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The optimization and comparison of a cerium salt-based phosphate filtration system to industry standard phosphate removal water filtration systems

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CHEMICAL AND LIFE SCIENCE

The optimization and comparison of a cerium salt-based phosphate filtration system to industry standard phosphate removal water filtration systems

ChemTreat, Inc.

CAPSTONE DESIGN EXPO 2015

Background

Phosphorus is one of the fundamental building blocks for biological molecules. Phosphorous removal from water is required at many wastewater treatment plants as phosphate helps encourage growth of cyanobacteria and algae. To adhere to federal regulation on phosphate removal, encourage most industrial waste water treatment facilities rely on either aluminum or iron based systems to remove the excess phosphorous in the form of reacted phosphate. The main drawback of these traditional systems is that they require a large amount of flocculants to process their phosphate-metal products. In this experiment our team evaluated the reactivity of the cerium chloride and phosphate ions in multiple conditions to optimize the yield and flocculating of cerium phosphate crystals.

$$CeCl_3(aq) + PO_4^{3-}(aq) \rightarrow CePO_4(s) + 3Cl^-(aq)$$

Hypothesis

The ideal reaction conditions for cerium phosphate generation would be at a 1:1 ratio in a basic environment at approximately 8 pH. Filtration can be avoided with the use of coagulants and flocculants.

Aims

- Identify the most significant reaction variables for cerium phosphate production.
- Evaluate the effect reagent concentration, filtration and pH has on cerium phosphate production.
- Evaluate the success of coagulants and flocculants on cerium-phosphate crystals in lab-grade, municipal and industry waste water.
- Conduct a financial analysis on the cost of a cerium salt based phosphate removal system to standard industry phosphate removal methods.

Methods

The concentration studies were conducted with the use of 1000ppm solutions of $CeCl_3$ and Na_2HPO4. The reactions were evaluated after mixing and a 10-20 minute settling time. The reacted solutions were analyzed through Inductive Coupled Plasma Mass Spectrometry (ICP-MS).The filtration experiments were conducted with the use of Thermo Scientific syringe filters. Both the filtration and concentration studies utilized a Design of Experiment and JMP software to determine the best reaction parameters. Standard water treatment flocculants were tested on reacted cerium phosphate solutions to evaluate the settling properties of the produced flock.

Concentration & Filtration Analysis

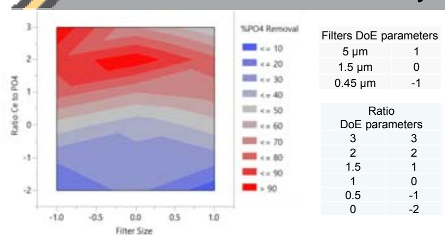

Figure 1: The ratio of cerium chloride (ppm) to dissolved ortho-phosphate (ppm) was tested with a decreasing filter size.

pH Analysis

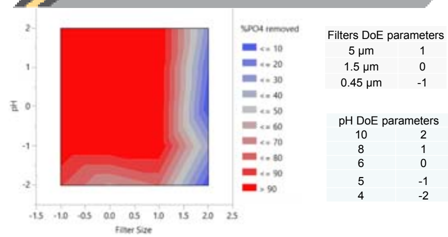

Figure 2: The pH of a 1:1 molar reaction between cerium chloride and dissolved ortho-phosphate and was increased with a decreasing filter size.

Coagulant & Flocculent Analysis

Modeling with lab grade water

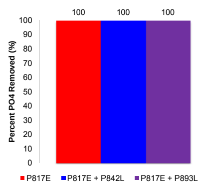

Figure 3: PO_4 percent removal from pure environment lab grade water

Modeling with James River & Reservoir water

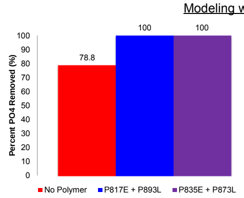

Figure 4: PO_4 percent removal in James River Water

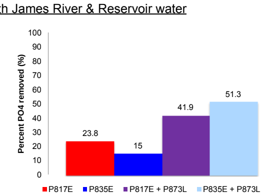

Figure 5: PO_4 percent removal from Reservoir Water

Modeling with ChemTreat Customer Account Water

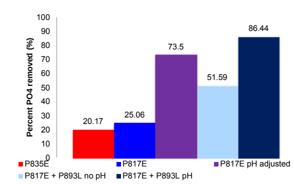

Figure 6: PO_4 percent removal from ChemTreat customer water

Financial Analysis

Table 1: Molar and Mass efficiency of the chemical reagents for phosphate removal

Chemical Reagent	Molar Efficiency (mol/mol of P)	Mass Efficiency (g/ g of P)
Alum:	22	420
Sodium Aluminte:	6	31
Ferric Chloride:	15	39
Ferric Sulphate:	15	190
Cerium Chloride	2	5

Table 2: Comparison of traditional removal agents with $CeCl_3$ for treating 5ppm PO_4^{3-} water at 10gpm

Chemical Reagent	Reagent Required (kg)	Cost of the Reagent ($)	Estimated Slude Production (kg)[1,2]	Sludge Disposal cost ($)[3]
Alum:	120	120	400-460	30-35
Sodium Aluminate:	8.5	6.4	43-71	3.2-5.3
Ferric Chloride:	10	12	23	1.7
Ferric Sulphate:	52	41	120	8.6
Cerium Chloride	1.5	1.7	4.4	0.34

Table 3: Comparison of traditional removal agents with $CeCl_3$ for treating 7ppm PO_4^{3-} water at 10gpm

Chemical Reagent	Reagent Required (kg)	Cost of the Reagent ($)	Estimated Slude Production (kg)[1,2]	Sludge Disposal cost ($)[3]
Alum:	160	160	560-650	42-48
Sodium Aluminate:	12	9.0	61-99	4.6-7.4
Ferric Chloride:	15	17	33	2
Ferric Sulphate:	73	57	160	12
Cerium Chloride	2	2.4	6.3	0.47

Citations:
1. Snurer, Helena. "Sludge Production from Chemical Precipitation" *Department of Chemical Engineering*. Lund Institute Technology.
2. C. James Martel, Francis A. DiGiano and Robert E. Pariseau. "Water Pollution Control Federation)
Vol. 51, No. 1 (Jan., 1979), pp. 140-14.
3. "Comission to Study Methods and Costs of Sewage, Sludge and Spetage Disposal" *HB 699 Chpater 253:1, Laws of 2007: 1-11*

Proposed Treatment Design

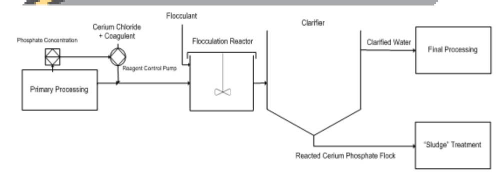

Figure 7: Displays the designed process flow diagram of a cerium-salt based water treatment plan.

This process consists of evaluating the phosphate concentration of primarily processed wastewater, using a pump to deliver the reagent, adding and agitating the flocculent and then separating the clean water from the flock in a clarifier. Additives will be dependent on water source.

Conclusions

- The optimal concentration ratio between was roughly 2:1.
- Cerium phosphate crystals are filtered out with a 1.5µm filter.
- The rate of reaction increased exponentially when the pH > 5.
- The coagulant analysis concluded that coagulants were necessary depending on the water to generate micro-flock in the samples.
- The flocculent analysis demonstrated that the anionic polymer was the most successful.
- The analysis with the ChemTreat account water demonstrated that the cerium chloride treatment is greatly influenced by the presence of other chemicals.

Next Steps

For the continued development of the cerium salt phosphate removal system, the reaction flocking agents need to be continually analyzed with each different water source. To support this system, investigation into the recycling of cerium from cerium phosphate should be investigated.

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