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Performance of aluminium formate in removal of colloidal latex particles from industrial wastewater

Marja Mikola*, Juha Tanskanen

Chemical Process Engineering Research Unit, Faculty of Technology, P.O. Box 4300, FI-90014 University of Oulu, Finland

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ABSTRACT

The coagulation efficiency of novel coagulant aluminium formate was studied in the treatment of highly contaminated effluent from a styrene butadiene latex manufacturing plant. The coagulation behaviour of the aluminium formate was compared to the behaviour of the commonly used polyaluminium chloride and aluminium sulphate. The effects of the coagulant type and dose and coagulation pH on the treatment efficiency were studied as well as the role of polyacrylamide coagulant aid. Floc separation was done using three different methods sedimentation, filtration and centrifugation. Their functionality was evaluated as part of the coagulation performance studies. Good purification results were obtained with all of the tested coagulants, the lowest residual turbidities achieved being 0.7 NTU with aluminium formate, 1.4 NTU with polyaluminium chloride and 0.7 NTU with aluminium sulphate. It was also observed that aluminium formate is as effective as commercial coagulants and is thus a potential novel coagulant chemical due to its less harmful and biodegradable counter anion. When using only aluminium coagulants, flocs were found to be too fine to be removed by sedimentation but they could be effectively removed by filtration or centrifugation. The use of polyacrylamide was found to be useful in the sense that it enables the separation of flocs by simple sedimentation because the floc size is significantly increased. In this study new knowledge about the coagulation behaviour of highly contaminated effluent from latex manufacturing was gained and aluminium formate was proved to be promising coagulant also in industrial effluent treatment.

1. Introduction

Coagulation is the most broadly applied method in water [1] and wastewater [2] treatment. In coagulation, small impurity particles are combined into bigger and more easily removable aggregates with the help of chemicals. Coagulation is commonly used in the purification of surface water to be used as potable or process water. In addition to this, coagulation is very often a part of the treatment process for industrial effluents. Coagulation has been studied broadly in the treatment of effluents for example from the pulp and paper industry [3], textile industry [4], tanneries [5], distilleries [6], petrochemical industry [7] and palm oil mill industry [8]. In industrial effluent treatment, coagulation is often used to remove such impurities that either cannot be removed with biological treatment or are harmful to its operation.

Coagulants are typically aluminium- or iron-based compounds. The popularity of aluminium and iron as coagulation chemicals is due to their ability to form both highly charged cations and hydroxide precipitates in water. Highly charged cations can effectively neutralise the surface charge of the impurity particles, which enables them to unite and thus form more easily separable flocs. The forming hydroxide precipitate effectively binds impurities to itself and thus forms larger removable aggregates [9]. Beside metal coagulants, organic polyelectrolytes can also be used as coagulants. The most commonly organic polyelectrolytes are used as a coagulant aid to increase the size and density of the flocs formed with metal coagulants [10].

Aluminium and iron salts such as aluminium sulphate and ferric chloride are the most typically used metal coagulants. Nowadays prehydrolysed compounds, most commonly polyaluminium chloride, are also widely used. Aluminium formate is a novel coagulant chemical in which the formate anion is used to replace chloride or sulphate as a counter anion to aluminium. Formate has some advantages over chloride or sulphate. For example, it is less corrosive than chloride [11], which makes it safer for process equipment. Formate is also a biodegradable anion, which is a beneficial prop-

* Corresponding author.
E-mail addresses: marja.mikola@oulu.fi (M. Mikola), juha.tanskanen@oulu.fi (J. Tanskanen).

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erty if aluminium formate is used in wastewater treatment because anions from the coagulant are removed during the biological treatment often used in both industrial and municipal wastewater treatment. Formate can also act as a carbon source in biological treatment, which may enhance the performance of the biological treatment especially if the treated water does not otherwise contain enough carbon. Earlier, aluminium formate has been studied only in the treatment of surface water [12–14]. No previous studies on the use of aluminium formate in industrial effluent treatment have been published.

Styrene butadiene latex is the most commonly used binder in the pigment coating of paper and board industry because of its good binding power. Styrene butadiene latex is produced by emulsion polymerization. The impurities in certain effluents coming from emulsion polymerization consists of colloidal latex particles and some dissolved compounds which need to be removed before the discharge of the effluents. Latex particles should be removed from these effluents before their biological treatment because the high latex amounts may hinder the operation of the biological process. Only a few studies on the treatment of effluents from the polymer industry have been made and none of them is about the treatment of effluents similar to those treated in this study [15,16].

In the present work, treatment of effluent collected from a latex manufacturing plant was studied. The coagulation performance of the novel self-prepared aluminium formate was evaluated and compared to traditional, commercially available polyaluminium chloride and aluminium sulphate. The effects of the coagulant type and dose on the treatment efficiency were studied. The impact of the coagulation pH and the use of polyacrylamide as a coagulant aid were also investigated.

2. Materials and methods

2.1. Chemicals

The aluminium formate used in this study was synthesised using aluminium hydroxide (55.6% Al_2O_3 reagent grade, Sigma Aldrich) and formic acid (98% (w/w), Riedel-deHaën, Reag. Ph. Eur.). A detailed description of the synthesis has been published earlier [13]. The coagulation performance of aluminium formate was compared to the coagulation performance of commercial aluminium sulphate (VWR BPH Prolabo AnalR Normalpur) and polyaluminium chloride (EKA WT91). For the jar tests, coagulants were diluted to an aluminium concentration of $20\,g\,L^{-1}$. Commercial anionic polyacrylamide (EKA PL7450) was used as a coagulant aid in some of the experiments. The polyacrylamide was dosed as a 0.1% solution. For pH adjustment 1 M NaOH solution (prepared from NaOH pellets, VWR BDH Prolabo, AnalR Normalpur) was used. All the solutions were prepared in ultrapure water (18.2 MΩ·cm).

2.2. Wastewater

The treated wastewater was collected from a latex manufacturing plant. The wastewater contained high amounts of latex particles with a dry matter content of 1 w-% and turbidity of 17000 NTU. The pH of the water was 6.5. The collected effluent was part of the effluent stream generated on a manufacturing plant.

2.3. Coagulation tests

The coagulation tests were conducted as jar tests with a six-paddle jar tester (Flocculator 2000, Kemira Kemwater). The jar tests were conducted with a sample amount of 800 ml at room temperature. At first, the water was mixed rapidly for 1 min at a speed of 400 rpm, during which the coagulant, as a solution containing 20 g/l aluminium, was added and the pH was adjusted with a drop-wise addition of 1 M NaOH solution. A VWR pHenomenal PC 5000H pH Meter using a VWR pHenomenal 111 electrode was applied for pH measurements. After rapid mixing, water was stirred at a speed of 20 rpm for 15 min to achieve floc growth. In the tests where polyacrylamide was used, it was added at the beginning of slow mixing as a solution containing 0.1 w-% polyacrylamide. After slow mixing, the system was allowed to settle for 30 min.

The amount of 150 ml of the supernatant was taken for analysis from a depth of 10 cm. The sample was divided into three subsamples, 50 ml each. One of the subsamples was analysed as it was, the second was filtered through filter paper of pore size 40 μm (Qualitative filter paper 417, VWR International) and the third was centrifuged using a Jouan C412 centrifuge with a relative centrifugation force of 560*g*-units. The coagulation efficiency was evaluated with turbidity measurements. Most of the coagulation tests are single measurements but a few of them was made in triplicate. Based on these repetitions experimental error can be evaluated to be less than 5% when measured turbidity is ≥ 1000 NTU, and less than 10% when measured turbidity is <1000 NTU.

2.4. Turbidity measurement

Turbidity was measured with a Hach Ratio/XR turbidity meter. The validity of the analyser was confirmed by measuring the Gelex turbidity standards once a day. The turbidity measurement was conducted by transferring the sample in the measuring cuvette and placing the cuvette in the measuring chamber of the analyser. The samples with turbidity over 2000 NTU was diluted with ultrapure zero turbidity water because the analyser does not detect turbidities above 2000 NTU. It was confirmed that the dilution factor does not affect to the turbidity value by measuring the diluted samples with different dilution factors.

3. Results and discussion

3.1. Effect of aluminium coagulant type, dose and pH

The effect of the coagulant type and dose was studied by conducting a series of jar tests with different coagulant doses with all three coagulants adjusting the coagulation pH to 6. Residual turbidity values are presented in Table 1. In the tables coagulants aluminium formate, polyaluminium chloride and aluminium sulphate are referred to as AF, PAC and $Al_2(SO_4)_3$, respectively.

During slow mixing, it was observed that some floc formation occurred in most of the tests. However, no settling occurred during the 30-min settling time. It can be seen in Table 1 that the turbidity of the settled samples with all of the coagulants and at all the tested doses was even higher than the turbidity of the treated wastewater, which was 17000 NTU. The chance in turbidity values may be due to the fact that, even though no settling occurred, some changes in particle size and shape, which affect the scattering of light [17], occurred during coagulation.

The reason for the poor separation of the latex from the water even though visible floc formation occurred during the slow mixing stage could be that the formed flocs are quite small and the flocs are not heavy enough to settle within the used 30-min of settling time. Filtration and centrifugation were studied as separation methods to see if the formed floc could be more effectively separated using them than by sedimentation. Reduction in turbidity could not be achieved with filtration or centrifugation without using any coagulant. However, when using filtration or centrifugation after coagulation, good turbidity removal was achieved. It can be seen from Table 1 that when the aluminium dose used was big enough, low residual turbidity values were obtained using filtration or centrifugation as the separation method. The general trend