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Sustainable Treatment of Water and Wastewater using Natural Plant-based Coagulants: A Review

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Abstract— **Water is one of the Primary needs for survival, in addition, to food, shelter as per Abram's Maslow's hierarchy. As of now there are not very much sufficient sustainable and low- cost technologies available for the treatment of water and wastewater. In rural areas of developing countries like India, majority of people below poverty line are presently drinking contaminated water, in the absence of knowledge of domestic drinking water treatment facilities and they cannot afford costly chemical coagulants on one hand and on the other hand their side effects are also alarming. This problem attracted the researcher'sattention so as to find sustainable domestic solution for poor and rural society. Natural coagulants (NC) are collected from plants that can be used as a coagulant in coagulation- flocculation process of water and wastewater treatment. Natural coagulants such as: Neem, Tulsi, Moringa, Orange Peel, Sponge Guard, vetiver, Banana Peel etc. can effectively be used in the treatment of water and wastewater. The authors after reviewing available literature have emphasized that Natural Plant Based Coagulants (NPBC) are very effective for sweeping physio-chemical parameter of water such as: turbidity, TSS, TDS, coliform bacteria and wastewater parameter such as: BOD, COD, Heavy metals (chromium, lead etc), colour etc. The authors also have emphasized the nature, mechanism of working, advantages and disadvantages of using these NPBC with their all-round performance in water and wastewater treatments.**

As per findings in literature NPBC are very effective coagulants, cationic charge density is very intense, polymer chain is very long, interparticle bridging agglomeration and precipitation, sustainable, less toxic compare with chemical coagulant, free from corrosion, biodegradability is very high, sludge volume reduction, denser flocs etc.

This paper reviews the studies performed in past few years on NCs, their pros and cons and identifies research gaps to provide scope for further study for their effective utilization for the treatment of water and wastewater.

Keywords—NPBC, NC, PBC, SWOC, OM etc.

I. INTRODUCTION

Water is one of the basic needs for all kinds of life on earth. Rapid urbanization and industrialization in developing countries is causing water demand increasing with growing population day by day. Scarcity of water has trigged more comprehensive research on water and wastewater [24].

Rain water is a vital natural resource for all. Potable water is the major concern all over the world. Contaminated water is responsible for water borne diseases i.e. cholera, typhoid, jaundice etc. [24].

It has been observed that in developing nations greater than 1.6 million people are using contaminated water & among them majority of the people suffering from water borne diseases [WOC 4]. Treatment cost of water and wastewater is very high because of importing cost of chemicals.[WOC 5] Physico-chemical treatment is widely used in water and wastewater treatment. The main objective of physiochemical treatment to remove suspended, colloidal particles to reduce turbidity of water body [20].

The process usually take place in sedimentation-cum coagulation tank in which influent water or wastewater enter the basin and it is mix with coagulants using a mechanical stirrer, followed by sedimentation process to remove suspended particle through gravity settling [20]. Each chemical coagulant having positive and negative impacts as shown in table 1.

TABLE 1: SYNTHETIC/INORGANIC COAGULANTS ADVANTAGES AND DISADVANTAGES

S.No.	Name	Advantages	Disadvantages
1.	Aluminium sulphate (Alum) $Al_2(SO_4)_3.18H_2O$	1. Easy to handle and use 2. More frequently used 3. Effective between PH 6.5 to 8.5	1. by adding salt it increases permanent hardness. 2. It is not effective beyond that PH range 3. It produces more sludge volume

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S.No.	Name	Advantages	Disadvantages
2.	Sodium aluminate $Na_2Al_2O_4$	1. Effective in hard water, frequently used to remove both temporary and permanent hardness 2. Less dose required	1.Often used with alum 2.Cost is very high 3. Not effective for hardness less 120 mg/l
3.	Poly Aluminium Chloride (PAC) $Al_{13}(OH)_{20}(SO_4)_2.Cl_{15}$	1. Floc Formation is rapid and very dense 2. Settling is faster than alum	1. Not frequently used 2. Little full-scale data compared to another aluminium derivative
4	Ferric Sulphate $Fe_2(SO_4)_3$	1. Effective between pH range 4-6 and 8.8-9.2	1. Increases salinity of water
5	Ferric Chloride $FeCl_{3.6}H_2O$	1. Effective between PH range 4-11	1. Increase salinity of water 2. Consume twice as alkalinity as alum
6	Ferrous Sulphate (Copperas) $FeSO_4.7H_2O$	1. Not as PH sensitive	1. Increase dissolved salts in water 2. Usually need to add alkalinity
7	Lime Ca $(OH)_2$	1. Most frequently used 2. May not add salt in effluent	1. Produced large quantity of sludge then alum 2. Overdose can result in poor effluent quality

Source: National Programme on Technology Enhanced Learning

However, the use of these chemicals resulted in many disadvantages such as toxic and harmful sludge production [20]. Natural coagulant is one of the sustainable solutions for the treatment water. Plant based coagulants considered 3 pillars of sustainability:

1) Plant based Natural coagulants are cost effective

2) Plant based Natural coagulants are environment friendly

3) Plant based Natural coagulants are socially acceptable specially in India which is a developing country and very rich in it!s own rituals associated with nature.

II.TYPES OF NATURAL COAGULANTS Sources of natural coagulants are plants, micro-organisms and animals [20]. Broad classification of natural coagulants is given in figure 1: In this paper the focus is towards natural plant based coagulants as described in table 2.

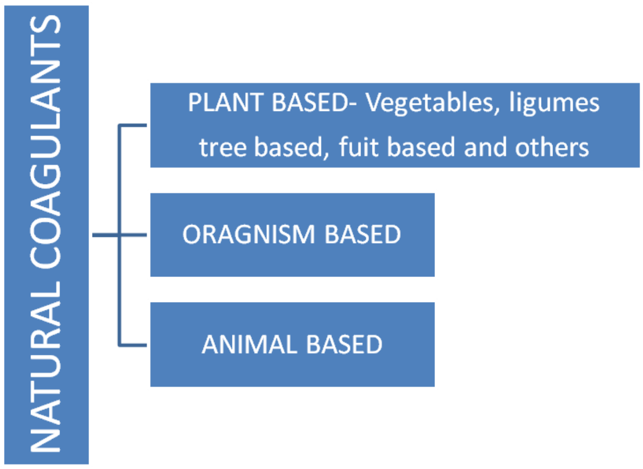

Figure 1: Broad classification of Natural Coagulants (NC)

Natural Plant Based Coagulants have various categories some of them are as follows:

Table 2: Different types of NPBC and their characteristics

S.no.	Types of NPBC	Operation Condition		Findings	Refrences
1.	Moringa oleifera	5-7 - 7 7.5 -	5-7 mg/l 20 mg/l 50 mg/l 2.5g/l 100mg/l	95% turbidity removal, coagulant aid in conjunction with alum dose 7.5 mg/l 85% chlorophyll and suspended particle removal 84% turbidity and 88% E. coli removal 92% fluoride removal and 82% turbidity removal % of turbidity reduction 94(high turbidity water), % of turbidity removal 60(low turbidity water) and 96 % reduction in total coliform count	Ref [1] and [2]
2.	Cicer arietinum	7-7.5	50-70 mg/l 50 mg/l	93% turbidity removal (high turbidity water) and 62% turbidity removal (low turbidity water) 90% reduction in total coliform count	
3.	Dolichos lablab	-	50-60 mg/l	84% turbidity removal (high turbidity water) and 49% turbidity removal (low turbidity water) 89% reduction in total coliform count	
4.	Ociumsanctun	-	3g/50ml	Percentage of biosorption for iron and lead was found to be 73% and 95% respectively. The sorption percentage increased with increase of time 210 minutes for iron and 180 minutes.	
5.	Roselle seeds	4 10	40 mg/l 60 mg/l	93% turbidity removal for synthetic wastewater 87% turbidity removal for industrial wastewater	
6.	Carica papaya Garcinia kola+ carica papaya (1;1)	- -	100 seed /100l 3%(v/v) 5%(v/v)	88% of E. coli bacteria and 90% turbidity removed from surface water 57% BOD removal and 67% turbidity removed 42% nitrate removal, total coliform removal 67%, E. coli removal 83%, faecal streptococcus 83%	
7.	Banana Pith Banana peel	4 - 7-8	$0.1 kg/m^3$ - 0.5g/100ml	80% of turbidity, cobalt, sulphates, nitrates, lead, zinc iron, chromium removal from paint industry The adsorption capacity was found to be 7.97 (Pb^{2+}), 6.88 (Ni^{2+}), 5.80 (Zn^{2+}), 4.75 (Cu^{2+}), and 2.55 mg/g (Co^{2+}) using banana peel More than 85% cadmium removal at optimum time 120 min @ 85rpm shaking speed	Ref [8]
8.	Orange peel	7.5 -	0.2g/l -	97% turbidity removal from dairy wastewater The adsorption capacity was found to be 7.75 (Pb^{2+}), 6.01 (Ni^{2+}), 5.25 (Zn^{2+}), 3.65 (Cu^{2+}), and 1.82 mg/g (Co^{2+}) using orange peel.	
9.	OcimumBasilicum	7.7	1.6 mg/l	68% of colour and 61% COD removal from model textile wastewater.	Ref[21, 23]
10.	Jack fruit	-	60 mg/l	43% turbidity removal from kaolin water	
11.	Margaritareadiscoidea	-	10ml/l	98% turbidity removal from synthetic turbid water	
12.	Jatropha curcas	3	120mg/l	JCSC- Nacl removed 99% turbidity in synthetic wastewater	

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S.no.	Types of NPBC	Operation Condition		Findings	Refrences
13.	Plantago ovata	7	0.25mg/l	99% turbidity removal	Ref[21, 23]
14.	Maerua decumbent	5-7	0.8-1.2kg/m³	99% turbidity, 78.6 % COD, 100% lead, 99% chromium removal from paint industry wastewater	
15.	Phaseolus vulgaris	7	1ml/l	Turbidity removal 95% from kaolin turbid water extraction with Nacl	
16.	Rice starch	3 4	120mg/l 120mg/l	80% micro algae removal in 30 min 50% of kaolin removal, increase up to 78% by adding a second step coagulation using PACl	
17.	Corn starch	4	0.5mg/l	98% removal of kaolin, Escherichia coli and staphylococus	
18.	PhylunthusEmblica	5-7	50g/l	82% alkalinity removal, 68% hardness removal and 92 % BOD removal @ 35 days.	
19.	marind shell	-	25mg/100ml	50% fluoride remove by using dip method Brown colour impart in water due to tamarind shell which is further removed by using hydrogen peroxide (8-10) drop.	
20.	Peanut husk	4	2g/l	45.7% lead (Pb) removal, 28.65% chromium (Cr) removal and 37% copper (Cu) removal from aqueous solution.	
21.	Java plum	7	100 mg/l	Solvent water, removal efficiency of turbidity 72% (low turbid water). High turbid water 69% Solvent 0.5M Nacl, removal efficiency 69% (low turbid water) and high turbid water is 63%	
22.	Custard apple shell	5	30 mg/l	Maximum removal efficiency 93% for lead and 71% for cadmium	
23.	Watermelon rind	2-3	1.5g/l	Maximum removal efficiency 90.8% for chromium	
24.	Neem saw dust	4	2g/l	56% chromium removal without cellulose, 82% removal without lignin	

Plant Based Coagulants (PBC) are divided in different categories such as: cationic, anionic or nonionic, and hence are described as polyelectrolytes (Yin 2010). Chitosan and cationic starches come under the category of cationic polymer. Sulfated polysaccharides and modified lignin sulfonates come under the category of anionic polymer. Starch and cellulose come under non-ionic natural polymers (Renault et al. 2009). On the basis their origin natural coagulants further classified in following categories as shown figure.

III. MECHANISM OF NATURAL COAGULANTS

There are usually four types of mechanism of conventional chemical coagulation which are as follows:

1) *Double layer compression*
2) *Polymer bridging*
3) *Charge neutralization*
4) *Sweep coagulation*

But in case of natural coagulants only two processes are applicable i.e. polymer bridging preceded by polymer adsorption [ioje 4]. In this process long chain polymers attach itself to the suspended particle because of attraction force between them. In this process fraction part of polymer attached with suspended particle while the remaining part will form loops and tails [ioje 5]. These loop and tails agglomerate with other colloidal particle form dense bridging. [Ioje 6]

p-electron systems of dyes and OH− groups of polysaccharides are responsible for adsorption and interparticle bridging between dye substances and polysaccharides (Miller et al. 2008; Yin 2010; Verma et al. 2012).

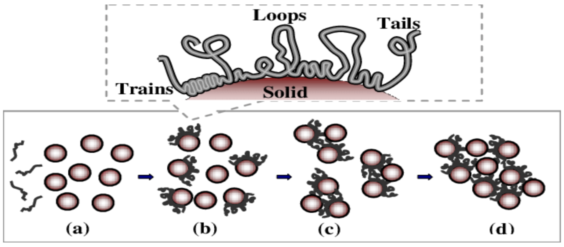

Figure 2: Mechanism of natural coagulants

In charge neutralization mechanism polycation used to stabilize the particles through minimize zeta potential. Charge density of the polyelectrolyte utilize to determine the optimum dose of coagulant needed. Charge density and dose of electrolyte are reciprocal to each other. [Ijoe 5]

IV. PROCESSING STEPS OF NATURAL COAGULANT

Processing steps for natural coagulants involve three phases only. All these phases are elaborated by using flow chart. In first phase; pulverisation of natural coagulants by manual or mechanical method. In second phase, organic and alcoholic solvents used to remove active agent. Last phase; involves dialysis, lyophilization, ion-exchange and precipitation to treat water and wastewater. [Woc 30]

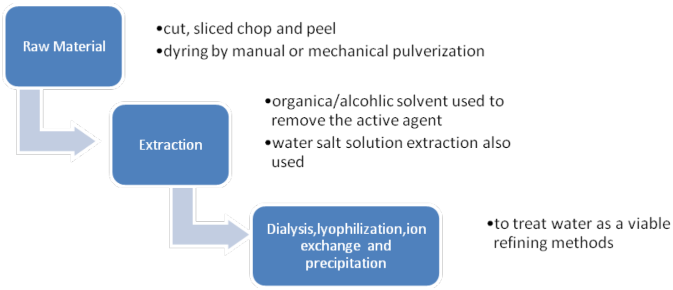

Figure 3: Processes phase of NC

V. ADVANTAGES AND DISADVANTAGES OF NPBC

Natural coagulants are more advantageous over chemical coagulants as they possess several novel characteristics. There are following benefits for natural coagulants –

- NPBC produce large, dense and compact flocs, due to this characteristic's flocs get heavier and increase settling velocity.
- NC having very wide application, it is not only applied in food and fermentation process but also in raw water and industrial effluent treatment (Renault et al. 2009).
- Residual NPBC will be safer then chemical coagulants for human being. During treatment of raw water there will be a possibility of residual coagulant present in it. It causes adverse impact on human health. If chemically treated water consumed, then it cause Alzheimer diseases. [ijoe 18]
- NPBC is very cheaper then chemical coagulants. chemical coagulants are required aid for increasing their efficiency and produced large volume of sludge. The cost of coagulant aid and sludge handling increased subsequently, it will increase the overall treatment cost. [26]
- NPBC generate less sludge volume (Ndabigengesere et al. 1995). Sludge generate from this process having high nutrient value (Choy et al. 2014). sludge can be used as condition for soil and increase the fertility of land.
- NPBC lower the coagulant dose requirement and reduced the load of heavy metal effectively (Kakoi et al. 2016).
- NPBC are highly biodegradable and less toxic because of this they are safe for human as well as aquatic life. (Choy et al. 2016)
- NPBC are eco-friendly, socially acceptable and economically viable. they produce minimum effect on global warming (Sharma et al. 2006). They possess the environmentally friendly characteristics (Freitas et al. 2015). Majority of NPBC not changed the pH of the water during treatment (Oladoja 2015). they are not susceptible to corrosion, eliminate pipe erosion(Choy et al. 2016)
- NPBC can reduce the cost effluent treatment cost if plant is locally available (Sanghi et al. 2006a; de Souza et al. 2014; Freitas et al. 2015).
- NPBC are known as "green" because they fulfill the requirement of green technology such as environmental sustainability— meeting the human needs without depletion of environment and natural resources. LCA form a design and process for manufacturing product which can be utilized further. Reduction of waste can be done at source by changing process and materials (Oladoja 2015)

Natural coagulants have some disadvantages also when copared to chemical/ synthetic coagulants. There are following limitation for natural coagulants –

- NPBC increase the amount of organic matter in water resulting microbial activity increased. The cost of disinfection agent has been increased [ijoe27;Anastasakis et al. 2009]. Operation and Maintenance (OM) are the source of odour, taste and colour [Choy et al. 2014; Oladoja 2015].
- NPBC are non-toxic but chemical coagulant used more effectively. Properties of chemical coagulant such as numbers and type of charged units, weight
- NPBC are bio degradable organic substance due to this shortage of storing life than synthetic polymer (Zahrim et al. 2011).

VI. SWOC ANALYSIS OF NPBC

Over the past few year various studies have been carried out in the field of natural plant-based coagulant and it is found that every natural plant-based coagulant has their strength, weakness, opportunity and challenges. SWOC analysis has been carried outfor some common coagulants as shown in figure below.**NPBC:** MOC, Cicer arietinum, Dolichos lablab, roselle seeds, banana pith, orange peel, jatropha curcas, plantago ovata, maerua decumbent etc.**DESCRIPTION**:These all coagulants possess similar characteristics. Efficiency of these coagulants depend on different parameters such as: pH, mixing time, dose, mixing speed etc.

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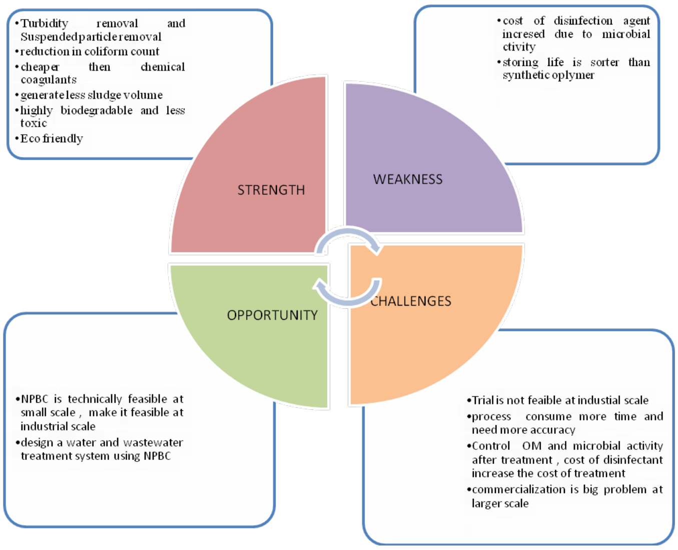

Figure 4: SWOC Analysis of NPBC

VII. CHALLENGES AND SCOPE OF THE RESEARCH

Sustainable treatment of water and wastewater are becoming very essential over the years. Management of waste has been done via clean production mechanism (Nouriet al. 2012; Wu et al. 2010). Every study discussed in this paper ephsizes and proves that NPBCs may be the potential alternative coagulant for treatment of water and wastewater (Choyet al. 2015) but these coagulants are having some limitations too. So there is an urgent need of being further studied and find out suitable improvement. There are following areas which have been identified as a research gap for further scope of study and improvement-

1) Though it is proven in laboratory that NPBC are technically feasible at small scale, this trial is not feasible at industrial scale (Oladoja2015) yet possibilities may be tried using continuous systems of treatment.

2) Feasibility of NPBC depends on the factors such as: dose type, pH, temperature, ionic strength, TDS etc {Santo et al. 2012). Therefore, optimization of these coagulants is required more time and accuracy in industrial application. Initially cost of treatment increase because of requirement of new tools and machinery but later in the long run this cost reduced considerably. Job creation is also an important part for plantation and their cultivation.

3) NPBC are biodegradable organic substance which add O&M cost in water after treatment. Amount of organic matter and dose of disinfectant are directly proportional to each other. Dose of disinfectant directly proportional to the cost of treatment.As microbial activity increase, it would increase the dose of chlorine. Undoubtedly this will increase the cost of treatment but there are possibilities of selecting such NPBC which are self disinfecting in nature and thereby reducing the cost of disinfection. So a further study needs to be done.

4) Commercialization is big problem at large- scale. Direct comparison between NPBC and chemical coagulant on following parameter such as: cost., type of coagulant, processes stage etc. is a major challenge (Yin 2010) but it may be frequently used at domestic level in rural and poor societies and the authors are sure that the domestic models wiil be very popular in short future. So, the development of domestic models and systems for water treatment still needs further study.

5) Public awareness towards sustainability and benefits will lead the success full commercialization of NPBC. Several benefits such as: tax rebate, subsidy in scheme, incentives, no side effect etc. will surely encourage the public participation.

CONCLUSION

There is an urgent need to carry out research work to obtain effective information on NPBC. It is important to have knowledge and research in impurities removal of water and wastewater for satisfying environmental needs. Many technologies have been developed for treatment of water and wastewater by considering environmental law, policy and regulation of CSR. After reviewing the available current literature the authors have reached a conclusion that coagulation/ flocculation process has been used effectively to remove turbidity. NPBC are very effective for sweeping physio-chemical parameter of water like turbidity, TSS, TDS, coliform bacteria and wastewater parameter such as: BOD, COD, heavy metals (chromium, lead etc), colour etc.

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