

COAGULATION PERFORMANCE AND MECHANISM OF A NEW COAGULANT (POLYALUMINIUM CHLORIDE-TAPIOCA PEEL POWDER) FOR LANDFILL LEACHATE TREATMENT

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Abstract

A combination of metal coagulant with an organic polymer at the optimum ratio can fully complement both outstanding and flaw properties of the separate elements. A novel composite coagulant called polyaluminium chloride (PAC)-tapioca peel powder (TPP) or PACTPP was used to treat landfill leachate in the optimum weight ratio of TPP/Al = 3.71. The coagulation performance of the new coagulant was evaluated and compared as well with other published composite coagulants. The performed jar tests with the influence of the optimum coagulant dose (2500 mg/L) and pH of leachate sample (pH 7) managed to remove about 59.8% of chemical oxygen demand (COD), 38.7% of ammonia nitrogen (AN), 95.5% of turbidity, 93.0% of colour, and 99.2% of suspended solids, respectively. The zeta (ζ)-potential of coagulants and treated leachate were studied to discover the possible exhibited coagulation mechanisms. The molecular weight and ζ potential of PACTPP were determined to be 1.59×10^7 g/mol and +3.45 mV, respectively. It was denoted that adsorption-bridging and sweep flocculation were the superior mechanisms when treating landfill leachate with PACTPP.

Keywords: Composite coagulant, Landfill leachate, Removal efficiency, Zeta potential.

1. Introduction

Leachate is produced when water percolates through solid wastes in landfill sites and often addressed as high-strength wastewater with risky contaminant content [1]. It is always addressed as highly polluted wastewater; however, the concentration of each contaminant may be different due to the landfill age [2], since the duration of the solid waste has been located in the landfill would influence the quality of the leachate. Based on the landfill age, it can be categorised as young (below than five years), which produce the young type of leachate, medium age (between five to 10 year), that resulted in intermediate leachate, and the old landfill (exist more than 10 years), which influence the production of stabilised leachates [2, 3]. As the landfills get older, the activity of anaerobic decomposition in the site would reduce the biodegradable fraction of organic pollutants, thus cause stabilised leachate to become higher polluted wastewater compare to the young ones [4]. Typically, old leachate is harder to be treated. This address that it is important to carry out leachate characterisation first to have a successful treatment strategy [5].

In general, biological treatment processes are applicable for fresh-produced leachate, which specifically to be less than five years old and incompetent for stabilised ones from older landfills [4, 6]. Contrarily, physical and chemical treatments are favoured for the treatment of stabilised leachates and do not recommend for young ones [6]. There is various kind of chemical and physical methods developed by the past decades for wastewaters, such as solvent extraction, oxidation/reduction, ion exchange, ozonation, electrochemical techniques [7], ammonium stripping, ultrafiltration, nanofiltration [8], reverse osmosis, sedimentation, and coagulation-flocculation [9] have been used worldwide. These developed methods are derived to comply with leachate characteristics, usually combined together as one physicochemical process since the mechanisms involved during treatment deal with physical and chemical properties.

Meanwhile, the technology of coagulation-flocculation has been used widely in diverse disciplines of water treatment [10], including leachates. Besides, this method is also efficient to treat partially stable and stabilised leachate [11]. The properties of used coagulants are the crucial factor in determining the coagulation performance, as it can boost or hinder the treatment efficiency [12, 13]. Chemical coagulant such as polyaluminium chloride (PAC) and aluminium sulphate are among the most used agents in wastewater treatment. They are used in the coagulation-flocculation process to reduce the content of impurities and organic matters that are affecting to water quality index [14, 15]. However, despite the superiority of commonly used of these chemical coagulants, they are also linking to some undesirable views, e.g., neurological disease such as Alzheimer, that happens when the aluminium residuals of water treatment penetrate into the human body and get accumulated in the brain [16, 17].

In the previous studies, there were many kinds of research have been done regarding natural coagulants as the next potential coagulants [18]. The natural materials could be extracted from animals, plants or even agro-wastes such as chitosan, *Moringa Oleifera* seeds, and mango peels to be used as primary coagulants or as an aids [19, 20]. They are favoured in the water treatments due to their non-toxic properties and easily available at affordable costs [18]. Nevertheless, the reused of starch extracted from the agro-waste of tapioca peel is considered new, especially when it is utilised as a substitute substance for

developing a new composite coagulant. Tapioca peel has the potential to be the polymer ingredient in the new coagulants. Chemically, starch from tapioca peel has the properties of amylose and amylopectin in anhydroglucose polymers units that make it a good coagulant with high molecular weight [21].

Mostly, the previous scholars [22-25], who studied composite coagulants had combined two chemical coagulants or chemical coagulant with synthetic polymer on wastewaters, but slight attention has been given to the combination of agro-waste with chemical coagulant on stabilised leachate. As the best to our knowledge, the application of composite coagulant made of from PAC and TPP has never been applied as a stabilised leachate treatment in the coagulation-flocculation process. Therefore, the objective of this study is to evaluate the coagulation performance and identify the mechanisms that possibly exhibited by PACTPP. It is crucial to study the possible exhibited mechanisms because the developed coagulant is considered new and unique. In order to achieve this, a series of jar tests and the analyses of zeta potential and molecular weight were performed in this study.

2. Materials and Methods

2.1. Landfill leachate

The leachate sample used in this study was taken from a landfill located in Simpang Renggam of Kluang district, Johor, Malaysia. Based on the availability of leachate treatment, the site can be classified as a Class III landfill. The landfill was alleged to generate stabilised leachate from the previous study [26]. In order to confirm the leachate status, the characterisation tests were done during the preliminary study for a duration of 12 months, from January to December of 2018. The characteristics of raw leachate (chemical oxygen demand (COD), biochemical oxygen demand (BOD₅), BOD₅/COD ratio, ammonia nitrogen (AN), turbidity, colour, suspended solids (SS) were identified as shown in Table 1. Dilution of 10-100 times with distilled water was required to produce a near a colourless sample [27]. This is because the instrument used to measure these characteristics usually has its own limit range to quantify the concentrations of the parameters. During jar tests, a 500 mL volume of leachate was used in the study of coagulation tests [27].

Table 1. Characteristics of raw leachate.

Parameter	Concentration
pH	8.11 - 7.76
COD (mg/L)	996 - 2954
BOD ₅ (mg/L)	54.38 - 253.88
BOD ₅ / COD	0.02 - 0.211
AN (mg/L)	131.21 - 963.24
Colour (ADMI)	1902 - 7101
Turbidity (NTU)	63.5 - 160
SS (mg/L)	69 - 291

2.2. Coagulation test

Coagulation experiments were performed in a conventional jar-test apparatus of VELP-Scientifica, Model: J LT6, Italy. The working conditions of jar tests were applied consistently throughout all tests, which involved rapid mixing at 200 revolutions per minute (rpm) for 4 minutes and slow mixing at 30 rpm for 15 minutes

[28]. Meanwhile, the settling process was set for 30 minutes [28]. The supernatant was collected three centimetres (cm) from the surface by using a plastic syringe for analytical measurement of treated leachate sample. Determination of PACTPP's coagulation performance involved two factors; the coagulant dose and pH of the leachate sample. The selected range of doses in the leachate treatment was from 500 mg/L to 4000 mg/L. This dosage range was decided based on the preliminary study of PAC's dosage optimisation, using both macro (1000 mg/L, 2000 mg/L, 3000 mg/L, 4000 mg/L, 5000 mg/L, and 6000 mg/L) and micro (250 mg/L, 500 mg/L, and 750 mg/L) ranges of coagulant dose. Leachate sample's pH was altered by using 1N hydrochloric acid (HCl) and 1N sodium hydroxide (NaOH) of analytical grade to obtain the desired pH 3-10 range [29]. In order to determine the best working dosage, the raw leachate sample was altered into pH 7 first since neutral pH is desired in most wastewater treatments [29]. The optimum conditions of these factors were determined by the highest removal of COD, AN, turbidity, colour, and SS. The analysis was done immediately to avoid any changes in the treated supernatant.

2.3. Analysis methods.

The removal parameters were analysed according to the standard methods for water and wastewater (APHA) as in Table 2. HACH DR6000™ UV-VIS Spectrophotometer (USA) device was used to read all respective parameters. Distilled water was set as a blank reference. The samples were analysed at room temperature, and the results were based on the triplicate analysis. The coagulation performance of PACTPP was studied according to the removal efficiency of COD, AN, turbidity, colour, and SS based on Eq. (1). The results were then analysed using Excel, which is also known as the conventional optimisation method or one-factor-one-time (OFOT) method that involved the try and error practices [11]. Meanwhile, for the measurements of ζ potential and molecular weight of coagulants, the method of dynamic light scattering was used using the Malvern Zetasizer Nano ZSP (UK).

Table 2. List of used standard methods in this study according to standard methods for water and wastewater (APHA).

Parameter	Methods
pH	Portable Multi-parameter (HANNA HI9829)
COD	APHA 5220 C & HACH 8000
BOD ₅	APHA 5210 & HACH 8043
AN	HACH 8038
Colour	HACH 8025
Turbidity	APHA 2130
SS	APHA 2540 D & HACH 630

$$Removal (\%) = \frac{Initial\ concentration - Final\ concentration}{Initial\ concentration} \times 100 \quad (1)$$

3. Results and Discussion

3.1. Evaluation of coagulation performance of PACTPP

In the preliminary study, it was denoted that the optimum weight ratio of PACTPP was TPP/Al= (4000 mg/1078 mg) = 3.71. Al here denotes the Al content in the

respective grams of PAC in 55,000 mg/L of PACTPP. Therefore, the following discussion was concerning the treatability studies of PACTPP based on the conventional optimisation method of coagulant dose and leachate sample's pH based on the triplicate analysis. The initial concentration of COD, AN, turbidity, colour, and SS here was 2166 mg/L, 786.99 mg/L, 157 NTU, 2537 ADMI, and 198 mg/L respectively.

Based on the observations in Fig. 1, it was perceived that the removal percentages for all parameters increased as the dosage increased, except for AN parameter with fairly good and almost constant removal. AN is a result of fermentation and hydrolysis of nitrogen that contains the fractions of the biodegradable refuse substrates [30], which can be significantly removed using biological practices [31]. The removal of AN was lower than other parameters here due to the inapt treatment of using the coagulation-flocculation technique. However, the maximum removal of AN could be seen at the dosage of 2500 mg/L, with 36.5% removal. The removal of AN started to drop at 3000 mg/L and at higher dosages as well. Since the removal of COD, turbidity, colour, and SS keep increasing as the dosage increased, the reduction percentage of AN became the key parameter to select the ideal dosage amount. Hence, it was decided that the optimum dosage for PACTPP at pH 7 was 2500 mg/L (490.1 mg/L of Al), by eliminating 59.3%, 36.5%, 81.6%, 82.7%, and 87.4% for COD, AN, turbidity, colour, and SS respectively. Figure 1 shows the varied dosages of PACTPP at 500-4000 mg/L applied on pH 7 leachate sample, while Fig. 2 shows the optimum 2500 mg/L dose of PACTPP with applied on varied pH 3-10 leachate sample, respectively.

In order to further improve the coagulation-flocculation process using PACTPP, the pH optimisation was determined at a wider range of pH between pH 3 to pH 10. The initial concentrations of COD, AN, turbidity, colour, and SS here was 2509 mg/L, 680.67 mg/L, 163.2 NTU, 2534 ADMI, and 244 mg/L respectively. Beneficially, based on the evaluation of Fig. 2, 2500 mg/L performed efficiently at neutral pH 7 by showing the highest removal. Dadrasnia et al. [32] also reported that pH 7 was responsible for the highest removal of COD and AN from leachate samples taken from *Pulau Burung* landfill site, Malaysia.

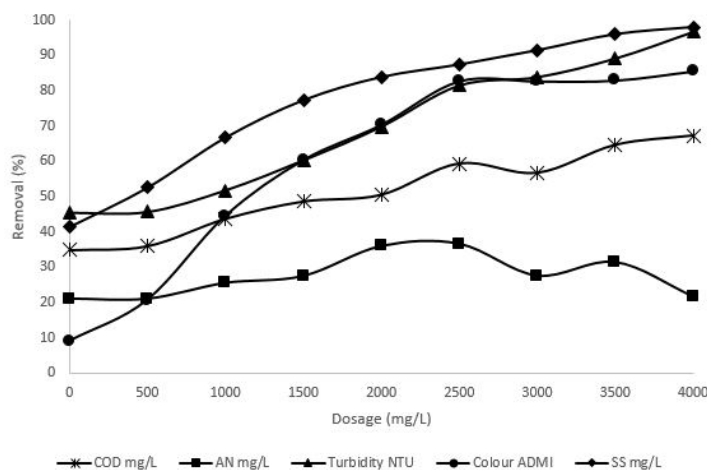


Fig. 1. Varied dosages of PACTPP at 500-4000 mg/L applied on pH 7 leachate sample.

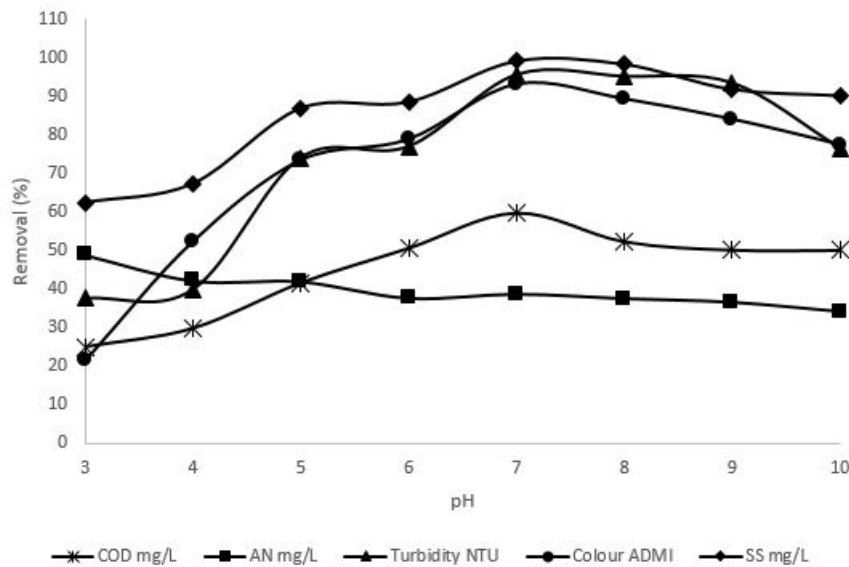


Fig. 2. Optimum 2500 mg/L dose of PACTPP with applied on varied pH 3-10 leachate sample.

The addition of NaOH and HCl during pH adjustment in leachate samples had created the chemical oxidation activity that initiated the precipitation process, and eventually improved the removal of all parameters [33]. However, the elimination of AN alone showed the best removal at pH 3 with 49%, which higher than the removal at pH 7 with 38.7%. Nevertheless, pH 3 was considered to be too acidic, rather than the advantageous neutral pH 7 [29].

This phenomenon might be due to the excess cations in the surrounding of pH 3, such as Na⁺, K⁺, Mg²⁺, and Ca²⁺ that responsible for the ion exchange actions [34]. Furthermore, silicate element was detected in the properties study of TPP [20], which in response, both of aluminium and silicone structures were jointly bounded by covalent bonds of mutual oxygen atoms [35]. In contrast, the existed cations were attached to the alum-silicate structure by electrostatic force, thus increased its ability to be substituted to remove ammonium ion [34]. Therefore, pH 7 was chosen as the optimum pH that worked the best for PACTPP, by reducing 59.8% of COD, 38.7% of AN, 95.5% of turbidity, 93% of colour, and 99.2% of SS.

The obtained removal by this new coagulant was compared with the previous studies that used composite coagulant as well that applied on leachate sample. However, the comparison was solely based on the removal percentages only, since the composite coagulants were made from different materials, such as the combinations of inorganic-inorganic, inorganic-organic, and inorganic-natural coagulants. Based on the literature, the treatability of leachate sample by using composite coagulants is considered a few, since most of the researchers preferred to use the low-strength wastewater or synthetic wastewater. According to Ghafari et al. [36], the precise implementation of operating variables such as coagulant dosage and pH value would affect the good applicability of the coagulation-flocculation process.

However, it is also subjected to the characteristics of coagulant used and the composition of pollutants in the respective wastewater treatments. The individual properties of the used coagulant play a vital role since it fundamentally determine the coagulation efficiency [11, 32]. Therefore, the removal percentages of selected parameters for the comparison studies would have an immense difference between each other.

Table 3 shows the comparison of the optimum conditions and the efficiency using various types of composite coagulants on the leachate sample. The application of PACTS, made from PAC and commercial tapioca starch (TS) with the optimum concentrations of 90 g/L and 20 g/L for PAC and TS respectively was investigated by Azizan [29] in the treatment of stabilised leachate from the same landfill.

The composition of the new PACTS was about the same as PACTPP, except the starch in the present study was extracted from the agro-waste of tapioca peel. The study indicated good removals with 46%, 28%, 83%, 86% and 98% of COD, AN, turbidity, colour, and SS, respectively. These results were obtained using 1500 mg/L of PACTS dose and at pH 5 of the leachate sample.

Here, the optimum pH condition at present study was at better pH 7, alongside better removals, but by applying higher dosage that had higher Al content. It was beneficial for PACTS that used lower Al content in the optimum dosage with 190.0 mg/L indeed. The result for COD in the present study was in agreement as to the analysis by Amokrane and Comel [37] who stated that the general removal percentage by using the coagulation-flocculation process happened at 50-65% from stabilised leachate. Similarly, a high COD elimination was obtained from studies of Li et al. [38] at 69% together with 79% of colour removal by using a new inorganic-organic coagulant PFM-PDMPDAAC (poly-ferric-magnesium-polydimethyldiallylammonium chloride). The preparation of PFM-PDMPDAAC also required an appropriate organic/inorganic weight ratio in order for it to be well-performed at the approximate neutral pH [39], similar to the present study.

Table 3. Comparison of the optimum conditions and the efficiency using composite coagulant on the leachate sample.

Optimum dosage (mg/L)	Optimum leachate pH	Removal parameter (%)				
		COD	AN	Tur	Co	SS
PACTPP 2500 mg/L [This study]	pH 7	59.8	38.7	95.5	93.0	99.2
PACTS 1500 mg/L [29]	pH 5	46.0	28.0	83.0	86.0	98.0
PFM-PDMPDAAC 1200 mg/L [39]	pH 7.5-8.1	69.0	-	-	79.0	-
PHITF 200 mg/L of Fe [11]	pH 5	60.0	11.0	-	96.0	98.0
PFZSSB 100 mg/L [38]	pH 6	51.09	13.68	59.09	-	-

COD = chemical oxygen demand; AN = ammonia nitrogen; Tur = turbidity; Co = colour; SS = Suspended solids

The next comparison was made with Shaylinda et al. [11]'s studies, which utilised the starch derived from tapioca as well in preparing a new PHITF (prehydrolyzed iron-tapioca flour) composite coagulant. It managed to abolish about 60% of COD, 11% of AN, 96% of colour, and 98% of SS. Except for AN parameter, the performance of PHITF could be analysed at par as PACTPP.

The combination of PHI with natural polymer would improve the aggregation process due to the longer molecular chain and weakly charged density of TF [11]. This was proven by the excellent removal of physical impurities gained. In another study, the reduction of COD, AN, and turbidity was 51.09%, 13.68%, and 59.09% respectively by using a new inorganic polymer flocculant; poly-silicate zinc ferric sulfate with boric acid radical, abbreviated as PFZSSB [38]. It was claimed to be appropriate for the organic pollutant's removal with micro-nanometre particles. In the study, just a low optimum dosage of 100 mg/L was required at acidic pH 6 condition of leachate sample to obtain fairly-good percentage removals.

The optimum dosage was decided after considering the cost and the actual effect that would happen if the overdose PFZSSB was applied [38]. Therefore, in contrast to the removal percentages from previous studies, the performance of this study using PACTPP could be considered satisfactory. This is due to the obtained removal percentages of respective parameters using PACTPP, which were observed to be in par/better than other former composite coagulants for the treatment of leachate samples.

3.2. Coagulation mechanism

In this study, in order to determine the coagulation mechanism of the new reagent, the molecular weight of PACTPP and individual coagulants (PAC and TPP) were measured. Besides, the ζ potentials of coagulants and treated leachate were analysed as well as displayed in Table 4.

Table 4 shows the pH, molecular weights, and ζ potentials of the coagulants, as well as the ζ potentials of their treated leachate. Zeta potential is a magnitude measure of nanoparticles' surface charges and also as a sign of its stability behaviour in suspensions or colloids [40]. It was denoted that the ζ potential of raw leachate was -18.73 millivolts (mV). This showed that landfill leachate was in a very stable state of negative colloidal particles. This also validated the ζ potential of leachate from Azizan [29]'s study with -17.83 mV at pH 8.3, respectively.

Beforehand, the removal percentages obtained by PACTPP were compared with single coagulants of PAC and TPP as in Table 5. Table 5 shows the highest removal percentages obtained by PACTPP, PAC, and TPP in their respective optimum dosage and pH. In the preliminary study, it was determined that the optimum pH of leachate before jar test for PACTPP, PAC, and TPP was pH 7, pH 6, and pH 3 respectively.

Previously, the conventional optimisation of 10% PAC shows that it worked best with the optimum conditions of pH 6 leachate and dose of 3750 mg/L with the initial concentrations of 2522 mg/L of COD, 1133.8 mg/L of AN, 137 NTU of turbidity, 2219 ADMI of colour, and 294 mg/L of SS. As the results, it managed to

remove about 54.1%, 28%, 91.1%, 98%, and 98% of COD, AN, turbidity, colour, and SS respectively.

Table 4. Characteristics of PACTPP, PAC, and TPP.

Coagulant	pH	Molecular weight (g/mol)	ζ -Potential of coagulant (mV)	ζ -Potential of treated leachate (mV)
PACTPP 2500 mg/L [This study]	3.45	1.59×10^7	+3.45	-16.17
10% PAC 3750 mg/L	3.36	8.55×10^4	+20.50	-7.56
1% TPP 1000 mg/L	6.33	5.67×10^6	-0.68	-14.93

Table 5. The highest removal percentages obtained by PACTPP, PAC, and TPP in their respective optimum dosage and pH.

Optimum dosage (mg/L)	Optimum leachate pH	Removal parameter (%)				
		COD	AN	Tur	Co	SS
PACTPP 2500 mg/L [This study]	pH 7	59.8	38.7	95.5	93.0	99.2
10% PAC 3750 mg/L	pH 6	54.1	28.0	91.1	98.0	98.0
1% TPP 1000 mg/L	pH 3	40.3	18.2	85.7	80.2	85.5

COD = chemical oxygen demand; AN = ammonia nitrogen; Tur = turbidity; Co = colour; SS = Suspended solids

Meanwhile, for the leachate treatment done by 1% TPP, it managed to eliminate about 40.3% of COD, 18.2% of AN, 85.7% of turbidity, 80.2% of colour, and 85.5% of SS alongside the optimum dose and leachate pH at 1000 mg/L and pH 3. The initial concentrations of COD, AN, turbidity, colour, and SS of used leachate sample here was 1481 mg/L, 785.51 mg/L, 109 NTU, 3843 ADMI, and 145 mg/L respectively. Here, it was experimental that PACTPP had the highest removal percentages of respective parameters compared to PAC and TPP.

The mechanisms behind these highest removals perhaps could be discovered and guesstimated through the ζ potentials of the coagulants and their treated leachate as in Table 4. Based on the observations in Table 4, the molecular weights of coagulants were in the sequence of PACTPP>TPP>PAC with PACTPP as the highest at 1.59×10^7 g/mol and the lightest was PAC at 8.55×10^4 g/mol respectively. Meanwhile, for ζ potential of each coagulant, 1% TPP was the only coagulant with a negative charge at -0.68 mV, 10% PAC had the highest positive charge content with +20.5 mV, and the combination of 7% PAC and 4% TPP in PACTPP generated a positive ζ potential in its nature with +3.45 mV, correspondingly. The addition of these coagulants also caused alteration in the ζ potentials of treated leachate samples [11, 30].

The occurred superiority of charge neutralisation here could be denoted in the sequence of PAC>TPP>PACTPP. PAC coagulant managed to reduce the charges

the most from -18.73 mV of raw leachate to -7.56 mV, followed by TPP (-14.93 mV), and PACTPP (-16.17 mV), respectively. It was aware that the charge neutralisation occurred in TPP was superior compared to PACTPP, despite its natural properties of having a ζ potential of coagulant. This was due to the optimum leachate pH, which happened to be at pH 3. The negatively charged colloidal in leachate had been partially neutralized by the addition of the analytical grade of hydrochloric acid itself. Here, it was concluded that the negative charges of colloidal leachate were not utterly neutralized since the ζ potential of treated leachate was not close to zero mV when the highest removal rate was achieved [39].

Therefore, charge neutralisation did not play a major role in the removal mechanisms of PACTPP, but more to adsorption bridging and sweep flocculation. These also were supported by the highest molecular weight that belongs to PACTPP. Simultaneously, adsorption bridging played its part due to the contact of high-molecular-weight of coagulant and natural polysaccharide structure with impurities in the leachate sample [39, 41].

Besides, PACTPP facilitated the destabilization of the colloid impurities through the formation of large and better settle-able flocs. The findings corresponded to the review of past studies that most fundamental and likely operational mechanisms of polyelectrolytes in this physico-chemical technique take place via adsorption and charge neutralisation during coagulation, and destabilization of particulate matters by bridging mechanism, which leads to enmeshment of colloids in precipitated solids through flocculation [42, 43]. The sweep flocculation mechanism occurred when the aluminium hydroxide ($\text{Al}(\text{OH})_3$) presented in excess after the hydrolysis activity once PACTPP was added into the leachate samples [44].

The excess $\text{Al}(\text{OH})_3$ would together swipe away the impurities and chemical contaminants on the way downward, thus producing large flocs [45] as illustrated in Fig. 3. Figure 3 elucidates the schematic diagram of charge neutralisation, adsorption bridging, and sweep flocculation mechanisms. This assumption was also in agreement with the previous study that claimed the mechanism involved was partially adsorption bridging and charge neutralisation, due to the opposite charges of both substances as well as the coagulant's molecular weight factors [29].

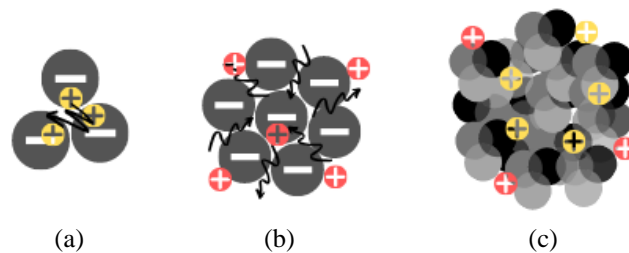


Fig. 3. Illustrations of (a) Charge neutralisation, (b) Adsorption bridging and (c) Sweep flocculation mechanisms.

4. Conclusion

The different weight ratio of dissimilar materials of PAC and TPP gives an essential effect in the development of a new coagulant (PACTPP) so that it can work efficiently

to perform a good coagulation performance. In this study, the optimum TPP/Al weight ratio = 3.71 of PACTPP managed to obtain higher removal percentages of COD, AN, turbidity, colour, and SS compared to the individual coagulants of PAC and TPP. PACTPP also went well with better optimum neutral pH 7 of leachate sample and lower dosage at 2500 mg/L as the optimal conditions. The performance of PACTPP was considered satisfactory when compared with the composite coagulants from other published studies. The measurement of ζ potentials and molecular weights proved that PACTPP underwent the adsorption-bridging mechanisms that more superior compared to charge neutralisation instead. In future works, both measurements of settling rate and volume index of produced sludge can be recommended for stronger evidence to validate coagulation mechanisms.

Acknowledgements

The authors are very pleased and grateful to Universiti Tun Hussien Onn (UTM), Malaysia and the Ministry of Higher Education, Malaysia for the *Geran Penyelidikan Pascasiswazah* (GPPS) VOT H014 and Fundamental Research Grant Scheme (FRGS) VOT 1570, respectively. This research article is funded by Research Fund E15501, Research Management Centre (RMC), UTM.

Greek Symbols	
ζ	Zeta potential
Abbreviations	
ADMI	American Dye Manufacturer's Institute
AN	Ammonia Nitrogen
APHA	American Public Health Association
BOD ₅	Biochemical oxygen demand
COD	Chemical oxygen demand
NTU	Nephelometric Turbidity Unit
OFOT	one-factor-one-time
PAC	Polyaluminium chloride
PACTPP	Polyaluminium chloride-tapioca peel powder
PACTSb	Polyaluminium chloride-tapioca starch
PFM-	Poly-ferric-magnesium-polydimethyldiallylammonium
PDMPDAAC	chloride
PFZSSB	Poly-silicate zinc ferric sulfate with boric acid radical
PHITF	Prehydrolyzed iron-tapioca flour
SS	Suspended solids
TPP	Tapioca peel powder
UV-VIS	Ultraviolet-visible

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