Original Article

Evaluation of Chemical Oxygen Demand and Color Removal from Leachate Using Coagulation/Flocculation Combined with Advanced Oxidation Process

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Abstract

Background: One of the basic practices in the field of waste management is the collection and treatment of leachate. Leachate from municipal waste due to high chemical oxygen demand (COD) and dark color is a potential pollutant of the environment, which causes a lot of problems in the absence of treatment and direct discharge to the environment. This study aimed to determine the efficiency of ultrasonic process in combination with coagulation and flocculation process using sodium ferrate in COD and color reduction. **Materials and Methods:** In this experimental study, all experiments were performed in batch conditions and with changing process variables such as pH and sonication time, and the effect of three parameters, including ultrasonic reaction time (15, 30, and 45 min), pH (2, 4, 5/5, and 7), and coagulant dosage (from 1 to 150 g/l) on the COD reduction and color removal, was evaluated. Coagulant concentration and then the removal efficiency of COD and color were analyzed by ANOVA using SPSS 18. **Results:** The COD reduction and color removal were 87.05% and 88.6% in optimal condition (using 120 g/L of sodium ferrate at pH 5.5), with coagulation/flocculation, after ultrasound (15 min). Ultrasound (15 min) + sodium ferrate (without coagulation/flocculation) achieved 46.25% of COD reduction and 90.35% of color elimination, whereas the ultrasonic process alone allowed removing the COD and color in the leachate by less than 50%. **Conclusion:** The results indicate that C–F followed by ultrasonic can be used to efficiently reduce the organic matter and color from municipal waste leachate, and it would be an ideal option for leachate treatment.

Keywords: *Chemical oxygen demand, coagulant, ferrate, landfill leachate, ultrasonics*

Introduction

In recent years, the amount and complexity of municipal solid wastes (MSW_s) have increased due to the growth of population, the rapid economic development, the acceleration of industrialization, and other factors.[1-3] Municipal solid waste disposal is performed commonly by landfilling, which results in the production of a complex and toxic liquid mixture known as leachate.[4,5] Leachate is persistent and highly polluted due to the formation of its hazardous compounds. Release of these toxic compounds into the natural environment poses a significant environmental problem associated with the disposal of solid waste.[6-10] The produced leachate varies in terms of composition and quantity that depends on several factors, such as the type and amount of disposed waste, degree of compaction, climate, and moisture content in waste.[5,11] This wastewater may contain large quantity of organic matter (biodegradable and refractory), ammonia, hydrocarbons, heavy metals, and inorganic salts; these compounds are the main contributors of high chemical oxygen demand (COD) and color pollution.[10,12] In order to reduce the potential environmental impacts, legal authorities throughout the world have arranged a set of regulations with respect to the maximum contaminants levels in treated leachate prior to disposal. Therefore, the reduction or elimination of these contaminants must be considered significantly before discharging leachate into the natural environment.[13,5] The leachate is considered one of the major problems related to solid waste management and needs to be treated in a proper way to prevent environmental hazards.[6-10]

Some of the leachate properties include high values of COD, ammonia nitrogen,

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Received: 09 March 2021
Revised: 16 September 2021
Accepted: 21 September 2021
Published: 29 April 2022

Access this article online
Website: www.advbiores.net
DOI: 10.4103/abr.abr_55_21
Quick Response Code:

How to cite this article: Tousizadeh S, Arbabi M, Tondro E, Sedehi M, Arbabi A. Evaluation of chemical oxygen demand and color removal from leachate using coagulation/flocculation combined with advanced oxidation process. Adv Biomed Res 2022:11:30.

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and heavy metals, as well as strong color and bad odor.[14-16] Landfill leachate is generally complex because its composition and varies greatly, making it difficult to deal with. Therefore, it is widely recognized that treatment of leachates is still a great concern in solid waste management.[3,17]

Leachate treatment technologies can be classified into two basic types based on the nature of the incorporated processes, as conventional and advanced treatments. The selection of the process of leachate treatment is often difficult and essential due to the variable quantity and quality of leachates.[18-20] Conventional major leachate treatment technologies, such as biodegradation (via aerobic and/or anaerobic processes), physicochemical methods (e.g., activated carbon adsorption, sedimentation/flotation, coagulation/flocculation, coagulation, chemical precipitation, chemical oxidation) have been studied. Each of the conventional methods is suitable for the treatment of certain types of waste leachates.[21-23]

However, these processes do not accomplish the increasingly strict regulations for leachate discharge and are found to be inefficient, giving most of the times incomplete and expensive treatment. Due to the toxic and nondegradable substances in the leachate, biological treatment alone is not sufficiently effective in removing the organic matter. Furthermore, disadvantages such as higher cost of chemicals, generation of hazardous by-products, environmental problems, and higher process time make chemical processes economically unfeasible, especially if operated individually, and combination methods can help in reducing the impact of these drawbacks.[6,21,24] It is quite challenging to treat these effluents by using only one treatment process, and combined methods are required to treat efficiently these wastewaters and comply with the discharge standards. In recent years, researchers have been focusing on alternate methods for leachate treatment. Technologies based on advanced oxidation processes (AOPs) as well as membrane technologies are regarded as alternatives for leachate treatment (advanced treatments).[19,20]

Advanced oxidation process is a combination of strong oxidants such as ozone and hydrogen peroxide, ultraviolet, ultrasonic, and catalysts such as intermediate metal ions.[25,26] The application of ultrasound is considered a possibility in wastewater treatment for several decades. This technology can remove contaminants through thermal decomposition and/or as a result of chemical reactions with free radicals produced inside cavitation bubbles, and it often leads to higher COD removal efficiency compared to other AOPs methods.[20,23,27] Furthermore, ultrasonic process does not require chemical reagents such as ozone and/or hydrogen peroxide and unlike other methods, it increases neither the turbidity nor the content of suspension in the effluent.[26,28] Cavitation is a phenomenon in which quick changes of pressure in a liquid lead to the formation of tiny vapor-filled cavities in places where the pressure is relatively low. When exposed to higher pressure, these cavities, called "bubbles," collapse and can produce a shock wave that is strong very close to the bubble, but rapidly weakens as it propagates away from the bubble. As a result, the combination of different oxidants with cavitations yields synergetic effects and maximizes the generation of hydroxyl radicals, which leads to efficient use of the oxidizer and therefore can increase the overall efficiency of the treatment process with maximized oxidation of complex compounds. It is obvious that the use of combined methods shows a better treatment efficiency of the landfill leachate and can significantly reduce the requirement of chemicals and process time compared to that of conventional oxidation processes.[22,29] However, there are several drawbacks of AOPs such as, high energy consumption and therefore, they are suitable for small quantity and high strength wastewater.

There are very few literatures reporting the use of cavitation for treatment of leachate.[30] Korniluk and Ozonek reported that cavitation is inefficient in leachate treatment and recommended the use of modified cavitation in combination with oxidants such as hydrogen peroxide or ozone for effective leachate treatment.[26] Bohdziewicz *et al*. employed cavitation for leachate treatment and found that the use of ultrasonic (300 s at 14 microns) increased the removal of COD by 7% compared to unconventional fermentation of wastewater.[31] Afsharnia *et al*. concluded that using ultrasound to purify leachate as a pretreatment could reduce volatiles in leachate.[1]

Our study focused on the use of alternative methods and materials that have the properties of coagulants and lead to minimal problems in terms of environment and by-product production. The objective of this study was to investigate the efficiency of the coagulation and flocculation process (using sodium ferrate) combined with ultrasonic in the removal of color and COD from leachate. Coagulation and flocculation is considered a relatively simple physicochemical method in wastewater treatment that could be an appropriate pretreatment for other leachate treatment methods of municipal waste disposal sites.[4,27] Lan *et al*. argued that COD was effectively removed by 36% after pretreatment with potassium ferrate under optimal conditions.[12,21]

Ferrate (VI) is a suitable compound for the removal of hazardous contaminants in water and wastewater[32,33] and is the only chemical that can be used simultaneously for oxidation, coagulation, and disinfection. Osu *et al*. employed potassium ferrate (K_2FeO_4) for leachate treatment and reported increased removal of COD, from 61.7% to 70%.[28,34] Iron is usually found in the oxidation states of Fe^{2+} and Fe^{3+}, and it can be converted to a higher oxidizing state (Fe^{6+}) under strong oxidation conditions. One of the prominent features of this process is the production of ferric or ferric hydroxide as a coagulant in the form of ferric oxide or ferric hydroxide. This method is used not only for leachate treatment but also for disinfection purposes in water and wastewater treatment, which usually uses the two main compounds of sodium ferrate (Na_2FeO_4) and potassium ferrate (K_2FeO_4). The use of sodium ferrate prevents the production of disinfection by-products (DBP) compared to other disinfectants such as bromine, iodine, and chlorine.[20] Due to the lack of production of DBP, ferrate is considered an environmental-friendly substance, and for this reason, the challenge of DBP, which is the problem of most chemicals, is partially solved. Sodium ferrate can also play an important and effective role in COD removal and reduction by focusing on the oxidation of nondegradable and resistant organic compounds. Therefore, in this research, hexavalent ferrate, which is one of the elements with a high capacity of iron and the most stable compounds among different types of ferrate, was used. The ultrasonic process is also considered one of the new and effective AOPs in the treatment of wastewater pollutants. (Use of sodium ferrate with US results in increased rate of hydroxyl radical generation and hence can give increase in the COD removal.) Therefore, the use of the ferrate along with the ultrasonic process is one of the innovations of this research for the first time. In the present study, a combination of sodium ferrate coagulant with ultrasonic was used to reduce both COD and color contents up to the legal levels for discharge into water bodies. This method is used not only for leachate treatment, but also recently for disinfection purposes in wastewater and water treatment. Due to the inefficiency and cost of other methods available for leachate treatment, the use of sodium ferrate coagulant was investigated in this study.

Materials and Methods

Materials

The chemicals used in this work include Freon reagent (1, 10 PHenanthrolines), iron sulfate, potassium dichromate, sodium hydroxide (NaOH), sulfuric acid, ferro-ammonium sulfate, and silver sulfate, which were obtained from Merck Co., Germany. Coagulation was performed using sodium ferrate as coagulant (with ≥95% chemical purity, 16 M) was purchased from Sarvar pooyan Rastakhiz Company (Isfahan-Iran).

Sample collection and leachate characterization

The raw leachate used in this study was obtained from the facility for waste management (waste collection trunks) in Shahrekord, Iran. Samples were collected during the period of 2018. The samples were stored in 20 L plastic containers made of polyethylene and then, transferred to the laboratory and stored at 4°C prior to analysis. The leachate's characterization was based on the standard methods for the investigation of water and wastewater[35] for the parameters such as COD, potential of hydrogen (pH), and color. Initial COD of the sample was observed to be 32,000 mg/L, whereas pH and color were 5.5 and 17,100 (in cobalt platinum), respectively.

Analysis

In the study, analytical equipment were precalibrated with standard solutions for analysis of leachate samples. The pH of each solution was measured using a hand-held pH meter (Metrohm 827 Co. Switzerland). EPA-approved reactor digestion method was used for analysis of COD (model 45600-00-HACH Co. USA), and color was measured using spectrophotometer (ADMI Method #100048, based on the cobalt platinum, model HACH DR/2000, CO, USA). Ultrasonic experiments were performed by an ultrasonic bath (Jeken model CD-4820). The coagulation experiments were performed using a jar test apparatus (Model Jeken CD-4820).[20,36,37] It should be noted that to increase the accuracy and precision, all measurements were performed with three repetitions. An analysis of variance (ANOVA) was applied to adequate the developed models with the observed data.

Experimental procedure

In this study, the sample size was calculated by the full scale experiments, and to increase the reliability, accuracy, and precision of the experiments, the sampling and analysis of samples were repeated three times in each step. The variables and their levels selected for the experiments were coagulant concentrations (1–150 g/L), ultrasound time (30–60 min), and pH (2, 4, 5.5, and 7), and the effect of these parameters was investigated on color and COD removal. The coagulant concentrations were selected on the test design and the pH values were within the range reported as the optimum by different authors. After performing the experiments using the results and the initial concentration of COD and color, the removal efficiency in different stages was calculated by the following equation:

$$\text{Eq. 1.... Removal (\%)} = \frac{\text{Ci - Ce}}{\text{Ci}} \times 100$$

In this equation, Ci and Ce are the initial and end concentrations for each parameter, respectively.

Finally, the data were analyzed using SPSS Statistical version 25 and statistical method of ANOVA and the efficiency of ultrasonic and coagulation processes was evaluated in color and COD removal.

Different approaches of AOPs (ultrasound with and without coagulation/flocculation) for leachate treatment were used to find the efficiency of the ultrasonic and coagulation processes. It should be noted that in all cases, different ultrasound duration of 15, 30, and 45 min were investigated.[23,38] Three approaches investigated were as follows:

Ultrasonic combined with sodium ferrate and coagulation-flocculation

In this case, the combined effect of sodium ferrate with cavitation and coagulation-flocculation was evaluated with variation in loading of sodium ferrate over the range of 1–150 g/L. After coagulation-flocculation and settling (30 min), supernatants were extracted. Then, 20 ml of the extracted solution was poured into separate containers and tagged. The samples were placed in the ultrasonic bath for 15, 30, and 45 min and then, given 20 min to rest. Finally, samples were collected to determine the COD and color.

Ultrasonic combined with sodium ferrate addition

The treatment was performed by the use of sodium ferrate combined with US. In order to investigate the effect of sodium ferrate with cavitation, 20 mL of the extracted solution was collected from beakers containing 1 L of leachate and different concentrations of sodium ferrate. The tagged containers were placed in the ultrasonic bath in the same manner as before, removed after the desired duration (15, 30, and 45 min), and rested for 20 min. Then, samples were collected to determine the COD and color.

Ultrasonic alone

In this case, 20 mL of raw leachate was poured in three containers and tagged. Then, leachate sample was treated with only cavitation for stirring of 15, 30, and 45 min. After rest (20 min), samples were collected to determine the COD and color.

Coagulation-flocculation

Coagulation experiments were performed using a jar test apparatus equipped with six beakers. One liter of the initial leachate was put into beakers and sodium ferrate was chosen as coagulant. The various concentrations of coagulant were added according to the experimental design. The concentrations were changed from 1 to 150 g/L. After coagulant addition and pH adjustment, a rapid stirring was applied (200 rpm for 5 min), followed by slow stirring (60 rpm for 55 min) and a lastly sedimentation for 30 min under idle conditions (no stirring). The operational condition stirring employed in coagulation-flocculation was based on previous works.[39] At the end, the samples were gathered from the supernatant liquid of the beakers and were analyzed for the extent of COD and color removal.

Optimal concentration sodium ferrate and pH

Ferrate (VI) can eliminate a wide range of organic and inorganic compounds in water and wastewater. The rate of decomposition of the ferrate depends on pH and initial concentration of the ferrate.[24] Therefore, it is necessary to find the optimal pH and coagulant dosage to increase the overall efficiency of the treatment process.[25] Effect of sodium ferrate loading on extent of COD removal was studied using different values of loadings. To evaluate the optimal concentration of the sodium ferrate, the jar test device was set up with 5 concentrations of 120, 90, 60, 30, 1, and 150 g/l of coagulant and different pH values of 2, 4, 5.5, and 7 were examined. It is important to note that the pH of each solution was adjusted by adding sulfuric acid (H_2SO_4) and NaOH.[20,37]

Results

The initial properties of the leachate including color, COD, and pH were measured at 32,000, 17.100 (in cobalt platinum), and 5.5 mg/L, respectively.

To evaluate the effect and efficiency of each factor (coagulant dose, pH, and ultrasound duration) in reducing COD and color by the studied processes, experiments were done by changing each effective factor in different amounts and keeping other factors constant at the optimum level.

Investigating the effect of coagulant concentration on color and chemical oxygen demand removal from waste leachate

Figure 1 shows the effect of coagulant concentration on COD and color removal efficiency in the coagulation process under study. According to jar test results, the concentration of 120 g/L had the highest COD and color removal efficiency, followed by the concentrations of 60 and 90 g/L in terms of removal efficiency. Therefore, according to the chart and related results, experiments were performed with three concentrations of 60, 90, and 120 g/L.

According to the results, Figure 1 depicts that as the coagulant level increases, the COD and color removal increase. Therefore, at concentrations higher than the optimal concentration, increasing the concentration of coagulant is associated with a decreasing trend in COD and color removal.

Investigating the effect of pH on color and chemical oxygen demand removal from waste leachate

Figure 2 illustrates the effect of pH on color and COD removal efficiency in the coagulation process at different pHs

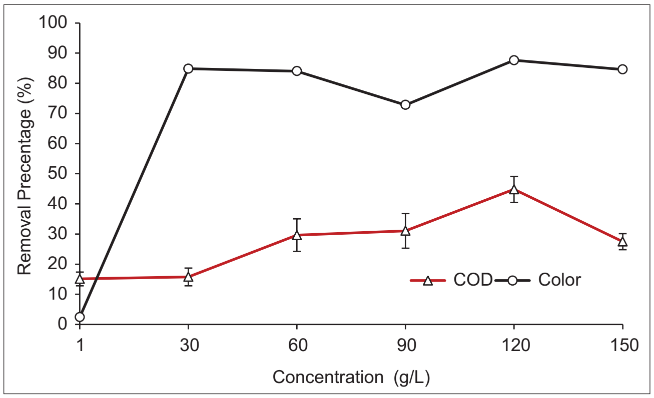

Figure 1: Effect of coagulant concentration on chemical oxygen demand and color removal efficiency in coagulation process (the initial properties of the leachate pH = 5.5, chemical oxygen demand = 32,000, color = 17100)

of 2, 5, 5.4, and 7 in which case the jar test was performed at an optimal concentration of 120 g/l. According to the results obtained in this step, a pH of 5.5 was selected as the optimal.

As shown in Figure 2, the highest COD removal rate occurred at pH 5.5 (raw leachate pH), whereas the highest color removal rate occurred at neutral pH (pH = 7). However, due to the high pollution load from COD, its removal efficiency is considered in this study, so pH = 5.5, which is the highest COD removal efficiency, was selected as the optimal pH. It should be noted that to convert hexavalent to trivalent iron, an acidic environment is required, and on the other hand, at pH <2, due to the formation of divalent iron complex, the COD removal efficiency decreases. Coagulant (sodium ferrate) does not affect alkaline pH; therefore, the selected pH range was 2, 4, 5.5, and 7. Also at neutral pH,[7] the COD removal efficiency has probably decreased due to approaching the alkaline pH range.

It can be concluded that the pH and coagulation dose cannot be predefined and differ in terms of leachate complexity.

Since the leachate samples are diverse depending on the place of production and the composition of the discarded waste, the importance of the current study in creating the optimal is clear.

Investigation of the effect of ultrasound time on color and chemical oxygen demand removal from waste leachate

The effect of the ultrasound duration on the COD and color reduction was studied separately by examining three test modes in combination with the coagulation process and jar test, which are described in Figures 3-6.

Using ultrasound and sodium ferrate with Jar test

At this stage of the experiments, the supernatant from the jar test was placed in an ultrasonic bath at three different durations. Due to the low COD removal efficiency at concentrations of 1, 30, and 150 g/l, experiments were performed with three concentrations of 60, 90, and 120 g/l. Figures 3 and 4 show the COD and color removal efficiencies for the jar test output samples in the coagulation and ultrasonic processes.The effect of ultrasound duration on the reduction of organic load and color is significant at different concentrations of coagulant [Figure 3].

According to Figure 3, different concentrations of coagulant at different ultrasound durations have different effects on leachate treatment. The duration of 30 min is considered as the turning point of the graph because, at concentrations of 90 and 120 g/L, the COD removal decreases with increasing ultrasound duration, while the removal rate increases at 60 g/L [Figure 4].

According to Figure 4, at a concentration of 120 g/l in 15 min, the color removal is 88.6%. However, because the concentration of 60 g/l was reduced by half compared to the concentration of 120 g/l, and a slight difference in the rate of color removal (87.72% at a concentration of 60 g/l) in these two concentrations, it had a significant effect on color removal at the concentration of 60 g/l in 30 min.

Rasool *et al*. in “Combined use of ozone and coagulation in leachate treatment” concluded that *Ocimum basilicum* L.

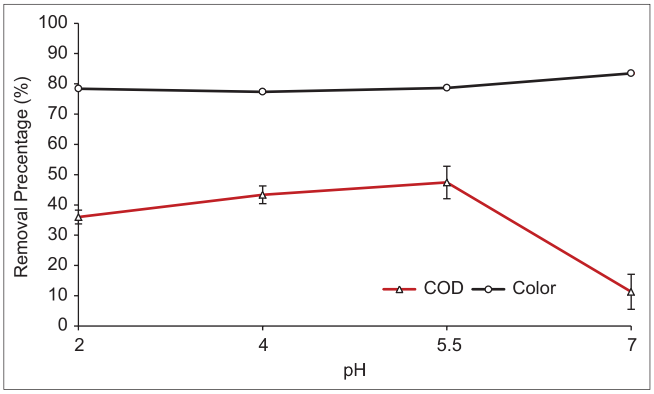

Figure 2: Effect of pH on the removal efficiency of chemical oxygen demand and color in the coagulation process at a (optimal coagulant concentration = 120 g/L, pH = 5.5, chemical oxygen demand = 16,829, color = 3646)

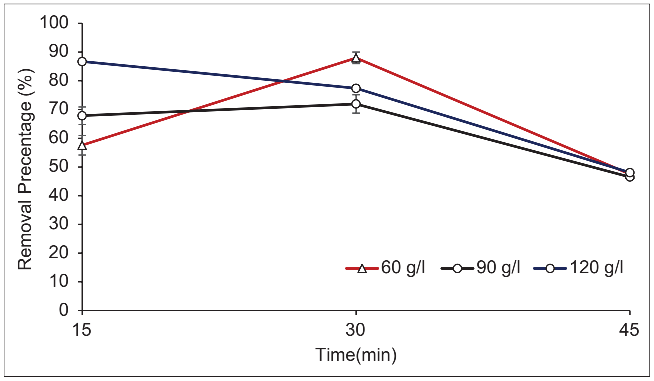

Figure 3: Effect of ultrasonic time and different concentrations of coagulant along with coagulation process on chemical oxygen demand reduction (optimal pH = 5.5, concentrations of coagulant respectively 60-90-120 g/l: 3856, 8992, 7245, respectively)

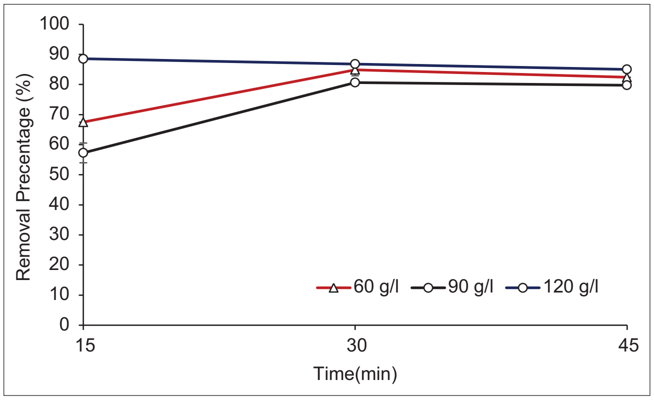

Figure 4: Effect of ultrasonic time and different concentrations of coagulant along with coagulation process on color reduction (optimal pH = 5.5, concentrations of coagulant respectively “ 60-90-120 g/l: 2582, 3309, 2256, respectively)

as a plant coagulant in combination with alum and ozone leads to increases color removal and reduction of COD removal by 92% and 87%, respectively.[5]

De Almeida *et al*. in “Assessment of coagulation and flocculation processes and nanoparticles in leachate treatment” concluded that the combination of coagulation and flocculation processes and nanoparticles is effective and efficient in the elimination of leachate-resistant compounds and NH3-N.[40]

Liu *et al*. in “Fresh Leachate Treatment from Municipal Solid Waste Incineration Plant with a Combination of Radiation and Coagulation Process” improved the percentage of COD removal by combining coagulation and gamma radiation. In particular, at a dose of 1 kg of radiation using iron salt for the coagulation process, the percentage of COD removal can be increased to 55.2. According to the present study, with the application of coagulant (sodium ferrate) and ultrasonic bath, the highest percentage of COD and color removal increases by 90.57% and 87.72%, respectively.[41]

Using ultrasound and sodium ferrate without coagulation

After mixing the leachate with sodium ferrate and placing it in the ultrasonic bath, the COD and color were measured again and the percentages of COD and color removal were presented by the ultrasonic process with sodium ferrate in Figures 5 and 6.

In Figure 5, the concentration of 90 g/l had the maximum COD removal (46.44%) in 45 min. At the same concentration in 15 min, the removal rate was 40%. Therefore, considering that, the use of ultrasonic devices is costly, and observing a small difference in the rate of COD removal in this concentration, the choice of shorter ultrasound duration was economically justified [Figure 6].

In Figure 4, the duration of 30 min is a turning point, so that at concentrations of 60 and 90 g/l with increasing ultrasound duration, color removal increased and it was reduced at 120 g/l. Although more removal was done at a concentration of 120 g/l, considering the cost and energy and due to the small difference in the removal rate, the concentration of 60 g/l in 30 min outperforms the concentration of 120 g/l in this graph.

Amuda *et al*. in “COD and color removal from sanitary waste leachate using the Fenton-Coagulation process” concluded that the use of $FeCl_3$ coagulant alone reduced COD and color by 37% and 62%, respectively. However, the combined process of Fenton, coagulation, and flocculation reduced COD and color by 88% and 98%, respectively.[37] Azizan *et al*. in “leachate treatment by the coagulation-flocculation process using polyamine chloride and tapioca starch (TS)” concluded that the chemical coagulant dose could be 40% (2.5 g/l to 1.5 g/l) and reduce the shortcomings without affecting its efficiency indirectly. Conversely, in the present study, with increasing the coagulant level (sodium ferrate), more COD was removed from the leachate; however, with increasing the sodium ferrate level from 120 g/l to 150 g/l, the removal rate decreased.[12]

Using ultrasound without sodium ferrate

Figure 7 depicts the COD removal efficiency of crude leachate by the ultrasound process without the use of coagulant (sodium ferrate) in 15, 30, and 45 min [Figure 7].

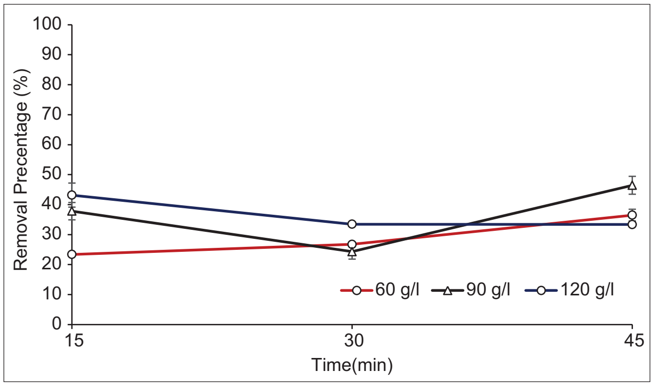

Figure 5: Chemical oxygen demand removal efficiency by ultrasonic process with different concentrations of sodium ferrate (optimal pH = 5.5, concentrations of coagulant 90 g/l in 45 min: 17,139)

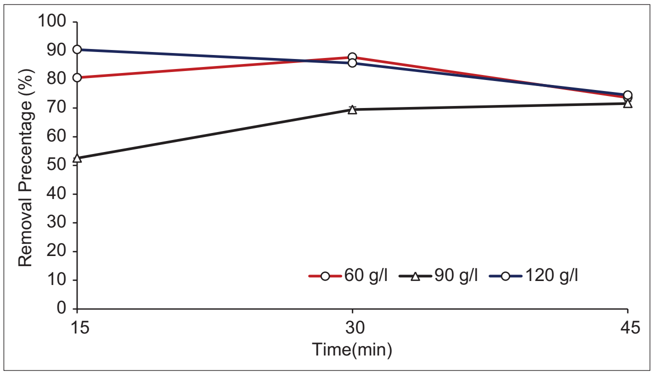

Figure 6: Color removal efficiency by ultrasonic process with different concentrations of sodium ferrate (optimal pH = 5.5, concentrations of coagulant 60 g/l in 30 min: 2105)

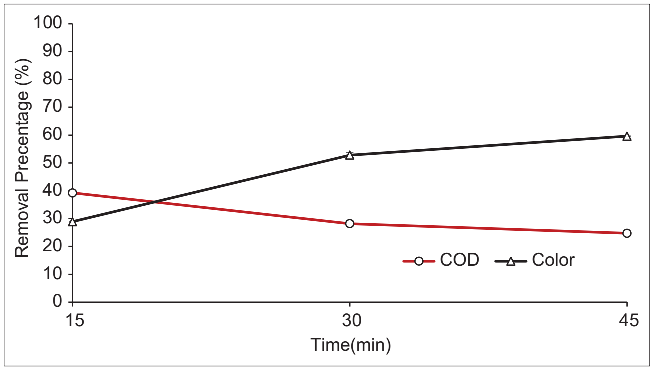

Figure 7: Chemical oxygen demand and color removal efficiencies of raw leachate color by ultrasonic process (optimal pH = 5.5, concentrations of coagulant = 120 g/l, chemical oxygen demand = 32,000, color = 17,100)

According to Figure 7, the experiments showed that ultrasonic results in only a small removal of COD, so that COD removal efficiency ultrasonic process in 15 min is 40% and the minimum removal rate in 45 min is 24.73%. The ultrasonic process has also been more effective in removing color than COD removal. In this regard, the study of Bis *et al*. in "leachate treatment with hydromechanical cavitation" reported that cavitation alone leads to a slight change in the COD level.[42] Ultrasonic technologies are often referred to as a method with very high operating costs, but in the present study, it was found that the use of ultrasound with the coagulation process seems to be an interesting option because it provides a new potential for alternative leachate treatment. Accordingly, Rojoiya *et al*. reported that the combination of ozone with cavitation leads to higher removal of COD compared to the use of ozone alone.[43] Cizam *et al*. in leachate treatment with ozone alone at a concentration of 80 g/m^3, showed a 27% removal of COD in 1 h. However, the auxiliary process by cavitation can have similar results with much less ozone consumption.[44] Chaouki *et al*. reported that combined coagulation-flocculation and adsorption processes could be a useful option for the treatment of solid-waste landfill leachate.[45] Hurairah *et al*. reported the combination of struvite precipitation and coagulation-flocculation method results in a percentage of removal of COD 48.6%, NH3-N 92.8%, and color 98.8%.[46] Azizan *et al*. reported that the dosage of chemical coagulant (polyaluminum chloride [PAC] and TS) could be reduced by 40% (2.5 g/l to 1.5 g/l) and indirectly decreased the drawbacks without affecting its efficiency.[47]

According to the present study, the combined application of coagulant (sodium ferrate) and ultrasonic bath results in the highest COD and color removal rates of 90.57% and 87.72%, respectively.

Conclusions

Waste leachate poses a serious environmental problem associated with municipal solid waste disposal. There are several known leachate treatment methods combining different physical, chemical, and biological processes. The results of this experiments revealed that the use of sodium ferrate as a coagulant in waste leachate treatment has been successful so that color removal and organic load should be enhanced by increasing the coagulant dose to reach the desired dose. It was also observed, although ultrasonic processes are used in leachate treatment, due to the high cost of the process and the low efficiency of COD and color removal, it is not recommended for high volumes of leachate. Generally, each of these two processes can reduce the organic load and color from municipal waste leachate and can be used as leachate pretreatment. The results of this study showed that the use of ultrasonic along with coagulation and flocculation with sodium ferrate is effective in COD and color removal by up to 85%. However, the application of the ultrasonic process alone for leachate treatment could reduce COD and color by <50%. Therefore, the application of ultrasonic process not only increases the efficiency of the coagulation and flocculation process, but also significantly reduces the need for chemicals and duration. It also makes chemical oxidation processes economically viable.

Acknowledgments

The authors express their gratitude to the Vice Chancellor for Research and Technology of Shahrekord University of Medical Sciences for their financial support in conducting this research, as well as the laboratory staff of the School of Health of Shahrekord University of Medical Sciences. This research was supported by grant NO. 3120 from the Student Research Committee of Shahrekord University of Medical Sciences.

Financial support and sponsorship

This study was financially supported by the Student Research Committee of Shahrekord University of Medical Sciences (grant NO. 3120).

Conflicts of interest

There are no conflicts of interest.

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