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Partial Replacement of Alum by Using Natural Coagulant Aid to Remove Turbidity from Institutional Wastewater

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Abstract: The quality of water is superior for the stability of the ecosystem. Institutional wastewater contains pollutants and exceed the level of contaminants beyond standards. Applications of natural coagulants are widely in practice due to abundant source, low price, environment-friendly and rapid biodegradable as compared to inorganic based coagulants. This study traces the potential removal of pollutants from institutional wastewater by coagulation-flocculation processes. Alum as primary coagulant and cassava peel starch as natural coagulant aid was used for removal of pollutants. The use of alum dose in wastewater treatment plant has harmful effects on human health and water drainage system, on the one hand and on the other hand, a process that alum coagulant dose used in wastewater treatment plant with a high processing cost. In this study, the use of cassava peels starch (CPS) (as a natural coagulant) instead of alum dose to treat wastewater to remove turbidity from institutional wastewater. The study samples were taken from the Tun Fatimah-UTHM. Experimental runs were carried out for three hours per run over weekend period with turbidities ranging from 20 to 400 NTU. Proven results of the study that by using natural coagulant CPS (which is a naturally contains potentials) instead of alum does not carry any impact on human health and has a high efficiency up to 81% in the removal of turbidity from institutional wastewater at pH 8. The turbidity ranges during most of the test runs satisfied the WHO and water quality standards (A & B) for potable water supplies.

Keywords: Cassava Peels Starch (CPS), wastewater, coagulation and flocculation, alum dosage, turbidity removal

1. Introduction

The production of safe and healthy water from most raw water sources is an essential part to complete the water cycle. Each year, a large quantity of institutional effluents containing organic and inorganic materials discharged into the environment without any cure. Clean water is very essential to human existence, and the unavailability of potable water is the predominant reason for most deaths and diseases. Major sources of institutional wastewater are households, institutions, and commercial buildings which contain large concentrations of organic and inorganic substances. Poor sanitation and unsafe water cause 88% of the 4 billion annual cases of diarrhea, resulting in the death of about 1.8 million people per annum. Safe water and hygienic environment can reduce about 94% of death cases [1].

Henze et al. [2] studied the composition of institutional wastewater and found it to contain turbidity, TSS and COD, coming from both domestic and surface runoff sources enters institutional wastewater treatment plants [3]. Pollutants loads from various sources such as human waste (0.60 kg/capita^{-1} year^{-1}); laundry detergent (0.30 kg/capita^{-1} year^{-1}), and other household cleaning products (0.10 kg/capita^{-1} year^{-1}) have been estimated to calculate the total load in the wastewater treatment plants and subsequent treated water and biosolids used for land application [4]. Such type of improper treated leads to cause approximately 75% of pollutant load may reach water streams and cause eutrophication [5].

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It is, however, important to subject water from every source to varying forms of treatment or purification before consumption or discharge back to the environment. The level of threat water poses determines the choice of treatment to be employed [6]. However, major improvements in health conditions through the provision of sufficient safe water can only be achieved through domestic hygiene practice and proper methods of water purification. The provision of water supply nearby for consumers and sufficient for their daily needs will help greatly in decreasing the incidence of skin diseases, eye infections and also reduce diarrhea diseases as well as most worm infections, particularly if the water is of good quality bacteriologically [7].

Coagulation/flocculation is wastewater treatment method that involves coagulants use at early stages in order to remove turbidity in the form of suspended and colloidal material. Many coagulants and flocculants are widely used in conventional wastewater treatment processes. These materials can be classified into inorganic coagulants and organic coagulants. Organic coagulants comprise aluminium that are commercially available and are the most extensively used coagulants in wastewater treatment all over the world [8]. Traditional in most treatment plant organic coagulants are widely used for wastewater and sludge dewatering.

The organic coagulants are polymers, possessing high cationic charge, which is necessary to destabilize negatively charged colloidal particles and ensure rapid flocculation. Organic flocculants contain water-soluble high molecular weight compounds, when administered in dispersions are adsorbed or chemically bound to the surface of the dispersed phase particles and particle agglomerates are combined (floccules), promoting their rapid deposition [9]. In this era there is considerable interest in the advance development and generation of natural coagulants usage which can be produced or been extracted from microorganisms, animal or plant tissues [10]. Such natural coagulants are easily biodegradable, environment friendly, recyclable (sludge) and are presumed to be safe for human health. In addition, natural coagulants produce readily biodegradable and less voluminous sludge that amounts only 20–30% that of alum-treated counterpart [11].

2. Background

Cassava peels starch is one of the most important starch and also a flexible food ingredient possessing value added attributes for innumerable industrial applications. The most common sources of food starch are corn, potato, wheat, cassava/tapioca, and rice. Cassava is the sweet potato as the most important starch rich root origin of the tropics [12]. The cassava plant has been classified botanical as *Manihot Utilissima Pohl* with *Euphorbiaceae* family. In recent investigations, however, the name Manihot esculenta Crantz is adopted to a greater extent [13]. Cassava grows under diverse ecological and agronomical conditions around the world particularly in the tropical and subtropical area between latitude 20N and 30S of the equator [14].

Cassava tuberous root formation commences by the end of the second month following planting. The tuberous roots continue to increase in size along with the time, caused by the deposition of a large amount of starch within the tuberous root tissue. As the tuberous roots become older, it becomes more lignified and fibrous which decreasing its total dry weight [15]. The color of the outer peel varies from white to dark brown. The peel is composed of the outer layer (called the periderm) and the inner layer (called the cortical region or cortex), which contains sclerenchyma, cortical parenchyma and phloem tissue [16]. The large central pith of the roots is the starch-reserve flesh, comprised of cambium and parenchyma tissue and xylem vessels.

The cassava roots are starchy, according to the climate conditions its harvesting growth may varied between 8 to 24 months of planting. A cassava that is almost ready for harvesting roots size ranges from 15 to 100 cm in length and from 0.5 to 2.0 kg in weight, subject to its growth and climate variations [17]. The root shape is similar to the circular and cross-sectional area. It is usually fatter at the proximal end and taper gently towards the distal end. Crosswise a cassava root consists of three main areas. The Periderma/periderm comprises the outermost layer of the root. It is composed mostly of dead cap cells, which seal the superficial of the root [18]. The periderm is only a single layer of cap cells thick and as the root increases continuously in diameter, the outermost portions of it are become weaker off and replaced by new bung formations from the inside layers of the periderm. The cortex is thick and ranges 1 to 2 mm that is located immediately lower the periderm known as the starchy flesh. Starch grains accumulated in the central portion of the root, consisting mainly of parenchyma cells [19].

According to FOA [20], the estimated total world-class cassava production was 230 million tons in 2010. Nigeria is the largest cassava producer with 37 million tons produced in 2010. After Nigeria, Democratic Republic of Congo, Angola, and Ghana are among the largest producer. [21] mentioned that cassava plays important roles in African development, as famine reserve crop, the rural staple food, cash crop, raw materials for feed and chemical industries.

In Malaysia, cassava has been planted mainly for starch extraction. A major proportion of this starch is used in the food processing industries such as the manufacturing of monosodium glutamate [22]. Estimate, 3000 tons of starch is used per month for this purpose. Other significant users of starch produced are manufacturers of glucose, bakery and biscuit products, textile and paper [23]. The Malaysia government has actively encountered greater agricultural output. This move has generated recently renewed enthusiasm in increasing cultivation of cassava for starch production, dried chips, livestock feeding and sweeteners [24]. Production of snack foods has become a promising alternative use of cassava.

Natural coagulants contain rich amount of proteins and polysaccharides that are terms as polyelectrolytes for being polymers [25]. According to Bisaria et al. [26], it has been sought in the biodiversity of natural resources such as; natural coagulant, biodegradable, with low toxicity, simple use, inexpensive and easily obtained, these are most economical ways to sustain pollutants in green way. Ferrari et al. [27] observed that the sludge resulting from the treatment of water or effluents, since it is organic, can be used as prime material to produce organic fertilizer, with slow and controlled nitrogen release, thus avoiding urea use, for example, the use of natural coagulants for effluent treatment can benefit the frigorific industry. In consideration that the effluent generation is unavoidable, the water obtained after treatment could be recycled in the industry outside areas and the generated sludge will be more easily eliminated due to their biodegradability [28].

The natural coagulant is a naturally occurred; plants-based coagulant that can be used in the coagulation-flocculation process of wastewater treatment for reducing turbidity, COD, TSS, by varying dosage as shown in Table 1. The objectives of this study were to assess the possibility of using natural coagulants as an alternative to the current commercial synthetic coagulant such as aluminium sulfate and to optimize the coagulation process [29]. In wastewater treatment, coagulation has been practiced since the earliest times and the main objective is to remove colloidal impurities from the wastewater.

The awareness of utilizing natural coagulants and flocculants for wastewater treatment dates back to over several ages ago, way before the advent of chemical coagulants [30]. The uses of natural coagulants and flocculants represent a vital development towards sustainable environmental technology as these materials are cost-effective, highly biodegradable and unlikely to produce treated water with extreme pH [31]. However, not many studies have been conducted in using cassava biomass in coagulation and flocculation process. [32] conducted research on the performance of two varieties of cassava as a coagulant in wastewater treatment and comparison with alum.

3. Cassava Peels Starch (CPS)

Starch granules are composed of two polysaccharides, linear amylose, and branched amylopectin molecules held together by hydrogen bonds, either directly or via hydrate bridges [33]. Extraction of starch from the plant is termed as “native starch”. Starch undergoes one or more chemical modifications depending on required specific properties and is called “modified starch” [34]. However, functional group (such as amine, carbamate and so on) is grafted onto the cross-linked starch, which enhances affinity with various molecules.

Cassava has a slightly acidic reaction (pH 5.5 to 6.0), which is typical for healthy plant tissues. According to [35] cassava peels distribution based on 3 layers namely; flesh, periderm, and cortex. Each layer has its own potential to carry the number of carbohydrates, proteins, and minerals as shown in Table 1. Cassava is easy to extract using a simple process (when compared to other starches) that can be carried out on a small scale with limited capital.

Table 1 - Composition of cassava peels starch (%) [36]

Component	Composition (%)	Component	Composition (%)
Moisture	70.25	Fats	0.41
Starch	121.45	Fibre	1.11
Protein	1.12	Ash	0.54
Sugars	5.13		

The range of molecular weight (Mw) of amylopectin was 0.82 to 2.50 ×108 g/mol, and there was also a negative correlation between amylopectin Mw with amylose content [37]. Amylose Mw ranged from 2.20 to 8.31×105 g/mol. After debranching the amylopectin with iso-amylase, the weight-average degree of polymerization (DP) for the long-chain fraction correlated positively with a higher amylose content.

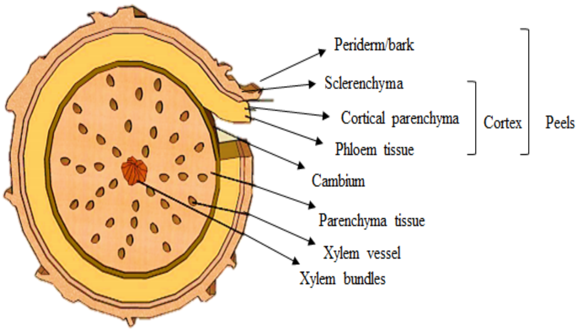


Fig. 1 - Structure of cassava peels [37]

Table 1 - Various natural coagulants used for wastewater treatment

Type of natural Coagulant	Type of coagulant	Type of water	Removal Parameters	Rapid mixing time (min)	Rapid mixing speed (rpm)	Slow mixing time (min)	Slow mixing speed (rpm)	Settling time (min)	pH	Average Removal Efficiency (%)	Coagulant Dosage	Authors
Calotropis Procera (Sodom Apple)	Leaves	Tap water, Textile wastewater	Color, TDS and Turbidity	2	200	1	50	30	2-11	Colour 69.48% Turbidity 0.53%	1-4.0 g	[38]
Chitosan	fiber	Food industry wastewater, Institutional wastewater	Turbidity, Color, pH optimization	3	200	20	40	45	6.5-7.5	75-95% Turbidity, Color, pH optimization	0.1 – 60 mg/L	[39], [40]
Moringa stenopetala	Seeds	Industrial wastewater	Turbidity, Heavy metals (Cd)	1	200	$5^{-1}0$	15-25	$60^{-1}20$	2-12	Cd removal up to 53.8%	2.50/100ml	[41], [42]
Moringa oleifera	Seeds	Institutional wastewater, Industrial wastewater	COD, Turbidity, BOD	1	100	30	30	30	3-11	COD, 46-73% Turbidity,85–94% BOD, 88-92%	$100^{-1}80$ mg/L	[43], [44]
Nirmali seeds (Strychnos potatorum)	Seeds	Turbid water	BOD, COD,	1	100+ 10	20	20+5	20	-	COD 65-75%	0.25-3.5 mg/L	[45], [46]
Tanin	Plant	Surface wastewater, institutional wastewater,	Turbidity, BOD COD	2	100	20	30	60	7	Turbidity BOD 85-90% COD (50%)	0-50ppm	[47]
Vicia faba	Seeds	Institutional, Texttile wastewater	Turbidity, TSS, TDS	3	300	-	-	7	7	Turbidity COD 60-70%	6.75mg/L	[48], [49]

4. Materials and Methods

Institutional wastewater samples were taken directly from the institutional wastewater treatment plant located behind Tun Fatimah hostel in University Tun Hussein Onn Malaysia (UTHM), 1°51 56′.99" N 103°05′22.08" E, as shown in Fig. 2. Institutional wastewater from different streams residential colleges, academic buildings, administration buildings, library, canteens and other premises along with surface runoff (rainwater) were discharged into sewage plant UTHM. Samples were collected from one of the mainstream discharge points, six times at 2-weeks interval, within about 3 months from June-August 2018. Sample collection and preservation were done in accordance with the Standard Methods for the Examination of Water and Wastewater [50]. The collected samples were stored at 4 ◦C. Characterization was carried out immediately after samples arrived in the laboratory.

Fig. 2 - Institutional wastewater discharge point, sewage plant, UTHM

Institutional wastewater characterization was based on wastewater standards effluent standards A and B. Table 2 shows raw characteristics of institutional wastewater.

Table 2 - Institutional wastewater characterization

Parameters	Range [a]	Mean [b]
Temperature (°C)	25–31	27
pH	8.2–8.5	8.4
Turbidity (NTU)	268–502	347

[a] *The values measurements are up to three averages. The differences between the measurements were less than 1%.*

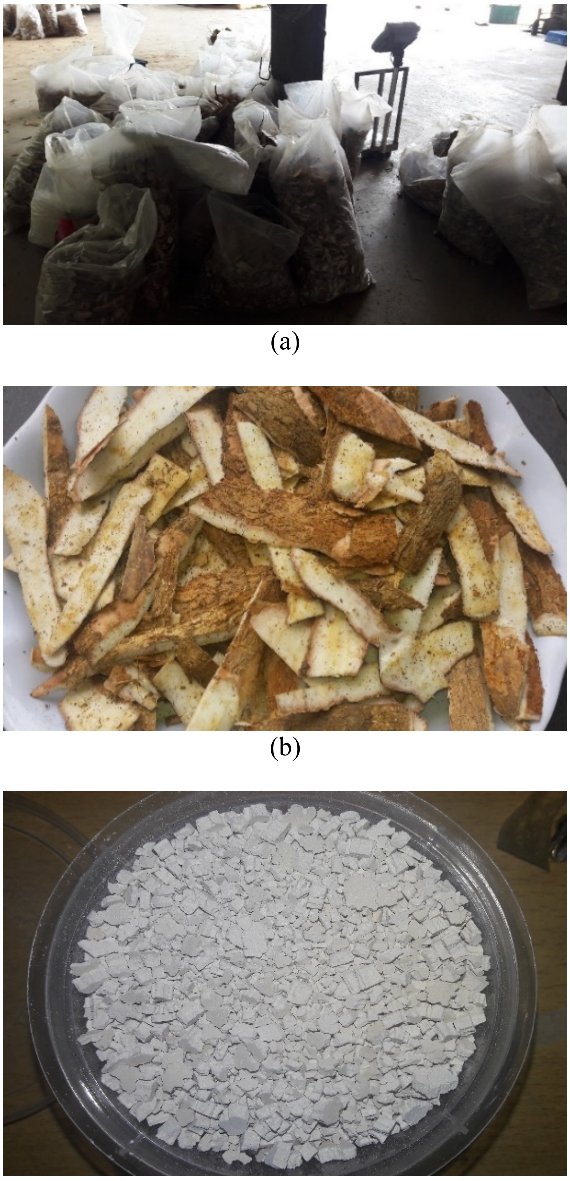
[b] *Samples taken from June to August 2018 were six averages.*

5. Collection and preparation of CPS as coagulant aid

In this study agriculture waste (cassava peels) were collected into polyethylene bags from the small-medium industry at Parit Raja, Batu Pahat. Each collected agricultural waste bags were measured by weight machines to ensure the production of mass per bag to produce bio coagulant that can be easily calculated. Each waste bag contains raw waste of 20-30 kg, after separation of excess waste from bag net weight of cassava peels were measure approximately 2 kg per bag. After the separation step following by filtration, peeling and drying, the net weight of bio coagulant as native cassava starch powder was obtained about 180-200g per bag as shown in Fig. 3.

6. Preparation of CPS stock solution

Stock solution for CPS was prepared by adding 200g of CPS powder into 1L of distilled water to produce a 0.1 percent suspension (Concentrated). After that, the suspensions were vigorously mixed by a magnetic stirrer for about 1 hour to ensure that it is properly mixed with distilled water.



(a)

(b)

(c)

Fig. 3 - (a) Agriculture waste produced by factory collected in polythene bags (b) Raw cassava peels obtained after separation process (c) Native cassava starch as bio coagulant powder

7. Coagulation and Flocculation

In this study two coagulants were practiced; alum as a primary coagulant and cassava peels starch (CPS) as a natural coagulant aid. The alum used in this study was in powder form with the formula $Al_2(SO_4)_3 \cdot 18H_2O$ (M= 666.42 g/mol, 51–59% $Al_2(SO_4)_3$, pH 2.5–4) and supplied by Merck, Germany. The stock solution was prepared accordingly in order to apply dosage at various ranges. Coagulation-flocculation experiments were carried out using a conventional jar-test apparatus (JLT 6, 6-position jar tester;). The rapid mixing and slow mixing time were obtained from studies conducted by different researchers [51-52]. Accordingly, for this research, in order to achieve optimum conditions, parameters were set as rapid mixing speed 200 rpm, slow mixing speed 50 rpm, rapid mixing time 1 min, slow mixing time 15 min, and settling time 30 min.

8. Results and Discussion

8.1 Effect of pH on Reduction of Turbidity

Raw institutional wastewater sample was controlled with a various range of pH and treated with a fixed dosage of the chemical coagulant (alum), biocoagulant (CPS) and combination of both (alum+CPS), for the determination of optimum pH. In this experiment, a series of jar test conditions were kept constant as reported by Zin et al. [53] in order to achieve suitable pH for turbidity removal. The average initial pH was recorded from the jar test series experiment was 6-8, later it was adjusted using HCl and NaOH 0.5M of the solution to adjust the pH. A fixed dosage of alum was used for the jar test to obtain an optimum reduction of turbid pollutants under different pH conditions [54]. The jar test was performed at pH 2-11 range revealed that removal efficiency of turbidity was 41%, it was observed that at pH 5, the optimum removal of pollutants as shown in Fig. 4. In all cases, the removal efficiency was found to increase from pH 2 to 5, with pH 5 as the optimum condition for alum dosage, pH 8 for CPS and alum+CPS, with removal efficiency of 54% and 69% respectively.

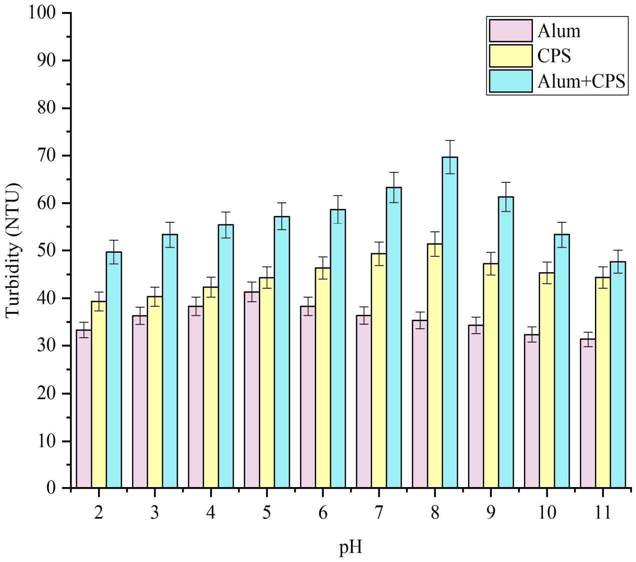


Fig. 4 - Effect of pH on the reduction of turbidity by using fixed dosage of alum, cps and alum+CPS

8.2 Effect of Alum Dosage on Reduction of Turbidity

At optimum pH 5, by keeping dosage constant in order to achieve optimum pH, various range of dosage were practiced on optimum pH5. A wide range of dosage were adjusted from 5-30mg/l. Through the experimental work, it was investigated that a gradual increase was observed, at the fixed point 30mg/l proven to remove turbid particles with removal efficiency of 74% as recorded in Fig. 5.

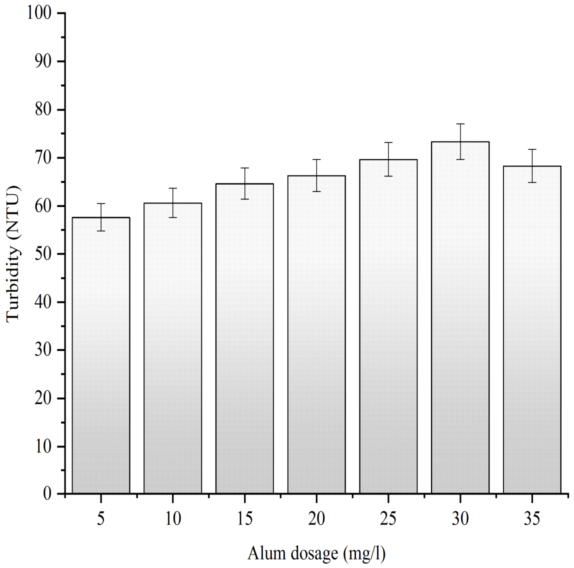


Fig. 5 - Effect of alum dosage on the reduction of turbidity

8.3 Effect of CPS dosage on reduction of turbidity

The removal of turbidity at the earlier stage was reduced after applying a dosage of 500-600 mg/L at pH 8, reduction in turbidity at higher dosage were also reported by [55]. The usage of natural coagulants at higher dose will reduce the removal of turbidity due to the suspended solids by total solids itself remain in suspension (Alias, 2004). The highest percentage removal recorded for turbidity is 62% at a dose of 400 mg/L. It was also observed that removal was recorded for CPS dosage. However, due to the no charge neutralization, due to its stable colloids but it was observed that bridge structure of particles as a bridging mechanism [56].

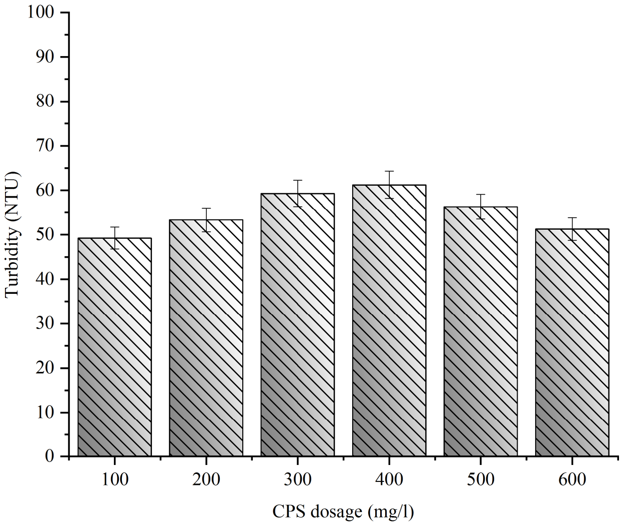


Fig. 6 - Effect of CPS dosage on the reduction of turbidity

8.4 Effect of alum+CPS dosage on reduction of turbidity

The institutional raw water sample was treated with different concentrations of CPS as bio coagulant aid and a fixed concentration of alum as a primary coagulant. The pH was fix at optimum value observed from section 8.1 as pH 8. The initialization of the experiments was carried out with the range of alum+CPS dose at 100:0, 80:20, 60:40, 40:60, 20:80 and 0:100 and optimized dose of alum at 30mg/l (optimum dose from single coagulant) and 400mg/l for CPS (coagulant aid). The results show the highest percentage removal for Turbidity was recorded at a ratio of 40:60 at pH 5 (optimum), where the removal efficiency was 81%. At the optimum removal of pollutants in the difference of percentage removal probably due to a lower dose of alum as used in existing study compared with other studies that consumed a high dose of chemical coagulant and due to different concentration of wastewater characteristics. However, from previous studies, as reported in literature shown (Table 1) that the removal of dual coagulant can be improved by applying the composite coagulant method since it can improve the coagulation efficiency, increased the percentage removal and consumed lower dosage. In order to improve and achieve the highest percentage removal compared with the single and dual coagulant plays a vital role in removal efficiency.

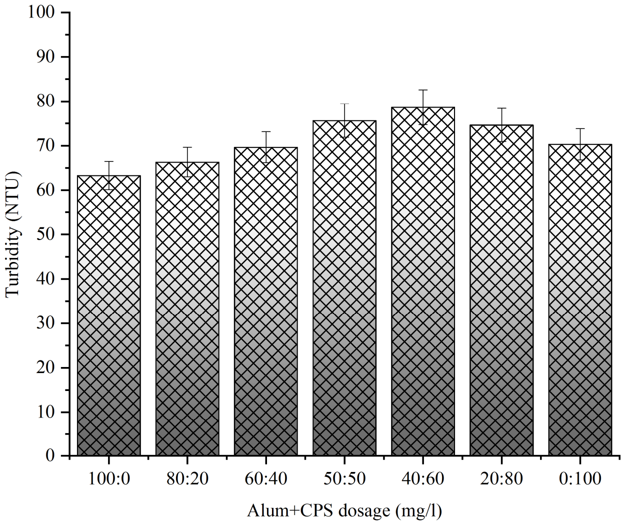


Fig. 7 - Effect of CPS dosage on the reduction of turbidity

9. Summary

It could be concluded that the application of CPS in the institutional wastewater treatment showed that it can be used effectively as a natural coagulant to replace chemical coagulant in removing turbid particles in wastewater, and it is effective in maintaining the health of water according to the recommended standards to discharge wastewater back to the environment after treatment. CPS used for the test runs was obtained from the jar test results are, 30 mg/L, and 40:60 mg/L for turbidity water removed an average 81 % of the initial turbidity of the raw water. The quality of water treated using CPS was well below the WHO and Effluent Standards sewage recommended by Indah water for water discharge at <5 NTU, Turbidity. This present research study shows from the result of the experimental data for the pollutants removal from the institutional wastewater demonstrated that CPS is a potential agriculture waste to produce coagulant aid due to availability amylose and amylopectin being an active starch-based agent to treat institutional wastewater according to Malaysian sewage effluent standards A and B.

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