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Contact stabilization process for hospital wastewater treatment: effects of colloidal organic matter

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ABSTRACT

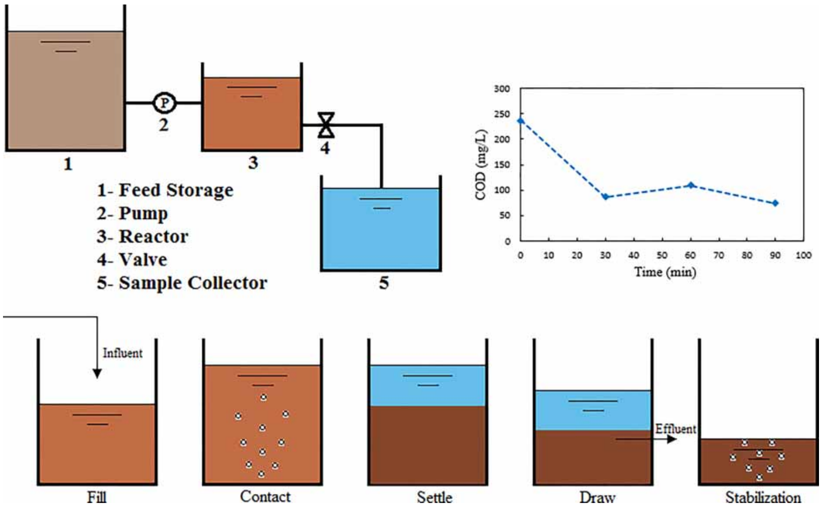
In this study, the treatability of hospital wastewater was investigated using a contact stabilization process on a laboratory scale. A detention time of one hour was selected for sludge settling and separation of treated effluent, and removal efficiency was measured at contact times of 30, 60, and 90 min, and stabilization times of 4.5 and 5.5 h. Based on the different detention times, 6 series of experiments were designed. Results showed that after an initial rapid COD removal in the first 30 min, COD values fluctuate in the time range of 30–90 min. However, in the case where COD values reduce in the second stage, this recovery is negligible; thus, the time of 30 min is considered as the optimal detention time for the contact reactor. Sludge volume index (SVI) values of 119.20 and 109.17 mL/g were obtained for stabilization times of 4.5 and 5.5 h, respectively. Therefore, the longer the stabilization time, the closer the SVI is to 100 mL/g. Moreover, lower settled sludge volume (SSV) value at 5.5 h of stabilization shows better characteristics compared to 4.5 h of stabilization. Furthermore, COD removal efficiency at the optimum contact time is higher when 5.5 h is selected for stabilization.

Key words: biological treatment, colloidal organic matter, contact stabilization process, detention time, hospital wastewater

HIGHLIGHTS

- A contact stabilization process was used for hospital wastewater treatment.
- Rapid decrease in COD was noticed in the early minutes of the contact reactor.
- Colloidal organic matter is physically adsorbed by microorganisms.
- Solubilized substrates from the colloidal organic matter breakdown are released.
- Residence time of 30 min is the best detention time for the contact reactor.

GRAPHICAL ABSTRACT



INTRODUCTION

Excessive utilization of water resources in various municipal, industrial, and agricultural activities leads to the production of large volumes of wastewater. Due to the variety of organic matter as well as pathogenic microorganisms present in the wastewater, it is necessary to treat wastewater before reusing or discharging it into the environment. In recent years, hospital wastewater has been considered as a source of contaminating receiving water bodies. Compared to municipal wastewater, hospital wastewater contains a wider range and higher concentrations of pharmaceuticals and pathogenic microorganisms (Chonova *et al.* 2016). Usually, hospital wastewater is discharged to the municipal wastewater collection system, resulting in significant amounts of contaminants entering the municipal wastewater treatment plant. Hospital wastewater treatment at the source of production has the advantages of preventing the spread of contamination in the environment and the elimination of various pharmaceuticals and pollutants in the municipal wastewater treatment plants and also creating a better efficiency of treatment (Kovalova *et al.* 2012; Casas *et al.* 2015b; Chonova *et al.* 2016). In recent years, the treatment of hospital wastewater has been studied by many researchers. Most of these researchers aimed to eliminate pharmaceuticals and micropollutants (Beier *et al.* 2010; Köhler *et al.* 2012; Kovalova *et al.* 2012, 2013; Antoniou *et al.* 2013; Casas *et al.* 2015a, 2015b; Mousaab *et al.* 2015; Souza *et al.* 2018; Vo *et al.* 2019; Khan *et al.* 2020), while the removal of organic contaminants have been rarely studied (Mousaab *et al.* 2015; Nguyen *et al.* 2016; Alsalhy *et al.* 2018; Lan *et al.* 2018; Vo *et al.* 2019).

Different biological processes have been used for the treatment of hospital wastewater, such as membrane bioreactor (MBR) (Beier *et al.* 2012; Kovalova *et al.* 2012; Mousaab *et al.* 2015; Nguyen *et al.* 2016), advanced MBR by combining an MBR process and reverse osmosis and nanofiltration (Beier *et al.* 2010; Lan *et al.* 2018), rotating biological contactor (RBC) (Su *et al.* 2015), and moving bed biofilm reactor (MBBR) (Casas *et al.* 2015b).

One of the most common and effective biological methods for wastewater treatment is the activated sludge process. Although this method has been used in most wastewater treatment plants to treat municipal wastewater, practical issues such as foaming, bulking, production of significant volumes of excess sludge, low resistance to shock loading, and aeration costs are the common problems of this method (Bunch & Griffin 1987; Jenkins *et al.* 2004). To meet specific treatment objectives, modifications to activated sludge have been developed over the years. Contact stabilization was mainly developed to considerably reduce treatment volumes. It is assumed that when microorganisms are in an endogenous state, the removal rate of the colloidal substrate is much more rapid compared to conventional activated sludge, thus the hydraulic retention time (HRT) in the aeration tank is significantly reduced, resulting in smaller treatment volumes. The contact stabilization process was first studied by Coombs in England in 1921, and later Ullrich and Smith, as well as Eckenfelder and Grich, attempted to address the shortcomings of this system (Gujer & Jenkins 1975; Bunch & Griffin 1987).

This process consists of three phases: (i) Contact phase in which wastewater and sludge are mixed and aerated for 30–90 min. Soluble matter is removed, and colloidal and suspended organic matter are adsorbed and then biodegraded by activated sludge flocs in the next step. (ii) Sedimentation phase of 30 min to 2 h to allow sludge separation; and (iii) Stabilization phase, in which a portion of the biological sludge is aerated for 3–6 h. Contact stabilization process can be used in both batch and continuous modes. In a batch system, all phases of aeration, biological treatment, and sedimentation are performed completely in one reactor, while in a continuous system, each phase takes place in different reactors. Among the effective parameters in this process are the food to microorganism (F/M) ratio, organic loading, mixed liquor suspended solids (MLSS), HRT, and sludge recycle rate (Lee & Lin 2007; Vasquez Sarria *et al.* 2011; Tchobanoglous *et al.* 2014).

Vasquez Sarria *et al.* (2011) investigated the effect of hydraulic retention time and sludge recycle rate on domestic wastewater treatment using contact stabilization process. Experiments were performed at different HRTs between 0.84 to 1.66 h in contact reactor and 2.65 to 4.65 h in stabilization reactor with sludge recycle rate between 40 and 100%. The best performance was obtained at 0.84 h in the contact reactor and 4.11 h in the stabilization reactor with removal efficiencies of 86, 87, and 82% for COD, BOD_5, and total suspended solids (TSS), respectively. The sludge recycle rate was 40%.

Advantages of the contact stabilization process over the conventional activated sludge method include smaller volume of aeration reactor, a high degree of purification, no need for initial sedimentation tank, and resistance to organic loading fluctuations (Ullrich & Smith 1951; Bunch & Griffin 1987). Moreover, this process has a great effect on controlling foaming and bulking phenomena, with high treatment efficiencies in the contact reactor without adverse effects on sludge properties such as poor sedimentation (Chudoba *et al.* 1973; Khararjian &

Sherrard 1978; Marten & Daigger 1997; Al-Mutairi *et al.* 2003). Due to the mentioned advantages, this process is very effective in the treatment of highly polluted wastewaters from industries, slaughterhouses, and hospitals. To the authors' knowledge no investigation has been done on the treatment of hospital wastewater using a contact stabilization process. Therefore, in this research, the performance of the contact stabilization process for the treatment of the organic matter in hospital wastewater has been investigated in a batch system. To evaluate the effect of detention time, different times have been considered for the contact and stabilization phases.

MATERIALS AND METHODS

Wastewater

The experiments were conducted on wastewater from Valiasr hospital located in Fasa, Iran. Wastewater was weekly collected from the influent of the primary settling basin of the hospital wastewater treatment plant and was stored in 4 °C before experiments. The characteristics of the wastewater are presented in Table 1.

Table 1 | Characteristics of the hospital wastewater

Parameter	Unit	Range value
pH		6.3–9.4
COD	mg/L	220–495
Conductivity	μS/cm	1,700–2,500

Experimental setup

In order to investigate the treatability of the wastewater by contact stabilization process, a batch system using sequencing batch reactor (SBR) process has been used. A schematic diagram of the system used in the laboratory is shown in Figure 1(a). The various phases of the process in the SBR, including contact, settling, and stabilization phases are also shown in Figure 1(b). A system using mechanical and electrical equipment was designed and implemented for performing experiments in different modes including various residence times. A plastic tank with a volume of 100 L was utilized for the feed storage. By connecting a pump to a timer and installing it inside the feed storage tank, influent flowrate was adjusted. Also, another container with an effective volume

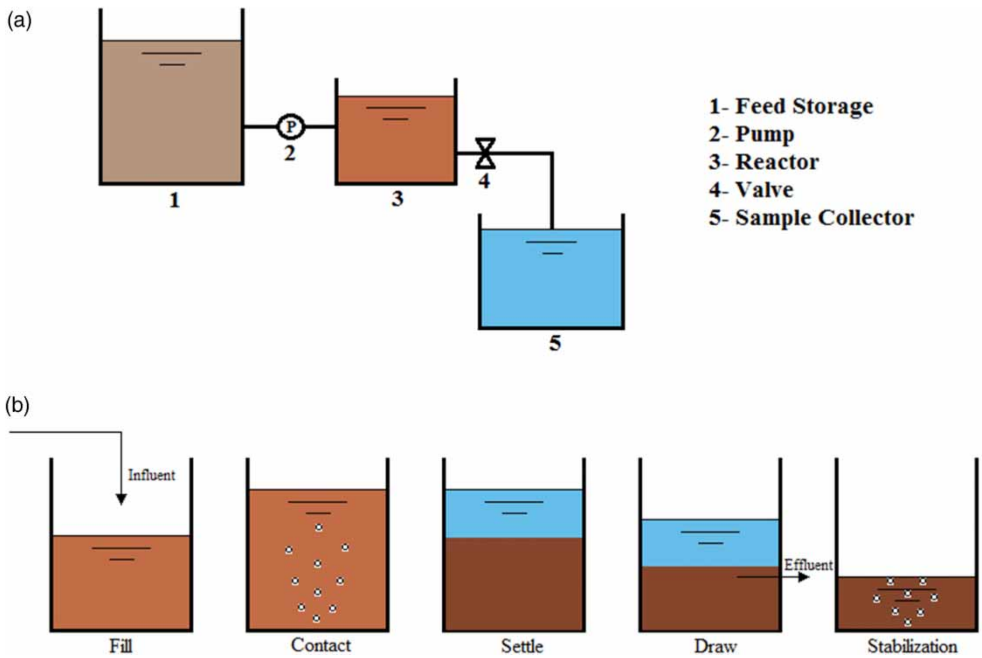


Figure 1 | (a) Schematic diagram of the experimental system, (b) Processes in the contact stabilization reactor.

of 9 L was considered as the main batch reactor for performing aeration, sedimentation, and stabilization phases. The components of this reactor included an electric valve placed on the reactor wall for discharging the treated effluent, and aquarium pumps and diffusers for aeration and supplying the oxygen needed for the biological process in the two phases of contact and stabilization. To turn the aeration diffusers on and off as well as to discharge the effluent at specific times, the aquarium pumps and electric valve were connected to timers. After the settling period, the treated effluent along with the excess sludge were discharged into the sample collector.

To start the experiments, return activated sludge of Valiasr hospital wastewater treatment with a concentration of about 9,000 mg/L volatile suspended solids (VSS) was used and diluted to be in the range of the recommended sludge concentration of 1,000–4,000 mg/L (Lee & Lin 2007; Tchobanoglous *et al.* 2014).

Process operating conditions

To investigate the effects of aeration time in the contact and stabilization reactors, detention times of 30, 60, and 90 min for the contact phase and 4.5 and 5.5 h for the stabilization phase were considered (Lee & Lin 2007; Vasquez Sarria *et al.* 2011; Tchobanoglous *et al.* 2014). Moreover, a detention time of one hour was chosen for sludge sedimentation and separation of the treated effluent. Table 2 shows the detention times in both contact and stabilization phases for the various experiments.

According to Figure 1(a), when the feed pump is turned on, wastewater from the feed storage enters the batch reactor. With the addition of wastewater to the sludge in this reactor, the contact phase begins (Figure 1(b)). After aeration of wastewater and sludge mixture for the periods specified in Table 2, the aeration system is switched off for one hour to allow the sludge to settle (settling phase). At the end of the settling phase, the electric valve installed on the reactor wall is switched on and the treated effluent and excess sludge are discharged. The aerators are then turned on and the sludge is aerated (stabilization phase). After the stabilization phase, the described steps are repeated. Wastewater sampling began after the sludge was acclimated (about 3 weeks from the start-up). For that, raw wastewater was continuously introduced into the reactor until the COD removal efficiency of the reactor was stabilized.

Table 2 | Hydraulic detention times in different experiments

Experiment no.	Contact (min)	Settle (h)	Stabilization (h)
1	30	1	5.5
2	60		
3	90		
4	30	1	4.5
5	60		
6	90		

Analytical methods

The characteristics of wastewater and sludge were assessed for different detention times in the contact and stabilization phases. Total and soluble COD concentrations of wastewater were measured using the closed reflux colorimetric method. The removal efficiencies were determined as follows:

$$\text{Removal}(\%) = \frac{C_i - C_e}{C_i} \times 100 \quad (1)$$

where C_i and C_e are the COD concentrations in the influent and treated samples, respectively.

MLSS, sludge volume index (SVI), and settled sludge volume (SSV) were determined according to standard methods for the examination of water and wastewater. Temperature and pH were monitored and recorded for different stages of the contact stabilization process.

RESULTS AND DISCUSSION

COD changes in experiments with a stabilization time of 5.5 h

In the first stage of the experiments, with a stabilization time of 5.5 h, the treated effluent was sampled at contact times of 30, 60, and 90 min. The results of the soluble COD are shown in Figure 2.

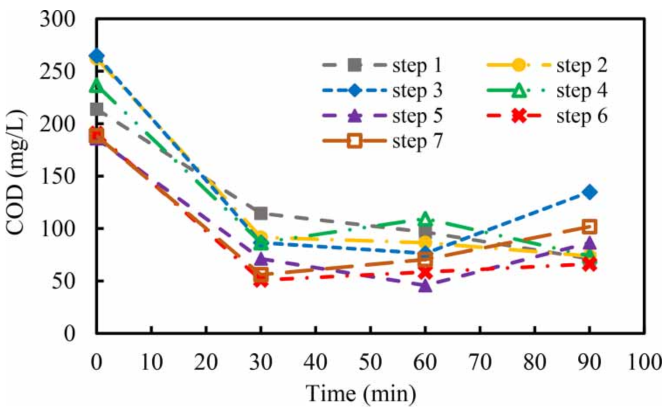


Figure 2 | Variations of COD of the treated wastewater for stabilization time of 5.5 h.

As shown in Figure 2, after an initial rapid COD removal in the first 30 min, COD values fluctuate in the time range of 30–90 min. According to the literature, a rapid reduction of colloidal organics is speculated to occur at the early stages of the aeration phase. Then, release of soluble organics followed by their utilization is assumed to happen as aeration continues (Figure 3) (Khararjian & Sherrard 1977; Bunch & Griffin 1987). Ullrich & Smith (1951) and Khararjian & Sherrard (1977) noticed a rapid decrease in BOD or COD in the early minutes of the contact reactor. Although Khararjian & Sherrard (1977) performed various experiments by changing the percentage of colloidal material in the influent wastewater to produce the relationship in Figure 3, they didn't notice any difference in the process of COD removal after the initial rapid reduction in the first minutes of the experiments. Therefore, they concluded that the percentage of colloidal organic matter does not affect the organic matter's removal curve.

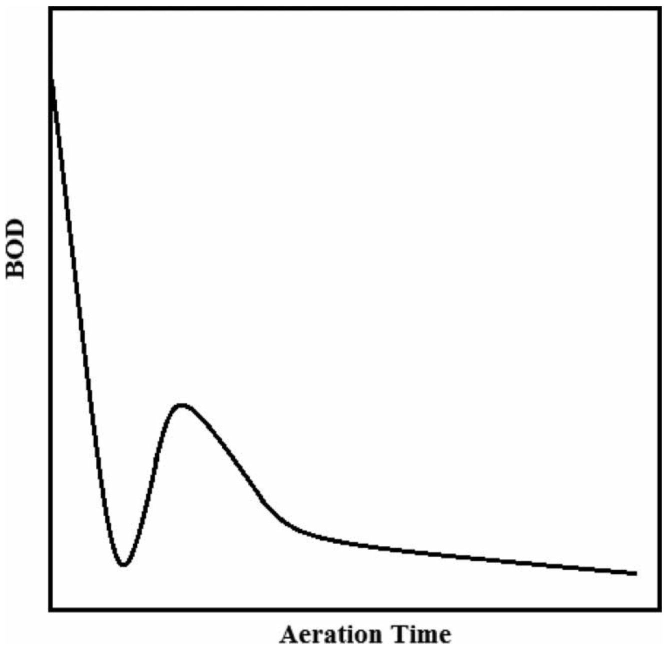


Figure 3 | Variations of BOD of the wastewater with aeration time.

Bunch & Griffin (1987) conducted more rigorous experiments by accurately determining the colloidal material in the wastewater using multiple filtrations in the COD test. They concluded that changes in COD concentration depend on the percentage of colloidal organic matter in the influent wastewater. A rapid removal of the colloidal matter was observed in the first minutes of the experiments, and in most experiments, 100% of the colloidal material was removed in the first 5 min. The results showed that the removal of colloidal materials occurs faster than soluble materials; however, no increase in soluble organic matter was observed after initial adsorption.

Comparison of total (unfiltered) and soluble (filtered) COD of the influent wastewater in the present study (Table 3) shows that significant amounts of 30%–47% of the input wastewater are suspended and colloidal materials. Therefore, the fluctuation in Figure 2 can be justified by assuming two stages in COD removal in the contact reactor. The first stage is the rapid drop in COD due to biosorption. Colloidal organic matters are physically adsorbed in the first stage by microorganisms, resulting in a rapid COD reduction in the contact reactor. In the following 60 min or the second stage, solubilized substrates resulting from the enzymatic breakdown of colloidal organic matter are released into the reactor and then are biodegraded by microorganisms. Thus, in the second stage, COD values in the contact reactor do not constantly decrease. However, based on whether the rate for soluble COD release is greater than the utilization rate or not, COD fluctuation, COD increase, or COD reduction may be observed in the contact reactor.

Table 3 | COD of influent and treated samples for stabilization time of 5.5 h

			Treated SCOD (mg/L)		
	Influent COD (mg/L)		Contact (min)		
Step no.	Total	Soluble	30	60	90
1	340.50	213.88	114.57	96.74	71.27
2	493.99	262.26	91.65	86.55	73.82
3	458.34	264.81	86.55	76.37	134.94
4	450.70	236.80	86.55	109.47	73.82
5	341.21	185.87	71.27	45.81	86.55
6	274.99	190.96	50.90	58.54	66.18
7	221.52	188.41	55.99	70.50	101.83

COD changes in experiments with a stabilization time of 4.5 h

In the second stage of the experiments, the treatment process was evaluated with a stabilization time of 4.5 h and contact times of 30, 60, and 90 min. The results of the sampling (soluble COD) for different times in the contact reactor are given in Table 4 and Figure 4. According to the graphs, in this experiment, the COD of the treated wastewater has the highest reduction in the first 30 min, and after that, the rate of COD removal dramatically drops.

Table 4 | COD of influent and treated samples for stabilization time of 4.5 h

			Treated SCOD (mg/L)		
	Influent COD (mg/L)		Contact (min)		
Step no.	Total	Soluble	30	60	90
1	338.66	269.90	96.74	78.92	71.28
2	361.58	277.54	91.65	66.18	61.09

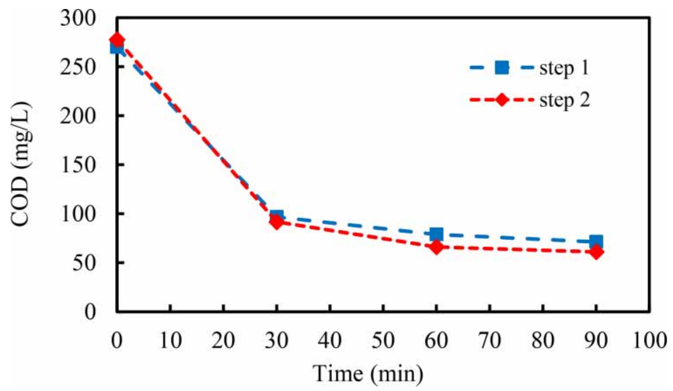


Figure 4 | Variations of COD of the treated wastewater for stabilization time of 4.5 h.

Total (unfiltered) and soluble (filtered) COD of the influent samples show the presence of 20%–23% of suspended and colloidal materials, which is lower than in the first stage of the experiment with a stabilization time of 5.5 h. The results at this stage show a gradual decrease in the COD of the treated effluent, which can be attributed to the higher percentage of soluble substances in the wastewater. In a study by Bunch & Griffin (1987), a similar decreasing trend was observed for soluble materials in the wastewater.

COD removal efficiency

To determine the best detention time for both contact and stabilization phases, the COD removal efficiency was evaluated in different stages. According to Figures 5 and 6, the changes in COD removal efficiency in the early minutes of the contact reactor are very large. In the first 30 min, the COD removal efficiency increases rapidly, and in most stages, it almost reaches a maximum value and then decreases over time. In some cases, an increasing trend is observed again; however, variations in removal efficiency after 30 min are negligible. Therefore, it can be concluded that 30 min is the best detention time for the contact reactor. To determine the best stabilization time between 4.5 and 5.5 h, Figures 5 and 6 were compared in the first 30 min (suitable contact detention time). According to the diagrams, in the first 30 min, the removal efficiency in the contact reactor increases form 67% for 4.5 h of stabilization to 73% for 5.5 h of stabilization. Therefore, it can be concluded that a detention time of 5.5 h is the optimal time for the stabilization phase.

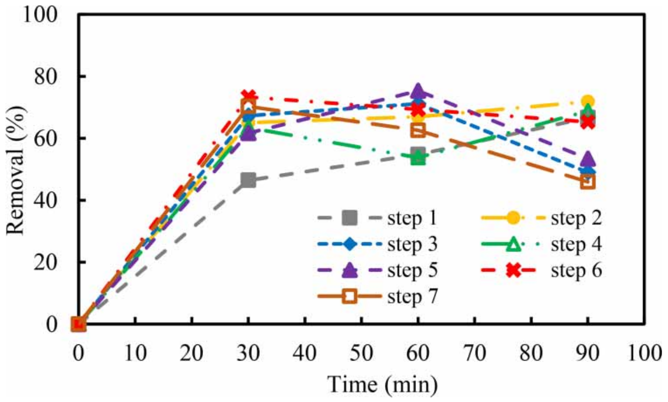


Figure 5 | COD removal efficiency at the stabilization time of 5.5 h.

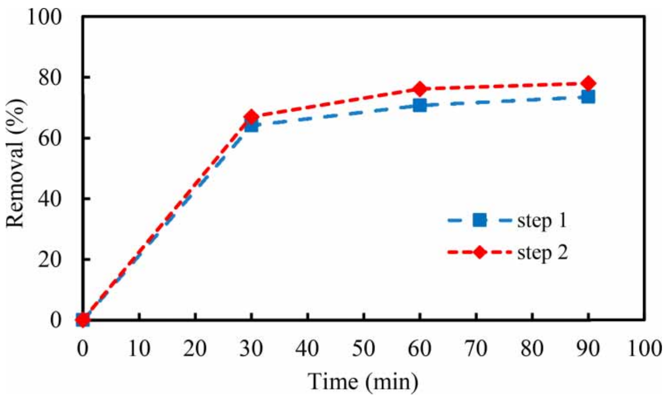


Figure 6 | COD removal efficiency at the stabilization time of 4.5 h.

MLSS in activated sludge

Figure 7 shows changes in MLSS at stabilization times of 4.5 and 5.5 h for different times in the contact reactor. MLSS concentrations of 1,000–4,000 mg/L in the contact reactor, and 6,000–10,000 mg/L in the stabilization reactor have been reported (Lee & Lin 2007; Tchobanoglous *et al.* 2014). The pilots were started with initial concentration of sludge greater than 4,000 mg/L in order to assure that in the acclimation phase the probable loss of MLSS does not affect the system. After acclimation, the concentration of MLSS remained slightly above 4,000

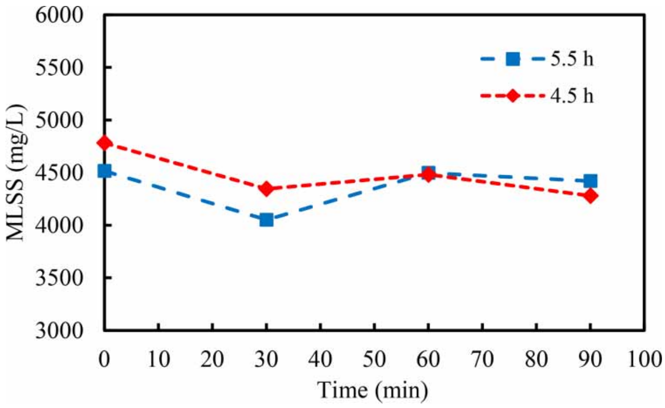


Figure 7 | MLSS values at stabilization times of 4.5 and 5.5 h.

and since the overall efficiency of the system was not deteriorated, MLSS concentration in the contact reactor was not reduced.

Sludge settling characteristics

An SVI with values equal to or less than 100 mL/g indicates a well-precipitated sludge. Values greater than 150 mL/g usually indicate the growth of filamentous bacteria (Tchobanoglous *et al.* 2014). The SSV index also shows the volume of sludge settling overtime or the rate of sludge settling. The results showed that SVI has values of 109.17 and 119.20 mL/g for stabilization times of 5.5 and 4.5 h, respectively. Therefore, the longer the stabilization time, the closer the SVI is to 100 mL/g. Also, according to Figure 8, which shows the settling heights in terms of time, SSV is smaller for the stabilization time of 5.5 h and the sludge has better properties than the stabilization time of 4.5 h.

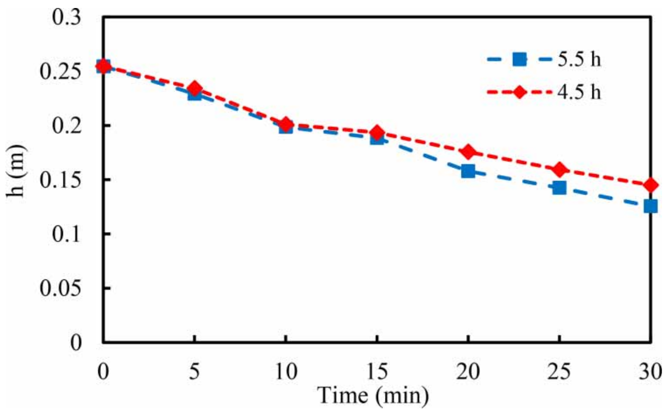


Figure 8 | Settled sludge heights at stabilization times of 4.5 and 5.5 h.

Temperature and pH

Environmental conditions such as temperature and pH have important effects on the growth of microorganisms. In general, the desirable growth of microorganisms occurs in relatively small ranges of temperature and pH, although most microorganisms can survive in a wider range. The optimum temperature for bacterial activity is in the range of 25–35 °C (Tchobanoglous *et al.* 2014). According to the results, the average temperature in the first and second stages of the experiments with the stabilization times of 5.5 h, and 4.5 h were measured to be 18 °C and 17 °C respectively.

pH is also a key factor in the growth of microorganisms. Most bacteria cannot tolerate pH above 9.5 or less than 4. To remove carbonaceous organic matter, pH in the range of 6–9 is tolerable for microorganisms. However, the optimal efficiency occurs at a pH close to neutral and in the range of 6.5–7.5 (Tchobanoglous *et al.* 2014). The results of the measured pH for the two stages with stabilization times of 4.5 and 5.5 h showed that the pH varies in the range of 7–8, which is a suitable range for the growth of microorganisms.

CONCLUSIONS

In this study, hospital wastewater treatment was investigated using the contact stabilization process. Because hospital wastewater may introduce a significant organic shock load, the contact stabilization process is a suitable method for its treatment. It should be noted that this method has a great impact on control and endurance against phenomena such as foaming and bulking. Also, this method reduces the volume of the aeration tank. Considering these benefits, the costs related to the design and construction of reactors and also the cost of aeration can be reduced.

Wastewater treatment was investigated in stabilization times of 5.5 and 4.5 h, and detention times of 30, 60, and 90 min for the contact reactor. The results showed that the presence of colloidal organic matter in the wastewater affects the treatment process and removal efficiency in this method. It was observed that presence of the colloidal substances increases the process of adsorption of organic matter and thus the reduction of COD in the early minutes of the experiment. According to the results, the COD removal efficiency in the first 30 min of the contact phase is very high and most of the COD removal occurs in this time period. After that, the removal efficiency decreases, and in some steps increases again, although the amount is very small compared to the first 30 min. Therefore, a residence time of 30 min can be considered as the best detention time for the contact reactor. Comparison of removal efficiency at the optimal contact time of 30 min, in two stages with stabilization times of 4.5 and 5.5 h, shows the comparative advantage of the stabilization phase with a detention time of 5.5 h. Therefore, a time of 5.5 h can be considered as the optimal detention time in the stabilization reactor.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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