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New Approaches in Drinking Water and Wastewater Treatment Coagulation System: A Mini-Review

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Abstract

Turbidity and natural organic matters (NOMs) cause change in odor, color, and taste of drinking water as well as increasing the concern of bacterial growth in water and wastewater. This article aims to review the coagulation process and to introduce the potential approaches that can help the water and wastewater authorities to come up with the best coagulant selection. The coagulation is a physicochemical process that is used in the conventional treatment process to reduce turbidity, suspended particles, and NOMs. Aluminum sulfate (alum) and ferric chloride are the most common coagulants that are used as chemical coagulants. However, there are some health concerns associated with the residual sludge and extra dose of chemical coagulants in treated water and wastewater such as increasing risk of Alzheimer and cancer. Natural Coagulants could be an alternative to reduce the dose of chemical coagulants and residual sludge and consequently reducing the health risks. Natural coagulants are effective in reducing particles, alongside the chemical coagulants or as a stand-alone process. The multidimensional nature of choosing the best process in water and wastewater treatment makes it difficult to select the best coagulant with the minimum health risk. Therefore, we need a systematic framework for modeling the coagulation process and selecting cost-efficient coagulant(s) to reduce health risk. Mathematical modeling and health risk assessment are two of the approaches that can be used to select the optimum range and track the residual and found to be helpful for the health risk reduction.

Keywords: Wastewater Treatment; Drinking Water; Natural Organic Matters

Introduction

Coagulation is among the most popular physicochemical processes for both drinking water and wastewater treatment. During the process, inorganic, organic or composite substance is employed to reduce turbidity, suspended particles, natural organic matters (NOMs), and color [1-4]. Turbidity can cause odor, color, and taste in drinking water, and it has become a health concern due to its alliance with suspended organic matter, bacteria, and other microorganisms [5]. Also, NOMs formed in aquatic environment by complex biological cycles are a removal target in water treatment plants because of their various undesirable effects on water quality by causing color, odor, and taste, forming toxic disinfection by-products and raising coagulant dosage as well as residual sludge [6]. The use of coagulants is one of the essential factors in the process of water and wastewater treatments. However, there is some health concerns associated with chemical coagulants that motivates the writing of this review article. Although there has been various research warning the effect the adverse health concerns of chemical coagulants residual, there is not a document available that gathers the mitigation techniques and approaches for the best coagulants selection to reduce the health risks [4,7]. Here, we reviewed various types of coagulants, coagulation process, residual sludge and associated risks, and finally approaches to reduce such risks.

Types of Coagulants

Metallic salts such as ferrous and aluminum-based salts are the most common coagulants which have been used in both water and wastewater treatment systems. The common aluminum-based reagents include aluminum sulfate (Alum) $Al_2 (SO_4)_3{\cdot}18H_2O$, sodium aluminate $Na_2Al_2O_4$, and polyaluminium chloride (PAC) $Al_{13}(OH)_{20}(SO)_4Cl_{15}$; and also, the common iron-based reagents have been known as ferrous sulfate $FeSO_4{\cdot}7H_2O$, ferric sulfate $Fe_2(SO_4)_3$, and ferric chloride $FeCl_3.6H_2O$ have been applied widely for coagulation in water and wastewater treatments [3,8]. Lime ($Ca (OH)_2$) has been also utilized to increase the alkalinity as well as the concentration of calcium in the water/wastewater treatment plants to improve the coagulation process [9,10]. There are also green natural polymeric genera of these chemicals that are renowned as non-conventional coagulants such as polyaluminium chlorohydrate (ACH) $Al_2(OH)_5Cl$, polyaluminium chloride (PACl) $Al_2(OH)_3Cl_3$, polyferric sulfate $Fe_2(OH)_{0.6}(SO_4)_{2.7}$ [3,11]. A novel approach to polish the effluent water from wastewater treatment plants (WWTPs) applies algae to take up all phosphorus and nitrogen from solution. Coagulation-flocculation process, then, can take place during warm-sunny days when algal cells assimilate the carbonate (alkalinity) of solution and naturally increase the pH, referring as auto-flocculation [9,10]. Since the warm-sunny days are limited to location and time, this method cannot provide a consistent approach to remove algae and sludge from solution. A method called high pH-induced flocculation, then, can be utilized by adding cheap sodium hydroxide (NaOH) salts to increase the pH [12]. The settled biomass can later be used to recover nutrients and energy and also possibly as a coagulant agent in different conversion techniques [13]. All coagulation methods described in this part has some advantages and drawbacks, and their selection will mostly be governed by the water/wastewater characteristics like the concentration of NOMs, pH, and cations, etc.

Coagulation Process

Coagulation has been used to remove organic and inorganic substances not only for stormwater and wastewater but also drinking water [14]. In the coagulation process, surface chemistry plays a vital role since almost all colloids have a negative surface charge in aqueous systems. Repulsion forces between these particles prevent floc settlement. Therefore, to neutralize the negative charge of particles, metallic salts have been commonly used as coagulant reagents, forming micro flocs [4,5,15]. The colloids are eliminated in the coagulation process by aggregation through the following mechanisms: 1) Compression of the electrical double layer, 2) Adsorption and charge neutralization, 3) Adsorption and interparticle bridging, and 4) Enmeshment in the precipitate (sweep flocculation). In the case of using inorganic coagulants, the trivalent ions of AL^{3+} and Fe^{3+} form positive soluble complexes that are readily adsorbed on the surface of the negative colloids. By reducing the repulsive force, these particles clump together below the van der Waals attraction force and form micro-flocs. In the flocculation section, micro-flocs agglomerate into large flocs by interparticle bridging and precipitation occurs through gravity settling [1,2,4,16].

To remove NOMs from water/wastewater the composition of these contaminants directly impacts the coagulation performance. NOMs can be broadly divided into humic and non-humic, hydrophobic and hydrophilic, and different size and weight categories with acidic, alkaline, and neutral nature [17,18]. It is well established in the literature that coagulation is more capable of removing hydrophobic better than hydrophilic NOMs. Also, higher molecular weight NOMs possess some ionized groups such as carboxylic which make them drastically negative in charge and ease the coagulation-flocculation process. In general, humic fractions which have more aromatic and hydrophobic content with higher charge density can be efficiently neutralized in the coagulation process and form insoluble charge-free flocs. Whereas, non-humic biopolymer-based fractions that contain hydrophilic constituents such as polysaccharides and proteins, can be removed by adsorption on metal hydroxide surface [18,19]. Therefore, the characteristics of particles which are supposed to remove from water/wastewater have a direct effect on coagulant type and efficiency.

Residual Sludge Causes Health Risk

Coagulant agents have been associated with some drawbacks such as sludge production and health concerns [20]. At the end of the coagulation process a large amount of metallic sludge is produced as the coagulation by-product which can be a threat to the environment because of its toxicity to fish, freshwater, algae, protozoa, and marine bacteria. Moreover, undesirable consequences happened in case if the sludge is utilized as a soil fertilizer [21,22]. For humans, the possible risks of exposure to aluminum compounds are associated with cancer and Alzheimer's disease [7]. Given the Al absorption in the human body and its related disorders, the concentration of residual Al in the effluent flow of water/wastewater treatment plant must be kept on a tight rein [4]. Although some advanced techniques have been employed to augment the coagulation efficiency such as membrane bioreactors, nanofiltration/reverse osmosis, and advanced oxidation; improving the performance of conventional treatment methods has remained a matter of interest because of their availability and cost-effectiveness [4,17]. Many studies proposed the same mechanisms on the water and wastewater treatment by natural coagulants. It has been reported that the primary mechanisms govern the coagulation activity are adsorption and charge neutralization. In many practical cases like moringa oleifera, coagulant agents are cationic proteins which adsorb particles that are negatively charged. For bridging mechanism, it is necessary to enhance adsorption sites by -OH and -COOH groups to engross other particles to the polymer chains. Carbohydrates, lipids, and alkaloids usually carry these adsorption sites in natural coagulants [23].

Role of Natural Coagulants to Reduce the Health Risks

Presence of organic matter is one of the critical factors that affect the dose of coagulant to be used in the treatment process [24]. Coagulation has been used by other techniques to improve efficiency. For instance, chemical coagulation can be used with the electrocoagulation process to remove heavy metals such as chromium [25]. Although some advanced techniques have been employed to augment the coagulation efficiency such as membrane bioreactors, nanofiltration/reverse osmosis, and advanced oxidation, improving the performance of conventional treatment methods has remained a matter of interest because of their availability and cost-effectiveness [17]. One method to improve the efficiency and reduce the dosage of chemical coagulants is by using natural coagulant aids that can be used both in drinking water treatment and wastewater treatment process [26]. Natural coagulants such as okra, starch, Moringa Oleifera seeds, etc. have been shown an effective way of reducing particles alongside the chemical coagulants or stand-alone process [27-30].

Decision-making and Modeling for the Best Coagulant Selection

The multidimensional nature of the decision making in drinking water and wastewater treatment process makes it difficult to select the most appropriate coagulant with the minimal health risk. Besides, usually, more than one decision-maker influences the final decision on the process of treatment and cost is usually the most important factor in selecting the coagulants for treatment process. Furthermore, most of the times the critical criteria affecting the process and the considerable health risk are being neglected. Thus, coping with multiple concerns needs a multi-criteria approach to enable us to come up with unique solutions that can both increase the efficiency and decrease the health issues associated with the process. Also, cost is one of the essential factors affecting the managers' decisions. Thus, expert's engagement using multiple criteria decision making and mathematical modeling considering the necessary criteria such as efficiency, health risks, and cost are needed in the process [31].

Modeling plays an important role to track residual contamination in drinking water and surface water, especially if there is a health risk associated with the process. Knowing which model can be helpful with this process to forecast the effects of health risks on consumers would enable the drinking water and wastewater authorities to come up with solutions [32]. Consequently, there is a considerable need for policy-makers to evaluate the health risk of contaminants (i.e., pesticides and emerging contaminants) being settled in the process of treatment in the sludge or getting out to the treated water. The process of risk transfer to the consumers should be investigated using health risk assessment techniques [33,34].

Conclusion

Coagulation process can be applied to remove turbidity, odor, color, and NOMs during water/wastewater treatment. Although there are some critical concerns associated with this process such as sludge production and health issues, utilizing natural coagulants and other modeling processes to select the optimum dosage of coagulant can help with decreasing the risks. These techniques as well as multi-criteria decision analysis are known as novel approaches to improve the coagulation process. Utilizing the organic polymers which adapted from natural matters is non-toxic to humans, biodegradable, and environmentally friendly. These natural coagulants can enhance efficiency while they reduce the associated health risks. Besides, the application of mathematical modeling can help the coagulation process to be controlled strictly by monitoring the residual particles in treated water, wastewater, and their health risk assessments.

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