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A Novel Natural Active Coagulant Agent Extracted from the Sugarcane Bagasse for Wastewater Treatment

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A Novel Natural Active Coagulant Agent Extracted from the Sugarcane Bagasse for Wastewater Treatment

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Abstract: The performance of extracted coagulant from the sugarcane bagasse was tested using synthetic wastewater for turbidity removal. Sugarcane bagasse was selected because it is available in abundance as a waste. This study was carried out to analyze the effect of the extraction process in optimizing the active coagulant agent of bagasse as a natural coagulant for optimum turbidity removal. Bagasse was characterized in terms of physical, chemical and morphological properties. The results showed bagasse has very high polysaccharide content which can act as an active coagulant agent together with hemicellulose and lignin. The extraction process for degradation of lignin and hemicellulose was run based on two different solvents (NaOH and H_2SO_4) with varying concentrations from 2% to 10% at different extraction temperatures varied from 60 °C to 180 °C for various extraction times (0.5 h to 3 h). The optimum polysaccharide content extracted from bagasse was 697.5 mg/mL by using 2% NaOH at 120 °C for 2 h extraction. The coagulation process using extracted bagasse showed the removal of suspended solids up to 95.9% under optimum conditions. The concentration of polysaccharides as the active coagulant agent plays a vital role where high polysaccharides content removes most turbidity at a lower dosage. Bagasse has the potential to be an alternative coagulating agent due to its efficiency, and eco-friendly properties for the treatment of wastewater.

Keywords: bagasse; active coagulant agent; polysaccharides

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1. Introduction

Water pollution is mainly caused by many sources such as industrialization activities, agricultural activities, and the release of improperly treated sewage into a water body [1]. It has now become more crucial to ensure the incoming pollutants into the water body do not adversely affect the carrying capacity of the water itself [2]. Various treatment methods such as coagulation-flocculation have been applied, and like any other conventional treatment, it shows promising pollutants removal performance. The coagulation process can be classified as a simple and effective treatment method with the use of divalent positively charged chemical coagulants [3]. The commonly used coagulants include metal salts coagulants such as aluminium sulphate or alum (Al_2SO_4), iron (III) chloride ($FeCl_3$), polyaluminium chloride (PACl) and iron (II) sulphate ($Fe_2(SO_4)_3$).

Despite their well-known performances, there are several disadvantages of using these chemical coagulants. It has been evidenced that the use of metal salts coagulant produces a large volume of toxic sludge, which can sometimes sufficiently be classified as scheduled waste. According to Zaidi et al. [4], it was estimated that the coagulation using chemical coagulant for big treatment plants produces around 60,000 tonnes of toxic sludge per year that requires high sludge treatment cost and proper treatment to ensure it did not cause further pollution. Besides, the use of the chemical coagulant without properly optimised dosing can chemically affect the treated water, where the residual chemical is remained in the treated water [4]. This residual chemical such as chlorine can then affect the health of water consumers.

Henceforth, identifying other alternatives to replace the conventional chemical coagulant is vital. Alternatives for more environmentally friendly coagulants are natural coagulants that are composed of polymers from natural sources that were extracted from plants, animals, and algae [5]. The application of natural sources for water and wastewater treatment was also practised in other treatment technologies, such as biofiltration treatment [6]. Natural coagulant such as *Moringa oleifera*, *Jatropha curcas*, and *Opuntia ficus indica* has been long tested for the removal of various pollutants. For example, *Moringa oleifera* shows good removal of total suspended solids and colour exceeding 90% removal [7]. A natural coagulant is also having good antimicrobial properties in removing bacteria, coliform, and fungi with percentage removal exceeding 95% compared to metal salts coagulants with percentage removal less than 40% [8]. The common limitation of the natural coagulant arises due to the production in ensuring a continuous supply as the source of the coagulant can be affected based on the seasonal variation and the lifespan of the natural sources [9].

The good performance of natural coagulants in removing pollutants relies on their physical, chemical, and morphological properties. Different natural coagulant has different properties. For instance, *Moringa oleifera* seeds rely on their superior protein content while *Jatropha curcas* relies on its high carbohydrate or polysaccharide content which acts as an active coagulant agent [10]. Currently, researchers are still unable to conclude the main properties of these sources to be used as natural coagulants as different sources have different properties that make them suitable to be used as natural coagulants [11]. The extraction process using solvents such as acid, alkali, and alcohol can extract more active coagulant agents to improve the natural coagulant. Due to the different active agents comprised in the coagulant, they basically react differently towards the extraction process. Natural coagulants based on seeds need the oil content to be removed first using alcohol to extract more protein [12], while the coagulants based on stems where the active coagulant agent is polysaccharide are preferred to be extracted using acid or alkali for deformation of hemicellulose and lignin [13]. However, natural coagulants, by using local waste such as sugarcane bagasse (*Saccharum officinarum*), have been the least studied. Bagasse is the major by-product and represents approximately 34% of its total weight. Typically, in sugar processing industries, around 34 tonnes of bagasse are produced from 100 tonnes of sugarcane [14]. Since bagasse has an almost similar feature as *Opuntia ficus indica*, it is expected that the use of bagasse as natural coagulants can have promising outcomes.

Although previous studies by Tahir et al. [15] and Rudresh Gowda et al. [16] have investigated coagulation performance by bagasse, emphasis on the effect of the extraction process towards active coagulant agent to optimize pollutants removal is still lacking. In discovering this new possible source, optimization is essential to maximize the active coagulant agent thus, increase the ability of natural coagulants to remove pollutants for wastewater treatment. Hence, this present study was conducted to analyse the effect of the extraction process in optimizing the active coagulant agent content of bagasse (*Saccharum officinarum*) as the natural coagulant for optimum turbidity removal.

2. Materials and Methods

2.1. Material and Reagent

Bagasse was used as a natural coagulant and it was collected from a vendor around Taman Universiti, Skudai, Johor Bahru, Malaysia. In addition, chemical reagents used for different analyses are summarized in Table 1.

Table 1. Chemical reagents used for analysis.

Chemical Reagent	Specification	Analysis
Bovine Serum Albumin (BSA)	Vivantis	Protein
Potassium sodium tartrate	AR QREC	
Sodium carbonate	AR QREC	
Sodium hydroxide	MERCK	
Copper (II) sulphate pentahydrate	AR QREC	
Folin reagent	Sigma Aldrich	
Glucose solution	Sigma Aldrich	Polysaccharide
Phenols	AR QREC	
Sulphuric acid	AR QREC	
High-range COD digestion reagent	HACH	COD
Kaolin	AR QREC	Synthetic wastewater
Sucrose	MERCK	
Ammonium chloride	AR QREC	
Potassium dihydrogen phosphate	AR QREC	

2.2. Preparation and Extraction of *Saccharum officinarum*

Bagasse (*Saccharum officinarum*) was collected from the vendor in Taman Universiti, Skudai, Johor Bahru, Malaysia. After collection, bagasse was washed with tap water and rinsed with distilled water to remove any dust or impurities on the surface. Then, the bagasse was oven-dried at 90 °C for 24 h. The dried bagasse was ground and sieved through a 500 µm sieve. For initial characterization, identification of protein and polysaccharide content was carried out. To identify the protein and polysaccharide content, the bagasse was prepared in a liquid slurry. For protein analysis, 2.5 g of ground powder bagasse was mixed with 200 mL distilled water, making it a concentration of 12.5 mg/mL. Meanwhile, for polysaccharide content, 5 g of bagasse powder was mixed with 200 mL of distilled water. Appropriate protein and polysaccharide standards were also prepared.

Collected bagasse was extracted to obtain a more active coagulant agent. The extraction process of bagasse is also known as the delignification process. Generally, the delignification process was carried out by mixing the solvent with bagasse at a certain temperature and mixed for a certain duration. Bagasse was extracted by using different solvents either sulphuric acid (H_2SO_4) or sodium hydroxide (NaOH). Table 2 shows the various concentrations, temperatures and mixing durations used in this study.

Table 2. Operating conditions of the extraction process using H_2SO_4 and NaOH solvents.

Operating Conditions	Unit	Variation Value
Concentration	%	2, 4, 6, 8, 10
Temperature	°C	60, 90, 120, 150, 180
Duration	h	0.5, 1.0, 1.5, 2.0, 3.0

Five grams of bagasse powder was mixed with 150 mL of solvent with different concentrations in a 500 mL beaker. The contents were heated according to the desired temperature. (Table 2). The heated mixture was prepared according to the mixing duration shown in Table 2. After various sample preparations are prepared, as shown in Table 2, the bagasse slurry mix was allowed to cool to room temperature (22 °C). Extracted natural coagulant was stored in the cold room (4 °C) until use.

2.3. Physical Properties Characterization

Yield and moisture content was determined by the recorded weight of oven-dried waste and powder. Equations (1) and (2) were used to determine yield and moisture content, respectively.

$$\text{Yield (\%)} = (\text{Weight powder}/\text{Weight raw}) \times 100\% \quad (1)$$

$$\text{Moisture content (\%)} = ((\text{Weight before dry} - \text{Weight after dry})/\text{Weight before dry}) \times 100\% \quad (2)$$

2.4. Chemical Analysis

Protein content in the bagasse was analysed using Lowry's method with modification according to Maehre et al. [17]. Polysaccharide content was determined based on the Dubois method [18]. The oil content of bagasse was determined using SPE-DEX 3100 oil and grease extractor (Biotage® Horizon 3100, Uppsala, Sweden). The sample was diluted to 1 L and pH was maintained below pH 2 for preservation purposes. The metal content was determined using Flame Atomic Absorption Spectrometer (FAAS) (Perkin Elmer PinAAcle 900T, MA, USA) while the functional group was analysed using Fourier-transform Infrared Spectroscopy (FT-IR) (Shimadzu FT-IR 8400, Kyoto, Japan, KBr pellet method).

2.5. Morphological Characterization

Characterization of morphological properties was conducted using the Scanning Electron Microscopy (SEM) technique (Hitachi TM3000, Tokyo, Japan, Quorum Sputter Coater) to determine the surface structure of the bagasse (*Saccharum officinarum*).

2.6. Preparation of Synthetic Wastewater

The synthetic wastewater was prepared based on the properties of wastewater from the food processing industry. For the preparation of the stock solution, 3 g of kaolin was added to 800 mL of distilled water. The solution was mixed at 90 rpm for 2 h and left for 24 h to allow for complete hydration. Then, 3 g of sucrose, 1 g of ammonium chloride (NH_4Cl), and 0.5 g of potassium dihydrogen phosphate (K_2HPO_4) were added to the mixture. The solution was then mixed again for 1 h, and then ready to be used.

2.7. Turbidity Estimation of the Treated Wastewater

Coagulation-flocculation experiment was carried out using jar test apparatus equipped with six jars. In the first stage, different coagulant dosage was used (50, 100, 200, 300, 400 and 500 mg/L) with a fixed pH of 6 and initial turbidity of 200 NTU. 150 mL diluted synthetic food processing wastewater was then added with various coagulant dosages. The solution was mixed for 1 min at 200 rpm, followed by 80 rpm of slow mixing for 30 min. After mixing, the solution was left for 1 h to allow sedimentation. The effectiveness of the coagulation process was determined via turbidity removal which was measured by using a portable turbidity meter (HACH 2100Q). Turbidity removal was calculated using Equation (3) and optimum coagulant dosage was determined. The experiments were repeated for pH variation (pH 2, 4, 6, 8, 10 and 12) at optimum coagulant dosage. pH was controlled by the addition of diluted H_2SO_4 to reduce the pH and NaOH to increase the pH.

$$\text{Turbidity removal (\%)} = ((\text{Initial turbidity} - \text{Final turbidity})/\text{Initial turbidity}) \times 100\% \quad (3)$$

2.8. Statistical Analysis

Optimization of turbidity removal by using bagasse as a natural coagulant was carried out by using the One Factor at Time (OFAT) method. The optimized operating conditions were coagulant dosage and pH. For the first stage, pH was fixed at pH 6 with ranges of coagulant dosage (50, 100, 200, 300, 400 and 500 mg/L). From the first stage, optimum

coagulant dosage will be obtained. For the second stage, the coagulant dosage was fixed at the optimum coagulant dosage obtained from the first stage with ranges of pH (pH 2, 4, 6, 8, 10, 12). From the second stage, the optimum pH of bagasse for optimum turbidity removal was obtained.

3. Results and Discussion

3.1. Physicochemical Characteristics of Bagasse

Table 3 shows the physicochemical properties of crude bagasse (*Saccharum officinarum*). Based on the table, the recorded moisture content in bagasse was 32.7%, slightly lower than in the previous studies. According to Kaewpradap et al. [19], the common recorded moisture content of bagasse was between 45% to 70%. Lower moisture content is preferable as lesser raw bagasse is required for powder production, can last longer, and produce higher powder yield. Agro-wastes with high moisture content, such as banana stems, need to be used in greater quantity compared to the wastes of sufficiently low moisture content. Moreover, agro-wastes with high moisture content tend to possess a shorter lifespan as they will decompose or even rot faster than oven-dried sources [20]. Not limited to that, raw agro-wastes with high moisture content will be difficult to grind as water act as a plasticizer that bridge the particles, hence increasing the cohesiveness of the powder [21,22].

Table 3. Physicochemical composition of *Saccharum officinarum*.

Composition	Unit	*Saccharum officinarum* (Bagasse)
Moisture content	%	32.7 ± 3.8
Yield	%	18.5 ± 5.6
Protein content	mg/mL	0.9 ± 0.2
Polysaccharide content	mg/mL	74.5 ± 2.4
Oil content	mg/L	14.4 ± 1.1
Ferric content	ppm	0.1 ± 0.003
Aluminium content	ppm	0.3 ± 0.02

Many studies have been carried out on different types of natural coagulants. Based on the studies, researchers agreed that active coagulant agents are mainly contributed by either protein or polysaccharide contents [23]. Based on Table 3, bagasse records higher polysaccharide content compared to protein content. This finding is in agreement with a study by Leang & Saw [24] who reported that protein content in bagasse is lower compared to polysaccharide content with a difference of up to 60%. Differences between current findings and previous findings may rise due to the raw agro-wastes themselves. Previous studies identify the protein and polysaccharide content from fresh sources while this study focuses on recycling agro-waste that will be later processed into natural coagulant. Comparing protein with polysaccharide content, protein is unsuitable to be considered as an active coagulant agent due to its very low concentration. If protein is considered as the active coagulant agent, a lot of raw agro-wastes are required to be processed into natural coagulants for commercial applications. In addition, based on previous studies, natural coagulant from sources from stem relies on high polysaccharide content while natural coagulant from seeds relies on high protein content [23].

All agro-products contain a certain amount of oil concentration in the form of crude fat content. According to Shan et al. [12], high oil content in agro products can reduce the extractability of active coagulant agents in the natural coagulant and require extraction using alcohol to remove. Based on Table 2, the oil content in bagasse was 14.4 mg/L. By comparing oil concentration with polysaccharide content, bagasse has a very low oil content. Similar to a study by Karim et al. [25], the concentration of oil in the stem is only 2% while the concentration of polysaccharides in stems can exceed 70%. Therefore, the extraction process using alcohol is unnecessary as the recorded oil content in bagasse is extremely low and alcohol extraction would not improve the active coagulant agent concentration.

Aluminium sulfate (Al_2SO_4) and ferric chloride ($FeCl_3$) are commonly used chemical coagulants that are rich in positively charged ions (Al^{3+} and Fe^{3+}) for water and wastewater treatment. Hence, this study analyzes metal content in bagasse to identify if metal contents could be a possible active coagulant agent. However, based on Table 2, aluminium and ferric contents were too low (less than 1 ppm) thus, conclude that the ability of bagasse as the natural coagulant does not depend on the metal content.

Based on the physicochemical characteristics, the polysaccharide is the active coagulant agent in bagasse. Agro-products from stems such as bagasse are rich with cellulose, hemicellulose and lignin. Lignocellulosic components contain excessive content of cellulose but are restrained by hemicellulose and lignin [13]. The extraction process using water and alcohol cannot degrade hemicellulose and move lignin to extract the abundant cellulose presence. Therefore, the extraction process using chemicals such as H_2SO_4 and NaOH can degrade the hemicellulose and move lignin to release the trapped cellulose [26].

3.2. Extraction Process of Saccharum officinarum

Figure 1 shows the extracted polysaccharide content from bagasse under different solvents (H_2SO_4 and NaOH) concentrations with fixed temperatures and mixing duration of 120 °C and 1 h, respectively. Based on Figure 1, bagasse shows good extraction of polysaccharides after being extracted with NaOH instead of H_2SO_4. The optimum extracted polysaccharide was 322.0 mg/mL with 8% NaOH as the extraction agent. Unlike NaOH, H_2SO_4 did not manage to extract as much polysaccharide content where the highest polysaccharide content that managed to be extracted was only 160.7 mg/mL using 10% of H_2SO_4. Such high extracted content is due to the lignin and hemicellulose content in bagasse. Cell walls are made up of middle lamella, primary wall, and secondary wall. Different sources have different thicknesses in each region containing various quantities of lignin and hemicellulose [27]. Extraction using acid mostly degrades hemicellulose while extraction using alkali affects both lignin and hemicellulose [28]. By comparing polysaccharide extraction of bagasse with other sources such as wheat straw [29] and barley straw [30], these sources require lower NaOH concentration while banana stem [31] is sufficient to be extracted using H_2SO_4. For optimum polysaccharide extraction, the optimum NaOH concentration required by wheat straw and barley straw is 1.5% and 2%, respectively while banana stem requires 2% of H_2SO_4. The lignin content of wheat and barley straws were about 15% [32] while the lignin content of bagasse is around 25%. High lignin content requires bagasse to be extracted using a slightly high NaOH concentration [33]. Therefore, in the extraction process of bagasse, we extract more polysaccharides while deforming the lignin. NaOH at 8% concentration was the most optimum concentration.

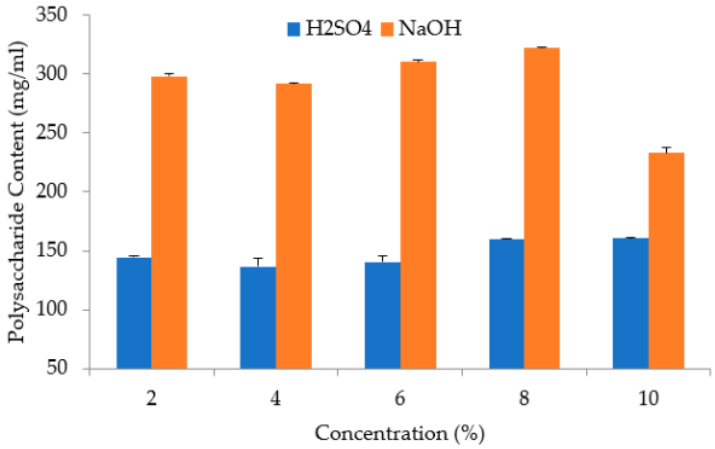


Figure 1. Polysaccharide extraction using H_2SO_4 and NaOH at different concentrations.

Figure 2 shows the extracted polysaccharide content from bagasse under different temperatures with fixed solvent concentration and mixing duration of 8% NaOH and 1 h, respectively. Based on Figure 2, the highest polysaccharide content that has been extracted from bagasse was 322.0 mg/mL upon extraction at 120 °C. At high temperatures, hemicellulose is degraded followed by cellulose and lignin [34]. This optimum temperature is well agreed upon by few researchers; Liu et al. [31] and Pedersen et al. [35] who used similar temperatures to extract active coagulant agents from corn straw and wheat straw. Extremely high temperature is required to degrade lignin, but the deformation of lignin alone is sufficient to extract more polysaccharides. At temperatures lower than the optimum temperature, hemicellulose will not be degraded, and lignin not deformed thus, the yield of extracted polysaccharides will be low.

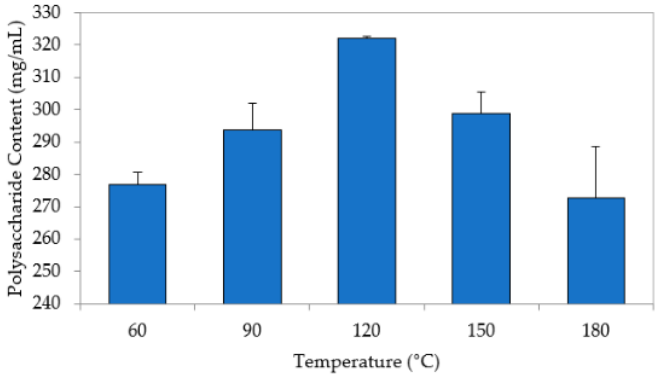


Figure 2. Polysaccharide extraction at different temperatures.

At an optimum temperature of 120 °C, hemicellulose was degraded, lignin was deformed indicating the lignin was moved, and the lignin-carbohydrate bond was broken resulting in more polysaccharide [36]. However, at temperatures beyond the optimum temperature, not only hemicellulose was degraded but the cellulose content was also degraded hence, resulted in the reduction of the extracted polysaccharide content [37]. In addition, extremely high temperature is also reducing the molecular weight of the natural coagulant thus, it is not preferable [36]. Natural coagulant with high molecular weight is preferable as it will have a longer polymeric chain that can enhance the coagulation process especially natural coagulant with interparticle bridging as its main mechanism.

Figure 3 shows the extracted polysaccharide content from bagasse under different mixing times with fixed solvent concentrations and temperatures of 8% NaOH and 120 °C, respectively. Based on the figure, the highest polysaccharide content was recorded upon bagasse extraction in a 2 h mixing period. Theoretically, a longer mixing duration will extract more polysaccharides. However, from the observation, a further increase in mixing duration resulted in an insignificant increase in the extracted polysaccharides content. In this study, the extracted polysaccharides content from bagasse at 2 h of mixing duration was 697.5 mg/mL while at 3 h of mixing duration was 709.2 mg/mL. Previous studies on various sources such as bagasse [38], wheat straw [36] and oil palm fronds [39] also showed similar findings that extending the mixing duration did increase the polysaccharide content, but the increment is not high enough compared to the required energy. A longer mixing duration indicates more energy requirement which increased the extraction cost. The optimum mixing duration for bagasse was 2 h.

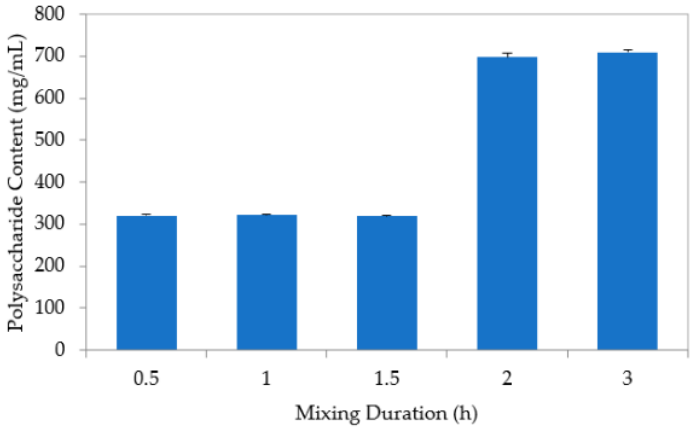


Figure 3. Polysaccharide extraction on different mixing duration.

3.3. Molecular Characterization of Stem from Saccharum officinarum

Bagasse is rich with a lignocellulosic component. FT-IR analysis was carried out to show the presence of cellulose, hemicellulose, and lignin. Besides, FT-IR analysis was also carried out to identify the effectiveness of the extraction process using NaOH to degrade the hemicellulose and deform lignin. Figure 4 shows the FT-IR analysis while Table 4 explains various peaks of FT-IR analysis. Based on Figure 4a and Table 3, raw bagasse has O-H stretching at peak 3338.1 cm^{-1} and C-H stretching at peak 1371.8 cm^{-1} indicating intramolecular hydrogen bonds for cellulose and ionic carboxylic groups that are usually present in cellulose. Cellulose is a polysaccharide composed of a linear chain of β-1,4 linked d-glucose units [40]. Besides, there are four (4) peaks that show the presence of lignin and hemicellulose. Peak 1728.7 cm^{-1} shows C-O stretching indicating the presence of acetyl and ester linkage in lignin and hemicellulose. Meanwhile, peaks 1243.4, 1160.3 and 1034.8 cm^{-1} also show C-O stretching but indicate stretching of hemicellulose and lignin [41,42]. Based on these peaks, it shows that raw bagasse consists of cellulose, hemicellulose and lignin that form lignocellulosic components. Therefore, the extraction process by using NaOH was carried out to degrade hemicellulose and deform lignin.

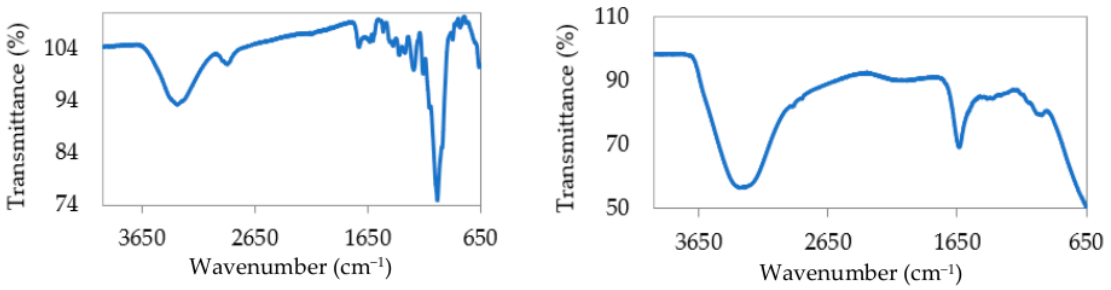


Figure 4. FT-IR graph for: (**a**) Raw bagasse and (**b**) extracted bagasse.

Table 4. Bagasse functional groups based on FT-IR analysis.

Wavenumber Range (cm^{-1})	Peak Wavenumber (cm^{-1})	Group	Indicator
		Raw Bagasse	
3500–3200	3338.1	O-H stretching	Intramolecular hydrogen bonds for cellulose
~1730	1728.7	C-O stretching	Acetyl and ester linkage in lignin and hemicellulose
~1369	1371.8	C-H stretching	Ionic carboxylic groups that usually present in cellulose.
	1243.4		
1300–950	1160.3	C-O stretching	Stretching of hemicellulose and lignin
	1034.8		
		Extracted Bagasse	
3500–3200	3339.0	O-H stretching	Intramolecular hydrogen bonds for cellulose
1649–1620	1638.0	C=C stretching	Aromatic ring present in lignin

Figure 4b shows the FT-IR analysis after bagasse was extracted by using 8% NaOH at 120 °C for 2 h. Based on Figure 4b and Table 3, extracted bagasse contains two (2) peaks. The first peak at 3339.0 cm^{-1} shows O-H stretching. This peak indicates the presence of intramolecular hydrogen bonds for cellulose. The second peak at 1638.0 cm^{-1} shows C=C stretching indicating an aromatic ring present in lignin [41,42]. As stated previously, extraction using alkali affects both lignin and hemicellulose. However, only hemicellulose will be degraded while lignin will be deformed thus, shows lignin content in the analysis. Raw bagasse shows more peaks as proof of the presence of more hemicellulose and lignin. However, after the extraction process, only the peak at 1649–1620 was identified as a source of lignin. Therefore, extraction by NaOH manages to degrade hemicellulose and deform lignin thus, results in high extracted polysaccharides.

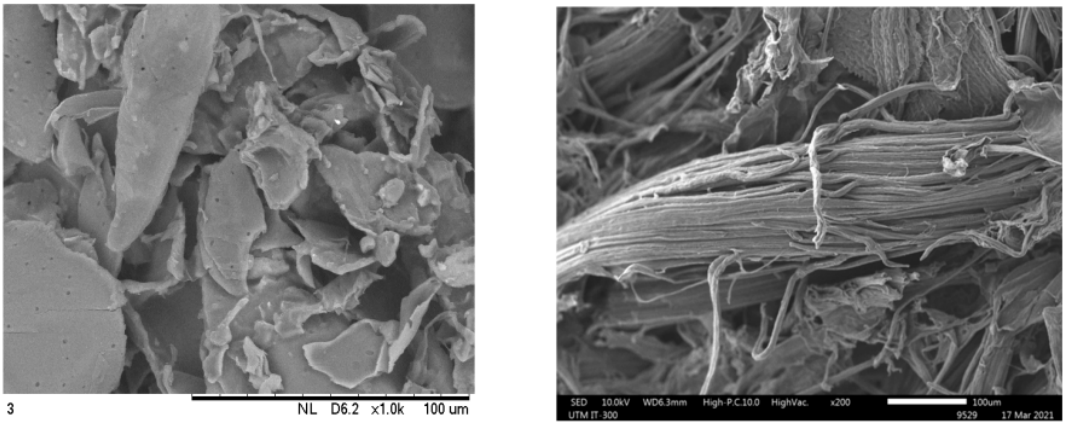
3.4. Surface Morphology of Saccharum officinarum

SEM analysis was carried out to investigate changes in surface morphology of bagasse before and after extraction under optimum NaOH extractant concentration, temperature, and mixing duration. Figure 5a shows the SEM image of raw bagasse while Figure 5b shows the image of extracted bagasse. Based on Figure 5a, raw bagasse has a smooth surface with no pores. The rough surface of agro-waste is due to the presence of porous properties on its surface. According to Shak & Wu [43], the presence of pores on the surface of coagulants reveals good coagulation-flocculation properties. The small pores can adsorb small-sized pollutants into pores and cover the surface [44]. After the coagulation process, the surface of the coagulant becomes smoother as the small pollutants filled the pores [45]. Besides, agro-wastes with rougher and porous surfaces have a larger surface area [46]. Coagulants with a larger surface area are preferable because they can increase the capability of bridging mechanisms as it has a higher density of adsorption sites [47].

Commonly studied natural coagulants such as *Moringa oleifera* [48] and *Opuntia ficus indica* [49] have rough and porous surfaces, unlike bagasse. Despite not having a rough and porous surface area, bagasse has a large surface area that can enhance the interparticle bridging mechanism. In addition, according to Shahimi et al. [22], bagasse can still become a good natural coagulant by removing significantly high turbidity content.

Figure 5b shows the SEM image of extracted bagasse. Before extraction, a smooth surface can be observed indicating an undisturbed cell wall surface. After extraction, the original smooth cell wall surface has become irregular from the apparent deposition of relocalized cell wall matrix material [50]. Upon the extraction process, an increase in fragmentation can be observed indicating the fibre cells are loosened and segregated from the larger particles. An increase in fragmentation is also attributed to depolymerisation and removal of lignin from the shared compound middle lamella which facilitates the fragmentation of individual cells from larger tissue culture [51]. The extraction process weakens the mechanical properties of the cell wall which deform the structure of the particles and as shown in Figure 5, major cracking on the surface of the bagasse. As a result

of the degradation of hemicellulose and deformation of lignin from the extraction process, an optimum polysaccharide was extracted that can be later used as a natural coagulant.



(**a**) (**b**)

Figure 5. SEM images of (**a**) raw bagasse; (**b**) extracted bagasse at 100 µm magnification.

3.5. Coagulation Process of Bagasse as Natural Coagulant

A jar test was carried out to identify the suitability of extracted bagasse for turbidity removal. Figures 6 and 7 shows jar test with different coagulant dosage and pH, respectively. Based on Figure 6, the highest turbidity removal was recorded at 58.5% by using a 50 mg/L coagulant dosage. However, all recorded turbidity removal with pH 7 at initial turbidity of 200 NTU is less than 60%. A study by Tahir et al. [15] and Rudresh Gowda et al. [16] also shows bagasse requires a lower coagulant dosage compared to other sources to obtain optimum turbidity removal. Alwi et al. [20] used banana stem as a source of natural coagulant for turbidity removal in coolant wastewater. Based on the study, the banana stem requires a high coagulant dosage for optimum turbidity removal. The difference in optimum coagulant dosage required is probably related to the active coagulant agent content in bagasse and banana stem. Polysaccharide content in bagasse is more than 40% while polysaccharide content in the banana stem is less than 30% [52,53]. In a comparison of the polysaccharide content and coagulation performance, higher polysaccharide content or active coagulant agent in natural coagulant will result in lower coagulant dosage required for optimum turbidity removal [54]. A higher coagulant dosage is undesirable as it will not only increase the cost but also can produce more sludge [55].

Jar test was further carried out to determine the optimum pH from the obtained optimum coagulant dosage. Figure 7 shows the turbidity removal recorded by using extracted bagasse on different pH. Based on Figure 7, the optimum pH of extracted bagasse was pH 4 with 95.9% turbidity removal while the lowest turbidity removal was 81.1% which was recorded at pH 12. Bagasse is more suitable to be used in acidic conditions. Generally, the pH of wastewater ranged from pH 4 to 10 [56].

Based on this finding, the possible coagulation mechanism of bagasse is interparticle bridging. Charge neutralization is not the possible coagulation mechanism of bagasse. The difference in maximum and minimum turbidity removal on different pH by using bagasse is small as it only differs by 14%. According to Bahrodin et al. [9], if there is no pH effect on turbidity removal, the coagulation mechanism is not due to charge neutralization. Abidin et al. [57] reported that the coagulation mechanism of *Jatropha curcas* is charge neutralization as the difference between maximum removal and minimum removal by using different pH is around 50%. Therefore, the possible coagulation mechanism of bagasse (*Saccharum officinarum*) is interparticle bridging because unlike charge neutral-

ization, interparticle bridging is least affected by pH but at lower pH, polymeric chains that are responsible for interparticle bridging will be extended and can attach to more pollutants [58,59].

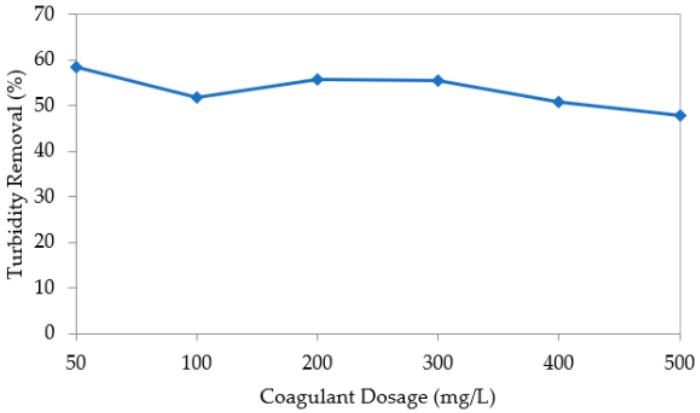


Figure 6. Turbidity removal using extracted bagasse as a natural coagulant with different coagulant dosages at a constant of pH 6.

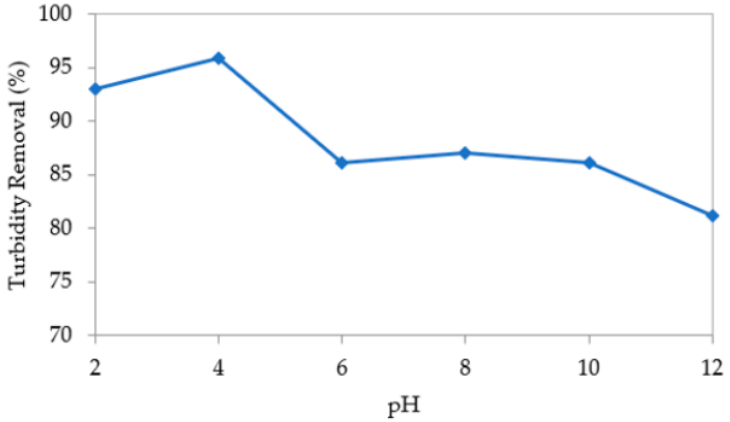


Figure 7. Turbidity removal using extracted bagasse as a natural coagulant on different pH at constant dosage of 50 mg/L.

4. Conclusions and Future Perspectives

This study has successfully examined the capability of extracted bagasse (*Saccharum officinarum*) to be used as a natural coagulant in replacing the use of the current chemical coagulants. Bagasse shows promising coagulation performance with turbidity removal exceeding 90%. Bagasse is comprised of high polysaccharide content, making it the main active coagulant agent. The study also showed that bagasse with high polysaccharide content requires a lower coagulant dosage. The coagulation mechanism is interparticle bridging and not charge neutralization.

From this finding, future perspectives should include the application of extracted bagasse as a natural coagulant in the removal of various other pollutants such as colour, biochemical oxygen demand (BOD) and heavy metals from other sources of wastewater such as palm oil mill effluent (POME). Besides, the coagulation process relies heavily on the operating conditions and the operating conditions should be optimized for optimum removal of pollutants.

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