A Review on Applications of Coagulation-Flocculation and Ballast Flocculation for Water and Wastewater

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Abstract - A coagulation and ballast flocculation process is chemical treatment for water and industrial wastewater. This technology is used as primary treatments for removal of particulate matter and organic matter effectively. The process is very efficient in removal of total solids (TS),Total suspended solids (TSS), total dissolved solids (TDS) and chemical oxygen demand (COD) , Color .This technology is applicable in water treatment and also tannery, coffee, detergent, tar and dairy wastewater efficiently. The present paper focusses on coagulation and ballast flocculation technology for water and industrial wastewater treatment. This review shows applicability of coagulation-flocculation for wastewater for textile, tannery, removal of surfactants for Detergent Wastewaters, as primary treatment before membrane application for dairy wastewater, heavy metal removal for leachate wastewater and also for Sand ballast flocculation for water treatment which indicates efficiency and applicability of this technology.

Keywords: Coagulation-flocculation , ballast flocculation , Affecting parameters, TS ,TDS ,Color and COD removal.

I. INTRODUCTION

Industrial wastewaters are clarified to remove turbidity and color from different industries like the textile, paper, tannery and other polluting industries. In a water treatment chemical treatment that will remove color and turbidity present in raw water in the form of flocs. Coagulants neutralize the repulsive electrical charges (typically negative) surrounding particles allowing them to "stick together" creating flocks. Flocculants facilitate the agglomeration of the coagulated particles to form larger floccules and thereby hasten gravitational settling.
In wastewater treatment, coagulation and flocculation are employed to separate suspended solids from water. Although the terms coagulation and flocculation are often used interchangeably, or the single term "flocculation" is used to describe both; they are, in fact, two distinct processes. Finely dispersed solids (colloids) suspended in wastewaters are stabilized by negative electric charges on their surfaces, causing them to repel each other. Since this prevents these charged particles from colliding to form larger masses, called flocks, they do not settle. For removal of colloidal particles from suspension, chemical coagulation and flocculation are required. These processes, usually done in sequence, are a combination of physical and chemical procedures. Chemicals are mixed with wastewater to promote the aggregation of the suspended solids in to particles large enough to settle or be removed. Coagulation is the destabilization of colloids by neutralizing the forces that keep them apart. Cationic coagulants provide positive electric charges to reduce the negative charge (zeta potential) of the colloids. As a result, the particles collide to form larger particles (flocks).Rapid mixing is required to disperse the coagulant throughout the liquid.

As the chemical method helps to remove turbidity, color and chemical oxygen demand reduction. The present study is on the performance of coagulation and ballast flocculation. The use ballast flocculation serves for floc formation and ballast to increase floc density and settling velocity and also used in treatment plant to reduce the clarifier surface area. As ballast flocculation technology has been applied for wet weather. It has also been applied for wastewater for turbidity and chemical oxygen demand removal .An approach of this technology is made for Vegetable Tannery Wastewater.

1.1 Scope of coagulation and ballast flocculation

As the chemical method helps to remove turbidity, color and chemical oxygen demand reduction. The present study is on the performance of coagulation and ballast flocculation. The use ballast flocculation serves for floc formation and ballast to increase floc density and settling velocity and also used in treatment plant to reduce the clarifier surface area. As ballast flocculation technology has been applied for wet weather. Sinha et al., (2002) for removal of particulates for water treatment ; It has also been applied for wastewater for turbidity and chemical oxygen demand removal (Wastewater Technology Fact Sheet).An approach of flocculation is used in tannery wastewater treatment for removal SS,TDS,COD,BOD and toxicity reduction Nazmul et al., (2011), Lofrano et al., (2006),also for different industrial wastewater treatment Sinha et al., (2002), M. A. Aboulhassan et al., (2008),Mohd Ariffin Abu Hassan O.S. Amudaet al.,2006), El Karamany studied the coagulation for wastewater treatment. Baisali Sarkar et al.,(2005) studied reuse of wastewater with RO for that they use coagulation and flocculation best treatment before the RO since the protein us materials of the dairy wastewater were found to be severe foulant for the existing membrane treatment. Discharge of detergent wastewater can cause serious environmental problems because detergent product and its ingredients can be relatively toxic to aquatic life, so Aygun A.et (2010) they carries Improvement of Coagulation-Flocculation Processfor Treatment of Detergent Wastewaters Using Coagulant Aids.cagilation flocculation also very effective in color removal in textile industry as wastewater treatments carried by Fkkksa et al., PeiWenWong et al., (2007). Also varies study is carried for coagulation flocculation as a physical and chemical treatment for various industrial wastewater treatment [Amuda O.S. et al (2007),Roussy] for beverage and ink wastewater treatment.
Ballast flocculation for water treatment Columbus et al (2006), Charles D.and it's friends,shahnawaz shinha and his freinds
for water and wastewater treatment as TSS.TDS.COD removal.

1.2 Coagulation and ballast flocculation process description

There are two general types of colloidal solids particle dispersion in liquid. When water is solvent, these are called the hydrophobic and hydrophilic collides. These two types are based on attraction of particles surface for water. Hydrophilic particles have relatively little attraction for water and hydrophilic particles have a great attraction for water. An important factor in the stability of collide particle is the presence of surface charge. It develops in a number of different ways, depending on chemical composition of wastewater and collides.
When the collide or particle surface became charge, some ions of opposite charge become attached to the surface they are held there through electrostatics and van der waals forces strongly enough to overcome thermal agitation. Surrounding this fixed layer of ions is a diffuse layer of ions, which prevent the formation of compact double layer consist of stern. To bring about the particle agitation, step must be taken to reduce particle charge. This can be accomplished by addition of potential –determining ions, addition of polymers and addition of chemicals.

Ballasted flocculation, also known as high rate clarification, is a physical-chemical treatment process that uses continuously recycled media and a variety of additives to improve the settling properties of suspended solids through improved floc bridging. The objective of this process is to form micro floc particles with a specific gravity of greater than two. Faster floc formation and decreased particle settling time allow clarification to occur up to ten times faster than with conventional clarification, allowing treatment of flows at a significantly higher rate than allowed by traditional unit processes. Ballasted flocculation units function through the addition of a coagulant, such as ferric sulfate, an anionic polymer, and a ballast material such as micro sand, a micro carrier, or chemically enhanced sludge. When coupled with chemical addition, this ballast material has been shown to be effective in reducing coagulation-sedimentation time (Liao, et al., 1999).

1.3 Parameters affecting the coagulation-flocculation process

1.31. Effects of polymer molecular weight and charge density

The effects of polymer molecular weight on flocculation are best described in terms of bridging and electrostatic patch character mechanisms. For systems in which bridging predominates irrespective of charge, an increase in molecular weight improves flocculation. Although anionic charge on polymer can impede adsorption onto a negative surface, it serves to promote extension of polymer chain through mutual charge repulsion, enhancing

its approachability. It has been observed that beyond an optimum molecular weight, flocculation efficiency decreases which is attributed to steric repulsion between polymer molecules. On the other hand, molecular weight effects are less well defined in systems where the electrostatic patch mechanism is rate controlling.
Optimum flocculent concentration has been found to be independent of molecular weight but dependent on ionic strength. Equally important is the configuration of the solvated polymer, particularly in bridging flocculation.

1.32 Effects of dosing and mixing conditions.

The degree of flocculation achieved can be markedly affected by dosing and mixing conditions. It has been found that for high solids concentrations and relatively low polymer doses, flocculation occurs rapidly, but the flocs are not stable and can be broken at moderate stirring rates. By reducing the rate of stirring shortly after polymer dosing, floc size (and settling rate) can be held at plateau levels, without subsequent decline, which, however, is difficult to achieve in practice because of the precise control required. Optimum flocculation occurs when half the area of solid is covered with polyelectrolyte. At higher concentration the degree of flocculation decreases and the particles may be completely covered by the absorbed polymer layer. Thus overdosing can be a serious mistake in that it may create a well established suspension that is extremely difficult to separate. But, in principle, a substantial degree of flocculation can be obtained with much lower polymer dosage than is usually required. Increased agitation leads to the production of smaller flocs, indicating that enhanced adsorption does not compensate for increased floc breakage. In fact the general rule seems that, provided adsorption does occur, the actual amount adsorbed varies inversely with the extent of flocculation.

1.33 Ionic Strength

The configuration of polyelectrolyte in solution is significantly affected by ionic strength and this effects flocculation. This is indicated by the increased viscosity of a polyelectrolyte solution as ionic strength decreases. Similar charges on the polymer chain tend to expand the chain as a result of mutual charge repulsion. As ionic strength increases, these charged sites are shielded and allow the polymer to fold and assume a smaller hydrodynamic volume, as indicated by a decrease in solution viscosity. These effects manifest themselves in the flocculation mechanism. In a high solids system to be flocculated by a high molecular weight charged polymer, decreasing ionic strength expands the polymer in solution and enhances bridging by increasing the effective particle radius. On the other hand, when charge-neutralization mechanism is operative, ionic strength effects will be realized through double layer compression in systems where flocculent and surface is oppositely charged.

1.34 pH Effects

With inorganic flocculants, the effective species can be a solvated metal ion, which affect flocculation through double-layer compression and Schulze-Hardy effects. With increase in pH, these species become charged and the mechanism of action changes. When the colloids are hydrophilic, e.g. humic acids, pH affects protonation. In presence of ionizable acidic or basic groups, colloid surface charge is affected by pH changes. In organic polymer flocculation as well, pH can affect polymer activity and the mechanism.

1.35 Effect of Particle Size

There exists a strong relation between aggregation of a given size and the molecular weight of the flocculent. They have explained the correlation between particle size and flocculent molecular weight in terms of floc formation forces provided by polymer bridging and floc breaking forces encountered in an agitated system. Decreasing settling rate of coal suspensions with decreased particle size. Increase in surface area that increased the charge neutralization capacity of the coal surface by the flocculent.

1.4 Coagulant and Coagulant aids

There are different substances have been used as coagulants. The clarification obtained depends upon type and quantity of chemicals used and the care with which the process is controlled. The most chemicals used as coagulants are

1. Alum

When alum is added in wastewater containing calcium and magnesium bicarbonate alkalinity, a precipitate of aluminum hydroxide is formed. The insoluble aluminum hydroxide is gelatinous floc that settles slowly through the wastewater and thus sweeping out suspended material and producing other changes.

2. Lime

The Molecular weight and density of lime is 74.1and 2200 kg/m^3 respectively. When lime is added it precipitate as calcium carbonate. A sufficient quantity of lime must be added to combine with all the free carbonic acid and with the carbonic acid of the bicarbonate to produce calcium carbonate. Much more lime is used when it used alone than used with sulfate of iron.

$A1_2(SO_4)_3 + 3\ Ca(HCO_3)_2$ ----------- $2\ Al(OH)_3 + 3CaSO_4 + 6\ CO_2$

Some advantages

a)It reduces taste and odour in addition to turbidity,
b) It is cheap
c) It is simple in working and doses skilled supervision is not required.
d) It produces crystal clear water.
e) The floc formed with alum is better than other coagulants.
f) Floc form are not broken easily.

Though it have same advantages it also have soma disadvantages as

a) It is very difficult to dewater the sludge formed
b) The effective rage of pH is very small which require the addition of lime or caustic soda for adjustment of pH and this will increases the cost.

3. Ferric chloride

Ferric chloride is the iron salt used most commonly in precipitation application. It's molecular weight is 162.1 and density is 2800 kg/m ^{3} The addition of ferric chloride to a wastewater produces the hydrolysis of the ferric chloride with the consequent formation of insoluble ferric hydroxide,
The insoluble ferric hydroxide forms a floc responsible for colloid removal. If the wastewater is not buffered the PH is decrease which will prevent the reaction from proceeding any further. In the presence of calcium or magnesium bicarbonate ferric chloride forms ferric hydroxide, which precipitates as before forming a sweeping floc responsible for colloid removal?

$2FeCl_3 + 3\ Ca(HCO_3)_2$ ----------- $2\ Fe(OH)_3 + 3CaCl_2 + 6CO_2$

4. Coagulant aids

Long- chained, high-molecular-weight, organic chemicals mostly used as coagulant aids together with the regular inorganic coagulants. Anionic (negatively charged) polymers are mostly used with metal coagulants. Low-to-medium weight positively charged (cationic) polymers are used alone or with combination of the aluminum and iron type coagulants to attract the suspended solids and neutralize their surface charge.

Polymers are effective over a wider pH range as compare to inorganic coagulants. They can be applied at lower doses, and they do not consume alkalinity. They produce smaller volumes of more concentrated floc which rapidly settling. The floc formed from use of a properly selected polymer results in cleaner effluent. Polymers are generally more costly than inorganic coagulants. Selection of the proper polymer for the application is very important which affect the efficiency of treatment. The polymers are generally formed in three types namely as cationic, anionic, and nonionic. All type polyelectrolyte are typically used to
coagulate colloids that are negatively charged, by charge neutralization and bridging of colloidal particles.

1.5 Advantages of coagulation- flocculation and ballast flocculation

1. Coagulation–flocculation is one of the

most important physicochemical treatment steps in industrial wastewater treatment to reduce the suspended and colloidal materials.
2. It reduces the organic matters which contributes to the BOD and COD content of the wastewater
3. Addition of coagulants involves destabilization of the particulate matters Present in the wastewater, followed by Particle collision and floc formation which results in the sedimentation.
4. Cagulation and flocculation can be used effectively for colour removal.
5. Large sand particle surface area serve as a "seed" for floc formation
6. Microsand and polymer produce a large, stable floc
7. Microsand (specific gravity 2.65) serves as a ballast for the formation of high-density floc
8. Enhance coagulation allows for variable process chemistry
9. The reduced surface area of the clarifiers minimizes short-circuiting and flow patterns caused by wind and freezing
10. Systems using ballasted flocculation can treat a wider range of flows without reducing removal efficiencies.
11. Ballasted flocculation systems reduce the amount of coagulant used, or improve settling vs. traditional systems for comparable chemical usage.
10. Enhanced primary clarification.

II. APPLICATIONS OF COAGULATION-FLOCCULATION AND BALLAST FLOCCULATION OF WATER AND WASTEWATER

This technology(coagulation-flocculation) is used as physical and chemical treatment for water and wastewater treatment as it is effective for removal of TSS, TDS, COD, BOD and color for dairy, coffee, beverage, detergent, tar, vegetable tannery wastewater and lichgate. This treatment is not costly as a biological treatment and also required less time. Ballast flocculation is used in water municipal treatment for removal of suspended and dissolved particulate with micros and to enhance floc formation with polymer. As coagulation-flocculation as it is effective for TS, TSS, TDS, COD and color removal or reduction this technology is used mostly usded. [G. Lofrano et al .,(2006)Toxicity Reduction in Leather Tanning Wastewater by Improved Coagulation Flocculation process., M. A. Aboulhassanet et al.(2008)studied Pollution reduction and biodegradability index improvement of Tannery effluents. Zayas P´erez Teresa et al.,(2006) carried out Chemical oxygen demand reduction in coffe wastewater through chemical flocculation and advanced oxidation processes]

2.1 For textile wastewater

Textile wastewater is generally characterized by high chemical oxygen demand (COD), biochemical oxygen demand (BOD), suspended solids (SS), conductivity and highly intense colors, which is to be treating before discharge in natural resources. Pei Wen Wong et al.,(2007) studied Efficiency of the Coagulation-Flocculation Method for the Treatment of Dye Mixtures Containing Disperse and Reactive Dye . Mohd Ariffin Abu Hassan et al., carrid out coagulation and flocculation treatment of wastewater in textile industry using chitosan for turbidity and COD removal. At varied pH, chitosan dose and mixing time the efficiency for COD and turbidity removal was checked. Sample of textile wastewater was collected from a textile company. For COD analysis the reagent vials used were in high range (0 to 15 000 mg/l) and for turbidity HACH Ratio/XR Turbiditimeter were used. 3g of chitosan in the form of white fine powder was mixed in 96g of distilled water and 1g of acetic acid to dilute the chitosan powder at the time of conducting the experiment. Jar test was performed for the study and the results for the effect of chitosan dose for removal efficiency was checked. The optimal coagulant dose in the range of 12 to 30 mg/L there was 94.90% and 72.50 % reduction in turbidity and COD. At a dose of 30 mg/l to 66 mg/l there was decrease in turbidity and COD reduction , This was due to the phenomenon of excess polymer adsorbed on the colloidal surfaces and producing restabilized colloids. As pH affects the stabilization of the suspension and also the solubility of chitosan in aqueous solution was influenced by pH value. The effect of pH was considered and results were at the range of pH 4 to 6 ,there was maximum reduction in both COD turbidity as over 72.5 %, 94.9 % respectively. The effect of mixing time on removal efficiency was analyzed at optimum dosage of 30 mg/L and optimum pH, pH 4, with 250 rpm of mixing rate for 10 minutes and 30 rpm for 20 minutes and 30 minutes of settling time for a range of mixing time which varied from 10 minutes to 30 minutes The results showed that over 70.9 % COD reduction and 93.3 % turbidity reduction can be achieved when optimum mixing time is 20 minutes. Also at longer mixing time of 30 minutes the percentage of reduction was lower.

2.2 For tannery wastewater

Nazmul et al; (2011) studied Efficiency of different coagulations combination for treatment of tannery effluent to check

Parameters as TS, SS, COD, Color, pH in which they use Chemicals alum, lime & combination of lime, alum and ferric chloride. The batch experiment is carried out with the jar test .The experiments involving rapid mixing, slow mixing and sedimentation. The apparatus allowed six beakers to be agitated simultaneously. Tannery wastewater with different combination of coagulants as 1.alum, 2. Lime, 3. Ferric chloride 4.(lime and alum), 5. (alum & ferric chloride) ,6.(lime and ferric chloride) and with 7.(lime, alum, ferric chloride) The different temperature chosen for jar experiments were in the range of 5 to 35°C.The results with different coagulant combinations are for alum as at pH 6.38 SS removal is 100 %, chromium reduction is 99.25 % and color removal is 85.43. For lime SS removal is 91.90%, chromium removal is 99.25%, and color removal is 75.94%. For ferric chloride SS removal is 79.87%, chromium removal is 99.12% and color removal is 82.55%. With the lime+ alum SS removal as 77.11%, chromium 99.72%, and color 82.04% removal. For alum+ ferric chloride SS 100%, chromium 99%.color 96, 87.46% removal. For lime+feeric chloride SS 76.58%, chromium 99.88%, color 52.04%. And for lime+ alum +ferric chloride combination SS 65.66%, chromium 99.91%, color 52.89% was achieved. From the experiment it was observed that alum and alum with ferric chloride was very effective for color removal with coagulation-flocculation process.

2.3 Methods for removal of surfactants for Detergent Wastewaters

Detergent wastewater discharge can cause serious environmental problems because detergent product and its ingredients can be relatively toxic to aquatic life. Anionic and nonionic surfactants are major components of synthetic detergents. Aygun A et.al.. Performed Improvement of Coagulation-Flocculation Process for Treatment of Detergent Wastewaters with Coagulant Aids and Six-place conventional jar-test apparatus with ferric chloride, polyelectrolyte, clay minerals, which is equipped with 6 beakers of 500 mL volume. The experimental process consisted of the initial rapid mixing for 5 min at 150 rpm, the

following slow mixing stage for 30 min at 30 rpm and the final settling step for 1 h. After 1 hour settling period, samples were withdrawn from supernatant for analyses.

Process performance was monitored by using COD values. Result for the same showed that the matter expressed as chemical oxygen demand (COD) was as high as 24.3 g/L while the biochemical oxygen demand was low. The coagulant dosage of ferric chloride ranged between 0.5g/L and 3 g/L, whereas the concentrations of polyelectrolyte and clay minerals varied between 5-75 mg/L and 25-750 mg/L, respectively. The optimal condition was obtained at the dosage 2 g/L ferric chloride at pH 11 with the COD removal efficiency of 71%. Addition of coagulant aids provided higher removal efficiencies. Using clay minerals at the dose of 500 mg/L with ferric chloride provided 84% of COD removal and the removal efficiency of COD increased with using polyelectrolyte resulting in an efficiency of 87%. The maximum removal efficiency was obtained with the addition of polyelectrolyte. The ferric chloride combination with coagulant aids provided higher removal efficiencies compared to coagulation with ferric chloride alone.

2.4 Coagulation as a primary treatment before membrane application

Dairy wastewater is the high BOD and

COD contents, high levels of dissolved or suspended solids including fats, oils and grease, nutrients such as ammonia or minerals and phosphates, color and therefore require proper treatment before disposal. Baisali

Sarkar et al.,(2006) studied Wastewater treatment in dairy industries- possibility of reuse in which they use membrane for treating the dairy wastewater and to make it fit for reuse. But with membrane they have to control the fouling and to improve the productivity and life of membranes, for that they gave the chemical treatment as coagulation-flocculation with electrolyte and for the pretreatment studies before membrane processing different types of coagulants like inorganic (alum and ferric chloride), polymeric (polyaluminium chloride) and natural organic (sodium carboxymethyl cellulose commonly known as Na-CMC, alginic acid, and chitosan)
Were tested. And they observed that as alum and ferric chloride dosages of the coagulants were increasing, the formation of floc followed by settling was increases at pH 6.5 and 8.0 with 500 mg/l for alum and ferric chloride they observed variation of TDS.
when treated with 10 mg/L chitosan at pH 4. chitosan was found to have significant effect as coagulant for the dairy wastewater
treatment It had lowered the TDS and COD values considerably at very low dosage as compared to the common coagulants. And also conductivity not increased which help to design RO in present dairy treatment as a pretreatment before RO to avoided fouling and increase life of membrane too.

2.5 Sand ballast flocculation verses conventional flocculation

Shahnawaz Sinha et al.,(2002) Carried out study on Standard Ballasted Flocculation Verses Conventional Coagulation. Coagulants such as ferric chloride, alum, PACI, and Polymer were used. Both bench scale and pilot scale experiments were conducted for particulate matter and organic matter removal. Jar test is used for both conventional coagulation and ballast flocculation. For conventional coagulation mixing condition used as one minute of rapid mixing at 100 rpm, ten minute at 60 rpm, ten minute at 40 rpm 1 minute with slow speed at 20 rpm and then allowed the sample to settle for 30 minute. And for ballast flocculation the mixing condition is as 2 minute for rapid mixing at 300 rpm with addition of coagulant and sand. Again additional 15 minute second at time of polymer addition then 5 minute at 200 rpm followed by 2 minute of settling. Results showed that Sand ballast is more effective in particulate and color removal than the coagulation alone, with PACI and ferric chloride. For organic matter reduction the PACI is more effective than the ferric chloride but ferric chloride is more effective in particulate and color removal. Ballast flocculation have small foot print as compare to conventional coagulation, also total time require for mixing with conventional and ballast flocculation as one hrs and 5 minutes thus the Ballast flocculation require less time to settle for particulate matter than conventional coagulation.

2.6 Heavy metal removal for leachate wastewater

Due to increasing industrialization and population there is increase in waste. Disposal of this waste is unplanned, and thus industrial solid waste is disposed on landfill. The unplanned disposal of solid waste on landfill gets result in leachate formation. Leachate contained large amount organic, heavy metal and other toxic compound. Afshin Maleki et al ; (2010) carry out Composting Plant Leachate Treatment by Coagulation-Flocculation Process. Result are this study is that at pH 10 of both alum and ferric chloride with dose of coagulant alum and ferric chloride 1.4 and 2 g/L removal of COD and heavy metals are 18%,28% and 90%,86% respectively. And they conclude that as the leachate is acidic in characteristics coagulation –flocculation gives discharging standers as compare to the other biological treatment.

III. CONCLUSION

The vegetable tannery wastewater contained high percentage of suspended and dissolved solids, high organic load and hence required the treatment before disposal in to the natural recourse. The chemical coagulation-flocculation is one of the simplest methods for the treatment of tannery wastewater but one of the disadvantages is production of sludge. The ballast flocculation as it is applied for water and wastewater treatment for turbidity and COD, BOD removal. It requires less area for clarifier, less duration so it is an efficient and cost-effective too.

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