao and Verma, 2015
51	Bitter gourd seed	Coal washery wastewater treatment	Powder	solution	400 ppm	Turbidity	61.03%	Babarao and Verma, 2015

Table 3: Summary of the key literature findings of industrial wastewater treatment by using natural coagulants

S.N.	Coagulant	Wastewater source	Original form of coagulant prepared	Form of coagulant used	Optimum dosage	Parameters	Removal efficiency	Reference
52	Cotton seed oil cake	Sago effluent	Oil	oil	30 mL	TSS	66.27%	Narmatha *et al.,* 2017.
53	*S. Potatorum*	Textile effluent	Powder	stock solution	60 mL	TDS BOD COD Turbidity	52.30% 65.23% 72.71% 75.20%	Dehghani and Alizadeh, 2016
54	*S. Potatorum* and Alum	Textile wastewater	Powder	Stock solution	40: 60 40: 60	TDS TSS BOD COD	67.91% 79.23% 69.43% 74.93%	Muralimohan *et al.*, 2015
55	Castor oil cake	Sago effluent	Oil	oil	40 mL	TSS	66.67%	Sheikh *et al.*, 2016
56	Surjana seed	Textile wastewater	Powder	powder	25 g/L 30 g/L	COD Color	74.11% 62.82%	Patel and Vashi, 2013
57	Maize seed	Textile wastewater	Powder	powder	30 g/L	COD Color	68.82% 47.03%	Patel and Vashi, 2013
58	Chayote and $FeCl_3$	Textile wastewater	Powder		15 mg/L and 47 mg/L	Turbidity COD	97.95% 83.84%	Almeida *et al.,* 2017
59	Banana juice	Spent coolant wastewater		juice	90 mL	COD SS Turbidity	80.10% 88.60% 98.50%	Alwi *et al.,* 2013
60	*P. ovata*	Textile wastewater	De-oiled seed powder	solution	1.5 mg/L	COD	89.30%	Ramavandi and Farjadfard, 2016

The sludge obtained after the treatment with natural coagulants is non-toxic and biodegradable and can be used for soil improvement. Paula *et al.* 2016 suggested the use of treated water for washing vehicles and flushing toilets. In the study, a portion of $Al_2(SO4)_3$ was used with *Moringa Oleifera* seed extract to make the concrete wastewater eco-friendly. For the treatment, MO and $Al_2(SO4)_3$ were used in the ratio of 20:80. 97.5% of turbidity was removed in 60 min using this arrangement. Feria-díaz *et al.* 2016 recommended the use of sludge produced, after treatment of water samples collected from Sinu River, Monteria, Cordoba using *Moringa oleifera*, for soil improvement. The study evaluated the agricultural application of the coagulation sludge from raw water treated with moringa. The properties of sludge were found to be suitable for application to soils (Feria-díaz *et al.,* 2016). Wei *et al.* 2018 suggested dewatering of the sludge and converting them into sludge cakes. Natural coagulants are cost-effective. Mohamed *et al.* 2014 after confirmatory experiments on commercial and natural coagulants for car wash wastewater treatment, recommended the use of natural coagulants as they are eco-friendly and involve low cost as compared to the chemical coagulants. Vijayaraghavan *et al.* 2011 in their work stated that the natural coagulants form stronger flocs via bridging effect as compared to alum. Even at high shear levels, these linkages are resistant to breakage (Karoliny *et al.,* 2018). Therefore, it can be said that natural coagulants form better flocs. Cost comparison between the synthetic and natural coagulants is interesting due to the consideration of a large number of parameters. The natural coagulants are locally sourced, are available in large amounts, produce less sludge, generate biodegradable sludge (which can be reused) and may be based on waste materials (such as banana peels, etc.). On the other hand, in comparison to synthetic coagulants, the natural coagulants generally require a higher dosage, need processing and storage, may not be available year-round, and may have alternate economically attractive applications. Due to the absence of detailed studies and field-scale data on some of these parameters, it is difficult to do a detailed cost comparison between the natural and synthetic coagulants (Ang and Mohammad, 2020). However, a number of recent studies have reported that natural coagulants are an economically attractive alternative to the synthetic coagulants (Behera and Balasubramanian, 2019; Daverey *et al.,* 2019; Meraz *et al.,* 2016).

Disadvantages of natural coagulants

A major drawback of using natural coagulants is their inability to manage large pH variation. Most of the coagulants work well under certain pH, beyond this range, their efficiency is severely affected. Vieira *et al.* 2010 used *Moringa Oleifera* for dairy wastewater treatment. The results demonstrated that the adsorption power of *Moringa Oleifera* seeds was best in the pH range of 5 - 8. Ferrari *et al.* 2016 used natural coagulants for the treatment of the food industry effluent in place of ferric chloride. Although the supernatant contained no traces of metal, Chitosan was found to be less efficient as its dilution occurs best at acidic pH. This may increase the cost of wastewater treatment using chitosan (Ferrari *et al.,* 2016). Natural coagulants contain organic matter and therefore the efficiency of these coagulants may decrease over time. Proper arrangements are required to store these coagulants in stock. This will increase the overall cost of the treatment. Another drawback of using natural coagulants for wastewater treatment is the requirement of high dosages as compared to the synthetic coagulants (Aliyu *et al.,* 2015). Aliyu *et al.,* (2015) used moringa and *Abelmoschus esculentus* for the treatment of the water from River Yamuna, India. Results showed that for treating the water from the same source, 150 mg/L to 200 mg/L of moringa and *Abelmoschus esculentus* were required, whereas better results were obtained using alum at a much lower dose of 30 mg/L under the same experimental conditions. In a comparative study between alum and natural coagulant *Moringa* for treatment of dairy industry wastewater, it was found that alum had better efficiency as compared to *Moringa oleifera* (Bangar *et al.,* 2017).

Issues in the large-scale implementation of natural coagulants

Natural coagulants are an economical and environment-friendly alternative to synthetic chemicals for wastewater treatment. Despite the enormous potential, the treatment using natural coagulants faces challenges, and this has limited the application of natural coagulants to the laboratory-scale studies so far. Some of the issues preventing the large-scale application of natural coagulants for wastewater treatment are:

1. Competitiveness

Many natural coagulants have varied applications and their use for wastewater treatment will affect the availability of these coagulants for other purposes. *Moringa oleifera* is used for the treatment of various diseases including asthma, syphilis, asthma, etc. (Somchit *et al.,* 2012). The use of *okra* for wastewater treatment also has various implications because of the multipurpose uses of the *Okra* plant. For instance, okra is consumed as a vegetable in Western Africa and Southeast Asia (Lamont 1999). Dried *okra* stems are used as a fuel as it burns considerably and produces considerable heat (Lamont 1999). *Okra* mucilage is used for manufacturing paper in Malaysia (Lamont 1999). Kumar Dutta *et al.* 2004 investigated the chemistry, properties, and applications of chitin and chitosan. Chitin and chitosan have also been used in various other fields like agriculture, cosmetics, photography, chromatographic separations, solid-state batteries, biomedical applications, burn treatment, wound healing/ wound dressing, artificial skin, Opthalmology, drug delivery system, and in LEDs (light-emitting devices) applications (Kumar Dutta *et al.,* 2004). To ensure the large-scale application of natural coagulant, a non-competitive coagulant needs to be found. Besides, plant-based materials that are otherwise considered waste may also be investigated for their coagulation potential. *Benincasa hispida*, commonly known as ash gourd, is a commonly used vegetable and source of Petha candy (a common sweet popular in Indian sub-continent). Its seed is usually discarded. The seed powder of *Benincasa Hispida* has recently been studied for its coagulation potential for the treatment of river water (Saini, 2017).

2. The absence of source for mass availability

Not all the natural coagulants discussed in this work are available universally and it raises concerns over the sustained mass-scale supply that would be needed for commercial applications. Due to the non-uniform distribution of plants, the same natural coagulant may be costlier as compared to the synthetic coagulants in some parts of the world (Kansal and Kumari, 2014). Chemical coagulants, on the other hand, can be produced in industries practically anywhere and supplied as needed. A potential solution is the application of locally sourced natural coagulants.

3. Potency losses

Natural coagulants contain organic matter and may decay over time. This decay may affect the efficiency of coagulants in treating wastewater. Studies on potency losses are non-existent and are required to determine the possibility of potency losses of natural coagulants. De Souza *et al.* 2014 studied the possibility of potency losses with the use of cactus. They studied the effects of the storage time and temperature on the coagulation efficiency of *Opuntia ficus-indica*. The study indicated that there was no effect on the efficiency for up to 4 days (De Souza *et al.,* 2014). However, no other research is available that discussed potency beyond 4 days or ways to improve the shelf life of natural coagulants. More research is needed in determining and enhancing the shelf life of natural coagulants.

4. High quantity requirement

For treating the same quantity of the wastewater with the same values of the various parameters, the optimum dosage is very high in the case of natural coagulants as compared to the chemical coagulants. This implies that the wastewater can be treated with a very small quantity of chemical coagulants as compared to the natural coagulants. Omar *et al.* 2008 used sago and potato flour for COD reduction from semiconductor wastewater. Poly aluminium chloride and aluminium sulfate coagulants were also used. The researchers found that sago helped in COD and turbidity reduction at a low dose of 1.5 g L^{-1}. On the other hand, considerable reductions in COD and turbidity were seen using poly aluminium chloride and ammonium sulphate at much lower concentrations (0.02–1.0 g L^{-1}), although much longer settling time of 30 to 60 min was required (Omar *et al.,* 2008).

5. High inventory and processing cost

Natural coagulants are likely to have high inventory and processing costs as compared to chemical coagulants due to their biodegradable nature. Also, storing the natural coagulants in stock for later use will require some arrangements.

6. Lack of awareness, market interest, and guidelines

There is currently a lack of awareness in general public and utility boards regarding the adverse effects of synthetic coagulants and the availability of natural coagulants as an eco-friendly alternative to synthetic coagulants. Due to economic uncertainties, utility services and plant operators are less likely to opt for a new technology esp. when there are more aspects of the natural coagulants that need detailed research. Standard guidelines related to the production, storage, and use of natural coagulants are not available. All these need to be taken care of, to promote the commercial adoption of the natural coagulants.

CONCLUSION

Synthetic chemicals have been used as chemical coagulants for the treatment of industrial wastewater for a long time. Aluminium salts are the most commonly used coagulants. Despite their high efficiency of treatment, chemical coagulants have inherent disadvantages. These include the production of nondegradable sludges, high cost, and (most importantly) medical conditions due to leftover aluminium in the water. Many studies have been conducted to assess the potential of using natural coagulants as an alternative to synthetic chemicals. Many of these plant-based coagulants (especially, *Moringa oleifera*) have shown significant promise in treating the wastewater emanating from different types of industries. This review comprehensively presented the advantages and disadvantages of both the natural and synthetic coagulants. Despite being the most economical and environment-friendly alternative, natural coagulants are not preferred over chemical coagulants for the wastewater treatment, esp. on a large scale. Competitiveness, high inventory, and operating cost, lack of source for mass availability are some of the hurdles in their large-scale application. There is a significant lack of studies to utilize the potential of natural coagulants for wastewater treatment. Studies to discover the shelf life of these coagulants will help in determining the possibility of the potency losses with these coagulants. This will be a major contribution in ascertaining a reduction in the efficiency of these coagulants over a given period of time. In addition, further studies can be conducted to determine the techniques to improve the shelf life of natural coagulants. There is a scarcity of literature to understand the nature of sludge produced. This may also help in encouraging the treatment using natural coagulants. The use of natural coagulants should be tested for large-scale wastewater treatment, to verify results obtained in the laboratory. Hopefully, the review presented here will stimulate the research in the identified directions and motivate the researchers in finding sustainable solutions to industrial wastewater treatment.

RECOMMENDATIONS

Given the inherent disadvantages of synthetic coagulants, it is recommended that the natural coagulants be used as an alternative for the treatment of industrial effluents. To support this transition, several areas of research have been identified, including, improvements in the processing, efficiency loss due to storage, use of waste plant-based products as coagulants, development of standard guidelines, etc. It is suggested that the natural coagulants are first used at small or medium-scale effluent treatment plants and the data and experience thus generated is used for large-scale implementation.

AUTHOR CONTRIBUTIONS

S. Gautam wrote the first draft of the manuscript. G. Saini developed the concept, supervised the manuscript preparation and edited it.

ACKNOWLEDGEMENT

The authors acknowledge the anonymous colleagues and reviewers for their valuable comments and suggestions that helped improve this manuscript.

CONFLICT OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this manuscript. In addition, the ethical issues, including plagiarism, informed consent, misconduct, data fabrication and/or falsification, double publication and/or submission, and redundancy have been completely observed by the authors.

ABBREVIATIONS

ANOVA	Analysis of variance
BOD	biological oxygen Demand
COD	Chemical oxygen demand
Cd	Cadmium
Cr	Chromium
Cu	Copper
$FeCl_3$	Ferric chloride
$FeSO_4$	Ferrous sulfate
g/L	grams per litres
$KAl(SO_4)_2{\cdot}12H_2O$	Potassium Aluminium Sulphate
KLD	Kilo litres per day
$MgCl_3$	Magnesium chloride
mg/L	Milligram per litre
mL/L	Milliliter per litre
MLD	Million litre per Day
Mg	Microgram
O&G	Oil and grease
PAA	Polyacrylamide
PAC	Poly aluminium chloride
PAFC	Poly aluminium ferric chloride
PASiC	Poly-aluminium-silicate-chloride
PFS	Polyferric sulfate
P. ovata	*Plantago ovata*
PsiFAC	Poly-aluminium-ferric-silicate-chloride
TDS	Total Dissolved Solids
TP	Total phosphorus
TSS	Total suspended solids
WHO	World Health Organization

REFERENCES

Aboulhassan, M.A.; Souabi, S.; Yaacoubi, A.; Baudu, M., (2014). Treatment of paint manufacturing wastewater by the combination of chemical and biological processes. Int. J. Sci. Environ. Technol., 3 (5): 1747–1758 **(12 pages)**.

Adebayo, A.G.; Akintoye, H.A.; Shokalu, A.O.; Olatunji, M.T., (2017). Soil chemical properties and growth response of *Moringa oleifera* to different sources and rates of organic and NPK fertilizers. Int. J. Recycl. Org. Waste Agricult., 6: 281–287 **(7 pages)**.

Aguilar, M.I.; Saez, J.; Llorens, M.; Soler, A.; Ortuno, J.F.; Meseguer, V.; Fuentes, A., (2005). Improvement of coagulation-flocculation process using anionic polyacrylamide as coagulant aid. Chemosphere, 58(1): 47-56 **(10 pages)**.

Ahangarnokolaei, M.A.; Ganjidoust, H.; Ayati, B., (2017).

Optimization of parameters of electrocoagulation/flotation process for removal of Acid Red 14 with mesh stainless steel electrodes. J. Water Reuse Desalination., 8(2): 278–292**(15 pages)**.

Ahmad, A.L.; Wong, S.S.; Teng, T.T.; Zuhairi, A., (2008). Improvement of alum and PACl coagulation by polyacrylamides (PAMs) for the treatment of pulp and paper mill wastewater. Chem. Eng. J., 137(3): 510–517 **(8 pages)**.

Ahmed, M.I.; Habib, M.; Habib, U.; Hai, A.; Khan, A.U., (2016). Analysis and treatment of tannery wastewater by using combined filtration and coagulation treatment process. Proc. Pak. Acad. Sci. B, 53(3): 179–183 **(5 pages).**

Ahmed, S.; Aktar, S.; Zaman, S.; Jahan, R.A.; Bari, M.L., (2020). Use of natural bio-sorbent in removing dye, heavy metal and antibiotic-resistant bacteria from industrial wastewater. Appl. Water Sci., 10:107 **(10 pages)**.

Akyol, A., (2012). Treatment of paint manufacturing wastewater by electrocoagulation. Desalination., 285: 91-99 **(9 pages)**.

Alavijeh, H.N.; Sadeghi, M.; Rajaeieh, M.; Moheb, A.; Sadani, M., (2017) Integrated ultrafiltration membranes and chemical coagulation for treatment of baker's yeast wastewater. J. Membr. Sci. Technol., 7(2) **(9 pages)**.

Al-Hamadani, Y.A.J.; Yusoff, M.S.; Umar, M.; Bashir, M.J.K.; Adlan, M.N., (2011). Application of psyllium husk as coagulant and coagulant aid in semi-aerobic landfill leachate treatment. J. Hazard. Mater., 190(1–3): 582–587 **(6 pages)**.

Aliyu, L.; Mukhtar, L.W.; Abba, S.I. (2015). Evaluation of coagulation efficiency of natural coagulants (*Moringa Oleifera*, Okra) and alum, for Yamuna Water Treatment. Int. J. Adv. Res. Sci. Eng. 4: 825-833 **(9 pages).**

Almeida, C.A.; Souza, M.T.F. De; Freitas, T.K.F.S.; Geraldino, H.C.L.; Garcia, J.C., (2017). Vegetable residue of Chayote (*Sechium edule SW.*) as a natural coagulant for treatment of textile wastewater. Int. J. Energy Water Resour., 1(1): 37–46 **(10 pages).**

Altaher, H; Alghamdi, A., (2011). Enhancement of quality of secondary industrial wastewater effluent by coagulation process: a case study. J. Environ. Protect. Ecol., 2(9): 1250–1256. **(7 pages).**

Alwi, H.; Idris, J.; Musa, M.; Halim, K.; Hamid, K., (2013). A preliminary study of banana stem juice as a plant-based coagulant for treatment of spent coolant wastewater, J. Chem., 2013 **(7 pages).**

Ameena, K.; Dilip, C.; Saraswathi, R.; Krishnan, P.N.; Sankar, C.; Simi, S.P., (2010). Isolation of the mucilages from *Hibiscus rosasinensis linn* and Okra (*Abelmoschus Esculentus linn*.) and studies of the binding effects of the mucilages. Asian Pac. J. Trop. Med., 3(7): 539–543 **(5 pages).**

Amuda, O. S.; Amoo, I. A., (2007). Coagulation/flocculation process and sludge conditioning in beverage industrial wastewater treatment. J. Hazard. Mater., 141(3): 778–783 **(6 pages).**

Anastasakis, K.; Kalderis, D.; Diamadopoulos, E., (2009). Flocculation behavior of mallow and okra mucilage in treating wastewater. Desalination. 249(2): 786–791 **(6 pages).**

Ang, W.L.; Mohammad, A.W., (2020). State of the art and sustainability of natural coagulants in water and wastewater treatment. J. Clean. Prod., 262: 121267.

Anteneh, W.; Sahu, O.P., (2014). Natural coagulant for the treatment of food industry waste water, Int. Lett. Nat. Sci., 9: 27–35 **(9 pages).**

Aravind, J.; Kanmani, P.; Sudha, G.; Balan, R., (2016). Optimization of chromium(VI) biosorption in industrial effluents using gooseberry seeds by response surface methodology. Global J. Environ. Sci. Manage., 2(1): 61-68 **(8 pages).**

Ariffin, M.; Hassan, A.; Li T.P.; Noor, Z.Z., (2009). Coagulation and flocculation treatment of wastewater in textile industry by using chitosan. J. Chem. Nat. Resour. Eng., 4(1): 43–53 **(11 pages).**

Ashmawy, M.A.; Moussa, M.S.; Ghoneim, A.K.; Tammam, A., (2012). Enchancing the efficiency of primary sedimentation in wastewater treatment plants with the application of Moringa Oleifera seeds and quicklime. J. Am. Sci., 8(2): 494–502 **(9 pages).**

Ashrafi, O.; Yerushalmi, L.; Haghighat, F., (2015). Wastewater treatment in the pulp-and-paper industry: A review of treatment processes and the associated greenhouse gas emission. J Environ. Manage., 158: 146–157 **(12 pages)**.

Awad, M.; Li, F.; Hongtao, W., (2013). Application of natural clays and poly aluminium chloride (PAC) for wastewater treatment. Int. J. Recent Res. Appl. Sci., 15(2): 287–291 **(5 pages).**

Awang, N.A.; Aziz, H.A., (2012). *Hibiscus rosa-sinensis* leaf extract as coagulant aid in leachate treatment. Appl. Water Sci., 293–298 **(6 pages)**.

Ayangunna, R.R.; Saidat, O.G.; Abdulwahab, G., (2016). Coagulation-flocculation treatment of industrial wastewater using tamarind seed powder. Int. J. Chemtech. Res., *9*(5): 771–780 **(10 pages).**

Azhar, A.W.M.; Hara, H.; Johari, M.M.N.M., (2016). A review on genetically engineered natural coagulant based on *Moringa Oleifera* for turbidity removal. Malay. J. Civil Eng., 28 (1): 26–34 **(9 pages)**.

Babarao, T.D.; Verma, S., (2015). Coal washery wastewater treatment using natural coagulants and chemical precipitation, Int. J. Sci. Res., 4(6): 1877–1881 **(5 pages)**.

Bangar, C.; Mhaske, P.; Parasur, V.; Pawar, S., (2017). Comparative study of removal of dairy waste characteristics by using various natural and chemical coagulants, Int. J. Res. Adv. Technol. Special Issue: National Conference "MOMENTUM-17", 14th & 15th February **(3 pages)**.

Behera, B.; Balasubramanian, P., (2019). Natural plant extracts as an economical and ecofriendly alternative for harvesting microalgae. Bioresour. Technol., 283: 45–52 **(8 pages).**

Beltrán-Heredia, J.; Sánchez-Martín, J.; Rodríguez-Sánchez; M.T., (2011). Textile wastewater purification through natural coagulants. Appl. Water Sci., 1: 25–33 **(9 pages)**.

Bhatia, S.; Othman, Z.; Ahmad, A.L., (2007). Pretreatment of palm oil mill effluent (POME) using *Moringa oleifera* seeds as natural coagulant. J. Hazard. Mater., 145(1–2): 120–126 **(6 pages)**.

Bhuptawat, H.; Folkard, G. K.; Chaudhari, S., (2007). Innovative physico-chemical treatment of wastewater incorporating Moringa oleifera seed coagulant. J. Hazard. Mater., 142(1–2):

477–482 **(6 pages).**

Bhutada, D. S.; Datar, M. T.; Kaul, S. N., (2006). Use of herbal coagulant for primary treatment of dairy wastewater. Int. J. Res. Eng. Mag.PC 22 (1): 139-148 **(10 pages)**.

Bidhendi, G.R.N.; Torabian, A.; Ehsani, H.; Razmkhah, N., (2007). Evaluation of industrial dyeing wastewater treatment with coagulants and polyelectrolyte as a coagulant aid. Iran J. Environ. Health Sci. Eng., 4 (1): 29–36 **(8 pages)**.

Bogacki, J.; Naumczyk, J.; Marcinowski, P.; Kucharska, M., (2011). Treatment of cosmetic wastewater using physicochemical and chemical methods. Chemik, 65 (2): 94-97 **(4 pages)**.

Brito, A.G.; Peixoto, J.; Oliveira, J.M.; Oliveira, J.A.; Costa, C.; Nogueira, R.; Rodrigues, A., (2004). Brewery and Winery Treatment: some focal points of design and operation, In: Oreopoulou, V.; Russ, W. (eds) Utilization of By-Products and Treatment of Waste in the Food Industry. Springer, Boston, MA., 109-131 **(22 pages)**.

Bustillo-Lecompte, C.F.; Mehrvar, M., (2015). Slaughterhouse wastewater characteristics, treatment, and management in the meat processing industry: A review on trends and advances. J. Environ. Manage., 161: 287–302 **(16 pages)**.

Carballa, M.; Omil, F.; Lema, J.M., (2005). Removal of cosmetic ingredients and pharmaceuticals in sewage primary treatment. Water Res., 39(19): 4790–4796 **(7 pages)**.

Carpinteyro-Urban, S.; Vaca, M.; Torres, L.G., (2012). Can vegetal biopolymers work as coagulant-flocculant aids in the treatment of high-load cosmetic industrial wastewaters? Water Air Soil Pollut., 223(8): 4925–4936 **(12 Pages)**.

Chaibakhsh, N.; Ahmadi, N.; Zanjanchi, M.A., (2014). Use of *Plantago major* L. as a natural coagulant for optimized decolorization of dye-containing wastewater. Ind. Crops Prod., 61: 169–175 **(7 pages)**.

Chaudhari, P.K.; Majumdar, B.; Choudhary, R.; Yadav, D.K.; Chand, S., (2010). Treatment of paper and pulp mill effluent by coagulation. Environ. Technol., 31(8): 357–363 **(7 pages).**

Chhonkar, P.K.; Datta, S.P.; Joshi, H.C.; Pathak, H., (2000). Impact of industrial effluents on soil health and agriculture - Indian experience: Part I – Distillery and paper mill effluents. J. Sci. Ind. Res., 59 (5): 350–361 **(12 pages).**

Chonde, S.; Raut, P., (2017). Treatment of dairy wastewater by *Moringa Oleifera* seeds. World J. Pharm. Res., 6(8): 1484-1493 **(10 pages)**.

Daverey, A.; Tiwari, N.; Dutta, K., (2019). Utilization of extracts of *Musa paradisica* (banana) peels and *Dolichos lablab* (Indian bean) seeds as low-cost natural coagulants for turbidity removal from water. Environ. Sci. Pollut. Res., 26: 34177–34183 **(7 pages).**

De Godos, I.; Guzman, H.O.; Soto, R.; García-Encina, P.A.; Becares, E.; Muñoz, R.; Vargas, V.A., (2011). Coagulation/flocculation-based removal of algal-bacterial biomass from piggery wastewater treatment. Bioresour. Technol., 102(2): 923–927 **(5 pages)**.

De Souza, M.T.F.; Ambrosio, E.; De Almeida, C.A.; De Souza Freitas, T.K.F.; Santos, L.B.; De Cinque Almeida, V.; Garcia, J.C., (2014). The use of a natural coagulant (*Opuntia ficus-indica*) in the removal for organic materials of textile effluents. Environ. Monit. Assess., 186(8): 5261–5271 **(11 pages)**.

Dehghani, M.; Alizadeh, M.H., (2016). The effects of the natural coagulant Moringa oleifera and alum in wastewater treatment at the Bandar Abbas Oil Refinery. Environ. Health Eng. Manage., 3(4): 225–230 **(6 pages)**.

Dhivya, S.; Ramesh, S.T.; Gandhimathi, R., (2017). Performance of natural coagulant extracted from *Plantago ovata* seed for the treatment of turbid water. Water Air Soil Pollut., 228: 423 **(11 pages).**

Dotto, J.; Fagundes-Klen, M.R.; Veit, M.T.; Palacio, S.M.; Bergamasco, R., (2019). Performance of different coagulants in the coagulation/flocculation process of textile wastewater. J. Clean. Prod., 208: 656-665 **(10 pages)**.

Ebeling, J.M.; Sibrell, P.L.; Ogden, S.R.; Summerfelt, S.T., (2003). Evaluation of chemical coagulation Á flocculation aids for the removal of suspended solids and phosphorus from intensive recirculating aquaculture effluent discharge. Aquacult. Eng., 29(1-2): 23–42 **(20 pages)**.

Ebrahimi, A.; Taheri, E.; Pashaee, A.; Mahdavi, M., (2014). The application of Polyaluminium Ferric Chloride for Turbidity and Color Removal from Low to Medium Turbid Water. Arch. Hyg. Sci. 3(1) :12-20 **(9 pages).**

Effendi, H.; Delima Sari, R.; Hasibuan, S., (2015). Moringa oleifera as coagulant for batik effluent treatment. IAIA15 Conference Proceedings, 15: 1–6 **(6 pages)**.

El-Awady, M.; El-Ghetany, H.; Aboelghait, K.; Dahaba, A., (2019). Zero liquid discharge and recycling of paper mill industrial wastewater via chemical treatment and solar energy in Egypt. Egypt J. Chem., 62: 37-45. **(9 pages).**

El-Gohary, F.; Tawfik, A., (2009). Decolorization and COD reduction of disperse and reactive dyes wastewater using chemical-coagulation followed by sequential batch reactor (SBR) process. Desalination., 249(3): 1159–1164 **(6 pages)**.

El-Naas, M.H.; Al-Zuhair, S.; Al-Lobaney, A.; Makhlouf, S., (2009). Assessment of electrocoagulation for the treatment of petroleum refinery wastewater. J. Environ. Manage., 91(1): 180–185 **(6 pages)**.

El Samrani, A.G.; Lartiges, B.S.; Villiéras F., (2008). Chemical coagulation of combined sewer overflow: Heavy metal removal and treatment optimization. Water Res., 42 (4-5): 951- 960 **(10 pages).**

Elsheikh, M., Al-Hemaidi, W.K., (2013). Approach in Choosing Suitable Technology for Industrial Wastewater Treatment. J. Civil Environ. Eng., 2(5) **(10 pages)**.

Fabres, R.B.; da Luz, R.B.; Soliman, M.C.; Staggemeier, R.; Fleck, J.D.; Nascimento, C.A.D.; Spilki, F.R., (2017). Evaluation of virus recovery methods and efficiency of tannin-derived coagulants in removing total coliforms, *E. coli* and enteric viruses in effluents of a domestic sewage treatment plant. Water Sci. Technol., 76(7-8): 2195–2202 **(8 pages).**

Fattah, A.; Bakar, A.; Halim, A.A., (2013). Treatment of Automotive Wastewater by Coagulation- Flocculation Using Poly-aluminum Chloride (PAC), Ferric Chloride (FeCl3) and Aluminum Sulfate (alum), AIP Conference Proceedings, 1571: 524-529 **(6 pages)**.

Feria-Diaz, J.J.; Tavera-Quiroz, M.J.; Vergara-Suarez, O., (2018). Efficiency of Chitosan as a Coagulant for Wastewater from

Slaughterhouses. Ind. J. Sci. Technol., 11(3): 1–12 **(12 pages)**.

Ferrari, C.T.R.R.; Genena, A.K.; Lenhard, D.C., (2016). Use of natural coagulants in the treatment of food industry effluent replacing ferric chloride: a review. Científica Jaboticabal, 44(3): 310-317 **(8 pages).**

Fitzpatrick, C.S.; Fradin, E.; Gregory, J., (2004) Temperature effects on flocculation, using different coagulants. Water Sci. Technol., 50:171–175 **(5 pages)**.

Folkard, G.; Sutherland, J.; Al-khalili, R. (1995). Natural coagulants — a sustainable approach. 21ST WEDC Conference sustainability of water and sanitation systems. 263-265 **(3 pages)**.

Gandhi, N.; Sirisha, D.; Sekhar, K.B.C.' (2013). Biodepollution of paint manufacturing industry wastewater containing chromium by using coagulation process. J. Arts Sci. Commer., 4(Vi): 110-118 **(9 pages)**.

Gaurang, P; Punita, P., (2012). An evaluation of turbidity removal from industrial waste by natural coagulants obtained from some plants. J. Environ. Res. Develop., 7(2): 1043–1046 **(4 pages)**.

Ghafari, S.; Aziz, H.A.; Isa, M.H.; Zinatizadeh, A.A., (2009). Application of Response surface methodology (RSM) to optimize coagulation-flocculation treatment of leachate using poly-aluminum chloride (PAC) and alum. J. Hazard. Mater., 163 (2–3): 650–656 (**7 pages).**

Green, R.E.; Newton, I.; Shultz, S.; Cunningham, A.A.; Pain, D.J.; Prakash, V.; Newtont, I.A.N.; Shultz, S.; Cunningham, A.A.; Gilbert, M., (2004). Diclofenac Poisoning as a Cause of Vulture Population Declines across the Indian Subcontinent. Proc. R. Soc. Lon. B, 271: S458-S460 **(3 pages)**.

Gregory, J.; Duan, J., (2001). Hydrolyzing metal salts as coagulants. Pure Appl. Chem., 73(12): 2017–2026 **(10 pages).**

Hamawand, I., (2015). Review of wastewater treatment chemicals and organic chemistry alternatives for abattoir effluent, Aus. Meat Processor Corp. **(1 page).**

Haydar, S.; Aziz, J.A. (2009). Coagulation-flocculation studies of tannery wastewater using combination of alum with cationic and anionic polymers. J. Hazard. Mater., 168(2–3): 1035–1040 **(6 pages)**.

Hemapriya, G.; Abhinaya, R.; Dhinesh, K.S. (2015). Textile Effluent Treatment Using Moringa Oleifera. Int. J. Innov. Res. Dev., 4(4): 385–390 (6 pages).

Hiremath, P.J.; Farmer, A.; Cannon, S.B.; Woodward, J.; Kudapa, H.; Tuteja, R.; Kumar, A.; Bhanuprakash, A.; Mulaosmanovic, B.; Gujaria, N.; Krishnamurthy, L.; Gaur, P.M.; Kavikishore, P.B.; Shah, T.; Srinivasan, R.; Lohse, M.; Xiao, Y.; Town, C.D.; Cook, D.R.; May, G.D.; Varshney, R.K., (2014). Large-scale transcriptome analysis in chickpea (*Cicer arietinum* L.), an orphan legume crop of the semi-arid tropics of Asia and Africa. Plant Biotechnol. J., 9(8): 922-931 **(10 Pages)**.

Imran, Q.; Hanif, M.A.; Riaz, M.S.; Noureen, S.; Ansari, T. M.; Bhatti, H.N., (2012). Coagulation/ Flocculation of tannery wastewater using immobilized chemical coagulants, J. Environ. Prot. Ecol. 13(3A): 1948-1957 **(10 pages)**.

Irfan, M.; Butt, T.; Imtiaz, N.; Abbas, N.; Khan, R.A.; Shafique, A., (2017). The removal of COD, TSS and colour of black liquor by coagulation–flocculation process at optimized pH, settling and dosing rate. J. Arab. Chem., 10(2): S2307–S2318 **(12 pages)**.

Jagaba, A.H.; Kutty, S.R.M.; Hayder, G.; Latiff, A.A.A.; Aziz, N.A.A.; Umaru, I.; Ghaleb, A.A.S.; Abubakar, S.; Lawal, I.M.; Nasara, M.A., (2020). Sustainable use of natural and chemical coagulants for contaminants removal from palm oil mill effluent: A comparative analysis. Ain Shams Eng. J., (in press) **(10 pages)**.

Jaseela, L.A.; Chadaga, M., (2015). Treatment of Dairy Effluent Using *Cicer Arietinum*, Int. J. Innov. Res. Sci. Engg. Technol., 4(6): 4881-4885 **(5 pages)**.

Jeon, J.R.; Kim, E.-J.; Kim Y.-M.; Murugesan, K.; Kim, J.-H.; Chang, Y.-S., (2009). Use of grape seed and its natural polyphenol extracts as a natural organic coagulant for removal of cationic dyes. Chemosphere, 77(8): 1090–1098 **(9 pages)**.

Jiang, J.; Lloyd, B., (2002). Progress in the development and use of ferrate (VI) salt as an oxidant and coagulant for water and wastewater treatment. Water Res., 36(6): 1397–1408 (**12 pages**).

Joudah, R.A., (2014). Effect of Temperature on Floc Formation Process Efficiency and Subsequent Removal in Sedimentation Process. J. Eng. Sustain. Dev., 18 (4): 1813–1822 (**10 pages**).

Kani, K., (2016). Accessing the Suitability of Using Banana Pith Juice as a Natural Coagulant for Textile Wastewater Treatment. Int. J. Sci. Eng. Res., 7(4): 260-264 **(5 pages)**.

Kansal, S.K.; Kumari, A., (2014). Potential of *M. oleifera* for the treatment of water and wastewater. Chem. Rev., 114(9): 4993-5010 **(18 pages)**.

Karamany, H.E, (2010). Study for industrial wastewater treatment using some coagulants. Fourteenth IWTC 14 2010, Cairo, Egypt. 479-482 **(4 pages)**.

Karoliny, T.; Souza, F.; Almeida, C.A. (2018). Textile Science and Clothing Technology book series (TSCT) Detox Fashion.

Katayon, S.; Megat, M.N.M.J.; Kien Tat, W.; Abdul Halim, G.; Thamer, A.M.; Badronisa, Y., (2007). Effect of natural coagulant application on microfiltration performance in treatment of secondary oxidation pond effluent. Desalination. 204 (1-3): 204–212 **(9 pages)**.

Kazi, T.; Virupakshi, A.; Scholar, M.T., (2013). Treatment of tannery wastewater using natural coagulants. Int. J. Inov. Res. Sci. Eng. Technol., 2(8): 4061–4068 **(8 pages)**.

Kobya, M.; Can, O.T.; Bayramoglu, M., (2003). Treatment of textile wastewaters by electrocoagulation using iron and aluminum electrodes. J. Hazard. Mater. 100(1-3): 163–178 **(16 pages)**.

Kumar Dutta, P.; Dutta, J. Tripathi, V.S., (2004). Chitin and chitosan: Chemistry, properties and applications. J. Sci. Indus. Res., 63: 20–31 **(12 pages).**

Kumar, S.; Dagnoko, S.; Haougui, A.; Ratnadass, A.; Pasternak, D.; Kouame, C., (2010). Okra (*Abelmoschus spp*.) in West and Central Africa: Potential and progress on its improvement. Afr. J. Agricul. Res., 25: 3590–3598 **(9 Pages)**.

Kumar, V.; Othman, N.; Asharuddin, S., (2017). Applications of Natural Coagulants to Treat Wastewater − A Review. MATEC Web of Conferences, 103 **(9 Pages).**

Lamont, W. J., (1999). Okra - A versatile vegetable crop. Hort. Technol., 9(2): 179–184 **(6 pages)**.

Liang, Z.; Wang, Y.; Zhou, Y.; Liu, H., (2009). Coagulation removal of melanoidins from biologically treated molasses wastewater using ferric chloride. Chem. Eng. J., 152 (1): 88–94 (**7 pages**).

Loloei, M.; Nekonam, G.; Alidadi, H.; Kor, Y., (2014). Study of the coagulation process in wastewater treatment of dairy industries. Int. J. Environ. Heal. Eng. 3 (1):17-21 **(5 Pages)**.

Madhavi, P.T.; Srimurali, M.; Prasad, N.K., (2014). Color Removal from Industrial Waste Water Using Alum. J. Environ. Res. Dev., 8(4): 890–894 **(5 pages)**.

Majumder, D.; Maity, J.P.; Tseng, M.-J.; Nimje, V.R.; Chen, H.-R.; Chen, C.-C.; Chang, Y.-F.; Yang, T.-C.; Chen, C.-Y., (2014). Electricity Generation and Wastewater Treatment of Oil Refinery in Microbial Fuel Cells Using *Pseudomonas putida*. Int. J. Mol. Sci., 15(9): 16772-16786 **(15 pages).**

Malerba, M.; Cerana, R., (2018). Recent Advances of Chitosan Applications in Plants. Polym., 10 (118) **(10 Pages)**.

Maya, S.R.M.R.; Mariam I.K.N.A.; Hashim, M.K.A., (2014). Efficiency of using commercial and natural coagulants in treating car wash wastewater treatment. Aust. J. Basic Appl. Sci., 8 (16): 227–234 **(8 pages)**.

Meraz, K.A.S.; Vargas, S.M.P.; Maldonado, J.T.L.; Bravo, J.M.C.; Guzman, M.T.O.; Maldonado, E.A.L., (2016). Eco-friendly innovation for *nejayote* coagulation–flocculation process using chitosan: Evaluation through zeta potential measurements. Chem. Eng. J., 284: 536–542 **(7 pages).**

Merzouk, B.; Gourich, B.; Madani, K.; Vial, C; Sekki, A. (2011). Removal of a disperse red dye from synthetic wastewater by chemical coagulation and continuous electrocoagulation. A comparative study. Desalination. 272(1–3): 246–253 (**8 pages**).

Miller S.M.; Fugate E.J.; Craver V.O.; Smith J.A.; Zimmerman J.B., (2008). Toward understanding the efficacy and mechanism of *Opuntia spp.* as a natural coagulant for potential application in water treatment. Environ. Sci. Technol. 42(12): 4274–4279 **(6 pages)**.

Mishra, A.; Bajpai, M., (2014). Flocculation behavior of model textile wastewater treated with a food grade polysaccharide with a food grade polysaccharide. J. Hazard. Mater., 118(1-3): 213-217 **(5 pages)**.

Mohamed, R.M.S.R.; Rahman, N.A.; Kassim, A.H.M., (2014). Moringa Oleifera and Strychnos Potatorum Seeds as natural coagulant compared with synthetic common coagulants in treating car wash wastewater: case study. Asian J. Appl. Sci., 2(5): 693–700 **(8 pages).**

Mohammadtabar, F.; Khorshidi, B.; Hayatbakhsh, A.; Sadrzadeh, M. (2019). Integrated coagulation-membrane processes with zero liquid discharge (ZLD) configuration for the treatment of oil sands produced water. Water, 11(7): 1348 **(12 pages).**

Mosaddeghi, M.R.; Shariati, F.P.; Yazdi, S.A.V.; Bidhendi, G.N., (2020). Application of response surface methodology (RSM) for optimizing coagulation process of paper recycling wastewater using *Ocimum basilicum*. Environ. Technol., 41(1): 100-108 **(9 pages)**.

Muralimohan, N.; Palanisamy, T.; Vimaladevi, M.N., (2014). Experimental study on removal efficiency of blended coagulants in textile wastewater treatment. Int. J. Res. Eng. Technol., 2(2): 15-20 **(6 Pages).**

Muthuraman, G.; Sasikala S., (2014). Turbidity removal from drinking water using natural coagulant. J. Ind. Eng. Chem., 20(4): 1727-1731 **(5 pages).**

Narmatha, M.; Sangavi, S.K.; Sripavithra, G., (2017). Effluent treatment of Sago wastewater by using natural coagulants. Int.J. Interndiscip. Res.,3(9): 53-59 **(7 pages).**

Nath, A.; Mishra, A.; Pande, P.P., (2020). A review of natural polymeric coagulants in wastewater treatment. Mater. Today: Proc., (in press) **(5 pages)**.

Naumczyk, J.; Bogacki, J.; Marcinowski, P.; Kowalik, P., (2014). Cosmetic wastewater treatment by coagulation and advanced oxidation processes. Environ. Technol., 35(5): 541–548 **(8 pages)**.

Ngan, N.V.C.; Thuy, L.T.D.; Trung, D.M., (2017). Apply *Cassia Fistula* seed gum as auxiliary bio-coagulant for fish processing wastewater treatment, Int. J. Adv. Sci. Res. Manage., 2(6): 46-51 **(6 pages)**.

Neethu, P.; Navami. D; Anitha, K., (2017). Treatment of dairy wastewater by *Moringa oleifera* as natural coagulant. Int. J. Adv. Res. Innovative Ideas Educ., 3(4): 1448–1453. **(6 pages).**

Nharingo, T.; Moyo, M., (2016). Application of *Opuntia ficus-indica* in bioremediation of wastewaters: A critical review. J. Environ. Manage., 166: 55–72 **(18 pages)**.

Nicholas, H.; Hoong, J.; Ismail, N., (2018). Removal of Dye in Wastewater by Adsorption- Coagulation Combined System with Hibiscus sabdariffa as the Coagulant, 1008., 9th Eureca 2017 Int. Eng. Res. Conf. MATEC Web of Conferences. 152 **(14 pages)**.

Niquette, P.; Monette, F.; Azzouz, A.; Hausler, R., (2004). Impacts of substituting aluminum-based coagulants in drinking water treatment. Water Qual Res. J. Can., 39(3): 303–310 **(8 pages)**.

Oaks, J.L.; Gilbert, M.; Virani, M.Z.; Watson, R.T.; Meteyer, C.U.; Rideout, B.A.; Khan, A.A. (2004). Diclofenac residues as the cause of vulture population decline in Pakistan. Nat., 427(6975): 630–633 **(4 pages)**.

Okuda, T.; Baes, A.U.; Nishijima, W.; Okada, M., (2001). Coagulation mechanism of salt-extracted active component in Moringa Oleifera seeds. Water Res., 35(3): 830–834 **(5 Pages)**.

Omar, F.M.; Rahman, N.N.N.A.; Ahmad, A., (2008). COD reduction in semiconductor wastewater by natural and commercialized coagulants using response surface methodology. Water Air Soil Pollut., 195(1–4): 345–352 **(8 pages)**.

Pal, A.; Gin, K.Y.H.; Lin, A.Y.C.; Reinhard, M., (2010). Impacts of emerging organic contaminants on freshwater resources: Review of recent occurrences, sources, fate and effects. Sci. Total Environ., 408(24): 6062–6069 **(8 pages)**.

Pallavi, N., Mahesh, S., (2013). Feasibility Study of *Moringa Oleifera* as a Natural Coagulant for the treatment of Dairy Wastewater. Int. J. Eng. Res., 2(3): 200–202 **(3 pages).**

Parmar, K.; Dabhi, Y.; Patel, R.; Prajapati, S., (2012). Effectiveness of Moringa oleifera as natural coagulant aid for waste water treatment of dairy industry. Asian J. Environ. Sci., 7(2): 167-171 **(5 pages)**.

Patel, H.; Vashi, R.T., (2013). Comparison of naturally prepared coagulants for removal of cod and color from textile wastewater. Glob. NEST J., 15(4): 522-528 **(7 pages)**.

Patil, C.; Hugar, M., (2015). Treatment of dairy wastewater by natural coagulants. Int. Res. J. Eng. Technol., 2(4): 1120-1125 **(6 pages).**

Paula, H.M. De; Sangoi, M.; Ilha, D.O.; Andrade, L.S., (2016). Chemical coagulants and Moringa oleifera seed extract for treating concrete wastewater, Acta Scient. Technol., 38(1): 57-64 **(8 pages).**

Perren, W.; Wojtasik, A.; Cai, Q., (2018). Removal of microbeads from wastewater Using electrocoagulation. ACS Omega, 3(3): 3357–3364 **(8 pages)**.

Prabhakaran, G.; Manikandan, M.; Boopathi, M., (2020). Treatment of textile effluents by using natural coagulants. Mater. Today: Proc., (in press) **(5 pages)**.

Prasad, S.V.M.; Rao, B.S., (2016). Influence of plant-based coagulants in wastewater treatment. Int. J. Lat. Technol. Eng. Manage. Appl. Sci., V(Iii): 45–48 **(4 pages)**.

Prodanovic, J.M.; Sciban, M.B.; Antov, M.G.; Kukic, D.V.; Vasic, V.M., (2015). Treatment of sugar beet extraction juice stillage by natural coagulants extracted from common bean. Acta Period. Technol., 46: 77-89 **(13 pages).**

Prodanović, J.; Šćiban, M.; Antov, M., (2013) Improvement of wastewater treatment by use of natural coagulants. J. Ecol. Dev. Environ. People, 2(2): 22-28 **(7 pages)**.

Quintero-Jaramillo, J.A.; Murillo-Arango, W.; Ceron-Salazar, I.X., (2016). Use of thermal water as a natural coagulant for domestic wastewater sustainable treatment. Rev. Fac. Ing., 26 (44), 35–45 (11 **pages**).

Ramavandi, B.; Farjadfard, S., (2016). Removal of chemical oxygen demand from textile wastewater using a natural coagulant. Korean J. Chem. Eng., 31: 81-87 **(7 pages)**.

Rameshraja, D.; Suresh, S., (2011). Treatment of tannery wastewater by various oxidation and combined processes. Int. J. Environ. Res., 5(2): 349–360 **(12 pages).**

Rao, L.N., (2015). Coagulation and Flocculation of Industrial Wastewater by Chitosan, Int. J. Eng. Appl. Sci., 2(7): 50–52 **(3 pages)**.

Rathi, A.K.A.; Puranik, S.A., (2002). Chemical Industry Wastewater Treatment Using Adsorption. J. Sci. Ind. Res., 61: 53–60 **(8 pages)**.

Rebah, F.B.; Siddeeg, S.E., (2017). Cactus an eco-friendly material for wastewater treatment : A review, J. Mat. Environ. Sci., 8(5): 1770–1782 **(13 pages)**.

Renault, F.; Sancey, B.; Badot, P.M.; Crini, G. (2009). Chitosan for coagulation/flocculation processes - An eco-friendly approach. Eur. Polym. J., 45(5): 1337–1348 **(12 pages)**.

Rizzo, L.; Lofrano, G.; Grassi, M.; Belgiorno, V., (2008). Pre-treatment of olive mill wastewater by chitosan coagulation and advanced oxidation processes. Sep. Purif. Technol., 63(3): 648–653 **(6 pages)**.

Saini, G. (2017). *Benincasa hispida* coagulant for water treatment and methods thereof. Patent App. 201711026431, India.

Saha, N.K.; Balakrishnan, M.; Batra, V.S., (2005). Improving industrial water use: Case study for an Indian distillery. Resour. Conserv. Recycl., 43(2): 163–174 **(12 pages).**

Saharudin, N.F.A.B.; Nithyanandam, R., (2014). Wastewater Treatment by using Natural Coagulant. 2nd Eureca. 2–3 **(3 pages)**.

Sahu, O. P.; Chaudhari, P.K., (2013). Review on Chemical treatment of Industrial Wastewater. J. Appl. Sci. Environ. Manage., 17(2): 241–257 **(17 pages).**

Salameh, W.K.B., (2015). Treatment of olive mill wastewater by ozonation and electrocoagulation processes. Civil Environ. Res., 7(2): 80–91 **(12 pages)**.

Saleem, M.; Bachmann, R.T., (2019). A contemporary review on plant-based coagulants for application in water treatment. J. Ind. Eng. Chem., 72: 281-297 **(17 pages).**

Saritha, V.; Karnena, M.K.; Dwarapureddi, B.K., (2020). Competence of blended coagulants for surface water treatment. Appl. Water Sci., 10: 20 **(11 pages).**

Sarkar, B.; Chakrabarti, P.P.; Vijaykumar, A.; Kale, V., (2006). Wastewater treatment in dairy industries-possibility of reuse. Desalination., 195 (1–3): 141-152**(12 pages)**.

Sarparastzadeh, H.; Saeedi, M.; Naeimpoor, F.; Aminzadeh, B., (2007). Pretreatment of municipal wastewater by enhanced chemical coagulation. Int. J. Environ. Res., 1(2): 104-113 **(8 pages).**

Savant, V.D.; Torres, J.A., (2000). Chitosan based coagulating agents for treatment of Cheddar cheese whey. Biotechnol. Prog., 16: 1091–1097 **(7 pages)**.

Sehar, S.; Aamir, R.; Naz, I.; Ali, N.; Ahmed, S., (2013). Reduction of Contaminants (Physical, Chemical, and Microbial) in Domestic Wastewater through Hybrid Constructed Wetland. Microbiol., Article ID 350260 **(9 pages)**.

Semblante, G.U.; Lee, J.Z.; Lee, L.Y.; Ong, S.L.; Ng, H.Y., (2018). Brine pre-treatment technologies for zero liquid discharge systems. Desalination., 441: 96–111 **(16 pages).**

Semerjian, L.; Ayoub, G.M., (2003). High-pH-magnesium coagulation-flocculation in wastewater treatment. Adv. Environ. Res., 7(2): 389–403 **(5 pages).**

Shamsnejati, S.; Chaibakhsh, N.; Pendashteh, A.R.; Hayeripour, S., (2015). Mucilaginous seed of *Ocimum basilicum* as a natural coagulant for textile wastewater treatment. Ind. Crop Prod., 69: 40–47 **(8 pages)**.

Shan, T.C.; Matar, M.A.; Makky, E.A.; Ali, E.N., (2017). The use of Moringa oleifera seed as a natural coagulant for wastewater treatment and heavy metals removal. Appl. Water Sci., 7(3): 1369–1376 **(8 pages)**.

Shankar, D.; Sivakumar, D.; Thiruvengadam, M.; Kumar, M.M., (2014). Colour removal in a textile industry wastewater using Coconut coir pith. Pollut. Res., 33(3): 499-503 **(5 pages)**.

Sheikh., M.S.; Vij. R.; Dharaniraj, B., (2016). Abattoir wastewater treatment using *Cicer arentinum* seed powder as natural coagulant, J. Chem. Pharm. Sci., 9(4): 2610–2612 **(3 pages).**

Silva, M.J.M.; Paterniani, J.E.S.; Francisco, A.R., (2013). Application of *Moringa Oleifera* natural coagulant for clarification and disinfection of treated wastewater in wetlands and multistage filtration. Afr. J. Agric. Res., 8(24): 3102–3106 **(5 pages).**

Sivakumar, D., (2013). Adsorption study on municipal solid waste leachate using *Moringa oleifera* seed, Int. J. Environ. Sci. Technol., 10: 113-124 **(12 pages).**

Sivakumar, D.; Balasundaram, V.; Venkatesan, G.; Saravanan, S.P., (2014). Effect of Tamarind kernel powder for treating dairy industry wastewater, Pollut. Res., 33 (3): 519-523 **(5 pages)**.

Sivakumar, D., (2015). Hexavalent chromium removal in a tannery industry wastewater using rice husk silica, Global J. Environ. Sci. Manage., 1 (1): 27-40 **(14 pages).**

Sivakumar, D.; Shankar, D.; Sundaram, S.J., (2016). Treating dairy industry effluent using orange peel powder, J. Chem. Pharm. Sci., 9 (3): 1550-1552 **(3 pages)**.

Somchit, M.N.; Mak, J.H.; Bustamam, A.A.; Zuraini, A.; Arifah, A.K.; Adam, Y.; Zakaria, Z.A., (2012). Zerumbone isolated from Zingiber zerumbet inhibits inflammation and pain in rats. J. Med. Plant Res., 6(2): 177-180 (**4 pages**).

Srinivasan, P.T.; Viraraghavan, T.; Subramanian, K.S., (1999). Aluminium in drinking water. Water SA, 25(1): 47-55 **(9 pages).**

Suarez, S.; Lema, J.M.; Omil, F., (2009). Pre-treatment of hospital wastewater by coagulation-flocculation and flotation. Bioresour. Technol., 100(7): 2138–2146 **(9 pages)**.

Sulaiman, M.; Umar, D.M.; Aliyu, B.; Manan, F.A., (2017). Moringa oleifera seed as alternative natural coagulant for potential application in water treatment : A review. J. Adv. Res. Mat. Sci. 56: 11-21 **(11 Pages).**

Sundaresan, A.; Anu, N., (2016). Feasibility of Natural Coagulant for the Treatment of Dairy Wastewater. Int. J. Sci. Eng. Res., 7(4): 245-249 **(5 pages)**.

Tariq. A.; Athar, M.; Ara. J.; Sultana. V.; Ehteshamul-Haque. S.; Ahmad. M., (2015). Biochemical evaluation of antioxidant activity in extracts and polysaccharide fractions of seaweeds, Global J. Environ. Sci. Manage., 1 (1): 47-62 **(16 pages).**

Tezcan, U.U.; Koparal, A.S.; Bakir Ogutveren, U., (2009). Electrocoagulation of vegetable oil refinery wastewater using aluminum electrodes. J. Environ. Manage., 90(1): 428–433 **(6 pages)**.

Thakur, S.S.; Choubey, S., (2014). Use of Tannin based natural coagulants for water treatment: An alternative to inorganic chemicals. Int. J. Chem. Technol. Res., 6(7): 3628–3634 **(7 pages)**.

Thirugnanasambandham, K.; Sivakumar, V.; Maran, J.P., (2014). Bagasse wastewater treatment using biopolymer - A novel approach. J. Serb. Chem. Soc., 79(7): 897–909 **(13 pages)**.

Tobajas, M.; Polo, A.M.; Monsalvo, V.M.; Mohedano, A.F.; Rodriguez, J.J., (2014). Analysis of the operating conditions in the treatment of cosmetic wastewater by sequencing batch reactors. Environ. Eng. Manage. J., 13(12): 2955–2962 **(8 pages).**

Tolkou, A.K; Zouboulis, A.I., (2014). Synthesis and coagulation performance of composite poly-aluminum-ferric-silicate-chloride coagulants in water and wastewater. Desalination. Water Treat., 53: 3309-3318 (10pages).

Triques, C.C.; Fagundes-Klen, M.R.; Suzaki, P.Y.R.; Mateus, G.A.P.; Wernke, G.; Bergamasco, R.; Rodrigues, M.L.F., (2020). Influence evaluation of the functionalization of magnetic nanoparticles with a natural extract coagulant in the primary treatment of a dairy cleaning-in-place wastewater. J. Clean. Prod., 243: 118634.

Vanerkar, A.P.; Satyanarayan, S.; Satyanarayan, S., (2013). Treatment of Food Processing Industry Wastewater by a Coagulation / Flocculation Process. Int. J. Chem. Phy. Sci., 2: 63–72 **(10 pages)**.

Verma, A.K.; Dash, R.R.; Bhunia, P., (2012). A review on chemical coagulation/flocculation technologies for removal of colour from textile wastewaters. J. Environ. Manage., 93(1): 154–168 **(15 pages)**.

Verma, M.; Kumar, R.N., (2018). Coagulation and electrocoagulation for co-treatment of stabilized landfill leachate and municipal wastewater. Water Reuse Desalination. 8(2): 234-243 **(10 pages).**

Vieira, A.; Vieira, M.; Marquetotti, A.; Vieira, S.; Vieira, M.F.; Silva, G.F. (2010). Use of Moringa oleifera seed as a natural adsorbent for wastewater treatment. Water Air Soil Pollut., 206: 273–281 **(9 pages)**.

Vijayaraghavan, G.; Sivakumar, T.; Kumar, V.A., (2011). Application of plant based coagulants for wastewater treatment. Int. J. Adv. Eng. Res. Stud., 1(1): 88–92 **(5 pages)**.

Walton, J.R., (2006). Aluminum in hippocampal neurons from humans with Alzheimer's disease. Neurotoxicol., 27(3): 385–394 **(10 pages)**.

Wan Ngah, W.S.; Teong, L.C.; Hanafiah, M.A.K.M., (2011). Adsorption of dyes and heavy metal ions by chitosan composites: A review. Carbohydr. Polym., 83(4): 1446–1456 (11 pages).

Wang, J.P.; Chen, Y.Z.; Wang, Y.; Yuan, S.J.; Yu, H.Q., (2011). Optimization of the coagulation-flocculation process for pulp mill wastewater treatment using a combination of uniform design and response surface methodology. Water Res., 45(17): 5633–5640 **(8 pages)**.

Wei, H.; Gao, B.; Ren, J.; Li, A.; Yang, H., (2018). Coagulation/flocculation in dewatering of sludge: A review. Water Res., 143: 608–631 **(23 pages).**

Wei, Y.; Lu, J.; Dong, X.; Hao, J.; Yao, C., (2017). Coagulation performance of a novel poly-ferric-acetate (PFC) coagulant in phosphate-kaolin synthetic water treatment. Korean J. Chem. Eng., 34(10): 2641–2647 **(7 pages)**.

WHO Guidelines, (2010). Aluminium in drinking water **(23 pages)**.

Wolf, G.; Schneider, R.M.; Bongiovani, M.C.; Morgan Uliana, E.; Garcia Do Amaral, A., (2015). Application of coagulation/flocculation process of dairy wastewater from conventional treatment using natural coagulant for reuse. Chem. Eng. Trans., 43: 2041–2046 **(6 pages).**

Wong, S.S.; Teng, T.T.; Ahmad, A.L.; Zuhairi, A.; Najafpour, G., (2006). Treatment of pulp and paper mill wastewater by polyacrylamide (PAM) in polymer induced flocculation. J. Hazard. Mater., 135(1–3): 378–388 **(11 pages)**.

Wu, J.; Xiao, Y.Z.; Yu, H.Q., (2005). Degradation of lignin in pulp mill wastewaters by white-rot fungi on biofilm. Bioresour. Technol., 96(12): 1357–1363 **(7 pages)**.

Yin, C.Y., (2010). Emerging usage of plant-based coagulants for water and wastewater treatment. Process Biochem., 45(9): 1437–1444 **(8 pages).**

Zhang, Z.; Jing, R.; He, S.; Qian, J.; Zhang, K.; Ma, G.; Chang, X.; Zhang, M.; Li, Y., (2018). Coagulation of low temperature and low turbidity water: Adjusting basicity of poly-aluminum chloride (PAC) and using chitosan as coagulant aid. Sep. Purific. Technol., 206: 131–139 **(8 pages).**

Zhu, G.; Zheng, H.; Chen, W.; Fan, W.; Zhang, P.; Tshukudu, T., (2012). Preparation of a composite coagulant: Polymeric aluminum ferric sulfate (PAFS) for wastewater treatment. Desalination. 285: 315–323 **(9 pages).**

Zouboulis A.; Tzoupanos, N., (2009). Polyaluminium silicate chloride-A systematic study for the preparation and application of an efficient coagulant for water or wastewater treatment. J. Hazard. Mater., 162(2-3): 1379-89 **(11 pages).**

Zouboulis, A.I.; Traskas, G., (2005). Comparable evaluation of various commercially available aluminium-based coagulants for the treatment of surface water and for the post-treatment of urban wastewater. J. Chem. Technol. Biotechnol., 80(10): 1136–1147 **(12 pages)**.

AUTHOR (S) BIOSKETCHES

Gautam, S., Post-graduate student, Department of Civil Engineering, School of Engineering and Technology, Sharda University, Uttar Pradesh, India. Email: *swatig764@gmail.com*

Saini, G., Ph.D., Associate Professor and Head of Department of Civil Engineering, School of Engineering and Technology, Sharda University, Uttar Pradesh, India. Email: *gaurav.saini@sharda.ac.in*

HOW TO CITE THIS ARTICLE

Gautam, S.; Saini, G., (2020). Use of natural coagulants for industrial wastewater treatment. Global J. Environ. Sci. Manage., 6(4): 553-578.

DOI: 10.22034/gjesm.2020.04.10

url: https://www.gjesm.net/article_39795.html