

Synthesis of magnetite iron pumice composite for heterogeneous Fenton-like oxidation of dyes

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Abstract. The removal of two dyes, namely Methylene Blue (MB) and Reactive Brilliant Red (RR) from aqueous solution was investigated using magnetite iron coated pumice (MIP) composite in the Fenton-like oxidation process. A weight ratio of 2.5 g (with the molar ratio of Fe³⁺ to Fe²⁺ to be 2) (5%) of iron to the total pumice (50 g) was enabled during synthesis of catalyst. Surface composition and characteristics of the catalyst were assessed by SEM-EDX, FT-IR, Raman spectral analysis. The effect of the amount of pumice solely used or MIP, H₂O₂ concentration, pH and initial concentration of MB or RR dyes on Fenton-like process efficiency was investigated. EDAX spectrums of pumice and MIP showed that oxygen and silisium are the major elements. The Fe content of MIP increased to 2.24%. SEM, FT-IR and Raman spectrums confirmed the impregnation of Fe on pumice surface. The experimental results revealed that high removal rates of dyes could be obtained using MIP that demonstrated a higher stability for removal of MB dye. pH affected the removal efficiency of both dyes and the degradation of both dyes was sharply dropped when pH was increased above 4. The removal of dyes did not significantly change with increasing H₂O₂ concentration. Degradation rates of both MB and RR dyes increased 3.3 and 2.8 times with the use of MIP compared to pumice alone, respectively. Furthermore, MIP enabled a good removal efficiency at higher dye concentrations. It can be emphasized that MIP composite can be used in the heterogeneous Fenton-like systems considering the economic and easily separation aspects.

Keywords: azo dyes; Fenton-like process; methylene blue; magnetite iron; pumice; reactive red

1. Introduction

Textile industry produces large amount of wastewater which consists a strong color that is mostly due to non-biodegradable azo dyes (Su *et al.* 2016). Furthermore, most of the dyes are toxic and tend to bio-accumulate in aquatic environments (Ramachandran and Kumarasamy 2013).

In recent years, advanced oxidation processes (AOPs) have become common methods for the reason of complete removal of recalcitrant and non-biodegradable dyes and among the AOPs, Fenton process has easy operation and is an effective method of dye removal, but the main disadvantage is that it produces of iron sludge at the end of reactions requiring further treatment

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(Su *et al.* 2016). In addition, the other drawbacks of Fenton system; it is good working only in acidic conditions and there is no recovery iron from wastewater in the system (Su *et al.* 2016). To overcome these drawbacks, researchers have focused on Fenton-like process using heterogeneous catalyst which contains iron precursors on the surface of support materials (Messele *et al.* 2015). Daud *et al.* (2010) reported that 99% of decolorization was obtain at 150 min Fenton-like oxidation using Fe-Montmorillonite K10 under the optimum conditions (0.14 wt.% Fe-Montmorillonite K10, 5.0 g/L of catalyst, pH 2.5, 16 mM of H₂O₂, 50 mg/L acid red 1 dye). Hassan and Hameed (2011) was found the 99% of reactive blue 4 decolorization using 5 g/L of 0.80 wt.% Fe-ball clay with pH 3, 8 mM H₂O₂, 50 mg/L dye after 140 min oxidation time. Daud and Hameed (2011) was obtained 98.46% of acid red 1 dye removal at pH 3, 8 mM H₂O₂ and 0.080 wt.% Fe-Kaolin after 240 min treatment.

Pumice has been reported a low-cost material with its large surface area of porous structure for the adsorption of dyes (Cifci and Meric 2015). Furthermore, researchers showed that iron coated pumice increased the removal of natural organic matter and methyl red dye (Kaplan Bekaroglu *et al.* 2016, Cifci and Meric 2015b, Kitis and Kaplan 2007, Alver *et al.* 2016). In the studies, it was stated that the use of iron coated pumice for natural organic matter removal by both adsorption and oxidation can be an effective and feasible material in water treatment processes (Kitis and Kaplan 2007, Alver *et al.* 2016). Fenton-like oxidation studies with iron coated pumice are mostly focused on natural organic matter removal and studies on dye removal are limited. The porous structure of the pumice will provide an advantage according to the other materials, as well as magnetic iron coating on pumice will allow to separate easily from the water.

The objective of this study is to investigate the removal of two dyes (MB and RR) from aqueous solutions using MIP as catalyst in the Fenton-like process. The effect of composite amount, H₂O₂ concentration and pH of the solution for the removal of dyes was studied. Reuse of MIP was also evaluated.

2. Materials and methods

2.1 Materials

Methylene blue (MB, Cat No: 1.05045), hydrogen peroxide (H₂O₂ 35% wt, Cat No: 1.08600), FeCl₃.6H₂O (Cat No: 1.03943), NH₃ (25%, Cat No: 1.05422), FeSO₄.7H₂O (Cat No: 1.03965), HCl (Cat No: 1.00314), HNO₃ (Cat No: 1.00456) and NaOH (Cat No: 1.06462) were purchased from Merck. Reactive Red 239 (RR, Remazol Brilliant Red 3BS) was purchased from DyStar Textilfarben GmbH&Co.

The pumice was obtained from a company located in Cappadocia region (Nevşehir city area, Mid-Anatolia) of Turkey, where a large pumice reserve is present. The particle size of pumice powder ranged from nano to micron (≤ 125 microns). All chemicals used during experiments were of analytical grade.

2.2 Synthesis of magnetite-pumice composite

FeSO₄.7H₂O (4.149 g) and FeCl₃.6H₂O (8.067 g) were first dissolved in 200 mL distilled water with the molar ratio of Fe³⁺ to Fe²⁺ to be 2 in the solution (Rusevova *et al.* 2012). An amount of 50 g of pumice added into this solution resulting a weight ratio of 2.5:50 (5%) of iron (2.5 g as a

mixture of Fe^{3+} and Fe^{2+}) to the total pumice. The pH of the solution was adjusted to 9.5 by adding 6 N NaOH. The solution was ultrasonicated for 15 min and heated at 70°C for 1 h. After that 5 mL of NH_3 solution was dropped and stirred for 24 h at room temperature. After 24 h, the MIP was rinsed with distilled water for several times to remove residual ions. Latter, the MIP was dried at 105°C for 24 h.

2.3 Fenton-like experiments

Fenton-like experiments were performed to investigate at the following conditions:

(i) In order to determine the effect of pumice amount on the dye removal, 5 different pumice amounts in the range of 0.025-0.5 g were investigated at 50 mg/L of MB or RR, pH 3, 2 mM H_2O_2 for MB and 3 mM H_2O_2 for RR H_2O_2 , 200 rpm agitation speed.

(ii) In order to determine the effect of H_2O_2 concentration on the dye removal, 5 different H_2O_2 concentration in the range of 0.5-5 mM H_2O_2 concentration were investigated at 50 mg/L MB or RR, pH 3, 0.25 g pumice or MIP, 200 rpm agitation speed.

(iii) In order to determine the effect of pH on the dye removal, 5 different pH in the range of pH 3-7 were investigated at 50 mg/L MB or RR, 0.25 g pumice or MIP, 1 mM for MB and 2 mM for RR H_2O_2 concentration, 200 rpm agitation speed.

(iv) In order to determine the effect of the initial dye concentration, 5 different initial dye concentration in the range of 10-100 mg/L MB or RR concentration were investigated at 0.25 g pumice or MIP, pH 3, 1 mM for MB and 2 mM for RR H_2O_2 concentration, 200 rpm agitation speed.

Experiments were performed using 50 mL sample volumes that were shaken at 200 rpm speed during 120 min and at room temperature using a rotary shaker (Biosan PSU-10i). The pH was adjusted only at the beginning of the experiment and the pH was not adjusted during the experiment. pH was adjusted to the desired levels dropping HNO_3 (1 N) and NaOH (1 N) into solutions. After that, supernatants centrifuged at 4000 rpm for 5 min before analysis.

2.4 Reuse of the catalyst

To evaluate the stability of MIP was recycled and reused 5 times at optimum conditions of MB and RR removals. Between each experiment, the catalyst was separated from the solution by filtration using coarse filter paper with a pore size of 12-25 μm and it was washed with deionized water several times and dried at 105°C for 24 h.

2.5 Analysis

The pH was measured using a pH meter (WTW pH 315i). MB and RR dyes were analyzed using a UV-Vis spectrophotometer (Shimadzu UV-2401 PC instrument) at 540 nm and 664 nm, respectively. Merck test kits (Fe-114761) and UV-Vis spectroscopy (Schimadzu UV-2401 PC) were used to analyze any residual iron leaching from the composite at $\lambda=562$ nm wavelength.

Synthesized magnetite-pumice composite was characterized using electron scanning microscopy (SEM)-energy dispersive X-ray analyzer (EDX) (FEI-QUANTA FEG 250) to obtain information about surface properties and chemical characterization of composite. SEM-EDX was operated at 2 kV accelerating at a constant magnification of 20000x. FT-IR performed at room temperature on a Bruker VERTEX 70 ATR and it used to evaluate and identify the formation of

functional groups formed during the synthesis of the MIP in the range of 400 to 4000 cm^{-1} . The Raman spectra of pumice and MIP were also recorded in a Thermo DXR dispersive Raman instrument using laser excitation of 780 nm in the range of 200-1200 cm^{-1} with a resolution below 5 cm^{-1} .

3. Results and discussion

3.1 Structure analysis of pumice and MIP

Surface of pumice is in irregular shape with porous and rough structure (Fig. 1). EDAX spectrums of pumice and MIP showed that oxygen and silisium are the major elements. Pumice mainly contains 60.4% O, 28.3% Si, 6.6% Al, 1.5% K, 2.9% Na and 0.3% Fe (Table 1). The Fe content of MIP increased to 2.24%. It can be seen from Fig. 1(b) that nano iron particles doped on the surface of pumice.

The FTIR spectra of pumice and MIP are given in Fig. 2(a). The strong peak at $\sim 1020 \text{ cm}^{-1}$ could be the Si-O-Si symmetric stretching vibration due to the groups of $(\text{SiO}_4)_2$ (Karimaian *et al.* 2013). The peak at $\sim 780 \text{ cm}^{-1}$ could be a vibration of Si-O-Si bond and the peak at 455 cm^{-1} indicates the Si-O-Si bending vibrations (Sepehr *et al.* 2013, Shayesteh *et al.* 2016). The peak at 578 cm^{-1} that was observed only for magnetite-pumice composite, could be the vibration of Fe-O bond of Fe_3O_4 (Guru *et al.* 2016, Jayarathne *et al.* 2012). Yang *et al.* (2010) observed the similar peak of Fe-O bond in the crystalline of Fe_3O_4 at 580 cm^{-1} . The peak around 3400 cm^{-1} shows OH bond vibrations to the presence of water molecules (Sepehr *et al.* 2014).

The Raman spectra of the pumice and MIP are shown in Fig. 2(b). The MIP shows three strong

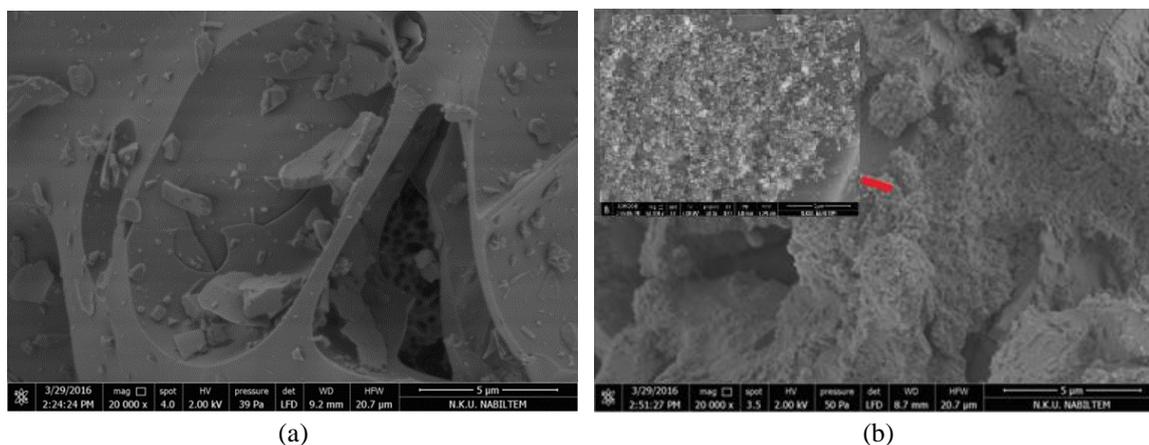


Fig. 1 SEM images of pumice (a) and MIP (b)

Table 1 Chemical composition of pumice and magnetite-pumice composite (%)

Catalyts	O	Na	Al	Si	K	Ca	Fe
Pumice	58.35	3.87	6.71	29.50	1.40	Trace	0.16
MIP	54.16	3.25	6.85	31.34	1.84	0.32	2.24

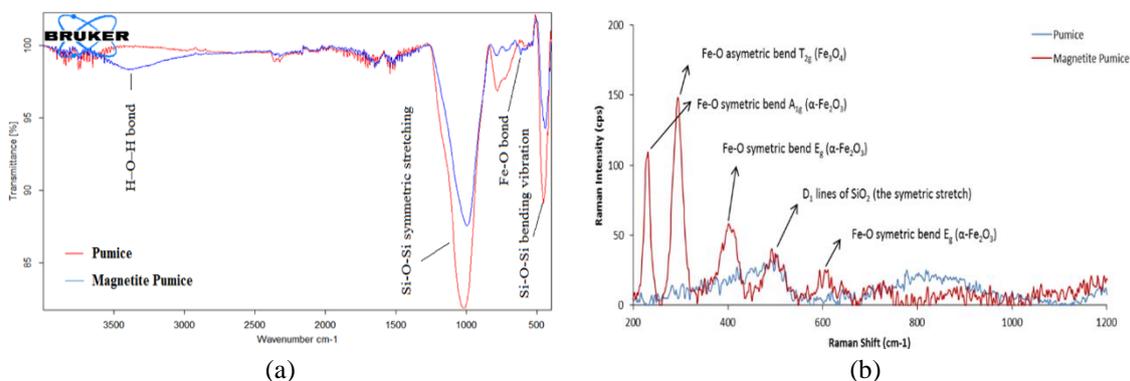


Fig. 2 FTIR transmission (a) and Raman spectra (b) of pumice and MIP

peaks at $\sim 297\text{ cm}^{-1}$ (T_{2g}), $\sim 523\text{ cm}^{-1}$ (T_{2g}) and $\sim 666\text{ cm}^{-1}$ (A_{1g}). In the MIP system, the strongest peak is that Fe-O asymmetric band of magnetite is in T_{2g} mode and hematite ($\alpha\text{-Fe}_2\text{O}_3$) also appeared at strong bands of $\sim 226\text{ cm}^{-1}$ (A_{1g}), $\sim 292\text{ cm}^{-1}$ (E_g), $\sim 406\text{ cm}^{-1}$ (E_g), $\sim 495\text{ cm}^{-1}$ (A_{1g}) and 600 cm^{-1} (A_{1g}) (Legodi and de Waal 2007, Das and Hendry, 2011). The Fe-O symmetric bend (in A_{1g} mode) and the Fe-O symmetric bend (in E_g mode) of $\alpha\text{-Fe}_2\text{O}_3$ are observed in magnetite-pumice composite system. The Raman wavenumbers at $\sim 495\text{ cm}^{-1}$ and $\sim 606\text{ cm}^{-1}$ are the defect lines D_1 and D_2 of SiO_2 indicating the symmetric stretch of four and three membered rings, respectively (Zotov *et al.* 1999, Awazu *et al.* 2003).

3.2 Effect of pumice and MIP concentrations

The effect of different amounts of pumice or MIP on the removal of MB and RR dyes were studied using $2\text{ mM H}_2\text{O}_2$ for MB and $3\text{ mM H}_2\text{O}_2$ for RR, respectively (Fig. 3). The decolorization efficiency of MB reached a 91.7% value after 15 min using 0.5 g MIP while a 89.3% removal of MB was obtained after 30 min oxidation using 0.25 g MIP (Fig. 3(a)). RR removal was obtained as 82.4% after 30 min oxidation using 0.5 g MIP and it was 81.1% after 45 min oxidation using 0.25 g MIP amounts (Fig. 3(b)).

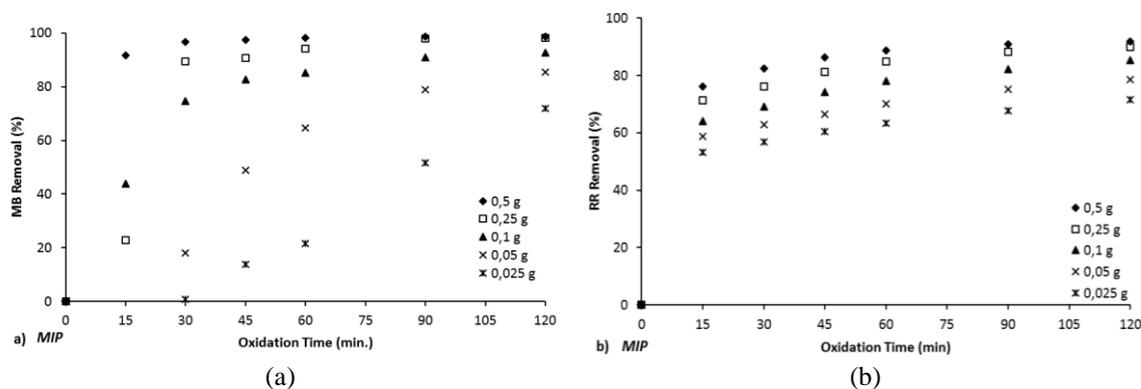


Fig. 3 Time-dependent variation of MB (a) and RR (b) dye removal in different amounts of MIP

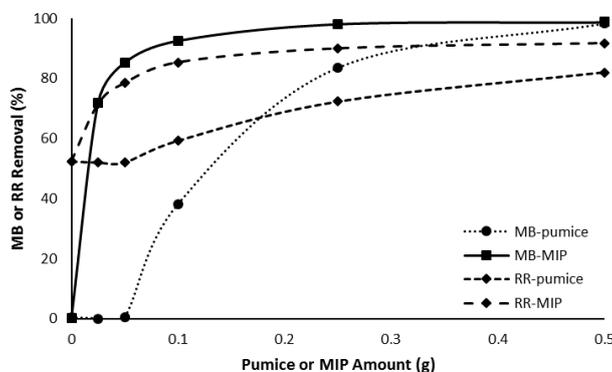


Fig. 4 Removal of MB and RR dyes using different pumice and MIP concentrations (MB or RR: 50 mg/L, pH: 3, H₂O₂ concentration: 2 mM for MB and 3 mM for RR, 120 min)

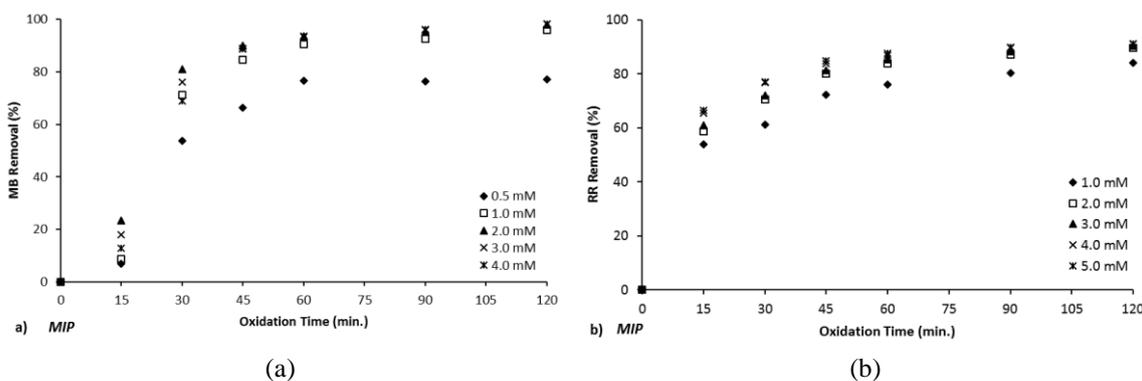


Fig. 5 Time-dependent variation of MB (a) and RR (b) dye removal in different concentration of H₂O₂

The removal of MB was not achieved at a high percentage when low pumice concentration (0.025 g) was used while a 71.9% removal of MB was obtained using MIP at the same concentration in the presence of H₂O₂ (Fig. 4). The removal of dyes increased due to the increasing of iron ions which provided the oxidation with hydroxyl radicals. On the other hand, approximately a 52% of RR removal was observed for the amount of 0.05 g magnetite-pumice composite. It is noted from Figure 3 that the presence of H₂O₂ stimulated the removal of both dyes at lower amounts of MIP, whereas at higher amounts of catalysts doses, the removal of dyes closed to each other as the ratio of H₂O₂/iron decreased. It was reported elsewhere that the surface modification on pumice using H₂O₂ would enhance the adsorptive removal of the metals (Cifci and Meriç 2017).

The optimum amount of MIP was concluded to be 0.25 g for the removal of MB and RR dyes resulting in a 98.1% and a 90.0% removal efficiencies respectively, in the presence of H₂O₂.

3.3 Effect of H₂O₂ concentrations

As it is well known in the literature, the ratio between H₂O₂ and Fe²⁺ is crucial for Fenton/Fenton like process to generate hydroxyl radicals, it should be considered that excessive

H₂O₂ could negatively affect the removal efficiency by scavenging hydroxyl radicals (Xavier *et al.* 2015). The decolorization efficiency of both dyes increased with increasing H₂O₂ concentration due to the production the hydroxyl radicals (Fig. 5). A rapid increase in dye removal was observed using H₂O₂ up to 1 mM for MB and 2 mM for RR at which the degradation efficiency of MB and RR dyes could reach up to 98.0% and 89.6% values, respectively (Fig. 5(a) and 5(b)). The removal of the dyes was not significantly affected by the increasing H₂O₂ concentration to above mentioned values (Fig. 6).

3.4 Effect of pH

pH displayed a great influence on the removal of MB or RR dyes by Fenton-like reaction using both pumice and magnetite-pumice composite (Fig. 7). In accordance with the literature, the maximum removal of MB or RR dyes was achieved at pH 3 using magnetite-pumice composite (Rache *et al.* 2014). That can be explained by the formation of higher oxidation potential of hydroxyl radicals resulting from the reaction of H₂O₂ with higher iron concentration doped on the surface of the composite (Xu and Wang 2012).

By varying the pH of the dye solutions below or above 3.0 the removal of MB or RR dyes

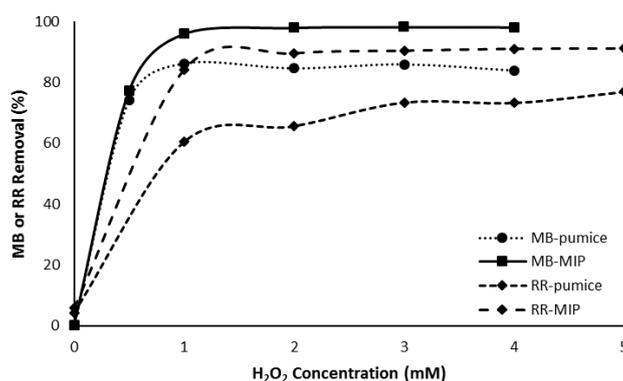


Fig. 6 Removal of MB and RR dyes using different H₂O₂ concentration (MB: 50 mg/L, pH: 3, MIP: 0.25 g, 120 min)

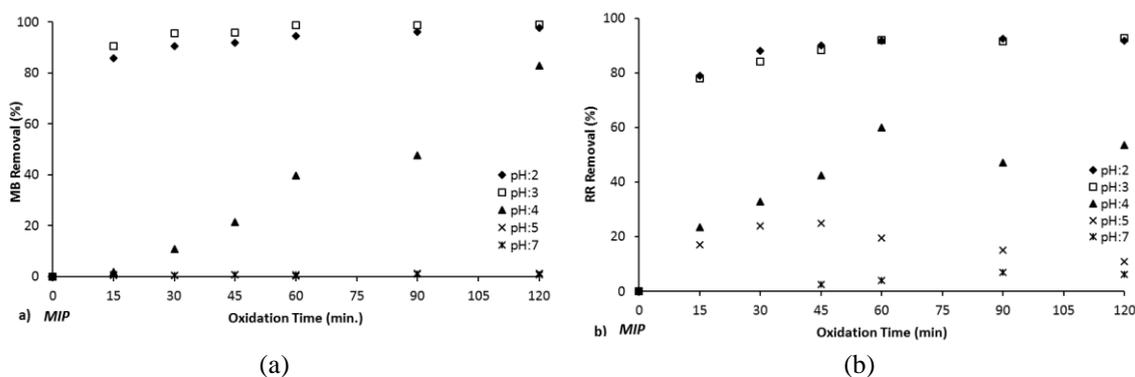


Fig. 7 Time-dependent variation of MB (a) and RR (b) dye removal in different pH values

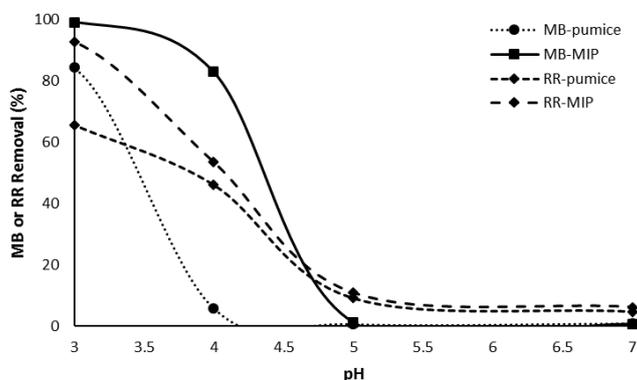


Fig. 8 Removal of MB and RR dyes at different pH values (MB: 50 mg/L, MIP: 0.25 g, H₂O₂ concentration: 1 mM for MB and 2 mM for RR, 120 min)

dramatically decreased due to the stability of H₂O₂ by the formation of H₃O₂⁺ and the decomposition of H₂O₂ and deactivation of iron or owing to the transition of less reactive peroxy radicals, respectively (Dükkancı *et al.* 2010, Daud and Hameed 2011) (Fig. 8).

3.5 Evaluation of adsorption and oxidation processes for removal of MB and RR dyes: kinetics

The adsorption of MB or RR without H₂O₂ is to be negligible as only 4.23% and 5.93% of RR were adsorbed after 120 min in the adsorption process using pumice and MIP, respectively (Fig. 9). By the addition of H₂O₂, a maximum decolorization of MB and RR was achieved after 60 min using MIP. There was no significant change in the removal of the dyes between 60 and 120 min. It was obviously seen that the removal of the dyes was in a great part due to oxidation. The removal of MB appears to be comparatively higher using MIP than pumice solely used.

When MIP is used, the removal of MB and RR increased from 84.3% to 99.1% and from 65.7% to 92.4% respectively. Accordingly, k_1 value of RR increased 2.8 times while it enhanced 3.3 times for MB using MIP (Table 2).

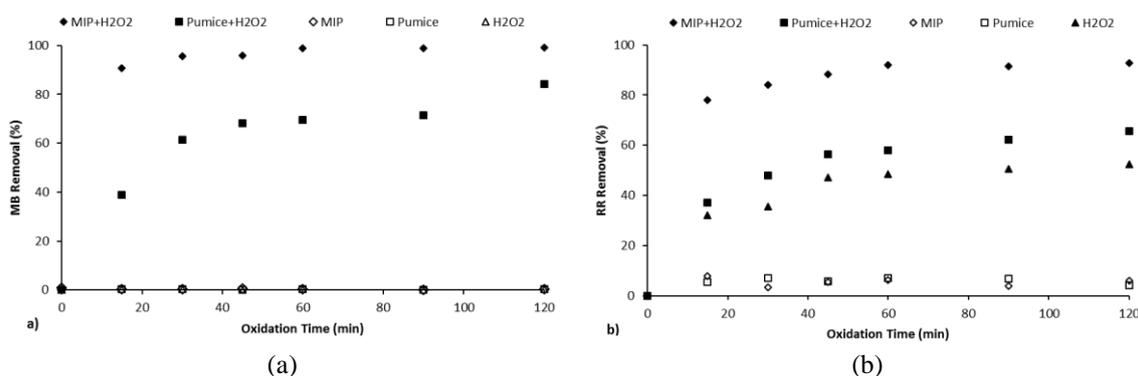


Fig. 9 Comparative evaluation of adsorption and oxidation processes for removal of MB (a) and RR (b) dyes (MB or RR concentration: 50 mg/L, MIP: 0.25 g both of dyes, pH: 3, H₂O₂ concentration: 1 mM for MB and 2 mM for RR, 120 min)

Table 2 Kinetics constants of pumice and MIP for removal of MB and RR dyes (MB or RR concentration: 50 mg/L, composite amount: 0.25 g, pH: 3, H₂O₂ concentration: 1 mM for MB and 2 mM for RR, 120 min)

	Methylene Blue (MB)			Reactive Red (RR)		
	Removal (%)	k ₁ (min ⁻¹)	R ²	Removal (%)	k ₁ (min ⁻¹)	R ²
Pumice+H ₂ O ₂	84.3	0.0232	0.8780	65.7	0.0167	0.8996
MIP+H ₂ O ₂	99.1	0.0769	0.9278	92.4	0.0465	0.9294

Table 3 Comparison of operational conditions for removal of azo dyes with Fenton-like process using various catalysts

Catalyst	Dyes	Fenton-like process conditions	Removal (%)	References
5% MIP	MB (50 mg/L)	pH: 3.0, H ₂ O ₂ : 1 mM, Cat: 5 g/L, time: 120 min	99.1	In this study
5% MIP	RR 239 (50 mg/L)	pH: 3.0, H ₂ O ₂ : 2 mM, Cat: 5 g/L, time: 120 min	92.4	In this study
0.08 wt.% Fe-kaolin	AR (50 mg/L)	pH: 3.0, H ₂ O ₂ : 4 mM, Cat: 4 g/L, time: 240 min	98.37	Daud and Hameed (2011)
0.14 wt.% Fe–Montmorillonite K10	AR (50 mg/L)	pH: 2.5, H ₂ O ₂ : 16 mM, Cat: 5 g/L, time: 150 min	99.0	Daud and Ahmad (2010)
FeZSM-5 zeolite	RR 141 (100 mg/L)	pH: 3.5, H ₂ O ₂ : 33 mM, Cat: 1 g/L, time: 120 min	100	Yaman and Gündüz (2015)
0.80 wt.% Fe–clay	RB 4 (50 mg/L)	pH: 3.0, H ₂ O ₂ : 8 mM, Cat: 5 g/L, time: 140 min	99.0	Hassan and Hameed (2011)
Fe-Mn-sepiolite	RBB (50 mg/L)	pH: 2.5, H ₂ O ₂ : 0.6 mL, Cat: 0.8 g/L, time: 60 min	91.98	Su <i>et al.</i> (2016)
nZVI/4A zeolite	MB (30 mg/L)	pH: 3.0, H ₂ O ₂ : 10 mM, Cat: 0.2 g/L, time: 180 min	100	Wu <i>et al.</i> (2014)
Magnetite mesoporous silica MCM-41	MB (50 mg/L)	pH: 3, H ₂ O ₂ : 10 mL, Cat: 1 g/L, time: 180 min	43 as TOC	Nogueira <i>et al.</i> (2014)
Fe-ZSM-5 zeolite	RBB KN-R (250 mg/L)	pH: 2.5, H ₂ O ₂ : 30 mM, Cat: 4 g/L, time: 20 min	90	Chen <i>et al.</i> (2008)

MB: Methylene Blue; RR: Reactive Red; AR: Acid Red 1; RB: Reactive Blue; RBB: Reactive Brilliant Blue

Compared to the literature, MIP showed a better removal than the other low-cost materials for the removal of dyes (Table 3). The MIP gained the advantages of both the shortening time and the decreasing the H₂O₂ costs compared to Fe-kaolin, Fe-montmorillonite and Fe-clay materials (Daud and Hameed 2011, 2010). Although, using zeolite in the Fenton-like experiments decreased the process time and the use of catalyst concentration, the amount of H₂O₂ in these studies are much higher than the pumice solely used in this study (Chen *et al.* 2008, Yaman and Gündüz 2015).

3.6 Effect of initial dye concentration

The effect of initial dye concentrations on the removal of MB or RR at pH 3.0 is shown in Figure 10. Complete removal of MB was obtained up to 75 mg/L MB concentration using MIP while MB removal decreased sharply above 50 mg/L in the pumice used system. This could be

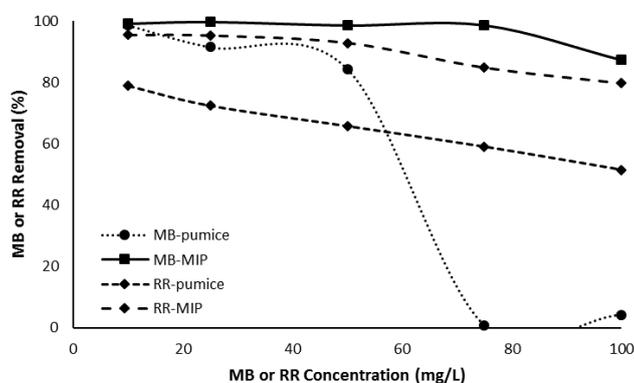


Fig. 10 Removal of MB and RR dyes at different initial dye concentrations (MIP: 0.25 g both of dyes, pH: 3, H₂O₂ concentration: 1 mM for MB and 2 mM for RR, 120 min)

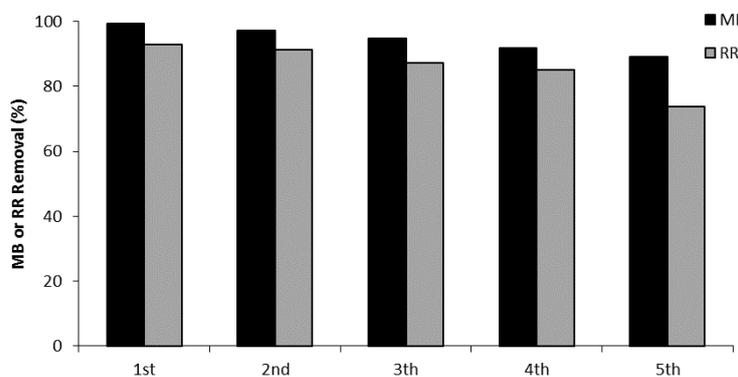


Fig. 11 Stability/Reuse of MIP for removal of MB and RR dyes (MB or RR concentration: 50 mg/L, composite amount: 0.25 g, pH: 3, H₂O₂ concentration: 1 mM for MB and 2 mM for RR, 120 min)

explained that as the dye molecules increase, OH radicals remain constant in the solution and as a result of this, the collision between dye molecules and OH radicals are reduced (Azmi *et al.* 2014). Similar trends were observed for RR dye removal that slightly decreased with enhancing the initial dye concentration using pumice. Compared to pumice, the effect of the MIP on the dye removal seems to be higher in high dye concentrations and high dye removal can be achieved after 120 min oxidation even at a higher initial dye concentration using MIP. It has been observed that the results obtained in this study are consistent with the literature (Azmi *et al.* 2014, Daud and Ahmad 2010).

3.7 Reuse experiments

MB removal was nearly the same for the third times used catalyst and any insignificant decrease in dye removal was observed after 2 h oxidation (Fig. 11). The removal efficiencies of MB using MIP were recorded to be 99.3%, 97.3%, 94.8%, 91.8% and 89.0% after 120 min for the first, second, third, fourth and fifth time use of the catalyst, respectively. However, the reaction rate of dye removal slightly decreased and to obtain high MB removal reaction time increased from 60 to 120 min. This is because the iron impregnated onto the pumice reduced to reacting

effectively with hydrogen peroxide after recycling and reuse. Although the removal of RR decreased more than MB removal, a 73.8% of RR removal could be noted, even after fifth times reuse of MIP.

Released iron from magnetite-pumice composite after 2 h oxidation time was measured to be approximately 150-200 ppb when 0.25 g amount of MIP was used for MB removal. Accordingly, it can be concluded that the magnetite-pumice composite displayed a good stability and the iron release from the composite was detected lower than wastewater discharge limit (<3 ppm) in Turkey (TWCPR 2004), treated water (<2 ppm) according to European Directives (1998) (Pastrana-Martinez 2015) and WHO (2011) drinking water guideline value of 0.4 mg/L.

4. Conclusions

Heterogenous Fenton-like oxidation process using MIP synthesized in this study, has been proved to be an effective method for removal of MB and RR azo dyes.

- The synthesized MIP has a high surface area and porosity due to a pumice characteristic feature.

- The optimum removal efficiencies of 99% and 92% for MB and RR dyes respectively, were achieved at the operating conditions of pH 3, 0.25 g MIP, 1 mM H₂O₂ for MB and 2 mM H₂O₂ for RR in 120 min oxidation time.

- The synthesized MIP catalyst exhibited a high stability and above 89% MB removal was obtained even after fifth times regeneration and reuse.

- The MIP was easily separated from the aqueous solution due to its magnetite feature. Also, leaching of Fe appears to be below the discharge standards.

The results of the study showed that magnetic pumice is highly efficient for the removal of methylene blue and reactive red 239 by Fenton-like oxidation and coating of magnetic iron on pumice will also facilitate the recovery from the system. The magnetic pumice has a consistently usable stability, with very little iron leakage from the pumice into the wastewater and the both dyes removal was obtained quite high even after 5 times using the magnetic pumice. The only drawback in the use of magnetic pumice in the Fenton-like oxidation process is that it gives good results only in acidic conditions as in the Fenton process.

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