

Application of a Polymer in Drinking Water Treatment: A Case Study

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Abstract

Original Research Article

The effect of an anionic polymer in removal efficiency for turbidity and total organic carbon measured as UV₂₅₄ from raw water at Dhaka was analysed. Adding 0.05 mg/L of the polymer with 85 mg/L of alum the increase in the % removal of turbidity is only 1.23% than the alum alone. By doubling the polymer dose with the same alum dose, the removal efficiency increases only by 0.47%. Addition of alum alone is found far more effective than adding only polymer for the removal of turbidity. Similarly, in the first arrangement in case of removal of UV₂₅₄, the removal efficiency is decreased by 3.06% rather than increased. Even doubling the polymer dose along with the same alum dose, removal of UV₂₅₄ is below what is achieved by alum alone. Therefore, extensive study is needed to decide on polymer as a workable, and dependable potable water treatment process aid at Dhaka.

Keywords: Coagulant, Drinking water treatment, Polymer, Turbidity.

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1. BACKGROUND

Dhaka now, with a population of over 15 million is one of the most populous and congested cities in the world. This mushrooming city is located on the northern bank of the river Buriganga and surrounded by other rivers, namely, the Turag to the west, the Tongi Khal to the north and the Balu & the Shitalakshya to the east. Yet, the city carried a legacy of water shortage since the independence of Bangladesh in 1971 up to very recently (DWASA, 2007; Serajuddin, M., 2009). Dhaka, the capital of Bangladesh and a premature megacity of today, with a population of 15 million+, was almost 87% dependent on ground water for its potable water upto first decade of the current century. Once, presumably cheap and abundant, the ground water source inside Dhaka has gradually been depleted so much that no further over extraction is possible. There is no other way but to switch over to surface water. In this context, Saidabad Water Treatment Plant (SWTP) in two phases was built with a total capacity of 450 million litres per day (MLD). The Shitalakshya river at the eastern periphery of Dhaka city is the source of raw water for the plant (Serajuddin *et al.*, 2018).

The river Shitalakshya has been recommended since the early eighties as the source of raw water for the aforesaid plants after several studies by the local and international experts (BCEOM, 1992; DWASA, 1994). Unfortunately, the Shitalakshya river has been facing serious problems of pollution, principally contributed by industries (Begum *et al.*, 2010; GOB & UNDP, 2010; Rahman *et al.*, 2005; Sania *et al.*, 2012). This severity of river water pollution started to be visible from around two decades back when the construction of the first plant started. The international specialists, who observed the severe pollution especially during dry season, proposed to use polymer as a purification aid in the treatment chain. The bidder's experts advocated that due to various reasons there are situations where inorganic flocculants cannot solve the problem caused by the poor quality of inflow water alone. They urged that the different behavior of polymer flocculants, as compared with the inorganic flocculants used in conventional water treatment plants, might have a positive effect on future water treatment process design as the destabilization of fine particles by organic polymer flocculants has been increasingly important, because of their demonstrated effectiveness

on poor raw water quality (BCEOM, 1992; Lee *et al.*, 1998; SNF, 2002; Huail *et al.*, 2013; Bobirić *et al.*, 2014; Mohamed, 2020; Ghimire *et al.*, 2020). But the authority at Dhaka declined to allow using polymer in this plant due to the almost unknown characteristics of polymer in drinking water in this country, furthermore, it was known that the uses of polymer in drinking water treatment are restricted in a country like Japan (Gregor *et al.*, 1993; Letterman *et al.*, 1990). The authority sought to know the details on it from the manufacturers.

This background incited the present study to see the effect of the use of polymer alone and with alum in the removal of pollutants especially the turbidity & organic material from the raw water of the Shitalakshya river, the source of the drinking water at Dhaka.

2. INTRODUCTION

The impurities in water occur in three progressively finer states - suspended, colloidal and dissolved matter. The particulate impurities (commonly called suspended solids) cover a broad size range. Smaller sized particles, such as spores, cysts, plankton, fine clays and silts with their associated bacteria, do not readily settle and treatment is required to produce larger particles that are more amenable to removal. These smaller particles are often called non-settleable solids or colloidal matter (Mahbi *et al.*, 2005).

The purpose of coagulation and flocculation in water treatment is to condition impurities, especially non-settleable solids and colour, for removal from the water being treated (Carty *et al.*, 2002). Chemicals used in coagulation / flocculation are referred to either as primary coagulants or as coagulant aids. The purpose of coagulant aids may be to condition the water for the primary coagulant being used, to add density to slow-settling flocs or toughness so the floc will not break up in the following processes (Carty *et al.*, 2002).

Salts of aluminium or iron are the most commonly used coagulant chemicals in water treatment because they are effective, relatively low cost, available, and easy to handle, store, and apply. Aluminium sulphate - commonly called alum or sulphate of alumina - is still very widely used although concern about the possible adverse effects of dissolved aluminium has recently been expressed in some quarters (Brateby, 1980). It has been reported that a high intake of aluminium ions in the water may cause neurological diseases such as Alzheimer's disease and pre-senile dementia. WHO has recommended regulating the residual aluminum ion concentration. In Bangladesh, from 1997 the acceptable residual aluminum ion level in drinking water has been regulated to be below 0.2 mg/L (DOE, 1997; EPA, 2012).

A. Organic polymers

Polymer flocculants are water soluble organic polymers carrying functional groups such as amino or carboxyl functionalities in their polymer backbone. Their molecular weight ranges from a few thousands to millions. According to the electric charge carried by the polymer flocculants in aqueous medium, they can be classified as cationic, anionic, and non-ionic (Lee *et al.*, 1998).

Organic polymers have been said to gain widespread use as water treatment coagulants and flocculants in a quite large number of developed countries since their introduction in the early 1950's and in enhancing the removal of turbidity and colour (Bolto *et al.*, 2007).

Organic polymers are long-chain molecules consisting of repeating chemical units (monomers) with a structure designed to provide distinctive physicochemical properties to the polymer. The polymers usually have an ionic nature, and are also referred to as polyelectrolyte. The total number and types of monomer units in a polymer can be varied in manufacture. Consequently, a large variety of polymers can be produced. Cationic polymers are used in the water treatment industry as primary coagulants, whereas nonionic and anionic polymers are used as flocculants or filter aids, and are usually used in conjunction with inorganic coagulants.

Polyelectrolytes as demanded by manufacturers offer an alternative means of improving the quality of the water by (sometimes) effectively removing particles and natural organic matter. As flocculants aids, polyelectrolytes reduce the dose of aluminium required to achieve acceptable quality water. Polyelectrolytes have two main objectives in water treatment; destabilization of colloids and particulates, and formation of larger and more shear-resistant flocs. Anionic, nonionic, and cationic polymers may function as bridging polymers increasing floc once destabilization has been achieved (Vajihinejad *et al.*, 2019).

In general, anionic polymers have been shown to be effective flocculation aids, while nonionic polymers have been effective as filter aids (Bae *et al.*, 2007). Over the past 25 years, an increasing number of polyelectrolytes have become available to the water treatment industry. Many of these products are merely different mixtures of, or polymers of slight modification to a much smaller group of mainstream polymers. Since manufacturers supply very little technical information on the polymers, and since the modes of action are less well understood than those of inorganic coagulants, selecting a polymer from these products to provide optimal treatment is generally done by product representatives and often by trial-and-error (NZWWA, 1999).

B. Concerns in use of Polymers

For many years and still in some countries yet, there was much reservation in the use of polymer in drinking water treatment due to the negative health effect of the polymer residual in the treated water (Xiong *et al.*, 2018). Switzerland and Japan do not permit the use of synthetic polyelectrolyte in drinking water treatment, and West Germany and France have stringent limits on application rates (Letterman *et al.*, 1990). It was concluded that acrylamide is a genotoxic carcinogen.

The most important source of drinking water contamination by acrylamide is the use of polyacrylamide flocculants that contain residual levels of acrylamide monomer. WHO guidelines value associated with cancer risk has been estimated at 0.5 microgram per liter. USEPA has set an MCLG (Maximum contaminant level goal) of zero mg/L (EPA, 2012).

C. Objective of the study

The prime objective of the study is to investigate the effect of a particular polymer in the flocculation efficacy with the raw water from the Shitalakshya river, the raw water used in the largest treatment plant in Bangladesh.

Polymer doses have been applied to Shitalakshya river water treatment plant in Bangladesh to check its efficiency in reducing turbidity and organic material. The effects of polymer, polymer quantity, initial turbidity, and pH of raw water on turbidity and organic material removal were also investigated. The motivation for this research on the use of polymer was inquisitiveness. Laboratory tests were carried out before taking a decision on the introduction of the synthetic polymer in drinking water treatment at Dhaka, though in a very limited quantity and duration, to be used as flocculants aids. The claim demanded by the constructor was that the technical efficacy of polymer as fluctuant aid in clarification as well as in cost savings is evident when polymer is used along with a coagulant

than the coagulant itself when used alone.

3. MATERIALS AND METHODS

A. Study Area, sample collection & analysis

The study area is Dhaka the capital city of Bangladesh with a population of more than fifteen million located in the central part of Bangladesh. Dhaka has a distinct monsoonal season, with an annual average temperature of 26°C (79°F) and monthly means varying between 19°C (66°F) in January and 29°C (84°F) in May, sometimes reaching 40 degrees Celsius. Approximately 87% of the annual average rainfall of 2,123 millimeters (83.6 inches) occurs between May and October. Dhaka is located at 23°42'N 90°22'E, on the banks of the Buriganga river and surrounded by other peripheral rivers. The largest surface water treatment plant of the country is situated beside the river Shitalakshya in the eastern periphery of Dhaka city at Latitude N 23° 43' 11.25" & Longitude E 90° 26' 14.25" (Serajuddin *et al.*, 2018) (Figure-1). The raw water from the intake of this plant was collected and taken to the laboratory by following the precautions laid by standard methods (APHA, 2005). Each of the water samples was analyzed for pH, turbidity, temperature, UV₂₅₄. Alum as an inorganic coagulant (Al₂(SO₄)₃·18H₂O), were used in the experiments. This Coagulant was collected from drinking water treatment plants which are produced by BSK chemical Industries, in Bangladesh. This Alum contain 17.10% water soluble aluminium compound as Al₂O₃, water soluble iron compound as Fe, 0.5%, Fe₂O₃, 0.5%, insoluble matters 0.5%, pH of 1% solution 3.5 – 4.5, colour milky white. Commercially available anionic polymer FLOERGER AN 934 SH produced by SNF FLOERGER, as was proposed by the constructor to be used in the plant was used in the study. In appearance it is white granular powder whose generic name is copolymer of acrylamide and sodium acrylate, anionic, with molecular weight 5 - 22 million, pH 4.08. All the chemical tests and analysis were done according to the Standard Method for examination of water & wastewater (APHA, 2005).



Figure 1: Raw water source from Shitalakshya river to Water treatment plant

B. Experimental Setup

A six-cube jar test apparatus was used with each 1litre jar containing 1 litre of water. The rapid mixing time for coagulant was 5 min at a paddle speed of 200 rpm (Figure-2). The slow mixing for flocculation was 5 min at 50 rpm, and the sedimentation time was 30 min. After settling, 50 ml of supernatant was taken out and turbidity (HACH 2100Qis) and pH (HACH SensIon+MM150) were measured immediately. UV₂₅₄ was determined (DR 6000) as a surrogate parameter to observe the removal of dissolved organic matter in the water by Alum and/or polymer.

One of the methods nowadays utilized to monitor organic load is the ultraviolet absorption of water at 254 nm wavelength UV₂₅₄. Because the UV₂₅₄ absorbance parameter is proportional to the concentration of organics in the water most natural

water sources such as raw water for drinking water and municipal wastewater have a good correlation between, for example, TOC and UV₂₅₄ absorption, and COD and UV₂₅₄ absorption (Edzwald *et al.*, 1985; Kim *et al.*, 2016; Quayle *et al.*, 2009; Serajuddin *et al.*, 2018). Many organic compounds occurring naturally in the environment, such as humic substances, are aromatic and exist in high concentrations in surface water. These compounds are known to be a major precursor of DBP formation. Therefore, UV₂₅₄ provides one of the best indications of water's potential to form DBPs upon chlorine addition and should be monitored throughout the treatment process to ensure organics are removed. The effective turbidity was measured at the end of each test. The concentration of total organic carbon in surrogate of UV₂₅₄ was measured by a DR 6000 spectrophotometer.



Figure 2: Experimental setup.

C. First test

On 14 March 2019 six jar tests were conducted with six different doses of alum alone then with six different doses of polymer alone & then three samples with combination of alum & polymer were conducted. The entire tests were done with the same sample of raw water.

D. Second test

On 25 March 2019, six jar test with this raw water sample were conducted simultaneously with six different doses and combination of Alum & Polymer doses being selected on the basis of plant operation experiences, namely: (1) with no chemical addition, (2) adding Alum alone with a concentration of 85 mg/L, (3) adding 0.05 mg/L of polymer alone, (4) adding 0.10 mg/L of polymer alone, (5) adding 0.05 mg/L of polymer along with 85 mg/L of alum and (6) adding 0.10 mg/L of polymer along with 85 mg/L of alum.

4. RESULTS AND DISCUSSIONS

A. Results from first test

1) Effect of addition of Alum alone & its variation in concentration

The rapid mixing was done for 2 minutes with a speed of 200 RPM and slow mixing was done for 20

minutes with a speed of 50 RPM. Chemical analysis was done after 30 minute. Alum dosing started with 90 mg/L of alum & progressively up to 140 mg/L with an incremental increase of 10 mg/L in each jar. At 90 mg/L of alum addition to the raw water the % removal of turbidity is 64.44% & at 140 mg/L the % removal is 73.88 % (Table 1).

It is seen that increasing the alum dose from 90 to 140 mg/L i.e. increasing the alum dose by 55.55% the percent increase in turbidity removal is only 9.44%. With progressive increase of 10 ppm of alum from 90 to 140 ppm i.e. with increase of alum dose by 11.11%, 22.22 %, 33.33%, 44.44%, & 55.55% the percent increase in turbidity removal are respectively 0.78%, 2.34%, 8.78%, 9.00% & 9.44%.

2) Effect of addition of Polymer alone & its variation in concentration

Similar six jar test were conducted with only polymer with doses of 1, 2, 3, 4, 5, & 10 ppm of polymer. 0.1% solution of polymer was used as stock solution. At 1 ppm addition of polymer the % removal of turbidity is 22% & at 10 ppm % removal of turbidity is 29.44% (Table 2).

It is seen that progressive increase in polymer dose does not increase turbidity removal rate proportionately yet sometimes decreases than the earlier lesser dose. By increasing polymer dose from 1 ppm to 10 ppm i.e. 10 times increase in polymer dose increase the % removal of turbidity only by 1.33 times.

With progressive increase in polymer dose namely 1, 2, 3, 4,5, & 10 ppm i.e. with increase of polymer dose by 100, 200,300,400, 500 & 1000 percent the percent increase in turbidity removal are respectively (-2.89)%, 5%, 2.11%, (-2.78)%, 2.34% & 5.77%.

It is not unlikely. When anionic organic polymers are used as coagulant aids with inorganic coagulants, dosages in the range of 0.1 to 0.5 ppm are most frequently employed. Dosages from 0.1 to 0.2 are usually sufficient for most waters. On the other hand drastic overdoses have little or no effect on the result. It is reported that good flocculation does not occur if more than 50% of the particle surface is covered by polymer (Cohen *et al.*, 1958).

On the same date another three jar test were conducted with the same raw water with combined

doses of alum + polymer respectively as (100+20), (100+0) & (0+ 100) ppm. Addition of 20 ppm of polymer with 100 ppm of alum increases the % removal of turbidity only by 8.22%.

3) Effect of pH on raw water turbidity removal with the addition of alum and polymer

Figure 3 shows the effect of alum dose on pH of the raw water & turbidity on pH. It is seen that with the increase in alum dose the pH of the water is gradually decreasing in a linear manner. Similarly with decrease in the turbidity of the water the pH of the water is decreasing. Thus there is more or less a definite straight line decrease pattern observed. But it is obvious that there is no direct influence of water pH on turbidity significantly but there might exist site specific certain insignificant positive correlation with other factors in specific water under testing (Mandal, 2014).

On the other hand with the increase of polymer dose (Figure 4) the pH of the raw water does not decrease or increase with a definite pattern. With the addition of incremental polymer doses the pH first increases then decreases then increases and so on. Similarly decrease in turbidity does not decrease or increase pH in definite pattern.

Table 1: Effect of adding alum alone on turbidity removal

Date		14/03/2019					
Stock solutions		Full strength coagulant					
Jar no.		1	2	3	4	5	6
Sample		Raw Water	Raw Water	Raw Water	Raw Water	Raw Water	Raw Water
Raw water characteristics	Raw water turbidity(NTU)	90	90	90	90	90	90
	Raw water pH	7.63	7.63	7.63	7.63	7.63	7.63
Adding Alum alone	Alum Dosage (PPM)	90	100	110	120	130	140
	Polymer Dosage (PPM)	0	0	0	0	0	0
	Time of flocculation / Settling time	20	20	14	14	13	13
	Flocculation rating / floc size	+	+	++	++	++	+
Chemical analysis of flocculated water after 30minutes	Turbidity	32.0	31.3	29.9	24.1	23.9	23.5
	pH	7.19	7.14	7.10	7.06	7.03	6.99
	% removal of Turbidity	64.44	65.22	66.78	73.22	73.44	73.88

Table 2: Effect of adding polymer alone on turbidity removal

Date		14/03/2019					
Stock solutions		0.1 % solution of polymers					
Jar no.		1	2	3	4	5	6
Sample		Raw Water	Raw Water	Raw Water	Raw Water	Raw Water	Raw Water
Raw water characteristics	Raw water turbidity (NTU)	90	90	90	90	90	90
	Raw water pH	7.63	7.63	7.63	7.63	7.63	7.63
Adding Only polymer	Alum Dosage (PPM)	0	0	0	0	0	0
	Polymer Dosage (PPM)	1	2	3	4	5	10
	Time of flocculation / Settling time	(-)	(-)	(-)	(-)	(-)	(-)
	Flocculation rating / floc size	(-)	(-)	(-)	(-)	(-)	(-)
Chemical analysis of flocculated water after 30minutes	Turbidity	70.2	72.8	68.3	70.8	68.7	63.5
	pH	7.81	7.74	7.75	7.74	7.77	7.74
	% Removal of Turbidity	22	19.11	24.11	21.33	23.67	29.44

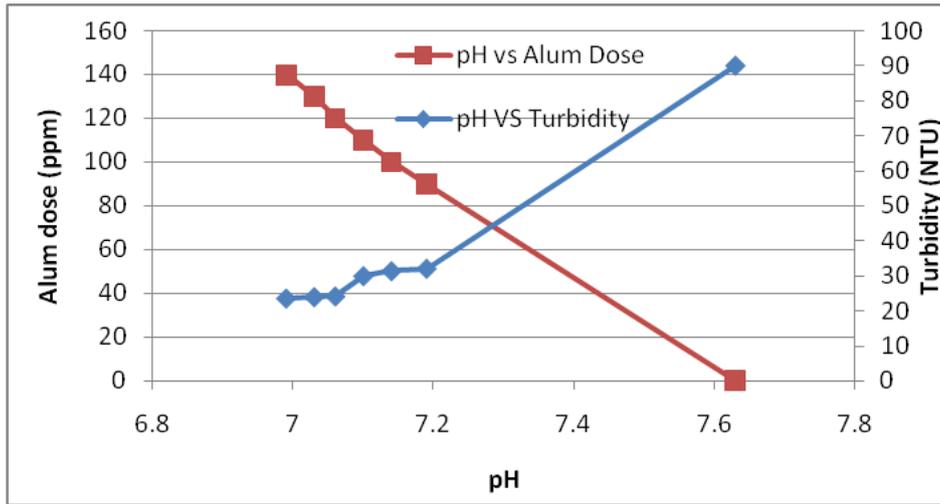


Figure 3: Effect of pH on raw water turbidity removal with the addition of alum

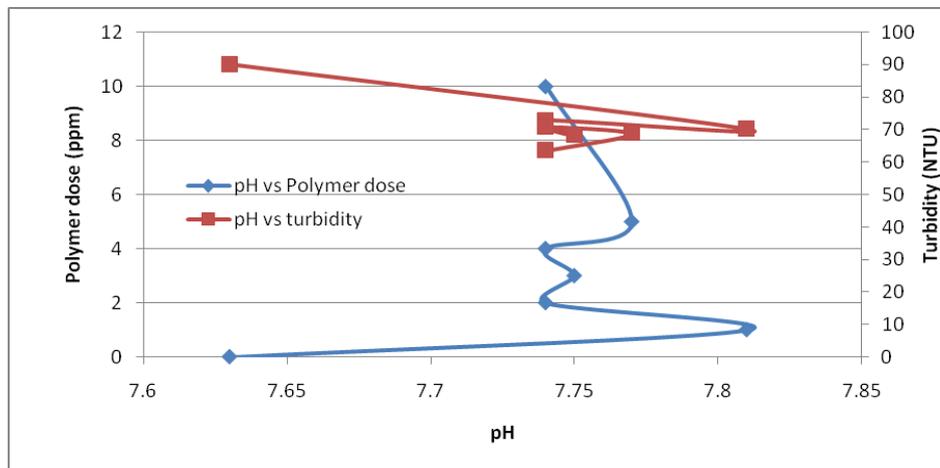


Figure 4: Effect of pH on raw water turbidity removal with the addition of polymer

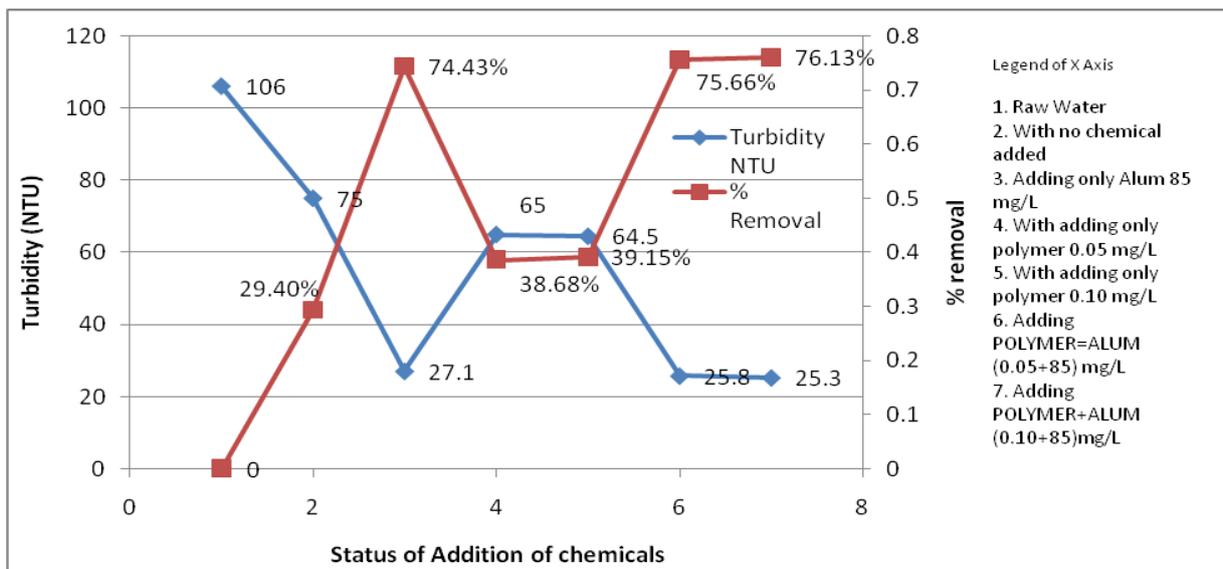


Figure 5: Effect of adding alum & polymer alone and in conjunction in turbidity removal

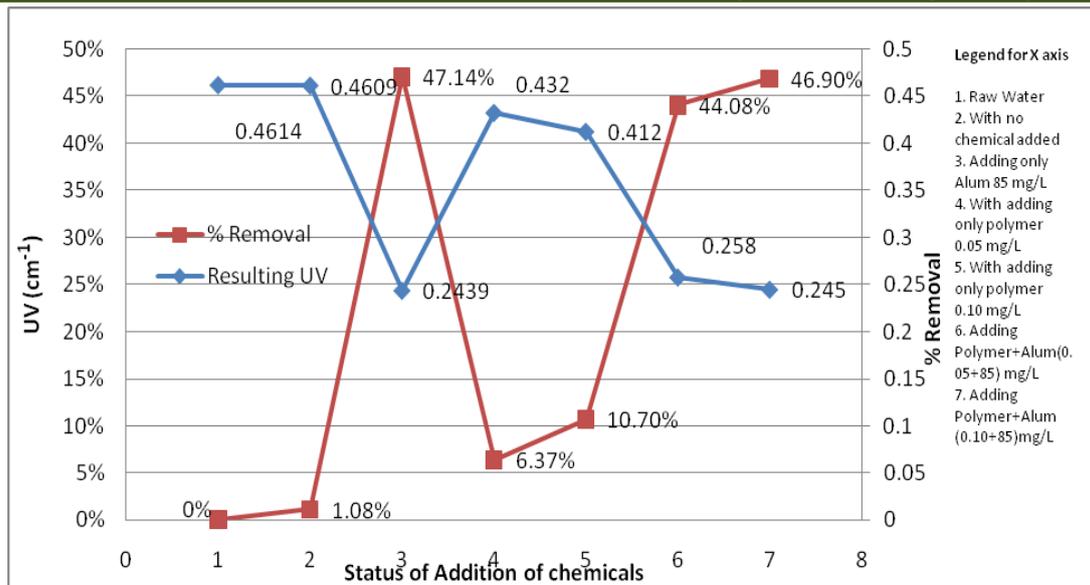


Figure 6: Effect of adding alum & polymer alone and in conjunction in organic carbon removal

B. Results from second test

The measured turbidity of the raw water sample was 106 NTU. The rapid mixing was done for 2 minutes with a speed of 200 RPM and slow mixing was done for 20 minutes with a speed of 50 RPM. Chemical analysis was done after 30 minutes. The primary findings from the chemical analysis are briefly discussed in the following.

1) Effect of no chemical addition

It is observed that even with adding nothing to the raw water sample, simple stirring and subsequent natural settlement resulted a turbidity of 75 NTU of the settled raw water from raw water turbidity of 106 NTU that is 29.4% of turbidity removal after 30 minutes (Figure 5).

2) Effect of addition of Polymer alone & doubling its concentration

Adding only 0.05 mg/L of polymer alone into the raw water gives a resulting turbidity of 65 NTU indicating 38.68% turbidity removals. Doubling the polymer dose that is by adding 0.10 mg/L of polymer alone the resulting turbidity is 64.5 NTU indicating a turbidity reduction of 39.15%. It is worth noting that by doubling the dose of polymer from 0.05 to 0.10 mg/L the change in turbidity removal is hardly increases least expecting double reduction in turbidity removal.

It is also apparent from level 4 & 5 (Figures 5 & 6) that adding only alum is more effective than adding only polymer in removing turbidity and organic material for this particular water. It coincides with earlier findings that with an anionic polyelectrolyte (hydrolysed polyacrylamide), although it functioned well as a flocculant aid, no significant turbidity removal was evident without prior aluminium sulphate addition. Dosage of the polyelectrolyte was very critical: excess dosages gave rise to restabilization.

3) Effect of addition of Alum alone

Adding 85 mg/L of Alum alone into the raw water the resulting turbidity gives a value of 27.1 NTU that is resulting 74.43% of turbidity removal.

It is evident that addition of Alum alone to the raw water is far more effective than adding only polymer in this particular sample of raw water for the removal of turbidity (Figure 5).

4) Effect of addition of Alum combined with Polymer

The next jar test with 85 mg/L of Alum along with 0.05 mg/L of polymer gives a resulting turbidity of 25.8 NTU that is 75.66% removal of turbidity. Thus keeping Alum dose fixed at 85 mg/L adding 0.05 mg/L of polymer the increase in the % removal of turbidity is only 1.23% which is insignificant (Figure 5).

By doubling the polymer dose that is instead of 0.05 mg/L adding 0.1 mg/L of polymer along with 85 mg/L of Alum as before the resulting turbidity stands to 25.3 NTU indicating 76.13% of turbidity removal. Thus keeping alum dose same at 85 mg/L, doubling the polymer dose from 0.05 to 0.10 mg/L turbidity removal increases only by 0.47% (Figure 5).

It is evident from the jar test result that adding this particular polymer alone or in combination with Alum coagulant, even doubling the dose of polymer did not bring any remarkable changes in the turbidity removal percentage than the result obtained by adding Alum alone to this particular raw water.

5) Effect in the removal of UV₂₅₄

Similar result is seen in case of removal of UV₂₅₄. With 85 mg/L of Alum alone the removal of UV₂₅₄ is 47.14% (Figure 6). When 0.05 mg/L polymer is added along with 85 mg/L of Alum the removal is

decreased by 3.06% rather than increase. Even adding 0.10 mg/L polymer along with 85 mg/L of Alum removal of UV₂₅₄ stands to 46.90% yet below what is achieved by adding Alum alone (Figure 6).

It is worthy to note that applying 0.1 ppm of polymer alone (When turbidity 106 NTU) we get 39.15% removal of turbidity (Figure 5) whereas applying 10 ppm (100 times higher) of polymer gives 29.44% removal of turbidity (When turbidity is 90 NTU) (Table 2).

Again adding 20 ppm of polymer with 100 ppm of alum gives 73.44% of removal of turbidity where as 0.1 ppm polymer + 85ppm Alum gives 76.13% removal (Turbidity 106 NTU).

5. CONCLUSIONS

The organic polymers and inorganic salts alone and in combination were applied to Shitalakshya river raw water in Bangladesh to check their efficiency in reducing in turbidity and TOC, measured in the form UV₂₅₄ as surrogate. It is observed overall that synthesized polymer flocculants can not improve removal efficiency of turbidity and TOC when applied alone or in combination. Progressive increase of polymer dose does not increase the turbidity removal proportionately, yet, sometimes the percentage removal decreases with the increase of polymer doses when applied alone. When polymer is added in addition to alum the increase in turbidity removal efficiency is not remarkable, even by doubling the polymer dose with the fixed alum dose it hardly gives any positive effect. It is evident that addition of Alum alone to the raw water is far more effective than adding only polymer in this particular sample of raw water for the removal of turbidity.

It is worth noting that by doubling the dose of polymer from 0.05 to 0.10 mg/L keeping the alum dose fixed the change in turbidity removal is hardly increases lest expecting double reduction in turbidity removal. In case of organic carbon removal as tested by UV₂₅₄ as surrogate the addition of polymer do not bring any positive result rather it decreases the removal efficiency of UV₂₅₄ than what is achieved by alum alone. The jar test result shows that adding this particular polymer alone or in combination with Alum coagulant, even doubling the dose of polymer did not bring any remarkable changes in the turbidity removal percentage than the result obtained by adding Alum alone.

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