

COMPARATIVE EFFICIENCY BETWEEN SOLAR PHOTOCATALYTIC AND MICROBIAL PROCESS FOR ORANGE DYE DEGRADATION

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ABSTRACT

Wastewater is exhausted in large volume every year during the manufacturing processes of textile industries such as dyeing and finishing. The effluent that comes from textile manufacturing factories does not only cause coloration of water but is also potentially harmful and poses health hazard to human and aquatic life. Physical and chemical treatment do not remove the colour and reduce the dye compound concentration. The main objective of this study was to evaluate the efficiency of degradation of Orange G dye using solar photocatalytic and microbial catalytic. Solar photocatalytic process was studied by using Titanium Dioxide (TiO₂) to remove dye contaminants while photocatalyst and bacteria *Pseudomonas aeruginosa* sp. were used as microbial catalyst to degrade the Orange G dye. This experiment deals with the percentage of degradation of the Orange G dye at different pH values and concentrations. The reaction time was set to 40 minutes. The results show that the degradation efficiency of Orange G dye was higher when treated with microbial catalytic compared to solar photocatalytic. The percentages of degradation of Orange G dye under solar photocatalyst were 22.6%, 16.14%, 31.07%, at 10 ppm, 15 ppm and 20 ppm concentrations respectively while the percentage of degradation of Orange G dye under microbial catalytic were 86%, 86.33% and 91.09%, at 10 ppm, 15 ppm and 20 ppm concentration respectively. Additionally, higher efficiency in the degradation process was observed in alkaline conditions compared to acidic conditions as the increase in pH value had caused the increase in percentage of degradation of the Orange G dye.

Keywords: solar photocatalytic, microbial process, Orange G dye, Titanium Dioxide (TiO₂), *Pseudomonas aeruginosa* sp. bacteria

1.0 INTRODUCTION

The textile industry is one of the most problematic among manufacturing industries. The industry uses an extremely large amount of water and produces large volumes of wastewater from its processes. Wastewater from textile industries constitutes a threat to the environment in large parts of the world. Textile wastewater is normally characterized by its low biodegradability due to the chemical stability of synthetic dyes in the environment. Wastewater generated from the textile industry is contaminated mainly with synthetic dyes. Traditional wastewater treatment technologies were proven to be noticeably unproductive in the treatment of wastewater that contains synthetic dyes. For the dyeing purpose, Azo dyes are the biggest group of highly water-soluble synthetic dye used in the textile industry [1].

Azo dyes are a major class of synthetic dyes which comprise more than 50% of all organic colorants available throughout the world. There is a constant demand in developing more applicable and longer lasting dyes. It must be constantly updated to produce colours that reflect the trend dictated by the changes in social styles and ideas. Brighter, longer lasting colours are regularly required to satisfy the demand [2]. Azo dyes are resistant to biodegradation. Hence, conventional biological treatment methods are unproductive in degrading the dye. The high concentration of dyes in discharged water changes the stream colour, and it will lower its aesthetic value. It will also affect the aquatic ecosystem tremendously due to the fact that azo dye is toxic. The presence of the pollutant in the water system creates serious environmental problems. The discharge of azo dye is a concern due to the colorization of the water. The reflection absorption of sunlight that falls upon the water bodies will interfere with the growth of bacteria and plants in the water ecosystem. Orange G dye is a type of synthetic azo that is acidic in nature and commonly used as a staining agent for fabrics [3].

Effluent of orange G dye is extremely toxic to both flora and fauna. Recent studies from Li et al. [4] and Shelke et al. [5] stated that orange G dye poses the same potential risk to both the environment and humans by causing negative bioaccumulation in wildlife and ecotoxicological effect. Meanwhile Bushra et al. [6] and Kurade et al. [7] further describe that orange G dye affects the aquatic ecosystem by forming toxic and potentially carcinogenic compounds. Untreated dyes also produce toxic substances that hinder photosynthetic processes of hydrophytes by blocking the light from penetrating the water [8].

Thus, wastewater effluent from textile industries must be treated before being discharged into the water body. To find an economic and proficient approach to treat textile dyeing wastewater, numerous methods have been developed including physicochemical, biochemical, combined treatment processes and other methods in the past several decades. Among the new treatment methods, solar photocatalyst has attracted increasing attention [9]. The combination of photocatalysis and solar technology can effectively destroy a lot of organic pollutants which structure is stable and difficult to degrade [3]. Photocatalysis is a light induced catalytic process that oxidizes organic pollutants through redox reactions that occur on the surface of metal oxides which act as photocatalyst. Photocatalytic degradation by using sunlight is considered as environmentally friendly process to degrade organic compounds [10]. The most commonly used photocatalyst are Titanium Dioxide (TiO_2) and Zinc Oxide (ZnO) because they have higher efficiency of removing wide range of organic chemicals and synthetic dyes [11]. When a photocatalyst absorbs sufficient amount of energy from sunlight, electrons on its surface will excite the conduction band and positive hole is produced in the valence band [12].

On the other hand, microbial degradation is an eco-friendly cost-competitive alternative to chemical decomposition process that could help reduce water consumption. Azo compounds are receptive to biological degradation under two conditions which are aerobic and anaerobic conditions [13]. Generally, microbial degradation of azo dyes involves reductive cleavage of azo bonds ($-\text{N}=\text{N}-$) with the assistance of an azo reductase enzyme under anaerobic conditions. This condition involves a transfer of four electrons which reducing equivalents. Then, it proceeds through two stages at the azo linkage and at every stage two electrons which act as the final electron acceptor, are transferred to the azo dye, resulting in decolorization of dye and the formation of colorless solutions [14]. The aromatic amines are the result of intermediate metabolites which further degraded aerobically or anaerobically [15].

In response to this situation, this study was conducted to evaluate and compare the efficiency of degradation of Orange G dye using solar photocatalytic and microbial catalytic. In this study, *Pseudomonas aeruginosa* sp. bacteria was used as a microbial catalyst to degrade the Orange G dye. The experiment was carried out by varying the pH of the sample solutions to determine the degradation efficiency of Orange G dye and the percentages of degradation of Orange G dye were observed at 10 ppm, 15 ppm and 20 ppm concentrations for both photocatalytic degradation and microbial catalytic degradation.

2.0 RESEARCH METHODOLOGY

2.1 Materials

All materials in this experiment were prepared in the laboratory and of analytical grade. The model dye, Orange G dye was purchased from Bendosen Laboratory Chemicals manufacturer and a stock solution of the dye (1 M) was prepared in distilled water. The instruments used in this experiment were UV-Vis Spectrophotometer – UV 1800 Shimadzu and Solar Power Meter TES 1333. All materials were prepared in the laboratory.

2.2 Methods

The degradation of Orange G dye process was operated in different conditions which were the presence of *Pseudomonas aeruginosa* sp. bacteria under microbial process, and TiO₂ under photocatalyst process. Then, the percentage of degradation of Orange G dye was analyzed with UV-Vis Spectrophotometer by tabulating the absorbance readings of the dye solution. The rate of degradation for the different conditions was also studied using the formula:

$$\text{Degradation efficiency (\%)} = [C_0 - C_t / C_0] \times 100 \quad (1)$$

Where C₀ is the initial concentration of dyes and C_t is the concentration of dyes at time 't'.

2.2.1 To study microbial process by *Pseudomonas aeruginosa* sp. bacteria

250 ml of conical flask which contains 0.4 ml of nutrient broth and 10 ml of 5 ppm of Orange G dye solution was autoclaved under 121°C for 15 minutes. 1 ml of *Pseudomonas aeruginosa* sp. bacteria was added into the 250 ml of conical flask which contained the mixture of solution. The pH meter was dipped into the solution to pledge the pH to approximately 3.5. The solution was incubated for 1 day under the room temperature of 25°C by using the incubate shaker. The pH reading and the temperature were recorded. The suspension was centrifuged under 3000 rpm within 40 minutes. The supernatant liquid was filtrated using filter funnel with filter paper. 3 ml of the liquid sample was obtained and monitored by UV/Vis spectrophotometer to get the absorbance readings of the degradation of the samples. All processes were repeated with the presence of bacteria at 10 ppm, 15 ppm and 20 ppm concentration in 10 min, 20 min, 30 min and 40 min respectively.

2.2.2 To study the effect of solar Irradiation to the rate of degradation.

5ml of Orange G dye solution was poured into 500 ml volumetric flask and the initial pH was recorded. The pH was controlled by dropping 0.01 M of H₂O₂ solution. The pH meter was dipped into the solution to ensure that the pH was around 3.5. Then the solution was exposed under the sunlight for 40 minutes. Next, a small amount of sample solution was obtained at a time interval of 10 minutes, 15 minutes and 20 minutes. The UV/Vis spectrophotometer was used to monitor the decolourization of the samples. The same procedure was repeated for pH 7.5.

2.2.3 To study Photodegradation process by TiO₂

The standard of Orange G samples from 10 ppm, 15 ppm and 20 ppm were analysed under UV-Vis spectrometer with 477 nm wavelength. Different concentrations of Orange G (10 ppm, 15 ppm and 20 ppm) were transferred into 250 ml beakers and exposed to sunlight for 40 minutes. The sample was analysed under UV-Vis Spectrophotometer with 477 nm wavelength and the degradation of Orange G dye over time

was monitored continuously. This experiment was carried out by varying the pH of the sample solution to determine the degradation efficiency of Orange G dye.

3.0 RESULTS AND DISCUSSION

3.1 Decolorization and degradation of Orange G dye

Table 1 shows that the absorbance readings for Orange G dye in solar condition for 10 ppm, 15 ppm and 20 ppm concentrations were 0.384, 0.566 and 0.741 respectively. The absorbance readings correspondingly increase from 0.384 to 0.741 with the increase of Orange G dye concentration. The readings of Orange G dye in microbial condition increase from 0.364 until 0.742 at 20 ppm. All the absorbance values were observed as the blank absorbance of Orange G dye before the reaction process begins.

The calculation of the percentages of Orange G absorbance is based on the following formula.

$$\text{Degradation efficiency (\%)} = [C_0 - C_t / C_0] \times 100 \quad (2)$$

Where C_0 is the initial concentration of dyes and C_t is the concentration of dyes at time 't'.

Table 1: The absorbance of Orange G dye by Solar and *Pseudomonas aeruginosa* sp. bacteria

Concentration (ppm)	Absorbance (nm)	
	Solar	<i>Pseudomonas aeruginosa</i> sp. bacteria
10	0.384	0.364
15	0.566	0.566
20	0.741	0.742

Table 2: The absorbance of Orange G dye under Solar at pH 3.5 and pH 7.5

Concentration (ppm)	Absorbance under Solar (nm)							
	pH 3.5				pH 7.5			
	10 min	20 min	30 min	40 min	10 min	20 min	30 min	40 min
10	0.592	0.578	0.571	0.547	0.59	0.585	0.562	0.541
15	0.788	0.763	0.747	0.701	0.87	0.834	0.827	0.775
20	0.949	0.907	0.897	0.87	1.908	1.708	1.54	1.356

Table 2 shows the absorbance of Orange G dye under solar photocatalytic at pH 3.5 and pH 7.5 at different concentrations. For pH 3.5, the absorbance readings for all concentrations decreased after 40 minutes reaction time. Similarly tabulated data for pH 7.5 show that the absorbance readings for all concentrations decreased over time. The absorbance reading for 10 ppm started at 0.590 nm after exposure to solar photocatalytic for 10 minutes and as the Orange G was exposed to sunlight longer, the readings gradually decreased to 0.585 nm, 0.562 nm and 0.541 nm after 20, 30, 40 minutes exposure respectively. The same trend can be observed for Orange G dye at 15 ppm and 20 ppm concentrations.

Table 3: The absorbance of Orange G dye under Microbial catalytic at pH 3.5 and pH 7.5

Concentration (ppm)	Absorbance under Microbial (nm)							
	pH 3.5				pH 7.5			
	10 min	20 min	30 min	40 min	10 min	20 min	30 min	40 min
10	0.156	0.155	0.151	0.131	0.124	0.119	0.11	0.094
15	0.164	0.158	0.157	0.141	0.174	0.172	0.171	0.119
20	0.26	0.253	0.227	0.179	0.226	0.2	0.194	0.175

For the degradation of dye under microbial catalytic at pH 3.5 and pH 7.5, the comparison of the concentrations of Orange G dye are shown in Table 3. The absorbance readings under microbial catalytic at pH 3.5 show the decreasing trend when the Orange G dye sample were exposed over 40 minutes reaction time. The absorbance of pH 7.5 for 15 ppm under microbial catalytic show the readings of 0.174 nm, 0.172 nm, 0.171 nm and 0.119 nm at 10,20,30 and 40 minutes respectively. The highest absorbance reading is 0.226 nm at 20 ppm, and the lowest absorbance reading is 0.110 nm at 10 ppm. It has been reported that, degradation of azo dye is not only influenced by the types of microorganism, but the efficiency of dye removal also depends on the various physico-chemical operational parameters, such as the level of agitation, oxygen, temperature, pH, dye structure and dye concentration [16].

3.2 Efficiency degradation of Orange G Dye

Based on the experiment, it can be observed that there is a great percentage difference between the performance of solar photocatalytic and microbial catalytic. The comparison of solar photocatalytic and microbial processes in the degradation of Orange G dye at 10 ppm are shown in Figure 1. It shows that microbial catalytic degrades the Orange G dye more than solar photocatalytic in 40 minutes. The percentage of degradation for Orange G dye at 10ppm concentration and pH 7.5 for microbial process and solar photocatalyst are 86.55% and 22.6 % respectively. This phenomenon shows that, *Pseudomonas aeruginosa* sp. bacteria are able to degrade the Orange G dye effectively than solar photocatalytic.

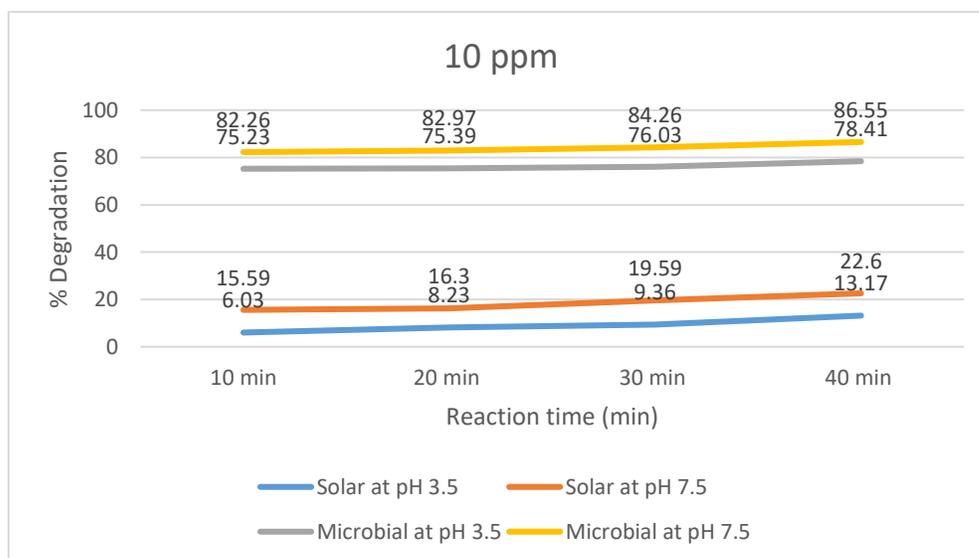


Figure 1: The comparison of solar and microbial processes in terms of the percentage of degradation for Orange G dye at 10 ppm

Based on Figure 1, at 10 ppm concentration, the percentage of degradation under solar photocatalytic at pH 7.5 is 15.59% for 10 minutes reaction time and gradually rises until it reaches 22.6% at 40 minutes reaction time. Similar trend can be observed for pH 3.5 where the percentage of degradation at 10 minutes is 6.03% and it reaches 13.17 % at 40 minutes. From the tabulated data, it can be observed that there is an increase of degradation percentage of Orange G dye from pH 3.5 to pH 7.5. It is proven that the efficiency of degradation related to pH and time. This finding is in line with a study conducted by [17], which state that pH is one of the most important parameters affecting the activity of enzyme and degradation potential of the bacteria. The pH impact on methyl red degradation was observed when the pH increased from the acidic to alkaline region. At pH 9, the decolorization rate increased (62.32%) and was found to decrease at low pH, which indicates that bacterial growth and enzymatic activity are affected at extreme alkaline and acidic conditions [17]. According to Zhuang et al., the pH range for bacterial biodegradation commonly optimizes from 6 to 10 [18]. Ikram et al. found that the biodegradation rate at pH 10 is the maximum. The decolorization of dyes is usually achieved under alkaline conditions at pH ranges of 6 to 10 [19].

Several studies have isolated and identified bacterial strains capable of decolorizing dyes in alkaline solutions. Sihaq et al. [20] worked with a strain of *Aeromonas hydrophila* capable of degrading the dyes Reactive Red 198 and Reactive Black 5 over a pH range of 5.5 to 10. The research of Bheemaraddi et.al [21] isolated a strain of *Comamonas* sp. from contaminated soil of industrial environment which was able to degrade the dye Direct Red 5B in a pH range of 6–12 but having its best activity in neutral pH range. However, a study conducted by Khan e.al [22] who worked with three different strains of bacteria belonging to genus *Halomonas* sp. isolated from textile effluents found that all of them performed the best decolorization in alkaline pH, with the highest activity achieved at the highest pH tested: 11. All these studies show that the best degradation activities are achieved in alkaline medium.

Figure 2 shows the comparison the percentages of degradation at 15 ppm against time interval for pH 3.5 and pH 7.5 under microbial catalytic and solar photocatalytic. Based on Figure 2, the percentage of degradation for Orange G dye is much higher with microbial catalytic (86.33%) at 40 minutes reaction time under pH 7.5 compared to the percentage of degradation for Orange G dye by solar photocatalytic (16.14%) under the same reaction time and at pH 3.5. It shows that, the process of degradation under solar photocatalytic at pH 7.5 was lower than the degradation process of Orange G dye at pH 3.5.

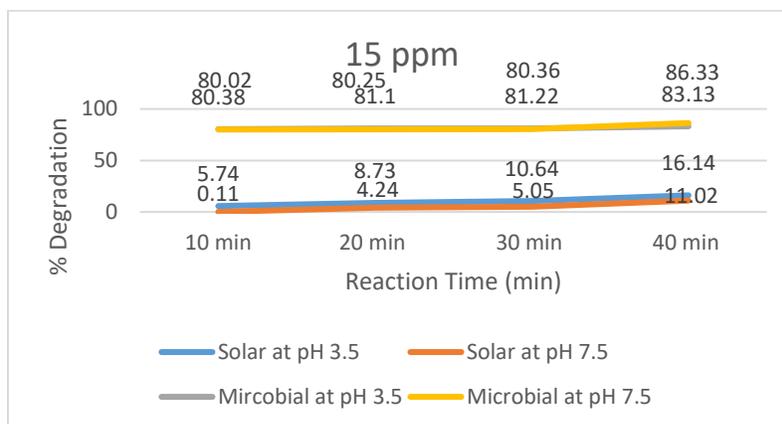


Figure 2: The comparison of solar and microbial processes in terms of the percentage of degradation for Orange G dye at 15 ppm

Figure 2 shows the comparison between solar photocatalytic and microbial processes in terms of percentage of Orange G dye degradation, after 10 minutes reaction time under pH 7.5. The percentage of degradation for Orange G dye is 0.11% at 10 minutes and increases to 4.24% after 20 minutes. The percentage gradually increases to 4.24%, 5.05% and 11.02% at 20, 30 and 40 minutes respectively. For microbial catalytic, the difference in the percentage of degradation for Orange G dye is not too big between pH 7.5 and pH 3.5 at 15 ppm. The percentage of degradation under pH 7.5 is 80.02% and the percentage of degradation for pH 3.5 is 80.38% after 10 minutes reaction time. After 30 minutes reaction time, the percentage of alkaline condition (pH 7.5) rises sharply to 80.36% as compared to the percentage of degradation of acidic condition (pH 3.5) which is 81.22%.

Time also affects the degradation activity of bacteria. The degradation of the dye was monitored up to 40 minutes. After 40 minutes, a maximum in degradation was observed. No significant increase in degradation was seen after 40 minutes. This is most likely due to reaching the stationary and death phase. Similar findings were reported by Ikram et al., with the biodegradation of another azo dye, Basic Orange 2, by *E. coli* throughout the course of three days of experimentation. It was also observed that the maximum decolorization has been noted after 3 days interval and after that no significant increase in degradation was observed [19].

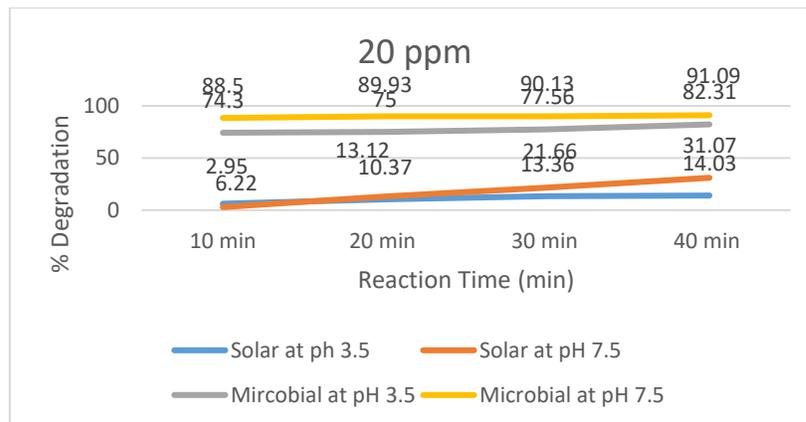


Figure 3: The comparison of solar and microbial processes in terms of the percentage of degradation for Orange G dye at 20 ppm

The comparison of the percentage of degradation of Orange G dye at 20 ppm for both solar and microbial catalyst at pH 3.5 and pH 7.5 is shown in Figure 3. Similar to Figure 1 and Figure 2, the percentage of degradation of Orange G dye is much higher using microbial catalytic (91.09%) at 40 minutes reaction time under pH 7.5 compared to the percentage of degradation of the dye using solar photocatalytic (31.07%) under the same reaction time and pH value. A study reported by Ikram et al. [17] state that the optimum dye concentration is found to be at 20 ppm. The study also observed that higher concentration (> 20 ppm) of dye might inhibit effective interaction between dye molecules and the precursor which would consequently limit the bacterial efficiency for dye degradation. Similar results were observed in the study by Zhuang et al. 2020, which claimed that high concentrations of dye due to toxicity would block the active sites of bacterial enzyme, thus having the tendency to inhibit the bacterial potential for dye degradation [18].

For solar photocatalytic, it shows that at 10 minutes of reaction time, the percentage of degradation in alkaline medium (pH 7.5) is lower than acidic medium (pH 3.5). It can be explained that, after 10 minutes reaction time, the TiO_2 solution that was added into a solution of Orange G dye had not completely settled at the bottom of the conical flask. From the tabulated data after 20 minutes of reaction time, the percentage of degradation of pH 7.5 is higher than pH 3.5. This is because the surface of TiO_2 within acidic media

(pH < 6.8) is positively charged whereas alkaline media is negatively charged (pH > 6.8). This can affect the rate of degradation which can rise slightly with the increase of pH values until it reaches the maximum at pH 10 [23].

4.0 CONCLUSION AND RECOMMENDATION

The experiment has proven that *Pseudomonas euroginosa* sp. bacteria are able to degrade the Orange G dye more effectively than solar photocatalytic. The experiment has also demonstrated that microbial process shows higher degradation rate of Orange G dye than solar photocatalytic after 40 minutes reaction time at 20 ppm concentration under pH 7.5 (alkaline medium). However, solar photocatalytic only shows highest percentage of degradation (31.07%) after 40 minutes treatment with pH 7.5 (alkaline medium) at 20 ppm concentration. In addition, the degradation process in alkaline media is more efficient compared to acidic media as the increase in pH value will increase the percentage of degradation of Orange G dye. For further research, to ensure the safety of the decolorized wastewater, studies should be conducted on the toxicity of the treated effluent/dye solutions. Based on the successful laboratory results, efforts should then be made to scale-up and apply bacterial decolorization techniques in real industrial effluents.

REFERENCES

- [1] Karthikeyan, C., Arunachalam, et al 2020. Recent advances in semiconductor metal oxides with enhanced methods for solar photocatalytic applications. *Journal of Alloys and Compounds*, 828, p.154281.
- [2] Bhatia, D., Sharma, N.R., Singh, J. and Kanwar, R.S., 2017. Biological methods for textile dye removal from wastewater: A review. *Critical Reviews in Environmental Science and Technology*, 47(19), pp.1836-1876.
- [3] Nasri, M., Rahman, A., Radzi, F. M., Farahiyah, W., & Kamarudin, W. (2017). Bacterial decolorization and degradation of azo dye. *Journal of Applied Environmental and Biological Sciences*, 7(5), 14-20.
- [4] Li, Z. and Yang, P., 2018, February. Review on physicochemical, chemical, and biological processes for pharmaceutical wastewater. In *IOP Conference Series: Earth and Environmental Science* (Vol. 113, No. 1, p. 012185). IOP Publishing.
- [5] Shelke, B.N., Jopale, M.K. and Kategaonkar, A.H., 2022. Exploration of biomass waste as low cost adsorbents for removal of methylene blue dye: a review. *Journal of the Indian Chemical Society*, p.100530.
- [6] Bushra, R., Mohamad, S., Alias, Y., Jin, Y. and Ahmad, M., 2021. Current approaches and methodologies to explore the perceptible adsorption mechanism of dyes on low-cost agricultural waste: A review. *Microporous and Mesoporous Materials*, 319, p.111040.
- [7] Kurade, M.B., Waghmode, T.R., Xiong, J.Q., Govindwar, S.P. and Jeon, B.H., 2019. Decolorization of textile industry effluent using immobilized consortium cells in up flow fixed bed reactor. *Journal of cleaner production*, 213, pp.884-891.
- [8] Ong, C.B., Mohammad, A.W., Rohani, R., Ba-Abbad, M.M. and Hairom, N.H.H., 2016. Solar photocatalytic degradation of hazardous Congo red using low-temperature synthesis of zinc oxide nanoparticles. *Process Safety and Environmental Protection*, 104, pp.549-557.
- [9] Chávez, A.M., Gimeno, O., Rey, A., Pliego, G., Oropesa, A.L., Álvarez, P.M. and Beltrán, F.J., 2019. Treatment of highly polluted industrial wastewater by means of sequential aerobic biological oxidation-ozone based AOPs. *Chemical Engineering Journal*, 361, pp.89-98.

- [10] Sudha, M., Saranya, A., Selvakumar, G. and Sivakumar, N., 2014. Microbial degradation of azo dyes: a review. *International Journal of Current Microbiology and Applied Sciences*, 3(2), pp.670-690.
- [11] Morajkar, P.P., Naik, A.P., Bugde, S.T. and Naik, B.R., 2019. Photocatalytic and microbial degradation of amaranth dye. In *Advances in Biological Science Research* (pp. 327-345). Academic Press.
- [12] Kamarudin, W.F.W., Rahman, M.N.A., et al 2022, June. Microbial degradation of food dye by *Pseudomonas aeruginosa*. In *AIP Conference Proceedings* (Vol. 2454, No. 1, p. 050029). AIP Publishing LLC.
- [13] Yang, H.Y., He, C.S., Li, L., Zhang, J., et al 2016. Process and kinetics of azo dye decolourization in bioelectrochemical systems: effect of several key factors. *Scientific reports*, 6(1),pp.1-9.
- [14] Saratale, R.G., Saratale, G.D., Chang, J.S. and Govindwar, S.P., 2011. Bacterial decolorization and degradation of azo dyes: a review. *Journal of the Taiwan institute of Chemical Engineers*, 42(1), pp.138-157.
- [15] Ngo, A.C.R. and Tischler, D., 2022. Microbial degradation of azo dyes: Approaches and prospects for a hazard-free conversion by microorganisms. *International Journal of Environmental Research and Public Health*, 19(8), p.4740.
- [16] Moyo, S., Makhanya, B.P. and Zwane, P.E., 2022. Use of bacterial isolates in the treatment of textile dye wastewater: A review. *Heliyon*, p.e09632.
- [17] Ikram, M., Naeem, M., Zahoor, M., Rahim, A., Hanafiah, M. M., Oyekanmi, A. A., ... & Sadiq, A. (2022). Biodegradation of azo dye methyl red by *pseudomonas aeruginosa*: Optimization of process conditions. *International Journal of Environmental Research and Public Health*, 19(16), 9962.
- [18] Zhuang, M., et al (2020). Azo dye degrading bacteria tolerant to extreme conditions inhabit nearshore ecosystems: optimization and degradation pathways. *Journal of environmental management*, 261, 110222.
- [19] Ikram, M., Zahoor, M., Khan, E., & Umar Khayam, S. M. (2020). Biodegradation of Novacron Turquoise (Reactive Blue 21) by *Pseudomonas aeruginosa*. *Journal of the Chemical Society of Pakistan*, 42(5).
- [20] Sihag, S., Pathak, H., & Jaroli, D. P. (2014). Factors affecting the rate of biodegradation of polyaromatic hydrocarbons. *International Journal of Pure & Applied Bioscience*, 2(3), 185-202.
- [21] Bheemaraddi, M. C., Shivannavar, et al (2014). Effect of carbon and nitrogen sources on biodegradation of textile azo dye Reactive Violet 5 by *Pseudomonas aeruginosa* GSM3. *Sch. Acad. J. Biosci*, 2, 285-289.
- [22] Khan, R., Bhawana, P., & Fulekar, M. H. (2013). Microbial decolorization and degradation of synthetic dyes: a review. *Reviews in Environmental Science and Bio/Technology*, 12, 75-97.
- [23] Bousalah, D., Zazoua, H., Boudjemaa, A., Benmounah, A. and Bachari, K., 2022. Degradation of Indigotine food dye by Fenton and photo-Fenton processes. *International Journal of Environmental Analytical Chemistry*, 102(16), pp.4609-4622.