A New Report of Rhodamine B Contaminated Wastewater Decolorization and Electricity Generation by Laccase Based Microbial Fuel Cell

Pimprapa Chaijak ^{1,2,*}, Purimprach Sinkan ¹, Areeyah Madloh ¹, Ariyaporn Chumkong ³

¹ Microbial Fuel Cell & Bioremediation Laboratory, Faculty of Science, Thaksin University, Phatthalung, Thailand

- ² Microbial Technology for Agriculture, Food and Environment Research Center, Thaksin University, Phatthalung, Thailand
- ³ Jiw Krajood Company, Khuan Khanun, Phatthalung, Thailand
- * Correspondence: chaijak.pimprapa@gmail.com;

Scopus Author ID 57195740686 Received: 3.11.2021; Accepted: 14.12.2021; Published: 23.01.2022

Abstract: Rhodamine B (RB) is a basic color for natural plant textile dyeing. This study aims to use the laccase and manganese peroxidase-producing consortium to degrade the RB and generate electrical energy in a novel model microbial fuel cell (MFC). The results revealed that the MFC with consortium KJW40 had current densities and power densities of 4,816.67±28.87 mA/m³, and 2,320.08±27.86 mW/m³, respectively. The RB removal rate was 80.56±0.13 % was reached. This work gained new knowledge about using a bacterial consortium producing laccase and manganese peroxidase to treat contaminated RB and generate electrical power.

Keywords: decolorization; bioremediation; microbial fuel cell; Krajood dyeing; Laccase.

© 2022 by the authors. This article is an open-access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https://creativecommons.org/licenses/by/4.0/).

1. Introduction

Grey sedge or Krajood (*Lepironia articulate* Retz.) is a native plant that occupies 5.54 square kilometers of Thale Noi wetland in Southern Thailand. It has recently been used as a raw material for a variety of products such as mats, bags, hats, and shopping baskets [1-2]. Raw Krajood fiber must be dyed in various colors to increase the variety and improve product quality. The rhodamine B (RB) wastewater treatment has been invested and developed for several years. The RB contaminated wastewater has been treated by photocatalytic treatment such as ultraviolet, photoperoxidation, and photo-Fenton processes [3]. These works establish that these treatments successfully decolorize and characterize some oxidation products and concerns. However, these processes limit operation due to their operating cost [3-6].

Biological treatment has been reported in the RB removal to reduce a chemical adding into the treatment system. The purified fungal laccase has been successfully used in RB decolorization [7]. The manganese peroxidase of the white-rot fungi also has been reported in RB removal [8]. Although, the limitation of a pure enzyme used in the decolorizing process is low operational stability and poor reusability [9]. Therefore, a whole-cell catalyst has been developed for improving a problem [10].

Microbial fuel cell (MFC) is a rapidly growing and eco-friendly technology. It has been reported in the RB removal by combination with the peroxicoagulation system [11]. This study

also attempted to integrate the novel model MFC with laccase-producing whole-cell catalyst on the anodic surface for RB removal and electricity generation.

2. Materials and Methods

2.1. Wastewater.

The dyeing wastewater was collected from Thale Noi wetland, Phatthalung, Southern Thailand. It was collected in a sterile plastic tube and stored in the icebox. Then suddenly transferred to the laboratory at Thaksin University, Thailand. The wastewater was kept at 4 °C to prevent biodegradation by native microbes living in wastewater. The characteristics of dyeing wastewater used in this experiment are shown in Table 1.

Characteristic	Amount	Unit	
Chemical oxygen demand (COD)	20,000±500	mg/L	
Total solid (TS)	$10,500{\pm}100$	mg/L	
Suspended solids (SS)	1.5±0.5	mg/L	
Rhodamine B (RB)	300±10	mg/L	
pH	5.7±0.2	-	

Table 1. The characteristics of dyeing wastewater used in this experiment.

2.2. Enrichment & enzyme activities.

The 100 soil sediment samples from the RB contaminated environment were collected from Thale Noi wetland, Phatthalung, Southern Thailand. It was collected in a sterile plastic tube and stored in the icebox. Then suddenly transferred to the laboratory. The 10 g of soil sediment was inoculated into the nutrient broth and incubated at 30 °C for 48 hr under facultative anaerobic conditions.

For enrichment, the 10% (v/v) of 48-hr old culture was inoculated into the 90% (v/v) of 300 m/L RB solution supplemented with 0.1% (w/v) yeast extract as nitrogen source. it was incubated at 30 °C for 48 hr under facultative anaerobic conditions. The mixed culture was transferred 5 times to ensure it could use the RB as an energy source. The candidate was selected for the growth potential in the RB solution. The 10% (v/v) of 48-hr old candidate consortium (1 x 10^8 cell/mL) was used to determine the laccase and manganese peroxidase activities according to Chandra & Chowdhary [12] and Huy *et al.* [13].

2.3. RB removal.

The 10% (v/v) of 48-hr old candidate consortium (1 x 10^8 cell/mL) was inoculated into the 90% (v/v) of 300 m/L RB solution supplemented with 0.1% (w/v) yeast extract as nitrogen source. it was incubated at 30 °C for 48 hr under facultative anaerobic conditions. The RB removal (%) was determined using a UV-Vis spectrophotometer (Shimadzu, Japan). The wavelength of 554 nm was selected to monitor the RB concentration, according to Hayeeya *et al.* [2]. The RB removal was calculated.

2.4. MFC design & Operation.

The novel MFC model diagram is shown in Figure 1; the cylinder-shaped tube with 100-mL working volume was used as an anode chamber. Four bamboo charcoal $(1.0 \times 5.0 \text{ cm} \text{ size})$ were used as an anode electrode. The stainless steel mesh (2.5 cm diameter) with coconut

coir was used as a cathode electrode; it was floated over an anolyte by the floating plate. The stainless steel wire (1.0 mm diameter) was used to connect between the electrodes.

For operation, the 7-days old yeast culture on coconut coir with approximately 60% moisture content was filled on a cathode electrode. The 100 mL of 48-hr old selected consortium in NB (1 x 10^8 cell/mL) was filled into an anode chamber and incubated at 30 °C for 5 days under the facultative anaerobic condition to immobilize the bacterial cell on the anodic surface. The solution was fed out, then the 100 mL of Krajood-dyeing wastewater with 300 mg/L RB was added into an anode chamber. The open-circuit voltage (OCV) was collected every 10 min for 48 hr. The close circuit voltage (CCV) was collected at 1,000 Ω external resistance. The electrochemical properties were calculated according to Chaijak *et al.* [14].



Figure 1. The diagram of novel model membrane-less MFC

2.5 Microbial community structure

The microbial diversity was analyzed by the DGGE method, total genomic DNA (gDNA) was extracted from 1 g of cell pellet using a TIANamp Genomic DNA kit (Tiangen, China). The microbial community structure of the selected consortium was carried out using a modified method of DGGE analysis according to De Lillo *et al.* [15] and Muyzer *et al.* [16].

3. Results

3.1. Enzyme activities & RB removal.

Among 100 samples, only 7 samples were selected owing to their growth potential in the 300 mg/L RB solution. The laccase (Lac) and manganese peroxidase (MnP) of selected consortia were studied using UV-Vis spectrophotometry. The highest Lac and MnP activities of 25.27±0.56 and 33.12±0.20 U/mL were achieved from the KJW40. The Lac and MnP activities of all consortia are shown in Figure 2.

The RB removal was carried out under static facultative anaerobic conditions. The highest RB removal of $75.50\pm1.01\%$ (113.25 ± 0.54 mg/day) was achieved from the KJW40. The RB removal (%) and the RB removal rate (mg/day) are shown in Figures 3 and 4.



Figure 2. The laccase (Lac) and manganese peroxidase (MnP) activities of selected consortia.



Figure 3. The RB removal (%) of candidate consortia when they were inoculated into 300 mg/L RB solution.





3.2. Electrochemical properties.

The highest laccase and manganese peroxidase activities consortium was selected. The selected consortium was KJW40, and it was inoculated into an anodic chamber was incubated under the static condition to immobilize the selected consortium onto the anodic surface. The 100 mL of raw dyeing wastewater with 300 mg/L RB was fed in for the operation. The OCV was collected every 10 min for 48 hr. The stationary phase of this system was ranged from 900 min to 1,440 min. The maximum OCV of 650 ± 10 mV was obtained. Whereas the OCV of 350 ± 10 mV was gained by the control (dyeing wastewater normal flora). The CCV was determined at 1,000 Ω external resistance when the stable OCV was expressed. The

electrochemical properties of the novel membrane-less MFC with KJW40 are presented in Table 2.

Characteristic	KJW40	Control			
CCV at 1,000 Ω (V)	481.67±2.89	45.00±5.00			
Current (mA)	0.48 ± 0.00	0.05±0.01			
Current density (mA/m ³)	4,816.67±28.87	450.00±50.00			
Power (mW)	0.23±0.00	0.00±0.00*			
Power density (mW/m ³)	2,320.08±27.86	20.42±4.50			
Internal resistance (Ω)	370.27±8.18	13,788.89±1,653.39			

Table 2. The electrochemical properties of the novel membrane-less MFC with KJW40

* Lower than 0.01 mW

3.3. Wastewater treatment.

After the MFC operation, the characteristics of Krajood-dyeing wastewater were determined. The results are displayed in Table 3. The results found the novel model membrane-less MFC gained a higher RB removal than *in vitro*.

 Table 3. The characteristics of dyeing wastewater after were treated by the novel membrane-less MFC with

 KIW/40

125 (* 10.				
Characteristic	Removal	Unit		
Chemical oxygen demand (COD)	50.20±0.45	%		
Total solid (TS)	48.01±1.52	%		
Suspended solid (SS)	80.15±0.89	%		
Rhodamine B (RB)	80.56±0.13	%		
рН	5.45±0.27	-		

3.4. Microbial structure.

The KJW40 community structure was determined using universal primers from the selected consortium's total DNA extracts analyzed by DGGE. The representative DGGE bands were excised from the gel and sequenced. The KJW40 consortium mainly composes *Acinetobacter* sp. and *Clostridium* sp.

4. Discussion

Owing to skin and respiratory tract irritation, RB has a high toxic impact on humans and animals [17]. It has been reported to use various methods for degradation, including biodegradation. Several bacteria have been described as producing laccase, but some cannot secrete laccase outside of the cell. Laccase has been discovered in bacteria from various genera, primarily gram-positive bacteria such as *Bacillus* sp., *Geobacillus* sp., and *Streptomyces* sp. Laccase can be produced by some gram-negative bacteria, including *Pseudomonas* sp., *Enterobacter* sp., and *Proteobacterium* sp. [18].

On the other hand, Kumar & Chandra reported that the consortium composed of *Klebsiella* sp., *Salmonella* sp., and *Enterobacter* sp. had been found in both laccase and manganese peroxidase [19]. In our study, the KJW40 was composed of *Acinetobacter* sp. and *Clostridium* sp., as reported in Kaur *et al.* [20] and David *et al.* [21]. The potential of rhodamine B contaminated wastewater treatment of this study, and other works are shown in Table 4.

Treatment system	Wastewater	COD	Color	Power	Reference
		removal	removal	output	
		(%)	(%)	(mW)	
Ozone synthesis	Textile dyeing	28	33.00	none	[22]
Bio-adsorption	Textile dyeing	-	90.00	none	[2]
Photocatalytic degradation	Synthetic	-	90.36	none	[9]
Photocatalytic degradation	Synthetic	-	96.00	none	[23]
Adsorption	Mixture dyeing	-	96.02	none	[24]
Photocatalytic degradation	Synthetic	-	99.00	none	[25]
Photocatalytic degradation	Synthetic	-	95.50	none	[26]
Photocatalytic degradation	Synthetic	-	93.00	none	[27]
Heterogeneous Fenton-like	Synthetic	-	100.00	none	[28]
oxidation					
Photocatalytic degradation	Synthetic	-	90.00	none	[29]
Photocatalytic degradation	Synthetic	-	95.00	none	[30]
Photocatalytic degradation	Synthetic	-	75.00	none	[31]
Photocatalytic degradation	Textile dyeing	-	99.00	none	[32]
Ultrasonic vibration	Textile dyeing		99.00	none	[33]
Degradation	Synthetic	-	96.30	none	[34]
Adsorption	Synthetic	-	90.90	none	[35]
Fento-like degradation	Synthetic	-	100.00	none	[36]
Adsorption	Synthetic	-	97.10	none	[37]
Membrane-less MFC	Textile dyeing	50.20±0.45	80.56±0.13	0.23±0.00	This study

 Table 4. The potential of Rhodamine-B removal by the novel model membrane-less MFC with KJW40 and

 other works

5. Conclusions

This research illustrates to our knowledge by using a laccase and manganese peroxidase producing consortium with a membrane-less MFC to treat toxic color while also producing electricity. The novel model of membrane-less MFC with KJW40 achieved COD and RB removal rates of 50.20 ± 0.45 % and 80.56 ± 0.13 %, respectively, after only 48 hours of operation, with an output power of 0.23 ± 0.00 mW. The findings demonstrate that the novel membrane-less MFC system with KJW40 could be developed for industrial use in future research.

Funding

This research received no external funding.

Acknowledgments

The author would like to thank the Department of Biology for laboratory support.

Conflicts of Interest

The authors declare no conflict of interest.

References

- 1. Wunbua, J.; Nakhapakorn, K.; Jirakajohnkool, S. Change detection and identification of land potential for planting Krajood (*Lepironia articulate*) in Thale Noi, Southern Thailand. *Songklanakarin Journal of Science and Technology* **2012**, *34*, 329-336.
- Hayeeya, F.; Satter, M.; Tekasakul, S.; Sirichote, O. Adsorption of Rhodamine B on activated carbon obtained from the pericarp of rubber fruit in comparison with the commercial activated carbon. *Songklanakarin Journal of Science and Technology* 2014, *36*, 177-187.

- 3. AlHamedi, F.H.; Rauf, M.A.; Salma, A. Degradation studies of rhodamine B in the presence of UV/H₂O₂. *Desalination* **2009**, *239*, 159-166, https://doi.org/10.1016/j.desal.2008.03.016.
- 4. Barros, A.L.; Pizzolato, T.M.; Carissimi, E.; Schneider, I.A.H. Decolorization dye wastewater from the agate industry with Fenton oxidation process. *Mineral Engineering* **2006**, *19*, 87-90, https://doi.org/10.1016/j.mineng.2005.04.004.
- 5. Jain, R.; Mathur, M.; Sikarwar, S.; Mittal, A. Removal of the hazardous dye rhodamine B through photocatalytic and adsorption treatments. *Journal of Environmental Management* **2007**, *85*, 956-964, https://doi.org/10.1016/j.jenvman.2006.11.002.
- Wang, J.; Li, R.; Zhang, Z.; Sun, W.; Wang, X.; Xu, R.; Xing, Z.; Zhang, X. Degradation of hazardous dyes in wastewater using nanometer mixed crystal TiO₂ powers under visible light irradiation. *Water Air and Soil Pollution* 2008, *189*, 225-237, https://doi.org/10.1007/S11270-007-9570-2.
- 7. Suwannawong, P.; Khammuang, S.; Sarnthima, R. Decolorization of rhodamine B and congo red by partial purified laccase from *Lentinus polychrous* Lev. *Journal of Biochemical Technology* **2010**, *3*, 182-186.
- 8. Singh, R.; Ahlawat, O.P.; Rajor, P. Decolorization of textile dyes by ligninolytic fungi isolated from spent mushroom substrate. *Bulletin of Environment, Pharmacology and Life Science* **2017**, *6*, 53-66.
- Zhang, X.; Wang, M.; Lin, L.; Xiao, G.; Tang, Z.; Zhu, X. Synthesis of novel laccase-biotitania biocatalysts for malachite green decolorization. *Journal of Bioscience and Bioengineering* 2018, *126*, 69-77, https://doi.org/10.1016/j.jbiosc.2018.01.021.
- Lee, S.Y.; Kim, H.U. Systems strategies for developing industrial microbial strains. *Nature Biotechnology* 2015, 33, 1061-1072, https://doi.org/10.1038/nbt.3365.
- 11. Jayashree. S.; Ramesh, S.T.; Lavanya, A.; Gandhimathi, R.; Nidheesh, P.V. Wastewater treatment by microbial fuel cell coupled with peroxicoagulation process. *Clean Technol Environ Policy* **2019**, *21*, 2033-2045, https://doi.org/10.1007/s10098-019-01759-0.
- Chandra, R.; Chowdhary, P. Properties of bacterial laccases and their application in bioremediation of industrial wastes. *Environmental Science: Processes & Impacts* 2015, 17, 326-342, https://doi.org/10.1039/c4em00627e.
- Huy, N.D.; Tien, N.T.T.; Huyen, L.T.; Quang, H.T.; Tung, T.Q.; Luong, N.N.; Park, S.M. Screening and production of manganese peroxidase from *Fusarium* sp. on residue materials. *Mycobiology* 2017, 45, 52-56, https://dx.doi.org/10.5941%2FMYCO.2017.45.1.52.
- Chaijak, P.; Sukkasem, C.; Lertworapreecha, M.; Boonsawang, P.; Wijasika, S.; Sato, C. Enhancing electricity generation using a laccase-based microbial fuel cell with yeast *Galactomyces reessii* on cathode. *Journal of Microbiology and Biotechnology* 2018, 28, 1360-1366, https://doi.org/10.4014/jmb.1803.03015.
- De Lillo, A.; Ashley, F.P.; Palmer, R.M.; Munson, M.A.; Kyriacou, L.; Weightman, A.J.; Wade, W.G. Novel subgingival bacterial phylotypes detected using multiple universal polymerase chain reaction primer sets. *Oral Microbiology and Immunology* 2006, 21, 61-68, https://doi.org/10.1111/j.1399-302x.2005.00255.x.
- Muyzer, G.; Dewaal, E.C.; Uitterlinden, A.G. Profiling of complex microbial populations by denaturing gradient gel electrophoresis analysis of polymerase chain reaction-amplified genes coding for 16S ribosomal RNA. *Applied and Environmental Microbiology* **1993**, *59*, 695-700, https://www.ncbi.nlm.nih.gov/pmc/articles/PMC202176/.
- 17. Rochat, J.; Demenge, P.; Rerat J.C. Toxicologic study of a fluorescent tracer: rhodamine B. *Toxicology European Research* **1978**, *1*, 23-36, https://europepmc.org/article/med/741466.
- 18. Chauhan, P.S.; Goradia, B.; Saxena, A. Bacterial laccase: recent update on production, properties and industrial applications. *3 Biotech* **2017**, *7*, 1-20, https://doi.org/10.1007/s13205-017-0955-7.
- Kumar, V.; Chandra, R. Characterisation of manganese peroxidase and laccase producing bacteria capable of degradation of sucrose glutamic acid-Maillard reaction products at different nutritional and environmental conditions. *World Journal of Microbiology and Biotechnology* 2018, 34, 1-18, https://doi.org/10.1007/s11274-018-2416-9.
- Kaur, S.; Khatri, M.; Arya, S.K.; Singh, G. Stimulating effect of nanoparticles and salt on thermos and halotolerant cell bonded laccase synthesis in *Acinetobacter* sp. UIETPU. *Biocatalysis and Agricultural Biotechnology* 2019, *18*, 1-6, https://agris.fao.org/agris-search/search.do?recordID=US201900184070.
- Davidi, L.; Morais, S.; Artzi, L.; Knop, D.; Hadar, Y.; Arti, Y.; Bayer, E.A. Toward combined delignification and saccharification of wheat straw by a laccase-containing designer cellulosome. *PNAS* 2016, 2016, 1-6, https://doi.org/10.1073/pnas.1608012113.
- 22. Zollinger, H. Color chemistry: Syntheses, properties, and applications of organic dyes and pigments, Wiley-VCN: Switzerland, **2003**, 1-637.

- Nguyen, H.T.T.; Tran, K.N.T.; Tan, L.V.; Tran, V.A.; Doan, V.D.; Lee, T.; Nguyen, T.D. Microwave-assisted solvothermal synthesis of bimetallic metal-organic framework for efficient photodegradation of organic dyes. *Materials Chemistry and Physics* 2021, 272, 125040, https://doi.org/10.1016/j.matchemphys.2021.125040.
- 24. Cao, N.; Zhao, X.; Gao, M.; Li, Z.; Ding, X.; Li, C.; Liu, K.; Du, X.; Li, W.; Feng, J.; Ren, Y.; Wei, T. Superior selective adsorption of MgO with abundant oxygen vacancies to removal and recycle reactive dyes. Sep Purif Technol 2021, 275, 119236, https://doi.org/10.1016/j.seppur.2021.119236.
- Zhao, S.; Chen, C.; Ding, J.; Yang, S.; Zang, Y.; Ren, N. One-pot hydrothermal fabrication of BiVO₄/Fe₃O₄/rGO compositie photocatalyst for the simulated solar light-driven degradation of rhodamine B. *Frontiers of Environmental Science and Engineering* 2022, *16*, 36, https://doi.org/10.1007/s11783-021-1470y.
- 26. Jin, J.C.; Yang, M.; Zhang, Y.L.; Dutta, A.; Xie, C.G.; Kumar, A. Integration of mixed ligand into a multivariate metal-organic framework for enhanced UV-light photocatalytic degradation of Rhodamine B. *Journal of the Taiwan Institue of Chemical Engineers* 2021, 129, 410-417, https://doi.org/10.1016/j.jtice.2021.08.041.
- Zheng, S.; Ding, B.; Qian, X.; Yang, Y.; Mao, L.; Zheng, S.; Zhang, J. High efficiency degradation of tetracycline and rhodamine B using Z-type BaTiO3/Y-Bi2O3 heterojunction. *Separation and Purification Technology* 2022, 278, 119666, https://doi.org/10.1016/j.seppur.2021.119666.
- Yu, H.; Liu, Y.; Xu, M.; Cong, S.; Liu, M.; Zou, D. Hydroxylamine facilitated heterogeneous fenton-like reaction by nano micro-electrolysis materials for rhodamine B degradation. *Journal of Cleaner Producton* 2021, *316*, 128136, https://doi.org/10.1016/j.jclepro.2021.128136.
- 29. Chankhanittha, T.; Nanan, S. Visible-light-driven photocatalytic degradation of ofloxacin (OFL) antibiotic and rhodamine B (RnB) dye by solvothermally grown ZnO/Bi2MoO6 heterojunction. *Journal of Colloid and Interface Science* **2021**, *582*, 412-427, https://doi.org/10.1016/j.jcis.2020.08.061.
- Ahmad, M.; Rehman, W.; Khan, M.M.; Qureshi, M.T.; Gul, A.; Haq, S.; Ullah, R.; Rab, A.; Menaa, F. Phytogenic fabrication of ZnO and gold decorated ZnO nanoparticles for photocatalytic degradation of rhodamine B. *Journal of Environmental Chemical Engineering* 2021, 9, 104725, https://doi.org/10.1016/j.jece.2020.104725.
- Mancipe, S.; Martinez, J.J.; Pinzon, C.; Rojas, H.; Solis, D.; Gomez, R. Effective photocatalytic degradation of rhodamine B using tin semiconductors over hydrotalcite-type materials under sunlight driven. *Catalysis Today* 2021, *372*, 191-197, https://doi.org/10.1016/j.cattod.2020.12.014.
- 32. Chennah, A.; Amaterz, E.; Taoufyq, A.; Bakiz, B.; Kadmi, Y.; Bazzi, L.; Guinneton, F.; Benlhachemi, A. Photoelectrocatalytic degradation of rhodamine B pollutant with a novel zinc phosphate photoanode. *Process Safety and Environmental Protection* **2021**, *148*, 200-209, https://doi.org/10.1016/j.psep.2020.10.012.
- Sharma, A.; Bhardwaj, U.; Kushwaha, H.S. Ba2TiMnO6 two-dimensional nanosheets for rhodamine B organic contaminant degradation using ultrasonic vibrations. *Materials Advances* 2021, 2, 2649-2657, https://doi.org/10.1039/D1MA00106J.
- Di, J.; Jamakanga, R.; Chen, Q.; Li, J.; Gai, X.; Li, Y.; Yang, R.; Ma, Q. Degradation of rhodamine B by activation of peroxymonosulfate using Co3O4-rice husk ash composites. *Science of the Total Environment* 2021, 784, 147258, https://doi.org/10.1016/j.scitotenv.2021.147258.
- 35. Liu, Z.; He, X.; Yang, X.; Ding, H.; Wang, D.; Ma, D.; Feng, Q. Synthesis of mesoporous carbon nitride by molten salt-assisted silica aerogel for rhodamine B adsorption and photocatalytic degradation. *Journal of Materials Science* 2021, 56, 11248-11256, https://doi.org/10.1007/s10853-021-05994-z.
- Zhu, X.; Zhang, L.; Zou, G.; Guo, Y.; Liang, S.; Hu, L.; North, M.; Xie, H. Carboxycellulose hydrogel confined-Fe3O4 nanoparticles catalyst for Fento-like degradation of Rhodamine B. *International Journal of Biological Macromolecules* 2021, 180, 792-803, https://doi.org/10.1016/j.ijbiomac.2021.04.067.
- Amdeha, E.; Mohamed, R.S. A green systhesized recyclable ZnO/MIL-101 (Fe) for rhodamine B dye removal via adsortion and photo-degradation under UV and visible light irradiation. *Environmental Technology* 2021, 42, 842-859, https://doi.org/10.1080/09593330.2019.1647290.