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Calculation Steps of Designing a conventional water purification plant

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ABSTRACT

This research investigated the design of a conventional drinking water treatment plant for a surface water source to serve urban area in Homs city. The treated water comes from a surface water; Orontes River with values of pH, electrical conductivity, temperature and hardness that meet the Syrian Standards No. 25. The average total suspended solids were 330 mg/L, the turbidity was between 20 and 200 Nephalometric Turbidity Unite (NTU), and the color was 50º. Therefore, the water had to undergo chemical treatment. The design flow was approximately 0.6 m^3/h. The treatment steps were recommended based on the water properties as follows: A mechanical rapid mixer for coagulation, aluminum sulfate was used; the dose was determined by jar test, a flocculation tank, a rectangular sedimentation tank, followed by rapid sand filters, the final stage is disinfection using chlorine.

Keywords: Coagulants, Electrical Conductivity, Purification Plant, Around–The–End Basin, Rapid Sand Filters, Hardness, Turbidity.

1. Introduction

Water is the most important element for life; it plays a big role in both the politics and the economy of societies. The scarcity of water resources has become an urgent issue in formulating sustainable development policies worldwide due to global economic development and rapid population growth[1,2]. The increase in population over the past few decades has caused real problems due to the increased water consumption around the world[3].

Surface water is the water that is open to the atmosphere, like rivers, lakes, etc... It is one of the main sources of potable water, but it is often not safe to be used without treatment.[4,5]. The water source should provide the needed quantity and quality of water for a long time[5]. Different kinds of treatment processes could be used according to the raw water proprieties[6]. Conventional water purification plants' complex processes are monitored and adjusted in order to provide high water quality for consumers[7,8].

Due to the ability of water to dissolve many gases and salts, pure water is almost rare, as it is very difficult to find usable water without the need to a prior treatment[9]. Natural water contains organic and inorganic substances. Water impurities are mainly classified according to: suspended impurities. Colloidal impurities and dissolved impurities[10].

Engineers involved in designing, implementing and operating water purification processes face great challenges when implementing purification plants with the lowest construction cost and greatest operating efficiency with the aim of obtaining the best water quality with the lowest investment costs. The operation and design of the purification plant needs many technical workers who are able to manage and operate the plants effectively.

1.1 Flash mixer:

It is the part of the plant that is designed to provide the time and conditions needed for the coagulation process, it consists of an electric motor-driven propeller with an either axial or radial impeller, see figure 1. Radial-flow impeller produces more turbulence and provides better mixing. Equation 1 describes the high-velocity gradient G that this tank is intended to produce. To create an atmosphere that is favorable for the coagulation process. This basin receives chemical injections.

$$G = \sqrt{\frac{P}{\mu .V}} \quad (1)$$

P: power input, Watt. μ: Dynamic viscosity, Pa.s. V: volume of water in the tank, m^3

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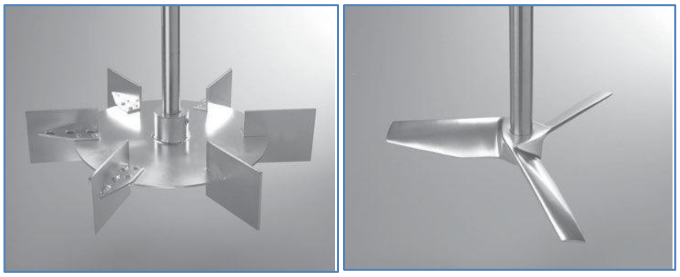

Figure.1 a: Radial-flow turbine impeller b: Axial-flow turbine [11].

1.2. Flocculation Basin:

The goal of this tank is to create the appropriate conditions for the particles to collide and reach a size where they can easily settle. An appropriate amount of mixing must be provided to bring the flocs into contact and prevent them from settling in this basin. Over-mixing causes the flocs particles to be sheared and finely dispersed. Therefore, the velocity gradient must be controlled. This basin can be hydraulic or mechanical. Figure 4 shows the hydraulic flocculation basin around the end tank.

This type of flocculator is commonly used with a horizontal settling tank and its length should correspond to one of the dimensions of the horizontal settling tank. It is a reinforced concrete tank with barriers at least 70 cm wide per corridor. The speed of the water is 0.1-0.3 m/s and 0.1 m/s at the beginning and the end of the chamber, respectively. The average depth is 2-3 m and the residence time is 20-30 minutes.

1.3. Sedimentation Basin:

To remove flocculants created after the coagulation and flocculation process, the sedimentation of these particles is needed. sedimentation is carried out in large basins using a slow mixing process. The study of this process is complex as it is influenced by several factors; the shape and dimensions of the particles and the characteristics of the water flow.

This stage allows water to remain relatively static for some time, so suspended materials settle.

Coagulants are added to water to increase the rate of sedimentation by increasing the collection rate of colloidal particles and forming a colloidal suspension that settles rapidly, carrying with it microorganisms and suspended particles[12]. Turbulent properties are observed during water movement in the sedimentation tanks, with horizontal and vertical velocity components occurring. The radial combination of these components determines the plankton's true speed during the sedimentation process and its direction of movement. The horizontal and vertical components of the flow velocity and sedimentation rate of molecules are influenced by their weight. This type of sedimentation process is used in systems with a flow rate of approximately 30,000 m^3/day.

1.4 Rapid Sand Filtration:

The filtering process removes suspended solids by passing water through the filtered material. The passage of water through a layer of sand or other material helps the water lose most of the remaining contaminants. Sand is the most common filter material used in water purification. There are so many media used for filtration, but sand is most commonly used because it is inexpensive and has consistent physical properties over time. Concrete or sprayed rectangular basins are used for rapid sand filtration. At the bottom of the pool, there is a drainage network with an overlying layer of gravel and sand. Rapid sand filters are used to filter cloudy and colored water after treatment with coagulants, as well as in some other cases to remove iron and hardness of water. Fast sand filters are much faster than slow filters that require cleaning, as can be seen from the experience of investing in filters.

2. The Gaussian

2.1 Raw Water Data:

This study describes a detailed optimal design of a conventional drinking water purification plant in an urban area in Syria. The raw water properties were tested on different days of the year and after periods of heavy rain. The pH values varied between 7.3 and 9.3, while the electrical conductivity varied between 320 and 500 µs/cm, the chloride and BOD5 values varied between 8 and 50 mg/L and 3 and 20 mg/L, respectively. Turbidity levels were high, varying between 10 and 250 NTU between sessions, and bacterial analyses indicated that the water required chemical treatment.

Table 1 shows the chemical tests of the raw water taken in the sampling stations. Table 2 describes the accepted values for some parameters according to Syrian standards.

Table.1: Raw water tests results in the sampling stations

Station name	Date	pH	E.coli 100 ml	Staphylococcus aureus
Omiri	7/1/2023	7.6	2×10^3	3360
Rabblah	7/1/2023	8	2×10^3	450
Qanater	7/1/2023	8.4	2×10^3	900
Alnabi Mando	7/1/2023	8.4	10×10^3	500
Omiri	5/5/2023	8.4	1×10^3	400
Rabblah	5/5/2023	8	1×10^3	450
Qanater	5/5/2023	8.1	1×10^3	800
Alnabi Mando	5/5/2023	8.4	25×10^3	460
Omiri	5/9/2023	7.9	7×10^2	500
Rabblah	5/9/2023	7.9	8×10^2	400
Qanater	5/9/2023	8.3	8×10^2	520
Alnabi Mando	5/9/2023	8	9×10^2	480
Omiri	5/11/2023	7.9	7×10^2	500
Rabblah	5/11/2023	8.2	5×10^2	520
Qanater	5/11/2023	8.6	6×10^2	480
Alnabi Mando	5/11/2023	7.9	$\times10^2$10	600

Alum was used to remove the high turbidity. The units for the purification process were chosen as the following: Mechanical Flash mixer; to mix the coagulant with the raw water, flocculation basin, around – the – End type to provide the time needed to flocs to flocculate, then a horizontal sedimentation basin followed with rapid sand filtration. Finally, Sodium hypochlorite NaClO was used to destabilize the water. Figure .2 shows a schematic overview.

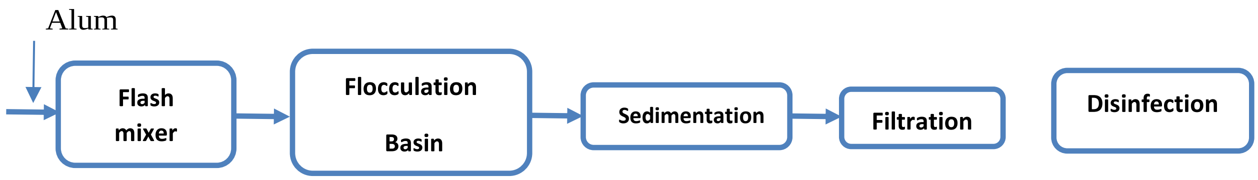

Figure.2 The designed Plant Scheme

Table 2: Syrian Standards for Drinking Water No.25

Parameter	Accepted level	Unit
Turbidity	1	NTU
Conductivity	1500	µs/cm
Total Hardness	500	mg/L
pH	6.5 -9	-
Color	15	TCU
COD	5	mg/L
Residual aluminum	0.1	mg/L
E.coli	0	/100 ml

Each of the treatment units was designed based on the designing criteria described in Table .3

Table 3: Basic Design Criteria for each basin:

Flash mixer	
Velocity Gradient	700-1000 sec $^{-1}$
Detention Time	30 – 60 sec
velocity	0.1 -0.3 m/sec
H/D Ratio	1:1 to 3:1
Flocculating basin	
Velocity Gradient	10-100 sec $^{-1}$
Detention Time	15 – 30 min
velocity	0.1 -0.3 m/sec
Wall thickness δ	15-20 cm
Horizontal Sedimentation basin	
Depth	3-5 m
L/H Ratio	10:1
L/W Ratio	4:1 to 6/1
Surface loading rate	1.25 – 2.5 m/h
Detention Time	1.5 – 4 h

3. Results and discussion

As the treated water is surface water, turbidity is a great issue, and it is clear that the most important concern is to remove it in order to reach the accepted limits. And as the plant is designed to provide water for an urban area, the conventional form selected is the most suitable for the situation. As it involves the needed process; coagulation, flocculation, sedimentation and, filtration.

Horizontal basins are much suitable for this relatively big flow, and therefore the flocculation tank designed was around the end matching their dimensions. The water moves from one unit to another was by gravity, taking into consideration that the water losses between coagulant and sedimentation basin is 0.5 m. between sedimentation tank and filters 0.3 m.

3.1 Designing The entrance channel:

Assuming the channel' width is 1.5 m, according to Manning's equation:

$$Q = \frac{1}{n} b.h.\left(\frac{b.h}{b+2h}\right)^{2/3}.\sqrt{i} \Rightarrow 0.556 = \frac{1}{0.014} 1.5.h.\left(\frac{1.5.h}{1.5+2h}\right)^{2/3}.\sqrt{0.0004} \Rightarrow h = 0.6\ m$$

Checking the velocity: v=0.556/1.5×0.6 = 0.62 m/sec accepted

3.2 Designing Flash Mixer:

When sweep coagulation is the dominated coagulation mechanism, too short detention time is not as important [11]. A mechanical flash mixer was selected, and 700 s^{-1} of velocity gradient should be provided by the paddles. The raw water enters the flash mixer at a flow rate of 0.556 m^3/sec. Figure 3 shows the designed flash mixer. The radial impeller was chosen as it provides more turbulence.

Detention time Assumed was 30 sec, then the volume of the tank is $V = Q \times t$

$= 0.556 \times 30 = 16.68\ m^3$, the flash mixer depth was assumed as 2.5 m, and then the diameter was calculated as the following:

$$V = \frac{\pi D^2}{4} \times h \Rightarrow D = 2.9\ m$$

H:D ratio = 1.16: 1 ok

Power required $P = G^2.\mu.V$; Assumed velocity gradient = 700 sec^{-1}

⇒ P= 700^2.0.001.16.68= 6004.8 watt = 360 watt/m^3

Impeller diameter = 0.4 × basin diameter = 0.4 × 2.9 = 1.16 m

Tangential velocity = (impeller speed × impeller periphery /60) = 150×π×1.16/60 = 9.11 m/sec

Relative velocity = 0.75 × Tangential velocity = 0.75 × 9.11 = 6.83 m/sec

Power requirement = $0.5 \times C_D \times \rho \times A_p \times v_r^3$

C_D : coffeicient of drags =1.8, ρ: density of water 988 kg/m^3 , A_p: area of paddles , V_r: relative velocity = 6.83. ⇒ A_p= 0.02 m^2 ; considering 4 paddles ; the area of each one is 0.005 m^2

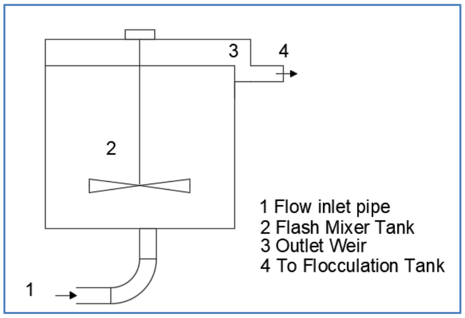

Figure 3: Mechanical Flash mixer

The next step was to design the sedimentation tank since the flocculation basin's width is typically intended to be equal to the total width of the tanks.

3.3 Horizontal Sedimentation Basin:

A rectangular sedimentation basin was used because it is the fundamental type for high-rate surface water load (SOR). Assumed parameters include a four-horizontal sedimentation basin (to provide redundancy), a deposition area depth of 2.8 m, and a precipitator continuity of 10 d between two cleanings. The Outlet include launders parallel to the basin's length.

K factor (the factor between horizontal and vertical velocity) is determined from the table.4 according to the L/H ratio; L/H = 15 ⇒ K =10 and α = 1.5

Table.4 values of K and α according to the ratio of L/H

The ratio L/H	10	15	20	25
K	7.5	10	12	13.5
α	1.33	1.5	1.67	1.82

Table.5: uo and v values according to the treatment

Water treatment method	uo mm/sec	Values of v are in mm/sec at values of K			
		7.5	10	12	13.5
For colored water with a concentration of 200-250mg/l for suspensions and treated with chemical solutions	0.35 0.4 0.45	2.6 3 3.4	3.5 4 4.5	4.2 4.8 5.4	4.7 5.4 6.1
For turbid water with a concentration of suspensions greater than 250mg/l, treated with chemical solutions	0.5 0.55 0.6	3.8 4.1 4.5	5 5.5 6	6 6.6 7.2	6.8 7.4 8.1
For turbid water not treated with chemical solutions	0.12 0.13 0.14 0.15	0.9 1 1.05 1.1	1.2 1.3 1.4 1.5	1.4 1.6 1.7 1.8	1.6 1.8 1.9 2

Horizontal velocity uo = 0.5 mm/sec then v =5 mm/sec . Total area of precipitators:

$$F_{tot} = \frac{\alpha . q}{3.6\, u_0} = \frac{1.5 \times 2000}{3.6 \times 0.5} = 1666.67\, m^2$$

Area of one precipitator: $F_1 = \frac{F_{tot}}{4} = 416.67\, m^2$

The sedimentation tank depth ranges between (2.5 -3.5) m, we chose H = 2.8 m:

$$L = \frac{\alpha\, H\, v_c}{u_0} = \frac{1.5 \times 2.8 \times 5}{0.5} = 42 \text{ m}$$

The precipitator width:

$$B = \frac{q}{3.6\, v_c HN} = \frac{2000}{3.6 \times 5 \times 2.8 \times 4} = 9.9 \text{ m} \approx 10 \text{ m}$$

The precipitator is divided into two parallel corridors by a longitudinal barrier, the width of one corridor is 3.3**.** The valume of the sediment collecting area is equal to:

$$V = \frac{q\, T\, (C_c - m)}{N\, \delta}$$

N: the number of operating sedimentation tanks. T: The work time between two washes (h). m: concentration of suspensions leaving the precipitator, g/m^3. δ : The solid concentration of sediments in the depositional part of the sediment (average concentration with height) is related to the turbidity of the initial water and the continuity of the period between two successive sediment releases. It was taken from Table .6.

Cc - the suspended materials concentration in the precipitator's inlet, it is calculated by the following

$$C_c = M + KD_C + 0.25C + B$$

Where M: concentration of suspensions in the raw water, g/m^3. K: A factor according to the coagulant type. It is taken as 0.55 for alum . Dc: coagulant dose, g/m^3

C: raw watercolor. B- The undissolved impurities added to the water with lime alkalization. B= (1-0.4) × 60; 40: the CaO Concentration in lime.

Table .6: solid concentration according to the suspended impurities

$\delta = 30000\ g/m^3$	C_{mid} up to 100 mg/L
$\delta = 30000 - 50000\ g/m^3$	C_{mid} 100 mg/L , 400 mg/L
$\delta = 50000 - 70000\ g/m^3$	C_{mid} 400 mg/L , 1000 mg/L
$\delta = 70000 - 90000\ g/m^3$	C_{mid} 1000 mg/L , 2500 mg/L

$$C_c = M + KD_C + 0.25C + B$$
$$= 330 + 0.55 \times 60 + 0.25 \times 50 + 0.6 \times 40$$
$$= 399.5 \text{ mg/L}$$

$$V = \frac{q\, T\, (C_c - m)}{N\, \delta} = \frac{1800 \times (399.5 - 9.5) \times 10 \times 24}{4 \times 50000} = 842.4 \text{ m}^3$$

The sediment compaction and condensation area height equals to:

$$hzn = \frac{V}{F} = \frac{842}{375} = 2.24 \text{ m}$$

3.4 Designing of Around- the –End flocculation basin:

The basin's volume was determined using the continuous equation with a suggested detention time of 15 minutes.

$$Q = \frac{V}{t} \Longrightarrow V = Q \times t = 0.556 \times 15 \times 60 = 500 \text{ m}^3$$

The area of the basin is: $F = \frac{V}{h} = \frac{500}{2.6} = 192.3 \text{ m}^2$

To calculate the Width of corridors (the width should be more than 0.7 m), water enters the basin from the area of the first corridor, so that it could be written as the following:

$$Q = A \times v = b \times h \times v \Longrightarrow b = \frac{Q}{v.h} = \frac{0.556}{0.15 \times 2.5} = 1.5 \text{ m} > 0.7 \text{ m} \quad \text{ok}$$

Assuming the thickness of the walls is 0.2 m, the Number of corridors would be **:**

$n = \frac{L}{b+\delta} = \frac{40}{1.5+0.2} = 23.5$, the number of corridors: 24

The length of the flocculation tank is equal to the length of one aisle: $L = \frac{F}{B} = \frac{192}{24} = 8$ m. Energy losses in a basin: $\Delta H = 0.15 \times v_{mid}^2 \times m = 0.15 \times 0.3^2 \times 10 = 0.135$ m

To make sure the mixing is in its appropriate form, the velocity gradient should be calculated:

$$G = \sqrt{\frac{n\, v^2 Q\, \rho}{2\, V\, \eta}} = \sqrt{\frac{24 \times 0.3^2 \times 0.556 \times 997.5}{2 \times 500 \times 0.001}} = 17.3 \text{ s}^{-1} \text{ accepted}$$

Cleaning the flocculator; the amount of water needed is: v=h×b×L = 2.5×35× 8= 600 m^3

Diameter of the chosen pipe is 600 mm, then the amount of water needed for washing is:

$$Q = \mu A \sqrt{2gH} = 0.62 \times \frac{\pi\, 0.6^2}{4} \times \sqrt{2 \times 9.81 \times \frac{2.5}{2}} = 0.87\, m^3/sec$$

Time needed for evacuation is 600/0.87 = 11.5 minute.

3.5 Rapid Sand filters Designing:

The total area of the Filters is calculated using the following equation:

$$\mathrm{F} = \frac{\mathrm{Q_{tot}}}{\mathrm{T.v} - 3{,}6.\mathrm{n.w.t_1} - \mathrm{n.t_2.v} - \mathrm{n.t_3.v}}$$

T: Continuity of operation of the purification station, v: filtration velocity.

n: Number of washing processes per day, once every couple day, n=0.5. w: Washing intensity; (5 – 15) assumed 6 l/s.m^2. t_1: washing Continuity ,0.13 h

t_2: Filter stopping time due to washing process, 0.22 h. t_3: time needed for throwing leachate into the sewage system after the process of filter washing, 0.17 h.

$$F = \frac{0.556 \times 60 \times 60 \times 24}{24 \times 6 - 3{,}6 \times 0.5 \times 6 \times 0.13 - 0.5 \times 0.22 \times 6 - 0.5 \times 0.17 \times 6} = 340.46\, m^3$$

Assuming the area of a filter is 43 m^2, ⇒ N= 8 filters. B = 3.9 m. length of the filter; L = 11 m.

- Design of the central channel for raw water distribution: the flow is divided into 8 filters, Q_f = 0.556/5=0.07 m^3/sec. assuming b = 0.7 m

$$\mathrm{Q} = \frac{1}{\mathrm{n}}.\mathrm{A.R}^{2/3}.\sqrt{\mathrm{I}} \Longrightarrow 0.07 = \frac{1}{0.014}.(\mathrm{b} \times \mathrm{h}).\left(\frac{\mathrm{b.h}}{2\mathrm{h}+\mathrm{b}}\right)^{2/3}.\sqrt{0.001} \Longrightarrow \mathrm{h} = 0.4\ \mathrm{m}$$

The filtration layer has sand with minimum diameters of 0.5 mm and 1.2 mm as maximum, this means equal diameter of (0.7-0.8 mm), and a height of 0.7-0.8 m. the filtration velocity is 5-6 h.

The flash mixer, flocculation, and sedimentation basins and filters are shown in figure.4.

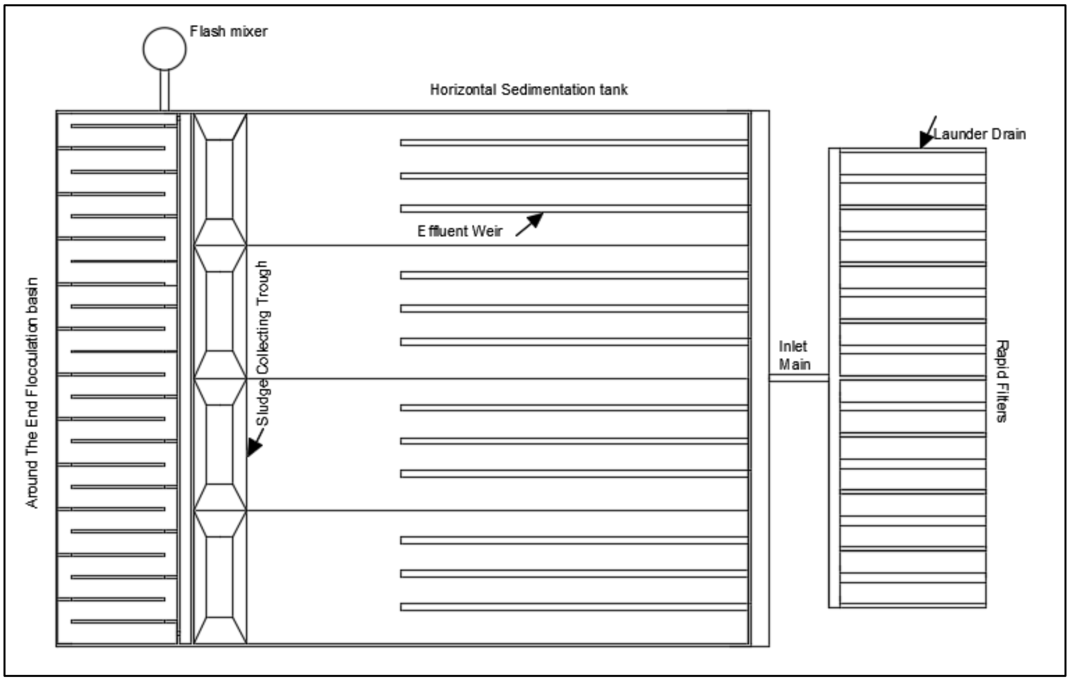

Figure.4 Flash mixer, Flocculation and sedimentation basin and filters

Conclusions

The objective of this study is to describe detailed calculations of a conventional purification plant units optimal design; the calculations were made to meet the designing criteria of each unit, according to the water characteristics. High levels of turbidity, and Bacterial that needed a coagulation process to be removed. Rectangular horizontal sedimentation tank was chosen because the flow of the plant is more than 30000 m^3/d. Thus, around – the – end flocculation basin was chosen, matching the width of the total sedimentation basins. Conventional treatment usually ends with filters because after sedimentation process, total suspended solids may still range between 8 and 12 mg/L. This article can be used as a reference study for the future designers of a conventional water purification plant.

Conflict Of Interest

The authors declare they have no conflict of interest.

Author's Contributions

Dr. Ruba Alsaeed, Prof. Bassam Alaji: Methodology, Data collection, Data analysis, Writing- original draft steps**,** Supervision, Review. **Ahmad Mowafak Moutey, Ahmad Arwana, and Karam Alsaid**: Writing- original draft, doing the calculations, drawing the AutoCAD files.

Ethics

There are no ethical issues with the publication of this manuscript.

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