

# Application of *Aloe Barbadensis Miller* for Water Purification: An Eco-Friendly Coagulation Approach

Amieza Omar<sup>1</sup>, Nurul Rabitah Daud<sup>1</sup>

<sup>1</sup>Faculty of Civil Engineering, Universiti Teknologi MARA, 40450 Shah Alam, Selangor, Malaysia

\*Corresponding author: [nurulrabitah@uitm.edu.my](mailto:nurulrabitah@uitm.edu.my)

Received: 31 July 2025 / Accepted: 11 February 2026 / Published online: 31 March 2026

---

## Abstract

The contemporary water treatment sector increasingly prioritizes sustainable and ecologically benign technologies that protect aquatic ecosystems and enhance public health and quality of life. Despite this progress, traditional treatment frameworks heavily rely on inorganic chemical coagulants, whose efficacy in contaminant removal is countered by risks of ecotoxicity and potential harm to human health. This investigation explores the potential of *Aloe barbadensis miller* (Aloe Vera) gel as a natural coagulant, targeting reductions in turbidity, suspended solids, and organic carbon in surface and simulated waste waters. The analytical approach centres upon a comprehensive series of jar tests, assessing the influence of coagulant dosage on specified water quality metrics: pH, turbidity, total suspended solids (TSS), and total dissolved solids (TDS). Measurement is performed using a calibrated pH meter, a turbidity sensor, and a spectrophotometer for dissolved organic carbon. In parallel, the coagulator is characterised by X-ray diffraction (XRD) and Fourier-transform infrared (FTIR) spectrometry to elucidate its crystalline phases and identify functional groups relevant to charge neutralisation and particle agglomeration. The combination of physico-chemical analyses and coagulation tests will substantiate the viability of Aloe Vera as a renewable, non-toxic alternative to traditional treatment reagents. The paper demonstrates that Aloe Vera represents a cost-effective, biodegradable alternative for the water treatment sector, capable of reducing reliance on traditional chemical coagulants while advancing public health objectives. The sustainability and eco-friendly treatment that can benefit the environment and improve the water treatment industry significantly uses chemical coagulants as a vital part of eliminating contamination and chemical substances in water samples. Nevertheless, this limitation may affect efforts to demonstrate the effectiveness of organic coagulants in water treatment, particularly in jar test experiments evaluating water quality parameters such as pH, turbidity, TSS, and TDS.

**Keywords:** Water Treatment, Organic Coagulant, Aloe Vera, X-ray Diffraction, FTIR

---

## 1.0 Introduction

Water remains fundamental to human health, sanitation, and the complex functioning of natural ecosystems. However, the rapid growth of industrial activities, urban centres, and intensive agriculture is progressively polluting aquatic resources, with surface waters, including rivers, lakes, and reservoirs, being especially vulnerable (Rahman & Khalid, 2009). Within Malaysia, the Klang River serves as a paradigmatic example of aquatic ecosystem collapse, primarily driven by the release of untreated domestic and industrial liquid wastes. Conventional treatment paradigms characterised by coagulation-sedimentation-filtration, followed by disinfection continue to dominate efforts to restore water quality; yet, these systems predominantly employ inorganic coagulants, particularly aluminium sulphate and ferric chloride. Although these chemicals can deliver satisfactory contaminant reduction, they pose significant environmental and public health risks

associated with the accumulation of toxic residual species in the distributed drinking water. Consequently, both researchers and water service authorities are increasingly directed towards organic coagulants derived from renewable sources, including terrestrial plants and agricultural by-products, in a concerted effort to realise treatment processes that are both ecologically benign and protective of human health (El-taweel et al., 2023).

*Aloe barbadensis miller* (Aloe Vera) has emerged as a noteworthy organic coagulant for water treatment, particularly within the family of plant-derived coagulants (Jiang, 2015). These natural agents feature biodegradability, economic viability, and a smaller ecological footprint than their chemical counterparts. Since they lack hazardous metals and do not generate toxic waste products, organic coagulants mitigate both waste disposal burdens and environmental risks (Ang & Mohammad, 2020). Their application aligns with the objectives of sustainable water management. Aloe Vera, including native polysaccharides and bioactive constituents, facilitates the aggregation of dispersed colloids, hence improving the clarity of raw water. (Sukmana et al., 2021). When applied to surface water from the Klang River, Aloe Vera could elevate water quality and concurrently lessen the reliance on synthetic coagulants, supporting broader sustainable treatment paradigms.

This research is significant because it tackles ecological sustainability and public health imperatives (Ernest et al., 2017; Koul et al., 2022). Introducing organic coagulants, specifically Aloe Vera, can curtail the reliance on synthetic chemicals in water treatment, lowering the risks these substances pose, including the emerging association between residual aluminium and neurodegenerative disorders. Adoption of plant-derived coagulants contributes to the conservation of aquatic systems by curbing the discharge of toxic by-products into surface waters. The relevance of the study is intensified in Malaysia, where the urgent need for effective and environmentally friendly treatment technologies is underscored by ongoing contamination of the Klang River, an essential water supply situated between industrial corridors and densely populated urban areas.

This study has three connected goals. First, it seeks to clarify the structural and compositional characteristics of Aloe Vera as a natural coagulant. It was done using laboratory methods like X-ray Diffraction (XRD) and Fourier Transform Infrared Spectroscopy (FTIR). Second, it aims to assess and compare key water quality parameters. These include pH, turbidity, total suspended solids (TSS), and total dissolved solids (TDS) in both the presence and absence of Aloe Vera in its aqueous and powdered forms. Third, it evaluates the effectiveness of Aloe Vera in improving the physicochemical quality of the Klang River. By achieving these goals, the study hopes to show that Aloe Vera can be a viable, environmentally friendly, and cost-effective alternative to synthetic coagulants, offering a new method for water filtration in Malaysia and similar areas.

## 2.0 Literature Review

Water purification is essential for delivering safe potable water for households, industries, and agriculture. Traditional treatment methods in Malaysia, like coagulation, flocculation, sedimentation, and filtration, are still commonly used. However, some treatment facilities have started to include ultrafiltration membranes (Pakharuddin et al., 2021). Coagulation is especially important among these processes. It helps the suspended particles clump together into larger flocs, making them easier to remove. Although aluminium sulphate and ferric chloride are the most commonly applied coagulants, their toxicological profiles and the environmental burden of sludge management have raised significant concerns. Consequently, there has been growing scholarly and practical interest in organic coagulants, naturally occurring extracts from plant or animal sources that can provide a safer, more ecologically responsible, and economically feasible substitute for the standard inorganic coagulants (Yin, 2010).

The recent preference for organic coagulants in water treatment is attributable to their favourable environmental profiles and lower risk to human health. Coagulants made from plant materials, like extracts of *Moringa oleifera* and different cactus species, use active biomolecules such as proteins and polysaccharides. These help neutralize surface charges and promote polymer bridging of colloidal particles (Badawi et al., 2023). Their inherent biodegradability further distinguishes them, as the resulting treatment sludge can be reincorporated into diverse

sectors, ranging from composite construction materials to organic fertilisers, thereby advancing the principles of a circular economy (Diver et al., 2023). Nevertheless, the commercial uptake of organic coagulants remains limited, primarily because their coagulation efficacy is sensitive to variations in influent water quality, the precision of dosage control, and variables in the treatment regime. Consequently, there is an urgent need for focused, empirical studies on specific plant-based agents, with Aloe Vera emerging as a particularly promising candidate. Research should prioritise the definition of dosage ranges, contact times, and pH windows that will yield reliable and reproducible performance across a spectrum of water quality conditions.

Aloe Vera is increasingly recognized as a viable alternative for water treatment owing to its complex array of bioactive constituents, which include polysaccharides, proteins, enzymes, vitamins, and minerals (Rahman et al., 2017). These biomolecules ground their action on pollutant abatement through charge neutralization and resultant floc formation (Irma et al., 2016; Darkun et al., 2024). Empirical investigations reveal that Aloe Vera can diminish turbidity and suspended solids with a corresponding reduction in the dosage of chemical coagulants, thereby attenuating the generation of toxic sludge (Ahmed, 2022; Bahrodin et al., 2021). Notwithstanding, its coagulative efficacy is markedly governed by several operational variables: pH, coagulant dosage, mixing velocity, and temperature (Kweiner Tetteh & Rathilal, 2020). Although current findings suggest this coagulant is promising, uncertainties persist regarding its longevity, the practical hurdles of scaling up for industrial use, and its performance across diverse raw water chemistries, especially within highly contaminated catchments like the Klang River.

Evaluating water quality is crucial in measuring the effectiveness of coagulation agents. Key factors, including pH, turbidity, suspended solids, and total dissolved solids (TDS), are essential to the improvements achieved during treatment (Alazaiza et al., 2022). The Jar Test method is still the preferred protocol for determining the best dosage and mixing parameters for both metallic and bio-based coagulants. Although many studies have focused on traditional aluminum and iron-based coagulants, there are relatively few empirical studies that have tested Aloe Vera using the same standard water quality tests, especially in river systems with diverse and changing pollutant profiles. Furthermore, a detailed evaluation of Aloe Vera's chemical structure, using analytical techniques like Fourier-transform infrared spectroscopy (FTIR) and X-ray diffraction (XRD), is still lacking. This characterization is important for understanding the specific functional groups involved in coagulation and linking their structural features to observed treatment efficiencies.

Research on Aloe Vera as a plant-based coagulant has gained interest, but significant gaps remain in the literature. Yin (2010) and Diver et al. (2023) noted the lack of thorough analyses regarding the scalability and cost-effectiveness of these organic coagulants in municipal and industrial water treatment facilities. Bahrodin et al. (2021) further observed that the performance of the coagulant in relation to key water quality variables of pH, alkalinity, salinity, and turbidity remains under-characterized. Systematic investigations that benchmark the efficacy of Aloe Vera against widely used chemical coagulants, particularly in highly contaminated environments such as the Klang River, are similarly sparse. It is essential to close these empirical and comparative gaps for Aloe Vera to be more widely accepted as a long-lasting coagulant that can reduce the use of synthetic alternatives and promote green water treatment techniques across Malaysia.

### **3.0 Methodology**

#### **3.1 Water Sample Collection**

Figure 1 shows the coordinates of the water samples taken from Taman Awam Pangkalan Batu along the Klang River in Selangor: 3°02'49"N, 101°26'33"E. The site was selected for its metropolitan significance and logistical accessibility, illustrating the river's water quality status within a developed catchment area. A grab-sampling design was utilized, whereby samples were withdrawn at a single site and moment, conforming with the protocols outlined in Standard Methods for the Examination of Water and Wastewater (APHA, 2017). During the initial sampling event, a total of 12 litres of unprocessed river water was obtained to facilitate two laboratory analytical series initiated within the same calendar day. The water was transferred into sterile, high-density

polyethylene (HDPE) bottles previously rinsed three times with the in-situ river flow to curtail any cross-contamination risk. The filled bottles were then immediately capped, tagged with the corresponding date, time, and geographic coordinate, and encased in a chilled transport cooler lined with ice packs to inhibit any biogeochemical alteration of the aqueous matrix before laboratory examination. The sampling operation was conducted under strict safety protocols. Crew members wore gloves, waterproof boots, and personal flotation devices (PFDs) to guard against both environmental hazards and damage to sensitive sampling instruments.

Samples were drawn from a secure launch point on the riverbank, minimizing the chance of slips or exposure to unstable ground. Once collected, the samples were taken to the field lab, immediately placed on ice, and maintained at a temperature of about 4 °C. They were analyzed within 24 hours to ensure that key physicochemical characteristics, pH, turbidity, total dissolved solids, and other relevant metrics remained essentially unchanged from the moment of collection until measurement.



**Figure 1.** Sampling location of water sample in Klang River (3°02'49"N, 101°26'33"E).

### **3.2 Preparation of Aloe Vera Coagulant**

Throughout this study, Aloe Vera was used to derive powdered and liquid formulations of organic coagulant. The specimens were sourced from a commercial supplier in Pasir Gudang, Johor. The overall processing occurred in a two-stage sequence: (i) transformation of Aloe Vera into powder form, and (ii) extraction of Aloe Vera in liquid form.

#### **3.2.1 Preparation of Aloe Vera Powder**

The sourced Aloe Vera plants underwent a thorough rinse using tap water to eliminate superficial contaminants. A clean stainless-steel knife excised the brittle outer cuticle from the mucilaginous central citrine gel (Figure 2). The cuticle and gel segments were laid into drying trays and dehydrated in a forced-air oven at a precisely controlled thermal setting. Drying continued until weight constancy was reached, signaling complete moisture removal.



**Figure 2.** The process of the Aloe Vera plant becomes powder form.

The dehydrated material was subsequently milled in a mechanical grinder and sieved through a nylon mesh of 0.35 mm aperture, yielding a fine powder that conforms to the desired particle size for coagulation efficacy. The sieved powder was transferred to sealed laboratory containers desiccated to equilibrium relative humidity, to avert hygroscopic weight gain and microbial colonization. The crystallographic and elemental composition of the powder was later elucidated using an X-Ray Diffractometer to map the spacings and ascertain phase purity of the constituent polysaccharides, phenolics, and minerals.

### 3.2.2 Preparation of Aloe Vera Liquid Extract

Aloe Vera liquid coagulant was produced by dispersing 25 g of powdered Aloe Vera in 1000 mL of distilled water. The suspension was agitated with a magnetic stirrer for 20 minutes to promote uniform dispersal. After stirring, the suspension was allowed to settle for 30 minutes to permit the sedimentation of fibrous and particulate matter. The supernatant was separated by passing the liquid through a filter with a pore size of < 8  $\mu\text{m}$ , thus yielding a clarified Aloe Vera extract (Figure 3). The resulting filtrate was stored in a BOD incubator, where temperature and light conditions were regulated until experimentation was needed. The presence of specific functional groups in the extract was confirmed by Fourier-transform infrared spectrophotometry (FTIR) analysis.



**Figure 3.** The process of Aloe Vera becomes a liquid form.

### 3.3 Coagulation – Flocculation Process

The coagulation–flocculation trials were carried out in a Jar Test apparatus to replicate water treatment's coagulation and sedimentation phases under standardized laboratory conditions. Two coagulant forms derived from Aloe Vera were employed: Aloe Vera powder (AV-Powder) and a liquid extract (AV-H<sub>2</sub>O). Their coagulation efficacy was judged by changes in turbidity, pH, total suspended solids (TSS), and total dissolved solids (TDS).



**Figure 4.** Jar test experiment on the coagulation process.

### 3.3.1 Experimental Configuration

Each experimental run employed six 1-L glass beakers, each containing 500 mL of distilled water. For each vessel, six different coagulant dosages were introduced: 0 mg/L (as a blank), 400 mg/L, 800 mg/L, 1,200 mg/L, 1,600 mg/L, and 2,000 mg/L. This cross-section of concentrations allowed for the generation of dose–response curves for the water-quality parameters (Benalia et al., 2021). Separate groups of beakers were devoted to AV-Powder and AV-H<sub>2</sub>O, permitting a direct comparison of coagulation performance between the two forms of Aloe Vera treatment.

### 3.3.2 Coagulation-Flocculation Protocol

The coagulation step was carried out with a two-stage mixing process. In the first rapid mixing phase, the rotor speed was set to 160 rpm for 3 minutes to achieve uniform distribution of the coagulant and to initiate the first destabilization of the suspended particles. After this initial spike, the speed was lowered to 30 rpm for 20 minutes. This gentler mixing allowed the smaller clusters of particles to collide with one another, weakly bond, and gradually develop into larger, more buoyant flocs, a process described by Benalia et al. (2021). Upon completion of the mixing, the samples were allowed to settle for 30 minutes, during which the flocs continued to grow, and the solid-liquid separation was driven by gravity. Once this settling period ended, the clear supernatant was carefully withdrawn from each container and stored for subsequent, more precise water quality analysis.

## 3.4 Evaluation Parameters

Evaluation of physicochemical water quality parameters is a critical step in ascertaining the effectiveness of Aloe Vera as a biocoagulant for pollutant removal and aesthetic enhancement in water treatment. These parameters yield precise quantitative indices of Aloe Vera extracts' capacity, administered as powdered agglomerate and as aqueous solution, to abate suspended matter, dissolved solids, and turbidity while maintaining desirable water chemistry. All investigative laboratory activities were performed in Environmental Laboratory 2, Faculty of Civil Engineering, Universiti Teknologi MARA. Performance assessment encompassed the percentage removal of turbidity, total suspended solids (TSS), total dissolved solids (TDS), and shifts in pH. The recorded removal efficiencies facilitated comparative judgements regarding the sustainability profile of Aloe Vera compared to conventional, non-renewable coagulant alternatives. The subsequent analysis of residual water quality after the coagulation–flocculation phase included the following critical physicochemical parameters:

1) pH: A calibrated ensemble of digital pH meters, operated in full accord with the procedures delineated in Standard Methods for the Examination of Water and Wastewater (APHA, 2017), was employed for the precise measurement of pH. Periodic pH surveillance was conducted to ascertain that the application of Aloe Vera extract did not provoke significant excursions toward either acidic or alkaline pH extremes, thereby preserving the overall physicochemical integrity of the treated water.

2) Turbidity: Turbidity was quantified employing a dedicated nephelometric turbidity analyzer. The output, reported in nephelometric turbidity units (NTU), directly quantified the enhanced optical clarity of the treated water.

3) Total Suspended Solids (TSS): Total suspended solids were determined by filtering known volumes of the effluent through pre-weighed, calibrated glass-fiber filters with a nominal pore diameter of less than 1.5 µm. After filtration, the filters were dried in a laboratory oven maintained at 105 °C until a constant weight was achieved. The concentration of total suspended solids was then computed as the mass difference between the dried filter and the retained particulate residue, expressed in milligrams per liter (mg/L).

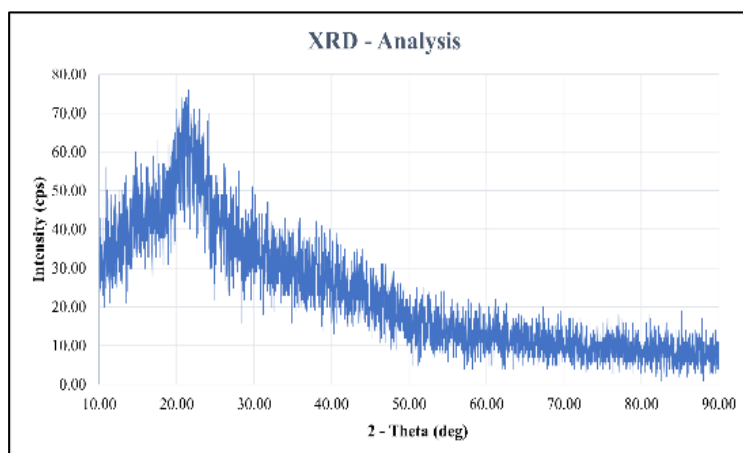
4) Total Dissolved Solids (TDS): A laboratory-grade digital conductivity meter assessed total dissolved solid's concentration. The conductivity readings obtained were referenced against a pre-established calibration curve to convert the measured conductance into mass concentration values, expressed in milligrams per liter (mg/L), thus yielding an approximate measurement of the dissolved ionic species within the treated aqueous sample.

## 4.0 Results and Discussion

### 4.1 Characteristics of Aloe Vera Plant

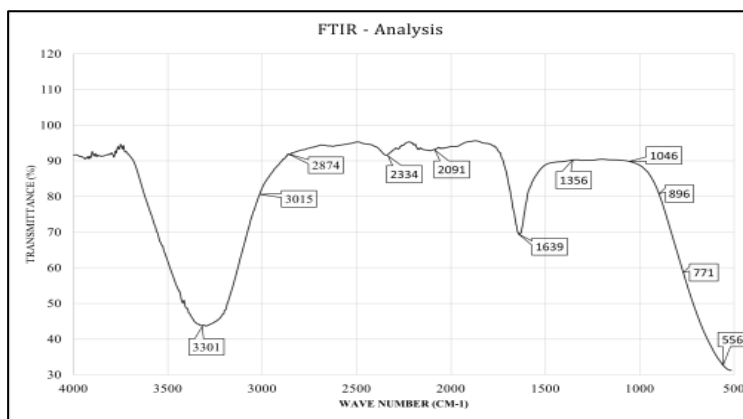
Advanced analytical methods were systematically deployed to elucidate the chemical and structural attributes of Aloe Vera, which were examined in both liquid and powder states to assess its viability as a natural coagulant. X-ray diffraction (XRD) quantification of the sample's crystalline phases was complemented by Fourier-transform infrared spectroscopy (FTIR) to elucidate the functional groups postulated to mediate coagulation.

For the powdered coagulant, crystalline characteristics were profiled via X-ray diffraction employing Cu K-alpha radiation (1.54 Å) at 40 kV and 30 mA, the diffraction pattern being acquired over a 10° to 90° scatter angular range (Figure 5). Aloe Vera leaf tissue comprises cellulose, hemicelluloses, lignin, and various polysaccharide matrices (Triantafyllou et al., 2024). The resulting XRD pattern, shown in the accompanying figure, represents powdered Aloe Vera in refined form, permitting clarification of its bulk structural coherence and the relative abundance of crystalline domains.



**Figure 5.** X-ray Diffractogram of Aloe Vera powder.

As shown in Figure 6, the infrared spectrum of Aloe Vera was recorded throughout 4000–500  $\text{cm}^{-1}$  with a Fourier-transform infrared spectrometer (Perkin Elmer Spectrum One, UiTM Shah Alam). A broad absorption at 3301  $\text{cm}^{-1}$  is attributable to hydroxyl groups arising from polysaccharides and intramolecular hydrogen bonding (Triantafyllou et al., 2024; Pop et al., 2022). A pronounced band at 1639  $\text{cm}^{-1}$  indicates the presence of carbonyl units (C=O) and is assigned to anthraquinones, saponins, and polysaccharides (Chrismina, 2024). The peak at 2874  $\text{cm}^{-1}$  is assigned to methylene ( $-\text{CH}_2-$ ) vibration (Lim & Cheong, 2015). Further, continuous absorption between 1635.14 and 1078.80  $\text{cm}^{-1}$  is consistent with a high concentration of acemannan, the principal mucopolysaccharide (Ray & Ghosh, 2018). Lower-intensity absorptions in the range of 896 to 556  $\text{cm}^{-1}$  are characteristic of C–H deformation within the pyranoside ring of mannose (Pop et al., 2022).



**Figure 6.** FTIR – Spectrum of Aloe Vera liquid.

X-ray diffraction patterns demonstrated clear distinctions between the powdered and liquid forms of Aloe Vera. The powdered sample presented sharp, well-resolved diffraction maxima, confirming the presence of crystalline phases including calcium carbonate, magnesium carbonate, and minor silicates; these species have been implicated in charge-neutralizing behavior during coagulation processes (Benalia et al., 2021). By contrast, the diffraction data for the liquid extract exhibited a limited number of broadly distributed intensity maxima, indicative of a largely amorphous character. The observed decrease in long-range order can be ascribed to the extraction and subsequent filtration stages, wherein crystalline entities are dissolved or reduced to colloidal-sized particles, enhancing their reactivity in subsequent water clarification operations.

FTIR spectroscopy corroborated our earlier findings by revealing distinctive functional groups in both Aloe Vera preparations. Adjacent peaks in the 1600–1650  $\text{cm}^{-1}$  range indicate C=O stretching linked to carboxylic and amide entities, whereas the 1000–1100  $\text{cm}^{-1}$  region is dominated by C–O–C stretching modes of polysaccharide backbones. The more intense absorbances recorded for the aqueous extract imply that the solvent medium promotes the liberation of these functional species, which likely assists in destabilizing particles and the subsequent aggregation observed during coagulation.

A comparative assessment indicates that the Aloe Vera powder is enriched in mineral constituents and exhibits a more orderly crystalline morphology, factors that can augment adsorption by charge neutralization. In contrast, the aqueous extract presents a greater density of accessible hydroxyl and carbonyl groups, strengthening its capacity to form hydrogen bonds and serve as bridging sites in flocculation. These divergent yet complementary traits suggest that the powder and the liquid extract give distinct benefits within water purification, the former enhancing adsorption kinetics. At the same time, the latter amplifies the overall chemico-reactive profile.

The complementary X-ray diffraction and Fourier-transform infrared spectroscopic analyses conclusively demonstrate that Aloe Vera harbors both inorganic mineral species and distinctive functional moieties that underpin its efficacy in coagulation. These findings collectively affirm that Aloe Vera may serve as an ecologically sound substitute for traditional synthetic coagulants, as its coagulative action appears to arise synergistically from mineral-phase adsorption and the selective interaction of the functional groups with colloidal particles.

#### **4.2 Effectiveness of Liquid and Powder Coagulants of Aloe Vera**

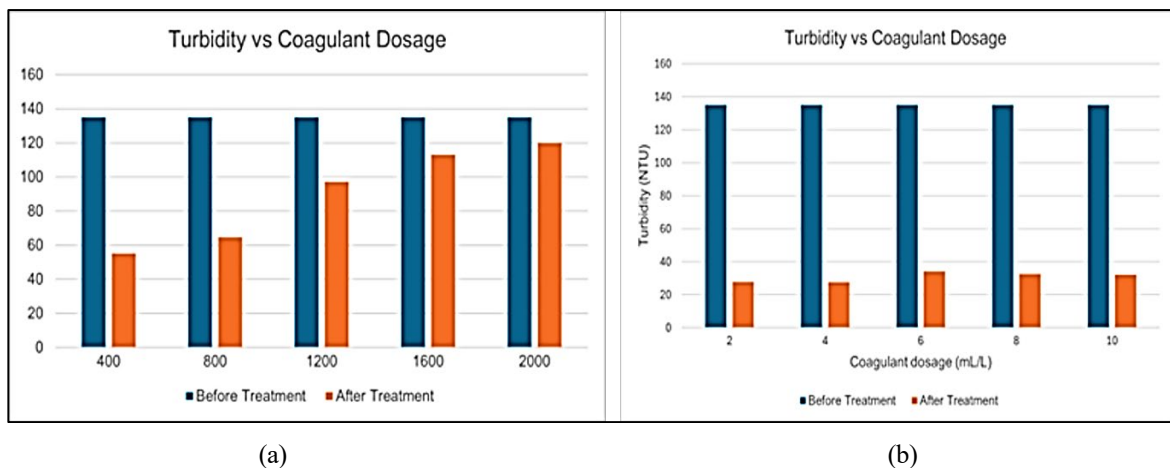
The preliminary analysis of water quality showed that the raw water sample possessed turbidity of 135 NTU, pH

of 7.97, TSS concentration of 31 mg/L, and TDS of 89 mg/L. According to National Water Quality Standards (NWQS) for Malaysia (Department of Environment, 2010), the metrics showed the water quality need substantial treatment for the water to conform to established quality specifications, with turbidity and TSS removal being critical. The performance of coagulants derived from Aloe Vera was compared in both liquid and powdered formulations, targeting reductions in the problematic parameters. The powdered coagulant exhibited pronounced efficacy in lowering turbidity and TSS, a phenomenon attributable to its elevated mineral load and well-defined crystalline morphology, both of which favour the mechanisms of particle adsorption and coagulation bridging. The resultant acceleration of particle settling corroborates the application of powdered Aloe Vera as an effective coagulant for preliminary solid–liquid separation.

Conversely, the liquid extract of Aloe Vera consistently demonstrated significant efficacy for water quality enhancement, especially in terms of pH stabilization, turbidity reduction, and dissolved solids minimization. This formulation possesses an elevated density of bioactive functional moieties, predominantly hydroxyl and carbonyl groups, promoting charge neutralization and fostering resilient inter-particle networks during the flocculation process. Subsequently, the liquid extract markedly elevated water clarity and diminished dissolved contaminants. The synergistic interaction between the powdered and liquid formulations indicates that Aloe Vera may fulfil the role of a sustainable coagulant; the powder excels in solid particle removal, while the liquid fraction augments chemical performance and stabilizes pH.

#### 4.2.1 Turbidity

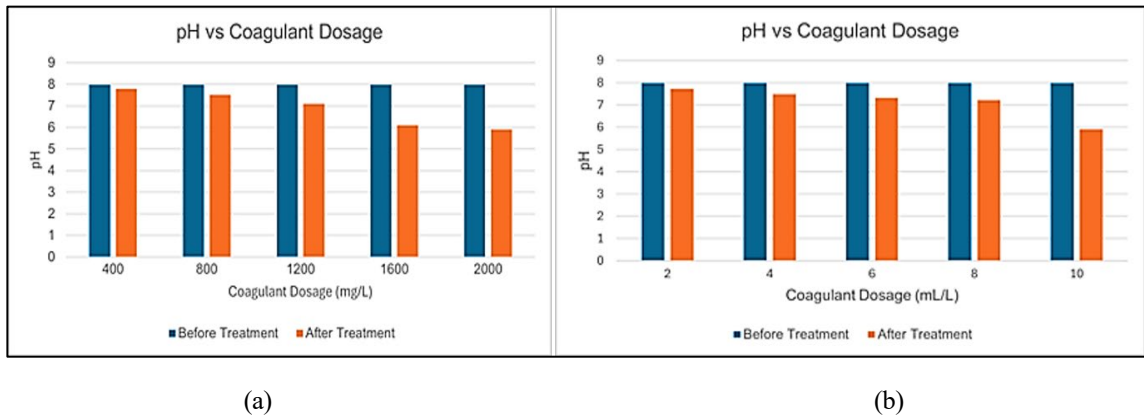
Figure 7 (a) indicates that Aloe Vera powder reduced turbidity from an initial 135 NTU to a minimum of 55.2 NTU at a dosage of 400 mg/L, yielding a removal efficiency of 59.1%. The influence of dosage reveals a subsequent turbidity increase at higher levels, attributable to the restabilization of colloidal particles, adversely affecting reduction efficiency (Benalia et al., 2024; Asrafuzzaman et al., 2011). In contrast, Figure 6 (b) presents the turbidity profile for Aloe Vera in liquid form, where a dosage of 4 mL/L lowered the turbidity to a minimum of 27.8 NTU, producing a removal efficiency of 79.3%. Increasing the dosage beyond this level maintained effective reduction, yet further gains in efficiency were modest. Subsequent increases in dosage maintained effective turbidity reduction, yet did not yield significant performance gains, suggesting that excessive dosing may compromise economic viability and operational efficiency (Benalia et al., 2024; Asrafuzzaman et al., 2011).



**Figure 7.** Turbidity vs Coagulant Dosage. (a) is the AV-Powder; (b) is the AV-H<sub>2</sub>O.

#### 4.2.2 pH

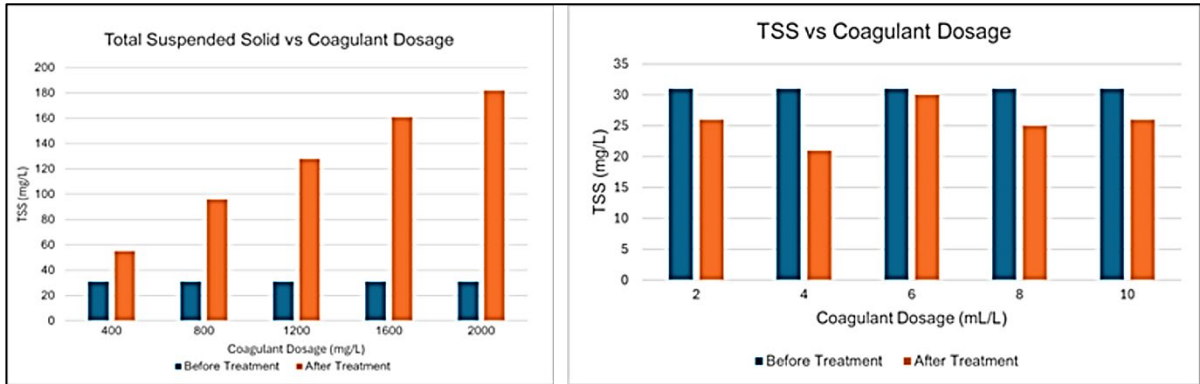
Figure 8 (a) illustrates that, upon increasing the Aloe Vera dosage, the solution pH diminished from 7.97 to 5.9, with the optimal turbidity removal of 59.1% at pH 7.79. This pH is comfortably within the NDWQS threshold of 5.5 to 9.0. However, a final pH of 5.9 reflects a condition of excessive acidity, leading to diminished coagulation efficiency attributable to insufficient charge neutralization (Hadadi et al., 2022). Figure 8 (b) shows a more refined Aloe Vera formulation of 8 mL/L yielding a final pH of 7.13, which remains within a neutral range. However, with 10 mL/L produce slightly acidic final pH 5.9. The process achieved a maximum turbidity reduction of 79.3% at pH 7.72, demonstrating that the liquid formulation effectively stabilizes pH within acceptable limits, thus enhancing treatment consistency.



**Figure 8.** The pH vs Coagulant Dosage. (a) is the AV-Powder; (b) is the AV-H<sub>2</sub>O.

#### 4.2.3 Total Suspended Solids (TSS)

Figure 9 (a) illustrates that powdered Aloe Vera increased total suspended solids (TSS) from 31 mg/L to 182 mg/L as the dosage rose, indicating that the powdered form added considerable organic matter and therefore did not achieve TSS reduction in this setting. Conversely, the data in Figure 9 (b) reveal that Aloe Vera as a liquid coagulant led to a gradual reduction in TSS, with levels decreasing from 31 mg/L to a minimum of 21 mg/L at the optimal dosage of 4 mL/L; beyond this point, TSS slightly rebounded at higher doses, suggesting that overdosing can impair sedimentation performance.



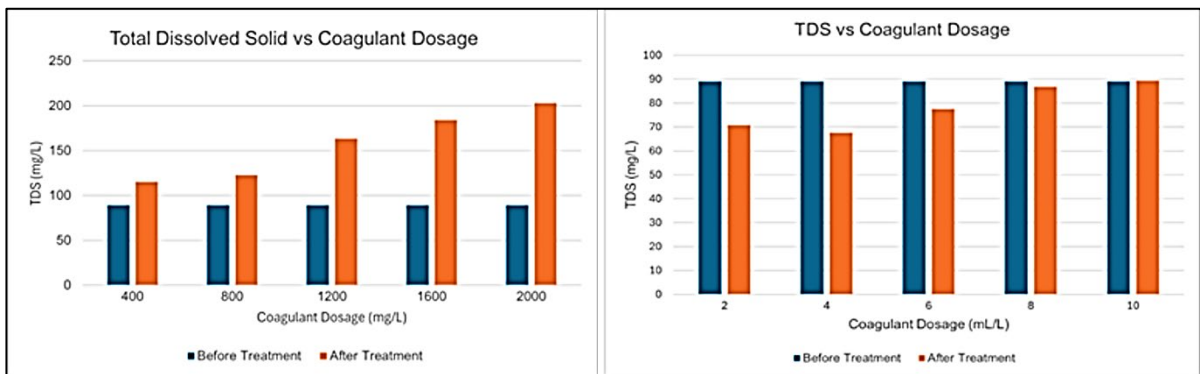
(a)

(b)

**Figure 9.** TSS vs Coagulant Dosage. (a) is the AV-Powder; (b) is the AV-H<sub>2</sub>O.

#### 4.2.4 Total Dissolved Solids (TDS)

Figure 10 (a) illustrates that Aloe Vera in powdered form produces an elevated total dissolved solids (TDS) profile that rises from 89 mg/L to 203 mg/L in response to increasing coagulant dosages. This trend can be attributed to releasing soluble bioactive compounds from the powder matrix, which are systematically leached into the water during experimental treatment. The resultant elevation in TDS level indicates a lack of capability for this matrix to limit dissolved solids in the water sample. In contrast, Figure 10 (b) records a modest decline in TDS attributed to the powdered Aloe Vera, which achieves a minimum level of 67.7 mg/L at an optimum dosage of 4 mL/L, thereby yielding a 24% removal efficiency. However, removal effectiveness diminishes at greater dosage increments, suggesting that excessive application could hinder coagulation mechanisms, possibly by exceeding optimal polyvalent ion adsorption sites. By comparison, the data unequivocally indicate that Aloe Vera in liquid form consistently exceeds the powder form in TDS reduction capability.



(a)

(b)

**Figure 10.** TDS vs Coagulant Dosage. (a) is the AV-Powder; (b) is the AV-H<sub>2</sub>O.

### 4.3 Removal Efficiency of Liquid and Powder Coagulants

Table 1 presents the removal efficacy of the coagulant derived from Aloe Vera powder. The reduction in turbidity was quantified at 59.1%, suggesting a moderate level of effectiveness in lowering turbidity in the experimental water samples. Conversely, the total suspended solids (TSS) exhibited a net increase from 31 mg/L to 55 mg/L, which signifies poor overall removal. This poor TSS performance can be attributed to an excessive dosage of Aloe Vera powder, which likely led to aggregation of particulate matter without subsequent compaction or sedimentation of the resulting floc. Consequently, fine particulate matter remained suspended in the supernatant after the test. The total dissolved solids (TDS) values similarly indicated inefficient treatment, as the Aloe Vera powder may leach organic solutes during coagulation, thus elevating TDS levels post-treatment. The aggregate performance of Aloe Vera powder coagulants, as documented in Table 4.4, reflects consistently low removal effectiveness across several water quality parameters, most notably total suspended and total dissolved solids.

**Table 1.** Removal efficiency for powder coagulants.

Parameter	Initial	Final	Powder Removal Efficiency (%)
Turbidity (NTU)	135	55.2	59.1
TSS (mg/L)	31	55	-77.4 % Not Efficient
TDS (mg/L)	89	115.1	-29.3 Not Efficient
		Average Efficiency	-

Findings presented in Table 2 indicate the effectiveness of Aloe Vera as a liquid coagulant in achieving turbidity and solid matter removal. The turbidity removal efficiency of 79.3% demonstrates a high level of effectiveness, confirming Aloe Vera gel's capacity to attenuate suspended particles in the water column. The total suspended solids (TSS) concentration decreased from 31 mg/L to 21 mg/L, yielding a removal efficiency of 32.3%, a value the literature characterizes as moderately effective relative to conventional coagulants. Total dissolved solids (TDS) underwent a smaller reduction, from 89 mg/L to 67.6 mg/L, producing a removal efficiency of 24%. The comparatively modest TDS removal coincides with the lower solubility of organic matter leached from the liquid coagulant. The results show a smaller dissolved load than conventional powder-based coagulants, where more organic matter may dissolve into the effluent. The average percentage removal efficiency of 45.2% for the liquid coagulant process signifies a balanced performance across the tested water quality parameters, validating its efficacy relative to powder-based approaches.

**Table 2.** Removal efficiency for liquid coagulants.

Parameter	Initial	Final	Liquid Removal Efficiency (%)
Turbidity (NTU)	135	27.9	79.3
TSS (mg/L)	31	21	32.3
TDS (mg/L)	89	67.6	24.0
		Average Efficiency	45.2

## 5.0 Conclusion

The present investigation has evidenced that Aloe Vera constitutes a viable organic coagulant for water treatment. Systematic laboratory assays demonstrated that Aloe Vera, particularly in its liquid extract, effectively diminished turbidity, total suspended solids (TSS), and total dissolved solids (TDS) in surface water matrices. This coagulation efficacy arises from the bioactive constituents of the plant, notably polysaccharides, proteins, and hydroxyl radicals, which promote the nucleation of flocs and the subsequent entrapment of dissolved and suspended contaminants. Characterization by X-ray diffraction (XRD) and Fourier-transform infrared spectroscopy (FTIR) substantiated the occurrence of functional groups and a semi-crystalline phase, favoring particle adhesion and aggregation. The concordance of such empirical findings with the initial research hypotheses corroborates the investigation's validity. It highlights the capacity of Aloe Vera to serve as a nature-derived substitute for synthetic coagulants in the water treatment sector.

This investigation delivers a noteworthy novel contribution by directly comparing Aloe Vera in powdered and liquid formulations, a distinction largely overlooked in earlier literature. Data show that the powdered version is better at reducing turbidity through particulate adsorption. The liquid version, on the other hand, encourages chemical interactions that improve pH control and lower dissolved solids. This combined performance gives it a functional complexity that is unusual for traditional single-phase coagulants. The study also confirms that Aloe Vera is non-toxic, biodegradable, and environmentally friendly, making it suitable for use in small, decentralized water purification systems, particularly in rural or resource-limited areas.

Future studies should focus on longer pilot-scale trials to determine the durability and cost-effectiveness of Aloe Vera in working water treatment plants. Using additional characterization methods, like scanning electron microscopy (SEM), will provide more insights into the coagulation processes. Exploring combinations that pair Aloe Vera with other natural or low-concentration synthetic coagulants may further enhance treatment effectiveness. These approaches position Aloe Vera as a practical, sustainable solution for improving global water quality while reducing dependence on traditional, chemical-heavy purification methods.

## Acknowledgments

The authors would like to thank examiners and reviewers for their invaluable comments for this manuscript. We acknowledge the Ministry of Higher Education (MOHE) for funding under the Fundamental Research Grant Scheme (FRGS-EC) (FRGS/1/2024/TK06/UITM/02/17). We are also grateful to Faculty of Civil Engineering, Universiti Teknologi MARA for the equipment and laboratory facilities for this research work. Special thanks to each one individual who have been lending their helping hands in data collection and analysis of this research work.

## Author Contributions

Amieza Omar contributed to conceptualization, software, methodology, investigation, formal analysis and writing original draft.

Nurul Rabahah Daud contributed to writing review and editing, investigation, data curation and methodology.

All authors read and approved the final manuscript.

## Declaration of Conflicting Interests

All authors declare that they have no conflicts of interest.

## Declaration of Generative Ai in The Writing Process

During the preparation of this work, the authors used generative AI tools to improve language and readability.

After using this tool/service, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

### **Data Availability/Supplementary Materials**

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

### **Ethics Statement**

The authors declare that this research did not involve human or animal subjects. All experimental procedures were performed following the institutional Safety, Health, and Environmental (HSE) protocols of Universiti Teknologi MARA.

### **References**

Ahmed, A. (2022). Practical efficiency comparison of different natural coagulants for water turbidity removal. *Sohag Engineering Journal*. <https://doi.org/10.21608/sej.2022.181026.1030>

Alazaiza, M., Albahnasawi, A., Ali, G., Bashir, M., Nassani, D., Al Maskari, T., Amr, S., & Abujazar, M. (2022). Application of natural coagulants for pharmaceutical removal from water and wastewater: A review. *Water*, 14(2), 140. <https://doi.org/10.3390/w14020140>

Ang, W. L., & Mohammad, A. W. (2020). State of the art and sustainability of natural coagulants in water and wastewater treatment. *Journal of Cleaner Production*, 262(121267), 121267. <https://doi.org/10.1016/j.jclepro.2020.121267>

APHA. (2017). *Standard Methods for the Examination of Water and Wastewater* (23 ed.). (A. D. Rodger B. Baird, Ed.) APHA, AWWA, WEF.

Asrafuzzaman, M., Fakhrudin, A. N. M., & Hossain, M. A. (2011). Reduction of turbidity of water using locally available natural coagulants. *ISRN Microbiology*, 2011, 632189. <https://doi.org/10.5402/2011/632189>

Badawi, A. K., Salama, R. S., & Mostafa, M. M. M. (2023). Natural-based coagulants/flocculants as sustainable market-valued products for industrial wastewater treatment: a review of recent developments. *RSC Advances*, 13(28), 19335–19355. <https://doi.org/10.1039/d3ra01999c>

Bahrodin, M. B., Zaidi, N. S., Hussein, N., Sillanpää, M., Prasetyo, D. D., & Syafiuddin, A. (2021). Recent advances on coagulation-based treatment of wastewater: Transition from chemical to natural coagulant. *Current Pollution Reports*, 7(3), 379–391. <https://doi.org/10.1007/s40726-021-00191-7>

Benalia, A., Derbal, K., Amrouci, Z., Baatache, O., Khalfaoui, A., & Pizzi, A. (2024). Application of plant-based coagulants and their mechanisms in water treatment: A review. *Journal of Renewable Materials*, 12(4), 667–698. <https://doi.org/10.32604/jrm.2024.048306>

Chismirina, S. (2024). Study of formulation and FTIR Analysis of Aloe Vera Gel for Periodontal

Disease Therapy. *Journal of Community Dentistry and Dental Research*, 2(1), 7–13.

Darkun, K., Mulyawati, I., Febrina, L., & Patulak, A. (2024). The influence of Aloe Vera biocoagulant and mixing time in reducing biological oxygen demand, chemical oxygen demand and total suspended solids levels. *Environmental Research, Engineering and Management*, 80(3), 149–161. <https://doi.org/10.5755/j01.arem.80.3.35873>

Department of Environment (DOE). (2010). National Water Quality Standards for Malaysia. Ministry of Natural Resources and Environment.

Diver, D., Nhapi, I., & Ruziwa, W. R. (2023). The potential and constraints of replacing conventional chemical coagulants with natural plant extracts in water and wastewater treatment. *Environmental Advances*, 13(100421), 100421. <https://doi.org/10.1016/j.envadv.2023.100421>

El-taweel, R. M., Mohamed, N., Alrefaey, K. A., Husien, S., Abdel-Aziz, A. B., Salim, A. I., Mostafa, N. G., Said, L. A., Fahim, I. S., & Radwan, A. G. (2023). A review of coagulation explaining its definition, mechanism, coagulant types, and optimization models; RSM, and ANN. *Current Research in Green and Sustainable Chemistry*, 6(100358), 100358. <https://doi.org/10.1016/j.crgsc.2023.100358>

Ernest, E., Onyeka, O., David, N., & Blessing, O. (2017). Effects of pH, dosage, temperature and mixing speed on the efficiency of watermelon seed in removing the turbidity and colour of Atabong River, Awka- Ibom State. *Int J Adv Eng Manag Sci*, 3(5), 427–434.

Hadadi, A., Imessaoudene, A., Bollinger, J.-C., Assadi, A. A., Amrane, A., & Mouni, L. (2022). Comparison of four plant-based bio-coagulants performances against Alum and ferric chloride in the turbidity improvement of bentonite synthetic water. *Water*, 14(20), 3324. <https://doi.org/10.3390/w14203324>

Irma, N. Y. A. E., Philippe, S., Abdoukarim, A., Alassane, Y. A. K., Pascal, A. C., Daouda, M., & Dominique, S. K. C. (2016). Evaluation of Aloe Vera leaf gel as a natural flocculant: phytochemical screening and turbidity removal trials of water by coagulation flocculation. *Research Journal of Recent Sciences*.

Jiang, J.-Q. (2015). The role of coagulation in water treatment. *Current Opinion in Chemical Engineering*, 8, 36–44. <https://doi.org/10.1016/j.coche.2015.01.008>

Koul, B., Bhat, N., Abubakar, M., Mishra, M., Arukha, A. P., & Yadav, D. (2022). Application of natural coagulants in water treatment: A sustainable alternative to chemicals. *Water*, 14(22), 3751. <https://doi.org/10.3390/w14223751>

Kweinor Tetteh, E., & Rathilal, S. (2020). Application of organic coagulants in water and wastewater treatment. *In Organic Polymers*. IntechOpen.

Lim, Z. X., & Cheong, K. Y. (2015). Effects of drying temperature and ethanol concentration on bipolar switching characteristics of natural Aloe Vera-based memory devices. *Physical Chemistry*

Chemical Physics: PCCP, 17(40), 26833–26853. <https://doi.org/10.1039/c5cp04622j>

Pakharuddin, N. H., Fazly, M. N., Ahmad Sukari, S. H., Tho, K., & Zamri, W. F. H. (2021). Water treatment process using conventional and advanced methods: A comparative study of Malaysia and selected countries. *IOP Conference Series. Earth and Environmental Science*, 880(1), 012017. <https://doi.org/10.1088/1755-1315/880/1/012017>

Pop, R. M., Puia, I. C., Puia, A., Chedea, V. S., Levai, A. M., Bocsan, I. C., & Buzoianu, A. D. (2022). Pot Aloe Vera gel – a natural source of antioxidants. *Notulae Botanicae Horti Agrobotanici Cluj-Napoca*, 50(2), 12732. <https://doi.org/10.15835/nbha50212732>

Rahman, S. A., & Khalid, R. M. (2009). Water resource management in Malaysia: legal issues and challenges. *International Journal of Sustainable Development and Planning*, 4(3), 258–264. <https://doi.org/10.2495/sdp-v4-n3-258-264>

Rahman, S., Carter, P., & Bhattarai, N. (2017). Aloe Vera for tissue engineering applications. *Journal of Functional Biomaterials*, 8(1), 6. <https://doi.org/10.3390/jfb8010006>

Ray, A., & Ghosh, S. (2018). Chemometrics for functional group distribution, and UV absorption potential of Aloe Vera L. gel at different growth periods. *Materials Today: Proceedings*, 5(10), 22245–22253. <https://doi.org/10.1016/j.matpr.2018.06.590>

Sukmana, H., Bellahsen, N., Pantoja, F., & Hodur, C. (2021). Adsorption and coagulation in wastewater treatment – Review. *Progress in Agricultural Engineering Sciences*, 17(1), 49–68. <https://doi.org/10.1556/446.2021.00029>

Triantafyllou, E., Karydis-Messinis, A., Moschovas, D., Kyriakaki, C., Vasilopoulos, K. C., Giannakas, A. E., Karakassides, M. A., Avgeropoulos, A., Zafeiropoulos, N. E., & Salmas, C. E. (2024). Microwave- assisted extraction of cellulose from Aloe Vera plant residue and preparation of cellulose nanocrystal- poly (vinyl alcohol) hydrogels. *Molecules* (Basel, Switzerland), 29(24). <https://doi.org/10.3390/molecules29246012>

Yin, C. Y. (2010). Emerging usage of plant-based coagulants for water and wastewater treatment. *Process Biochemistry* (Barking, London, England), 45(9), 1437–1444. <https://doi.org/10.1016/j.procbio.2010.05.030>