RESEARCH

Correlation between operating parameters and removal efficiency for chemically enhanced primary treatment system of wastewater

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Abstract

Background: "Chemically enhanced primary treatment" (CEPT) is an approach to wastewater treatment. It can be utilized as a specially designed step in "biological" secondary treatment processes. The aim of this study is to create an empirical model of separation efficiency for wastewater chemically enhanced primary treatment.

Methods: The empirical model is undertaken using the simulation of the data obtained from pilot plant experimental studies using different types of coagulant ($FeCl_3$, alum, lime, and Magna-floc155).
The empirical modeling techniques used multivariate regression model. Different values of BOD_5, COD, TSS, as well as separation efficiencies for COD and TSS were investigated in accordance to achieve final effluent results that would meet the Egyptian standards limit.

Results: Multiple regression analysis showed that removal efficiencies of COD and TSS can be predicted to be (R^2 = 0.973 and 0.978, respectively).

Conclusion: The present work provides an approach for using chemically enhanced primary treatment of wastewater. The obtained results showed that the empirical model can predict removal efficiencies with R^2 = 0.973, and 0.978 for COD and TSS. The advantage of this model is that it would allow better process control and treatment efficiency. The results show that chemically enhanced primary treatment method can be used as an efficient method in conventional municipal wastewater treatment plants to reduce the organic load of biological treatment and enhance nutrients removal.

Keywords: Activated sludge, Multiple regression analysis, Wastewater treatment plant, Chemically enhanced primary treatment

Background

"Chemically enhanced primary treatment" (CEPT) is an approach to wastewater treatment and considered an alternative to the conventional primary treatment. It can be utilized as a specially designed preliminary step in "biological" secondary treatment processes. CEPT encompasses coagulation and flocculation processes and achieves significant accretion increases in the deletion of pollutants from the influential stream (Ismail et al., 2012; Parker et al., 2000; Bisinella de Faria et al., 2015; Wang et al., 2009).

Efficiencies of removal rely upon mixing times, type of mixing (mechanical or hydraulic), and type of coagulant. Fresh alum "($Al_2(SO_4)_3 \cdot 18H_2O$)" is commonly used in wastewater treatment as a coagulant for "chemical precipitation" (Dong et al., 2019; Mian et al., 2018). The coagulant dose needed for a cure is based on wastewater nature, pH value, phosphate level, and injection factor (Tik & Vanrolleghem, 2016; Abdel Fatah & Al Bazedi, 2019).

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CEPT can be used to achieve many different goals in wastewater treatment facilities: (i) to increase the TSS elimination performance of the primary settling process based on substantial treatment, (ii) to limit organic loading rates thereby reducing the demand for oxygen in aerobic biological treatment facilities, (iii) to achieve excessive phosphorus removal through precipitation and ultimately to achieve excessive phosphorus removal through precipitation, and ultimately (iv) to allow increased hydraulic charging quotes to an existing PST, thereby enhancing plant life with excessive moist weather flows (Ayoub & Abdel-fattah, 2016; Ayoub et al., 2017; Neupane et al., 2008).

During the CEPT process, larger flocs are assembled and these flocs are decumbent to faster settling. The treatment efficiency also increases with the increase of floc size significantly. Different studies showed that CEPT process has effectively removed 85% and 57% of total suspended solids (TSS) and biological oxygen demand (BOD), respectively. There were also significantly higher efficiencies in chemical oxygen demand (COD) and suspended solids (SS) removal such as 76% and 85%, respectively (Svardal & Kroiss, 2011; Kalogo & Verstraete, 2000). Some researchers also investigated the impact of polymer addition in COD removal. There was a higher achieved efficiency in the removal of COD by adding a metal salt and anionic polymer in comparison with the addition of metal salt alone. In some studies, contradictory results indicate that adding polymer in each case does not contribute to performance (He et al., 2016; Irene, 2000; Guven et al., 2019). In the CEPT process, in addition to particulate COD, soluble COD may also be removed to some extent. It improves the transfer of COD from the liquid phase to the phase of sludge (Aiyuk et al., 2004).

Researchers have assessed and developed different models concerning CEPT (Parker et al., 2000) and assessed CEPT, while Ouali et al. (Ouali et al., 2009) have developed an empirical model between the physicochemical and biological parameters. Belhaj et al. (Belhaj et al., 2014) have studied the water parameters of sewage treatment plant after rehabilitation and explore them through descriptive and multivariable analysis. Arnell et al. (Arnell et al., 2016) developed a model for anaerobic co-digestion in Benchmark Simulation, while Arnell et al. (Arnell et al., 2017) created a multi-objective performance assessment for wastewater treatment plants by combining plant process models and life. Different researchers have assessed the use of coagulants and the effectiveness of combining chemical treatment with conventional processes. The current work investigates combining different coagulants together to reach acceptable removal efficiency to reduce the organic load of biological treatment and enhance nutrients removal.

Methodology

The main objective of the analysis was to investigate the relation between the operating parameters including COD, pH, TSS, TDS, and the removal efficiency of both COD and TSS using enhanced primary treatment technology in Gitis and Hankins (Gitis & Hankins, 2018). For the present work, samples were collected at the discharge from the grit removal chamber from the municipal wastewater treatment plant of Zenein, and of the effluent from the primary settling tank were collected; Table 1 below summarizes the wastewater's characteristics. Different types of coagulant ($FeCl_3$, alum, lime, and Magna-floc155), as well as different treatment capacities, were investigated. The effect of "pH" on the efficiency of the process has been assessed for each coagulant type, e.g., the removal percentage of "COD", turbidity, and "TSS". The effect of coagulant type and dosage, as well as pH, was investigated. Investigated pH range is between 4 and 11.5.

1. Coagulants
   (a) Alum $Al_2(SO_4)_3$ - $16H_2O$ with a purity of 97% and M.W.630.38 (ADWIC, El-Nasr Pharmaceutical Chemical Co.) investigated doses from 10 to 70 mg/l
   (b) Fe Cl_3 with a purity of 99% M.W.162.21 (Riedel-deHaen) investigated doses from 10 to 70 mg/l
   (c) Lime with a purity of 90% M.W.74.09 (S.d Fine-Chem Ltd Boisar) investigated doses from 200 to 500 mg/l
2. Coagulant aids
   (a) Magnafloc155, Magnafloc1011

A mathematical correlation was formulated using a multivariate regression model for experimental results between operating parameters and removal efficiency, and operating parameters and suspended solids level. The mathematical model is based on a list of experimental trials. According to the developed statistical analysis, we can detect the removal efficiency of an effective treatment design package. The validity of the developed model was conducted on the results of a list of experiments.

Results
Experimental results

According to the lab test results, it was readily noted that the pH optimal values are 6, 4, and 11.2 for alum,

Table 1 Analysis of municipal wastewater sample

Parameter	Grab samples
COD, mg/l	430–800
Turbidity, FTU	260–400
TSS, mg/l	377–825
pH	7–8.2
Temperature, °C	22–27

FeCl$_3$, and lime, respectively. Experiments with alum show higher COD removals than those with FeCl$_3$ and lime. A removal percentage as high as 85% was recorded for alum (at pH = 6) when the dose was 50 mg/lit. With FeCl$_3$ 70% removals were reached at pH = 4.7 with lime, COD removals reached 62% on average. It should be noted, however, that all experiments do not have the same initial conditions.

Figure 1 depicts the removals obtained when using Alum at a dosage of 50 mg/l, Alum + Magna-floc155 at dosages of 0.1 and 0.2, and Alum + Magna-floc 1011 at dosages of 0.1 and 0.2. Comparison of the results obtained indicates that the addition of 0.2 mg/l Magna-floc 1011 improves the removal percentage about 2% only, overusing Alum alone.

Figure 2 shows the effect of adding coagulant aids to FeCl$_3$ and using other coagulants (Alum/Lime) with it. It is observed from the figure that the addition of coagulant aids has no significant effect on removal percentages.

Figure 3 shows the addition of aid to lime, which shows it has no effect and using Lime alone is much better than using it in combination with any type of aid.

Regression analysis
The relation between TSS and operating parameters
The correlation between TSS and operating parameters (COD, pH, and TDS) using multiple regression analysis with coefficient of determination R^2 = 0.997. The relation is presented below.

$$SS = -312.25 + (0.62203 \times COD) + (30.03359 \times pH) + (0.127156 \times TDS)$$

Correlation between COD removal efficiency and operating parameters
The correlation between TSS and operating parameters (COD, pH, settling time, temperature, flow rate, TSS, and TDS) using multiple regression analysis with coefficient of determination R^2 = 0.973. The relation is presented below.

$$\%\textbf{COD removal} = 153.33 + (-0.01574 \times time) \\ +(-0.00338 \times Q) + (0.330142 \times temp.) \\ +(-4.74168 \times pH) + (0.02196 \times TDS) \\ +(-0.02651 \times SS) + (-0.02337 \times COD)$$

Correlation between SS removal efficiency and operating parameters
The correlation between SS and operating parameters (COD, pH, settling time, temperature, flow rate, SS, and TDS) using multiple regression analysis with Co-efficient of determination R^2 = 0.978. The relation is shown below.
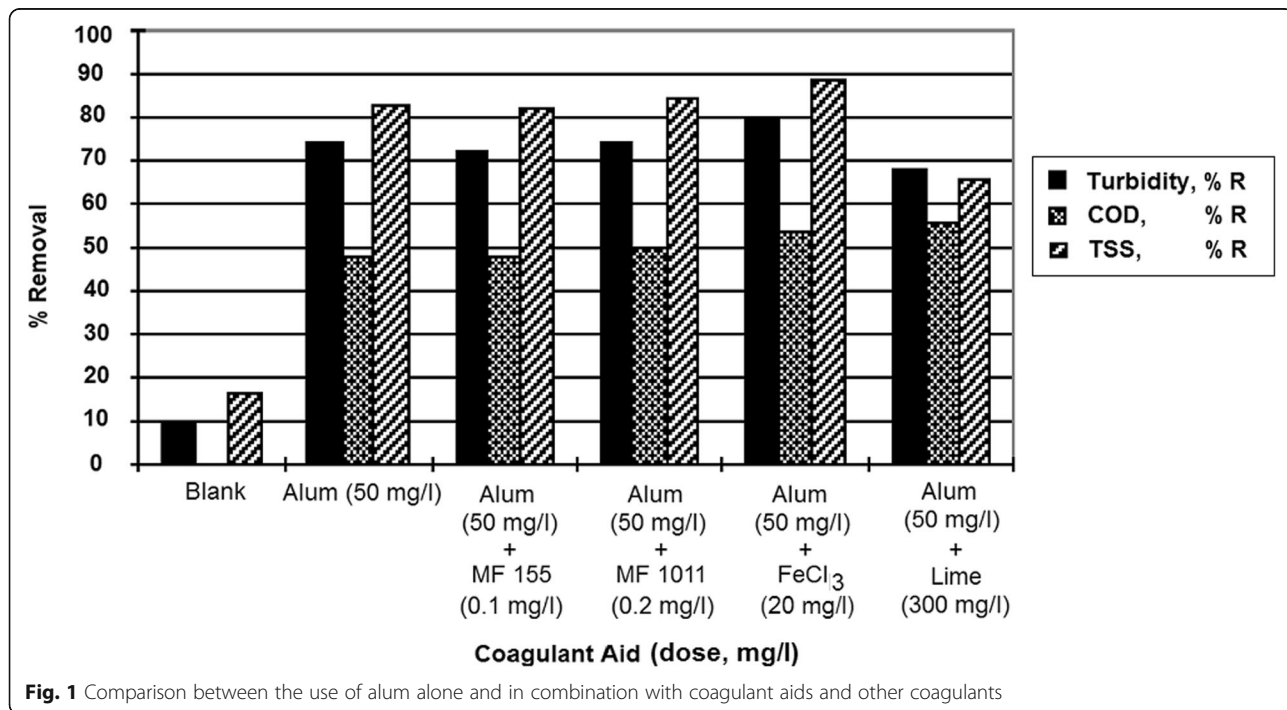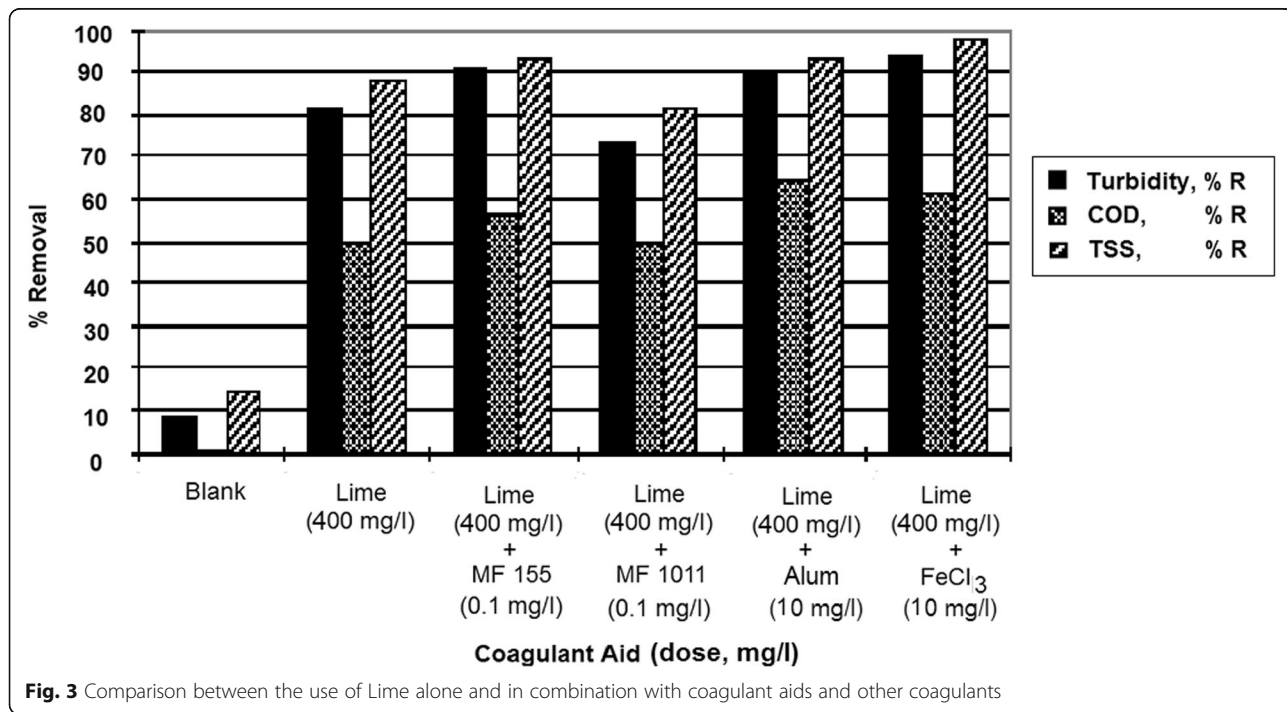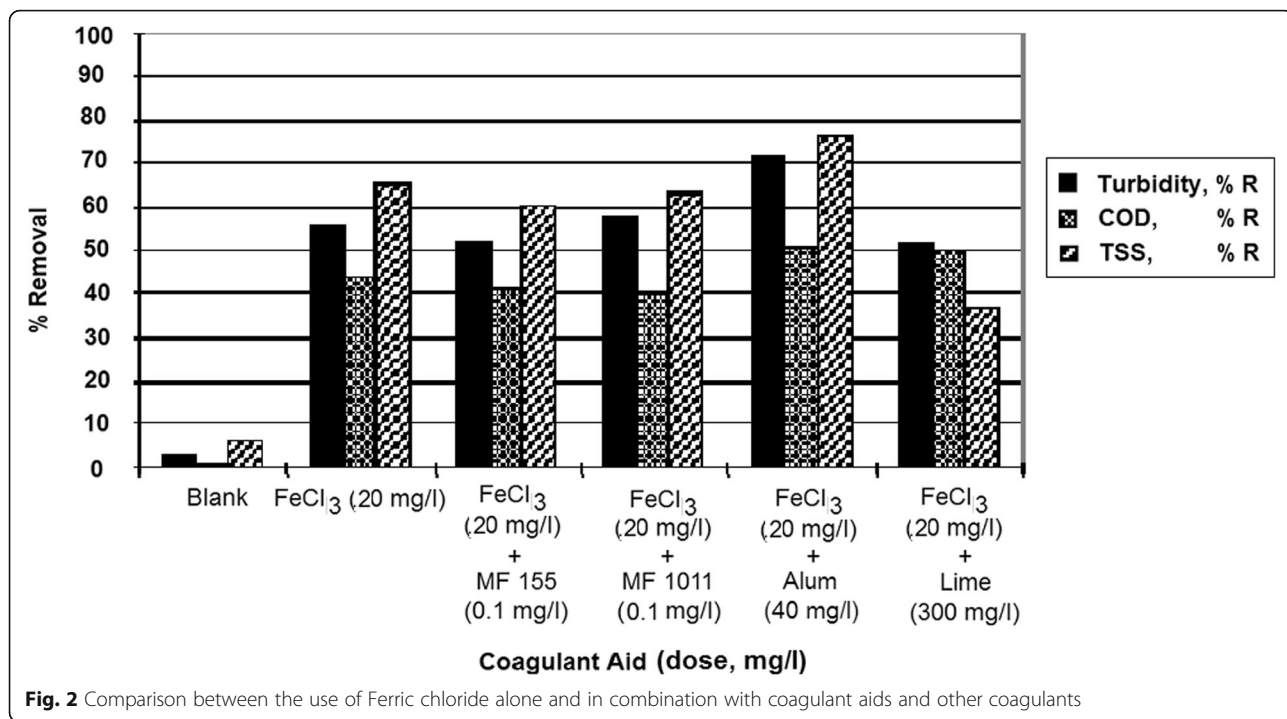

Fig. 1 Comparison between the use of alum alone and in combination with coagulant aids and other coagulants

Fig. 2 Comparison between the use of Ferric chloride alone and in combination with coagulant aids and other coagulants

Fig. 3 Comparison between the use of Lime alone and in combination with coagulant aids and other coagulants

$$\begin{aligned}
\%\mathbf{SS\ removal} = {} & 164.276 + (-0.01905 \times \text{time}) \\
& + (-0.00295 \times Q) \\
& + (0.2437 \times \text{temp.}) + (-5.446 \times \text{pH}) \\
& + (0.01004 \times \text{TDS}) \\
& + (-0.0673 \times \text{SS}) \\
& + (0.002039 \times \text{COD})
\end{aligned}$$

Discussion

Investigating the turbidity removal efficiency for various coagulant dosages indicates that $FeCl_3$ and Alum are eminently effective coagulants for turbidity, with removal efficiency above 90%. Lime shows to be less adequate and mediocre, where the removal efficiency reaches 80% when using a lime with a dose of 400 mg/l. There is no appreciable effect of differing lime concentrations on turbidity removal efficiency. High removal efficiencies of 100% of total suspended solids were recorded with the use of Alum as a coagulant. High removals ($> 90\%$) were also attained with $FeCl_3$, while Lime gave a "TSS removal" of almost 80%. The average removal ratio does not alter with an increase in the Lime dosage.

From the previous data, an Alum dosage of 50 mg/l is taken as the optimum dose. With $FeCl_3$, it was noticed in dosages of 40 mg/l and higher, while for Lime, the optimum dosage was determined to be 400 mg/l. The experiments revealed that it is better to use each coagulant alone due to interference between coagulant mixtures, which leads to undesired changes in pH. Treatment with the use of Alum was proved to be more efficient than when using $FeCl_3$ and lime, with the advantage that higher removal rates are attained at normal pH levels. Use of Alum has the additional advantage that there are fewer corrosion problems.

The regression analysis is used to predict the system's performance and its control level as the basis for further technique and control processes for Alum dosing-enhanced primary treatment. Correlation matrix for the inlet parameters pH, TSS, COD, and BOD_5 of raw sewage entering the treatment plant is developed, in addition to % TSS removal and % COD removal.

The correlation matrix investigated the relationship between the selected variables. It was found that there is a strong relationship between the investigated variables and the pond recovery showed in the high coefficient of determination value. The results showed that the % rejection of COD and SS was highly dependent on the variable flow rate, pH, and TDS in the feed stream and independent of the TSS, COD, and settling time. The equation is valid for feed Alum dose of 50–80 mg/l and flow rate 10,000–16,000 m³/day.

Conclusion

Multivariate regression model empirical model was developed using the simulation data obtained from the pilot plant and the experimental studies using different types of coagulant ($FeCl_3$, alum, lime, and Magna-floc 155). The removal efficiencies of COD and TSS can be predicted to be (R^2 = 0.973 and 0.978, respectively). The advantage of this model is that it would allow a better process control.

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