



**HAL**  
open science

## **Enhance microalgae growth and biological treatment of municipal wastewater using Fe<sub>3</sub>O<sub>4</sub> nanoparticles**

Mobina Golbabai, Sara Akbari, Amirhossein Khourshidi, Fatemeh Ajam, Poone Yaqoubnejad, Masoud Rabieian, Mohsen Taghavijeloudar

### ► **To cite this version:**

Mobina Golbabai, Sara Akbari, Amirhossein Khourshidi, Fatemeh Ajam, Poone Yaqoubnejad, et al.. Enhance microalgae growth and biological treatment of municipal wastewater using Fe<sub>3</sub>O<sub>4</sub> nanoparticles. 7th Intern. Conference on Applied Researches in Science & Engineering, Mar 2023, Aachen, Germany. ⟨hal-04589950⟩

**HAL Id: hal-04589950**

**<https://hal.science/hal-04589950v1>**

Submitted on 28 May 2024

**HAL** is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.



HAL Authorization



## Enhance microalgae growth and biological treatment of municipal wastewater using Fe<sub>3</sub>O<sub>4</sub> nanoparticles

Mobina Golbabai Kotenai<sup>a</sup>, Sara Akbari<sup>b</sup>, Amirhossein Khourshidi<sup>c</sup>, Fatemeh Ajam<sup>d</sup>, Poone Yaqoubnejad<sup>e</sup>, Masoud Rabieian<sup>f</sup>, Mohsen Taghavijeloudar<sup>g\*</sup>

<sup>a</sup> MSc. Student of Department of Civil and Environmental Engineering, Babol Noshirvani University of Technology, 47148-71167, Babol, Iran; [m.golbabaee@stu.nit.ac.ir](mailto:m.golbabaee@stu.nit.ac.ir)

<sup>b</sup> MSc. Student of Department of Civil and Environmental Engineering, Babol Noshirvani University of Technology, 47148-71167, Babol, Iran; [sara\\_akbari@stu.nit.ac.ir](mailto:sara_akbari@stu.nit.ac.ir)

<sup>c</sup> MSc. Student of Civil and Environmental Engineering, Babol Noshirvani University of Technology, 47148-71167, Babol, Iran; [amirhosein\\_khorshidi@stu.nit.ac.ir](mailto:amirhosein_khorshidi@stu.nit.ac.ir)

<sup>d</sup> MSc. Student of Civil and Environmental Engineering, Babol Noshirvani University of Technology, 47148-71167, Babol, Iran; [fateme\\_ajam@stu.nit.ac.ir](mailto:fateme_ajam@stu.nit.ac.ir)

<sup>e</sup> MSc. Department of Civil and Environmental Engineering, Babol Noshirvani University of Technology, 47148-71167, Babol, Iran; [poone.yaqoubnejad1992@gmail.com](mailto:poone.yaqoubnejad1992@gmail.com)

<sup>f</sup> PhD. Student Department of Civil and Environmental Engineering, Babol Noshirvani University of Technology, 47148-71167, Babol, Iran; [m.rabieian@stu.nit.ac.ir](mailto:m.rabieian@stu.nit.ac.ir)

<sup>g</sup> PhD. Department of Civil and Environmental Engineering, Seoul National University, 151-744, Seoul, South Korea; [mohsen@snu.ac.kr](mailto:mohsen@snu.ac.kr)

### Abstract

Water resources crisis and concerns about environmental pollution led to promote different wastewater treatment processes. Biological wastewater treatment through microalgae cultivation is one of the promising methods that perfectly remove nutrients. In this study, nanoparticle of Fe<sub>3</sub>O<sub>4</sub> was used as trace element to enhance microalgae growth and biological wastewater treatment by removing nutrients (e.g. COD, nitrate (NO<sub>3</sub><sup>-</sup>), phosphate (PO<sub>4</sub><sup>-3</sup>)) and heavy metals (HMs) (e.g., Cr and pb) from municipal wastewater (MWW). *C. sorokiniana* was used as microalgae in this study. According to the results, maximum biomass concentration of 1.8 g/L was achieved in the presence of 80 mg/L of Fe<sub>3</sub>O<sub>4</sub>. *C. sorokiniana* microalgae showed a high capacity to remove 89% of Nitrate (NO<sub>3</sub><sup>-</sup>), 95% of phosphate (PO<sub>4</sub><sup>-3</sup>), 81% of COD, 80% of Cr and 98% of Pb from real municipal wastewater.

**Key words:** Wastewater treatment, Microalgae production, Heavy metal removal, Fe<sub>3</sub>O<sub>4</sub> nanoparticle



## 1. Introduction

The increasing use of water in urban area due to increased industrialization and population growth resulted in generate large amount of municipal wastewater [1]. Wastewater consists of different substances, some of them at concentrations that are highly toxic to organisms. Eutrophication of aquatic environments caused by excessive loadings of phosphorus (P) and nitrogen (N) results in environmental concerns such as the generation of wastes [2]. Moreover, the presence of heavy metal in wastewater has become a major health concern all over the world due to its inability to decompose and obstinate nature [3]. The most common toxic metals are Cr(II) and Pb (II) found in the water of industry which have highly toxic causing serious illnesses, having a carcinogenic effect, and interfering with the nervous and biological systems in living beings even when the concentration is low [4].

Therefore, much effort has gone into developing wastewater treatment methods, including chemical/physical such as electrochemical or chemical oxidation [5]. and biological treatments such as conventional activated sludge process [6], and anaerobic sequencing batch reactor [7]. However, most of chemical/physical methods are not environmentally friendly and in the case of biological methods, removal efficient in nitrogen and phosphorus may not be satisfactory [8]. Among them, microalgae have received many attentions due to their multiple applications for wastewater treatment and producing high-valuable bio-products [9]. Microalgae can be grown in wastewater medium and used to remove both nutrients such as nitrogen and phosphorus and heavy metals by consuming them as major source to improve the growth rate of microalgae biomass [10].

Several studies have shown that microalgae can remove P, N, along with heavy metals from wastewaters. The microalgae *Chlorococcum sp. RAP-13* has the ability to significantly reduce organic pollutants, including chemical oxygen demand (COD) and biochemical oxygen demand (BOD), in dairy wastewater. The reduction rates of COD and BOD have been reported as 93% and 82%, respectively, indicating the effectiveness of *Chlorococcum sp. RAP-13* in treating this type of wastewater[11]. In another attempt, Novoveská et al. (2016) used *scenedesmus dimorphus* microalgae for raw municipal wastewater treatment. They could achieve 75% of total nitrogen, 93% of phosphorus and 92% BOD removal efficiency [12]. In addition, microalgae due to their functional groups (e.g. hydroxyl and carboxyl groups) have the ability to adsorb heavy metals onto their cell surfaces via a biosorption process [13]. However, the low



ability and limited capacity of microalgae cells for HMs removal at just toxicity levels limited their use in large-scale applications.

In recent years, various metal oxides, especially iron oxides ( $\text{Fe}_2\text{O}_3$  and  $\text{Fe}_3\text{O}_4$ ), have attracted wide attention due to their good selectivity and affinity in the adsorption process [14]. Iron is a vital micronutrient required for the growth of microalgae, as it plays a role in various enzymatic reactions. These include redox reactions, photosystem II, oxygen carrier proteins, nitrogen consumption, and chlorophyll synthesis. The preference of microalgae for iron sources varies among microalgae species. For instance, *Chlorella vulgaris* and *Nannochloropsis oculata* are commonly used for cultivation and wastewater treatment using ferric iron such as  $\text{FeCl}_3$ , while *Chlorella* sp. can be grown with ferrous iron like  $\text{FeSO}_4$  [15].

In this study, we attempt to enhance the microalgae growth and its ability for an efficient remove of nutrients such as COD, nitrate, phosphate and heavy metals (Cr and Pb) from municipal wastewater. To do this, the effect of  $\text{Fe}_3\text{O}_4$  nanoparticles on microalgae growth rate and wastewater treatment was investigated. Gompertz model was used to simulate the microalgae growth behavior.

## 2. Materials and methods

### 2.1. Microalgae cultivation and chemical material ( $\text{Fe}_3\text{O}_4$ )

A new strain of *Chlorella sorokiniana* pa.91 was chosen for this research [19]. 5% (v/v) of *Chlorella sorokiniana* was inoculated in 250 ml conical flasks with BG-11 medium and cultured under a light intensity of 2800 lux at 30 °C, pH 7.1, and a cycle of light/dark 12/12 h [16]. In order to prepare magnetite ( $\text{Fe}_3\text{O}_4$ ) nanoparticle,  $\text{FeCl}_2 \cdot 4\text{H}_2\text{O}$  and  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  were used, while  $\text{NH}_4\text{OH}$  was employed as a reactant.

### 2.2. Wastewater characteristic

Raw municipal wastewater was obtained from a wastewater treatment plant in Sari, Iran, after undergoing preliminary settling tank treatment. Once the solids were separated from the wastewater, it was used as the culture medium for testing the microalgae's potential for nutrient removal from real municipal wastewater. Prior to each experiment, the wastewater was centrifuged at 10000 rpm for 20 min to eliminate any solid particles. The physicochemical properties of the culture mediums were presented in Table 1[10].



**Table 1.** The physicochemical characteristics of the culture mediums used in this study

Parameters	Real municipal wastewater (RMWW) (mg/L)
sCOD	211.4 ± 3.0
NO <sub>3</sub> <sup>-</sup>	17.11 ± 0.8
NH <sub>3</sub>	10 ± 2.8
PO <sub>4</sub> <sup>-3</sup>	6.1 ± 0.5
Cr	60.1
Pb	25.7
pH	7.8 ± 0.3

## 2.3. Analytical methods

### 2.3.1. Determination of microalgae growth and productivity

During cultivation, the optical density of microalgae biomass concentration was determined daily by using a UV spectrophotometer (2800 UV/VIS UNICO, China) at the wavelength of 680 nm (OD<sub>680</sub>). The standard curve was plotted with OD<sub>680</sub> in the different range of microalgae biomass concentration. The correlation between OD<sub>680</sub> and biomass concentration (C) (g/L) of the microalgae were obtained as Eq. (1):

$$C = 1.824 OD_{680} + 0.043 \quad (R^2 = 0.9889) \quad (1)$$

### 2.3.2. Nutrients removal

In order to quantify the removal efficiency of the nutrients through microalgae cultivation the concentration of nitrate (NO<sub>3</sub><sup>-</sup>), phosphate (PO<sub>4</sub><sup>3-</sup>) and COD were measured based on APHA standard methods [17]. According to the standard method, COD was measured by using the standard curve of potassium hydrogen phthalate (KHP). The amount of nitrate and phosphate concentrations were determined based on brucine sulfate and phosphorus solution methods, respectively. During cultivation period, the sample of microalgae culture medium was taken daily and after centrifugation at 4000 rpm for 15 min, the supernatant was used for measuring the nutrients concentration. The nutrient removal rate (%) was calculated as Eq (2): [18].

$$\text{Removal rate} = (C_0 - C_f)/C_0 \times 100 \quad (2)$$

Where,  $C_0$  and  $C_f$  are the initial and final nutrient concentrations at day  $t_0$  and  $t_f$ , respectively. The pH was measured daily by pH meter. Light intensity was measured in all experiments by a digital light meter (Mastech MS6610, USA).



### 2.3.3. Heavy Metal removal

Measurements of Cr and Pb were performed using a Shimadzu AA-6300 atomic absorption spectrophotometer equipped with a GFA-EX7i graphite furnace atomizer and an ASC-6100 auto sampler. A normal graphite tube was used in the furnace. Background correction was accomplished by the deuterium lamp method (Shimadzu). Sampling was performed in a laminar flow fume hood to prevent contamination from ubiquitous microorganisms. A 3 mL sample were taken from the culture medium every two days and centrifuged. The supernatant was used for final heavy metal analysis. The initial value for heavy metals used in calculations was taken after microalgae inoculation. The heavy metal removal efficiency was calculated as Eq 3:

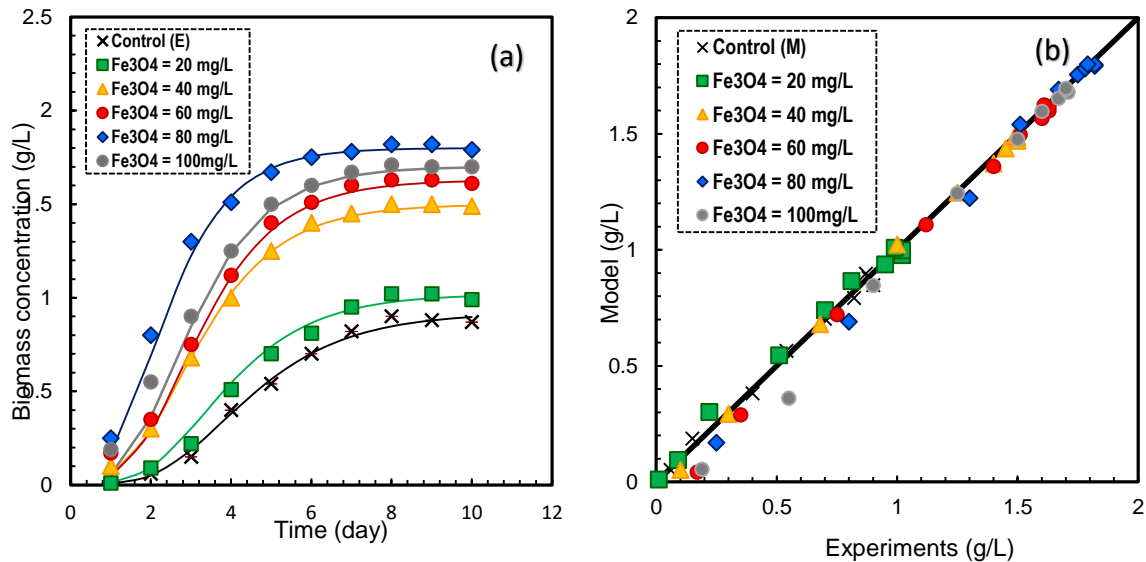
$$\text{Removal efficiency (\%)} = \frac{\text{Initial concentration} - \text{Final concentration}}{\text{Initial concentration}} \times 100 \quad (3)$$

## 3. Results

### 3.1. The effect of Fe<sub>3</sub>O<sub>4</sub> on microalgae growth rate

Fig. 1 demonstrates the growth of *C. Sorokoniana* cultured in MWW by adding five different dosages of Fe<sub>3</sub>O<sub>4</sub> (20, 40, 60, 80 and 100 mg/L), during the 10 days of cultivation period. As can be seen in Fig. 1a, the microalgae showed a poor growth rate (maximum biomass concentration ~ 0.9 g/L) without adding Fe<sub>3</sub>O<sub>4</sub>. In the case of using 40 mg/L of Fe<sub>3</sub>O<sub>4</sub> relatively better growth was obtained as maximum concentration of 1.5 g/L on the 8<sup>th</sup> day of cultivation. However, a significant improvement in microalgae growth was observed in the medium with 80 mg/L Fe<sub>3</sub>O<sub>4</sub>. Maximum biomass concentration of 1.83 and 1.7 g/L were achieved for the cases of using Fe<sub>3</sub>O<sub>4</sub> at 80 and 100 mg/L after 8 days, respectively.

Additionally, Gompertz model was used to simulate microalgae growth behavior at the different cases (Fig. 1b). The simulation results showed that the microalgae cultivated in the medium with 80 mg/L Fe<sub>3</sub>O<sub>4</sub> had the best accordance with the experimental data ( $R^2 = 0.999$ ) compared to the other mediums. It was also observed that it had a short lag phase ( $\lambda = 0.85$  d). Eventually, the growth experiments and modeling results revealed that the presence of adequate micronutrients provided in the culture medium at high concentration of Fe<sub>3</sub>O<sub>4</sub> (80 mg/L), can act as the trace element and resulted in improving microalgae growth rate.



**Fig.1.** Microalgae growth (a) experiments and (b) modeling during the 10 days of cultivation in wastewater with addition of five different dosages of Fe<sub>3</sub>O<sub>4</sub>

### 3.2. The effect of Fe<sub>3</sub>O<sub>4</sub> on microalgae in wastewater treatment

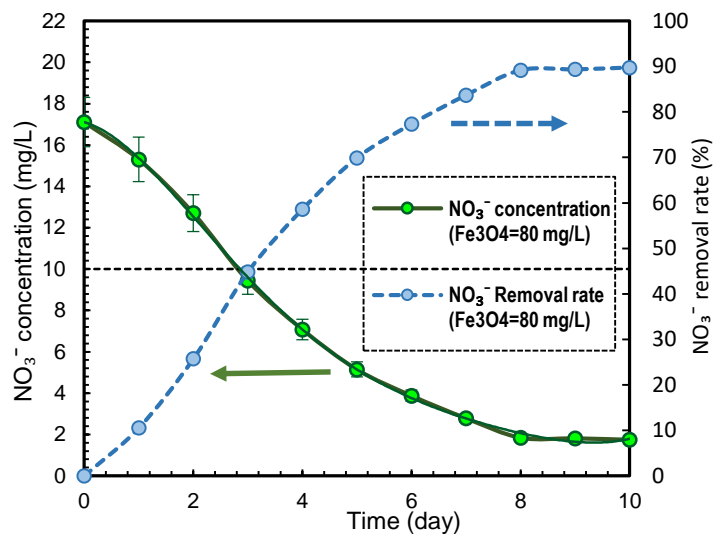
The consumption of nutrient from municipal wastewater by microalgae cells and the addition of Fe<sub>3</sub>O<sub>4</sub> nanoparticle can improve microalgae growth rate and wastewater treatment. In order to evaluate the feasibility of Fe<sub>3</sub>O<sub>4</sub>-microalgae based wastewater treatment using *C. sorokiniana*, the removal of nutrients such as nitrate (NO<sub>3</sub><sup>-</sup>), phosphate (PO<sub>4</sub><sup>-3</sup>) and chemical oxygen demand (COD) from real municipal wastewater influent was investigated.

#### 3.2.1. Nitrate (NO<sub>3</sub><sup>-</sup>) removal efficiency

Among different nutrients, nitrogen is the main source for microalgae growth. Fig. 2 shows the performance of the microalgae cultivated in the municipal wastewater at optimum dosage of Fe<sub>3</sub>O<sub>4</sub> (80 mg/L) which the concentration and removal rate of nitrate (NO<sub>3</sub><sup>-</sup>) was measured during 10 days. According to Fig. 2, the NO<sub>3</sub><sup>-</sup> concentration decreased from 17.11 mg/L to 1.75 mg/L during 10 days and it met the standard level for agriculture water reuse (NO<sub>3</sub><sup>-</sup> < 10 mg/L) after 3 days. Although during the first two days microalgae was almost ineffective in removing nitrate from



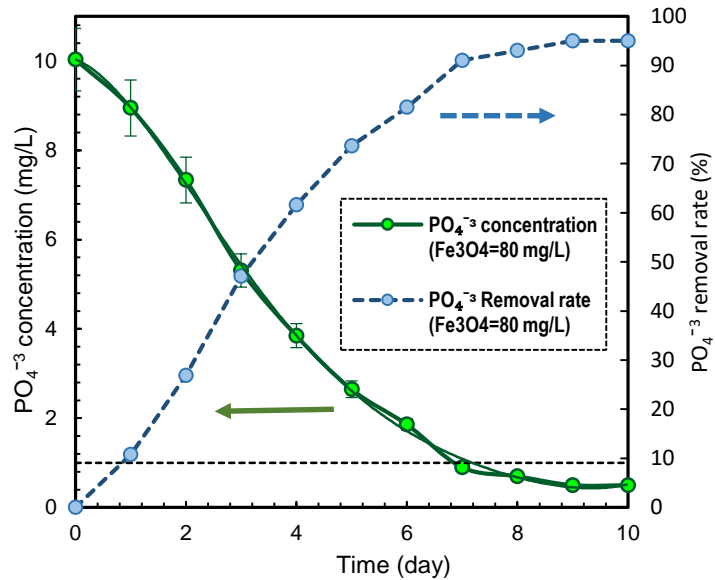
wastewater due to the adoption period, after the adoption period (the 3rd day) the removal efficiency was significantly increased up to 89% until the 8th day. Therefore, using  $\text{Fe}_3\text{O}_4$  in wastewater medium could improve microalgae potential to remove nitrate from municipal wastewater.



**Fig. 2.** Removal rate and concentration of nitrate  $\text{NO}_3^-$  from real municipal wastewater during cultivation of *C. sorokiniana* in the presence of  $\text{Fe}_3\text{O}_4$

### 3.2.2. Phosphate ( $\text{PO}_4^{3-}$ ) removal efficiency

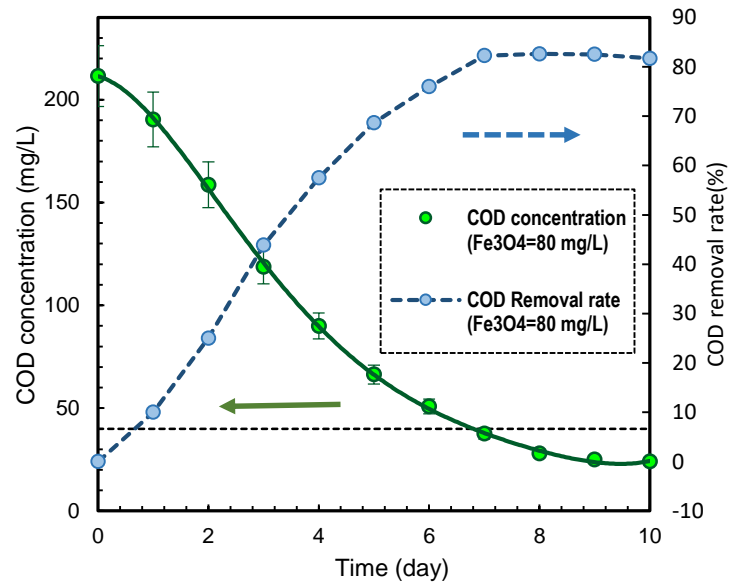
Phosphate is another nutrient that can be used for microalgae growth while the current wastewater treatment technologies showed a poor performance in an efficient removal of phosphate from wastewater. According to Fig. 3 demonstrates removal rate and the consumption of phosphate ( $\text{PO}_4^{3-}$ ) by microalgae at optimum dosage of  $\text{Fe}_3\text{O}_4$  nanoparticle. As in can be seen from Fig. 3, a similar trend was observed with nitrate removal from wastewater. However, the final removal rate of the phosphate (95%) was higher than nitrate (89%) which might be attributed to the initial concentration of the nutrients in the culture medium. As showed in Fig. 3, the  $\text{PO}_4^{3-}$  concentration decreased substantially from 10.03 to less than 1 mg/L within 8 days, which was below the acceptable level of the surface water quality standard (1 P-mg/L). The findings of this study suggested that *C. sorokiniana* has high capacity of orthophosphate storing from the wastewater culture medium in the presence of  $\text{Fe}_3\text{O}_4$  nanoparticle.



**Fig. 3.** Removal rate and concentration of phosphate  $\text{PO}_4^{3-}$  from real municipal wastewater during cultivation of *C. sorokiniana* in the presence of  $\text{Fe}_3\text{O}_4$

### 3.2.3. Chemical oxygen demand (COD) removal efficiency

Chemical oxygen demand (COD) has been reported as the most challenging problem in wastewater treatment process due to its re-increasing in the medium. As illustrated in Fig 4, the COD was removed from 211 to 24 mg/L with removal rate of 81% during 10 days cultivation of microalgae. It was observed that the COD level could meet the standard level for agriculture water reuse (COD < 40 mg/L) after 7 days. Generally, microalgae release organic matter after utilization of COD components which resulted to increased COD in the culture medium. However, it seems that the wastewater in this study has provided sufficient carbon source for the microalgae cells for metabolism process.



**Fig. 4.** Removal rate and concentration of COD from real municipal wastewater during cultivation of *C. sorokiniana* in the presence of  $\text{Fe}_3\text{O}_4$

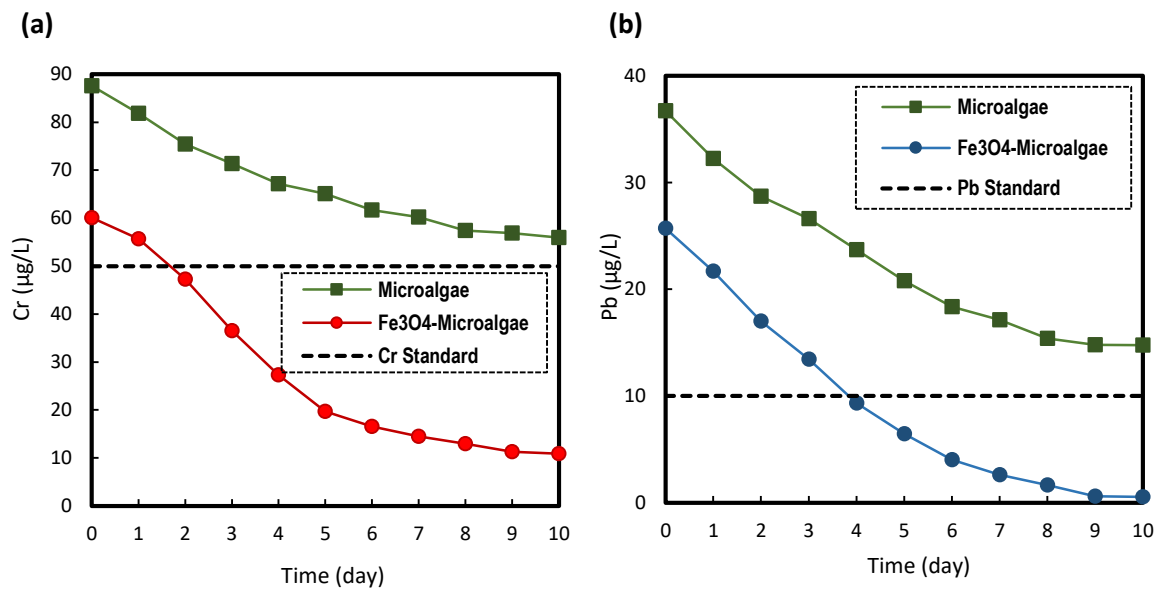
### 32.4. Heavy metals (Cr and Pb) removal

Fig. 5 shows the concentration reduction of the heavy metals of Cr and Pb by the microalgae cells cultivated in the wastewater at optimum dosage of  $\text{Fe}_3\text{O}_4$  (80 mg/L) during 10 days. As shown in Fig. 5a, the microalgae cultivation in the wastewater without adding  $\text{Fe}_3\text{O}_4$  could not reduce Cr concentration below acceptable level for drinking water ( $< 50 \mu\text{g/L}$ ) and just remove 36% of Cr. However, in the case of using 80 mg/L  $\text{Fe}_3\text{O}_4$  in culture medium, the Cr concentration ( $36.5 \mu\text{g/L}$ ) met the standard level for drinking water after 3 days of cultivation period as well as the highest microalgae growth rate was achieved in this medium. Therefore, microalgae in the presence of  $\text{Fe}_3\text{O}_4$  could satisfactorily remove Cr from the wastewater (up to 80%) and reduce the Cr concentration from 60.1 to  $10.9 \mu\text{g/L}$ , after 10 days of cultivation. According to Shen et al. the main functional groups of  $-\text{NH}$ ,  $-\text{NH}$  and  $\text{C}-\text{H}$  of aliphatic participate as electron donors results in reduction of Cr (VI) to Cr (III) by microalgae [14].

In the case of pb (Fig. 5b), the concentration of Pb was reduced from 36.7 to  $14.75 \mu\text{g/L}$  in the case of microalgae alone (control) and from 25.7 to  $0.55 \mu\text{g/L}$  in the presence of  $\text{Fe}_3\text{O}_4$  in culture medium after 10 days of microalgae cultivation. By adding  $\text{Fe}_3\text{O}_4$  to the microalgae culture medium, the removal efficiency of Pb improved and reached to 98% as well as the final concentration of Pb could meet the standard of Pb



level in drinking water (< 10 µg/L) within 4 days. The mechanism of Pb removal is related to the biosorption of Pb<sup>2+</sup> by the fictional groups of carboxyl, hydroxyl, amide, amine and carbonyl.



**Fig. 5.** The removal of (a) Cr and (b) Pb during microalgae cultivation in the wastewater at optimum dosage of Fe<sub>3</sub>O<sub>4</sub> (80 mg/L)

## Conclusion

The use of Fe<sub>3</sub>O<sub>4</sub> nanoparticle in microalgae culture medium could improve the microalgae growth and the cell's capability to remove nutrients and heavy metal from wastewater. In this context, the maximum microalgae biomass concentration of 1.83 g/L at the dosage of 80 mg/L of Fe<sub>3</sub>O<sub>4</sub> was achieved after 10 days of cultivation. Moreover, this approach showed an excellent nutrient and heavy metal removal ability from wastewater by achieving removal rates of 89%, 95%, 81%, 80% and 98% for nitrate (NO<sub>3</sub><sup>-</sup>), phosphate (PO<sub>4</sub><sup>-3</sup>), COD, Cr and Pb, respectively. The results of this study suggested a promising method enhancing both microalgae growth rate and municipal wastewater treatment.



## References

- [1] A. K. Ahangar, P. Yaqoubnejad, K. Divsalar, S. Mousavi, and M. Taghavijeloudar, "Design a novel internally illuminated mirror photobioreactor to improve microalgae production through homogeneous light distribution," *Bioresour. Technol.*, vol. 387, no. July, p. 129577, 2023, doi: 10.1016/j.biortech.2023.129577.
- [2] S. Abdolalian and M. Taghavijeloudar, "Performance evaluation and optimization of ZnO-PVP nanoparticles for photocatalytic wastewater treatment: Interactions between UV light intensity and nanoparticles dosage," *J. Clean. Prod.*, vol. 365, no. May, p. 132833, 2022, doi: 10.1016/j.jclepro.2022.132833.
- [3] J. Shi, X. Teng, Q. Suo, A. Mojiri, M. Taghavijeloudar, and S. Rezania, "Novel magnetic polyethersulfone-polyethyleneimine-based microbeads for removal of lead ions from water: Kinetics and thermodynamics," *J. Mol. Liq.*, vol. 387, no. May, p. 122632, 2023, doi: 10.1016/j.molliq.2023.122632.
- [4] B. Nazari, S. Abdolalian, and M. Taghavijeloudar, "An environmentally friendly approach for industrial wastewater treatment and bio-adsorption of heavy metals using Pistacia soft shell ( PSS ) through flocculation-adsorption process," *Environ. Res.*, vol. 235, no. March, p. 116595, 2023, doi: 10.1016/j.envres.2023.116595.
- [5] M. Rabieian and M. Taghavijeloudar, "Simultaneously removal of PAHs from contaminated soil and effluent by integrating soil washing and advanced oxidation processes in a continuous system: Water saving, optimization and scale up modeling," *Water Res.*, vol. 256, no. April, p. 121563, 2024, doi: 10.1016/j.watres.2024.121563.
- [6] Y. Sun, Y. Guan, M. Pan, X. Zhan, Z. Hu, and G. Wu, "Enhanced biological nitrogen removal and N<sub>2</sub>O emission characteristics of the intermittent aeration activated sludge process," *Rev. Environ. Sci. Biotechnol.*, vol. 16, no. 4, pp. 761–780, 2017, doi: 10.1007/s11157-017-9444-z.
- [7] H. Shabanizadeh and M. Taghavijeloudar, "Performance evaluation of membrane bioreactor ( MBR ) for pulp and paper wastewater treatment," pp. 0–7.
- [8] K. Li *et al.*, "Microalgae-based wastewater treatment for nutrients recovery: A review," *Bioresour. Technol.*, vol. 291, no. June, p. 121934, 2019, doi: 10.1016/j.biortech.2019.121934.
- [9] M. Taghavijeloudar, D. Y. Kebria, and P. Yaqoubnejad, "Simultaneous harvesting and extracellular polymeric substances extrusion of microalgae using surfactant: Promoting surfactant-assisted flocculation through pH adjustment," *Bioresour. Technol.*, vol. 319,



p. 124224, Jan. 2021, doi: 10.1016/J.BIORTECH.2020.124224.

- [10] P. Yaqoubnejad, H. A. Rad, and M. Taghavijeloudar, "Development a novel hexagonal airlift flat plate photobioreactor for the improvement of microalgae growth that simultaneously enhance CO<sub>2</sub> bio-fixation and wastewater treatment," *J. Environ. Manage.*, vol. 298, p. 113482, Nov. 2021, doi: 10.1016/J.JENVMAN.2021.113482.
- [11] A. K. Priya *et al.*, "Heavy metal remediation from wastewater using microalgae: Recent advances and future trends," *Chemosphere*, vol. 305, no. June, p. 135375, 2022, doi: 10.1016/j.chemosphere.2022.135375.
- [12] L. Novoveská, A. K. M. Zapata, J. B. Zabolotney, M. C. Atwood, and E. R. Sundstrom, "Optimizing microalgae cultivation and wastewater treatment in large-scale offshore photobioreactors," *Algal Res.*, vol. 18, pp. 86–94, 2016, doi: 10.1016/j.algal.2016.05.033.
- [13] E. Romera, F. González, A. Ballester, M. L. Blázquez, and J. A. Muñoz, "Comparative study of biosorption of heavy metals using different types of algae," *Bioresour. Technol.*, vol. 98, no. 17, pp. 3344–3353, 2007, doi: 10.1016/j.biortech.2006.09.026.
- [14] L. Shen *et al.*, "A high-efficiency Fe<sub>2</sub>O<sub>3</sub>@Microalgae composite for heavy metal removal from aqueous solution," *J. Water Process Eng.*, vol. 33, no. July 2019, p. 101026, 2020, doi: 10.1016/j.jwpe.2019.101026.
- [15] M. Rizwan, G. Mujtaba, and K. Lee, "Effects of iron sources on the growth and lipid/carbohydrate production of marine microalga *Dunaliella tertiolecta*," *Biotechnol. Bioprocess Eng.*, vol. 22, no. 1, pp. 68–75, 2017, doi: 10.1007/s12257-016-0628-0.
- [16] P. Yaqoubnejad and M. Taghavijeloudar, "Municipal wastewater treatment through cultivation of a new strain of microalgae *Chlorella sorokiniana* pa . 91 in flat plate photobioreactor ( FP-PBR )," no. 3.
- [17] Z. Xu, "Dissolved Oxygen Dynamics and Modeling - A Case Study in A Subtropical Shallow Lake," *Elsevier Sci. Ltd*, vol. 22, p. 114, 2014.
- [18] M. Taghavijeloudar, P. Yaqoubnejad, A. K. Ahangar, and S. Rezanian, "A rapid, efficient and eco-friendly approach for simultaneous biomass harvesting and bioproducts extraction from microalgae: Dual flocculation between cationic surfactants and bio-polymer," *Sci. Total Environ.*, vol. 854, p. 158717, 2023, doi: <https://doi.org/10.1016/j.scitotenv.2022.158717>.