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Optimization of ACH coagulant, settling time and powdered activated carbon as coagulant aid with economic analysis

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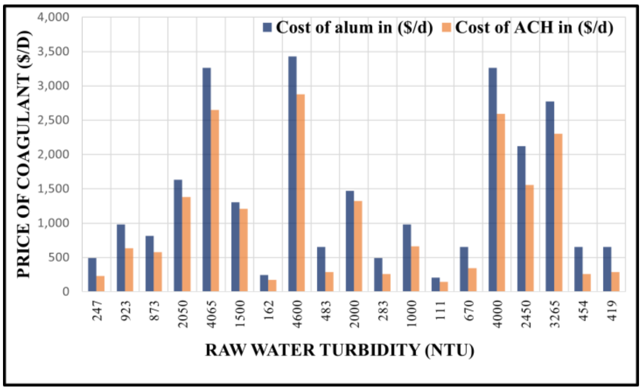
Graphical abstract



Abstract

Regular water treatment-plant (WTP) comprises of a number of units. Of course, problems exist throughout design and operation of the WTP units. Consequently, the current research aimed to minimize the shortcomings of the coagulation, sedimentation, and the adsorption methods through applying optimal process for these units. Additionally, economic analysis and the derivation mathematical models for the new coagulant (Aluminum Chlorohydrate (ACH)) and the traditional aluminum sulphate coagulant (Alum) were another objective of this work. Optimum coagulants for alum and ACH were obtained and presented for different raw water turbidities. The optimum settling time of 30 minutes and 40 minutes have been found for the settling of 1000 and 2000 NTU raw water samples. Best dosages of 0.1 and 0.25 g/L of powdered actived carbon (PAC) were obtained for raw water turbidity of 419, and 1000 NTU which increased the removal efficiency of 28.95%, and 25.71%, respectively. Furthermore, the economic study for alum and ACH revealed that using ACH instead of alum led to reduction of cost by 32%. Commonly, it can be concluded that using ACH instead of alum is better because it is cheaper and more efficient. The predicted equations for the optimum dosages (Y) for alum (mg/L) and ACH (µl/L) dosages (X) were $Y=0.04x+14.42$, and $Y=0.01x+0.72$, respectively.

Keywords: Adsorption, coagulation, Greater-Zab river, optimization, settling, treatment units.

1. Introduction

Water treatment plant (WTP) can be described as water processing to attain water quality that meets specific end-user or community objectives or norms through its regulatory organizations (Crittenden *et al.*, 2012). Most present drinking WTPs use conventional treatment methods like intake, coagulation-flocculation, sedimentation, sand filtration, and disinfection to produce fresh potable water (Spellman, 2003, Aziz and Mustafa, 2019). The individual treatment plant units have been intended to take into account the drinking water requirements and to identify areas that need enhancement to improve the functioning of WTP and to achieve better outcomes in terms of water quality, operating costs, water wastage, etc. (Khan and Ahmad, 2018). WTP practice development has a rich background of empirical and science innovations and difficulties that have been addressed and overcome (Crittenden *et al.*, 2012). A WFP's performance assessment is a method for measuring functioning efficiencies based on certain performance indices such as degree of removal of pollutants such as turbidity, color, suspended impurities, etc. (Vieira *et al.*, 2008).

Water treatment or purification is regarded as a critical challenge, particularly in developing countries since this treatment is an important tool for preserving public health and the environment by eliminating of waterborne diseases and pathogens (Issa, 2017). The most prevalent issues facing WTPs today are the non-optimized use of chemicals, operation of unit processes, sludge production, and energy consumption (Vieira *et al.*, 2008).

Erbil City in Kurdistan region-Iraq is currently served by two main types of water resources, surface water and groundwater. Surface water is the first significant source of drinking water in Erbil City. There are four WTPs (Ifraz 1, Ifraz 2, Ifraz 3 and Qandil) on Greater-Zab River, three of them are constructed on Greater-Zab River at Ifraz village, and produce with about 60% of the total drinking water consumed in Erbil City (EWD, 2019). While, Qandil WTP is

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located near Shaqlawa District. However, there are about 1000 deep wells served in Erbil City as a second source of drinking water and they produce about 40% of the total demand for drinking water (EWD, 2019).

The quality of water, especially the turbidity, varies in winter and summer. The high concentration of turbidity in incoming water into the WTP during the winter season causes problems. Sometimes the WTPs stopped working due to high turbidity. In addition, corrosion due to the use of coagulant is another problem in the mixing coagulant tanks, especially in Ifraz-2 WTP. Furthermore, sometimes some parameters of treated water exceeded drinking water standards. Thus, the aim of this study has been to minimize the effect of quality fluctuations on the operation and performance of WTP units, solve coagulant process problems, and improve the quality of the treated water. In the current work, Ifraz-2 and Qandil WTPs were studied.

The objectives of the proposed work were: 1) To evaluate Greater-Zab River water quality by measuring several parameters, 2) To find optimum settling time, dosage for the coagulants, and PAC) for the adsorption process, and 3) To study the cost of the coagulant.

2. Materials and methods

2.1. Greater-zab river water quality

The Greater-Zab River, shared by Iraq and Turkey, originates from Turkey's Ararat Mountains, passes through the central northern part of Iraq, and then connects to the Tigris River south of Mosul City traversing a distance of 372 km (Figure 1). Greater-Zab and its tributaries namely Shamdinan, Haji Beg, Rawanduz, and Khazir-Gormal, are situated between latitudes 36° N and 38° N, and longitudes 43.3° E and 44.3° E (Abbas *et al.*, 2016). It drains an area of 26473 km^2, 65% of which is in Iraq and the rest in Turkey (Al-Ansari *et al.*, 2014). The mean annual temperature for Greater-Zab River is 14.3 C° and the mean annual rainfall is 570 mm, ranging from 350 mm to 1000 mm (Abbas *et al.*, 2016). Grater-Zab River is the only surface water supply accessible for drinking water and other purposes in Erbil City (Shareef and Muhamad, 2008).

An average of two sets of samples per month was collected from November 2018 to April 2019, for both Ifraz-2 and Qandil WTPs. Raw water and treated water samples were gathered in plastic containers and transferred to the Laboratory instantly. They were stored in the refrigerator at 4°C before experimental use to prevent biological activities and changes in their characteristics (APHA, 2005).

The collected samples were analyzed for 14 water-quality parameters. These parameters were as follows: Turbidity (NTU), pH, electrical conductivity (EC) (µs/cm), total dissolved solids (TDS) (mg/L), total alkalinity (mg/L), total hardness (mg/L), calcium (Ca) (mg/L), chloride (Cl) (mg/L), sulphate (SO_4) (mg/L), sodium (Na) (mg/L), potassium (K) (mg/L), magnesium (Mg) (mg/L), and nitrate (NO_3) (mg/L). In addition, Total coliform (MPN/100 mL) analyzed for treated water. The experiments were carried out in the Laboratory of the Erbil Water Directorate, General Directorate of Water and Sewerage, Ministry of Municipality and Tourism, Erbil City, Kurdistan region, Iraq.

Figure 1. Map of Greater-Zab River.

Figure 2. WTPs on Greater-Zab River

2.2. WTPs

Ifraz-2 and Qandil WTPs are constructed to treat Greater-Zab River water, Figure 2. River water withdrawn by intake structure and conveyed the raw water by a 800 mm pipe with length of 27.65 km to Ifraz-2 WTP in Erbil City. While, intake structure and the units for the Qandil WTP are located on the Greater-Zab River. Details of Ifraz-2 and Qandil WTPs are given in Table 1.

2.3. Optimization of parameters

Optimization of coagulant dosage, a settling time, and PAC are shown in the following sections.

2.3.1. Coagulants

The most commonly used aluminum coagulant is aluminum sulfate. It is available in a number of solid forms such as block, kibbled or ground and can also be used as a solution. In waterworks, aluminum sulfate is often referred to as ' alum ' but wrongly. The solid form has the composition $Al_2(SO_4)_3xH_2O$ wherexmay range from 14 to 21 containing

14 to 18% w/w Al_2O_3 (alumina) or 7.5 to 9% w/w Al (aluminum), depending on the number of molecules of water (x) (Brandt *et al.*, 2017).

Two different types of coagulant alum and ACH used in the Jar tests, solid alum $Al_2(SO_4)_3\,{}_{18}H_2O$, which is already used in Ifraz-2 WTP and alum with polymer are used in Qandil WTP. The general formula of ACH $(Al_n(OH)_mCl_{(3n-m)})_x$and have a polymeric structure, totally soluble in water. The length of the polymerized chain, molecular weight and number of ionic charges is determined by the degree of polymerization.

Aluminum Chlorohydrate (ACH, n=2 and m=5).

An important property of ACH is its basicity. This is the ratio of hydroxyl to aluminum ions in the hydrated complex and in general the higher the basicity, the lower will be the consumption of alkalinity in the treatment process and hence impact on pH. ACH is selected for this study according to the chemical properties and some advantages of using ACH as the following:

Table 1. Details of Ifraz-2 and Qandil WTPs (EWD, 2019)

No.	WTP name	Year of built	Area of service	Place of project	Location of the Projects	Primary design capacity (m³/day)	Designed capacity (m³/day)	Produced Capacity (m³/day)
1	Ifraz-2	1983	Erbil-City	Erbil-City	Longitude, E 43° 59′ 44″ Latitude N 36° 12′ 58″	69120	69120	44000
2	Qandil	2013	Shaqlawa District and Salahaddin sub-District	Makerdan village	Longitude, E 44° 06′ 56″ Latitude N 36° 36′ 05″	64800	120000	64800

Table 2. PAC Specifications (www.world.taobao.com)

Properties	Unit	Descriptions and values
Appearance	-	Black fine powder
Application	-	All kinds of water plants, sewage treatment plants, pharmaceutical industry, food industry, chemical additives, purification, deodorant, cleaning and so on
Water soluble content	%	5 max.
Iodine value	mg/g	850-950 min.
Methylene blue adsorbate	mg/g	130-180
Surface area	m^2/g	2000
% Degree of fineness through 80 mesh size	0.177 mm	10
% Degree of fineness (100 mesh size)	0.154 mm	10
% Degree of fineness (200 mesh size)	0.074 mm	20
% Degree of fineness (300 mesh size)	0.045 mm	20

This salt also have a number of additional benefits: it limits aluminum residuals whilst maintaining optimum coagulation properties; it produces stronger and more readily settleable floc than aluminum sulfate, thus reducing the need for polyelectrolytes as coagulant aids; coagulation is less affected by low temperature and produces less sludge than aluminum sulfate (Brandt *et al.*, 2017). ACH-2316 is a coagulant with a following property: 1) Odorless, 2) Transparent appearance, 3) Physical state liquid, 4) pH (5%)=4.1 ± 0.2, 5) Aluminum oxide (AL_2O_3%)=23 ± 0.5, 6) Density (g/mL)=1.32, and 7) Relative basicity (%w/w)=82%. Jar test was applied for determining optimum alum and ACH dosages.

2.3.2. Settling process

In the conducted Jar tests, settling time was studied to achieve the optimum settling time in both coagulants. The effect of settling time was studied by allowing the mixers to turn off and the containers were allowed to settle from 1 to 60 minutes. The interval time for settling from 1, 5, 10, 15, 20, 30, 40, 50, and 60 minutes used in the experiments to find the optimum settling time. Then the turbidity and the corresponding pH value of each container was measured at each time, while keeping other parameters such as coagulant dosage, mixing condition, and the time of stirring constant.

2.3.3. PAC as coagulant aid

Although PAC is widely used for the removal of organic compounds that cause taste and odor (Kristiana *et al.*, 2011), it was used as a coagulant aid in this study. It is a black fine powder which commercially available and derived from wood or anthracite as raw material by advanced technology; physical and chemical including screening, drying with a special production process is refined. After steam activation; refined processing, dewatering, drying and grinding together. The current surface area of PAC that was used in this study about 2000 m^2/g required from the purchasing company (Taobao Online Shop). The specifications of used PAC are shown in Table 2.

PAC used during the coagulation process in Jar tests as coagulant aid to find its effect on turbidity removal efficiency, while the selection of optimum PAC dosage was based on the best removal efficiencies of turbidity. The amount of PAC which used in the experiment are from 0.05, 0.1, 0.15, 0.2, 0.25, 0.4, and 0.5 g/L added to each beaker and mixed by a jar test mixer with a constant speed for all beakers. To determine optimum PAC dosage, the removal efficiency of turbidity was determined.

3. Results and discussions

3.1. Greater-zab river water characteristics

The collected samples were tested for thirteen parameters. The results of the characteristics of raw water near Ifraz-2 and Qandil WTPS are listed in Tables 3 and 4. Turbidity value ranged between 17 to 705 NTU and from 13.8 to 826 NTU for both locations, it is over the standard. Since turbidity values were greater than the WHO standard for the drinking water, the treatment processes are essential for the Greater Zab River water to adjust the turbidity values to the acceptable levels to supply potable and safe water to the consumers.

Table 3. Results of raw water at Ifraz 2 WTP

No.	Date	Turbidity	pH	EC	TDS	Totla Alkalinity	Total Hardness	Ca^{++}	Cl-	SO$_4^{--}$	Mg^{++}	Na^{+}	K^{+}	NO$_3^{-}$
1	12/11/2018	121	7.80	356	231.4	212	314	79	9	26	56.4	10	1.1	9
2	21/11/2018	55.5	7.86	366	237.9	203	288	72	12	27	51.84	9	1	8.25
3	02/12/2018	419	8.20	376	244.4	198	310	78	16	62	55.68	10	1.8	9
4	18/12/2018	62.5	7.80	373	242.45	201	254	64	9	28	45.6	10	1.1	9
5	05/01/2019	89	7.83	384	249.6	205	262	66	11	36	47.04	10	1.2	6
6	23/1/2019	13.8	7.87	439	285.35	219	268	67	10	47	48.24	9	1	3
7	04/02/2019	58.1	7.80	396	257.4	211	300	75	10	39	54	6	0.8	3.75
8	12/02/2019	49.5	7.7	392	254.8	208	290	73	12	31	52.08	5	0.7	4.25
9	04/03/2019	48.5	7.7	392	254.8	201	300	75	8	47	54	10	0.9	4.5
10	25/3/2019	110	7.1	424	275.6	186	308	77	11	56	55.44	14	2.1	4.5
11	01/04/2019	300	7.9	372	241.8	194	305	76	7	25	54.96	7	1.3	4.75
12	22/4/2019	826	7.80	330	214.5	186	292	73	13	36	52.56	6	0.9	2.5
Drinking water standard	(WHO, 2011)	5	6.5-9.5	1000	500	200	200	200	250	200	30	200	10	50
	Iraqi Standard 1986	Less than 10	6.5-8.5	1000	600	200	500	200	250	400	50	200	N/A	45
Irrigation standard	(Medcalf and Eddy, 2014), (Ayers and Westcot, 1985)	N/A	6.5-8.4	< 700	< 450	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5-30
Constraction standard	(Kucche et al., 2015)	N/A	≥ 6	N/A	N/A	N/A	N/A	N/A	≤500 mg/L	≤500 mg/L	N/A	N/A	N/A	N/A

The pH values exceed 7.5 in most cases. This may be attributed to the erosion of carbonate ions from soils, and waters were in the alkaline pH range without remarkable variations, which was within the recommended range for drinking water quality standard (WHO, 2011). Also, the pH values were safe for construction (Kucche *et al.*, 2015). A similar trend of pH values in different branches of Greater-Zab river was recorded by (Aziz, 2008; Toma, 2013; Hanna and Shekha, 2015). The values of pH were suitable for irrigation purposes according to Ayers and Westcot (1985).

The observed results for water in Greater-Zab showed Cl content values ranged from 8 mg/L to 17 mg/L in Table 4 and 7 to 16 mg/L in Table 3. Water quality standards for construction require Cl concentrations of 500 mg/L for reinforced concrete, and 2000 mg/L for plain concrete (Kucche *et al.*, 2015; Aziz *et al.*, 2017). The obtained chloride values show that water in Greater-Zab can be used for construction because the concentrations of chloride were less than 500 mg/L. The concentration of Cl can be considered as weak water type (< 70 mg/L) which is suitable for almost all plants irrigation according to Shekha (2016).

Sulfate figures were ranged between 10 to 92 mg/L for Ifraz-2 in Table 4, and 25 to 62 mg/L in Table 3 for Qandil location which are less than the declared standards. Thus, water in Greater-Zab is within permissible level according to water quality standard for Iraqi standard for drinking water and safe for construction (Kucche *et al.*, 2015; Aziz *et al.*, 2017). Also, Sulfate concentration is within the permissible level for irrigation purposes according to (Abbas, 1986; Aziz, 2006).

TDS value ranged from 214.5 to 285.35 mg/L for Ifraz-2, and from 217.7 to 300.3 mg/L for Qandil which are within the range of WHO and Iraqi standards for drinking water. A similar trend of TDS was reported by (Aziz, 2008; Shekha, 2016) at the monitored river. The concentration of TDS is entirely safe for irrigation according to Aziz *et al.* (2017).

EC for collected samples was ranged from 330 to 439 µs/cm in Ifraz-2 location and from 335 to 462 µs/cm for Qandil location, which are within the standards. Puri *et al.* (2015) in Nagpur city, Maharashtra India, indicated that the greater values in the rainy season could be due to surface runoff from the surrounding areas that might have brought in ionic substances such as nitrates, chlorides, and phosphates from fertilizers. A similar trend of results has been noted by (Aziz, 2008; Kafia *et al.*, 2009; Shekha, 2016). The concentration of EC is falling in good class for irrigation according to Aziz *et al.* (2017).

Total Alkalinity for collected samples ranged from 186 to 219 mg/L in Ifraz-2 and from 161 to 236 mg/L which was above WHO and Iraqi standards for drinking water.

Total Hardness are ranged between 254 to 314 mg/L in Ifraz-2, and from 246 to 380 mg/L in Qandil location which are above the WHO standard, but within Iraqi standard as mentioned in Tables 3 and 4. The results obtained by Toma (2013) showed that total hardness values were often higher than the minimum permissible level recommended by the WHO for drinking water.

The concentration of Ca, Cl, SO_4, Na, K, and NO_3 for water samples from Greater-Zab River are within (WHO, 2011) and Iraqi standard. A similar trend observed by Shekha (2016).

Mg for collected samples was ranged from 45.6 to 56.4 mg/L near Ifraz-2, and from 44.1 to 68.4 mg/L near Qandil, which exceeded WHO and Iraqi standards. Shekha (2016) observed Mg values exceeding the permissible range, while the values of Mg which reported by Toma (2013) were within the WHO and Iraqi standard. It is obvious from the reported data that the Greater-Zab River quality needs treatment before using and not safe for drinking, but it is safe for construction and irrigation.

Table 4. Results of raw water at Qandil WTP

No.	Date	Turbidity	pH	EC	TDS	Totlal Alkalinity	Total Hardness	Ca^{++}	Cl-	SO_4^{--}	Na^+	K^+	Mg^{++}	NO_3^-
1	09/11/2018	375	7.5	432	280.8	195	300	75	13	65	13	1.1	54	9
2	29/11/2018	640	7.11	360	234	161	292	73	12	45	12	1.2	52.56	13
3	17/12/2018	142	7.7	393	255.45	219	246	62	8	38	8	1	44.16	10
4	27/12/2018	81.5	7.8	420	273	236	290	73	17	44	11	1.1	52.08	11
5	06/01/2019	17	7.8	425	276.25	207	380	95	10	10	8	1	68.4	12
6	27/1/2019	25.2	7.7	430.0	279.5	228.0	290.0	73.0	12.0	49.0	10.0	1.1	52.08	2.5
7	17/2/2019	460	7.6	406	263.9	215	290	73	10	59	8	1.1	52.08	4.75
8	26/2/2019	51.2	7	462	300.3	185	339	85	11	18	21	2.2	60.96	5.5
9	04/03/2019	90.2	7.7	396	257.4	204	300	75	12	47	13	1.2	54	5
10	17/3/2019	280	7.5	391	254.15	245	300	75	12	70	9	1.4	54	7
11	02/04/2019	705	7.9	339	220.35	217	285	71	12	92	29	1.2	51.36	7
12	23/4/2019	40.5	7.6	335	217.75	212	340	85	11	38	29.2	1.4	61.2	3.5
Drinking water standard	(WHO, 2011)	5	6.5-9.5	1000	500	200	200	200	250	200	200	10	30	50
	Iraqi Standard 1986	Less than 10	6.5-8.5	1000	600	200	500	200	250	400	200	N/A	50	45
Irrigation standard	(Medcalf and Eddy, 2014), (Ayers and Westcot, 1985)	N/A	6.5-8.4	< 700	< 450	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	5-30
Constraction standard	(Kucche et al., 2015)	N/A	≥ 6	N/A	N/A	N/A	N/A	N/A	≤500 mg/L	≤500 mg/L	N/A	N/A	N/A	N/A

During the study according to the collected data for both stations. In general, all the parameters from Ifraz-2 station were higher than in Qandil station except for pH parameter which shown in Figure 3, which include the mean values for all the parameter tested during the study period.

There are significant variations between the value of turbidity in the two places. Depending on the site investigations there are two main reasons for the high turbidity of Ifraz-2 location compare with Qandil location. The first reason was because of Bastora tributary which feeds Greater-Zab River in the rainy season which effect on the raw water at Ifraz-2 station, and the second reason due to existing some Quarries of sand and gravel at Greater-Zab river near Ifraz-2 station which increased the turbidity in Ifraz station.

EC is a measurement for the ability of water to conduct an electrical current. The ability is a result of the presence of ions in water such as Ca, Cl, SO_4, Na, K, and Mg (Shekha, 2016), these ions at Ifraz-2 station were greater than at Qandil station, consequence to EC at Ifraz-2 station higher than EC at Qandil station. The high concentration of Mg and

Ca at Ifraz-2 station compare to Qandil station led to higher total hardness at Ifraz-2 station.

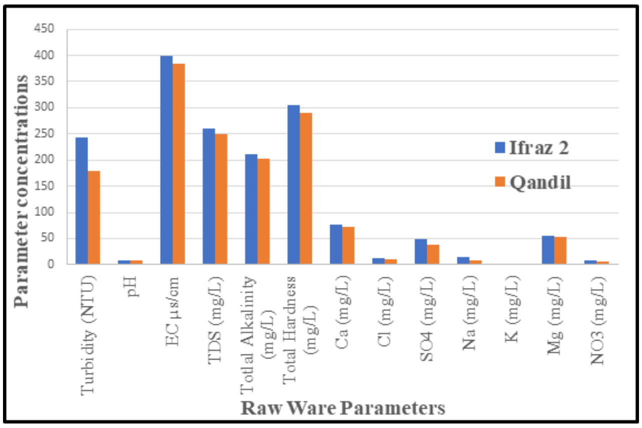


Figure 3. Mean values of the parameters in Ifraz-2 and Qandil stations.

3.2. *Optimization of parameters for coagulation process*

During the study period coagulants, settling time, and PAC dosage were studied and optimized by conducting Jar tests.

3.2.1. *Coagulants*

The efficiency of ACH and alum through conducting nineteen Jar tests are studied comparatively in this work. The minimum and the maximum raw water turbidity for the samples used in the experiments were 111 NTU and 4600 NTU. The removal of suspended solids and the optimum dosage for each coagulant were carefully monitored and they are used for the evaluation of effectiveness for each coagulant, as well as for the determination of optimal operative conditions.

Table 5 presents a sample of conducting the Jar test for 1000 NTU raw water sample. The optimum dosage of alum was 60 mg/L, while the optimum dosage of ACH was 11.5 µl/L for the sample. According to Brandt *et al.* (2017), the turbidity after sedimentation process must be between 1 to 5 NTU, but the turbidity of 7 NTU for both coagulants were selected as optimum dosages due to 30 minutes settling time in conducted Jar tests, while the settling time in the sedimentation tank in the WTP normally ranged between 2 to 3 hours which give us a result of turbidity less than or equal to 5 NTU due to more removal efficiency with more settling time.

From the results of pH values in conducted Jar test in Table 5, the value of pH was decreased with increasing of alum dosage, while the value of pH was increased with increasing of ACH dosage because of high basicity, this status also mentioned by (Brandt *et al.*, 2017).

The optimum dosage of coagulants in the jar tests started from 12.5 to 210 mg/L for Alum, and from 2.5 to 50 (µl/L) for ACH coagulant. Table 6 shows a summary of optimum alum and ACH results for different turbidities of 19 Jar tests.

Table 5. The optimum dosage of alum and ACH for raw water turbidity of 1000 NTU conducted on 18-3-2019

		Jar test using alum (mg/L)						Jar test using ACH (µl/L)					
		Alum	**Alum**	**Alum**	**Alum**	**Alum**	**Alum**	**ACH**	**ACH**	**ACH**	**ACH**	**ACH**	**ACH**
Coagulant dosage		**30**	**40**	**50**	**60**	**70**	**80**	**8**	**10**	**11**	**11.5**	**14**	**16**
Rapid mix speed	(rpm)	100	100	100	100	100	100	100	100	100	100	100	100
Rapid mix duration	(min.)	1	1	1	1	1	1	1	1	1	1	1	1
Slow mix speed	(rpm)	20	20	20	20	20	20	20	20	20	20	20	20
Slow mix duration	(min.)	20	20	20	20	20`	20	20	20	20	20	20	20
Sedimentation Period	(min.)	30	30	30	30	30	30	30	30	30	30	30	30
pH	7.43	7.27	7.24	7.22	7.20	7.22	7.20	7.25	7.25	7.32	7.36	7.32	7.36
Turbidity	NTU	17.0	13.4	9.0	7.0	4.5	3.8	14.2	11.3	8.7	7.0	4.6	3.3

From the data in Table 6, the prediction equation of the relationship between raw water turbidity and alum optimum dosage is:

$$Y=0.04x+ 14.42$$

as shown in Figure 4.

Where: -

Y= alum optimum dosage (mg/L)

X=raw water turbidity (NTU)

The relation between raw water turbidity verses alum optimum dosage as shown in Figure 4.

The prediction equation between raw water turbidity and ACH optimum dosage is as shown in Figure 5 as the following:

$$Y=0.01x+ 0.72$$

Where: -

Y= ACH optimum dosage (mg/L)

X=raw water turbidity (NTU)

Figure 6 explained the different weight between alum and ACH for different raw water turbidity. In all cases weight of alum is more than weight of ACH.

From the results of 19 conducted Jar Tests, it concluded that there are some advantages of using ACH instead of alum as the following:

I. By using ACH products, do not need to make solutions as an alum. ACH is liquid, because of that it does not need a mixer and not need manpower.

II. Ease of use, less dangerous product, and friendly with the environment.

III. ACH easy for storage and dosing.

IV. By using ACH, the overall coagulant use will reduce, this means a reduction of the used energy for dosage pumps compare with alum coagulant.

V. Residual Aluminum rate is always less than the value of the world standard according to WHO by using ACH (Brandt *et al.*, 2017).

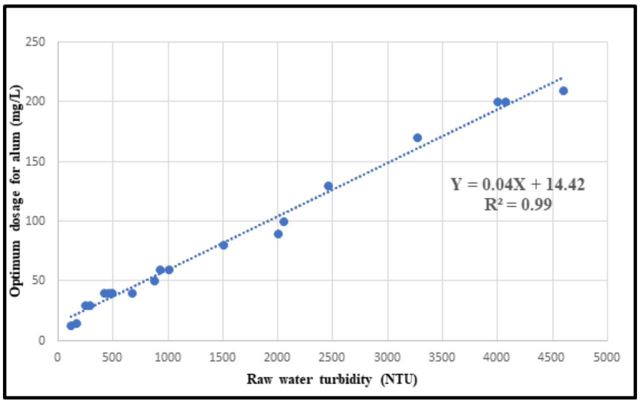


Figure 4. The model prediction between alum and raw water turbidity

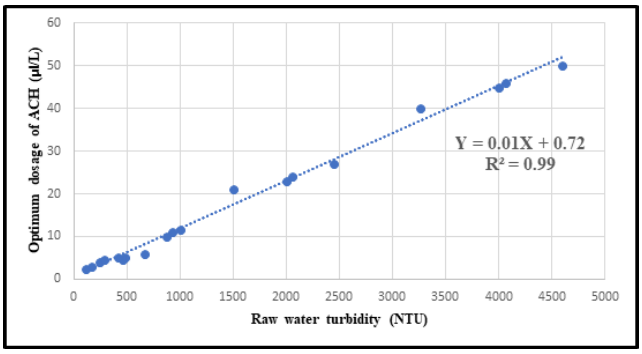


Figure 5. The model prediction between ACH and raw water turbidity.

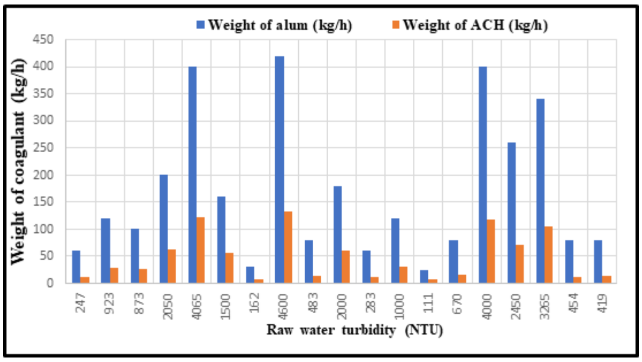


Figure 6. Coagulant weight with different raw water turbidity.

3.2.2. Settling time

The optimum settling time by using optimum dosages of alum and ACH coagulants were studied by conducting Jar tests with varies settling times from 1 to 60 min for raw water turbidities of 1000 and 2000 NTU as shown in Table 7.

The reduction of turbidity was measured each time while keeping the optimum dosage of the coagulant. The effect of settling time on the reduction of turbidity was illustrated in Figures 7 and 8.

The results showed that 30 min. and 40 min. are the optimum settling time for 1000 and 2000 NTU, respectively since the result remained with few changes.

It is obvious from Figures 7 and 8 that the settling time for ACH in the first ten minutes was very speed, this is due high effective of ACH coagulant in which generated the flocs in bigger sizes and led to fast settling.

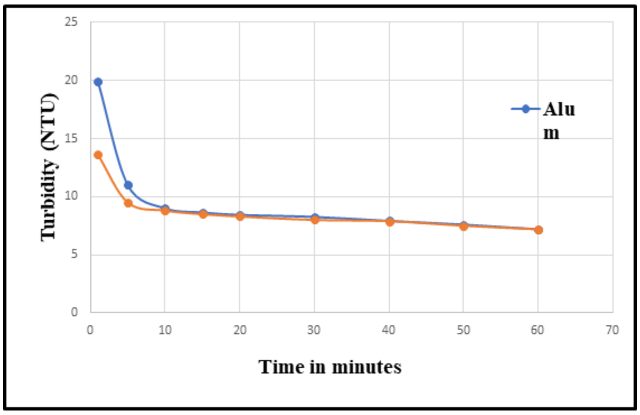


Figure 7. Settling time using alum and ACH for 1000 NTU turbidity

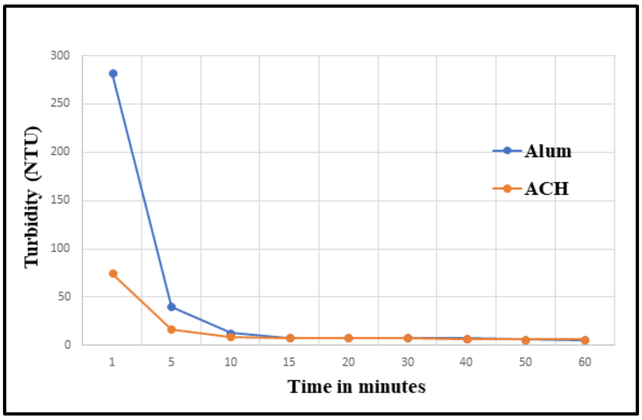


Figure 8. Settling time using alum and ACH for 2000 NTU turbidity

3.2.3. PAC

The turbidity of the sample, optimum alum dosage, and sedimentation time were kept constant for determination of optimum PAC dosage. The selection of optimum PAC dosage was based on the optimum removal of turbidity for each dosage.

The concentration and removal of suspended solids are illustrated in Table 8 for two different raw water turbidity samples 419 and 1000 NTU because in other parameters like optimum coagulants and settling time the same raw water turbidity of 1000 NTU were used. In addition, the sample with 419 NTU also optimized to determine PAC efficiency in more than one sample to confirm the effect of the PAC on turbidity removal.

Table 6. A summary of optimum alum and ACH results for different turbidities

No.	Date of Test	pH	Temperature C°	Turbidity of Raw water (NTU)	Optimum dosage of alum from Jar Tests (mg/L)	Optimum dosage of ACH from Jar Tests (µl/L)
1	02/01/2019	7.49	11.7	247	30	4
2	20/1/2019	7.00	13.8	923	60	11
3	21/01/2019	7.11	13.6	873	50	10
4	23/1/2019	7.16	14.2	2050	100	24
5	27/1/2019	7.21	12.1	4065	200	46
6	30/1/2019	7.08	14.3	1500	80	21
7	05/02/2019	6.94	13.1	162	15	3
8	06/02/2019	7.00	12.6	4600	210	50
9	27/02/2019	7.22	11.7	483	40	5
10	04/03/2019	7.24	13.6	2000	90	23
11	17/3/2019	7.61	12.8	283	30	4.5
12	18/3/2019	7.33	12.2	1000	60	11.5
13	25/3/2019	7.43	15.4	111	12.5	2.5
14	04/04/2019	7.71	18.7	670	40	6
15	08/04/2019	7.31	18.7	4000	200	45
16	09/04/2019	7.31	19.5	2450	130	27
17	12/04/2019	7.45	20.2	3265	170	40
18	13/4/2019	7.10	21.8	454	40	4.5
19	17/04/2019	7.00	22	419	40	5

Table 7. Settling time for alum and ACH coagulants

No.	Interval of settling time in minutes	Initial Turbidity of 1000 NTU		Initial Turbidity of 2000 NTU	
		Turbidity (NTU) by using optimum dosages of alum and ACH		Turbidity (NTU) by using optimum dosages of alum and ACH	
		Alum (60 mg/L)	ACH (11.5 *µl*/L)	Alum (90 mg/L)	ACH (23 *µl*/L)
1	1	19.9	13.6	282.0	75.0
2	5	11.0	9.5	40.0	17.0
3	10	9.0	8.8	13.0	9.0
4	15	8.6	8.5	8.0	8.0
5	20	8.4	8.3	8.0	8.0
6	30	8.2	8.0	7.8	7.7
7	40	7.9	7.9	7.1	7.0
8	50	7.6	7.5	6.0	6.0
9	60	7.2	7.2	5.7	6.0

Table 8. The effect of adding PAC to coagulant on turbidity

PAC dosage (g/L)	Raw water turbidity=419 NTU			Raw water turbidity=1000 NTU		
	Optimum alum dosage (mg/L)	Turbidity after Jar test	Removal efficiency of PAC %	Optimum alum dosage (mg/L)	Turbidity after Jar test	Removal efficiency of PAC %
0	40	6.84	0.00	60	7	0.00
0.05	40	4.98	27.19	60	6.4	8.57
0.1	40	4.86	28.95	60	6.2	11.43
0.15	40	4.91	28.22	60	6	14.29
0.2	40	4.97	27.34	60	5.75	17.86
0.25	40	5.1	25.44	60	5.2	25.71
0.4	40	5.4	21.01	60	5.4	22.86
0.5	40	6.9	-0.88	60	7	0.00

Alum and ACH coagulants were used in the experiments, but PAC only works with alum and increased the removal efficiency of suspended solids in the samples, while the removal efficiency was decreased with ACH. This is due to the interactions between ACH and activated carbon because ACH includes chlorine and adding it with carbon together at the same point will minimized the removal efficiency of the turbidity (Spellman, 2003).

The optimum dosage of PAC was 0.1 g/L for the sample with raw water turbidity 419 NTU. The impact of adding 0.1 g/L of PAC to the coagulant decreased the turbidity from 6.84 to 4.86 NTU as shown in Figure 9. This means that the efficiency of coagulant increased by 28.95% by adding 0.1 g/L of PAC.

The optimum dosage of PAC was 0.25 g/L for the sample with raw water turbidity 1000 NTU. As a result of PAC addition with the coagulant decreased the turbidity from 7 to 5.2 NTU as shown in Figure 10. This means that the efficiency of coagulant enhanced by 25.71% by adding 0.25 g/L of PAC.

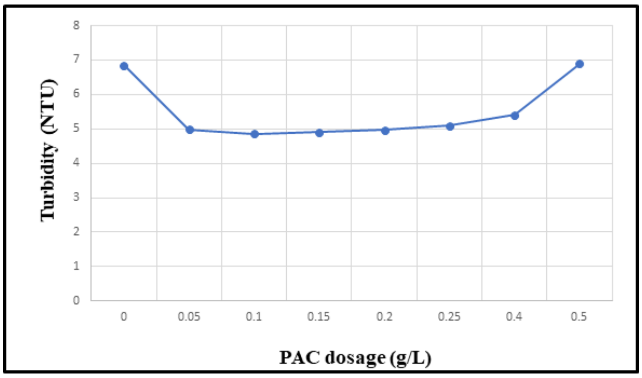


Figure 9. Optimum PAC dosage for the sample of 419 NTU

Kristiana *et al.* (2011) investigated the impact of the addition 0.15 g/L of PAC to an enhanced coagulation treatment process at an existing water treatment plant on the efficiency of natural organic matter removal. As a result of the PAC addition, the removal improved by 70%.

Ali (2017) added 0.1 g/L of PAC to synthetic wastewater, the removal efficiency of turbidity increased by 96.5%.

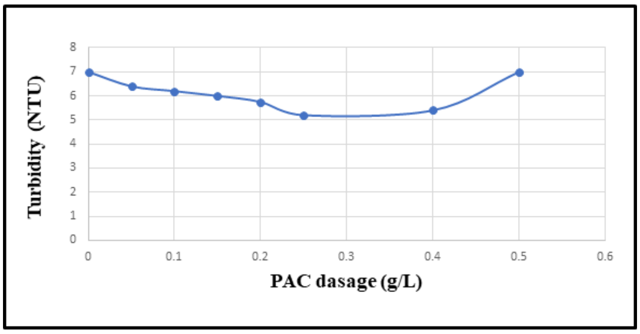


Figure 10. Optimum PAC dosage for the sample of 1000 NTU.

3.3. Economic study

During the evaluation of the coagulants, considerations were made concerning potential costs associated with each particular coagulant. Table 9 illustrates the summary finding of optimum dosage and the daily cost for each coagulant in different raw water turbidities. Figure 11 shows the relationships between coagulant costs at varying turbidities relative to each other. Alum was shown to have a higher cost in $/d relative to ACH within the same efficiency. The details of the calculations of the first test with raw water turbidity of 247 NTU in Table 9 are shown below:

Average input flow to the WTP is 2000 m^3/h for all cases which means that the total quantity of income flow equal to 48000 m^3/day so that it can represent the real quantities as in Ifraz-2 WTP, Cost of alum/ACH per day

Weight of alum=30 mg/Lx2000 m^3/hx1000 L/m^3/(1000000 mg/kg)=60 kg/h

Volume of ACH=4 µl/Lx2000 m^3/hx1000 L/m^3/(1000000 µl/L)=8 L/h

Density of ACH=1.32 kg/L,

Weight of ACH (kg/h)=8 L/hx1.32 kg/L=10.56 kg/h

Price of alum=340 $/ton

Cost of alum in ($/d)=60 kg/hx24 h/dx340 $/ton/(1000 kg/ton)=489.6 $/d.

Cost of ACH = 1200 $/ m3, it is available in Turkey

Price of ACH in ($/d)=8 L/hx24 h/dx1200 $/$m^{3/}$(1000 L/ m^3)=230.4 $/d.

This reveals that the cost ratio for one day of ACH to alum=230.4/489.6=0.47 %, this means that by using ACH instead of alum in coagulation-flocculation process decrease the total cost to near the half for the first case of raw water turbidity of 247 NTU.

The average cost of ACH to alum for all cases is 68%, which means the reduction of total costs by using ACH instead of alum is about 32%.

Commonly, it can be concluded that using ACH instead of alum is cheaper and more efficient.

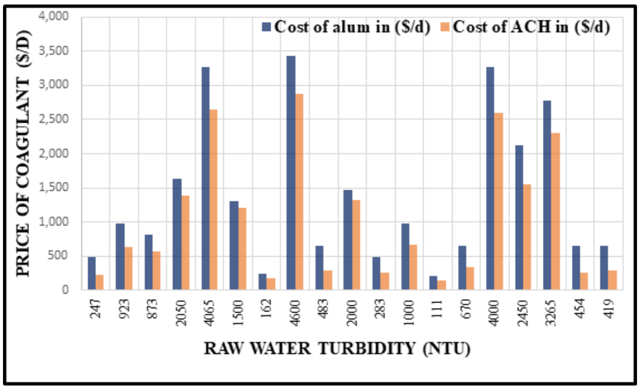
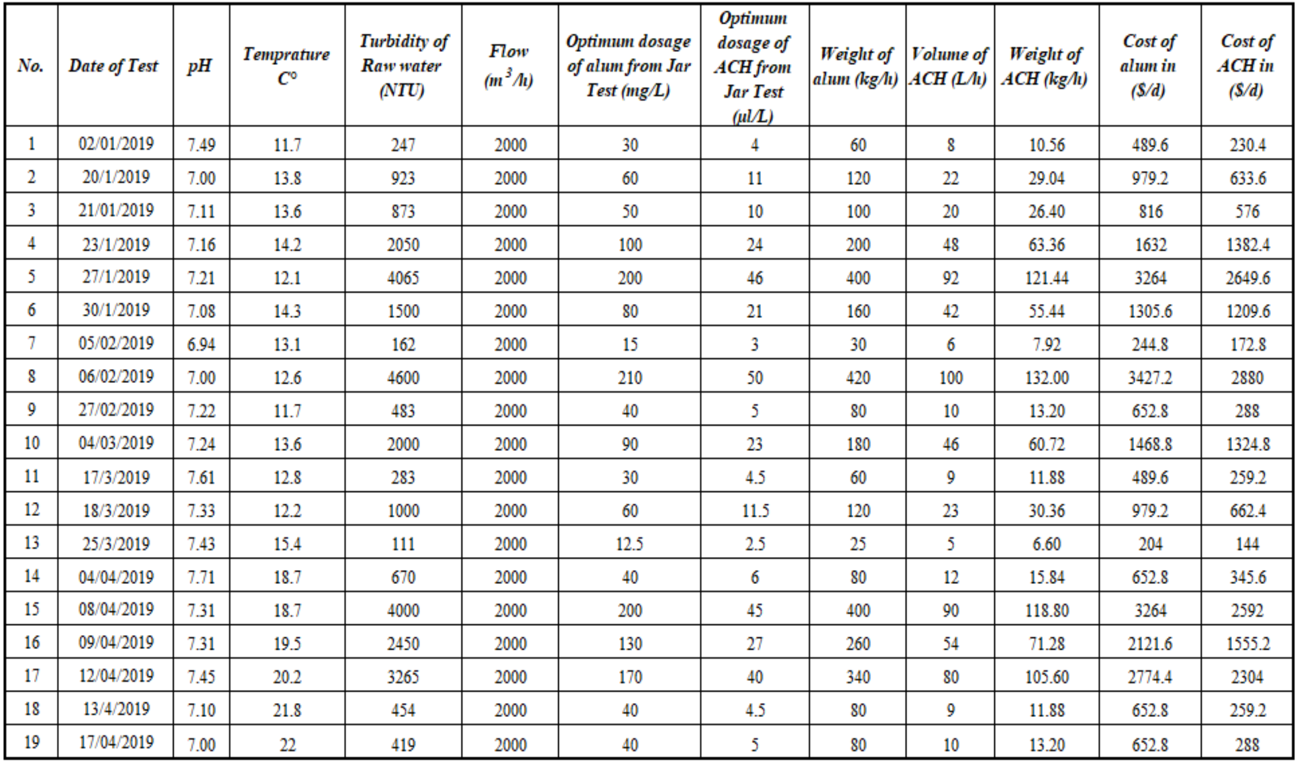


Figure 11. Coagulant costs with different raw water turbidity

4. Conclusions

The results revealed that the Greater-Zab River is safe for construction, and irrigation, but need treatment for drinking. The optimal settling time for the sedimentation process was 30 minutes and 40 minutes for raw water turbidity of 1000 and 2000 NTU, respectively. The optimum coagulant dosages were obtained and presented from alum and ACH for different raw water turbidities, and the optimum dosage of PAC as coagulant aid of 0.1 and 0.25 g/L for raw water samples of 419 and 1000 NTU was determined in the experiments and reported, which increased the removal efficiency of the turbidity removal with 28.95% and 25.71% compared with absent of PAC. Moreover, the economic analysis for alum and ACH exposed that using ACH instead of alum led to reduction of cost by 32%. Generally, it can be concluded that using ACH instead of alum is better because it is cheaper and more efficient. The expected equations for the optimum dosages (Y) for alum (mg/L) and ACH (µl/L) dosages (X) were Y= 0.04x+ 14.42, and Y=0.01x+ 0.72, respectively.

Table 9. Cost of Ach and Alum per day



No.	Date of Test	pH	Temprature C°	Turbidity of Raw water (NTU)	Flow (m^3/h)	Optimum dosage of alum from Jar Test (mg/L)	Optimum dosage of ACH from Jar Test (µl/L)	Weight of alum (kg/h)	Volume of ACH (L/h)	Weight of ACH (kg/h)	Cost of alum in ($/d)	Cost of ACH in ($/d)
1	02/01/2019	7.49	11.7	247	2000	30	4	60	8	10.56	489.6	230.4
2	20/1/2019	7.00	13.8	923	2000	60	11	120	22	29.04	979.2	633.6
3	21/01/2019	7.11	13.6	873	2000	50	10	100	20	26.40	816	576
4	23/1/2019	7.16	14.2	2050	2000	100	24	200	48	63.36	1632	1382.4
5	27/1/2019	7.21	12.1	4065	2000	200	46	400	92	121.44	3264	2649.6
6	30/1/2019	7.08	14.3	1500	2000	80	21	160	42	55.44	1305.6	1209.6
7	05/02/2019	6.94	13.1	162	2000	15	3	30	6	7.92	244.8	172.8
8	06/02/2019	7.00	12.6	4600	2000	210	50	420	100	132.00	3427.2	2880
9	27/02/2019	7.22	11.7	483	2000	40	5	80	10	13.20	652.8	288
10	04/03/2019	7.24	13.6	2000	2000	90	23	180	46	60.72	1468.8	1324.8
11	17/3/2019	7.61	12.8	283	2000	30	4.5	60	9	11.88	489.6	259.2
12	18/3/2019	7.33	12.2	1000	2000	60	11.5	120	23	30.36	979.2	662.4
13	25/3/2019	7.43	15.4	111	2000	12.5	2.5	25	5	6.60	204	144
14	04/04/2019	7.71	18.7	670	2000	40	6	80	12	15.84	652.8	345.6
15	08/04/2019	7.31	18.7	4000	2000	200	45	400	90	118.80	3264	2592
16	09/04/2019	7.31	19.5	2450	2000	130	27	260	54	71.28	2121.6	1555.2
17	12/04/2019	7.45	20.2	3265	2000	170	40	340	80	105.60	2774.4	2304
18	13/4/2019	7.10	21.8	454	2000	40	4.5	80	9	11.88	652.8	259.2
19	17/04/2019	7.00	22	419	2000	40	5	80	10	13.20	652.8	288

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