Utilization of Fruit Wastes (Jackfruit and Mango Seeds and Banana Trunk) as Natural Coagulants in Treating Municipal Wastewater

Nur Shahzaiwa Wafa Shahimi¹, Nur Syamimi Zaidi¹*, Muhammad Burhanuddin Bahrodin¹ and Amir Hariz Amran¹

¹School of Civil Engineering, Faculty of Engineering, Universiti Teknologi Malaysia, 81310 UTM Johor Bahru, Johor, Malaysia.
*Corresponding author: nursyamimi@utm.my

ABSTRACT. The adequacy of chemical coagulant such as alum is all around perceived. However, there are numerous drawbacks including impeding impacts on human well-being and generation of high sludge volumes. Therefore, this study was conducted to investigate potential of fruit wastes - jackfruit (artocarpus heterophyllus) seeds, banana trunk peduncles (musa) and mango (mangifera indica) seeds in becoming natural coagulant to treat wastewater. A series of jar test was performed to determine the effect of individual coagulants on turbidity removal, coagulation activity and COD removal under various operating factors such as type and concentration of solvents used for extraction, pH and coagulant dosage. From the findings, optimum solvent concentration of 2.5M of sodium hydroxide (NaOH) reacted with banana trunk peduncles at optimum pH and dosage of pH 7 and 50 mg/L, respectively with turbidity removal of 90.2%, coagulation activity of 83.4% and chemical oxygen demand (COD) removal of 94.8%.

1. Introduction
Based on the Compendium of Environment Statistics 2017 by the Department of Statistics, Malaysia has a population of 32 million. Due to this increased population, the estimated volume of wastewater has also increased to more than 3 billion cubic meters per year [1]. Wastewater is the by-product of many uses of water. Presently, wastewaters are dominantly comprised of suspended and dissolved materials that include both organic and inorganic matter as well as biological organisms. Domestic wastewater or sewage comprises of effluent from household uses such as showering, dishwashing, laundry and flushing the toilet [2].

Upon preserving the environment and surface water quality, it is mandatory to treat the wastewater before it is being discharged into surface waters. The quality of effluent from treatment plants is regulated by Environmental Quality (Sewage) Regulations 2009. There are various technologies that have been used to remove particulates from water such as coagulation, flotation, ion exchange and electrolytic methods [3]. Among all technologies, coagulation is the most common and its ability to remove colloidal particles, natural organic matters, microorganisms and inorganic ions are rather efficient [4].

Conventionally, coagulation process relies on chemical coagulants such as aluminium sulphate (alum) and ferric chloride [5]. Coagulation is a process of destabilization of the suspended colloidal particles. It can be achieved via four mechanisms, namely the double-layer compression, charge...
neutralization, bridging as well as sweep coagulation [6-7]. These coagulation mechanisms acted based on different principles and one or more mechanisms could be employed for more effective particles’ destabilizations. Although chemical coagulants used in water is effective in removing particulates and reduce the turbidity of wastewater, it poses several drawbacks. Residuals that been produced from the use of chemical coagulant in treating wastewater are linked to neurodegenerative diseases such as Alzheimer’s as well as neurotoxic and exhibited carcinogenic effects. Other than that, the use of chemical coagulants can increase the cost of treatment due to high cost of chemical coagulant itself. Furthermore, the chemical coagulants produce voluminous sludge, hence it requires expensive treatment in order to stabilize the organic materials in sludge [8-9].

The option of chemical coagulant, which is natural coagulant has been utilized in many countries as an effective coagulant. These coagulants were produced from different materials such as plant seeds, leaves and roots [7]. Due to its promising results, lots of developing countries are now using natural coagulant in their water and wastewater treatment on small scale [10]. Undeniably, using natural coagulant for large scale might be an obstacle due to limited sources. However, more research on natural coagulant may allow researcher to further explore suitable sources. Currently, there are a few researches that mix several sources to produce good natural coagulant with promising pollutant’s removal. A lot of research on natural coagulant was carried out but limited to the established sources. Among the common and established natural coagulants are *moringa oleifera*, *jatropha curcas*, *strychnos potatorum* and *hibiscus sabdariffa*, *nirmali* seeds and cactus [4,6]. These coagulants are sustainable due to less wellbeing risks and the expenses of delivering these natural coagulants were more affordable than the chemical coagulants since it is locally accessible. The natural coagulants can also treat water of high turbidity of range 50 NTU to 500 NTU and having remarkable removal efficiency [11]. Although natural coagulants are known in terms of efficiency in reducing turbidity but little is known about its performance in treating wastewater specifically in reducing the organic content.

To date, the chemical coagulants are ending up less sustainable for coagulation of water and wastewater treatment due to different adverse impacts. It is then crucial to supplant these coagulants with natural coagulants that can minimize the downsides. Hence, the aim of this study is to investigate potential of selected natural coagulants towards sustainable wastewater clarification. Upon variation of local fruit wastes to be used as natural coagulants in this study, the comparison can be made in terms of their physical characterization and the effects on wastewater removal performances.

2. Methodology

2.1. Collection of wastewater

Raw municipal wastewater sampled from MBJB sewage treatment plant was used in this study. The samples were collected at the point after grease chamber and preserved in the cool room at temperature of below 4°C. Upon usage, wastewater will be taken out without requiring any pretreatment as wastewater was collected after grease chamber that remove oil, grease or any solids.

| Table 1. Characteristics of Municipal Wastewater |
|-----------------|-----------------|-----------------|-----------------|
| Turbidity (NTU) | COD (mg/L)      |
| Sample          | 120 - 135       | 473 - 483       |

2.2. Selection and preparation of natural coagulants

This study focused on the use of local fruit wastes which can be found abundantly namely *artocarpus heterophyllus* (jackfruit), *musa* (banana trunk) and *mangifera indica* (mango). Jackfruit seeds, banana trunk peduncles and mango seeds were selected as potential natural coagulant in this study. All fruit waste materials were cleaned thoroughly beforehand and been cut into smaller parts. After cleaning, different fruit wastes were oven dried at different temperature. Seeds of jackfruit and mango were oven dried at 45°C for 63 hours while, banana trunk peduncles were oven dried at 50°C for 72 hours. The oven-dried fruit wastes were then grinded into fine powder of 0.3 mm [3].
2.3. Analytical methods

The prepared natural coagulants were physically and chemically characterized for yield, moisture contents and surface charge. Yield is defined as an amount of the dry powder from the initial raw material of the selected natural coagulant. The percentage of yield can be determined using Eq. (1). The moisture content was analysed in order to determine how much water content in each prepared coagulant. The moisture content can be expressed in percentage as shown in Eq. (2). The surface charge was determined by colloidal titration method with some modifications been made. Value of the surface charge can be determined using Eq. (3).

\[
\text{Yield} \, (\%) = \frac{\text{Weight of powder (g)}}{\text{Weight of dried raw materials (g)}} \times 100
\]

(1)

\[
\text{Moisture Content} \, (\%) = \frac{\text{Weight before dry} - \text{Weight after dry}}{\text{Weight before dry}} \times 100
\]

(2)

\[
\text{Surface charge} \,(\text{meq/g}) = \frac{(A-B) \times N(1000)}{(V \times NCC)}
\]

(3)

where,
- A = Volume of PVSK titrated to the sample (mL)
- B = Volume of PVSK titrated to blank sample (mL)
- N = Normality of PVSK (eq/L)
- V = Volume of natural coagulant (mL)
- NCC = Concentration of natural coagulant (g/L)

Turbidity was measured using 2100P (HACH) Portable Turbidimeter while chemical oxygen demand (COD) was conducted based on Standard Method APHA (2005). The removal of both parameters were determined by computing the differences between raw concentration and treated concentration after been added with coagulant. Coagulation activity was determined by jar test. The wastewater was filled into the beakers and mixed at 200 rpm. Various doses of coagulant extracts were added into the beakers and mixed for 1 min. The mixing speed was then reduced to 80 rpm and kept for another 30 min. Then the suspensions were left for sedimentation. After 1 hour of sedimentation, clarified samples were collected from the top of the beakers, and residual turbidity was measured (Fe). The same coagulation test was conducted with no coagulant as a blank (Fo). Coagulation activity was calculated as in Eq. (4).

\[
\text{Coagulation activity} \,(\%) = \frac{F_0 - F_e}{F_0} \times 100
\]

(4)

2.4. Jar test

In this study, jar test was performed in order to evaluate the effect of different extraction solvents as well as to determine the optimum coagulant dosage and pH. The solvent used throughout this study were sodium chloride (NaCl) and sodium hydroxide (NaOH). Distilled water was used as a control. Natural coagulants were extracted using NaCl and NaOH of 0.5 M, 1.0 M, 1.5 M, 2.0 M and 2.5 M. As to determine the optimum dosage and pH, six (6) beakers were filled with 200 mL wastewater and were placed on each slots of the jar tester machine. Each coagulant extracts were added to each beaker with various dosages and various pH. For each variation, another parameter was set constant. Table 2 summarizes the coagulant dosage and pH that were applied in the jar test.
Table 2. Variation of coagulant dosage and pH that been used for optimization studies

| Materials          | Wastewater Sample (mL) | pH   | Dosage (mg/L)     |
|--------------------|------------------------|------|-------------------|
| Mangifera Indica   | 200                    | 4-9  | 50, 75, 100, 125, 150, 175 |
| (seed)             |                        |      |                   |
| Artocarpus Heterophyllus | 200          | 4-9  | 50, 75, 100, 125, 150, 175 |
| (seed)             |                        |      |                   |
| Musa (peduncle)    | 200                    | 4-9  | 25, 50, 75, 100, 125, 150 |

The jar test consists of a series of simultaneous batch experiments involving three stages, which are rapid mixing, slow mixing and sedimentation. For rapid mixing, the samples were agitated for 2 minutes at 200 rpm. Then, the speed was reduced to 40 rpm for another 20 minutes as to allow slow mixing. All suspensions in each beaker were left to settle for 30 minutes.

3. Results and Discussions

3.1. Physical characteristics of natural coagulants

Based on Table 3, jackfruit seed shows the highest yield with recorded initial weight of 282g and resulted yield was 133.62g. From the recorded weight, it shows that 47.4% of the jackfruit seed can be used as an accessible natural coagulant. The second highest yield was from banana peduncle. The recorded initial weight was 102g while the resulted yield was 27.08g. 26.55% of the whole banana peduncle is accessible to be used as natural coagulant. Compared to jackfruit seed, the yield percentage is lower. A lot of banana peduncle is required to produce powdered natural coagulant. However, the lowest recorded yield percentage from this study is mango seed. The recorded initial dry weight is 90g and yield obtained is 15.16g. This contribute to 16.84% of the mango seed are accessible as natural coagulant. Based on results from Table 3, it indicates that jackfruit seed is more valuable to be used as material for natural coagulant as it can produce more natural coagulant with lesser mass. Higher yield is better as lesser fruit wastes required to treat water compared to lower yield as it need more fruit waste to treat water.

Table 3. Physical characteristics of natural coagulants

| Materials          | Jackfruit Seed | Banana Peduncle | Mango Seed  |
|--------------------|----------------|-----------------|-------------|
| Yield (%)          | 47.4           | 26.6            | 16.8        |
| Moisture content (%)| 53.5           | 88.4            | 30.2        |
| Surface Charge (meq/g) | -0.05         | -0.12           | 0.03        |

Based on Table 3, banana peduncle has the highest moisture content followed by jackfruit seed and mango seed. The weight of banana peduncle, jackfruit seed and mango seed before dry are 878g, 593g, and 129g, respectively. These resulted moisture content of banana peduncle, jackfruit seed and mango seed are 88.38%, 52.455 and 30.23% respectively. Based on these results, it is expected that mango seeds can perform better as coagulant compared to banana peduncle. This is due to active coagulant agent that comprises in mango seed could have sufficient capability to adsorb wastewater particles. Unfortunately, high moisture content will decrease the adsorb ability of the coagulant because the active sites were blocked by water [12]. Besides that, the waste needs to be processed into powder form. High moisture content will disturb preparation of powdered natural coagulant [13].

In addition, the natural coagulant can be classified as cationic coagulants and anionic coagulants. Cationic coagulants are referred to as polymeric molecules that possess net positive charges, typically at investigated coagulation pH of 7 or less, whereas anionic coagulants are referred to as polymeric
molecules that possess net negative charges, typically at investigated coagulation pH of 6.5–8.5 or above [14]. This classification can also be identified through the value of its surface charge. Based on Table 3 the surface charge of jackfruit seed and banana peduncle are classified as anionic material while mango seed is classified as cationic material with the recorded surface charge as -0.05 meq/g, -0.12 meq/g and 0.03 meq/g respectively. Natural coagulant with positive surface charge is more preferable as colloids present in wastewater are usually negatively charged. Therefore, positively charged natural coagulant can attach to negatively charged colloids and will neutralize the charges [15-16]. However, study by [17] using Opuntia spp. with negative surface charge manages to remove 98% turbidity despite both colloids and coagulant has similar surface charge.

Based on the physical characteristics of the studied fruit waste, jackfruit seed is better material for natural coagulant as it has highest yield and lower moisture content. However, mango seed can also become a good natural coagulant as it is a cationic coagulant. Generally, to ensure an efficient coagulant process, a coagulant must have positive surface charge. The positive charge would bind towards the negative charged particles that acted as pollutants in the wastewater [7].

3.2. Effects of solvents as extracting agent of natural coagulant
In this study, two types of extracting agents were used. There are sodium hydroxide (NaOH) and sodium chloride (NaCl). Distilled water was used mainly for control set. Figure 1 shows results of turbidity removal and coagulation activity of the tested natural coagulant when using distilled water for extraction. The turbidity removal is in range of 59.8% to 63.7%. Meanwhile the coagulation activity is between 25.1% and 33.0%. Natural coagulant relies on active coagulant agent such as protein and polysaccharide content. From these results, it shows that water did not manage to extract sufficient active coagulant agent for successful turbidity removal and good coagulation activity. Therefore, extraction process using solvents such as sodium chloride (NaCl) and sodium hydroxide (NaOH) is required [7].

![Figure 1. Turbidity removal and coagulation activity of natural coagulant](image)

Figure 2 show the effects of extraction process by using sodium chloride (NaCl) towards tested natural coagulants on turbidity removal and coagulation activity. Based on Figure 2, it shows that sodium chloride has great potential to extract the active coagulant particles in mango seed when its molarity is on 1.5 M followed by jackfruit seed at 2.5M and banana peduncle at 0.5M. However, sodium chloride was not sufficient enough to extract the active coagulant agent in banana peduncle. The turbidity removal and coagulation activity by using banana peduncle as natural coagulant shows least percentages of turbidity removal and coagulation activity. The turbidity removal and coagulant activity of mango seed as natural coagulant with NaCl extraction were 70.44% and 49.75% respectively. By referring to mango seed, increase in NaCl concentration will increase the turbidity removal and coagulation activity. This phenomenon is known as salting in effect as the coagulant agent dissolve in the extracting solvent. NaCl concentration beyond the optimum concentration will decrease the turbidity removal and coagulation activity due to salting out effect where the coagulant...
agent is less soluble at high salt concentration [18-19]. This result is in contrast with study by [20] that used NaCl extraction on seeds of mango and lime which resulted in turbidity removal of more than 90%. Salt content in NaCl can place intense force in breaking plant cells that can greatly improve coagulation process. However, previous study by [21] proves otherwise and agrees with the findings. Use of salt for extraction process reduced the turbidity removal due to the alteration of polysaccharide’s functional group. Presences of salt encourage polysaccharide chain and cause aggregations which reduce the bridging of colloids with natural coagulant.

Figure 2. Effect of NaCl molarity on turbidity removal and coagulation activity

Figure 3 shows the effects of extraction process by using sodium hydroxide (NaOH) towards tested natural coagulants on turbidity removal and coagulation activity. It can be generalised that the sodium hydroxide demonstrates the great performances of turbidity removal and coagulation activity at 2.5 M. Indeed, jackfruit seed seemed to have the greatest turbidity removal and coagulant activity among all natural coagulants. As visualised in Figure 3, the turbidity removal and coagulation activity by jackfruit seed were 87.9% and 78.1% respectively. By sequence, the results followed by banana peduncle and mango seed. Extraction of natural coagulant using NaOH demonstrates better turbidity removal and coagulation activity compared to NaCl. Therefore, extraction using NaOH will be used for the rest of the analysis. This finding is not aligned with study by [22] that reported on advantage of NaCl extraction over NaOH.

Figure 3. Effect of NaOH molarity on turbidity removal and coagulation activity
3.3. Effects of natural coagulant dosage and pH in treating wastewater

Figure 4 illustrates effects of dosage of jackfruit seed, banana peduncle and mango seed on turbidity removal and coagulation activity. Different natural coagulants have different optimum dosage. Banana peduncle record highest turbidity removal and coagulation activity of 80.36% and 63.52% respectively with least dosage of 50 mg/L. The second natural coagulant with best turbidity removal and coagulation activity is jackfruit seed and followed by mango seed. The recorded turbidity removal of jackfruit seed and mango seed are 76.55% and 70.98% respectively. Meanwhile, the coagulation activity of jackfruit seed and mango seed are 56.27% and 46.10% respectively. Even though jackfruit record higher turbidity removal and coagulation activity but mango seed require lesser dosage to achieve optimum dosage at 100 mg/L compared to jackfruit seed at 125 mg/L. This factor may be attributed to high charge density of the coagulant whereby lesser dosages are sufficient for destabilization of suspended particles and dosage beyond than the optimum cause interferences [3].

Figure 4. Effect of coagulant dosage on turbidity removal and coagulation activity

Since the pH of water affects the surface charge of the coagulants as well as degree of stabilization of the suspension, then it is crucial to investigate the effect of pH on turbidity removal and coagulation activity [23]. The pH range was between pH 4 and pH 9. For the optimization, the jar test was conducted at optimum coagulant dosage that had been obtained earlier.

Figure 5 interpret effect of different pH of the sample on turbidity removal and coagulation activity by using jackfruit seed, banana peduncle and mango seed. Generally, the efficiency of the turbidity removal of natural coagulants range from 87.44% to 90.22% whereas the coagulation activities range
Different natural coagulants have different optimum pH that results in highest turbidity removal and natural coagulant. Banana peduncle record highest turbidity removal and coagulation activity of 90.22% and 83.42% under neutral condition at pH 7. Next, the highest turbidity removal and coagulation activity was recorded by mango seed followed by jackfruit seed. The turbidity removal and coagulation activity of mango seed are 90% and 83% respectively. However, the recorded turbidity removal and coagulation activity is under little acidic condition and alkaline condition at pH 6 and pH 9. Meanwhile, the turbidity removal and coagulation activity by using jackfruit seed was observed to occur under acidic condition of pH 4 with percentage of turbidity removal and coagulation activity 87.44% and 78.86% respectively.

**Table 4. Optimization of natural coagulants**

| Material     | Jackfruit Seed | Banana Peduncle | Mango Seed |
|--------------|----------------|-----------------|------------|
| Dosage (mg/L)| 125            | 50              | 100        |
| pH           | 9              | 7               | 6,9        |

The optimum dosage and pH will lead to the optimum conditions of jar test [11]. Table 4 shows the summary of optimum coagulant dosage and pH based on the tested natural coagulants. The optimization as shown in Table 4 had resulted towards maximum turbidity removal and coagulation activity. All materials have demonstrates a great performance of removing turbidity effectively. This is because the turbidity removal for all materials recorded more than 80.0%. However, among all the tested materials, banana peduncle is the most feasible in such sense as it requires minimal dosage with neutral pH condition to perform efficient coagulation process. Banana peduncles have negative surface charge. Colloids present in wastewater are negatively charge. Based on Figure 5, despite both natural coagulant and colloids are of same charges, the turbidity removal and coagulation activity recorded is exceeding 80%. This proves that the electrostatic repulsion between natural coagulants and colloids is weak and it prevents successful coagulation and the mechanism most likely not to be charge neutralization [14].

Thus, its active coagulant particles enhance bridging mechanism in order to coagulate colloids in wastewater. Bridging refers to adsorption of coagulant segments onto adjacent colloidal surfaces (in the presence of divalent metal ions usually), thereby binding them together. Based on Figure 4, it was observed that the dosage of natural coagulant affecting the coagulation activity. The percentage is lower at too high or too low dosage of natural coagulant which consistent with a bridging mechanism. It shows the stoichiometric relationship between colloids and coagulant dose [24].

This phenomenon can be explained by the fact that the pH of the wastewater influences the surface charge of the active natural coagulants’ particles in the solution. The pH for the active natural coagulants’ particles was determined range from 4 to 9. By considering the actual pH of each batch jar test, the optimum pH was selected with the lowest chemical addition in wastewater.

### 3.4. Effect of natural coagulant on COD removal under optimized conditions

It is clearly shown that banana’s peduncle have better removal of chemical oxygen demand followed by jackfruit’s seed and mango’s seed. Thus, the results can be compared with standard as in regulation in sewage quality standards. As in Environmental Quality (Sewage) Regulations 2009, standard A allows sewage discharge with COD limit below 120 mg/L, whereas 200 mg/L for standard B. Thus, only two of natural coagulants that are good in reducing COD which are banana peduncle and jackfruit seed with 25 mg/L and 59 mg/L respectively, after the jar test. Both banana peduncle and jackfruit seed are negatively charged but manage to remove COD. Despite having similar charges between coagulant and colloids, mechanism by interparticle bridging manage to remove pollutants of high degree. Figure 6 shows the effects of optimisation of dosage and pH of different types of natural coagulants on chemical oxygen demand removal.
Figure 6. COD removal on optimum condition of natural coagulant

4. Conclusion
The natural coagulants represent an alternative for chemical coagulants. The use of natural coagulants derived from fruit wastes represents a vital development in sustainable environmental technology since it focuses on the improvement of quality of life for communities. Nonetheless, there are many pressing issues that are hindering process development of these coagulants, namely, absence of mass plantation of the plants that affords bulk processing, perceived low-volume market and virtually non-existent supportive regulation that stipulates the quality of the processed coagulant extracts. The last factor is especially vital since it is normally difficult for regulatory authorities to endorse a product for sale to the general public. In a nutshell, jackfruit seed records highest yield, low moisture content and weak surface charge that may indicate it as good natural coagulant. However, upon extraction using NaOH at optimum dosage and pH, banana peduncle shows better performance. Recorded turbidity removal and coagulation activity are 90.22% and 83.42% respectively.

5. References
[1] Kuyama T, Secretariat W, Management W R and Strategies G E 2017 Current Situation of Domestic Wastewater Management in Asian Region -Insights from WEPA- Preparation Workshop on the Asia Wastewater Management Partnership (AWaP) (Melia Yangon: Institute for Global Environmental Strategies) pp 1-20
[2] Sperling M V 2007 Biological Wastewater Treatment Series Volume 1: Wastewater characteristics, treatment and disposal (London: IWA Publishing).
[3] Kakoi B, Kaluli J W, Ndiba P and Thiong’o G 2016 Banana pith as a natural coagulant for polluted river water, Ecological Engineering 95 699–705
[4] Antov M G, Šćiban M B and Petrović N J 2010 Proteins from common bean (Phaseolus vulgaris) seed as a natural coagulant for potential application in water turbidity removal, Bioresource Technology 101(7) 2167–2172
[5] Saharudin N F A and Nithyanandam R 2014 Wastewater Treatment by Using Natural Coagulant, 2nd eureka 2014
[6] Amran A H, Zaidi N S, Muda K, Loan L W 2018 Effectiveness of Natural Coagulant in Coagulation Process: A Review, International Journal of Engineering and Technology. 7(3.9) 34-37
[7] Choy S Y, Prasad K M N, Wu T Y and Ramanan R N 2015 A review on common vegetables and legumes as promising plant-based natural coagulants in water clarification, International Journal of Environmental Science and Technology 12(1) 367–390
[8] Shamsnejati S, Chaibakhsh N, Pendashteh A R and Hayeripour S 2015 Mucilaginous seed of Ocimum basilicum as a natural coagulant for textile wastewater treatment, Industrial Crops and Products 69 40–47
[9] Souza M T F D, Almeida C A D, Ambrosio E, Santos L B, Thábata Karoliny Formicoli De Souza Freitas, Manholer D D, … and Garcia J C 2016 Extraction and use of Cereus peruvianus cactus mucilage in the treatment of textile effluents, Journal of the Taiwan Institute of Chemical Engineers, 67 pp 174–183.

[10] Zaidi N S, Muda K, Rahman M A A, Sgawi M S and Amran A H 2019 Effectiveness of Local Waste Materials as Organic-Based Coagulant in Treating Water, IOP Conference Series: Materials Science and Engineering 636 012007

[11] Kumar V, Othman N and Asharuddin S 2017 Applications of Natural Coagulants to Treat Wastewater – A Review, MATEC Web of Conferences 103

[12] Setyiwan H 2017 Effectiveness of Moringa Seeds Powder and Tamarind seeds Powder Asnatural Coagulant for Increasing Tofu Industrial Waste Water Quality, International Journal of ChemTech Research 10(12) 248–255

[13] Abdul Rahman M A and Zaidi N S 2019 Effect of Natural Coagulant on the Treatment of Polluted River Water Degree Dissertation (Malaysia: Universiti Teknologi Malaysia)

[14] Saleem M and Bachmann R T 2019 A contemporary review on plant-based coagulants for applications in water treatment, Journal of Industrial and Engineering Chemistry 72 281–297

[15] Ramavandi B, Hashemi S and Kafaei R 2015 A novel method for extraction of a proteinous coagulant from Plantago ovata seeds for water treatment purposes, MethodsX 2 278–282

[16] Hendrawati, Yuliastri I R, Nurhasni, Rohaeti E, Effendi H and Darusman L K 2016 The use of Moringa Oleifera Seed Powder as Coagulant to Improve the Quality of Wastewater and Ground Water, IOP Conference Series: Earth and Environmental Science 31

[17] Miller S M, Fugate E J, Craver V O, Smith J A and Zimmerman J B 2008 Toward Understanding the Efficacy and Mechanism of Opuntia spp. as a Natural Coagulant for Potential Application in Water Treatment, Environmental Science & Technology 42(12) 4274-4279

[18] Birima A H, Hammad H A, Desa M N M and Muda Z C 2013 Extraction of natural coagulant from peanut seeds for treatment of turbid water, IOP Conference Series: Earth and Environmental Science 16

[19] Abidin Z Z, Shamsudin N S M, Madehi N and Sobri S 2012 Optimisation of a method to extract the active coagulant agent from Jatropha curcas seeds for use in turbidity removal, Industrial Crops and Products 41 pp 319-323

[20] Seghosime A, Awudza J A M, Buamah R, Ebeigbe A B and Kwarteng S O 2017 Effect of Locally Available Fruit Waste on Treatment of Water Turbidity, Civil and Environment Research 9 7 – 15

[21] Choudhary M, Ray M B and Neogi S 2019 Evaluation of the potential application of cactus (Opuntia ficus-indica) as a bio-coagulant for pre-treatment of oil sands process-affected water, Separation and Purification Technology 209 714-724

[22] Muthuraman G, Sasikala S and Prakash N 2013 Proteins from Natural Coagulant for Potential Application of Turbidity Removal in Water, International Journal of Engineering and Innovative Technology (IJEIT) 3 278-283

[23] Ramavandi B 2014 Treatment of water turbidity and bacteria by using a coagulant extracted from Plantago ovata, Water Resources and Industry 6 36–50

[24] Lek B L C, Peter A P, Chong K H Q, Ragu P, Sethu V, Selvarajoo A and Arumugasamy S K 2018 Treatment of palm oil mill effluent (POME) using chickpea (Cicer arietinum) as a natural coagulant and flocculation: Evaluation, process optimization and characterization of chickpea powder, Journal of Environmental Chemical Engineering 6 6243-6355

Acknowledgement
The authors would like to thank Ministry of Higher Education (MOHE) Malaysia of FRGS Grant (Grant Project No: 5F218) for financial support.