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Treatment of highly polluted grey waters using Fenton, UV/H_2O_2 and UV/TiO_2 processes

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Abstract. Household or office wastewater consists of two parts of faecal and non-faecal wastewater. Non-faecal section, which accounts for more than 60% of household wastewater, is known as grey water. Treating this part of sewage and using it in various areas can greatly reduce the consumption of potable water. In this research, three methods of advanced oxidation processes including Fenton, UV/H_2O_2, and UV/TiO_2 were investigated for treatment of two grey water sourced from Shif Island and Persian Gulf University restaurant in Bushehr province of Iran. These grey waters were highly polluted with COD content of 600 mg/L and 1400 mg/L, respectively. The efficiency of each process was determined by measuring the COD removal rate. Results showed that at optimum reaction conditions, the COD removal efficiency of the UV/H_2O_2 process was the best, compared to the other two processes. The COD removal efficiency of UV/H_2O_2 process at pH = 3 and H_2O_2 = 1500 and 750 mg/L for grey water of the Shif Island and Persian Gulf University restaurant were 88% and 90%, respectively. Therefore, the treated gray waters can be reused economically.

Keywords: grey water; Fenton process; UV/H_2O_2 process; UV/TiO_2 process

1. Introduction

Water is one of the most important resources for the survival of planetary organisms and an essential tool for the healthy development of humans. Today, due to various reasons such as industrial growth, population growth, climate change, and the simplification of water use water consumption and pollution have increased, and on the other hand, access to clean water has decreased (Khan *et al.* 2016, Wang *et al.* 2019, Behrouzeh *et al.* 2020, Melo *et al.* 2020). As a result, in addition to managing water resources, planning for the reuse of contaminated water resources is inevitable (Cha *et al.* 2020, Kumar *et al.* 2020). One of the resources available for reuse is household sewage. Household sewage includes sewage of the toilet, kitchen, and bathroom. Moreover, it includes part of sewage from stores, restaurants, and other institutions (Shamabadi *et al.* 2015, Leong *et al.* 2018b). This resource is one of the largest water resources and its recycling can reduce 30-50% of potable water consumption (Al-Jayyousi 2003, Oh *et al.* 2018). Household sewage consists of two categories: the first is black-water that defined as toilet sewage and the second is grey water that includes other household sewage sources, which is 67% of total household sewage (Chanakya and Khuntia 2014, Boguniewicz-Zablocka *et al.* 2019, Ligaray *et al.* 2019). The amount of pollutants in grey water depends on several factors such as living standards, population structure, customs and habits, water and wastewater distribution systems, water abundance, type and amount of chemicals that usually used by people (Tsoumachidou *et al.* 2017). The existence of a wide range of contaminants makes researchers to use different physical, chemical, and biological methods to achieve the best method for treating grey water (Ghaitidak and Yadav 2013). Physical methods such as screening and filtration (Šostar-Turk *et al.* 2005, Katukiza *et al.* 2014, Leong *et al.* 2018a), chemical methods such as coagulation, ion-exchange, and advanced oxidation processes (AOPs) (Šostar-Turk *et al.* 2005, Pidou *et al.* 2008, Ghaitidak and Yadav 2013, Chong *et al.* 2015) and biological processes such as rotary biological contactors, continuous batch reactors, membrane bioreactors, and moving bed biofilm reactor (Nolde 2000, Merz *et al.* 2007, Chrispim and Nolasco 2017, Prajapati *et al.* 2019) have been investigated. Each of these methods has advantages and disadvantages and choice of the appropriate method for treatment of grey water depends on the grey water source, the quantity, quality, location specifications and its reuse (Edwin *et al.* 2014). However, among the methods mentioned, AOPs have been getting increasingly important due to the high strength of organic compounds decomposition (Fang *et al.* 2017). In these methods, •OH is produced which is the strongest free radical after fluorine. This compound is highly reactive, unstable, and has an average life of less than nanoseconds (Munter 2001), which quickly reacts with compounds in grey water and decomposes pollutants. So far, many studies have been carried out on grey water treatment with AOPs. Li *et al.* (2004) utilized constructed wetlands and subsequently photocatalytic oxidation. They

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were able to eliminate all organic compounds in a relatively long time period. Yonar *et al.* removed 95% COD content using UV/H_2O_2 method in optimum conditions for solution pH and H_2O_2 concentration (Yonar *et al.* 2006). Chin *et al.* reduced 87% of COD content using UV/H_2O_2 under optimal conditions (Chin *et al.* 2009). They also investigated kinetic of the reaction and concluded that the reduction of COD follows the second-order kinetic equation. Sanchez *et al.* investigated grey water treatment using photocatalytic process and recorded 65% TOC removal (Sanchez *et al.* 2010). They also could eliminate anionic surfactants, which are major contaminants of grey water. Hernandez *et al.* investigated four methods consist of aerobic, aerobic and anaerobic, aerobic and active carbon, and aerobic and ozone combinations. They concluded that aerobic biological treatment, followed by the use of activated carbon and ozone, could eliminate the contaminants of grey water (Leal *et al.* 2012). Tony *et al.* (2016) used Fenton method for treatment of grey water. They showed the ability of this process for removing 95% of COD content of grey water. Concerning the high potential of AOPs, in this research, it has been tried to compare three methods of AOPs consist of Fenton, UV/H_2O_2, and UV/TiO_2 for real grey waters treatment. Grey water sources are collected from two rural and urban sites. The first source is collected from the household sewage of the rural Shif Island in the Bushehr province of Iran, which lacks a wastewater treatment plant. The second source of gray-water is collected from the Persian Gulf University (PGU) restaurant in Bushehr city.

2. Materials and methods

Ferrous sulfate heptahydrate (purity ≥ 99%), Hydrogen peroxide (purity 30%), Titanium dioxide Degussa P-25 (surface area = 50 m^2/g and particle size = 21 nm), Sulfuric acid (purity 97%), and Sodium hydroxide (purity ≥ 99%) were purchased from Merck Chemical Company (Germany).

A 8W 254 nm UV lamp was utilized in the UV process. Chemical oxygen demand (COD) measurement was carried out using DR900 Hach photometer and quick test cuvettes ranging from 0-1500 mg/L. To prepare each sample for COD analysis, 2 mL of the sample was poured into quick test cuvette and the cuvette placed in the COD reactor at 150°C for 2 h. Then the cuvette was placed out of the reactor to reach ambient temperature. Biochemical oxygen demand (BOD) was analyzed using BD-600 Lovibond tintometer. The pH and electrical conductivity (EC) of the grey waters were measured with a multi-9620 WTW multimeter. Also, nitrate, phosphate, and sulfate, chloride, oil and surfactant concentrations were determined using 4500 NO_3-E, 4500 P-C, 4500 SO_4-C, 4500 Cl-B, 5520-B, and 5540-C standard protocols, respectively. The Fecal coliform as well as total coliform were determined by most probable number (MPN) method. The measured parameters of the two grey waters are shown in Table 1.

To perform various experiments related to the designed processes, a 1.5-liter pyrex cylindrical glass reactor was used. In each experiment, 1 liter grey water was introduced into the reactor and then the reactor was transferred on a digital magnetic stirrer at 300 rpm.

Table 1 Detailed parameters of two types of real grey waters

Grey water	Shif Island	PGU Restaurant
COD (mg/L)	600	1400
BOD (mg/L)	225	415
Fat and oil (mg/L)	129.6	383
pH	7.8	8.5
EC (mS/m)	16.72	18.58
Chloride	177	280
Fecal coliform (MPN)	90	0
Total coliform (MPN)	300	0
Sulfate (mg/L)	64	665
Nitrate (mg/L)	100.4	10.5
Phosphate (mg/L)	38.3	22.5
Surfactant	0.252	0.796

After that, in the Fenton process: 150-1250 mg/L Ferrous Sulfate- as the source of Fe^{2+} ion- and 250-3000 mg/L H_2O_2 was poured into the reactor. After the reaction had finished, excess Fe^{2+} was precipitated during 2 h by adding 1 M NaOH solution. Also, for the UV/H_2O_2 process: UV lamp was placed inside the reactor and then 125-2500 mg/L H_2O_2 was added to the reactor. In addition, for the UV/TiO_2 process, after inserting the UV lamp, 0.25 to 1.5 g/L TiO_2 was added to the reactor. For all processes, after the process had started the sampling took place at regular intervals. After that, each sample was filtered by glass fiber filter to separate precipitated solids and TiO_2-except for UV/H_2O_2 samples-and to ensure that no interactions were caused by H_2O_2, samples were placed at 50°C in an oven for 1 h. For each of three processes, sulfuric acid and sodium hydroxide were used to adjust the solution pH.

3. Results and discussion

3.1 Application of Fenton process for treatment of grey waters

To investigate the ability of the Fenton process for COD removal of grey water, the effect of various parameters such as process time, Fe^{2+} content, H_2O_2 content and the solution pH were examined on the process efficiency. The design of experiments is based on that the effect of each parameter will be carried out at fixed value of the other variables.

3.1.1 Effect of time on COD removal by the Fenton process

To find out the effect of time on COD removal by the Fenton process, COD removal test was carried out for two samples of grey water. The results of the COD removal due to Fenton process are shown in Fig. 1.

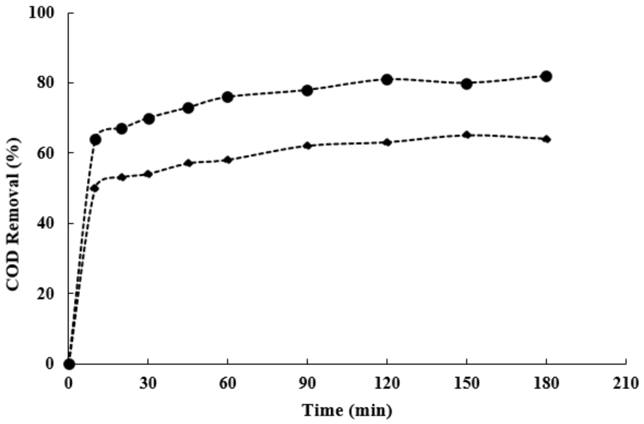


Fig. 1 Effect of time in Fenton process for COD removal of grey waters of Shif Island (●) and PGU restaurant (♦) (pH = 3, Fe2+ = 250 mg/L and H_2O_2 = 500 mg/L)

As it can be seen from the Fig. 1, COD removal due to organic compounds decomposition for both grey waters from the Shif Island and PGU restaurant is rapid in the early times (0-10 min), and then the rate of decomposition of the compounds decreases after 90 min. Also, the process of decomposition continues at a very slow rate until 180 min. To justify this phenomenon, the reactions associated with the initiation of the Fenton process can be used as below (Harimurti *et al.* 2010):

$$Fe^{2+} + H_2O_2 \rightarrow Fe^{3+} + \cdot OH + OH^- \quad (1)$$

$$\cdot OH + Fe^{2+} \rightarrow OH^- + Fe^{3+} \quad (2)$$

$$Fe^{3+} + H_2O_2 \rightarrow Fe - HO_2^{2+} + H^+ \quad (3)$$

$$Fe - HO_2^{2+} \rightarrow HO_2^{\cdot} + Fe^{2+} \quad (4)$$

$$HO_2^{\cdot} + Fe^{2+} \rightarrow Fe^{3+} + HO_2^{\cdot} \quad (5)$$

$$Fe^{3+} + HO_2^{\cdot} \rightarrow Fe^{2+} + H^+ + O_2 \quad (6)$$

$$\cdot OH + H_2O_2 \rightarrow H_2O + HO_2^{\cdot} \quad (7)$$

$$2H_2O_2 \rightarrow 2H_2O + O_2 \quad (8)$$

Fenton process initiate with reaction 1 that •OH is generated and this step is carried out rapidly. After that, a complex reaction sequence will generate products that were shown in reactions 2 to 8. In the presence of grey water, generated •OH quickly enter the chain reactions for decomposition of grey water compounds. Therefore, the decomposition process rate is fast at early minutes. After that, based on the reactions 3 and 4, the reduction of Fe^{3+} to Fe^{2+} will compete with reaction 1 and hence it will limit the efficiency of COD removal (Neyens and Baeyens 2003). Another reason for the slowdown COD removal efficiency is carbonate and bicarbonate production during the reaction that can act as a scavenger for •OH (Buxton *et al.* 1988).

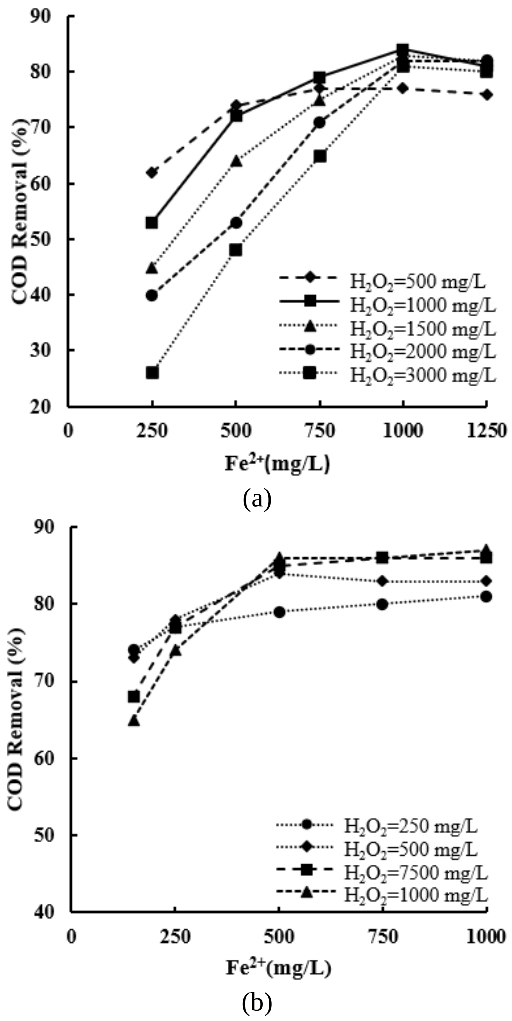


Fig. 2 Effect of various H_2O_2 and Fe^{2+} concentration on COD removal efficiency of: (a) PGU restaurant and (b) Shif Island grey water at pH= 3 & Time=90 min

3.1.2 Effect of Fe2+ and H2O2 concentration in Fenton process

In this section, effect of various concentration of Fe^{2+} and H_2O_2 on COD removal efficiency have been investigated. Fe^{2+} and H_2O_2 concentration were selected 150-1250 mg/L and 250-3000 mg/L, respectively. The results of COD removal for Shif Islands and PGU restaurant grey waters are shown in Fig. 2. Analysis of data presents that for both grey waters, there is an optimum value for Fe^{2+} concentration at constant H_2O_2. Under this optimum value, raising Fe^{2+} concentration causes increase in COD removal efficiency. In fact, the higher the Fe^{2+} concentration means the higher amount of catalyst to react with H_2O_2 and hence the higher •OH production according to the reaction 1. However, when the Fe^{2+} concentration goes higher than optimum value, causes reduction in COD removal efficiency, which is converting Fe^{2+} to Fe^{3+} according to the reaction 2. In fact, Fe^{2+} at high concentrations reacts with the •OH and neutralizes its effect. Another point that can be drawn from the results is that increasing H_2O_2 concentration at a constant Fe^{2+} concentration can reduce COD removal efficiency. This point is also justified by reactions 7 and 8.

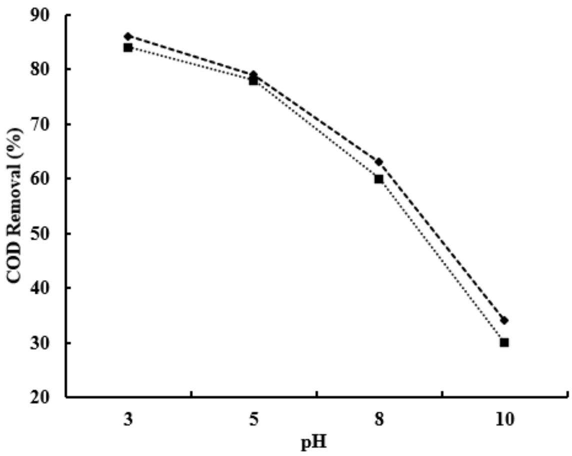
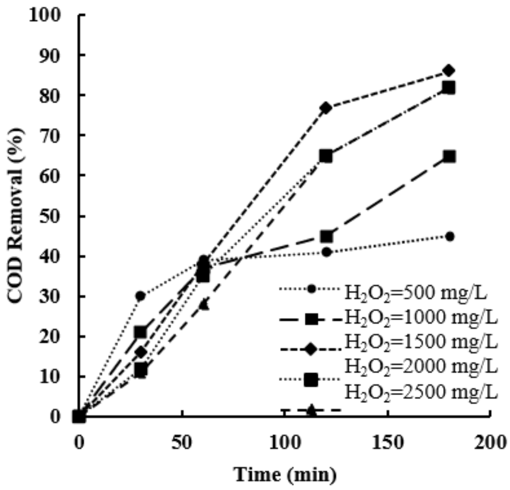


Fig. 3 Effect of different pH on COD removal efficiency in Fenton method (PGU restaurant (■): Fe^{2+}=1000 mg/L, H_2O_2=1000 mg/L; Shif Island (♦): Fe^{2+}=500 mg/L and H_2O_2=500 mg/L; Time=90 min)



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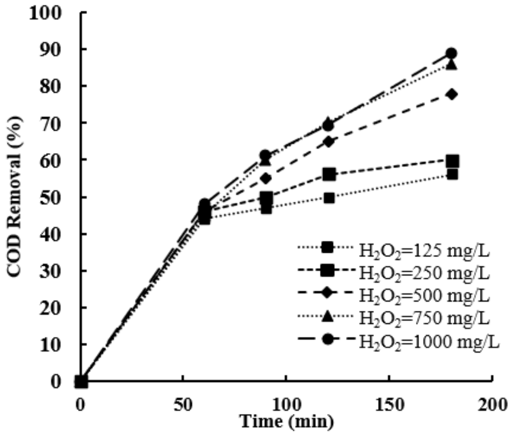


(b)

Fig. 4 Effect of time and various H_2O_2 concentrations on COD removal efficiency of: (a) PGU restaurant and (b) Shif Island grey water by UV/H_2O_2 process; at initial pH = 8

Increasing H_2O_2 concentration will increase the pair collisions of H_2O_2-H_2O_2 and H_2O_2-•OH which would neutralize H_2O_2 effect and eventually reduce the reaction efficiency (Wu *et al.* 2011, Babuponnusami and Muthukumar 2014).

In order to evaluate the results in the best way and to obtain optimal parameters for the highest efficiency in COD removal, H_2O_2:Fe^{2+} ratio can be used. According to the trends of Fig. 2, when the ratio is 1:1, the highest efficiency is observed in COD removal (84% COD removal for PGU restaurant at Fe^{2+} = 1000 mg/L and H_2O_2 = 1000 mg/L and 86% COD removal at Fe^{2+} = 500 mg/L and H_2O_2 = 500 mg/L for Shif Island grey water), and if this 1:1 ratio kept constant, increasing the Fe^{2+} and H_2O_2 concentration, will improve COD removal efficiency (Hassanshahi and Karimi-Jashni 2018).

3.1.3 Effect of pH in Fenton process

To investigate the effect of solution pH on COD removal efficiency, the pH range of 3 to 10 were selected for both grey water sources in Fenton process. Fig. 3 shows the results of both PGU restaurant and Shif Island samples. The results indicate that pH around 3 has the highest COD removal efficiency. It should be noted that at this solution pH, the concentration of Fe^{2+} is at its maximum and therefore the rate of Fenton process will be as high as possible (Rivas *et al.* 2001, Babuponnusami and Muthukumar 2011). At pH higher than 5, Fe^{3+} that produced according to the reaction 1, will deposit and hence the concentration of Fe^{2+} in the solution will decrease. Also, at high pH, there is a potential for H_2O_2 decomposition according to the reaction 8 and consequently less •OH is produced.

3.2 Application of UV/H_2O_2 process for treatment of grey waters

3.2.1 Effect of time and H_2O_2 concentration in UV/H2O2 process

To obtain the effect of time and H_2O_2 concentration on COD removal efficiency in the UV/ H_2O_2 process, different concentration of H_2O_2 from 125 to 2500 mg/L were tested. After the reaction was begun, samples were taken from the solutions. Results of COD removal for Shif Islands and PGU restaurant are shown in Fig. 4. As shown in Fig. 4, COD reduction increases with time significantly at initial according to equation 9 (Muruganandham and Swaminathan 2004), due to the high concentration of H_2O_2, •OH radical production is much higher, which leads to the accelerating the COD removal process. After that, due to decreasing H_2O_2 concentration and also the creation of side reactions, the rate of COD removal is reduced. About effect of H_2O_2 concentration it must be noted that, increasing the concentration of H_2O_2 has improved the efficiency of the COD removal. But it has an optimum value, and excess H_2O_2 may act in a reverse way.

$$H_2O_2 + hv \rightarrow 2 \cdot OH \quad (9)$$

$$H_2O_2 \leftrightarrow HO_2^- + H^+ \quad (10)$$

$$HO_2^{\cdot} + HO_2^{\cdot} \rightarrow H_2O_2 + O_2 \quad (11)$$

Indeed, as noted in section 3.1.2 and according to the reaction 7, increasing the concentration of H_2O_2 increases the possibility of the collision between H_2O_2 molecules and •OH radical. Thus, H_2O_2 can acts as •OH scavenger and reduces the process efficiency (Yonar *et al*. 2006).

3.2.2 Effect of pH in UV/H2O2 process

The pH values between 3 and 12 were selected for investigating the effect of solution acidity or alkalinity on the COD removal in UV/H_2O_2 process. As shown in Fig. 5, at the pH value of 3 the COD removal is the highest values respect to other values of the solution pH. In fact, in the neutral and alkaline pH, the presence of initial carbonates in grey water has the potential to consume •OH radicals and reduce process efficiency. Also, the possibility of H_2O_2 decomposition increases according to the reaction 8 (Muruganandham and Swaminathan 2004).

3.3. Application of UV/TiO2 process for treatment of real grey waters

In this method, the UV radiation as well as TiO_2 nano-particles were used for COD removal from grey water samples. The effects of process time, nanoparticle concentration, and initial solution pH were investigated for getting the best results of COD removal efficiency.

3.3.1 Effect of time and TiO2 concentration in UV/TiO2 process

To evaluate the effect of time and TiO_2 concentration on COD removal efficiency in the UV/ TiO_2 process, the TiO_2 concentration was varied between 0.25 to 1.5 g/L. After the reaction was begun, samples were taken from the solution. The results of COD removal were shown in Fig. 6 using UV/TiO_2 process. The trends of the results are the same for both UV/ TiO_2 and UV/H_2O_2 processes. At early times, the rate of COD removal is high but after with the continuation of the reaction, the rate of COD removal reduced. The removal efficiency of COD was increased by increasing photocatalyst concentration. This phenomenon may be due to increasing the number of active sites by increasing photocatalyst concentration. But, the COD removal from grey water of PGU restaurant was decreased when the photocatalyst concentration increased from 1.0 g/L to 1.5 g/L. The results showed that photocatalyst concentration has an optimum value and above this concentration, the photon absorption coefficient will decrease rapidly. The presence of excess amounts of TiO_2 nanoparticles result in the scattering of photons, a decrease in the surface area of the TiO_2 nanoparticles which is exposed to radiation, reduction of light penetration through the solution, and a reduction in the efficiency of the photocatalyst process (Gaya and Abdullah 2008). For the Shif Island grey water, an increase in TiO_2 concentration from 0.5 g/L to 0.75 g/L causes a rapid increase in the COD removal efficiency. But afterward, at higher catalyst concentration, increasing TiO_2 concentration has not a significant impact on the COD removal efficiency. Of course, for Shif Island grey water, due to the lower initial COD concentration, the phenomenon of reduced light transmission in grey water occurred at higher concentrations of TiO_2 nanoparticles.

3.3.2 Effect of pH in UV/TiO2 process for treatment of real grey waters

In photocatalytic systems, the solution pH is one of the most important parameters. The pH will have an effect

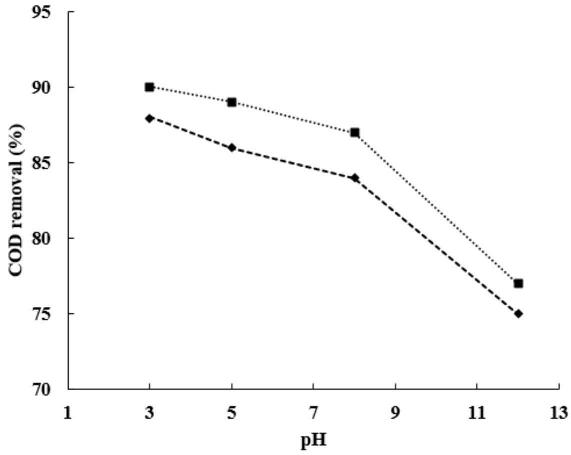
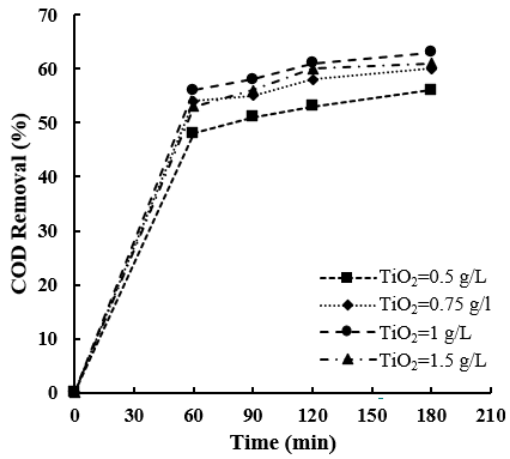
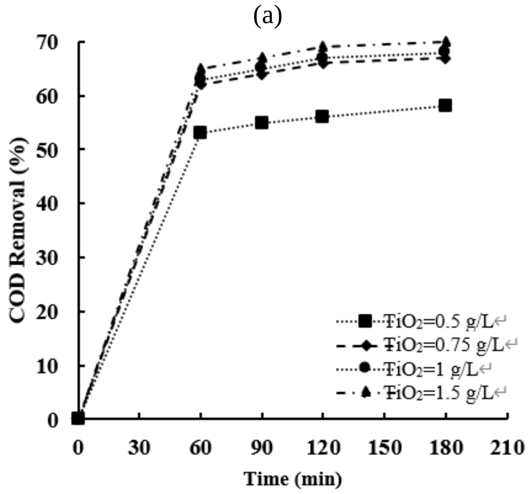


Fig. 5 Effect of different pH on COD removal efficiency in UV/H_2O_2 process (PGU restaurant (♦): H_2O_2 = 1500 mg/L and Shif Island (■): H_2O_2 = 750 mg/L; Time = 180 min).



(a)



(b)

Fig. 6 Effect of time and various TiO_2 concentrations on COD removal efficiency of: (a) PGU restaurant and (b) Shif Island grey water by UV/ TiO_2 process; at initial pH

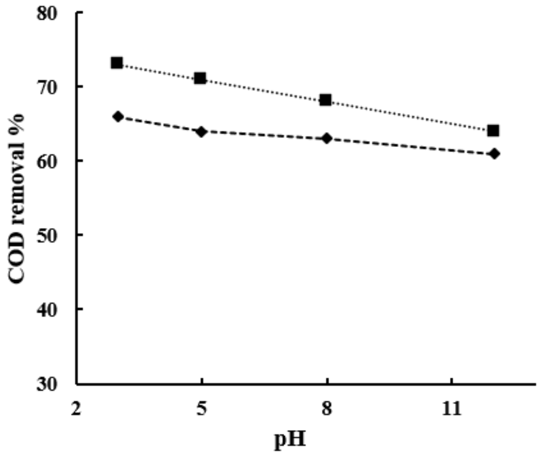


Fig. 7 Effect of different pH on COD removal efficiency in UV/TiO2 process (PGU restaurant (♦): TiO_2 = 1 g/L and Shif Island (■): TiO_2 = 1 g/L; Time=180 min).

on the charge of photocatalyst particles, photocatalyst agglomeration, and the position of valence/conduction bands. To evaluate the effect of acidity and alkalinity on the photocatalytic process, pH values between 3 and 12 were selected. According to Fig. 7, the best COD removal efficiency was been obtained at pH = 3. The COD removal efficiency has decreased by increasing the pH of the solution. This phenomenon relates to the properties of the photocatalyst. In fact, the point of zero charge (PZC) of the photocatalyst is important in evaluating the initial solution pH effect. At lower and higher pH of the solution respect to the PZC, the net surface charge will be positive and negative, respectively. When the pH of the solution is less than the PZC of photocatalyst particles, more negatively charged compounds (anion) adsorbed on the surface of the photocatalyst due to increasing positive charge of these nanoparticles. Conversely, when the surface charge of the photocatalyst is negative, the tendency to adsorb cations increases in the solution. It should be noted that the grey waters used contains many compounds that contain cations and anions, each of which exhibits different behavior at different pH of the solution. Due to the high concentration of surfactants in the grey water, both wastewaters contain a wide range of anions. The PZC of TiO_2 solution is around 6.5, thus, it can adsorb more anions in acidic pH of the solution. Also, the pH of solution can cause increasing radical scavenging. Therefore, the process has higher efficiencies in acidic solution pH (Kang *et al.* 2011, Boyjoo *et al.* 2012).

3.4 Comparison of the best COD removal efficiencies of processes

The optimal COD removal results for both grey water sources with the Fenton, UV/H_2O_2, and UV/TiO_2 processes are summarized in Table 2. Based on the results on both PGU and Shif Island grey water samples, 90 min and 180 min process time is the best operating time for Fenton and UV/H_2O_2 as well as UV/TiO_2, respectively. Moreover, the results showed that high acidity of samples (pH = 3) is the most favorable solution pH for COD removal in all

Table 2 Comparison of optimal COD removal efficiencies (%) for Fenton, UV/H_2O_2, and UV/TiO_2 processes for PGU restaurant and Shif Island grey waters

Method / Grey water	**Fenton**	**UV/H_2O_2**	**UV/TiO_2**
PGU restaurant	84	88	66
Shif Island	86	90	73

processes. Based on the results, the UV/H_2O_2 process for both grey waters has the highest COD removal efficiency under the optimum conditions. These results are acceptable in comparison with previous literature results such as: 87% COD reduction of gray water using UV/H_2O_2 process (Chin *et al*. 2009), 65% TOC removal of gray water using photocatalytic process (Sanchez *et al*. 2010) and removing 95% of COD content of grey water using Fenton method (Tony *et al*. 2016).

4. Conclusions

In this research, besides of the investigation of the ability of Fenton, UV/H_2O_2, and UV/TiO_2 processes for COD removal of grey water, various parameters including time, Fe^{2+} content, H_2O_2 and TiO_2 concentrations, and pH of aqueous solution were evaluated. Experimental results showed that for the Fenton process, the ratio of Fe/H_2O_2 set to 1 was the best, and it was observed that at this ratio, increasing Fenton concentration can enhance the COD removal efficiency. Moreover, it was found that optimal acidity for this process was pH = 3. For the UV/H_2O_2 process, it was also found that increasing the H_2O_2 concentration in a limiting value could raise the COD removal efficiency. The limiting value of H_2O_2 concentration corresponded to the acidity of the aqueous solution that its optimized value is pH = 3. Also, in the photocatalytic method, it was found that by increasing the photocatalyst concentration, COD removal efficiency will increase. But over-optimal concentration can reduce the efficiency of the process. In fact, it can be concluded that the UV/H_2O_2 process for both Shif Island and PGU restaurant has the highest COD removal efficiency that corresponds to 88% and 90%, respectively. Of course, for discharging the treated wastewaters to the environment or treat/eliminate the intermediaries, additional processes such as adsorption, membrane or novel processes probably needed because the degradation process must have non-toxic end products. In the other hand, various parameters plus ultimate COD of treated wastewaters is considered in different environmental standards for discharging treated wastewaters, and this subject can be investigated in future researches.

References

Al-Jayyousi, O.R. (2003), "Greywater reuse: Towards sustainable water management", *Desalination*, **156**(1-3), 181-192. https://doi.org/10.1016/S0011-9164(03)00340-0.

Babuponnusami, A. and Muthukumar, K. (2011), "Degradation of phenol in aqueous solution by fenton, sono-fenton and sono-photo-fenton methods", *Clean Soil Air Water*, **39**(2), 142-147. https://doi.org/10.1002/clen.201000072.

Babuponnusami, A. and Muthukumar, K. (2014), "A review on Fenton and improvements to the Fenton process for wastewater treatment", *J. Environ. Chem. Eng*., **2**(1), 557-572. https://doi.org/10.1016/j.jece.2013.10.011.

Behrouzeh, M., Abbasi, M., Osfouri, Sh. and Dianat, M.J. (2020), "Treatment of DMSO and DMAC wastewaters of various industries by employing Fenton process: Performance efficiency and kinetics study", *J. Environ. Chem. Eng*., **8**(1), 103597. https://doi.org/10.1016/j.jece.2019.103597.

Boguniewicz-Zablocka, J., Klosok-Bazan, I., Naddeo, V. and Mozejko, C. A. (2019), "Cost-effective removal of COD in the pre-treatment of wastewater from the paper industry", *Water Sci. Technol*., **81**(7), 1345-1353. https://doi.org/10.2166/wst.2019.328.

Boyjoo, Y., Ang, M. and Pareek, V. (2012), "Photocatalytic treatment of shower water using a pilot scale reactor", *Int. J. Photoenergy*, https://doi.org/10.1155/2012/578916.

Buxton, G.V., Greenstock, C.L., Helman, W.P. and Ross, A.B. (1988), "Critical review of rate constants for reactions of hydrated electrons, hydrogen atoms and hydroxyl radicals (·OH/·O− in aqueous solution", *J. Phys. Chem. Ref. Data*, **17**(2), 513-886. https://doi.org/10.1063/1.555805.

Cha, M., Kim, S. and Park, C. (2020), "Recent advances and future potential of anaerobic ceramic membrane bioreactors for wastewater treatment: A review", *Membr. Water Treat*., **11**(1), 31-39. https://doi.org/10.12989/mwt.2020.11.1.031.

Chanakya, H. and Khuntia, H.K. (2014), "Treatment of gray water using anaerobic biofilms created on synthetic and natural fibers", *Process. Saf. Environ*., **92**(2), 186-92. https://doi.org/10.1016/j.psep.2012.12.004.

Chin, W., Roddick, F. and Harris, J. (2009), "Greywater treatment by UVC/H_2O_2", *Water Res*., **43**(16), 3940-3947. https://doi.org/10.1016/j.watres.2009.06.050.

Chong, M.N., Cho, Y.J., Poh, P.E. and Jin, B. (2015), "Evaluation of Titanium dioxide photocatalytic technology for the treatment of reactive Black 5 dye in synthetic and real greywater effluents", *J. Clean. Prod*., **89**, 196-202. https://doi.org/10.1016/j.jclepro.2014.11.014.

Chrispim, M.C. and Nolasco, M.A. (2017), "Greywater treatment using a moving bed biofilm reactor at a university campus in Brazil", *J. Clean. Prod*., **142**, 290-296. https://doi.org/10.1016/j.jclepro.2016.07.162.

Edwin, G.A., Gopalsamy, P. and Muthu, N. (2014), "Characterization of domestic gray water from point source to determine the potential for urban residential reuse: A short review", *Appl. Water Sci*., **4**(1), 39-49. https://doi.org/10.1007/s13201-013-0128-8.

Fang, Z., Zhang, K., Liu, J., Fan, J. and Zhao, Z. (2017), "Fenton-like oxidation of azo dye in aqueous solution using magnetic Fe_3O_4-MnO_2 nanocomposites as catalysts", *Water Sci. Eng*., **10**(4), 326-333. https://doi.org/10.1016/j.wse.2017.10.005.

Gaya. U.I. and Abdullah. A.H. (2008), "Heterogeneous photocatalytic degradation of organic contaminants over titanium dioxide: A review of fundamentals, progress and problems", *J. Photoch. Photobio. C*, **9**(1), 1-12. https://doi.org/10.1016/j.jphotochemrev.2007.12.003.

Ghaitidak, D.M. and Yadav, K.D. (2013), "Characteristics and treatment of greywater—a review", *Environ. Sci. Poll. Res*., **20**(5), 2795-2809. https://doi.org/10.1007/s11356-013-1533-0.

Harimurti, S., Dutta, B.K., Ariff, I.F.B., Chakrabarti, S. and Vione, D. (2010), "Degradation of monoethanolamine in aqueous solution by Fenton's reagent with biological post-treatment", *Water Air Soil Poll*., **211**(1-4), 273-286. https://doi.org/10.1007/s11270-009-0298-z.

Hassanshahi, N. and Karimi-Jashni, A. (2018), "Comparison of photo-Fenton, O_3/H_2O_2/UV and photocatalytic processes for the treatment of gray water", *Ecotox. Environ. Safe*., **161**, 683-690. https://doi.org/10.1016/j.ecoenv.2018.06.039.

Hernández-Leal, L., Temmink, H., Zeeman, G., Buisman, C.J.N., (2011), "Removal of micropollutants from aerobically treated grey water via ozone and activated carbon", *Water Res*. **45**(9), 2887-2896. https://doi.org/10.1016/j.watres.2011.03.009.

Kang, J., Lu, L., Zhan, W., Li, B., Li, D., Ren, Y. and Liu, D. (2011), "Photocatalytic pretreatment of oily wastewater from the restaurant by a vacuum ultraviolet/TiO_2 system", *J. Hazard. Mater*., **186**(1), 849-854. https://doi.org/10.1016/j.jhazmat.2010.11.075.

Katukiza, A., Ronteltap, M., Niwagaba, C., Kansiime, F. and Lens, P. (2014), "Grey water treatment in urban slums by a filtration system: Optimisation of the filtration medium", *J. Environ. Manage*., **146**, 131-41. https://doi.org/10.1016/j.jenvman.2014.07.033.

Khan, M.I., Wu, L., Mondal, A.N., Yao, Z., Ge, L. and Xu, T. (2016), "Adsorption of methyl orange from aqueous solution on anion exchange membranes: Adsorption kinetics and equilibrium", *Membr. Water Treat*., **7**(1), 23-38. http://doi.org/10.12989/mwt.2016.7.1.023.

Kumar, J.E., Mulai, T., Kharmawphlang, W., Sharan, R.N., and Sahoo, M.K. (2020), "Decolourisation, mineralisation and detoxification of mixture of azo dyes using Fenton and Fenton-type advanced oxidation processes", *Chem. Pap*., **74**(9), 3145-3159. https://doi.org/10.1007/s11696-020-01147-9.

Leal, L.H., Soeter, A., Kools, S., Kraak, M., Parsons, J., Temmink, H., Zeeman, G. and Buisman, C. (2012), "Ecotoxicological assessment of grey water treatment systems with Daphnia magna and Chironomus riparius", *Water Res*., **46**(4), 1038-1044. https://doi.org/10.1016/j.watres.2011.11.079.

Leong, J.Y.C., Chong, M.N. and Poh, P.E. (2018a), "Assessment of greywater quality and performance of a pilot-scale decentralised hybrid rainwater-greywater system", *J. Clean. Prod*., **172**, 81-91. https://doi.org/10.1016/j.jclepro.2017.10.172.

Leong, J.Y.C., Chong, M.N., Poh, P.E., Vieritz, A., Talei, A. and Chow, M.F. (2018b), "Quantification of mains water savings from decentralised rainwater, greywater, and hybrid rainwater-greywater systems in tropical climatic conditions", *J. Clean. Prod*., **176**, 946-958. https://doi.org/10.1016/j.jclepro.2017.12.020.

Li, Z., Gulyas, H., Jahn, M., Gajurel, D. and Otterpohl, R. (2004), "Greywater treatment by constructed wetlands in combination with TiO_2-based photocatalytic oxidation for suburban and rural areas without sewer system", *Water Sci. Technol*., **48**(11-12), 101-106. https://doi.org/10.2166/wst.2004.0815.

Ligaray, M., Kim, M., Shim, J., Park, J. and Cho, K.H. (2019), "Performance evaluation of organic matter adsorption from actual graywater using GAC: Orbitrap", *Membr. Water Treat*., **10**(6), 471-484. https://doi.org/10.12989/ mwt.2019.10.6.471.

Merz, C., Scheumann, R., El Hamouri, B. and Kraume, M. (2007), "Membrane bioreactor technology for the treatment of greywater from a sports and leisure club", *Desalination*, **215**(1-3), 37-43. https://doi.org/10.1016/j.desal.2006.10.026.

Melo, M.O.M., Duarte, J.L.S, Ferro, A.B., Meili, L. and Zanta, C.L.P.S., (2020), "Comparing electrochemical and Fenton-based processes for aquaculture biocide degradation", *Water. Air Soil Poll*., **231**, 79. https://doi.org/10.1007/s11270-020-4454-9.

Munter, R. (2001), "Advanced oxidation processes–current status and prospects", *Proc. Estonian Acad. Sci. Chem*., **50**(2), 59-80. https://doi.org/10.1007/978-1-59745-029-4_14.

Muruganandham, M. and Swaminathan, M. (2004), "Photochemical oxidation of reactive azo dye with UV–H_2O_2

process", *Dyes. Pigments*, **62**(3), 269-275. https://doi.org/10.1016/j.dyepig.2003.12.006.

Neyens, E. and Baeyens, J. (2003), "A review of classic Fenton's peroxidation as an advanced oxidation technique", *J. Hazard. Mater.*, **98**(1-3), 33-50. https://doi.org/10.1016/S0304-3894(02)00282-0.

Nolde, E. (2000), "Greywater reuse systems for toilet flushing in multi-storey buildings–over ten years experience in Berlin", *Urban Water*, **1**(4), 275-284. https://doi.org/10.1016/S1462-0758(00)00023-6.

Oh, K.S., Leong, J.Y.C., Poh, P.E., Chong, M.N. and Von Lau, E. (2018), "A review of greywater recycling related issues: Challenges and future prospects in Malaysia", *J. Clean. Prod.*, **171**, 17-29. https://doi.org/10.1016/j.jclepro.2017.09.267.

Pidou, M., Avery, L., Stephenson, T., Jeffrey, P., Parsons, S.A., Liu, S., Memon, F.A. and Jefferson, B. (2008), "Chemical solutions for greywater recycling", *Chemosphere*, **71**(1), 147-155. https://doi.org/10.1016/j.chemosphere.2007.10.046.

Prajapati, B., Jensen, M., Jørgensen, N. and Petersen, N. (2019), "Grey water treatment in stacked multi-layer reactors with passive aeration and particle trapping", *Water Res.*, **161**, 181-190. https://doi.org/10.1016/j.watres.2019.05.096.

Rivas, F.J., Beltran, F.J., Frades, J. and Buxeda, P. (2001), "Oxidation of p-hydroxybenzoic acid by Fenton's reagent", *Water Res.*, **35**(2), 387-396. https://doi.org/10.1016/S0043-1354(00)00285-2.

Salazar, R. and Ureta-Zañartu, M.S. (2012), "Mineralization of triadimefon fungicide in water by electro-fenton and photo electro-fenton", *Water Air Soil Poll.*, **223**(7), 4199-4207. https://doi.org/10.1007/s11270-012-1184-7.

Sanchez, M., Rivero, M. and Ortiz, I. (2010), "Photocatalytic oxidation of grey water over titanium dioxide suspensions", *Desalination*, **262**(1-3), 141-6. https://doi.org/10.1016/j.desal.2010.05.060.

Shamabadi, N., Bakhtiari, H., Kochakian, N. and Farahani, M. (2015), "The investigation and designing of an onsite grey water treatment systems at Hazrat-e-Masoumeh University, Qom, Iran", *Energy Proc.*, **74**, 1337-1346. https://doi.org/10.1016/j.egypro.2015.07.780.

Šostar-Turk, S., Petrinić, I. and Simonič, M. (2005), "Laundry wastewater treatment using coagulation and membrane filtration", *Resour. Conserv. Recy.*, **44**(2), 185-196. https://doi.org/10.1016/j.resconrec.2004.11.002.

Tony, M.A., Parker, H.L. and Clark, J.H. (2016), "Treatment of laundrette wastewater using Starbon and Fenton's reagent", *J. Environ. Sci. Heal. A*, **51**(11), 974-99. https://doi.org/10.1080/10934529.2016.1191817.

Tsoumachidou, S., Velegraki, T., Antoniadis, A. and Poulios, I. (2017), "Greywater as a sustainable water source: A photocatalytic treatment technology under artificial and solar illumination", *J. Environ. Manage.*, **195**, 232-421. https://doi.org/10.1016/j.jenvman.2016.08.025.

Wang, Q., Liu, S. and Gao, H. (2019), "Treatment of hydroxyquinone-containing wastewater using precipitation method with barium salt", *Water Sci. Eng.*, **12**(1), 55-61. https://doi.org/10.1016/j.wse.2019.03.003.

Wu, Y., Zhou, S., Ye, X., Zhao, R. and Chen, D. (2011), "Oxidation and coagulation removal of humic acid using Fenton process", *Colloid. Surface. A.*, **379**(1-3), 151-156. https://doi.org/10.1016/j.colsurfa.2010.11.057.

Yonar, T., Kestioglu, K. and Azbar, N. (2006), "Treatability studies on domestic wastewater using UV/H_2O_2 process", *Appl. Catal. B-Environ.*, **67**(3-4), 223-228. https://doi.org/10.1016/j.apcatb.2006.04.022.

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