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Evaluation of a number of coagulants and coagulation aids in removing water turbidity

Ahlam Abdul -Rheem Farhan¹

¹Institute of Technology, Middle Technical University, Baghdad, Iraq.

Abstract. The physical efficiency of a number of coagulants alum, ferrous sulfate and ferric chloride in addition to coagulation organic aids like poly ethylene glycol (PEG), polyacrylamide (PAM) and non-organic like Bentonite in removing turbidity of raw water in its high and low turbidity 850 NTU ,52 NTU respectively was studied. The optimal dose was determined for each of them that give less turbidity and higher removal percentage. The results declared that alum was the best removal for both high and low turbidity which reach 99.59% and 97.54% respectively. Ferrous sulfate, Ferric chloride, and calcium oxide were the best for removing turbidity of high turbid raw water 98.26, 98.66 and 92.18% respectively. For coagulation aids, the best of them was (PAM) for both raw water turbidity, while (PEG) record good removal percentage for low turbidity that reach 89.81%. Bentonite give lowest removal percentage for low turbidity 31.92%, on contrast with high turbidity 74%. used of Bentonite with alum improved the removal to 88.92%.

1. Introduction

Water is considered the essence of life. Man has always cared about the quality of drinking water, how to use it and how to maintain it. Thus , it should be free of pollution and impurity.

Turbidity means there are suspended solids or impurities materials in water [1] . Suspended solids consist of organic, inorganic and sludge. Besides, it contains some microorganisms such as algae, bacteria and fungi. Since they are very small with large surface area compared to its weight , they keep them suspended in water and they do not precipitate [2].

The maximum allowable turbidity in tap water according to WHO (World Health Organization) is 5 (NTU) [3]. Turbidity can be removed by coagulation process, followed by flocculation using organic, inorganic chemicals and natural materials. They are called coagulants. The coagulation process include addition of chemicals and mixing at high speed for short; time (30 sec – 2 mint). The second step (flocculation) the water stirred at slow mixing for (20- 45 mint) in order to form large flocs, which are easily settled and separated from the effluent stream , in a sedimentation step [4,5]. The mechanism of coagulation process involves decreasing or neutralizing the electric charge on suspended particles or Zeta potential . These small particles have negative charge which leads to their repulsion. Hence remain suspended in water coagulation / flocculation process reduces the negative charge of particles. It permits the (van der Waals) force of attraction to promote initial aggregation of colloidal and find suspended material to form micro floc particles which accumulate forming bigger flocs by means of mixing or by the effect of flocculants such as long chain polymers[1].



Coagulants and Coagulant aids: Organic Coagulants like PolyAMINEs and PolyDADMACs are used, inorganic coagulants used are Aluminum Sulfate (Alum) which is the most used in water treatment, in addition to Aluminum Chloride, Polyaluminum Chloride (PAC), Ferric Sulfate, Ferrous Sulfate and Ferric Chloride [6].

Coagulant aids can be used to improve the coagulation process whether they are organic or inorganic by producing bigger flocs and reducing the amount of coagulants used [4]. Common coagulant aids used are Bentonite, Calcium carbonate, Sodium silicate, Anionic polymer, Nonionic polymer.

Many studies dealt with using kinds of both organic and inorganic coagulants and coagulant aids to remove water turbidity [1,4] and to remove some heavy metals.[7] there are also natural materials used as coagulants and coagulant aids instead of chemical coagulants for reducing the quantity used [5,8,9]. Polyacrylamide (PAM) is a multi-charge organic polymers $(C_3H_5NO)_n$ with high molecular weights, water soluble or swell able polymers, formed from acrylamide or its derivatives. It has successfully removed organic and inorganic substances in the treatment of raw water and wastewater when used alone or with inorganic compounds such as alum [10, 11]. The derivatives of Polyacrylamide are Anionic PAM, Cationic PAM, Nonionic PAM. It is widely used in waste water treatment of chemical industry, municipal sewage treatment and separating mixed organic and inorganic suspension[12].

Polyethylene glycol (PEG) is an organic polymeric material $(C_{2n}H_{4n+2}O_{n+1})$ that has many uses in various industries including pharmaceutical industries [13]. It has been used alone as a Coagulant and with the addition of $CaCl_2$ as coagulation aid to reduce the turbidity of water from mining residues [14]. There is a reservation from some countries for the use of organic polymers in drinking water treatment. Polyacrylamide is one of them. Polyacrylamide has no effect on health, but its effect is caused by its containment on non-polymerized acrylamide units called monomer. A few countries have developed strict laws to restrict the use of organic polymers and their proportion in drinking water cannot be exceeded[15]. Polymer coagulation aids are very efficient in removing turbidity from water even with small doses. They operate within a wide range of water pH [15]. The sludge formed is of a small size and high density particularly in the case of Polyacrylamide compared with sludge formed from other coagulants and other coagulation aids [11, 15].

In this work a number of coagulants such as alum, Ferric chloride, ferrous sulfate, calcium oxide and coagulation aids such as PAM, PEG, and Bentonite were used separately; one combination was also used (alum and Bentonite) to decrease turbidity of raw water. The turbidity levels of raw water tested are; 52 and 850 NTU.

2. Material and methods :

2.1. Raw water samples

The raw water samples were taken from the Tigris river after being pumped into the collection tank of the Al Wahda Water Project. The turbidity was adjusted to obtain the required turbidity of 52 and 850 NTU by adding the clay taken near the river.

2.2. Coagulants and coagulation aids prepared solutions

2.2.1. Alum and other coagulants solution.

Alum taken from Al Wahda Water Project; stock solutions of alum were prepared by dissolving 10 g of the $Al_2(SO_4)_3$ into one liter of distilled water to produce 1% solution concentration. So each 1ml of this solution is equivalent to 10 mg of alum used for high turbidity of raw water. And 0.1% solution concentration was prepared by dissolving 1 g of alum into one liter of distilled water to be used for low turbidity of raw water. The stock solutions for other Coagulants. Ferric Chloride, Ferrous Sulfate and calcium oxide Prepared in the same way as alum (1% and 0.1%)

2.2.2. Bentonite.

Bentonite is a clay mineral and is used as coagulation aid which is a fine grained inorganic clay of the mineral montmorillonite. Bentonite has a negative charge and can add weight to flocs, joining them together to produce larger, tougher and faster settling flocs [16]. A weight of 1g of Bentonite was added to 100ml of distilled water and stirred well to produce 1% solution concentration

2.2.3. Polyacrylamide (PAM).

The PAM is a coagulants aids with molecular weight 10,000 , anion type from Kemira SUPERFLOC (Finland). Solutions of PAM were prepared by dissolving 0.05 g of PAM in 100 mL of distilled water and stirred well. Then getting the following concentrations 0.05-0.5 mg / l when added to 1 liter of Raw water in the jar test

2.2.4. Polyethylene glycol (PEG).

PEG is a coagulants aids with molecular weight 4000 ,also from Kemira. dissolving 1g of PEG in 100ml of distilled water, was used for high turbidity of raw water. Dissolving 1g of PEG in 1 liter of distilled water for low turbidity of raw water.

2.3. Jar test :

Jar test were carried out to determine the optimal dosage for each coagulants and coagulant aids. Six 1 liter beaker was used containing six paddles, various dosages of each coagulant was added. Then a rapid mixing for 1 minutes and 200 rpm was subjected to the samples then 20 min with a slow mixing at 50 rpm, when the mixing was completed, the flocs allowed to settle for 20 minutes. In order to measure the residual turbidity, samples were withdrawn using a pipette from a height of 5cm below the surface of each beaker. Then determine the optimal dosage that gives low turbidity for each coagulants .

2.4. Analysis

The tests were carried out according to the standard methods of water tests[17].Turbidity, pH and Conductivity. Measurements were carried out with pH meter (98107 HANNA HI) , turbidity meter (Turbicheck Lovibond) and (98303 HANNA HI) for Conductivity.

3. Results and discussion

A number of experiments were performed to determine the optimal dose of coagulants and coagulation aids in reducing water turbidity. which were compared with each other to recognize the best of them in turbidity removal for high and low initial raw water turbidity 850 NTU and 52 NTU, respectively.

Some properties of raw water are shown in (Table 1), 'Figure 1' show the apparent decrease in residual turbidity when using alum for both high and low turbidity of raw water. The colloids most commonly found in natural waters are negatively charged, hence a cation is required to neutralize the charge, when using Alum the Aluminum ions (Al^{+3}) will neutralize negatively charged ions causing them to aggregate and easily to precipitate , but increasing the dose over the optimal one will increase the turbidity because of the excess in (Al^{+3}) ions in the form of complex hydroxides and without contact with the negative charged ions of the suspended colloidal particles causing increase in the turbidity and decrease pH [18].

Iron salts (ferrous sulfate and ferric chloride) are good in removing turbidity after alum, Figures 2, 3 and Ferric chloride is slightly better than ferrous sulfate in removing low turbidity. The mechanism of coagulation for metal salts of aluminum and iron involves either the adsorption of coagulant species to the contaminant to be removed or the entrapment of the contaminant within a hydroxide precipitate [5,19].

The efficiency of calcium oxide is less than iron salts in removing turbidity for high and low turbidity of raw water respectively, yet it's good at high turbidity ' figure 4' and so is advised to be used in high turbidity of raw water. The effect of the addition of CaO on raw water is show in (tables 2,3) which decrease

the residual turbidity and hardness and increase pH at high raw water turbidity and at low turbidity pH increase, but the residual turbidity and hardness is decreased at low amount of CaO, then increased as the dose of CaO is increased. The solubility of CaO in water causing to form Ca(OH)_2 which attract suspended particles causing their aggregation and sedimentation and calcium ions appears to be more effective at high levels of turbidity and high potency. This can be explained by the fact that high concentration suspensions are more affected by dissolved Ca^{+} ions. There is many studies in which CaO is used together with alum and ferric chloride to improve removal of both high and low turbidity.[20,21]

The coagulation aids PAM, Bentonite and PEG in 'figures 5, 6, 7'; the PAM is the best in removing turbidity and for both low and high than PEG. While Bentonite was the least in this manner especially at low turbidity, The mixture of 10 mg/l from both alum and Bentonite give a removal percent 88.92% at low turbidity of raw water as declared in 'figure 8'. So it is better to use Bentonite with coagulants especially alum to improve efficiency of turbidity removal [22]. (tables 4,5) and 'figure 9' shows the percentage removal of turbidity with 52,850 NTU raw water turbidity at the optimal dose of coagulants and coagulation aids.

Table 1. Characteristics of the raw water

initial turbidity	pH	Conductivity $\mu\text{s/cm}$
52-57	8.2-8.5	700-770
850	8-8.5	600-890

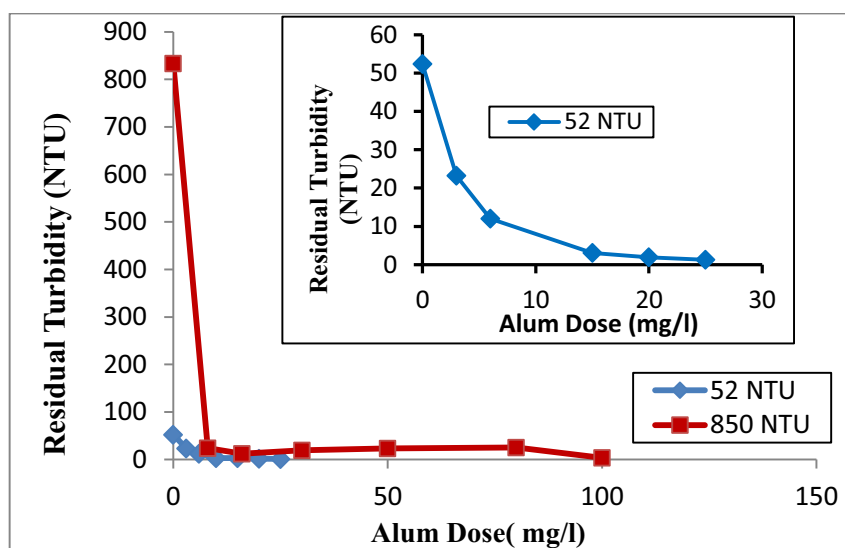


Figure 1. Effect of Alum dose on residual turbidity at high and low initial turbidity

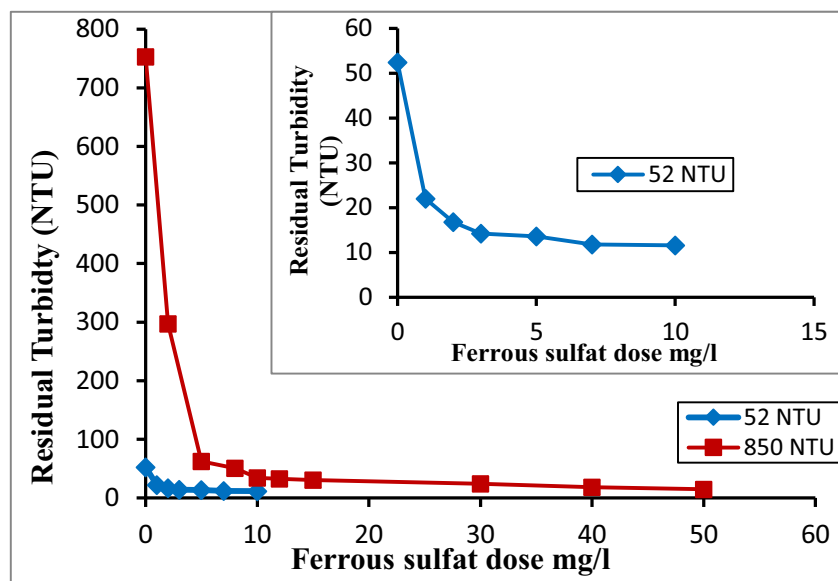


Figure 2. Effect of Ferrous sulfate dose on residual turbidity at high and low initial turbidity

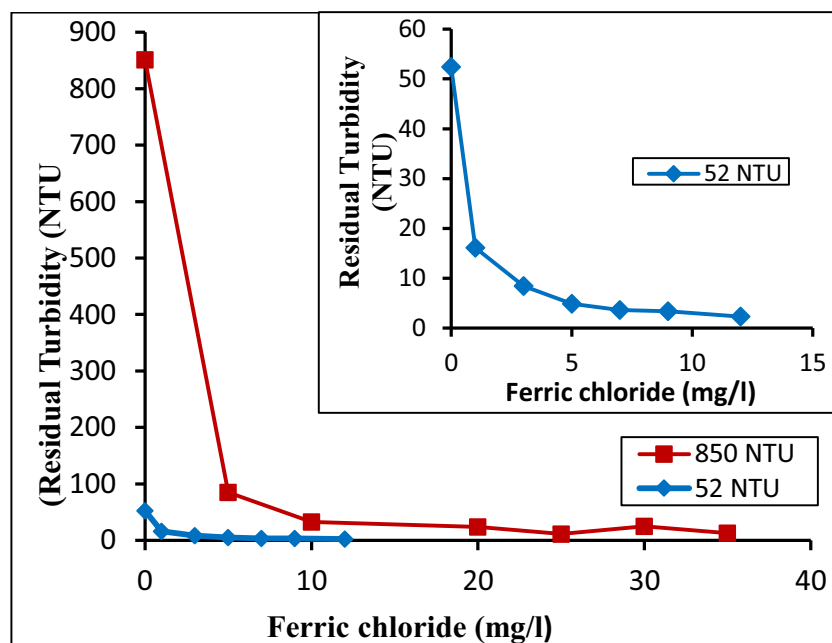


Figure 3. Effect of Ferric chloride dose on residual turbidity at high and low initial turbidity

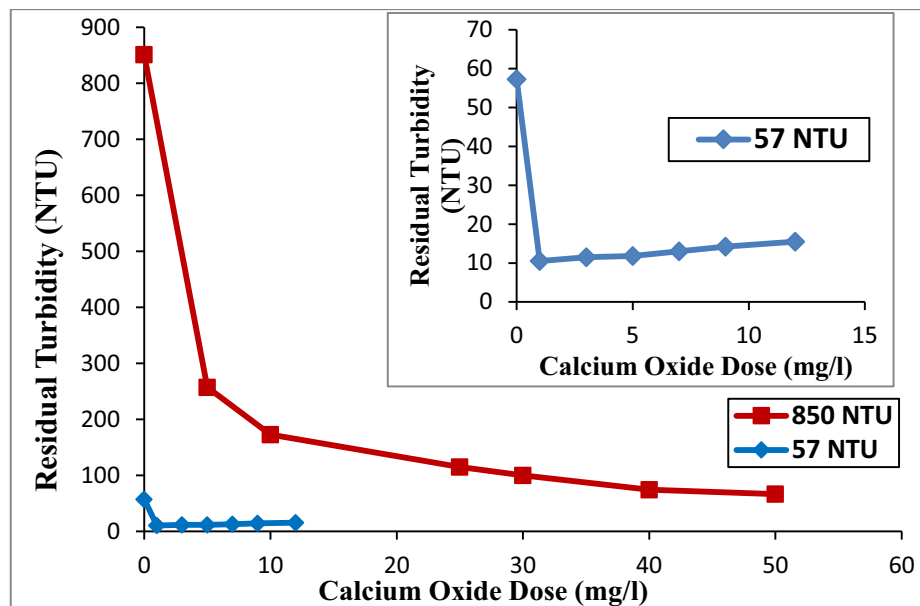


Figure 4. Effect of Calcium Oxide dose on residual turbidity at high and low initial turbidity

Table 2. Effect of Calcium Oxide dose on residual turbidity, total hardness and pH at low initial turbidity

Calcium Oxide mg/l	Residual turbidity NTU	pH	Total hardness mg/l
0	57.3	8.5	92
1	10.5	8.8	32
3	11.5	9.1	24
5	11.8	9.3	16
7	13	9.5	44
9	14.2	9.6	68
12	15.5	9.9	64

Table 3. Effect of Calcium Oxide dose on residual turbidity, total hardness and pH at high initial turbidity

Calcium Oxide mg/l	Residual turbidity NTU	pH	Total hardness mg/l
0	851	8.5	115
5	257	8.9	108
10	173	9.1	84
25	115	8.6	80
30	100	8.5	76
40	74.4	8.6	64
50	66.5	8.7	56

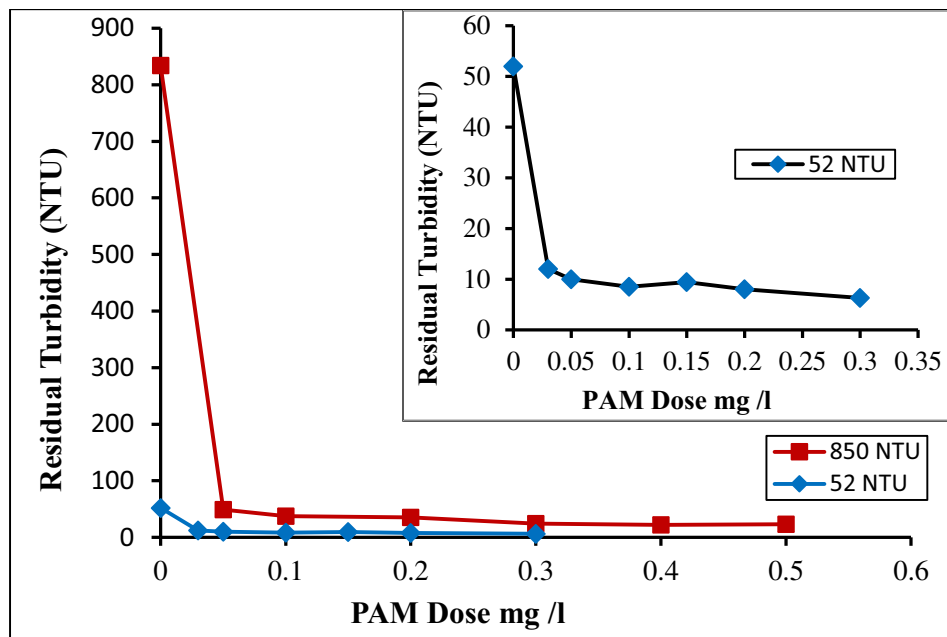


Figure 5. Effect of PAM dose on residual turbidity at high and low initial turbidity

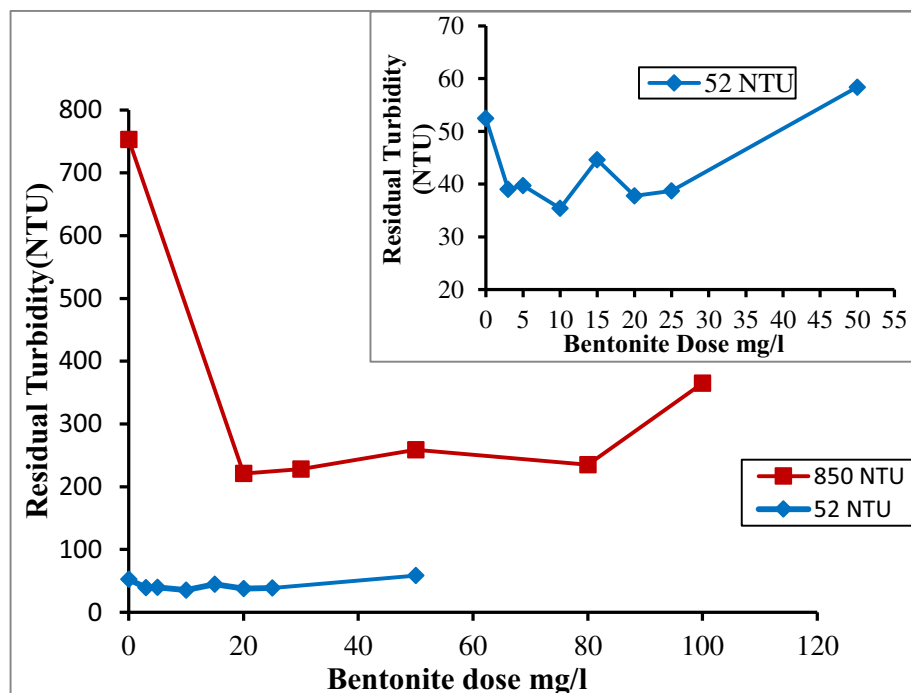


Figure 6. Effect of Bentonite dose on residual turbidity at high and low initial turbidity

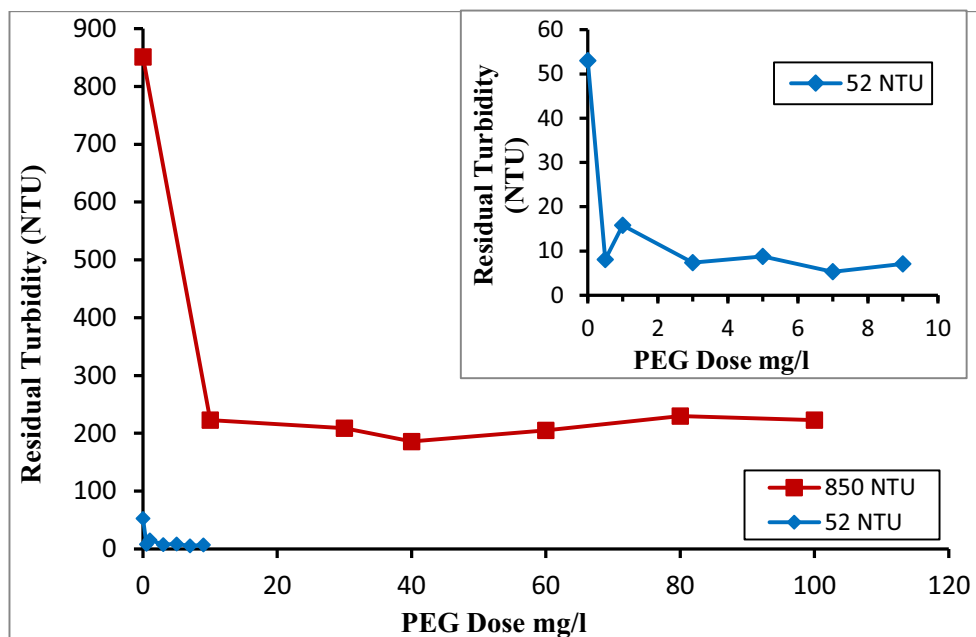


Figure 7. Effect of PEG dose on residual turbidity at high and low initial turbidity

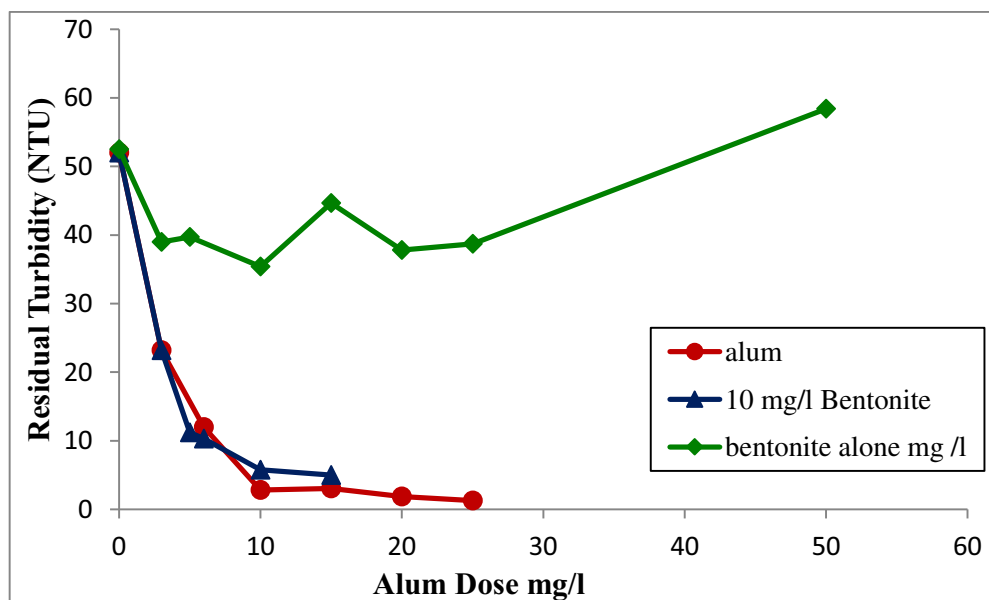


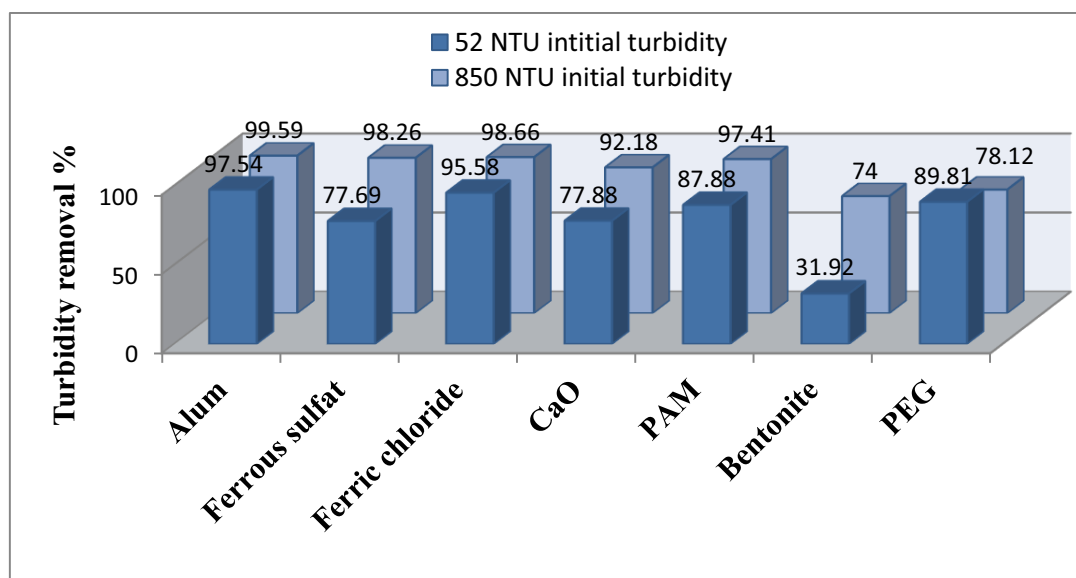
Figure 8. Residual Turbidity alum , Bentonite and mixing 10mg/l Bentonite with different dose of alum for low raw water turbidity 52 NTU

Table 4. Effect of coagulants and coagulation aids in removing turbidity of raw water with turbidity 52 NTU

coagulants and coagulation aids	Dosing mg/l	Residual Turbidity NTU	Turbidity Removal %
Alum	25	1.28	97.54
Ferrous sulfat	10	11.6	77.69
Ferric chloride	12	2.3	95.58
CaO	3	11.5	77.88
PAM	0.3	6.3	87.88
Bentonite	10	35.4	31.92
PEG	7	5.3	89.81
Bentonite+ Alum	10+10	5.76	88.92

Table 5. Effect of coagulants and coagulation aids in removing turbidity of raw water with turbidity 850 NTU

coagulants and coagulation aids	Dosing mg/l	Residual Turbidity NTU	Turbidity Removal %
Alum	100	3.5	99.59
Ferrous sulfat	50	14.8	98.26
Ferric chloride	25	11.4	98.66
CaO	50	66.5	92.18
PAM	0.4	22	97.41
Bentonite	20	221	74.00
PEG	40	186	78.12

**Figure 9.** Turbidity removal % of coagulants and coagulant aids for low and high initial Turbidity

4. Conclusions

- 1- The efficiency in removing turbidity by alum was the highest at all levels of initial turbidity, then iron salts (ferric chloride and sulfur sulphate), especially at high turbidity.
- 2- It is recommended to use calcium oxide at high turbidity.
- 3- PAM was the best Coagulation aids then PEG. Bentonite was good at high turbidity and less at low turbidity, but when used with alum, it gave better removal.
- 4- Some coagulation aids can be used alone as coagulant, which gives a high removal rate such as PAM.

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