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ORIGINAL RESEARCH ARTICLE

# Effects of initial turbidity and myco-coagulant dose on the effectiveness of the coagulation process in water treatment

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## ABSTRACT

High turbidity is a pollutant that requires coagulants to be removed from treated water and wastewater. This study was conducted to characterize and analyze the potential of myco-coagulant-producing fungus isolated from the moist area of a kitchen. Myco-coagulant production was carried out using solid-state fermentation using coco peat as a substrate. One factor-at-a-time analysis (OFAT) was carried out to assess the capacity of the produced myco-coagulant in various initial turbidities and myco-coagulant doses. The potential of myco-coagulant was tested using turbid synthetic water with different turbidity levels (50, 100, 150, 200, 250 and 300 NTU). The results showed that turbidity removal by the myco-coagulant was influenced by the initial turbidity. The coagulant was less efficient at low turbidity levels, which was approximately 5% for 50 NTU, while the highest was 52% for 300 NTU water. Furthermore, the results demonstrated that myco-coagulant could remove the highest possible turbidities on day 6 with all initial turbidity values studied in this work. Different myco-coagulant doses ranging from 1 to 10% (v/v) were also used to determine the optimum dose for effective flocculation. The highest turbidity removal of 57% could be obtained at an optimum coagulant dose of 4% (v/v). Like any other commercial coagulant, the residual turbidity value increased at a coagulant dose higher than the optimum dose of 4% (v/v).

***Keywords:*** myco-coagulant; coco peat substrate; turbidity removal; turbidity

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## 1. Introduction

Surface water resources frequently have a high level of turbidity which must be removed via flocculation or coagulation before the water is potable. Turbidity also negatively impacts consumer acceptance of water; visible cloudiness in finished water may create the perception for consumers that it is not clean or safe to drink. Turbidity is not necessarily a direct measure of microbial contamination, but microbes are often associated with particles in water[1]. Traditional water treatment methods involve the use of flocculants and coagulants[2]. These substances can be divided into synthetic organic polymers like polyacrylamide derivatives and polyethylene imine and inorganic coagulants like aluminium and ferric salts. They are effective in removing turbidity from raw water[3]. The cost of the coagulation agents plays a major role in how much it costs financially to achieve the target level of water quality[2].

Alum coagulants are the most popular agents utilized in wastewater treatment[4] owing to characteristics that include their high effectiveness, low cost and easy availability. The use of alum salts, however, has come under scrutiny recently because of some drawbacks, including the possibility of Alzheimer's disease, the fact that they are pH-sensitive and the presence of a significant amount of residual sludge in the treated water[5,6]. As a result, several researchers are now focusing on safer coagulants that may be more efficient, safe for human health, affordable and biodegradable[6].

During the previous few years, research has been done on different kinds of natural coagulants that come from fruit pieces like *Moringa oleifera*[7], animals like crab, lobster[8] and shrimp shells[8,9], bacteria like Serratia marcescens[10] and *Chryseobacterium daeguense*[11], or fungi like *Lentinus squarrosulus*[12]. These substances have shown significant coagulant capacities. Where, the *Moringa oleifera* coagulant was able to achieve 87% turbidity removal from river water[13], while the crab shell was able to remove 94.39% of turbidity from abattoir wastewater[14]. Shrimp shell was removed 83% of turbidity presented on water-based paint factory effluent (RPFE)[15]. Serratia marcescens bio-flocculant reached 85.45% turbidity removal from a real aquaculture effluent[16]. Bio-flocculant produced from *Lentinus squarrosulus* recorded 90% turbidity removal from kaolin suspension[12].

Natural coagulants are considered more environmentally benign than inorganic and organic coagulants owing to their biodegradability[2]. Compared to chemical coagulants, bio-coagulants also have several benefits, such as low cost, less sludge production and low toxicity[2,17]. Due to these characteristics, bio-coagulants are advantageous as water treatment tools and prospective alternatives to chemical coagulants.

The use of microorganisms in wastewater treatment has been extensively studied. Coagulation based on fungi, however, is a more recent technological advancement than coagulation based on bacteria. A few studies have been done in this area, but they are still in their early phases[18]. However, for some reasons, filamentous fungi-based coagulation is a cost-effective and environmentally friendly technology with bright future potential[19].

A process for bacterial or fungal culture called "solid-state fermentation (SSF)" or "bioconversion fermentation" is utilized to produce substances and products with industrial value[20]. Compared to traditional submerged fermentation (SF), SSF has several advantages, including being an easier process, consuming less energy, producing less pollution, recovering more of the product and more nearly simulating the microbes' natural habitats[21]. Microorganisms are grown in SSF using an inert or natural substrate as a solid support and a little free water or its absolute absence[21,22]. Agro-industrial residues are commonly considered the best substrates for the SSF process[23].

One of the most popular cultivation matrices in industrial agriculture is coco peat, which is made from coconut peal. Moreover, coco peat has a significant potential for storing fertilizer and conserving water. It is regarded as the best substitute for natural peat due to its appropriate porosity and strong air permeability. It is also a type of sustainable agriculture substrate[23].

The optimization of the coagulation/flocculation process reduces the use of chemicals and protects the environment[24]. Therefore, many research works have been done to optimize the coagulation/flocculation processes, which depend on several factors, the most relevant being initial turbidity, pH, reagents (coagulant, adjuvant) dosage and type, system hydrodynamics in coagulation and flocculation stages, temperature and alkalinity[25].

In this study, coco peat was used to produce myco-coagulants in solid-state using the tray method from a fungal strain that was isolated from a moist kitchen area in Gombak. The effect of the operational parameters, including the myco-coagulant dose and initial water turbidity, was studied to better understand the coagulation process using the produced myco-coagulant, where the One factor-at-a-time (OFAT) analysis was performed.

Scanning electron microscopy (SEM) was also used to examine the morphological structure and mycelium development of fungi.

# 2. Materials and methods

## 2.1. Material

### 2.1.1. Microorganisms

The fungal cultures used were obtained from the environmental engineering laboratory in the Department of Chemical Engineering and Sustainability (CHES) of IIUM Gombak, Selangor, Malaysia.

### 2.1.2. Coco peat

The coco peat was purchased from the local market in Kuala Lumpur. Using a sieve shaker, the coco peat was crushed and sieved to a particle size of less than 0.3 mm.

### 2.1.3. Chemical and Reagents

Malt Extract Broth (MEB) and Potato Dextrose Agar (PDA) were acquired from Oxoid and Difco™, respectively. D(+)-Glucose, kaolin clay, buffer solution (phosphate) pH 7 and NaOH were purchased from R&M Chemical (Malaysia).

## 2.2. Methodology

### 2.2.1. Media preparation

This study made use of D(+)-Glucose and MEB. 3% of MEB and 2.5% of glucose were combined with distilled water to make 100 mL of media. Then, the mixture's pH was raised to 7 using NaOH before being combined with coco peat and autoclaved for 15 min at 121 °C.

### 2.2.2. Kaolin synthetic water preparation

Kaolin was used in this investigation as a stand-in for water in this experiment. The stock kaolin solution was prepared by dissolving some kaolin powder in 10 L of distilled water. To produce a constant dispersion of kaolin particles, the mixture was mixed at 200 rpm for 1 hour using a jar apparatus. To ensure that the kaolin was fully hydrated, the suspension was then left to stand for 24 h[26].

### 2.2.3. Isolation and culture of fungus

In Petri dishes, fungus tissues were cultivated using 20 mL of PDA, which was made in accordance with the product's instructions. PDA was suspended in 1 L of distilled water, heated for 1 min, and then vigorously stirred to ensure complete dissolution. The combined components were placed into sterilized Petri dishes and autoclaved for 15 min at 121 °C to allow the mixture to polymerize for at least 30 min[27]. After that, a fungus strain was inoculated. Later, the plates underwent a 10-day incubation period at 30 °C to finish the mycelial growth. After that, a portion of the mycelium was placed in sterile Petri dishes with PDA and the isolated fungus was purified and re-cultured in a fresh medium.

### 2.2.4. Preparation of mycelial suspensions

The spores were used for inoculating a prepared substrate. Mycelial suspensions were prepared from the cultures of fungus. To do this, fungi were extracted from the media of the plates using a sterile loop and put into a beaker with sterile distilled water. Spore aggregates were separated into beakers by shaking. An amount of distilled water (18%) was deducted from the total volume that was used for the media to get the inoculum volume.

### 2.2.5. Myco-coagulant production

To produce of the myco-coagulant, coco peat (25%) and prepared media (75%) were mixed. Then, the

mixture was poured into an aluminium tray and covered with aluminium foil. The aluminium tray was inserted in the autoclave when the mixture was sterilized at 121 °C for 15 min autoclave. The mixture was poured into a sterilized plastic tray. Then, mycelial suspension was used to inoculate the tray for further multiplication of the inoculum. A prepared tray was covered with aluminium foil and incubated at 25 °C for 10 days. The myco-coagulant production steps are presented in **Figure 1**.

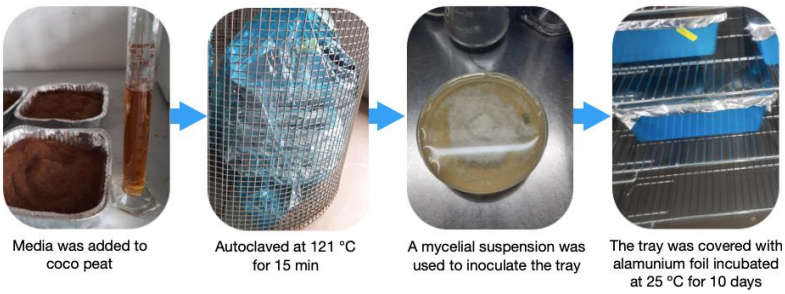


**Figure 1.** Myco-coagulant production steps.

### 2.2.6. Myco-coagulant extraction

To get 10 mL of myco-coagulant extract, 4 g of culture (after ten days of incubation) were transferred into conical flasks, which were then mixed with 20 mL of buffer solution (pH 7). The flasks were stirred for 60 min at room temperature and 250 rpm. The myco-coagulant was separated from the biomass using a centrifuge running at 9000 rpm for 5 min at 25 °C. Using the Jar apparatus method, the supernatant's flocculating activity was assessed after being collected 10 mL from the supernatant.

### 2.2.7. Assessment of Turbidity Removal

**Effect of the initial turbidity concentration:** OFAT analysis was selected to assess the myco-coagulant potential. To evaluate the effect of initial turbidimetry values on the turbidity removal (%), kaolin suspensions were used with different initial turbidity values (50, 100, 150, 200, 250 and 300 NTU). A total of six different initial turbidities were prepared by diluting a kaolin stock of 700 NTU with distilled water.

The activity of myco-coagulant was assessed using kaolin clay suspension. A turbidity meter was used to measure the initial turbidity. Each 300 mL of kaolin suspension was mixed with 3% v/v of myco-coagulant in a different beaker. The beakers were then stirred for varying periods and speeds, including 7 min of rapid mixing (250 rpm) and 22 min of slow mixing (90 rpm). Then, the suspensions were allowed to settle for 60 min. All experiments were carried out at natural pH conditions without the addition of any chemicals.

To determine the final concentration, samples were obtained using a pipette from the centre of the supernatant. To determine the effectiveness of turbidity removal, the percentage of removal was determined using Equation (1).

$$Turbidity\ efficiency\ (\%) = \frac{(initial\ turbidity - final\ turbidity)}{initial\ turbidity} \times 100 \quad (1)$$

**Effect of the myco-coagulant dose:** Following the determination of the initial turbidity levels with the maximum flocculation activity, another OFAT study was conducted to measure the flocculation activity of various myco-coagulant doses. Ten different myco-coagulant dose variations (1%–10%) were evaluated. 300 mL of kaolin suspension was combined with different amounts of extracted myco-coagulant to prepare different doses (% v/v). During this step, operational settings including a 300 mL total volume in a 1000 mL beaker glass, the initial turbidity based on an earlier OFAT, rapid mixing at 250 rpm for seven minutes, slow mixing at 90 rpm for 22 min and sedimentation period of 60 min were used (**Table 1**). Using Equation (1), the flocculation activity was calculated.

**Table 1.** Operational settings.

| Parameters | Values |
|---|---|
| The total volume of synthetic kaolin | 300 mL |
| The initial turbidity | based on an earlier OFAT |
| Rapid mixing | 250 rpm for 7 min |
| Slow mixing | 90 rpm for 22 min |
| Sedimentation period | 60 min |

### 2.2.8. Scanning electron microscopy (SEM)

The morphology and microstructure of fungi growing on coco peat were examined using a JEOL-IT 100 SEM instrument. After incubation for 10 days, the colonies of the isolates were inspected for morphology. The sample was placed on carbon tape, transferred to a metallic stub and then left to air dry in a hood. The sample was then coated with a thin layer of gold (10-20 nm) for 50 s using a Quorum Q300TD and a 20-mA sputter current. The measurement equipment included with the JEOL IT100 SEM was used to measure cell size (InTouchScope$^{TM}$ version 1.060).

## 3. Results and discussion

### 3.1. Scanning electron microscopy (SEM)

The morphological structure and mycelium development of fungi were observed using scanning electron microscopy. In **Figure 2**, the fungus' micrographs are displayed. The results of the SEM analysis showed that the fungus's mycelium was filamentous and interconnected to create a spatial network. The coco peat substrate was completely colonized by the fungus, as illustrated in **Figures 2a, 2b**. The hyphae of the fungus are visible in **Figure 2c**, with a mean hyphae diameter of around 0.7 µm. This result indicated that the coco peat was an effective substrate for fungus colonization. The main objective of the SEM imagery was to investigate the growth of fungal mycelium in the substrate, instead of finding any relation of the SEM images with turbidity removal.

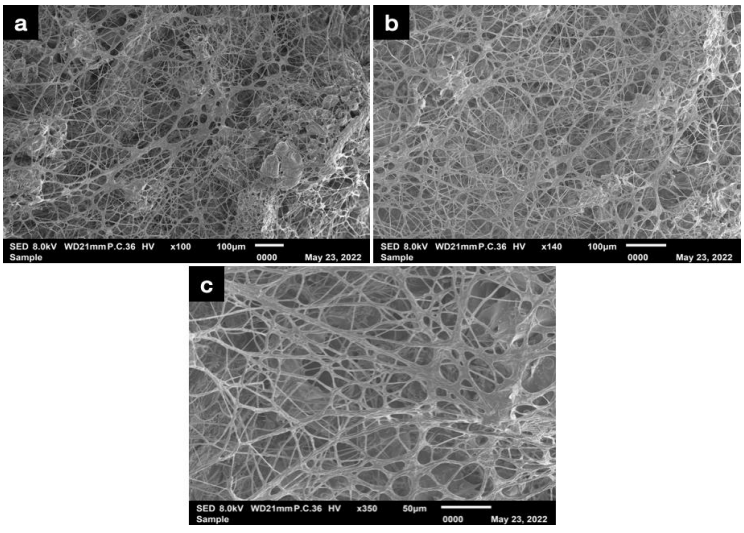


**Figure 2.** Scanning Electron Microscopy (SEM) micrographs of fungal colonies on cocopeat after 10 days of incubation (magnification of **(a)** 100, **(b)** 140, **(c)** 350).

### 3.2. Assessment of turbidity removal

A myco-coagulant was produced and then evaluated in terms of turbidity removal by flocculating the kaolin suspension using jar testing, which is the primary method for assessing coagulant efficiency[26].

### 3.2.1. Effect of initial turbidity concentration

The effectiveness of the produced myco-coagulant was evaluated using a range of initial turbidity concentrations. **Figure 3** shows the flocculation activity of the myco-coagulant isolated for several days using varying initial turbidity. In general, the bioflocculant exhibited minimal activity on all days when turbidity was low, while the bioflocculant performed well when turbidity increased to 300 NTU. Furthermore, the results revealed that myco-coagulant was able to remove the highest possible turbidities on Day 6 with all differing initial turbidities. While the lowest turbidity removals were recorded on Day 10. The lowest turbidity removal was 5% which was observed at 50 NTU, while the highest turbidity removal was 52% which was obtained at 300 NTU. According to this finding, the produced bioflocculant is more suitable for usage in high-turbidity water than in low-turbidity water. Similar results have been reported by other studies, which found that biocoagulants and bioflocculants performed better in high turbidity compared to medium or low turbidity[2,10,28–31]. This is because most bio-coagulants and bio-flocculants contain a mechanism for floc formation that makes particle bridging more effective in the presence of more dense suspended particles[10]. A high level of turbidity owing to a larger particle concentration in water leads to an increase in the frequency of collisions between suspended particles and coagulants, permitting a more effective coagulation-flocculation process. According to Stoke's law, thicker and denser flocs would form with more contact and interaction between coagulating and suspending particles, increasing the rate of sedimentation throughout the treatment process[32].

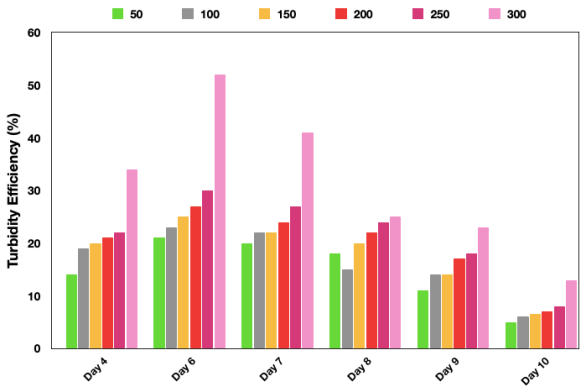


**Figure 3.** Removal of turbidity (%) from kaolin suspension using different initial turbidity values (speed mixing at 250 rpm for 7 min, slow mixing at 90 rpm for 22 min, and sedimentation period of 60 min).

### 3.2.2. Effect of myco-coagulant dose

In this study, ten myco-coagulant doses were employed to investigate its effect on turbidity removal. The results of OFAT analysis for various myco-coagulant doses are shown in **Figure 4**.

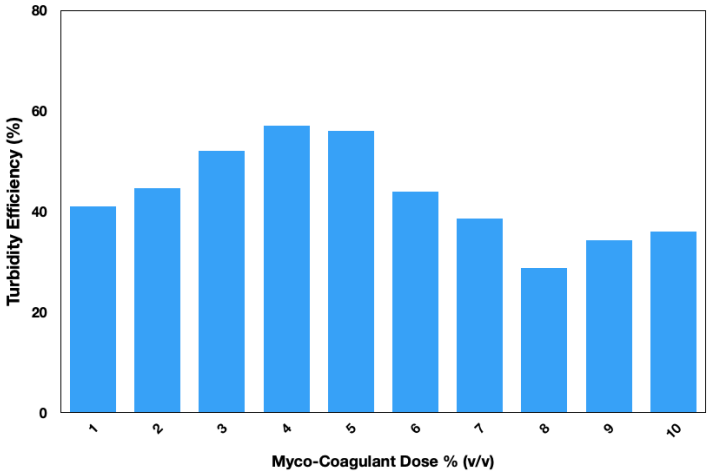


**Figure 4.** Removal of turbidity (%) from kaolin suspension using different myco-coagulant doses (speed mixing at 250 rpm for 7 min, slow mixing at 90 rpm for 22 min, and sedimentation period of 60 min).

The flocculant activity gradually increased with the increase in the myco-coagulant dose. The highest removal of turbidity of synthetic kaolin wastewater was recorded at 57% due to a dose of 4% (v/v). On the other hand, when the myco-coagulant dose was increased in the kaolin solution to 5% (v/v) and above, the turbidity removal declined. There was a significant decrease in coagulation performance from 56% to 29%, with the increase of myco-coagulant dosage from 5% to 10% (v/v), respectively. Using a higher bio-flocculant dose (more than 4%) did not increase the flocculation activity. Similar research showed that increasing the amount of flocculants did not significantly enhance the total removal and even decreased the removal of turbidity from water[2,10,28,29]. An excessive amount of flocculant will not interact with the suspended particles, leading to the formation of more suspended solids, which in turn increases turbidity[10]. The optimum doses of various types of coagulants are given in **Table 2** for comparison purposes, which also varies with the initial turbidity of the water.

**Table 2.** The optimum dose of different coagulants for various initial turbidity.

| Source of Coagulant | Initial Turbidity (NTU) | The Optimum Coagulant Dose | Reference |
|---|---|---|---|
| $CaCl_2$–PAM (calcium chloride-polyacrylamide) | 353–399 | 2–3 mg/L | [33] |
| *Moringa oleifera* | 50 and 150 | 150 mg/L | [30] |
| Pine cones | 67 and 75 | 0.5 ml/L | [34] |
| Chitosan | 200 | 0.5 mg/L | [35] |
| Graphene oxide (GO) | 193.34 | 4.0 mg/L | [36] |
| *Lemna perpusilla* | 300 | 30 mg/L | [37] |
| *Lentinus squarrosulus* | 600 | 1% (v/v) | [38] |
| Myco-coagulant | 300 | 4% (v/v) | This Study |

## 4. Conclusion

Myco-coagulant produced by isolating white rot fungi from a wet kitchen area displayed great potential for removing turbidity from highly turbid water. The myco-coagulant performed better in high turbidity water compared with low turbidity water. Thus, the produced myco-coagulant was found to be ineffective with low turbidity water but effective with medium and high turbidity water. A myco-coagulant dose of 4% v/v was the optimum for turbidity removal. The results demonstrated that the initial turbidity had an impact on turbidity removal, while the myco-coagulant dose had no impact on the removed turbidity. SEM micrographs showed that white rot fungi effectively colonized the solid substrate. This result indicated that the coco peat was an effective substrate for fungus colonization.

## Author contributions

Conceptualization, AAM and RN; methodology, RN; formal analysis, RN, AAM and MZA; investigation, RN and AAM; resources, RN; data curation, RN and AAM; writing—original draft preparation, RN; writing—review and editing, AAM and MZA; supervision, AAM; project administration, AAM. All authors have read and agreed to the published version of the manuscript.

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## Conflict of interest

The authors declare no conflict of interest.

## References


1. Soros A, Amburgey JE, Stauber CE, et al. Turbidity reduction in drinking water by coagulation-flocculation with chitosan polymers. Journal of Water and Health. 2019, 17(2): 204-218. doi: 10.2166/wh.2019.114
2. Ramavandi B. Treatment of water turbidity and bacteria by using a coagulant extracted from Plantago ovata. Water Resources and Industry. 2014, 6: 36-50. doi: 10.1016/j.wri.2014.07.001
3. Antov MG, Šćiban MB, Prodanović JM. Evaluation of the efficiency of natural coagulant obtained by ultrafiltration of common bean seed extract in water turbidity removal. Ecological Engineering. 2012, 49: 48-52. doi: 10.1016/j.ecoleng.2012.08.015
4. Ahmad NSB, Mamun AA, Nedjai R. Assessment of expired coagulant for water treatment. AIP Conference Proceedings. Published online 2023. doi: 10.1063/5.0129719
5. Adnan O, Abidin ZZ, Idris A, et al. A novel biocoagulant agent from mushroom chitosan as water and wastewater therapy. Environmental Science and Pollution Research. 2017, 24(24): 20104-20112. doi: 10.1007/s11356-017-9560-x
6. Oladoja NA. Headway on natural polymeric coagulants in water and wastewater treatment operations. Journal of Water Process Engineering. 2015, 6: 174-192. doi: 10.1016/j.jwpe.2015.04.004
7. Ueda Yamaguchi N, Cusioli LF, Quesada HB, et al. A review of Moringa oleifera seeds in water treatment: Trends and future challenges. Process Safety and Environmental Protection. 2021, 147: 405-420. doi: 10.1016/j.psep.2020.09.044
8. Chi FH, Cheng WP. Use of Chitosan as Coagulant to Treat Wastewater from Milk Processing Plant. Journal of Polymers and the Environment. 2006, 14(4): 411-417. doi: 10.1007/s10924-006-0027-2
9. Vishali S, Sengupta P, Mukherjee R, et al. Shrimp shell waste – a sustainable green solution in industrial effluent treatment. DESALINATION AND WATER TREATMENT. 2018, 104: 111-120. doi: 10.5004/dwt.2018.21923
10. Kurniawan SB, Abdullah SRS, Othman AR, et al. Isolation and characterisation of bioflocculant-producing bacteria from aquaculture effluent and its performance in treating high turbid water. Journal of Water Process Engineering. 2021, 42: 102194. doi: 10.1016/j.jwpe.2021.102194
11. Liu W, Cong L, Yuan H, Yang J. The mechanism of kaolin clay flocculation by a cation-independent bioflocculant produced by Chryseobacterium daeguense W6. AIMS Environmental Science. 2015, 2(2): 169–179. doi: 10.3934/environsci.2015.2.169
12. Jebun NX, Mamun AA, Alam MdZ, et al. Production and stability of myco-flocculants from Lentinus Squarrosulus RWF5 and Simplicillium Obclavatum RWF6 for reduction of water turbidity. IIUM Engineering Journal. 2018, 19(1): 48-58. doi: 10.31436/iiumej.v19i1.843
13. Muyibi SA, Mohd. Noor MJM, Leong TK, Loon LH. Effects of Oil Extraction from Moringa Oleifera Seeds On Coagulation Of Turbid Water. International Journal of Environmental Studies. 2002, 59(2): 243-254. doi: 10.1080/00207230210924
14. Okey-Onyesolu CF, Chukwuma EC, Okoye CC, et al. Response Surface Methodology optimization of chito-protein synthesized from crab shell in treatment of abattoir wastewater. Heliyon. 2020, 6(10): e05186. doi: 10.1016/j.heliyon.2020.e05186
15. Solaiappan V, Mukherjee R, Sengupta P, et al. Evaluation of promising coagulant shrimp shell on paint factory effluent: Studies on mixing pattern, isotherms, kinetics, and thickener design. Desalination and Water Treatment. 2020, 201: 204-218. doi: 10.5004/dwt.2020.26103
16. Kurniawan SB, Imron MF, Abdullah SRS, et al. Treatment of real aquaculture effluent using bacteria-based bioflocculant produced by Serratia marcescens. Journal of Water Process Engineering. 2022, 47: 102708. doi: 10.1016/j.jwpe.2022.102708
17. Freitas TKFS, Oliveira VM, de Souza MTF, et al. Optimization of coagulation-flocculation process for treatment of industrial textile wastewater using okra (A. esculentus) mucilage as natural coagulant. Industrial Crops and Products. 2015, 76: 538-544. doi: 10.1016/j.indcrop.2015.06.027
18. Tsilo PH, Basson AK, Ntombela ZG, et al. Isolation and Optimization of Culture Conditions of a Bioflocculant-Producing Fungi from Kombucha Tea SCOBY. Microbiology Research. 2021, 12(4): 950-966. doi: 10.3390/microbiolres12040070
19. Ahmed SF, Mofijur M, Parisa TA, et al. Progress and challenges of contaminate removal from wastewater using microalgae biomass. Chemosphere. 2022, 286: 131656. doi: 10.1016/j.chemosphere.2021.131656
20. Khalil H, Legin E, Kurek B, et al. Morphological growth pattern of Phanerochaete chrysosporium cultivated on different Miscanthus x giganteus biomass fractions. BMC Microbiology. 2021, 21(1). doi: 10.1186/s12866-021-02350-8
21. Wang F, Xu L, Zhao L, et al. Fungal Laccase Production from Lignocellulosic Agricultural Wastes by Solid-State Fermentation: A Review. Microorganisms. 2019, 7(12): 665. doi: 10.3390/microorganisms7120665

22. Aidoo KE, Hendry R, Wood BJB. Solid Substrate Fermentations. Advances in Applied Microbiology. Published online 1982: 201-237. doi: 10.1016/s0065-2164(08)70236-3
23. Lu B, Liu N, Li H, et al. Quantitative determination and characteristic wavelength selection of available nitrogen in coco-peat by NIR spectroscopy. Soil and Tillage Research. 2019, 191: 266-274. doi: 10.1016/j.still.2019.04.015
24. Khettaf S, Khouni I, Louhichi G, et al. Optimization of coagulation–flocculation process in the treatment of surface water for a maximum dissolved organic matter removal using RSM approach. Water Supply. 2021, 21(6): 3042-3056. doi: 10.2166/ws.2021.070
25. Mensah-Akutteh H, Buamah R, Wiafe S, et al. Optimizing coagulation–flocculation processes with aluminium coagulation using response surface methods. Applied Water Science. 2022, 12(8). doi: 10.1007/s13201-022-01708-1
26. Zainol NA, Goh HT, Syed Zainal SFF. Effectiveness of Mushroom (Pleurotus Pulmonarius) Waste as Natural Coagulant for Kaolin Synthetic Water via Coagulation-Flocculation Process. IOP Conference Series: Earth and Environmental Science. 2021, 920(1): 012020. doi: 10.1088/1755-1315/920/1/012020
27. Galadima AI, Salleh MM, Hussin H, et al. One-Step Conversion of Lemongrass Leaves Hydrolysate to Biovanillin by Phanerochaete chrysosporium ATCC 24725 in Batch Culture. Waste and Biomass Valorization. 2019, 11(8): 4067-4080. doi: 10.1007/s12649-019-00730-w
28. Gaikwad VT, Munavalli GR. Turbidity removal by conventional and ballasted coagulation with natural coagulants. Applied Water Science. 2019, 9(5). doi: 10.1007/s13201-019-1009-6
29. Asrafuzzaman Md, Fakhruddin ANM, Hossain MdA. Reduction of Turbidity of Water Using Locally Available Natural Coagulants. ISRN Microbiology. 2011, 2011: 1-6. doi: 10.5402/2011/632189
30. Nkurunziza T, Nduwayezu JB, Banadda EN, et al. The effect of turbidity levels and Moringa oleifera concentration on the effectiveness of coagulation in water treatment. Water Science and Technology. 2009, 59(8): 1551-1558. doi: 10.2166/wst.2009.155
31. Baptista ATA, Silva MO, Gomes RG, et al. Protein fractionation of seeds of Moringa oleifera lam and its application in superficial water treatment. Separation and Purification Technology. 2017, 180: 114-124. doi: 10.1016/j.seppur.2017.02.040
32. Hadadi A, Imessaoudene A, Bollinger JC, et al. Comparison of Four Plant-Based Bio-Coagulants Performances against Alum and Ferric Chloride in the Turbidity Improvement of Bentonite Synthetic Water. Water. 2022, 14(20): 3324. doi: 10.3390/w14203324
33. Lee KE, Teng TT, Morad N, et al. Flocculation of kaolin in water using novel calcium chloride-polyacrylamide (CaCl2-PAM) hybrid polymer. Separation and Purification Technology. 2010, 75(3): 346-351. doi: 10.1016/j.seppur.2010.09.003
34. Hussain S, Ghouri AS, Ahmad A. Pine cone extract as natural coagulant for purification of turbid water. Heliyon. 2019, 5(3): e01420. doi: 10.1016/j.heliyon.2019.e01420
35. Hesami F, Bina B, Ebrahimi A. The effectiveness of chitosan as coagulant aid in turbidity removal from water. International Journal of Environmental Health Engineering. 2013, 2(6): 46–51. doi: 10.4103/2277-9183.131814
36. Rezania N, Hasani Zonoozi M, Saadatpour M. Coagulation-flocculation of turbid water using graphene oxide: simulation through response surface methodology and process characterization. Environmental Science and Pollution Research. 2020, 28(12): 14812-14827. doi: 10.1007/s11356-020-11625-y
37. Prihatinningtyas E. Removal of turbidity in water treatment using natural coagulant from Lemna perpusilla. IOP Conference Series: Earth and Environmental Science. 2019, 308(1): 012007. doi: 10.1088/1755-1315/308/1/012007
38. Nessa J. Development of Locally Isolated Microbial Coagulant for Removal of River Water Turbidity [PhD Thesis]. International Islamic University Malaysia.