Research Article

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A comparative study of different coagulants used in treatment of turbid water

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Abstract: Turbidity is one of the major problems in the treatment of drinking water. Turbid water contains molecules, plankton, and colloids, and is dealt with through the addition of coagulation chemicals in processes called coagulation and flocculation. In this research, three of the most commonly used coagulants utilized in the process of turbid water treatment are examined for their efficiency in reducing turbidity. The three types of different coagulants that have been employed are aluminum sulfate (alum), ferric chloride, and poly aluminum chloride (PACl). The samples are taken from the Tigris River at various levels from the water's surface (60, 120, 180, 240, and 300 cm). The results showed that PACl is more efficient in removing turbidity than alum and ferric chloride. Ferric chloride is a more efficient coagulant than alum at different ranges of turbid water. In this study, the effects of employing a natural coagulant such as "Walnut coat" with PACl and synthetic polyacrylamide with PACl for removing turbidity are compared to using PACl alone. When compared to PACl alone, polyacrylamide with PACl was effective in removing turbidities of 22.8 and 25.7 NTU. Walnut coat was also proven to be more effective when combined with PACl for lower turbidities (20.7 and 21 NTU). Within the first 5 min of slow mixing with polyacrylamide, large, transparent, and readily settled flocs formed, whereas the same flocs formed after 30 min of slow mixing with PACl and walnut coat as flocculant. With both polyacrylamide and walnut coat as coagulants, better sludge properties were obtained, with low water content and high density that can be readily dried and disposed of.

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1 Introduction

One of the effects of the turbidity on the level of water quality could be resulting in an effect on aquatic life. It limits oxygen uptake and reduces the food availability by causing sediments [1]. Turbidity and light penetration are important variables that influence abundance and distribution of aquatic plants [2] including plankton. Turbidity is of critical importance because it has impacts on an ecosystem level.

As a result, the kind of suspended elements in water is vital in selecting the type of coagulant to be employed to eliminate turbidity during water treatment. Colloids are surface water contaminants that are not eliminated naturally or during settlement processes, necessitating the use of coagulants in proper quantities and chemical quality to remove them.

Therefore, coagulation is the process used for reducing turbidity and organic matter. Thus, it results in an effective performance even when it involves greater share in the cost of operation of water treatment.

Before being cleansed into potable water, water that is generally polluted by humans in their everyday activity should go through several treatment stages. Screening, flocculation, coagulation, sedimentation, filtering, and disinfection are all processes used in traditional water treatment plants [3].

The coagulation (or rapid-mix) step is separated from the flocculation (or slow-mix) stage in traditional water treatment plants. Sedimentation and subsequently filtering follow these two phases. Direct filtration plants send their water straight from the flocculation stage to the filtration stage. The raw water quality in these systems is usually better. Both the rapid-mix and slow-mix equipment in conventional plants can have variable mixing rates. Multiple feed points for coagulants, polymers, flocculants, and other chemicals can be given, and there is usually enough room to segregate incompatible compounds from the feed points. Plants with traditional retention times are more conservative. They normally necessitates big process basins and a substantial quantity of land for the plant site. Prior to design, an on-site pilot plant evaluation by a certified engineer knowledgeable with the water quality is advised [4].

Flocculation, a gentle mixing stage in a water treatment plant, raises particle size from submicroscopic microflocs to visible suspended particles. When microfloc particles encounter, they join together to form pinflocs, which are larger, visible flocs. Additional collisions and interactions with added inorganic polymers (coagulant) or organic polymers increase the size of the floc. Macroflocs are generated and coagulant aids, or high molecular weight polymers, may be introduced to help bridge, bind, and reinforce the flocs, as well as add weight and speed up their settling rate. The water is ready for sedimentation once a floc has acquired its optimal size and strength.

The coagulation process is assessed in this study for its ability to remove low levels of turbidity and color from water using various coagulants. Some research reveals that poly aluminum chloride (PACl) at a dosage of 5 mg/L is the best coagulant for removing turbidity (99–99.8%) and color (100%) on an experimental scale utilizing a jar test apparatus [3].

The type of suspended solid to be removed, raw water conditions, facility design, and chemical cost all play a role in the coagulant chemical selection. Jar testing and plant-scale evaluation should be used to make the final decision on which coagulant (or coagulants) should be used. The needed effluent quality, the impact on downstream treatment processes, performance, cost, sludge handling and disposal methods and costs, and the cost of the dose required for effective treatment must all be taken into account [5].

Some natural coagulants have been utilized in such studies, for example, red bean, sugar, red maize, cactus latifera, and seed powder of prosopis juliflora and others [6]. Natural coagulants have a promising future in water filtration, according to numerous studies, due to their large supply, low cost, environmental friendliness, multifunctionality, and biodegradability.

The coagulants' assistance are divided into two categories: natural coagulants and synthetic coagulants.

One study used synthetic turbid water manufactured to look like drinking water to assess the capacity of three plant materials (seeds such as *Moringa oleifera*, *Strychnos potatorum*, and *Phaseolus vulgaris*) to behave as natural coagulants [7]. The active coagulant agent *M. oleifera*, *S. potatorum*, and *P. vulgaris* seeds were extracted using an enhanced and alternative method that was compared to the traditional water extraction method. To extract the active coagulant agent from natural coagulants, the seeds were extracted using various solvents of NaCl and NaOH. Ultrasound was also looked into as a possible way to help with the extraction procedure.

Batch coagulation studies were carried out to see how well the extracted coagulant performed under various schemes. The best turbidity removal level was examined at varied beginning synthetic wastewater turbidity values ranging from 100 to 500 NTU. When compared to NaOH and distilled water extract, sodium chloride at 0.5 M provided a high turbidity removal of >99%.

M. oleifera seed extracts outperformed the other two coagulants in terms of turbidity reduction [8].

Different forms of synthetic coagulants that operate on the water to be treated to destabilize both suspended and dissolved particles could be utilized [9]. Synthetic coagulants are designed to generate clots that can be separated using solid–liquid separation techniques. The most commonly employed processes are precipitate sedimentation and flotation.

The impact of coagulation on water treatment efficiency for turbidity reduction will be examined in this study. Many researchers have been studying the separation of suspended particles from river water for many years. Coagulation–flocculation, sedimentation, and filtration units are commonly used in conventional treatment. The removal efficiency of all of these activities is highly reliant on particle size, which may normally be improved by aggregation of tiny particles in the coagulation flocculation sequence. The nature and quantity of colloidal pollutants, the kind and dosage of chemical coagulant, the usage of coagulant aids, and chemical features of the water, such as pH, temperature, and ionic character, all influence turbidity removal by coagulation [10].

Chemical coagulation and flocculation are also assumed to be dependent on physical processes in water treatment. The mixing procedure for inducing aggregation of destabilized colloids is affected by the coagulant dosage, pH, and coagulant aids used. The coagulation flocculation system's efficiency is determined by subsequent settling and filtering [11].

The project's main goal is to use the coagulation process to reduce the turbidity rate of a certain water model. The effectiveness of each of the three distinct coagulants in eliminating water turbidity is investigated in this study. This research looks at three different types of coagulants: aluminum sulfate (alum), ferric chloride ($FeCl_3$), and poly aluminum chloride (PACl).

The effect of using natural coagulant aids with the most effective coagulants in removing turbidity and synthetic polymer aid on turbidity removal compared to other coagulants is also being investigated. The study compares the effects of using both the natural coagulant assistance "Walnut coat" and the synthetic polyacrylamide with the most effective coagulant on turbidity reduction to using the most efficient coagulant alone at various concentrations.

2 Materials and methods

The experiments took place in a sterile laboratory at Wasit University's College of Engineering. All coagulation tests were conducted with natural turbid water collected from several areas along the Tigris River and at various depths. The investigations employed a standard jar test apparatus to coagulate a sample of turbid water using coagulants. In this study, a number of variables were looked into. The following measurement methods were investigated:

- A turbidity meter was used to measure turbidity using the Nephelometric method.
- A pH meter was used to determine the pH.
- Total dissolved solids (TDS) and electric conductivity (EC) meters were used to assess TDS and EC.

2.1 Preparation of turbid water

The samples for this study were taken from the same location of the Tigris River but at various levels of depth. Thus, each sample has its unique quantity of turbidity which was significantly different from one sample to another.

The method that was utilized to draw samples of turbid water at different levels at the same location was by a simple technique. A simple tube whose diameter and length were known was used to withdraw samples. A pump was used which was attached to the long tube whose height was around 3 m (>300 cm). The samples were taken at various water heights using the pump and the tube whose height was known. The withdrawing of water was achieved at the same time at different heights of the same area in the Tigris River. The heights were 60, 120, 180, 240, and 300 cm. Figure 1 shows the method of withdrawing samples at various depths.

2.2 Stock solution of natural and synthetic coagulants

For our experiment, three different types of coagulants were used in this research, which are: alum, ferric chloride, and PACl. At the beginning of this project, jar test experiments

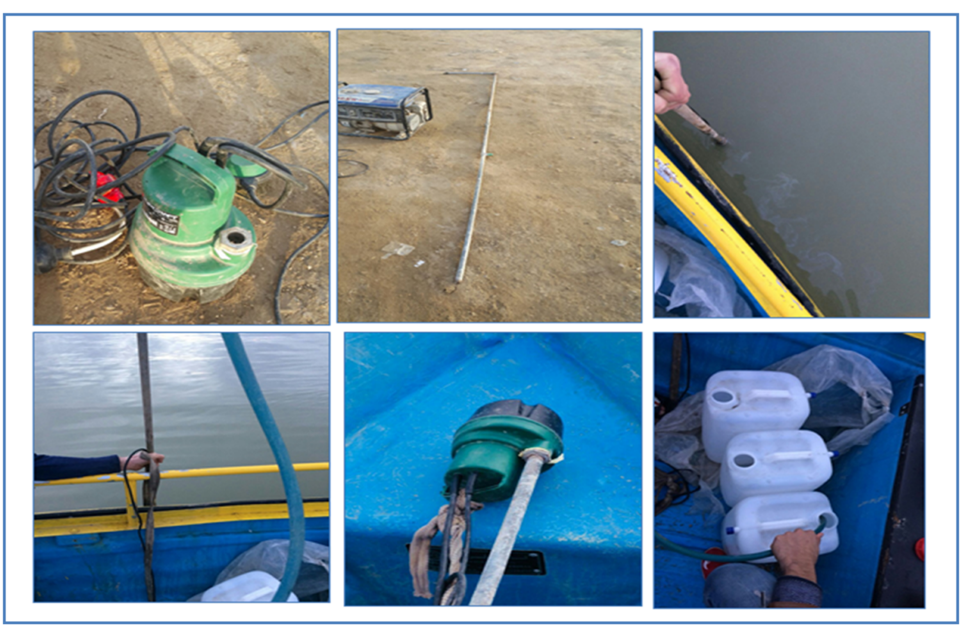

Figure 1: The method of withdrawing samples of water at various depths.

were carried out on those three types of chemical coagulants to investigate which one of those chemical coagulants was considered to be the best one in removing turbidity from water samples. After that, the one that had the highest efficiency in removal of turbidity was added to coagulant aids. The coagulant aids that were utilized in the research were natural (walnut coat) and synthetic (polyacrylamide). Different concentrations were used for the three types of chemical coagulants which were 10, 20, 30, and 40 mg/L. According to the natural coagulant aid, its concentrations were 20, 40, 60, and 80 mg/L, and in respect of the synthetic coagulant aid, its concentrations were 10, 20, 30, and 40 mg/L.

For a natural coagulant aid, walnut (*Juglans* spp.) coats were used as the coagulant aid. The coats were separated from the nut. The coat collected was fresh and mature. The coat was ground to make a fine powder using a blender to make it approximately 200 μm in size, to obtain pass-through powder to use in this research. The 200 μm is used in which it demonstrates that D50 is 200 m, meaning that 50% of particles are smaller than 200 μm (i.e., the median diameter). Similarly, D10 and D90 indicate that 10 and 90% particles, respectively, are below these two distances. It should be noticed that each D10, D50, and D90 is a size value rather than a range for the specific size measurement. These values are modified at different measurements or different samples. D50 is defined as the size value that corresponds to the cumulative size distribution at 50%. This size value describes the size of particles that make up 50% of the sample. 1% suspension was prepared by adding tap water to the powdered walnut coat. The magnetic stirrer was used for shaking the suspension for 45 min.

Furthermore, regarding synthetic coagulants, powder of polyacrylamide was used, which was bought from local market. 1% suspension was prepared for the powder using tap water. Magnetic stirrer was utilized for shaking the suspension for 45 min to prevent agglomeration and to promote the suspension to be homogenous.

Regarding the stock solutions, it was prepared daily to prevent any effect in the characteristics such as changing in the pH and viscosity. The effect of viscosity is obtained in the distortion in the velocity pattern of the solution by hydrated molecules of the solute. Moreover, the viscosity increases with the increase in the concentration of the solutions because of the increase in hydrogen bonding with hydroxyl groups that leads to the theory of intermolecular activity. Also, those solutions prepared from synthetic coagulant were shaken vigorously before use.

2.3 Jar test operations

Additionally, a jar test is an experimental procedure to illustrate the coagulation and flocculation concepts associated with natural water. From this experiment, the optimal pH, coagulant dose, and coagulant aid could be determined. Therefore, coagulation and flocculation were designed to remove microorganisms and colloids that caused turbidity and toxic compounds that are sorbed into particles (Figure 2).

Hence, by using the jar test experimentation, the optimum concentration of coagulant to be added to the turbid water can be determined. Thus, the best ratio for

Figure 2: Jar test apparatus.

the removal efficiency using either natural or synthetic coagulant can also be determined.

2.4 Analytical methods

Different analytical procedures are used to perform several investigations for the study of turbidity and pH values of the source water.

Also, the TDS and EC tests were conducted for some suspensions of coagulants with the natural and synthetic coagulant aids to determine TDS and EC which are considered to be essential water quality parameters for describing the salinity levels. TDS analysis is vital because it can define groundwater quality too.

2.5 Experimental setup

For the experimental process, the steps can be presented as follows:

- Different water samples have been taken from the Tigris River at various depths.
- The samples were taken at 60, 120, 180, 240, and 300 cm from the water surface at the same location.
- Three different coagulants have been used (alum, ferric chloride, and PACl).
- Different concentrations have been utilized which are 10, 20, 30, and 40 mg/L from different coagulants (alum, ferric chloride, and PACl). These concentrations were utilized starting with low concentration going up to high concentrations.
- A jar test is used for the purpose followed with rapid mixing for 2 min and then slow mixing for 20 min. Then, the sample is left for at least 30 min to settle down.
- pH and turbidity are measured before and after the jar test. The data are recorded again for all types of coagulants.
- After the data were collected, analyses were carried out on those three types of coagulants.
- PACl was then mixed with two different types of coagulant aids. PACl was utilized in this study because it showed the best removal efficiency among the three coagulants.
- The first coagulant aid which was a natural one (walnut coat) was used with different concentrations (20, 40, 60, and 80 mg/L) using jar test experiments with various concentrations of PACl.
- The second coagulant aid which was a synthetic aid (polyacrylamide) was utilized with various concentrations (10, 20, 30, and 40 mg/L) using jar test experiments with the same concentrations of PACl.
- Several measurements have been arranged with water samples such as TDS, EC, pH, and turbidity.

3 Results and discussion

3.1 The effect of coagulant type on pH

In this research, analysis has been carried out on the basis of the data that are collected. Three different types of coagulants are used in this research. These are alum, ferric chloride, and PACl.

Figure 3 represents the relationship between pH values and the dosage of alum as a chemical coagulant in this research. It is clear that at various concentrations of alum, there is significantly no effect on the pH values for the four concentrations that are mentioned above. This chart represents the sample taken at a height of 60 cm from the water surface. For alum coagulant, the pH values are in the range from 8.0 to 8.20 for all concentrations of the chemical coagulant.

However, in terms of other coagulants, such as ferric chloride, it is obvious that there is a significant change in the pH values for all dosages of the samples. Moreover, in terms of PACl, there is more change in pH values. Essentially, all dosages of PACl has a significant effect on the pH values of samples. The pH values ranged from 7.0 to 8.0 for PACl. The pH of alum increased when the dosage was 20 mg/L, and then increased using 30 mg/L, and then decreased using 40 mg/L. Thus, the

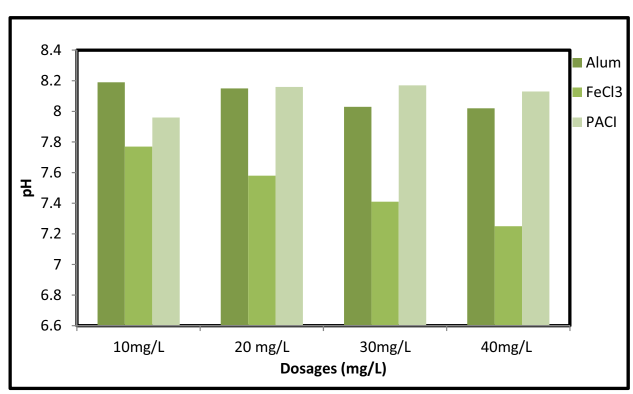

Figure 3: The relation between pH and dosage of coagulants for samples taken at a height of 60 cm.

variation in the pH depends on the coagulant material and the dosages of the coagulant agent. It was found that coagulant dosages needed for efficient coagulation depends on the pH. Indeed, the addition of alum or what is called aluminum sulfate, to the source water, combines with the bicarbonate alkalinities in the water to generate a sticky substance in which the flocs attract other particles and suspended materials in the water, eventually settling to the bottom of the container. Also, alum is soluble in raw water which promotes particle collision by neutralizing the charge in the process of purification of water and water treatment.

Additionally, it needs to be explained as to why the pH of PACl decreased when the dosages were increased. In the introduction of PACl to the solution, the formation of donor-acceptor complexes was observed. The dissociation of aluminum chloride and adsorption of aluminum cation to the anion of functional groups formed complex groups. The formed complexes may interact with one another to form large aggregations precipitating in the form of flocs. Aluminum salts undergo hydration, there is a relation between the pH value and the hydroxocomplex adsorption potential. It could be the ability to dissociate from other functional groups that is related to the pH value. There are electrostatic attractions between PACl and H_2O functional groups. Some parameters play an effective role in the variation in the pH range with the adsorption between PACl as a material with the water solution. In neutral pH, with the increase in the dosages of alum and ferric chloride, the reductions in the pH values are observed because the adsorption ability on the surface of positive hydrocomplexes was noticed by functional groups. Moreover, the variation in pH is also affected with the depth of water. At 60 cm depth, the initial turbidity was 48.4 NTU with a pH of 8.25.

From Figure 4, we can see the relationship between pH and the dosage of three types of coagulants for samples at 120 cm height from the water's surface. For the alum coagulant, the data illustrate a minor change in the pH values for different concentrations of the samples. The range of pH is 7.6 which reached to 7.8. So, this shows that the ferric chloride coagulant represents a little change in the pH values for all concentrations. However, in terms of PACl, there is a little change in the pH values for all doses of the samples. There is a little change in pH values. There is, meaningfully, an effect on the pH values which has fluctuated from 8.14 to 8.2.

Figure 5 displays the correlation between pH values and the dosage of the samples at 180 cm height. It is clearly demonstrated that the pH values have a significant change in terms of the alum coagulant at the 180 cm depth.

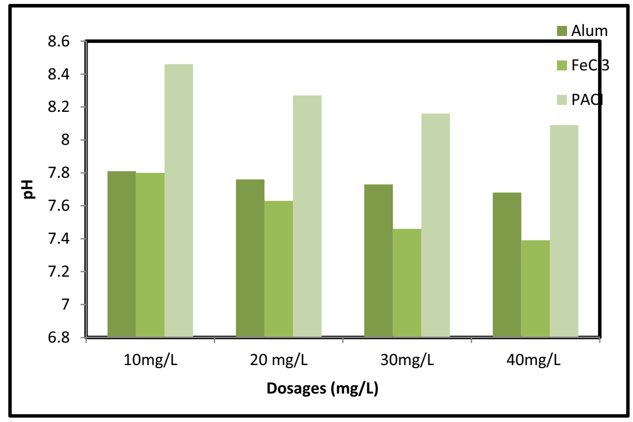

Figure 4: The relation between pH and dosage of coagulants for samples taken at 120 cm height.

Because in adding of alum to source water, reactions can occur with the alkalinities of bicarbonate forming flocs which settle down. Also, the effect of concentrations of alum on the pH, where alum is soluble in water, promotes particle collision by neutralizing charge in the purification of water leading to the variation in the pH.

While in terms of other coagulants, $FeCl_3$ and PACl, there is a slight change in the pH values with respect to the dosages. For instance, the pH values ranged from 7.8 to 8.0 for PACl. This illustration is for the sample at 180 cm height of the water column. Thus, the pH decreases with increase in the dosages for alum and ferric chloride, while for PACl, the reverse happened because of the adsorption ability of the PACl with the functional groups of water that leads to neutralization particles and formation of flocs. It could be the ability to dissociate from other functional groups that are related to the pH value. There are electrostatic attractions between PACl and H_2O functional groups. Thus, the variations in the pH values are observed in relation to the different dosages of PACl as coagulant material.

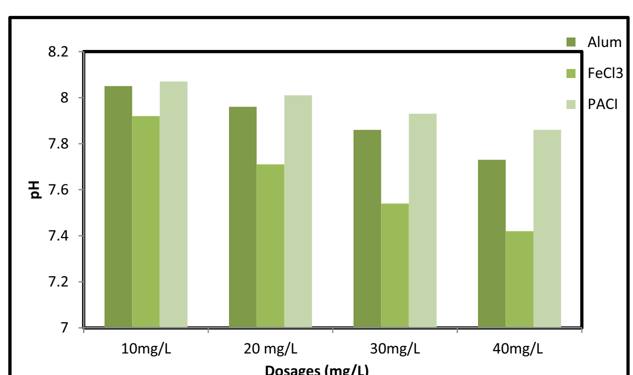

Figure 5: The relation between pH and dose of coagulants for samples at 180 cm height.

Figure 6 exhibits the relationship between pH values vs the concentrations of samples (10, 20, 30, and 40 mg/L). For alum coagulant, there is no effect on the pH values in terms of different dosages of alum. The pH ranges from 7.7 to 7.9. Moreover, the PACl represents only a little change in the pH values. The pH ranges from 8.0 to 8.1. Thus, there is obviously no effect in the pH values for all doses. But for ferric chloride coagulant, there is essentially some change in the pH values. The pH value started from 7.3 and reaches up to 7.9.

In Figure 7, it is demonstrated that alum has little change in the pH values; it starts from 7.7 and goes up to 8.0. Meanwhile, for the PACl, there is a little alteration in the pH values in terms of the dosage of PACl. But for ferric chloride, there is a little more variation in the pH values for all doses of the coagulant. Thus, all the three types of coagulants represent little effect in the pH values in terms of their concentrations. It is shown that the pH for alum as a coagulant increased at low concentrations and decreased at high concentrations, it was in the range from 7.8 to 8 which is considered as a little change. The change might be related to different locations of samples.

Finally, the value of pH is around 7.5 based on the above results which indicates that there is a significant change in pH value in case of using alum alone as a coagulant, and also with using ferric chloride as another coagulant material in the purification of water samples. All published materials concerning alum proved that alum has a substantial consequence on the pH of water. Also, there is little modification in case of using PACl as coagulant with percentages of 50, 60, and 75% for samples at various heights from the water surface. But based on the observation, a slight variation in pH is found in case of using ferric chloride. The high value of pH of 7.8 was recorded when PACl was used (10 mg/L). Therefore, there is a relationship between pH and the depth of water. The pH fluctuates with depth. The depth can be affected by the characteristics of the river system. It was shown that the range of change in pH value from 7.8 to 8 which is considered to be range from neutral to base limit. The flow velocity can impact the flow of water within a river. The location of the withdrawal can be affected by the flow velocity, the amount of soil in the river, and the sediment load.

As a result, the depth of water might affect the position of withdrawal and discharge. The changes in these locations serve to diminish water depth, raise water temperature, and amplify the detrimental effects of sediment oxygen demand and pH variations.

3.2 Effect of coagulant aids on pH

In this research, two types of coagulant aids have been used on the basis of our analyses. The natural coagulant was walnut coat, while the synthetic coagulant aid was polyacrylamide. These coagulant aids were used with PACl as a chemical coagulant.

On the basis of the Figure 8, we can see the relationship between pH and dosage of PACl with coagulant aid for samples at 60 cm height. For the PACl alone, there is no change in the pH values in terms of the dosage of the coagulant. However, there is a little alteration in respect of the PACl with the polyacrylamide. The pH ranges from 8.0 to 8.1. Additionally, there is more change in the pH values in terms of PACl with a natural coagulant aid (walnut (Juglaus. SPP) coat). The pH variations are from 8.0 to 8.5. The primary values, which indicate various types of coagulant aids at various concentrations, have a greater impact on pH performance. The pH increased with the increase in the dosage of PACl + walnut coat for samples at 60 cm depth. It is clear that the pH values

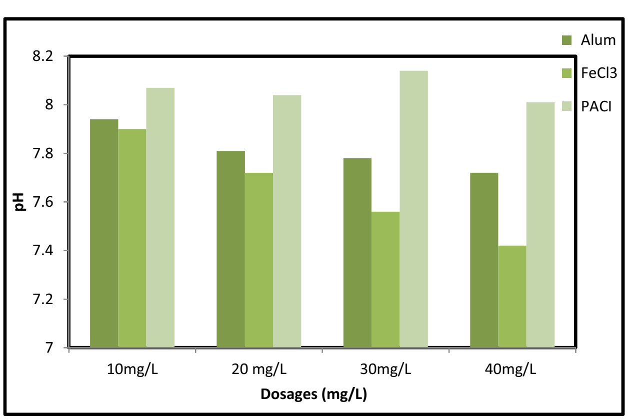

Figure 6: The relation between pH and dosages of coagulant for samples at 240 cm height.

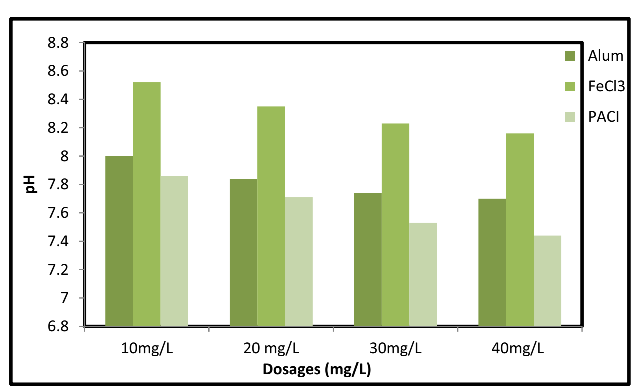

Figure 7: The relation between pH and dosages of coagulants for samples at 300 cm height.

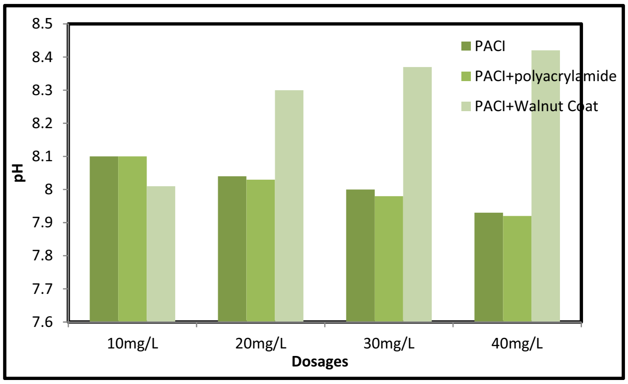

Figure 8: The relation between pH values and coagulant and its aids for samples at a water column height of 60 cm.

without adding any assistant coagulants be changed with increasing the value of pH while in the decreasing the value of pH is considered to be increased then decreased with the value of pH and this changeable values related to the materials added to the stock solution in which play a big role in changing the value of pH. From all these results, the pH varied from neutral to base values in real situation and these values need to be neutralized by treating them before transferring them to another unit in the treatment. Thus, neutralization could be a real solution for treating these values and bringing them to neutral value [3].

From Figure 9, it is clear that there is a little change in pH values with the PACl and walnut coat at this water column height, and there was a change in pH at a depth of 60 cm too. No change in the pH values was observed with the PACl and walnut coat. The main pH values ranges from 8.37 to 8.39 at 120 cm height. Actually, in terms of PACl with polyacrylamide, the pH levels have shifted slightly. The pH level varies between 7.7 and 7.9. Furthermore, there is little change in pH values in terms of PACl. At various concentrations of PACl, there is a little disparity in pH values such as the pH is altered from 7.7 to 8.1. Thus, the coagulant type as well as the coagulant's aid's effect is seen on the performance of pH, so it has an effect on the water treatment as well.

It is obvious from Figure 10 that there is no alteration in pH values in terms of PACl with natural coagulant. The pH is approximately 8.5. However, there is a little difference in pH values in terms of PACl alone. The pH is varied from 8.5 to 8.6. In terms of PACl, there is also a slight shift in pH with polyacrylamide. The variations are from 8.6 at the higher concentration of PACl to 8.5 at the lower concentration of PACl, with lower concentration of synthetic coagulant. Thus, there is significantly little change in pH with PACl mixed with a coagulant aid compared with the PACl alone. This indicates that the effect of a coagulant aid on pH will have an effect on the water treatment.

In Figure 11, it is noticed from the chart that there are no alterations in pH values in terms of PACl alone as a chemical coagulant. The pH ranges from 7.0 to 7.2. However, there are some modifications with the addition of a coagulant aid. By using a natural coagulant aid, the pH is varied from 8.0 to 8.5. Furthermore, the pH is altered from 6.0 to 7.2 with the use of polyacrylamide as a synthetic coagulant aid. In general, the type of coagulant aid employed in water treatment causes a significant shift in pH.

It was noticed based on Figures 7–11 that the value of pH increases with the PACl with polyacrylamide or with walnut coat. However, the value of pH is alone it considered to be changeable. The pH values with pH related to the materials used with the PACl coagulant in which adding assistant coagulant could enhance and reduce the pH values in which not a big change and could be considered as neutral or base solution and can be treated before it goes to another unit in treatment plant.

On the basis of Figure 12, there is no change in the pH values with respect to the walnut coat with PACl. The pH

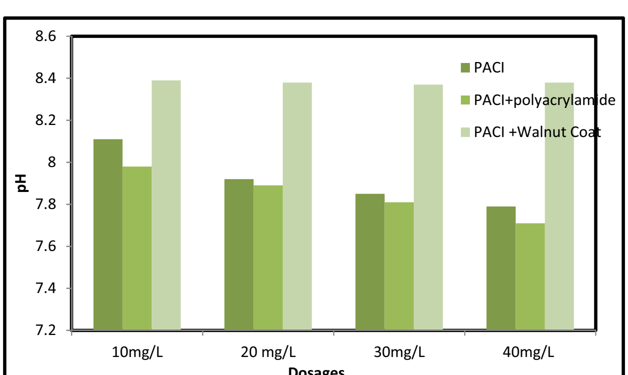

Figure 9: The relation between pH and dosages of coagulant and its aids for samples at 120 cm height.

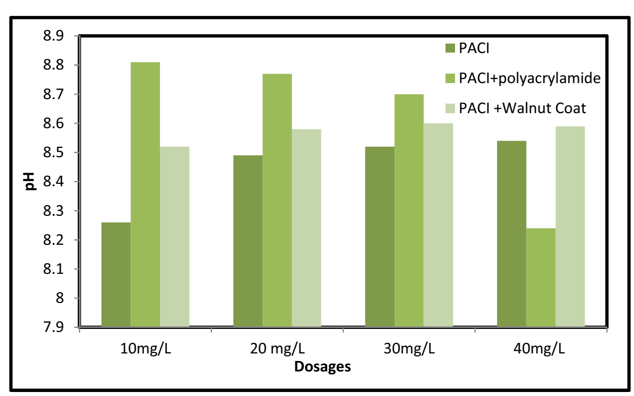

Figure 10: The relation between pH and dosages of coagulant and its aids for samples at 180 cm height.

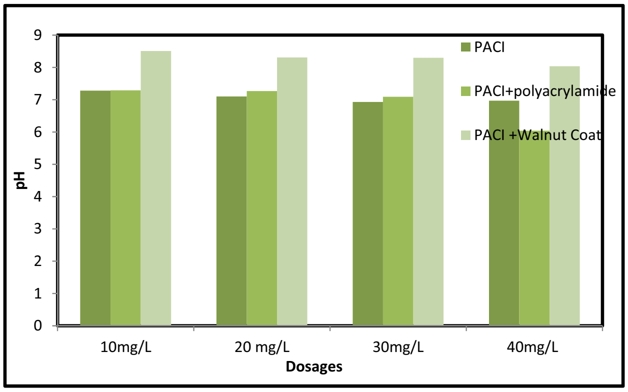

Figure 11: The relation between pH and dosages of coagulant and its aids for samples at a height of 240 cm.

is altered from 8.2 to 8.5. Thus, there is significant evidence of its effect on the water sample. Likewise, the pH values of water samples for polyacrylamide with PACl represent no differences in them in terms of various concentrations. However, there is a little change in pH values with respect to the PACl alone, i.e., the pH is altered from 7.0 to 7.5. In general, depending on the type of coagulant aid used, the coagulant, and the height of water samples employing a coagulant aid with PACl alters pH values. As a result, when polyacrylamide was combined with PACl, the average fall in pH was greater than when PACl was used alone, while an increase in pH value was obtained with the use of walnut coat with PACl.

3.3 Effect of EC and TDS on the coagulant

Regarding the EC as shown in Table 1, the value was varied from 1,200 to 1,300 µs/cm for PACl, and from

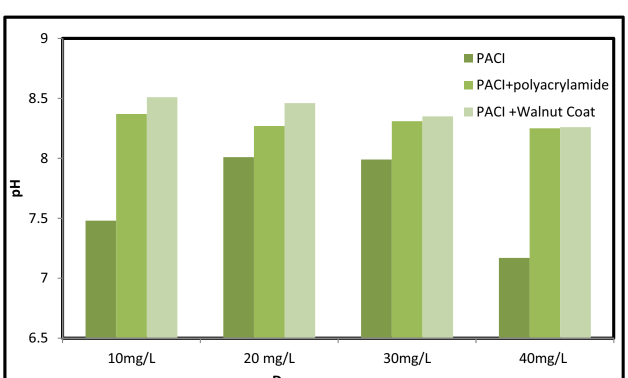

Figure 12: The relation between pH and dosages of coagulant and its aids for samples at 300 cm height.

Table 1: The EC and TDS values for PACl solution

Samples	60 cm	120 cm	180 cm	240 cm	300 cm
EC (µs/cm) for PACl solution					
10 mg/L	1,314	1,218	1,287	1,285	1,222
20 mg/L	1,234	1,217	1,230	1,230	1,208
30 mg/L	1,228	1,219	1,232	1,231	1,212
40 mg/L	1,219	1,221	1,219	1,219	1,203
TDS (mg/L)					
10	565	568	561	561	560
20	561	559	565	565	560
30	564	556	562	562	558
40	563	557	559	559	554

1,200 to 1,300 µs/cm for polyacrylamide with PACl and from 1,100 to 1,280 µs/cm for walnut coat with PACl as shown in Table 2. The data are represented in Tables 1 and 2. Meanwhile, the TDS concentration was diverse from 550 to 570 mg/L for PACl because it is related to the impurities existing in the stock solution. The TDS value was altered from 550 to 580 mg/L for polyacrylamide with PACl as it is related to impurities exist in stock solution. Finally, the TDS value changed from 480 to 550 mg/L in terms of walnut coat with PACl.

3.4 Effect of coagulant type on removal of turbidity

3.4.1 Case (I) using alum, $FeCl_3$, and PACl as coagulants

The Figure 13 displays the effectiveness of various doses of alum, $FeCl_3$, and PACl in treating water with a turbidity of 48.4 NTU for samples at a height of 60 cm. On the basis of the figure, we can see that PACl is significantly more effective in removing turbidity compared with others.

Table 2: The EC and TDS values for polyacrylamide with PACl

Samples	60 cm	120 cm	180 cm	240 cm	300 cm
EC (µs/cm) for PACl + polyacrylamide solution					
10 mg/L	1,221	1,222	1,212	1,207	1,225
20 mg/L	1,215	1,217	1,214	1,205	1,210
30 mg/L	1,217	1,210	1,219	1,200	1,211
40 mg/L	1,203	1,209	1,298	1,204	1,201
TDS (mg/L)					
10	559	549	575	549	551
20	549	563	561	558	548
30	547	558	551	540	544
40	546	556	559	554	541

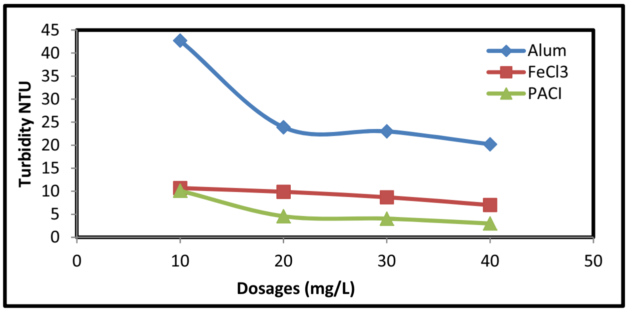

Figure 13: The relationship between coagulants and final residual turbidity for samples at a height of 60 cm.

The high concentration of PACl can remove turbidity by93.8%. However, at 30 mg/L of PACl, it represents a lower percentage of residual turbidity (91.6%) compared with other doses of PACl. The graph shows lower percentages of removal of turbidity which are 90.5 and 79.11%, respectively, at 10 and 20 mg/L of PACl. PACl is the first coagulant in improving the separation of suspended solids and more sufficiently in removing turbidity of water samples at different heights. However, $FeCl_3$ illustrates better performance in removing turbidity when compared with alum.

Figure 14 depicts the performance of various types of coagulants in treating water with a turbidity of 55.9 NTU using various doses of alum, $FeCl_3$, and PACl at varied concentrations. The ultimate residual turbidity was 1.95 NTU, and the removal percentage was 96.5% utilizing $FeCl_3$ at a dosage of 10 mg/L. The ultimate residual turbidity with alum is 4.2 NTU, with a removal rate of 92.4%, and it is 3.95 NTU with a dose of 10 mg/L of PACl (93%). As a result, $FeCl_3$ was determined to be more successful than others at removing turbidity at lower concentrations of these three forms of coagulants. Nevertheless, PACl displays improvement in treating water compared to alum at the same concentration of the coagulant. Moreover, at higher doses of $FeCl_3$, 40 mg/L, the percentage removal of turbidity is 94.3%. In terms of alum and PACl, the removal percentages of turbidity are 94 and 91.2%, respectively. The $FeCl_3$ is considered to be the suitable coagulant for removing turbidity as shown in Chua et al. (2020) study. In their study, it was displayed that with 10.2 mg/L of $FeCl_3$ and 4.52 mg/L of sesbania seed gum (SSG), a promising turbidity reduction of 98.3% was achieved in the treatment of drinking water. As a result, SSG showed promise as a coagulant aid in the treatment of drinking water [6].

Figure 15 illustrates the relationship between three kinds of coagulants and the final turbidity for samples at 180 cm height of the water column. On the basis of the above results, the percentage removal of turbidity at lower doses of PACl is 92.1%, and it is 95.6% at 20 mg/L of PACl. However, at higher doses of PACl, at 30 and 40 mg/L, it displays turbidity removal of 94.5 and 94.7%, respectively. Thus, at 20 mg/L of PACl, it represents an effective performance in removing turbidity in treating water. The ultimate residual turbidity is 2.86 NTU, and the removal percentage is 94% when employing $FeCl_3$ at a concentration of 40 mg/L. At a dose of 40 mg/L of alum, the final residual turbidity is 3.72 NTU, and the clearance percentage is 92.4%. In general, when comparing the dosages of PACl with other coagulants, this coagulant denotes a sufficient enhancement in eliminating turbidity in water with an initial turbidity of 49.5 NTU.

Additionally, Figure 16 explains the correlation between the three different kinds of coagulants, and a final residual turbidity for water samples at 240 cm height of with initial turbidity of 81.9 NTU. Based on these results, it is verified between the $FeCl_3$ and PACl compared to Alum. At higher doses of $FeCl_3$, it demonstrates that the percentage removal of turbidity is 94% with final turbidity around 4.91 NTU. At 30 mg/L of $FeCl_3$, the proportion of removal turbidity is about 92.3% with 6.34 NTU. But the percentage of turbidity

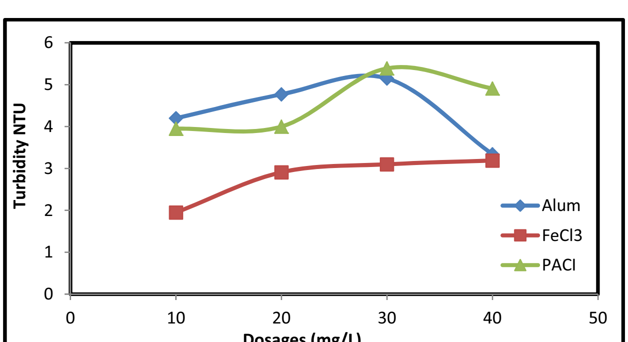

Figure 14: The relation between coagulants and final residual turbidity of water sample at 120 cm.

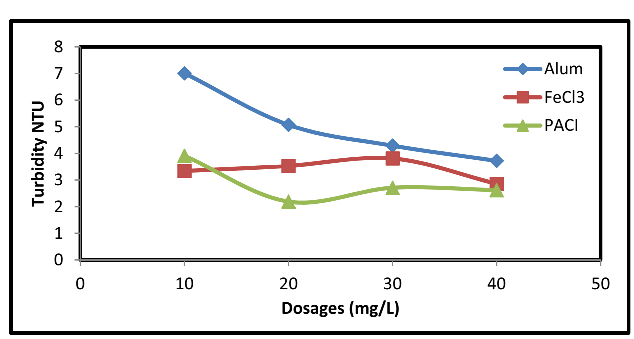

Figure 15: The relation between coagulants and final residual turbidity for samples at 180 cm height.

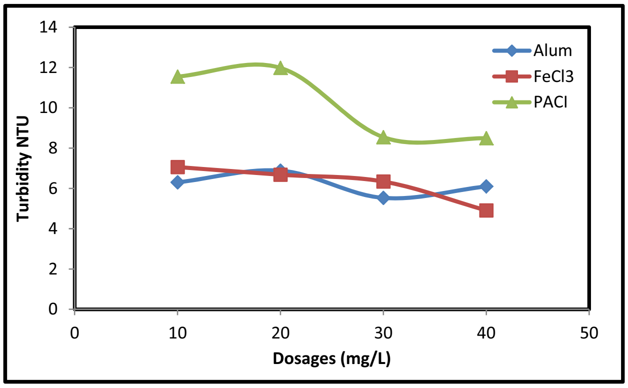

Figure 16: The relation between coagulants and final residual turbidity for samples at 240 cm.

removal is a little lower by PACl than $FeCl_3$ at the same doses. It is approximately 90% in using PACl coagulant associated to $FeCl_3$ and Alum. To sum up, the $FeCl_3$ coagulant symbolizes more performance in removing turbidity in treating water compared to others. However, PACl still shows better enhancement in removing turbidity compared to alum and $FeCl_3$ at lower doses.

Figure 17 indicates that the correlation between different coagulants with final turbidity can be found at 300 cm height from the water surface. With the first turbidity of 52.4 NTU, the results demonstrate that PACl is the most efficient chemical coagulant in removing turbidity compared to others. It indicates that the final residual turbidity is 3.96 NTU at a 40 mg/L dose of PACl which is equal to 92.44% of removal of turbidity. In addition, at 30 mg/L dosage of PACl, the final residual turbidity is 4.36 NTU, or 91.7%, unlike $FeCl_3$ which shows a little improvement in removing turbidity than PACl.

Thus, the results above indicate that among the three different types of coagulants, PACl is the most effective coagulant in removing turbidity at five different heights of water columns at various doses of PACl (Banihashemi et al. [3]). After that, the $FeCl_3$ comes next in the performance of removing turbidity in treating water. Subsequently, alum is considered to be with lowest performance in removing turbidity of water. In general, PACl can be considered the best coagulant because it leaves low residual turbidity that can be handled.

3.5 Effect of a coagulant aid with PACl on removal of turbidity

3.5.1 Case (II) using natural and synthetic coagulants

The jar test operations were carried out in several turbidity ranges and at varied levels of turbid water using two distinct coagulant aids. The effectiveness of walnut coat extracts (*Juglans* spp.) led to its usage as natural coagulants for water clarity. Polyacrylamide, another synthetic coagulant, was utilized in this study as a coagulant assist in eliminating turbidity in water clarifying.

Figure 18 shows the correlation between the natural coagulant with PACl and synthetic coagulant with PACl. It is found that at 22.8 NTU of raw water turbidity, the results indicate a reduction in turbidity to 1.67, 0.52, 0.95, and 0.15 NTU with using polyacrylamide with PACl. Thus, the percentage removal of turbidity is 92.6, 97.7, 95.8, and 99.1% for 10, 20, 30, and 40 mg/L of polyacrylamide with 10, 20, 30, and 40 mg/L of PACl. However, in using a natural coagulant, the percentage removal of turbidity is 77.6, 83.9, 86.6, and 85.6%, respectively. Comparing with PACl alone, the PACl shows better performance in removing turbidity than with a natural coagulant. In general, good turbidity reduction is presented with polyacrylamide with PACl, especially at higher doses. This indicates that at higher concentrations of polyacrylamide, the turbidity reduction increases with the increase

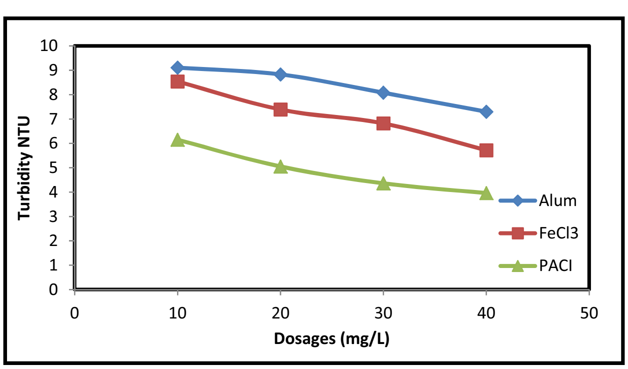

Figure 17: The relation between the coagulants and the final residual turbidity for samples at 300 cm height.

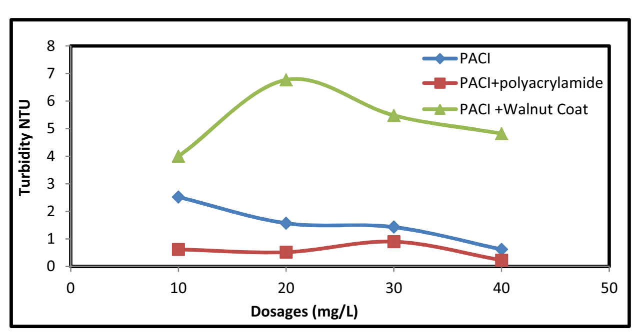

Figure 18: The relation between the coagulant aids and final turbidity for water samples at a height of 60 cm.

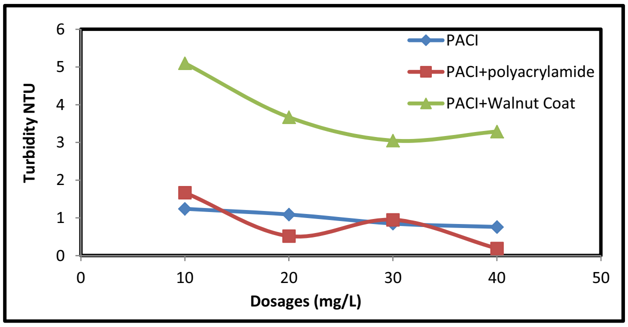

Figure 19: The relation between coagulant aids and final turbidity for water samples at 120 cm height.

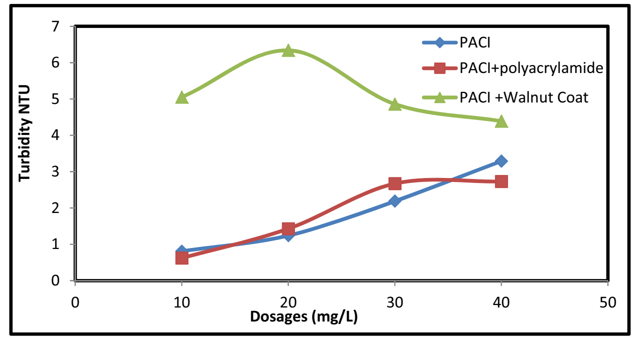

Figure 20: The relationship between a coagulant aid and final turbidity for water sample at 180 cm height.

in the doses. Therefore, the turbidity reduction is low when using a natural coagulant as presented here.

Figure 19 shows the relationship between dosages of coagulant aids and final turbidity at a height of 120 cm in turbid water. The results of removing turbidity with different doses of natural aid and polyacrylamide with PACl are shown. It is found that the turbidity of the water is 25.7 NTU. It is demonstrated that the turbidity reduced to 0.62, 0.52, 0.90, and 0.23 NTU when using polyacrylamide with doses of 10, 20, 30, and 40 mg/L mixed with PACl with the same doses. The removal percentages of turbidity are 97.6, 97.9, 96.5, and 99.1% by utilizing polyacrylamide with PACl. However, the results show that the percentage removal of turbidity is 84.4, 73.7, 78.7, and 81.2% with the use of walnut coat with PACl. Thus, the reduction in turbidity is found to be 4, 6.77, 5.48, and 4.82 NTU, respectively. However, using PACl alone indicates better performance in removing turbidity than using a natural coagulant aid. In general, the polyacrylamide demonstrates a better reduction in turbidity when used with PACl than others for the clarification of water. At higher doses of synthetic coagulant, it is found to increase the reduction in turbidity.

Figure 20 shows the relationship between coagulants and final turbidity at 180 cm height of turbid water. It is found that the polyacrylamide with PACl shows a reduction in turbidity at various doses. The percentage removal of turbidity of polyacrylamide with PACl is 97.3, 93.7, 88.3, and 88.1%, respectively, at 10, 20, 30, and 40 mg/L doses. The reduction in turbidity is 0.62, 1.43, 2.67, and 2.73 NTU in using polyacrylamide with PACl. Moreover, the percentages in removal of turbidity are 96.44, 94.6, 90.4, and 85.6%, respectively, with the usage of PACl alone. Both PACl and PACl with polyacrylamide illustrate a efficient performance in removing turbidity in the clarification of turbid water. The PACl minimizes the final residual turbidity to 0.81, 1.24, 2.19, and 3.29 NTU, respectively, at various doses. At higher concentrations of polyacrylamide, it signifies good reduction in final turbidity compared to others. However, as compared to other methods, walnut coat performs poorly in eliminating turbidity. Turbidity removal percentages are 77.9, 72.2, 78.7, and 80.7%, respectively. In one word, using polyacrylamide confirms effective performance in removing turbidity at various concentrations.

The results from Figure 21 show the correlation between different coagulant aids with PACl as chemical coagulant. The results confirm that the walnut coat with PACl has displayed better performance in reducing turbidity than the others. Following that, polyacrylamide is more successful than PACl alone at removing turbidity. The percentage removal of turbidity is 97.9, 97.7, 98.1, and 99.3% for 20, 40, 60, and 80 mg/L of walnut coat with PACl at different doses. The turbidity was reduced to 0.42, 0.47, 0.38, and 0.14 NTU at various doses of natural coagulant aids with PACl. Moreover, the results display lower performance of polyacrylamide with PACl in removing turbidity at an original turbidity of 20.6 NTU. Therefore, the percentage removal of turbidity is 96.5, 96.3, 96.99, and 94.7% of polyacrylamide with PACl, as well as the reduction in turbidity for the same doses of PACl which are 0.72, 0.76, 0.62, and

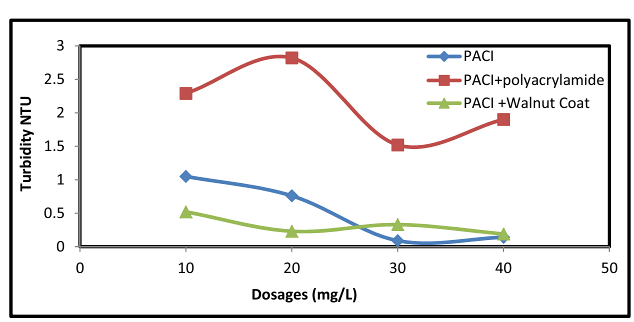

Figure 21: The relation between coagulant aids and final turbidity for water samples at a height of 240 cm.

1.09 NTU, respectively. Furthermore, the percentage reduction in turbidity is 95.8, 95.6, 94, and 94.5% for PACl alone, corresponding to the final residual turbidity which is 0.85, 0.9, 1.23, and 1.14 NTU, respectively.

In this case, both coagulant aids have efficient enhancement in reducing turbidity to a level which might be acceptable. The natural coagulant aid has a significant effect on pollutant removal, and is also economically viable. However, based on our studied natural coagulant, it is only efficient in higher turbidity ranges at 240 cm height of raw water than other turbid waters.

As a result, interest in natural coagulants has grown throughout time, particularly as a means of reducing water and wastewater treatment difficulties in developing nations, while also avoiding health dangers. For example, many developing countries have turned to adopting natural coagulants such as specific plants as a feasible coagulant in water and wastewater treatment on a modest scale, as a result of many findings from this study.

These results based on Figure 22 are not significantly different than the previous one. The percentage removal of turbidity is 95, 96.4, 99.6, and 99.3%, respectively, for PACl alone. The PACl alone displays a reduction in final turbidity to 1.05, 0.76, 0.09, and 0.14 NTU at 10, 20, 30, and 40 mg/L of PACl. By using polyacrylamide as the coagulant aid with PACl, the percentage removal of turbidity is 89, 86.6, 92.7, and 90.9%, respectively. Moreover, the reduction in turbidity was reduced to 2.29, 2.82, 1.52, and 1.9 NTU when using polyacrylamide with PACl. However, better performance in removing turbidity is shown with the usage of walnut coat. For instance, the percentage removal of turbidity is 97.8, 98.9, 98.4, and 99.1%, respectively, at various doses of 20, 40, 60, and 80 mg/L of natural coagulant aid. The reduction in turbidity is 0.52, 0.23, 0.33, and 0.19 NTU at the same doses of walnut coat. In general, using a coagulant aid, either natural or synthetic, represents better improvement in reduction in turbidity and clarification of water. However,

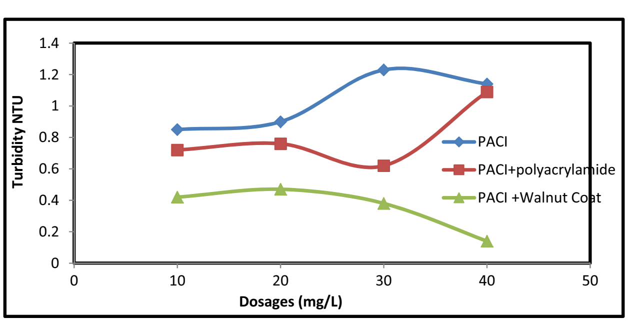

Figure 22: The relation between a coagulant aid and final turbidity for water sample at 300 cm height.

PACl alone is better for turbidity reduction efficiency of different doses in different turbidity ranges. Thus, the polyacrylamide reduced the maximum turbidity among all coagulant aids used.

To summarize, coagulation is a process in which a chemical coagulant is thoroughly mixed with water, and various species of positively charged particles (such as Al^{3+}, Fe^{3+}) adsorb to negatively charged colloids such as color, clay, turbidity, and other particles through charge neutralization processes, resulting in microflocs. The microscopic suspended particles, known as microflocs, can cling together once the charge has been neutralized.

In the case of high turbidity, both coagulation and flocculation are performed with the smallest amount of the best coagulant. When the turbidity of raw water is low, the turbidity is reduced manually with clay. Sludge from sludge lagoons is sometimes used to increase turbidity. This sludge contains some coagulating components, which can save 40% of coagulant volume in addition to creating the needed sludge. However, because chemicals and other related costs account for a major portion of treatment plant operating costs, efforts to lower coagulant prices make sense. Other techniques can be used to remove efficiency such as electromagnetic field.

Abdulhasan et al. [12] showed that the outcomes demonstrated that the pH values are unaffected by EMF. The meaning of turbidity is in which determines how well the unit performs; the result indicates the highest efficiency elimination at the smallest diameter (2.54 cm), and 99.99% in three reactors with three different numbers of coils turns [12].

4 Conclusion and recommendation

During the treatment of surface water, some classical chemicals are used at various stages. Synthetic, organic, and inorganic chemicals are commonly utilized in various treatment units. These are usually pricey since they are required in higher doses and do not demonstrate cost efficiency. Many of the substances have also been linked to health and environmental issues in humans (Kaggwa [10]). As a result, there was a rush to develop water purification techniques that were both cost-effective and environmentally beneficial.

Thus, the primary purpose of this research is to employ alum, $FeCl_3$, and PACl as coagulants, as well as natural and synthetic coagulant aids, to remove various levels of turbidity from water in order to enhance drinking water quality at a low cost. The study found that using the abovementioned materials as coagulants is effective, particularly at low turbidity levels (i.e., less than 25 NTU) and at a dose of not more than 40 mg/L of these three forms of coagulants. Polyacrylamide has been demonstrated to be very successful as a coagulant aid with PACl at doses as high as 10 mg/L for low and intermediate initial turbidity levels (not more than 25 NTU).

Furthermore, the polyacrylamide shows better performance in removing turbidity at high ranges of turbidity at various concentrations. Nevertheless, at lower ranges of turbidity, the walnut coat displays good improvement in the reduction in turbidity at low levels of turbidity (20 and 21 NTU). Therefore, both types of coagulant aids represent efficiency in the minimization of turbidity compared with PACl alone at some levels of height, while others, both PACl alone and polyacrylamide with PACl, signify higher percentage of removal of turbidity at different levels of turbid water.

Furthermore, water samples from the Tigris River were taken for research purposes. The samples were immediately transferred to the jar test apparatus, where several dosages of alum, $FeCl_3$, and PACl were added to the water to identify the best coagulant dosage. The three types of coagulants were used in this investigation at varying dosages of 10, 20, 30, and 40 mg/L. The amount of time it took for the coagulant to settle varied depending on the dose. Using a suction equipment attached to a vacuum source, 100 mL samples were taken from 1 cm below the water's surface at the end of the settling period. To calculate the turbidity reduction percentage, the residual turbidity was measured.

As a result, utilizing polyacrylamide as a coagulant aid with PACl can remove turbidity of severe murky water at a high percentage. When used alone, the performance of PACl is recommended because the final turbidity is lower than when combined with other coagulant aids such as walnut coat. The final reduction in water turbidity is effectively influenced by increasing the dosages of coagulants and coagulant aids with varied percentages.

The value of pH increased as the dosage values of polyacrylamide coagulants were increased. Furthermore, after the coagulant assistance has been added, the values of TDS, EC, and salt have not changed. Furthermore, subsequent experiments with the same coagulant and coagulant assistance but with different values of high initial water turbidity, such as 1,000, 2,000, and 3,000 NTU, may be advised.

Significant improvement in eliminating turbidity and total coliforms from raw water was reported using several locally accessible natural coagulants, such as *Moringa oleifera*, *Cicer arietinum*, and *Dolichos* lablab. Highly turbid waters showed the greatest reduction in turbidity. Also, it was obvious that after dosage, the natural coagulant reduced total coliforms by 89–96%. Polyacrylamide was shown to be the most effective of the coagulant aids employed in this investigation for turbidity reduction, reducing up to 95.89% turbidity from the raw river water.

Using a jar test device, this study was conducted to see how effective $FeCl_3$, alum, and PACl are at removing turbidity and reducing organic content in raw water. When compared to $FeCl_3$, the results showed that PACl was more effective at eliminating primary turbidity. According to the findings, the coagulation process helps to destabilize colloids in a water supply. According to the literature, this technique can eliminate natural water-soluble organic materials in addition to destabilizing organic and inorganic colloids. Primary turbidity has an effect on removal efficiency; the higher the primary turbidity, the greater the removal efficiency.

Other ways for removing turbidity utilizing the same coagulants and coagulant aids with higher levels of turbidity that should be more than 1,000 NTU are also needed, as are more research to test numerous factors.

In this work, experimental research on the effects of pH and various dosages of alum, $FeCl_3$, PACl on turbidity removal efficiency was conducted. The effectiveness of PACl's coagulation process for eliminating the starting turbidity quantity and pH had a direct impact on the turbidity. The efficiency of turbidity was improved in turbidity level. The PACL was a successful coagulant in a wide range of pH. With increasing the value of pH, the coagulant efficiency improved to remove the colloids and suspended matter.

The NTU approach is used to achieve a turbidity removal efficiency of almost 95 utilizing a coagulant with 5 ppm of PACl. In this study, it was showed that the PACl was effective and more sufficient in removing turbidity as compared to other coagulants especially with adding coagulant aids including both natural and artificial.

Therefore, by increasing the amount of PACl in the sample, the possibility of colloids and PACl contacting each other as a coagulant is increased, floc formation efficiency is increased, and so is coagulation efficiency. The amount of suspended solids and colloids in the sample decreases, increasing the coagulation efficiency. In other words, because no floc formed and additional PACl remained in the water, the saturation point of the aqueous solution was attained. As a result, adding more PACl led to turbidity in samples and a decline in the percentage of turbidity removed in the end.

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References

[1] EIFAC. European inland fisheries advisory committee, WORKING PARTY ON WATER QUALITY CRITERIA FOR EUROPEAN FRESHWATER FISH, REPORT ON FINELY DIVIDED SOLIDS AND INLAND FISHERIES. Air Water Pollut. 1965;9(3):151–68.

[2] Jahn SAA. Using Moringa seeds as coagulants in developing countries. J Am Water Work Assoc. 1988;80(6):43–50.

[3] Alavi Moghadam SMR, Bani Hashemi A, Maknoon R, Nik Azar M. Application of poly aluminum chloride in removing turbidity from Tehran water. Case study: Jalalieh water treatment plant. Educ Technol bulletin. 2008;3(2):109–13.

[4] Ghernaout D. Magnetic field generation in the water treatment perspectives: An overview. Int J Adv Appl Sci. 2018;5:193–203.

[5] McConnachie GL, Folkard GK, Mtawali MA, Sutherland JP. Field trials of appropriate hydraulic flocculation processes. Water Res. 1999;33(6):1425–34.

[6] Chua S-C, Chong F-K, Malek MA, Ul Mustafa MR, Ismail N, Sujarwo W, et al. Optimized use of ferric chloride and sesbania seed gum (SSG) as sustainable coagulant aid for turbidity reduction in drinking water treatment. Sustainability. 2020;12:2273. doi: 10.3390/su12062273.

[7] Ghebremichael KA. Moringa seed and pumice as natural alternative materials for drinking water treatment, Ph.D. thesis. KTH Land and Water Resources Engineering; 2004.

[8] Muthuraman S. Removal of turbidity from drinking water using natural coagulants. J Ind Eng Chem. 2014;30(4):1727–31.

[9] Kawamura S. Effectiveness of natural polyelectrolytes in water treatment. J Am Water Work Assoc. 1991;83(10):88–91.

[10] Kaggwa RC, Mulalelo CI, Denny P, Okurut TO. The impact of alum discharges on a natural tropical wetland in Uganda. Water Res. 2001;35(3):795–807.

[11] Gunaratna KR, Garcia B, Andersson S, Dalhammar G. Screening and evaluation of natural coagulants for water treatment. Water Sci Technol. 2007;7(5–6):19–25.

[12] Abdulhasan MJ, Al-Mansori NJH, Nasir MJ. Removal turbidity of water by application of electromagnetic field technology. J Ecol Eng. 2022;23(1):51–4. doi: 10.12911/22998993/143751.