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ENHANCING THE EFFICIENCY OF TREATMENT PLANTS: INTEGRATION OF MAGNETITE IN HYBRID COAGULATION-FLOCCULATION PROCESSES

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ABSTRACT

There is a growing concern about meeting the worldwide need for clean drinking water due to factors such as the acceleration of population increase, industrialization, and urbanization. In order to prepare untreated water for human consumption, a water treatment facility is necessary. The three main steps in treating water are filtration, sedimentation, and coagulation-flocculation. The first and foremost step in therapy is the coagulation-flocculation process. In order to improve the overall treatment efficiency, this study examines and analyzes the optimization tactics of a coagulation-flocculation process. In order to have a better understanding of the treatment procedure, the coagulation-flocculation process is first explained. After that, we'll talk about how chemical coagulants, which are based on aluminum, are important since they can enhance the process. The coagulation-flocculation method was examined for its ability to remove natural organic matter (NOM), which is a common cause of water discoloration. Also covered was the topic of optimizing coagulant dose in order to illustrate the impact of unregulated dosage. Lastly, we covered real-time dose control systems, including both direct and indirect dosing.

KEYWORDS Coagulation-flocculation, Dosage Control, Water Treatment Process

INTRODUCTION

The value of the world's water resources has skyrocketed in recent years due to the exponential rise in both human population and the rate of social development. Even while water makes up 70% of the Earth's surface, only 2.5% of that water is drinkable, and there is a severe shortage of freshwater resources. The number of people facing water shortage is predicted to rise to over two billion in emerging nations by 2050, from an estimated four billion in the present. The supply of water for plants, animals, and people is negatively impacted by the discharge of untreated effluent from human industrial operations into natural water bodies. There are three main categories into which the traditional methods used to purify water fall: physical, chemical, and biological. To target compounds that are insoluble or suspended in water, physical procedures such as filtration, air flotation, and sand sedimentation may be used. Chemical processes such as oxidation, ion exchange, coagulation and flocculation, and others may convert poisonous or insoluble compounds into ones with minimal toxicity or no toxicity at all.

There are two primary types of biological techniques that are now in use: activated sludge and biofilm. These techniques use environmentally friendly microbes to break down big organic compounds into smaller ones, which may then undergo further treatment to accomplish the goal of water purification. Low treatment efficiency, high energy consumption, and high treatment costs are only a few of the problems that these technologies often face, even if they may remove contaminants from water to some amount. One of the most important and common methods for treating surface water is coagulation and flocculation, which removes organic materials, colloidal particles, and phosphorus. Flocculation mostly occurs by adsorption, bridging, electro-neutralization, bilayer compression, netting, and sweeping.

In order to create flocs, flocculants destabilize the initial colloidal particles in wastewater by acting on dissolved and suspended chemicals. Net sweeping, adsorption bridging, and other processes increase their size until they are in bigger flocs. The last step is sedimentation, which turns the flocs into sludge while also decreasing the water's turbidity, chromaticity, and suspended particles. Organic flocculants include cationic polyacrylamide (PAM) and anionic PAM, while inorganic flocculants include silicates, iron salts, and aluminium salts. Natural flocculants include humic acid and starch. Scientists have developed a variety of flocculants to optimize the treatment process. To overcome the shortcomings of individual flocculants and improve therapeutic efficacy, a number of flocculants have been blended together. However, because of its insufficient therapy impact, it cannot meet the necessary treatment standards. elimination of phosphorus from wastewater from both homes and businesses. A magnetic composite flocculant (MFPFS) containing Fe3O4 nanoparticles and polymeric ferric sulphate (PFS) was used in the research carried out by Liu et al. [51]. The findings showed that the flocculant could remove chromaticity to an extent of 80% and COD to an extent of 60%.

In addition, by utilizing sulphate radical oxidation technology in conjunction with flocculation of MFPFS, the remaining pollutants were efficiently removed through Fe2+-activated sulphate radical oxidation. This not only greatly improved the removal rates of COD and chroma, but also allowed for further increases to 75% and 95%, respectively. The effectiveness of sulfate radical oxidation in addressing organic compounds that are difficult to handle was shown. Not only did this combination method increase the water treatment performance generally, but it also improved the removal of organic debris. In order to improve the magnetic flocculation process for treating secondary effluent from municipal wastewater treatment facilities, Wang et al. [52] used RSM and ANN in conjunction with magnetic flocculation.

LITERATURE REVIEW

Zhao (2010) investigated the integration of magnetite in hybrid coagulation-flocculation systems for industrial wastewater treatment. Their study highlighted the enhanced removal of suspended solids and turbidity, emphasizing magnetite’s role in improving particle aggregation and settling velocity.

Li and Wang (2011) explored the use of magnetite as a coagulant aid in hybrid coagulation processes. Their research demonstrated a significant reduction in chemical oxygen demand (COD) and enhanced floc stability, making it suitable for municipal wastewater treatment.

Choi (2012) studied the role of magnetite in removing organic pollutants from agricultural runoff. They found that the integration of magnetite with traditional coagulants improved flocculation efficiency and achieved superior pollutant removal compared to standalone processes.

Sharma and Aggarwal (2015) evaluated the performance of magnetite in hybrid coagulation-flocculation processes for heavy metal removal. Their findings revealed that magnetite enhanced the adsorption of heavy metals onto flocs, leading to improved water quality and reduced treatment time.

Zhang (2017) examined the scalability of integrating magnetite in treatment plants. Their research focused on pilot-scale experiments, demonstrating that magnetite-based hybrid systems significantly enhanced the efficiency of nutrient removal and overall plant performance.

RESEARCH METHODOLOGY

Research Design

The colloidal particles are destabilized in this chemical process by adding hydrolyzing electrolytes, which include metal salts, synthetic organic polymer, or the metallic chemical coagulant. Having this chemical coagulant in the water causes a number of processes to occur during the coagulation-flocculation process. The primary coagulation process responsible for destabilizing and removing particles is described in this section.

There are four mechanisms involved in this phenomenon:

(1) double layer compression,

(2) adsorption and charge neutralization,

(3) adsorption and interparticle bridging, and

(4) enmeshment in a precipitate, or "sweep floc."

Double-Layer Compression

A repulsive energy barrier stabilises the negatively charged particles floating in surface water. It is possible to destabilize these particles by penetrating the electrical double layer that surrounds them by adding electrolytes or metal coagulants to the stable colloidal water concentration. When this procedure is coupled with macro- and micro-flocculation, the double-layer may be compressed.Some positive ions are drawn to the negative colloid, which forms a strongly bound layer around the surface of the colloid. While an increasing number of counter ions are drawn to the negative particles, a diffuse layer of counter ions is formed as some are repulsed by the stern layer or other counter ions. Both the charged atmosphere in the diffuse layer and the attached counter ions in the stern layer make up the double layer.

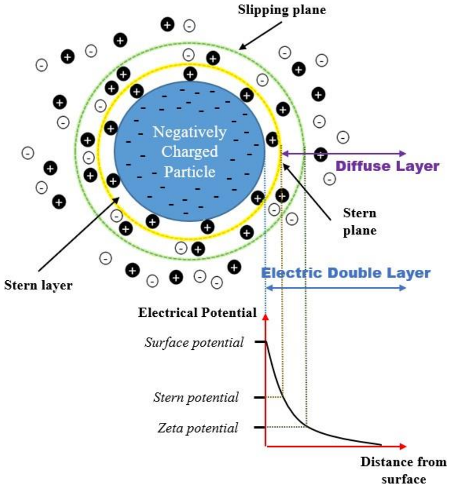

Figure 1. Design of a bilayer electrical system.

Adsorption and charge neutralization

There are a number of ways in which chemical agents may destabilize and coagulate particles in suspension. Particles undergo instability and aggregation when their charges are neutralized by adsorption and charge neutralization, which reduces electrostatic repulsion. Particles will clump together due to van der Waal forces if their surfaces do not have any net charges, which means there will be no electrical double layer.

Adsorption and Interparticle Bridging

Using polyelectrolytes as coagulants to enhance micro-floc aggregation during flocculation might lead to inter-particle bridging instability due to their active surfaces and linear or branched topologies. Coulombic, dipole, hydrogen bonding, and van der Waals forces cause the polymer chain to adsorb onto the surfaces of the particles. A bigger particle is formed, which may sink more readily, when the remaining polymer chain is absorbed onto another particle's surface in the water, thereby producing a "bridge" between the two.

Enmeshment of particles in the precipitate, or "sweep floc"

The colloid in the raw water becomes entangled in the amorphous precipitates that develop when coagulants like alum or ferric chloride are applied at high enough dosages to cause the formation of an insoluble precipitate. Sweep coagulation is a frequent name for this technique, which is used to destabilize turbid suspensions.

Analysis

As a method of control, multivariate statistical analysis (also known as multivariate regression) is useful when dealing with data that contains many measurements of different variables or objects. Research using complicated data is seeing a steady increase in the use of this control strategy. When there are several independent or dependent variables, each with varying degrees of association, it may give analysis. Furthermore, MVR is often accompanied with projection to latent structures, such as partial least squares (PLS), and strong chemometric methods like principal components analysis (PCA). The use of MVR analysis has been suggested in several papers. Predicting the doses of coagulant (alum) in coagulation (turbidity and color removal) and enhanced coagulation (NOM removal) operations is the goal of this set of regression models.

Model

Over the last three decades, engineers have discovered several uses for fuzzy controllers or models. Their operation involves receiving data in real-time and then using a set of logic rules (if-then) to produce an output signal that maintains the parameters as near to the setpoint as feasible. Fuzzification is achieved by applying a membership function to the input variables; this function is a curve that converts the input variables to membership grades between 0 and 1, with 0 being a totally false assertion and 1 a totally truthful one.

RESULT

Aluminum-Based Coagulants

The efficacy of coagulation-flocculation procedures in the production of potable water, with an emphasis on aluminum sulfate (Alum) as the conventional coagulant, is the subject of this study. Because it enhances the removal of particulate, colloidal, and dissolved particles, alum is the most often employed aluminum-based coagulant in this procedure. Other inorganic coagulants based on aluminum that are comparable include sodium aluminate and aluminum chloride ($AlCl_3$).

The addition of alum to a water solution results in the production of sulfuric acid and aluminum hydroxide ($Al(OH)_3$). Sulfuric acid lowers the pH of the raw water by reacting with its alkalinity to create carbon dioxide. Even with higher doses of alum, pollutants like NOM can only be removed to a limited degree. But, alum's usage may result in relatively high aluminum residuals in the treated water, particularly at low pH levels or cold temperatures; these residuals might be harmful to humans or even disrupt the distribution system.

Surface water treatment is a common practice, but the process of eliminating any remaining metal is underappreciated. The World Health Organization (WHO) has established a maximum of 0.2 mg/dm3 for residual aluminum in drinking water, whereas the Environmental Protection Agency (EPA) suggests a range of 0.05-0.2 mg/dm3.

There are a number of potential alternatives to aluminum-based coagulants that might treat water with less metal residue. A promising alternative is PACPE, an inorganic pre-polymerized coagulant that combines a cationic polyelectrolyte (p-DADMAC) with an organic coagulant. Polyaluminum chloride (PACl) and polyaluminum sulfate (PAS) are examples of pre-hydrolyzed aluminum coagulants that have been developed and studied in recent times.

Removal of Natural Organic Matter (Nom) By Coagulation-Flocculation

The complex matrix of hydrophobic and hydrophilic chemicals present in water sources is known as NOM, or Natural Organic Matter. This matrix is the result of several interactions between hydrology, biology, and geology. You may find it in lakes and rivers, among other water sources. The quantity, nature, and features of this substance might vary significantly depending on where the water comes from. Functional group charges, molecular weight (MW), and hydrophobicity/hydrophilicity are the three main criteria for classifying NOM. Many techniques exist for characterizing substances, including resin adsorption, size exclusion chromatography (SEC), fluorescence spectroscopy, nuclear magnetic response (NMR) spectroscopy, and others. The presence of NOM in drinking water sources is detrimental because it changes the taste and smell of potable water and creates disinfection by-products (DBP), which are damaging to public health. We must not disregard the critical need to remove NOM from drinking water treatment. Conventional methods for eliminating NOM include culmination-flocculation, sedimentation/flotation, and sand filtering, in that order of prevalence and economic viability.

Optimization of Coagulant Dosage

The production of water of acceptable quality depends on the efficient and correct regulation of coagulation, the first stage in conventional treatment. The coagulation dose is one of the most important considerations for figuring out the optimal parameters for the coagulation-flocculation process. In order to obtain the required treated water quality with the least number of coagulants, the appropriate dose is determined. Figure 2 shows that when the dose of the coagulant increases from zone 1 to 4, four distinct zones are formed.

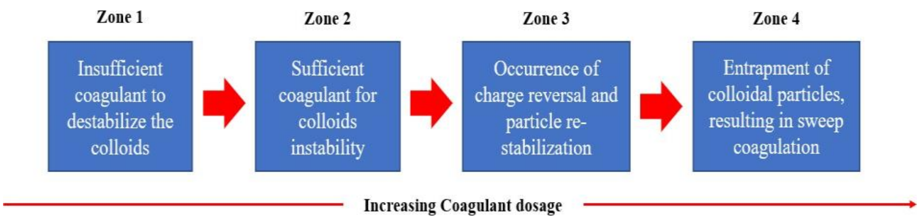

Figure 2. Reactions with different amounts of coagulant.

The reactions that occur during underdosing, which prevents the water quality goal from being reached, are shown in Zone 1. In contrast, the responses associated with an overdose are seen in Zones 3 and 4. The removal effectiveness of turbidity is reduced when the dose of the coagulant is increased because of these responses.

CONCLUSION

Producing potable water of high quality relies on a number of elements, one of which is the coagulation process in water treatment plants. Studying the operating principle is vital for optimizing the coagulation process when applied in a water treatment process. Various physical and chemical modifications that improve process efficiency have been suggested or examined in the literature examined in this research. The current elements influencing the coagulation process at the water treatment facility should be considered while evaluating these modifications. Controlling the amount of coagulants is one of the most important aspects that will influence the coagulation process. The results of the coagulation process and, maybe, the therapy that follows are both impacted by uncontrolled dose. There are two possible approaches of controlling the dose in real-time based on the raw water condition: indirect dosing control, which employs software sensors, and direct dosing control, which uses physical equipment. In order to increase the total treatment efficiency, the water treatment plant might use the optimization approach to the coagulation process, taking into account the available resources and any difficulties.

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