

Expanded Shale Flue Dust as an Additive for the Coagulation-Flocculation of Wastewater

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Abstract: Municipal and industrial wastewater production in North America is estimated at 85 cubic kilometers per year, and a significant proportion of this wastewater is treated using coagulation-flocculation systems. Therefore, there is an interest to develop new effective, low cost coagulants to be utilized in these systems. This study demonstrates the feasibility of a novel, low cost coagulant blend of expanded shale, a ceramic derived from the concrete industry, and an industry standard coagulant, ferric sulfate. Triplicate jar tests were operated using synthetic wastewater flocculated with varying concentrations of either ferric sulfate, expanded shale, or a combination of both components. The wastewater was subsequently analyzed for turbidity removal. The optimum concentration for turbidity removal, 0.1 g/L expanded shale and 0.01 g/L ferric sulfate, removed 84.7% and 91% of turbidity and suspended solids, respectively. This blend outperformed the ferric sulfate only treatment, demonstrating expanded shale as an effective additive to traditional coagulation-flocculation systems. Additionally, zeta potential was used to determine the mechanism of flocculation for this novel treatment blend.

Keywords: Expanded shale, Coagulation-flocculation, Wastewater, Jar-testing, Zeta potential

I. INTRODUCTION

The use of coagulation-flocculation for the removal of suspended solids and turbidity from wastewater is widely used in many treatment facilities [1,2]. High levels of total suspended solids (TSS) and associated high water turbidity can reduce dissolved oxygen to concentrations hazardous to aquatic life through the inhibition of photosynthesis. Coagulation-flocculation removes suspended solids and turbidity from wastewater through the addition of a coagulant. The coagulant counteracts the electrostatic repulsion between the colloidal particles, allowing particles to aggregate and settle via gravitational settling, removing the particles from solution [3]. Common coagulants are aluminum or iron salts and high molecular weight polymers [4]. These coagulants, especially polymeric coagulants however are expensive (approximately \$10/kg) and can be a significant contribution to the overall operating costs of a treatment facility [5]. Therefore, the development of new, low cost coagulants is needed to reduce operating costs of treatment facilities while providing a high level of treatment for the wastewater.

II. BACKGROUND AND RELATED WORK

One potential low cost coagulant is expanded shale. Expanded shale is widely used as concrete aggregate to produce lightweight structural concrete [6]. Expanded shale has been demonstrated as a filter media to reduce turbidity in storm water and municipal wastewater treatment operations [7,8]; however, knowledge is limited on the use of expanded shale as a traditionally used coagulant in wastewater systems. This study explores the use of expanded shale both as a stand-alone coagulant and as an additive to a conventional coagulant in order to develop a low cost, effective coagulation-flocculation treatment strategy.

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III. SCOPE OF RESEARCH

The overall goal of this study was the removal of suspended solids in municipal wastewater to help water professionals by identifying an inexpensive coagulant for wastewater treatment. The specific objective of this study was to test the use of expanded shale both as a stand-alone coagulant and as an additive to a conventional coagulant to develop a low-cost, effective coagulation-flocculation treatment strategy.

IV. PROPOSED METHODOLOGY

Expanded shale for this study was obtained from a concrete aggregate manufacturer (Utelite Corporation Coalville, UT, USA). Elemental composition of expanded shale was determined by X-ray fluorescence (XRF) by the contract laboratory DCM Science Laboratory (Wheat Ridge, CO, USA). Constituents with a mass fraction >1% are listed in Table 1.

Table 1. Expanded shale elemental analysis.

Constituent	Mass fraction (%)
SiO ₂	56.6
AlO ₃	14.2
CaO	6.02
Fe ₂ O ₃	4.21
MgO	2.25
K ₂ O	1.98

To examine the effects of ferric sulfate and expanded shale in combination as a coagulant system, jar testing was performed. Triplicate Jar tests, as described by ASTM D2035, were operated using synthetic wastewater amended with either ferric sulfate, expanded shale or a combination of both components. Jar tests (DBT6 batch jar tester EC Engineering, Canada) were operated by flash mixing (300 rpm) for 1 min, followed by 15 minutes of moderate mixing at 30 rpm, and a 30-minute settling time. Concentrations of each coagulant tested were 0, 0.1 g/L, and 1 g/L expanded shale and 0, 0.01 g/L, and 0.1 g/L ferric sulfate, where each concentration of each compound was tested in combination with every other concentration of the other compound.

Synthetic wastewater consisted of 100 mg/L of kaolin powder (Sigma-Aldrich) and 10 mg/L of humic acid (technical grade, Sigma-Aldrich) in distilled water and mixed for 12 hours as described by [4]. Measured turbidity, total suspended solids (TSS), zeta potential, and pH of the synthetic wastewater was 163 Nephelometric Turbidity Units (NTU), 103 mg/L, -65.1 mV and 6.0 respectively.

After the conclusion of each jar test, turbidity (Hach 2100Q, USEPA Method 180.1 compliant) of the supernatant was measured. Supernatant samples were collected from a port is located 133 mm from the bottom of the reactor (1/3 of the reactor height). The optimum treatment combination, as determined by reduction of turbidity, was subsequently tested for removal of suspended solids and solution zeta potential. TSS was measured using standard method 2540B [9,10]. Zeta potential was measured using a Brookhaven Zeta-Plus (Holtville, NY, USA) and is reported as an average of 10 measurements plus or minus the standard error.

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Statistical Methods

Jar tests were operated in triplicate. Turbidity from each treatment groups was analyzed using 2-way analysis of variance (ANOVA). Subsequent pairwise comparisons of treatment groups were compared using the Tukey- Kramer method. P-values <0.05 were considered to be statistically significant.

V. EXPERIMENTAL RESULTS AND DISCUSSION

Flocculation Performance

The final turbidity of the wastewater after jar testing varied widely across coagulant combination groups (Fig. 1). This variation is statistically significant with a 2-way ANOVA p-value <0.0001. Additionally, pairwise comparisons of the individual treatment combinations indicates that the nine treatment combinations tested can be grouped into seven groups (labeled A-G in Fig. 1) that result in statistically different final turbidity values. (p-values <0.05, Tukey-Kramer Method).

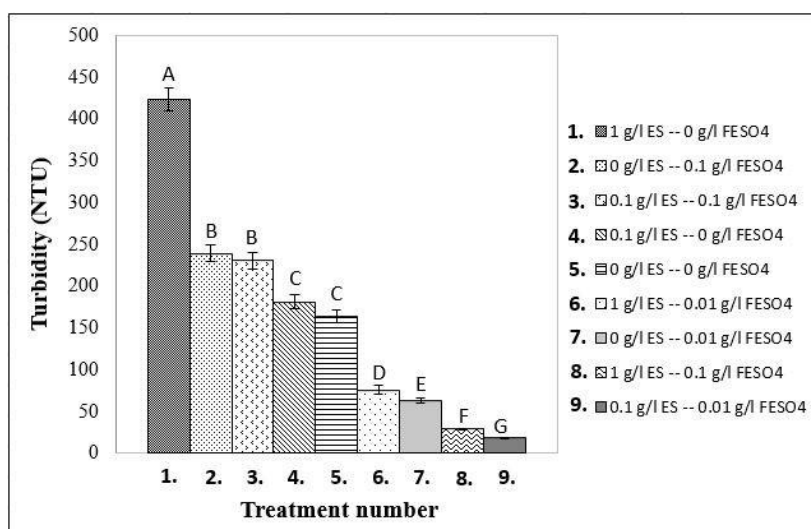


Fig. 1. Final turbidity of each jar test. Treatment combinations where different letters indicate a statistically significant difference between groups (Tukey adjusted P- value < 0.05). Error bars represent 95% confidence intervals. ES denotes expanded shale, FESO4 denotes ferric sulfate.

The coagulant combination of 0.1 g/L expanded shale and 0.01 g/L ferric sulfate (Treatment 9) resulted in the lowest final turbidity of 20.6 NTU, corresponding to an 87.4% removal of the initial turbidity and a suspended solids removal of 86.5 mg/L (91%). This turbidity reduction is a significant improvement to the flocculation performance of ferric sulfate of the same concentration without expanded shale (Treatment 7) (38.0% vs. 87.4%). Comparing Treatments 1 and 6 shows the strong effect of decreasing turbidity by adding a small amount of ferric sulfate. Also the addition of expanded shale without ferric sulfate results in an increase in turbidity due to the fine particle colloidal nature of the expanded shale. Moreover, both 10:1 expanded shale to ferric sulfate ratio (m/m) treatments (#8, #9) significantly outperformed the ferric sulfate alone (Treatments 2, 7) and control (Treatment 5, no coagulant amendment) treatments. A three-way interaction of wastewater particles, expanded shale, and ferric sulfate appears to be critical in reducing turbidity. These results indicate that expanded shale could be used in a variety of concentrations as a low cost amendment to current ferric sulfate coagulation-flocculation systems to improve overall performance.

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Treatment using expanded shale without the addition of ferric sulfate (Treatments 1 and 4) did not improve turbidity reduction significantly compared to the control group (Treatment 5). Conversely, turbidity increased proportionally to the concentration of expanded shale added. This increase in turbidity suggests that it is unlikely that expanded shale cation constituents including Al, Ca, Fe, Mg, and K (Table 1) were involved in charge neutralization reactions with the wastewater colloids. Based on these results, expanded shale is not an appropriate coagulant when used independently.

Turbidity increase compared to the control was also observed in the 0.1 g/L ferric sulfate alone treatment group (Treatment 2). This increase in turbidity is common when coagulant dosage is large enough to cause charge reversal and re-stabilization of colloids.

Coagulation Mechanism

To further characterize the expanded shale-ferric sulfate coagulant combination, the coagulation-flocculation mechanism was explored. Suspended colloids in wastewater carry a net negative charge that causes the particles to remain dispersed and stable, and the quantification of that stability is indicated by measurement of the zeta potential [3]. Measurement of Zeta potential before and after treatment using a coagulant is a common indicator of coagulant behavior and particle charge destabilization [11]. The zeta potential of the synthetic wastewater, -65.1 ± 6.4 mV, was significantly reduced to -2.5 ± 1.6 mV by Treatment 9 (0.1 g/L expanded shale and 0.01 g/L ferric sulfate). This change in zeta potential indicates charge neutralization of the wastewater colloids and also indicates that both charge neutralization and sweep coagulation/adsorption are important mechanisms of coagulation in this system [12].

Furthermore, results of ANOVA analysis suggests that both treatment factors, ferric sulfate concentration and expanded shale concentration, as well as the interaction between the treatment factors all significantly contribute to the final turbidity of the jar tests (p - values <0.001). The statistically significant interaction effect between ferric sulfate and expanded shale concentration likely indicates a physical-chemical interaction of the two coagulants in solution.

VI. CONCLUSION

This study demonstrated the feasibility of the utilization of expanded shale as a low cost additive to improve performance of traditional ferric sulfate coagulation-flocculation systems. The addition of 0.1 g/L of expanded shale improved the turbidity removal capacity of 0.01 g/L ferric sulfate by 49.4%. Furthermore, expanded shale-ferric sulfate coagulant blend was demonstrated to neutralize colloid charge in the process of flocculation.

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