Global Journal of Engineering and Technology Advances, 2019, 01(01), 001–009

Global Journal of Engineering and Technology Advances

Cross Ref DOI: 10.30574/gjeta

Journal homepage: http://www.gjeta.com

(RESEARCH ARTICLE)

Microwave-assisted extraction of banana peel bio-flocculant and its potential in wastewater treatment

Lau Zhi Eng [1] and Kiew Peck Loo [2,*]

[1] *Department of Chemical and Petroleum Engineering, Faculty of Engineering, UCSI University, 56000 Cheras Kuala Lumpur, Malaysia.*
[2] *Department of Chemical and Petroleum Engineering, Faculty of Engineering, UCSI University, 56000 Cheras Kuala Lumpur, Malaysia.*

Publication history**:** Received on 13 October 2019; revised on 22 November 2019; accepted on 30 November 2019

Article DOI: https://doi.org/10.30574/gjeta.2019.1.1.0001

Abstract

Coagulation-flocculation process has been continuously investigated as a significant process to reduce water turbidity in wastewater treatment, owing to the process simplicity and economic feasibility. In this research, the performance of extracted banana peel as bio-flocculant for turbidity removal under different extraction methods and conditions was investigated. Microwave-assisted extraction (MAE) was found to be more effective compared to conventional heating extraction (CHE), with higher turbidity removal efficiency at 45.16%, shorter extraction time and lesser energy requirement. The most optimum turbidity removal percentage was attained by using bio-flocculant extracted with low microwave power, 30 s of extraction duration and banana peel dosage of 5 g/100 ml distilled water. The banana peel bio-flocculant demonstrated potential to be used as a replacement to alum as the turbidity removal as high as 97.06% was recorded using bio-flocculant alone, which was not significantly different from 99.22% removal through the utilization of alum. This offered a greener option in coagulation and flocculation process in reducing utilization of chemical-based coagulant.

Keywords: Banana peel; Bio-flocculant; Turbidity removal; Microwave; Extraction

1. Introduction

Water is a fundamental human need and is essential for human lives. According to the data collected by the National Academy of Sciences [1], each person on Earth requires at least 20 – 50 litres of clean water a day for drinking, cooking and simply keeping themselves clean. As such, more than 60 billion m^3 water is needed annually to meet the demand of 80 million people worldwide [2]. According to Choy et al. [3], 71% of the elements on earth is water but only 2.5% of them is consumable freshwater. However, water scarcity and pollution issues are getting more serious in recent years. To make things worse, most countries are now highly industrialized and rapidly developed which rely substantially on large-scale industrialization to boost their global economic competitiveness [4]. At the same time, tremendous economic growth which is spurred by the robust manufacturing industries has also generated significant quantities of organic, inorganic and metal contaminants to the wastewater streams [4]. As the immediate result, influx of these anthropogenic-based contaminants into the earth's surface environment, particularly the surface water environment, has increased substantially over the past century [4]. This caused adverse effects to the water quality due to the presence of large amount of suspended and colloidal particles which led to high turbidity problems. Turbidity caused by suspended chemical and biological particles, may lead to both water safety and aesthetic implications for drinking water supplies. According to the National Academy of Sciences [1], at least 1.8 million people die every year of diarrheal diseases such as cholera while approximately 10 millions of others are seriously sickened due to water-related ailments. Hence, maintaining good water quality is a growing concern in water resources management around the world.

* Corresponding author
E-mail address: kiewlpl@ucsiuniversity.edu.my

Coagulation-flocculation process has been continuously investigated as a significant process in water and wastewater treatment, owing to the process simplicity and economic feasibility. Generally, coagulation and flocculation process serves as a wastewater pre-treatment and strongly contributes to the overall wastewater treatment efficiency. Coagulants neutralise repelling charges opposite to those of the colloid turbid particles in water. Alum, a metallic chemical coagulant that is commonly used in wastewater treatment removes the contaminants in water such as suspended solid, colloidal particle, chemical oxygen demand (COD) and biochemical oxygen demand (BOD) [5]. Flocculants cause considerable increase in the size and density of coagulated particles resulting in a faster settling rate of the particles in wastewater [6]. Different types of coagulant and flocculant are widely adopted and applied in wastewater treatment plants nowadays. They are normally categorized as chemical-based, organic-based and plant-based. Among all, chemical-based coagulants and flocculants are the most preferred choice in the industry due to their superiority in wastewater treatment efficiencies and cost, compared to the remaining two types [7]. The examples of chemical-based coagulant and flocculant are aluminium sulphate (alum), aluminium chloride, iron chloride and calcium chloride [7]. They are highly demanded due to their relatively low cost, simplicity of treatment process, small dosage required and the possibility of achieving high efficiency in the removal of suspended solids [5]. However, they exhibit several disadvantages such as requirement for pH adjustment before or after treatment, highly sensitive to temperature changes, sensitive to wastewater specific characteristics and composition, as well as generation of excessive sludge after the treatment [7]. Another potential problem associated with chemical-based coagulants or flocculants is the lacking of biodegradability that can lead to environmental hazards and affect human health when the residual of metal ions remains in treated water. In view of that, residual aluminium in alum treated water has been the highlight of various debates as it is linked to serious health issues such as the Alzheimer's disease [3].

Owing to the downfalls of chemical and organic coagulant, there is a need to consider other potential alternatives for water clarification to minimize the environmental damages and to safeguard the wellbeing of human population [3]. The ability of plant-based coagulant or flocculant is studied by many researchers on their flocculation properties compared to chemical flocculants. Plant-based bio-flocculants are made up of natural polymers or complexes formed of polysaccharide from the sugar-based monosaccharides, for example cellulose, starch, mucilage, natural gums, etc [8]. These polysaccharides had been recognized as an excellent alternative for chemical-based flocculants to produce more safe-to-drink water from wastewater treatment. Environmental friendly bio-flocculants can be produced by a simple and economically viable process which exhibit high removal efficiencies and considerably denser flocs is regarded as a promising material for the application from both performance and cost perspectives [9]. In comparison of performances between bio-flocculants and chemical-based flocculants, the former has less requirement on pH adjustment for the wastewater treatment process due to its original pH that is close to neutral [10]. In addition, bio-flocculants produce lower sludge volume compared to chemical flocculants [4]. Hence, upgrading of renewable agriculture and household wastes by transforming them into bio-flocculants serves as an interesting attempt to reuse the waste materials. Plant-based bio-flocculants derived from some plant species such as *Hibiscus/Abelmoschus exculentus* (okra), *Tamarindus indica* (leguminous tree), *Trigonella foenum-graecum* (Fenugreek), etc. have shown promising results in the suspended solid removal treatment of biological effluent, landfill leachate, dye-containing wastewater, textile wastewater, tannery effluent, and sewage effluents [8].

Conventionally, bio-flocculants are extracted from plant materials through time-consuming drying and water bath extraction method [11]. Both methods require a significant amount of energy which leads to high operating cost [11]. Hence, the selection of appropriate extraction method with optimization of its extraction conditions is significant to minimise the extraction time required in the production of highly efficient bio-flocculants. With this purpose, the present study is carried out to investigate the extraction behaviour of bio-flocculant using banana peel and to compare the extraction efficiencies of polysaccharides (bio-flocculants) between conventional heating method (CHE) and advanced extraction method that is, microwave-assisted extraction (MAE). MAE method is performed in order to evaluate the possibility of improvement in extraction efficiency with reduction of extraction time, increment of extraction yield and enhancement of the bio-flocculant quality.

2. Material and methods

2.1. Materials

Banana peel were collected from local morning market and nearby wet market in Batu Sembilan, Cheras, Malaysia. Unless stated otherwise, all chemicals (alum, hydrochloric acid, kaolin and sodium hydroxide) are of analytical grade and used without pre-treatment.

2.2. Preparation of bio-flocculants

The preparation of banana peel powder (raw material) was conducted as described by Lee [5] and Chong and Kiew [12] with slight modifications. Before proceeding with the extraction process, the banana peels were washed and cut into small pieces and dried at 100^{o}C for 1 hr. It was ground into fine powder and sieved. The powdered sample was then stored in an airtight container prior to the bio-flocculant extraction process.

2.3. Extraction of bio-flocculant by conventional heating extraction (CHE)

The banana peel powder was soaked into 100 ml distilled water and heated at 70oC and stirred at high stirring speed (500-700 rpm) for 1.5 hrs on a hot plate stirrer**.** The solution was then filtered through a filter paper and the filtrate (bio-flocculants) was used in the experiment.

2.4. Extraction of bio-flocculant by microwave-assisted extraction (MAE)

The banana peel powder was soaked into 100 ml distilled water and placed into a microwave under different extraction time, microwave power and dosage of banana peel powder, for the extraction of bio-flocculants. The solution was then filtered through a filter paper and the filtrate (bio-flocculants) was used in the experiment.

2.5. Preparation of synthetic turbid water

2.5 g of kaolin clay was dispersed in 500 ml of distilled water. The mixture was stirred at 100 rpm for 30 min for uniform dispersion of kaolin particles in the water. After kaolin clay was completely dissolved, the turbid water was allowed to settle for 30 min. The turbid supernatant was removed, stored and ready to be used.

2.6. JAR test

The coagulation-flocculation test was carried out using JAR test. The study involved a few steps such as rapid mixing, slow mixing and sedimentation by gravity in the batch system process at a given coagulation, flocculation and sedimentation time. During the rapid mixing, agitator was turned on at the speed of 200 rpm for 10 min after the bio-flocculant or alum was added into each beaker of 400 ml synthetic turbid water [13]. Then, slow mixing was conducted at 40 rpm for 20 min before the samples were left over to sediment for 30 min. After sedimentation, a few ml of sample was taken without affecting the sediments at the bottom, for the measurement of final turbidity using turbid meter.

The effects of extraction time, microwave power and dosage of banana peel powder were evaluated by measuring the treated water residual turbidity. Following the flocs formation, the sedimentation time of approximately 30 min was allocated to allow separation of liquid and solid layers to obtain a clarified layer of treated water that will then be used for turbidity measurement. The percentage of turbidity removal was calculated by using the equation:

% of turbidity removal = (initial turbidity - final turbidity)/ initial turbidity × 100.

2.7. Effect of extraction method

The performances of the extracted banana peel bio-flocculants using both conventional heating method (CHE) and microwave-assisted extraction (MAE) were compared. CHE was conducted at the extraction temperature of 70^{o}C, extraction time of 1.5 hrs with a ratio of 100 ml distilled water to 5 g bio-flocculants. On the other hand, MAE was performed by using microwave with medium power, extraction time of 1 min with the ratio of 100 ml distilled water to 5 g bio-flocculants. Subsequently, JAR test was performed at room temperature and the 50 ml of extracted bio-flocculants was dosed into 400 ml synthetic turbid water for both CHE and MAE bio-flocculants. Similar JAR test procedures as described previously were performed. The turbidity removal percentages for both bio-flocculants were calculated and compared.

2.8. Effect of microwave power

The effect of microwave power on the performance of extracted bio-flocculants from banana peel powder in turbidity removal was investigated by varying the microwave power from low, medium to high. The tolerance level of polysaccharide extraction towards the power of microwave was investigated at fixed pH of 7, 5 g dosage of banana peel powder in 100 ml of distilled water, 1 min of extraction time and initial turbidity of the turbid water at 100-200 NTU. Similar JAR test procedures as described previously were performed. Final turbidity removal percentages for bio-flocculant extracted from each microwave extraction power were compared.

2.9. Effect of banana peel dosage

The effect of banana peel powder dosages on the performance of extracted bio-flocculants from banana peel in turbidity removal was studied by fixing the microwave power at medium power, 1 min of extraction time, pH 7 and initial turbidity of the turbid water at 100-200 NTU. Various dosages of banana peel powder were investigated from the range of 2.5 g to 15 g at the interval of 2.5 g to be extracted in 100 ml of distilled water. 50 ml of the extracted bio-flocculant was dosed into 400 ml of synthetic turbid water, for the determination of turbidity removal percentage. Similar JAR test procedures as described previously were performed. Final turbidity removal percentages of bio-flocculant extracted from each dosage of banana peel powder were compared.

2.10. Effect of extraction time

The effect of extraction time on the performance of extracted bio-flocculants from banana peel was investigated by fixing the microwave power at medium power, pH 7, initial turbidity of synthetic turbid water at 100-200 NTU and 5 g of banana peel powder dosage. Various extraction time of bio-flocculants was investigated from 30 s to 90 s for the analysis of turbidity removal percentage. Similar JAR test procedures as described previously were performed. The final turbidity removal percentages for bio-flocculant extracted from each extraction time were compared.

2.11. Potential of bio-flocculant as coagulant aid to alum

The experiments were conducted as described by Zurina et al. [14] with slight modifications. The ratios of bio-flocculants to alum were varied from the range of 0 to 100%, respectively to investigate the optimum combination of alum and bio-flocculants for the best turbidity removal percentage. The ratio variation was made at 0/100, 20/80, 40/60, 50/50, 60/40, 80/20 and 100/0 in percentages for bio-flocculants to alum, respectively. Similar JAR test procedures as described previously were performed. The final turbidity removal percentage for each ratio was compared.

3. Results and discussion

The comparison of coagulation-flocculation activities between bio-flocculant from different extraction conditions were performed and analysed. The agitation period and speed for JAR test were remained constant throughout the study at different stages such as 5 min mixing period for pre-coagulation (200 rpm), 10 min coagulation at high speed (200 rpm), 20 min flocculation at low speed (40 rpm) and 30 min sedimentation. The result to be investigated was the percentage of turbidity removal in the synthetic turbid water after JAR test.

3.1. Effect of extraction method

In this study, conventional heating extraction (CHE) and microwave-assisted extraction (MAE) were performed to study the effects of different extraction method on the percentage of turbidity removal in synthetic turbid water. As presented in Figure 1, the turbidity removal percentage by MAE (45.16%) was higher than CHE (16.18%). It demonstrated that the MAE was the better extraction method that produced bio-flocculant with better flocculating efficiency. In fact, this could be achieved with shorter extraction time compared to CHE. Garcia-Ayuso et al. [15–16] agreed that microwave assisted extraction process was energy-saving, promoted good reproducibility and required minimal sample manipulation for extraction process [17], especially due to reduction in extraction time needed for the process.

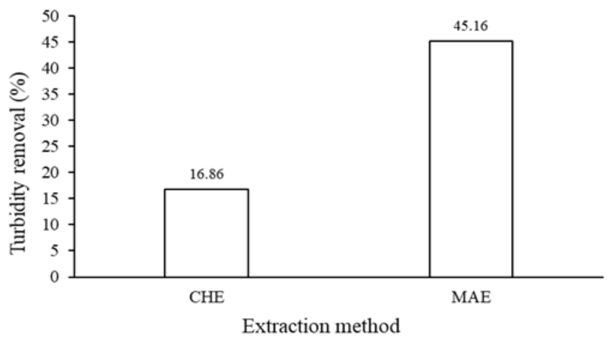

Figure 1 The effect of MAE and CHE method on turbidity removal percentage

A similar result was reported by Lee [5] in the study of extraction of mucilage from Okra. Also, as stated by Emeje et al. [18], extraction of mucilage from okra by using CHE required higher temperature at 70°C and longer extraction time of 2 hrs to obtain extraction yields of 20%. In contrast, MAE method used in the research conducted by Lee [5] was shown to be more effective compared to CHE as the extraction yield extracted by MAE was doubled (48.7%) with shorter extraction time in 10 min. In both studies, the turbidity removal efficiency was assumed to be directly proportional to the amount of extracted yield produced from the extraction processes.

In this study, the turbidity removal percentage demonstrated by bio-flocculant extracted via CHE was observed to be lower at 16.86%. This could be caused by the reduced amount of polysaccharide extracted from the banana peel. According to Zheng et al. [19], long exposures to high temperature caused thermal degradation and damage to the structure of polysaccharides. This was evidenced as the bio-flocculant extracted by MAE in this study was observed to result in higher turbidity removal percentage at 45.16%. The superiority in performance of MAE extracted bio-flocculant could be associated with microwave power which penetrated the banana peels. Heat energy was generated through microwave heating and interaction of the microwave energy with the polar and ionic molecules in extracting solvent that resulted in volumetric heating [5]. Subsequently, the volumetric heating of solvent caused sudden increased in temperature of the solvent, asserted pressure that created stress on banana peel cell walls which resulted in swelling and bursting [5]. According to Destandau et al. [20], this mechanism shortened the time for the diffusion of solvent into plant cells and released of intracellular components such as polysaccharide into the solvent. Hence, this explained the observation in this study that extracted polysaccharide by MAE led to better flocculation of suspended particles and enhanced the turbidity removal performance. As such, MAE was proven as an alternative extraction technique to replace CHE in the extraction of bio-materials, especially bio-flocculants in the present study.

3.2. Effect of microwave power in bio-flocculant extraction

The effect of microwave power on the extraction of bio-flocculant had been investigated in low, medium and high power. Figure 2 depicts the turbidity removal of turbid water by using bio-flocculant extracted at different microwave power. As the microwave power was increased, the turbidity removal performance of bio-flocculant was found to be declined. The highest percentage of turbidity removal at 48.29% was observed at low microwave power while the lowest percentage of turbidity removal was observed at high microwave power at 14.67%.

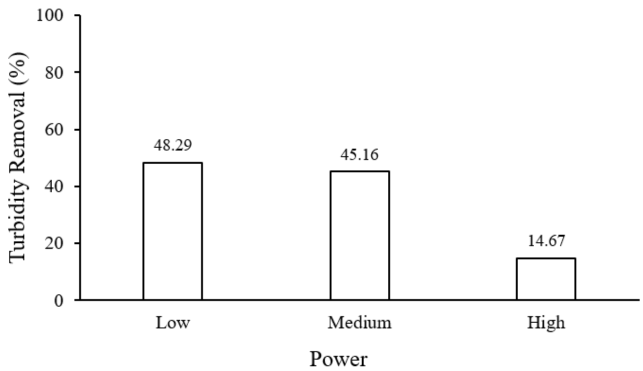

Figure 2 The effect of microwave power on turbidity removal percentage

According to results reported by Lee [5] in the CHE and MAE of Okra, the extraction yield increased with temperature until the optimum temperature was achieved. The increased in initial temperature resulted in the reduction of viscosity and surface tension of solvent. Consequently, it increased the solubility and diffusion of solutes from cell walls of the plant into the extracting solvent [21–23]. However, further increased in microwave power beyond the optimum condition caused reduction in the turbidity removal percentage due to overheating of solvent at higher power. The overheated solvent led to degradation of thermolabile components caused by prolonged heating at high temperatures [5]. Similar trends were observed in other related studies [21–24]. At the same time, it was reported that the extraction temperature imposed significant impact on the thermal depolymerisation of plant bioactive compounds by affecting its intrinsic viscosity, average molecular weight and promoted degradation during microwave heating process [21–24].

3.3. Effect of extraction time in bio-flocculant extraction

The effect of extraction time on the extraction of bio-flocculant to the turbidity removal efficiency was also another notable factor that required proper investigation. Figure 3 shows the results of turbidity removal percentage by banana peel bio-flocculant at extraction time of 30 s, 60 s and 90 s. It was observed that the turbidity removal percentage decreased with increasing bio-flocculant extraction time. The best turbidity removal performance was demonstrated by bio-flocculant extracted at 30 s with 48.54% removal while the lowest percentage turbidity removal was recorded using bio-flocculant extracted at 90 s with -6.15%. The negative percentage turbidity removal indicated increased in the amount of suspended solids in the treated turbid water after flocculation process.

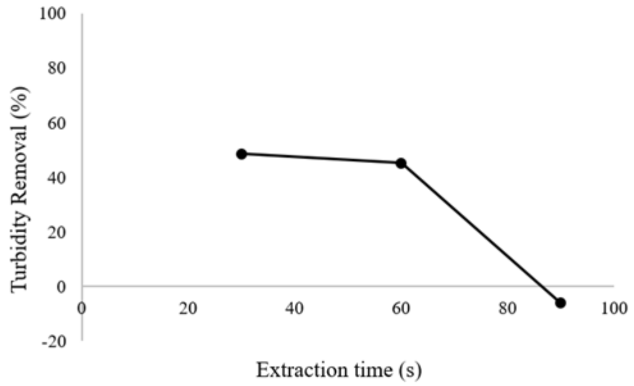

Figure 3 The effect of extraction time on turbidity removal percentage

According to Cai et al. [25] the extracted yield of polysaccharides from *Opuntia milpa alt* declined with increased extraction time. This could be due to thermal degradation and oxidation of polysaccharide molecule structures. The degradation mechanism of bio-flocculant could be described by hydrolytic cleavage of polysaccharide chains led to the breaking of intermolecular hydrogen bonds [26]. The breaking of intermolecular hydrogen bonds caused the reduction in intrinsic viscosity and molecular weight of bio-flocculant [27]. Therefore, the degradation of polysaccharide reduced the flocculation mechanism of suspended solids by forming smaller flocs. In view of this, the negative percentage turbidity with extraction time at 90 s could be correlated to severe degradation of polysaccharide which led to the loss of flocculating ability and its transformation into suspended solids instead.

3.4. Effect of banana peel dosage in bio-flocculant extraction

Bio-flocculant extracted from different dosages of banana peel in turbid water was also among the significant variables affecting the turbidity removal efficiency. Results illustrated in Figure 4 reveal that the turbidity removal percentage in water increased when the banana peel dosages for extraction process was increased from 2.5 g to 5 g in 100 ml of extracting solvent. However, beyond the optimum dosage of 5 g, a decreasing trend in the percentage of turbidity removal was observed until it reached constant at 10 g to 15 g. Therefore, the optimum turbidity removal performance was observed at 5 g in this study, resulted in 45.16% turbidity removal.

Generally, solvent loading refers to the ratio of extracting solvent to the amount of fruit peel added for the extraction process. In a separate study conducted by Qiao et al. [28] and Ying et al. [29] on the extraction of bio-flocculant through CHE approach, a similar trend in the effect of raw material dosage was reported as well. In this study, with the MAE approach, the highest removal of suspended solids was observed at solvent loading of 20 v/w (100 ml extracting solvent/ 5 g banana peel). Increased in solvent loading through reduction of banana peel dosage at constant extracting solvent implied a greater concentration difference between the interior banana peel cells and the exterior solvent, resulted in improvement of driving force for mass transfer of polysaccharide from the peel into extracting solvent. Hence, increased in solvent loading for the bio-flocculant extraction improved the efficiency of turbidity removal. However, further increase in solvent loading to 40 v/w (100 ml extracting solvent/ 2.5 g banana peel) during the extraction process led to reduction in turbidity removal performance, probably due to insufficient dosage of banana peel. The non-uniform distribution and exposure of banana peel to microwave due to insufficient peel could result in a lower yield of polysaccharide produced [30].

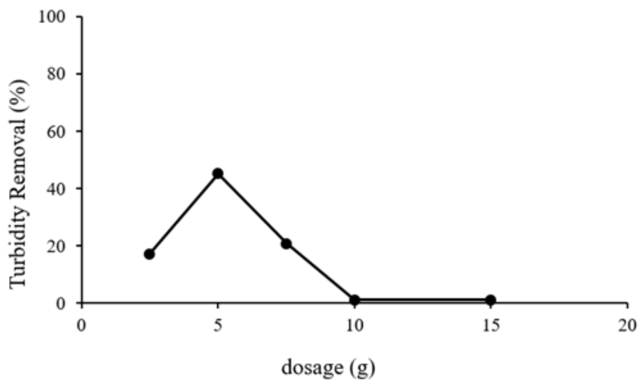

Figure 4 The effect of dosage of banana peel for MAE on turbidity removal percentage

3.5. Potential of bio-flocculant as coagulant aid to alum

The main coagulation and flocculation mechanisms involved in coagulation-flocculation activity are known as charge neutralisation and bridge formation. In a common coagulation process, chemical-based coagulant with opposite charge to suspended solids is added first into wastewater to neutralise the negatively-charged suspended solids such as clay and organic substances [31]. The repulsive forces between destabilized suspended solids will be reduced, resulting in the formation of microflocs [8]. Rapid mixing will be carried out at this stage to induce the collision between coagulant and suspended solids in order to promote the production of microflocs [8]. Following that, the formation of bridge linkages between the suspended solids will then promote the binding effect among them, inducing the formation of larger flocs in the subsequent flocculation process [8].

In this study, flocculation process was carried out under highly alkaline (pH 12) condition where it was determined as the best operating pH for banana peel bio-flocculant in a separate study prior to this [12]. An optimization study was carried out in the range of 0-100% dosage ratio of bio-flocculant to alum in order to determine the optimum combination of bio-flocculant and alum for turbidity removal. Based on Figure 5, the turbidity removal percentage in synthetic turbid water by pure alum (0/100) was 99.22% and pure banana peel bio-flocculant (100/0) was found to be 97.06%, respectively. The usage of pure alum and pure bio-flocculant illustrated the highest and the lowest percentage turbidity removal among all the ratio tested. However, these percentages of turbidity removal were observed to be no significantly different from each other. Hence, pure bio-flocculant (100/0) was suggested as the best option as it resulted in high percentage of turbidity removal comparable with the performance of alum, indicating the potential to replace alum usage in wastewater treatment. The application of 100% dosage bio-flocculant as an alternative for alum is regarded as a green solution for wastewater treatment since it can prevent the environmental and health impacts caused by utilization of chemical-based coagulant. This approach could be an interesting attempt to the industrial wastewater treatment to reduce the demand on alum, which also diminish the cost required for advanced treatment on the residual aluminium ions in water yet maintaining high efficiency of turbidity removal. In addition, the solid waste treatment and landfill cost for the disposal of banana peel waste could be reduced by exploiting it in wastewater treatment.

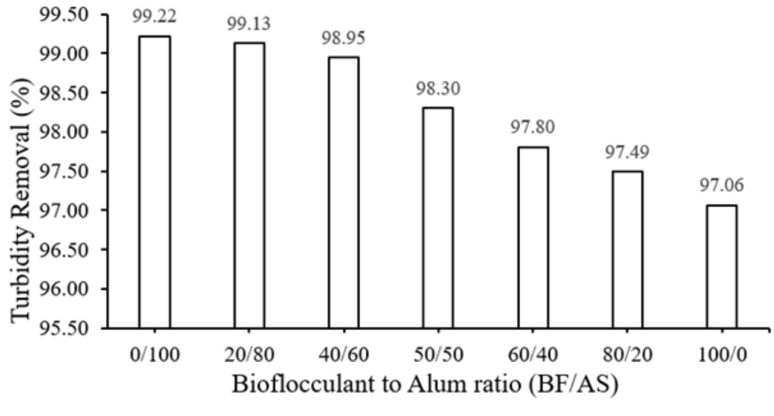

Figure 5 The effect of dosage ratio of alum to bio-flocculant on turbidity removal percentage

4. Conclusion

The comparison of turbidity removal efficiency by banana peel bio-flocculant extracted using different methods and conditions was performed in this study. MAE was found to be a more effective extraction method as it produced bio-flocculant with higher turbidity removal efficiency. The effect of extraction conditions on MAE was investigated. The optimum conditions for the extraction of banana peel bio-flocculant were determined as low microwave extraction power, 30 s of extraction time and 5 g of banana peel dosage in extracting solvent to generate bio-flocculant that resulted in the highest turbidity removal. Lastly, the potential of banana peel as coagulant aid to alum was studied. It was found that the performance of 100% bio-flocculant was comparable with alum in terms of turbidity removal, indicating the extracted banana peel bio-flocculant has potential as an alternative to chemical-based coagulant. To conclude, the findings in this research offer a great opportunity to reduce the heavy dependency on chemical-based coagulant in wastewater treatment.

Compliance with ethical standards

Acknowledgments

This work is financially supported by UCSI University under PSIF grant (Pioneer Scientist Incentive Fund, grant no. Proj-In-FETBE-048).

Disclosure of conflict of interest

All authors would like to declare that there is no conflict of interest relevant to this article.

References

[1] NA. (2007). Why is Safe Water Essential? National Academy of Sciences.

[2] Warren VJ. (2006). Population and Water Resources. Science and Issues Water Encyclopedia

[3] Choy SY, Krishna MNP, Wu TY, Mavinakere ER and Ramakrishnan NR. (2014). Utilization of plant-based natural coagulants as future alternatives towards sustainable water clarification. Journal of Environmental Sciences, 26(11), 2178–2189.

[4] Yin CY. (2010). Emerging usage of plant-based coagulants for water and wastewater treatment. Process Biochemistry, 45(9), 1437–1444.

[5] Lee CS. (2017). Extraction of bio-flocculant from okra using hydrothermal and microwave extraction methods combined with a techno-economic assessment. Ph.D. thesis, University of Nottingham, Malaysia.

[6] Ellis WS. (1988). Chlorination and disinfection of water. Journal, American Water Association, 336(4), 28–44.

[7] Tzoupanos ND and Zouboulis AI. (2008). Coagulation-flocculation processes in water/wastewater treatment: The application of new generation of chemical reagents. 6th IASME/WSEAS International Conference on Heat Transfer, Thermal Engineering and Environment, Rhodes, Greece, 22-28 August 2008, 309–317.

[8] Lee CS, Robinson J and Chong MF. (2014). A review on application of flocculants in wastewater treatment. Process Safety and Environmental Protection, 92(6), 489–508.

[9] Okaiyeto K, Nwodo UU, Okoli SA, Mabinya LV and Okoh AI. (2016). Implications for public health demands alternatives to inorganic and synthetic flocculants: Bioflocculants as important candidates. Microbiology Open, 5(2), 177–211.

[10] Hu CY, Lo SL, Chang CL, Chen FL, Wu YD and Ma JL. (2013). Treatment of highly turbid water using chitosan and aluminium salts. Separation and Purification Technology, 104, 322–326.

[11] Sánchez-Martín J, Beltrán-Heredia J and Peres JA. (2012). Improvement of the flocculation process in water treatment by using Moringa oleifera seeds extract. Brazilian Journal of Chemical Engineering, 29(3), 495–501.

[12] Chong KH and Kiew PL. (2017). Potential of banana peels as bio-flocculant for water clarification. Progress in Energy and Environment, 4(5), 47–56.

[13] Al-Mamun A and Basir ATA. (2016). White popinac as potential phyto-coagulant to reduce turbidity of river water. ARPN Journal of Engineering and Applied Sciences, 11(11), 7180–7183.

[14] Zurina AZ, Mohd Fadzli M and Abdul Ghani LA. (2014). Preliminary study of rambutan (Nephelium Lappaceum) seed as potential biocoagulant for turbidity removal. Advanced Materials Research, 917, 96–105.

[15] Garcia-Ayuso LE, Luque D and Castro MD. (1999). A multivariate study of the performance of a microwave-assisted soxhlet extractor for olive seeds. Analytica Chimica Acta, 382(3), 309–316.

[16] Garcia-Ayuso LE, Luque D and Castro MD. (2001). Employing focused microwaves to counteract conventional soxhlet extraction drawbacks. Trends Analytical Chemistry, 20(1), 28–34.

[17] Proestos C and Komaitis M. (2008). Application of microwave assisted extraction to the fast extraction of plant phenolic compounds. Food Science and Technology, 49, 479–724.

[18] Emeje M, Isimi C, Byrn S, Fortunak J, Kunle O and Ofoefule S. (2011). Extraction and physicochemical characterization of a new polysaccharide obtained from the fresh fruits of Abelmoschus Esculentus. Iranian Journal of Pharmaceutical Research, 10, 237–246.

[19] Zheng X, Yin F, Liu C and Xu X. (2011). Effect of process parameters of microwave on polysaccharides yield from pumpkin. Journal of Northeast Agricultural University, 18(2), 79–86.

[20] Destandau E, Michel T and Elfakir C. (2013). Chapter 4: Microwave-assisted extraction. In: Mauricio AR and Juliana MP (Eds), Natural product extraction: Principles and applications. The Royal Society of Chemistry, 113–156.

[21] Carr AG, Mammucari R and Foster NR. (2011). A review of subcritical water as a solvent and its utilisation for the processing of hydrophobic organic compounds. Chemical Engineering Journal, 172, 1–17.

[22] Ye CL and Jiang CJ. (2011). Optimization of extraction process of crude polysaccharides from Plantago asiatica L. by response surface methodology. Carbohydrate Polymers, 84, 495–502.

[23] Samavati V. (2013). Polysaccharide extraction from Abelmoschus esculentus: Optimization by response surface methodology. Carbohydrate Polymers, 95, 588–597.

[24] Veggi PC, Martinez J and Meireles MAA. (2013). Chapter 2: Fundamentals of microwave extraction. In: Chemat F and Cravotto G (Eds). Microwave-assisted extraction for bioactive compounds: Theory and practice, 15–52.

[25] Cai W, Gu X and Tang J. (2008). Extraction, purification, and characterization of the polysaccharides from Opuntia milpa alta. Carbohydrate Polymers, 71, 403–410.

[26] Wang JL, Zhang J, Zhao BT, Wang XF, Wu YQ and Yao J. (2010). A comparison study on microwave-assisted extraction of Potentilla anserina L. polysaccharides with conventional method: Molecule weight and antioxidant activities evaluation. Carbohydrate Polymer, 80, 84–93.

[27] Valdir S. (2012). Chapter 14: Stability and degradation of polysaccharides. In: Severian D (Ed), Polysaccharides: Structural diversity and functional versatility, 2nd ed. Marcel Dekker, New York, 395–410.

[28] Qiao DL, Hu B, Gan D, Sun Y, Ye H and Zeng XX. (2009). Extraction optimized by using response surface methodology, purification and preliminary characterization of polysaccharides from Hyriopsis cumingii. Carbohydrate Polymers, 76, 422–429.

[29] Ying Z, Han XX and Li JR. (2011). Ultrasound-assisted extraction of polysaccharides from mulberry leaves. Food Chemistry, 127, 1273–1279.

[30] Afoakwah AN, Owusu J, Adomako C and Teye E. (2012). Microwave assisted extraction (MAE) of antixoxidant constituent in plant materials. Global Journal of Bio-science & Biotechnology, 1(2), 132–140.

[31] MRWA (Editor). (2003). Coagulation and Flocculation Process Fundamentals. MRWA: Minnesota Rural Water Association.

How to cite this article

Lau ZE and Kiew PL. (2019). Microwave-assisted extraction of banana peel bio-flocculant and its potential in wastewater treatment. Global Journal of Engineering and Technology Advances, 1(1), 01-09.