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Enhancement of water quality in water treatment plant using bentonite as coagulant addition

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Abstract

A novel method has been employed to treat low-turbidity water utilising bentonite with a decreased amount of alum for the aim of employing alum in large amounts in low-turbid water treatment. As bentonite has a negative charge, it is added to the raw water to add weight to the blocks, which are then joined together to form huge blocks that settle faster. It enhances the weight of the suspension and the density of the particles, as well as providing a broad surface for organic compound adsorption. The amount of bentonite clay used varies between 10 and 50 mg/ l. In the Karbala water treatment plant, the efficiency of water quality index (WQI) was poor (71.16 percent) at turbidity 20NTU using alum alone. The efficiency of WQI was also low in the pilot plant under the identical conditions (72 percent). When utilizing bentonite in the pilot plant, the efficiency of WQI was increased to 97.2 percent by raising the turbidity of the water to 120 NTU. The turbidity of the water was elevated to 200 NTU and the efficiency of WQI was boosted to 98.9 percent when bentonite was added to it. The use of bentonite resulted in a high efficiency of WQI, as well as a low-cost substance with no side effects or infections.

Keywords: Turbidity, Water treatment, Bentonite, WQI, efficiency.

1.Introduction

Colloids make up a significant amount of the suspended particles in water that are too tiny to be removed in a sedimentation basin. Colloidal particles have a great surface area to volume ratio because of their tiny size. In water, the majority of colloidal particles are negatively charged, stable, and incapable of sedimentation or clarity [1, 2, 3]. When water turbidity is low (nanoparticle concentration is low), the pace of interaction and attraction of these particles restricts the total coagulation process [4]. Low water turbidity can be handled by sweeping coagulation, which uses alum (aluminium sulphate) to promote efficient coagulation [5]. Because of the large dose of alum employed in this form of coagulation, aluminium hydroxide precipitates, causing collisions between suspended particles, which are then removed by sedimentation. When a considerable amount of alum is used in this sweeping coagulation process, a big volume of waste sludge is generated, as well as a high concentration of aluminium in the treated water at alkalinity and acidity. All of these increases will exacerbate public health issues [6]. It is necessary to destabilise those colloids in order for them to come into contact and combine. Mud metals, such as bentonite, are inorganic clay particles that are remarkably similar to Montmorillonite metal. Because of its excellent absorption and ion exchange properties, bentonite is frequently employed in water treatment. This absorption may be divided into two types: physical absorption and exchange adsorption [7]. Many researchers have undertaken extensive and detailed investigations on natural mud minerals uses such as bentonite clay in the removal of organic, inorganic, and biological contaminants from drinking water [8,9,10]. Bentonite has a number of characteristics, including excellent adsorption, nontoxicity, and ion exchange ability. Using these mineral resources as flocculants has a number of advantages, including high availability, little secondary pollution, and low cost. It was discovered that the raw water entering the Kerbala water treatment plant had low turbidity due to particles of infinite size, and that it is required to remove it. Because nanoparticle concentrations in water are low, the rate of attraction and interaction between these particles is limited, limiting the total coagulation process [11]. Water with low turbidity is treated by sweeping coagulation, which uses alum (aluminium sulphate) to promote efficient coagulation [12]. Because the amount of alum utilised in this form of coagulation is large, amorphous precipitation of aluminium hydroxide occurs, which increases the frequency of particle collisions, collides with suspended particles, and is therefore eliminated by sedimentation. The sweeping coagulation method, which uses alum, generates a lot of waste sludge and keeps the aluminium content in the treated water high at both acidity and alkalinity, posing a public health risk. When a high alum dosage is employed in the sweeping coagulation process, aluminium hydroxide, an amorphous precipitate, forms, increasing particle collisions and collisions with suspended particles to form a big floc, which is then removed by sedimentation [13]. Low-turbid water treatment necessitated the development of a novel sweeping coagulation technique. Flocculants materials consisting of flocculation of bentonite mixed with alum during the coagulation process are used in this mechanism[14]. It was focused toward the usage of bentonite in this study as well as another goal of increasing the turbidity of the raw water. As a result, when utilizing bentonite as a coagulant substance, the best removal efficiency for low water turbidity is achieved. The major goal of this study is to exam the use of bentonite and to compare with the use of alum material alone in terms of removal efficiency.

2. Materials and Method

2.1 Conventional Clariflocculator

The whole model of the water treatment plant was produced and replicated by the original model, and it consists of the following components: (a rapid mix unit, clariflocculator and clarifier and filtration tanks). For injecting coagulant into the system, one dosing tank (20 litres capacity) was provided. Another 1000 liters capacity dosing tank was installed for preparing turbidity using a 0.3 KW motor with a speed control for the turbidity dosing tank to set turbidity values. The model's flow rate was 0.475 m3/h, whereas the station's corresponding flow rate was 1050 m3/h. The mechanical mixing unit (mixing basin) was made of galvanised plate and was built for a 78-second detention duration for raw water mixing with coagulants for uniform distributed coagulation. The tank's diameter and height were calculated to be 24.5 cm and 21 cm, respectively. The flash mixing tank is seen in Figure 1.

Figure 1. Flash Mixing Tank

The Clariflocculator is made up of two concentric reservoirs, one of which acts as a flocculation basin and the other as a clarifier. For the transmission of water from the flash mixer tank to the flocculation tank, a 2.54 cm diameter influential tube has been attached. The clarifier was designed to work in an upflow configuration. The clariflocculator and clarifier had diameters of 31.0 cm and 91.0 cm, respectively. At the bottom of the tank, a sludge drain line with a valve was connected to transport the sludge out at regular intervals. The cleared water was collected in a conduit at the top of the clarifier basin called the Peripheral channel. A schematic representation of a traditional clariflocculator is shown in Figure 2.

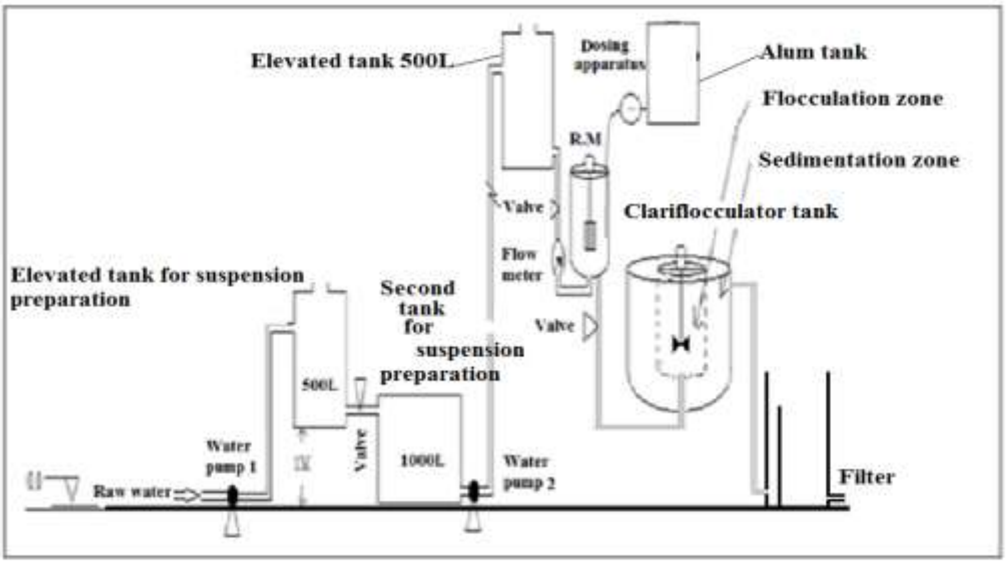

Figure 2. Schematic Diagram of Conventional Clariflocculator

2.2 The Filters Distribution Unit

The settled water is transported to the filtration unit (single-media filter) via a hose-tube of 20 mm after the sedimentation process. The filter utilised in this investigation was 0.34m long, 0.17m wide, and 2.2m tall, and was composed of galvanised plate with a thickness of 1.5mm. The bottom of the filter was filled with four graded layers of gravel, with a total depth of 500mm for the support gravel layer. This filter's media is silica sand with a bed depth of 700mm, which is put above the support gravel and is referred to as single media, as shown in Figure 3.

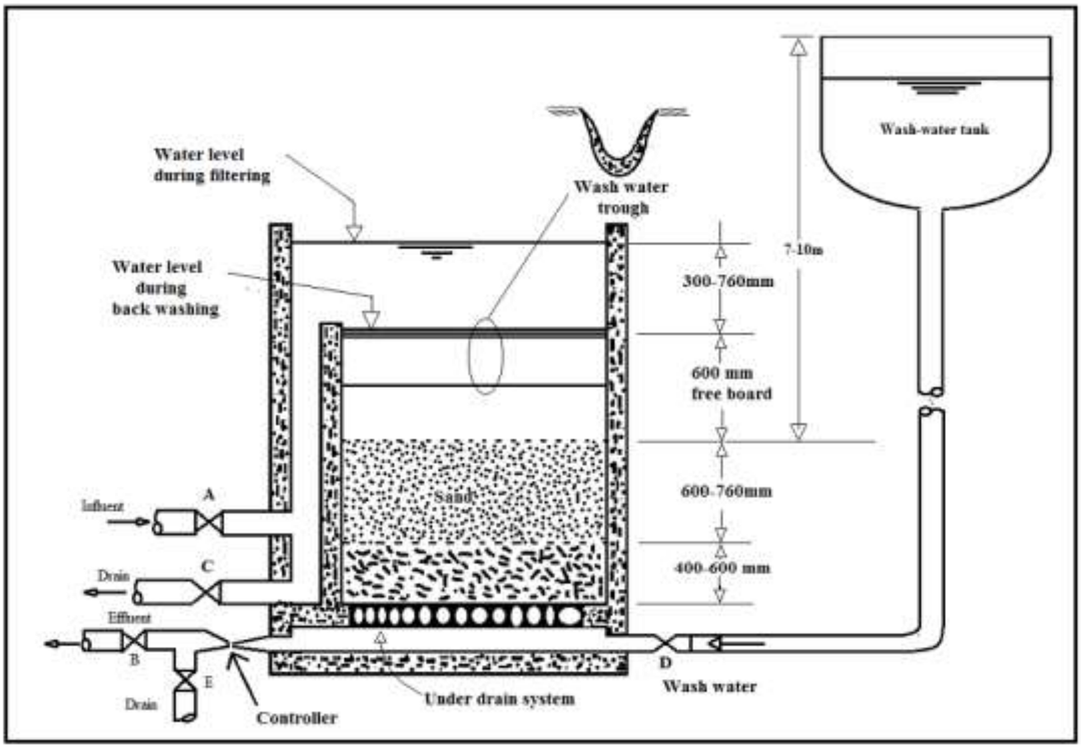

Figure 3. Typical Gravity Flow Filter Operation

2.3 Raw Water Samples

The raw water samples were taken from Euphrates river after being pumped into receiving well of the Kerbala Water treatment plant. The turbidity was adjusted to obtain the required turbidity of 120 and 200 NTU by adding the bentonite clay. Table (1) was selected to developed the required index [15].

Table 1. Parameters of water treatment plant in Karbala

2.4

Parameter	Tur. NTU	pH	E.C $\mu S/cm$	Alk. mg/L	T.H mg/L	Ca mg/L	Mg mg/L	Cl mg/L	SO_4 mg/L	TDS mg/L
Standard Value	5	8.5	2000	125	500	75	50	250	250	1000

Experimental preparation

This model was used to test four different turbidities, each with a different coagulant dose. As previously stated, the raw water used to operate the models came from the receiving well that supplies raw water to the station. Because the turbidity of the raw water supply was minimal, the testing was done using exogenous turbidity, such as bentonite clay. In the model's dosing tank, a 1 gramme per litre bentonite solution was introduced. A motorised stirrer was used to keep the particles in suspension, preventing the bentonite particles from settling and ensuring uniform mixing. Alum, which is accessible in both liquid and powder form, was utilised as the coagulant in this investigation. When the turbidity is less than 30 NTU, the standard coagulation dosage at the station is 25 ppm. The bentonite clay was purchased from a variety of local and commercial sources. One litre of river water has been obtained for the purpose of creating turbid water, and after measuring the turbidity, bentonite has been added in progressive amounts of 1 g per litre until the needed turbidity has been reached and the quantity of bentonite used has been measured. The Euphrates River is the only source of water for water treatment plants in Kerbala Governorate. According to data from tests conducted in the Kerbala governorate's water treatment facility from 2014 to 2016, the turbidity of the river water is low and consistent throughout the year. From 2014 to 2016, Table (2) shows the rate of monthly turbidity levels.

Table (2). The Annual Mean Turbidity Values During Years (2014-2016)

Year	Raw Turb.	Clear Turb.	Raw TDS	Clear TDS	Raw EC	Clear TDS	Raw pH	Clear pH
2014	20.19	1.3	536.7	548.5	1147.2	1150.9	7.8	7.7
2015	18	1.3	663	634	1390	1397	7.43	7.51
2016	19	1	534.7	552.9	1122.5	1127.4	7.5	7.5

To make a comparison between the two methods, the first was a traditional clariflocculator that was run at an equivalent flow of 0.475m3/hr. using bentonite, and the second methodology was based on data from a water treatment facility (2014-2016).

2.5 Chemical Analysis

During the period 2014-2019, the drinking water treatment plant in Imam Aun district, Kerbala governorate, was chosen for the goal of assessing the quality of produced water using mathematical index and comparing it to the experiment work of removal efficiency while utilising bentonite soil. The facility is capable of producing 10,500 m3/h. Turbidity (Turb.), pH, electrical conductivity (EC), Sulphate ($SO4^{-2}$), alkalinity (Alk.), total hardness (T.H), chloride (Cl), calcium (Ca^{+2}), magnesium (Mg^{+2}), and total dissolved solids (TDS) were among the physiochemical characteristics employed in this study (TDS). The turbidity is measured with a Nephelometric turbid meter (HANNA-HI88703) equipment. China produced the portable pH-TDS meter. The pH meter was calibrated with a reference buffer solution prior each to the pH value test. The electrical conductivity meter type is (HANNA - EC215).

2.6 Water quality index (WQI)

The water quality index (WQI) is one of the instruments for assessing water quality for a variety of purposes, including drinkable, agricultural, recreational, and industrial. They are thought to be extremely effective and beneficial since they are based on a set of measurable criteria and are gathered in a numerical classification to assess water quality and compare it to standards suggested by human health agencies [16,17]. The water quality scale index was produced in this study using a weighted arithmetic index to evaluate the Kerbala water purification plant project in the Imam Aun region. As mentioned earlier, this method is used to calculate water quality based on three equations that play a very important role in determining the indicator. These are shown in the following steps [18]:

Step 1:- To obtained the value of ‘qn’ ,which is the quality rating or sub-index, using the following equation :

$$qn = [(\boldsymbol{Vn}-\boldsymbol{V0}.)\ (\boldsymbol{Sn}.-\boldsymbol{V0}.)\ ]*\ 100 \text{-------------------------}(1)$$

where :

Vn= Estimated value of each parameter from the water analysis.

Vi or $V0$ = The ideal value of each parameter counted as zero, except the value of pH parameter = 7 and Do =14.6 mg/l.

Sn= The standard parameter recommended for the water quality.

Step 2:- In this step, the relative unit weight of the parameter (Wn) can be calculated by using the formula :

$$Wn=K/Sn \text{---}(2)$$

where:

K is the proportionality constant, found by the formula (3) :

$$K=\frac{1}{\Sigma(\frac{1}{V_{n.}})} \text{---}(3)$$

Step 3:- In this step it can be found the total Arithmetic Water Quality Index WQI using formula :

$$\text{WQI}=\frac{\sum q_n * W_n}{\sum W_n} \quad \text{--(4)}$$

The improvement ratio in water quality (Removal efficiency) is calculated according to the following equation [19]:

$$\text{Improvement ratio (E \%)} = \frac{(\text{WQI of raw water} - \text{WQI of treated water})}{\text{WQI of raw water}} * 100 \quad \text{-----------------(5)}$$

Table (3) shows the categories of water quality classification based on the Weighted Arithmetic index value [19,20].

Table (3). Classification of Water Quality Based on Weight Arithmetic Index

The Value Of Water Quality Index	Category Of Water Quality	Grading
0-25	Excellent	A
26-50	Good	B
51-75	Poor	C
76-100	Very Poor	D
>100	Unsuitable for drinking	E

3. Results and discussion

3.1 WQI for Real Turbidity in WTP

The results of the water quality indicator for the water treatment plant in kerbala are presented in tables 4 to 10 for the years (2014-2016) under conditions: T= 20 NTU, Q_p= 0.475 m^3/h and Q_e= 1050 m3/h. Table 4 shows the WQI for raw water at T=20 NTU, and Q_p = 0.475 m^3/h in 2014. As mentioned in table 3, the results of WQI at T= 20 NTU, Qp = 0.475 m3/h is 271.21 which its unfit for consumption [20]. Table 5 show the WQI for clear water at T=20 NTU, and Q_p = 0.475 m^3/h in 2014.

Table 4. WQI for raw water at T=20 NTU and Q_p = 0.475 m^3/h

WQI at raw water =20NTU and flow rate = 0.475 m³/h in 2014										
parameter	BIS Standard (Sn)	1/Sn	∑1/Sn	K=1/∑1/Sn	W1=Wn=K /Sn	Ideal value (Vo)	Mean conc. value (Vn)	Vn/Sn	Qn = (Vn*Sn) *100	Wn* Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	20.19	4.038	403.8	251.2
pH	8.5	0.32	0.3215	3.11	0.366	7	7.81	0.54	54	19.76
EC	2000	0.0005	0.3215	3.11	0.002	0	1147.2	0.57	57	0.09
TDS	1000	0.001	0.3215	3.11	0.003	0	536.7	0.54	54	0.17
Sum		0.3215								271.21
WQI = 271.21 Unfit For Consumption										

Table 5. WQI for clear water at T=20 NTU and Q_p = 0.475 m^3/h

WQI at clear water =20NTU and flow rate = 0.475 m³/h in 2014										
parameter	BIS Standard (Sn)	1/Sn	∑1/Sn	K=1/∑1/Sn	W1=Wn= K/Sn	Ideal value (Vo)	Mean conc. value (Vn)	Vn/Sn	Qn = (Vn*Sn)*1 00	Wn*Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	1.3	0.26	26	16.17
pH	8.5	0.32	0.3215	3.11	0.366	7	7.7	0.47	0.46.67	17.08
EC	2000	0.0005	0.3215	3.11	0.002	0	1151.9	0.58	57	0.09
TDS	1000	0.001	0.3215	3.11	0.003	0	548.5	0.55	55	0.17
Sum		0.3215								33.51
WQI = 33.51 Good for Consumption										

As mentioned in table 3, the results of WQI for clear water at T= 20 NTU and Qp = 0.475 m3/h in 2014 is 33.51 which its good for Consumption. Table 6 shows the WQI for raw water at T=20 NTU and Q_p = 0.475 m^3/h in 2015 for raw water.

Table 6. WQI for raw water at T=20 NTU, and Q_p = 0.475 m^3/h in 2015

WQI at raw water =20NTU and flow rate = 0.475 m³/h										
parameter	**BIS Standard (Sn)**	**1/Sn**	**∑1/Sn**	**K=1/∑1/Sn**	**W1=Wn= K/Sn**	**Ideal value (Vo)**	**Mean conc. value (Vn)**	**Vn/Sn**	**Qn = (Vn*Sn)*100**	**Wn*Qn**
Turb.	5	0.2	0.3215	3.11	0.622	0	18	3.6	360	223.95
pH	8.5	0.32	0.3215	3.11	0.366	7	7.43	0.29	28.67	10.49
EC	2000	0.0005	0.3215	3.11	0.002	0	1390	0.70	69.5	0.11
TDS	1000	0.001	0.3215	3.11	0.003	0	663	0.66	66.3	0.21
Sum		0.3215								234.76
WQI = 234.76 Unfit for Consumption										

As mentioned in table 3, the results of WQI for raw water at T= 20 NTU, Qp = 0.475 m3/h in 2015 is 234.76 which its unfit for consumption. Table 7 shows the WQI for clear water at T=20 NTU, and Q_p = 0.475 m^3/h in 2015 [19].

Table 7. WQI for clear water at T=20 NTU and Q_p = 0.475 m^3/h in 2015

WQI for clear water =20NTU and flow rate = 0.475 m³/h in 2015										
parameter	**BIS Standard (Sn)**	**1/Sn**	**∑1/Sn**	**K=1/∑1/Sn**	**W1=Wn= K/Sn**	**Ideal value (Vo)**	**Mean conc. value (Vn)**	**Vn/Sn**	**Qn = (Vn*Sn)*100**	**Wn*Qn**
Turb.	5	0.2	0.3215	3.11	0.622	0	1.3	0.26	26	16.17
pH	8.5	0.32	0.3215	3.11	0.366	7	7.51	0.34	34	12.44
EC	2000	0.0005	0.3215	3.11	0.002	0	13972	0.70	69.85	0.11
TDS	1000	0.001	0.3215	3.11	0.003	0	634	0.63	63.4	0.20
Sum		0.3215								28.92
WQI = 28.92 Good for Consumption										

As mentioned in table 3, the results of WQI for clear water at T= 20 NTU and Qp = 0.475 m3/h in 2015 is 28.92 which its good for consumption. Table 8 shows the WQI for raw water at T=20 NTU, and Q_p = 0.475 m^3/h in 2016 for raw water [20].

Table 8. WQI for raw water at T=20 NTU, and Q_p = 0.475 m^3/h in 2016

WQI at raw water =20NTU and flow rate = 0.475 m³/h in 2016										
parameter	**BIS Standard (Sn)**	**1/Sn**	**∑1/Sn**	**K=1/∑1/Sn**	**W1=Wn= K/Sn**	**Ideal value (Vo)**	**Mean conc. value (Vn)**	**Vn/Sn**	**Qn = (Vn*Sn) *100**	**Wn*Qn**
Turb.	5	0.2	0.3215	3.11	0.622	0	19	3.8	380	236.39
pH	8.5	0.32	0.3215	3.11	0.366	7	7.5	0.33	33.33	12.2
EC	2000	0.0005	0.3215	3.11	0.002	0	1122.5	0.56	56.125	0.09
TDS	1000	0.001	0.3215	3.11	0.003	0	534.7	0.53	53.47	0.17
Sum		0.3215								248.85
WQI = 248.85 Unfit for Consumption										

As mentioned in table 3, the results of WQI for raw water at T= 20 NTU and Qp = 0.475 m3/h in 2016 is 248.85 which its unfit for consumption[21].

Table 9 shows the WQI for clear water at T=20 NTU and Q_p = 0.475 m^3/h in 2016. As mentioned in table 3, the results of WQI for clear water in 2016 is 24.90 which its good for consumption [21].

Table 9. WQI For clear water at T=20 NTU and Q_p = 0.475 m^3/h in 2016

WQI at clear water =20NTU and flow rate = 0.475 m³/h in 2016										
parameter	BIS Standard (Sn)	1/Sn	∑1/Sn	K=1/∑1/Sn	W1=Wn= K/Sn	Ideal value (Vo)	Mean conc. value (Vn)	Vn/Sn	Qn = (Vn*Sn)*100	Wn*Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	1	0.2	20	12.44
pH	8.5	0.32	0.3215	3.11	0.366	7	7.5	33.33	33.33	12.20
EC	2000	0.0005	0.3215	3.11	0.002	0	1127.4	56.37	56.37	0.19
TDS	1000	0.001	0.3215	3.11	0.003	0	552.9	55.29	55.29	0.17
Sum		0.3215								24.90
WQI = 24.90 Excellent for Consumption										

Table 10 illustrates the overall results of the water quality indicator extracted for the years 2014-2016.

Table 10. Total WQI at T=20 NTU and Q_p = 0.475 m^3/h from (2014-2016)

Water quality index (WQI)			
year / Type of water	2014	2015	2016
Raw water	271.21	234.7	248.85
Treated water	33.51	28.92	24.90
Grade	Good	Good	Excellent

3.2 WQI in pilot plant using bentonite

Table 11 is listed the characteristics of raw and treated water using bentonite matter.

Table 11. characteristics of raw water and treated water using bentonite

Test type	Raw water	Treated water (Filtered water)
Turbidity	120	1.3
EC	1215	1195
TDS	692	682
pH	8.3	8.1
Temp.	17	17

Table 12 illustrates the quality index calculation for raw water at flow rate 0.475m^3/h utilizing bentonite.

parameter	standard (Sn)	1/Sn	∑1/Sn	k= ∑1/Sn	Wn=k/ Sn	Ideal value(Vo)	Mean con. Value (Vn)	Vn/Sn	Qn= (Vn/Sn)*100	Wn*Qn
Turb.	5	0.2	0.3215	3.11	0.622	0	120	24	2400	1493
pH	8.5	0.12	0.3215	3.11	0.366	7	8.3	0.86	86	31.47
EC	2000	0.0005	0.3215	3.11	0.002	0	1215	0.61	61	0.12
TDS	1000	0.001	0.3215	3.11	0.003	0	692	0.69	69	0.21
Sum		0.3215			1					1525
WQI of raw water = 1525 (Unfit for Consumption)										

Table 12. WQI for raw water at conditions T=120 NTU and Q_p = 0.475 m^3/h

As mentioned in table 3, the results of WQI for raw water utilizing bentonite =1525 is unfit for consumption at T= 120 NTU and Q_e = 0.475 m^3/h in pilot plant. The WQI is enhanced when turbidity is increased from 20 to 200 NTU as shown in figure 4.

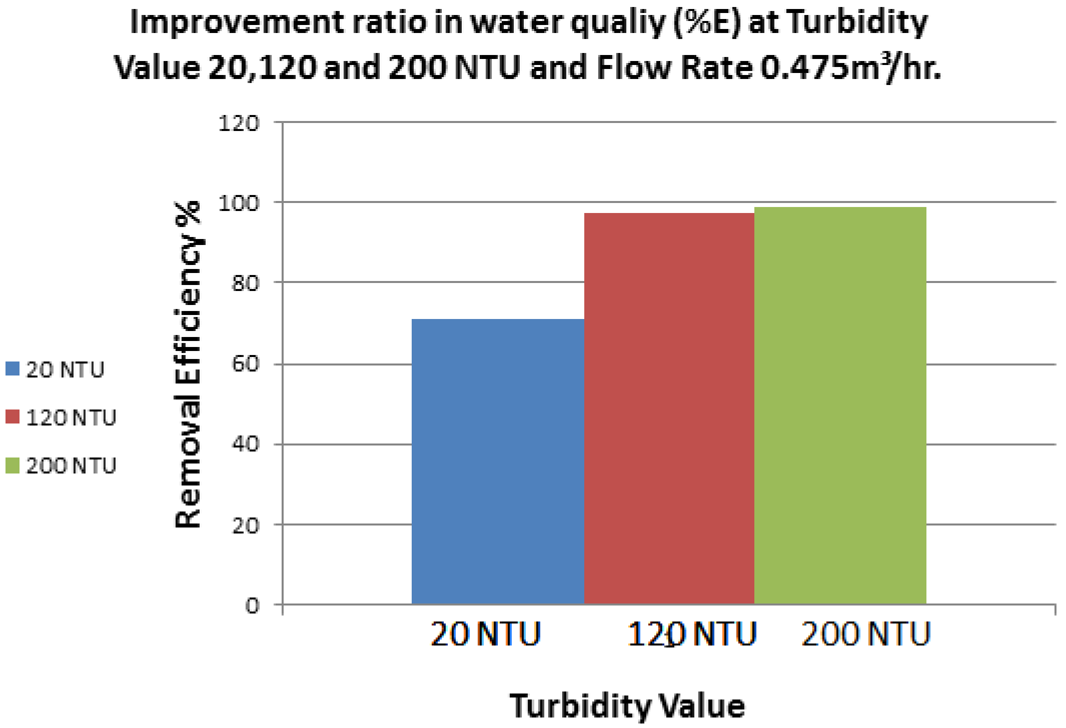

Figure 4. Enhancing of water quality (E%) at 20,120 and 200 NTU in Pilot plant

The improvement ratio in water quality was 71.16 % when using river raw water in pilot plant at 20 NTU. When using turbidity value at 120 and 200 NTU with bentonite, the improvement ratio in water quality were 97.2 and 98.9% respectively. This bentonite mechanism has been proven [21].

4. Conclusion

Since the supernatant became clearer as the amount of bentonite rose, the greatest results were achieved by adding bentonite to low-turbid raw water to increase turbidity. By reducing electrostatic forces and generating more flocs, the process of bentonite addition will reduce turbidity. Raw water with low turbidity should not be treated directly, according to this. Bentonite should be added to increase turbidity, and the water should subsequently be processed. There are several reasons for using bentonite in treatment :

- Raw water with low turbidity requires a higher coagulant dose, such as aluminum sulphate, in order to be cleared; nevertheless, too much alum might induce Alzheimer's disease
- When added to water, bentonite is a natural ingredient that has no detrimental effects.
- A number of treatment plants in the area do not add alum to low-turbid water; instead, water is passed directly from sedimentation basin sediment to filters without treatment, and this process puts pressure on the filters, which are the only ones that reduce turbidities, requiring them to be washed frequently.

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