PRELIMINARY WATER TREATMENT PLANT

Florida International University – Department of Civil and Environmental Engineering – ENV4401 – Water Supply Engineering – Dr. Laha

Laramie City

22.8 MGD Conventional Water Treatment Plant

Yenileivys Dominguez

4000454

Preliminary design proposal for a new softening plant for Laramie City.

Given parameters:

Flow Rate (Q) =1 m^3/s
Average annual water temperature (T) = 10°C

(I) RAPID MIX SYSTEM

Assumptions for a rapid mix tank:

Tank configuration: squared plan with depth = 1.25 x width
Detention time (Θ) = 45 s
Velocity gradient (G) = 900s^{-1}
Mixer: Available mixers for rapid mix and flocculation tanks are provided in the table below

Table. 1 JTQ models for rapid mix and flocculation mixes.

Model	Rotation speeds, rpm	Power, kW
JTQ25	30,45	0.18
JTQ50	30,45	0.37
JTQ75	45,70	0.56
JTQ100	45,110	0.75
JTQ150	45,110	1.12
JTQ200	70,110	1.50
JTQ300	110,175	2.24
JTQ500	110,175	3.74
JTQ750	110,175	5.59
JTQ1000	110,175	7.46
JTQ1500	110,175	11.19

rpm=revolutions per minute
JTQ-F models have variable speeds from 1-45 rpm. These may be used for the flocculation tanks.

1. NUMBER AND DIMENSIONS OF TANKS

Total volume of water (V) to be handled in the rapid mix tank(s)

$$\boxed{V = Q\theta = \left(\frac{1m^3}{s}\right)(45s) = 45m^3}$$

As suggested by Dr. Davis, the volume of a rapid-mix tank seldom exceeds 8 m^3 because of mixing equipment and geometry constrains. (Davis p6-33)

Number of tanks required = $\frac{45m^3}{8m^3} = 5.625$
Number of tanks was set to 8 for redundacy
Volume per tank = $\frac{45m^3}{8} = 5.63\ m^3$

Dimension of each rectangular tank

Volume= Length * Width * Depth

X = Length = Width

Depth = 1.25X

V = $1.25X^3 = 5.63\ m^3$

X = 1.65 m

Length: 1.65 m
Width: 1.65 m
Depth: 2.06 m

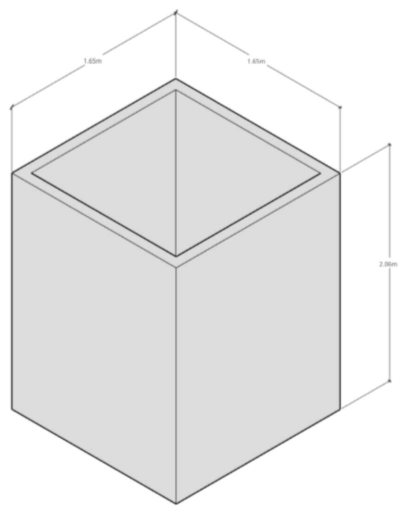


Figure 1-1 Conceptual drawing for rapid mix tank

The 45 m^3 volume of water will be directed to 8 equal rapid mix tanks of 1.65 m width, 1.65 length, and 2.06 m depth. Each tank will be handling a capacity of 5.63 m^3 of water volume.

2. WATER POWER INPUT IN kW

Water power input (P) was calculated using Stein's equation (Davis, P 6-25)

$$G = \left(\frac{P}{\mu V}\right)^{\frac{1}{2}} \qquad where \quad P = G^2 \times \mu \times V$$

P=power imparted to water in a single mixing tank

$\mu_{10^{\circ}C}$=dynamic viscosity of water= (1.307×10^{-3} Pa.s from Appendix A Davis pA-1)

V=volume of water per mixing tank = 5.63 m^3

G= Velocity gradient = 900^{-1}s

P=$(900/s)^2(1.30710^{-3}$Pa.s)(5.63m^3)

P=5.93 kW

The efficiency of transfer of motor power to water power is assumed to be of 0.8 for single impeller (Davis, p 6-35)

$$\frac{Water\ Power\ (P_W)}{Motor\ Power\ (P_M)} = 0.8$$

P_M= 5.93 kW/ 0.8
P_M= 7.41 kW

3. JTQ MIXER MODEL NUMBER

From Table.1, Mixer JTQ1000 offers a power of 7.46 kW, since the values of G for mechanical mixing in stirred tanks can have values in the range of 600 to 1000-1s (Davis, p6-33), the velocity gradient can be recalculated (G_0) in order to use this specific mixer model.

P_W=0.8(P_M) =0.8(7.46 kW)
P_W=5.968 kW
G_0= $(5.968Kw/(1.307*10^{-3})(5.63\ m^3))^{1/2}$
G_0= 903.16 s^{-1} 600 s^{-1}< 903.16 s^{-1}<1000 s^{-1}

The mixer **JTQ1000** with a power of 7.46 kW and a rotational speed range of 110, 175 rpm was selected. The velocity gradient was recalculated to 903.16 s^{-1} which is still between the recommended value ranges.

4. IMPELLER TYPE

A radial-flow impeller, turbine type, 6 flat blades is selected in order to provide more turbulence during the rapid mixing process. (Davis p6-33)

5. DIAMETER OF IMPELLER IN METERS

Table .2 Tank and impeller geometries for mixing (Davis, p6-35)

Geometric Ratio	Range
D/T (radial)	0.14-0.5
D/T (axial)	0.17-0.4
H/D (either)	2-4
H/T (axial)	0.34-1.6
H/T (radial)	0.28-2
B/D (either)	0.7-1.6

D=impeller diameter
T=equivalent tank diameter= $(4A/\pi)^{0.5}$
A=the plan area
H=water depth
B=water depth below the impeller*
*the recommended value of B is 1/3 of the water depth (Davis p6-35)

The impeller diameter (Di) can be calculated using the Rushton's equation (Davis, p6-34) and then adjusted to the values given in Table. 3 for available radial impellers.

$$P = N_p(n)^3(D_i)^5\rho \qquad where \;\; D_i = \sqrt[5]{\frac{P}{N_p(n)^3\rho}}$$

P = power (W) = Pw = 5.968 kW = 5968 W
N_p = impeller constant (from Table. 3)
n = rotational speed (rps) =175 rpm * m/ 60 s= 2.917 rps
D_i = impeller diameter (m)
P = density of liquid (kg/m^3) = $1000 Kg/m^3$

Selecting N_p=6.3 for radial-flow turbine impeller from Table. 3.

$D_i=[(5968W)/(6.3)(2.917rps)^3(1000kg/m^3)]^{1/5}$
$\boxed{D_i=0.54m}$

The impeller diameter obtained from calculations is 0.54 m

Checking if the diameter selected meets all the geometric constraints for radial impellers as indicated in Table. 3,

$A=x^2=(1.65m)^2=2.73\ m^2$
$T=(4A/\pi)^{0.5}=(4*2.73/3.14)^{0.5}=1.86$
B=1/3(X)=1/3(1.65m)=0.69m

D/T=0.54/1.86=0.29 $\rightarrow 0.14<0.29<0.5$
H/D=2.06/0.54=3.79 $\rightarrow 2<3.79<4$
H/T=2.06/1.86=1.11 $\rightarrow 0.28<1.11<2.0$
B/D=0.69/0.54=1.26 $\rightarrow 0.7<1.26<1.6$

Where D is the impeller diameter.

All requirements met. Softening chemical should be added in the rapid mix tanks.

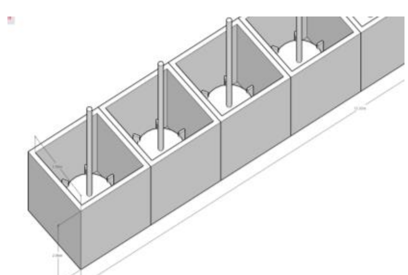


Figure 1-2. Conceptual drawing for the rapid mix system

Table. 4 Rapid Mix System design parameters obtained from calculations

Number of tanks	**8**
Water power input in kW	**5.97 KW**
Tank dimensions	**Width:1.65 m** **Length: 1.65 m** **Depth: 2.08 m**
JTQ mixer model number	**JTQ1000** **P_M=7.46kW**
Velocity gradient	**903.16s^{-1}**
Impeller type	**Radial**
Diameter of the impeller	**0.54 m**
Rotational speed of impeller	**175 rpm**

(II) FLOCCULATION SYSTEM

Given:

Number of basins = Number of rapid mix tanks=8

Tapered G in three compartments: 90s^{-1}, 60s^{-1}, 30s^{-1}

G_{t0}=12000

Length=Width=Depth, for each compartment

Impeller type: propeller, pitch of 1, blades 3

1. WATER POWER INPUT IN Kw

Each rapid mix tank is connected to a tapered flocculation basin consisting of three equal-sized chambers with design velocity gradient set at 90s^{-1}, 60s^{-1}, 30s^{-1} respectively.

The power input for each chamber is calculated using Stein's equation

$$G = \left(\frac{P}{\mu V}\right)^{\frac{1}{2}} \qquad where \quad P = G^2 \times \mu \times V$$

The volume of water flowing into each flocculation basin (V_F) is calculated as follow:

$V_F = Q_F \Theta_F$

Where

Q_F=Q/8= (1m^3s^{-1}/8)=0.125 m^3/s

$\Theta_F = G_{t0}/G_{ave}$={120000/[(90$s^{-1}$+60$s^{-1}$+30$s^{-1}$)/3]}=2000 s

V_F=250.00 m^3

For redundancy, volume calculations were adjusted. In this case 7 of the 8 basins will be able to handle the incoming flow rate.

V_F=285.71 m^3

The volume of water flowing into each flocculation chamber (V_{CH}) is given by:

$V_{CH} = V_F/3$

V_{CH}=285.71 m^3/8

V_{CH} =95.24 m^3

The power input required by **Chamber A**, with $G=90s^{-1}$, is calculated as follow:

$P_{CH.A}=(90s^{-1})^2(1.307*10^{-3}Pa.s)(95.24m^3)$

$P_{CH.A}=1.003\ kW$

For **Chamber B**, with $G=60s^{-1}$:

$P_{CH.B}=0.446\ kW$

For **Chamber C**, with $G=30s^{-1}$:

$P_{CH.C}=0.111\ kW$

2. TANK DIMENSIONS IN METERS

Each of the three chambers on a basin receive a water volume of $V_{CH}=95.24\ m^3$; and has the given dimensions

Length=Width=Depth=X

$V_{CH}=(X)^3$ and $X=(V_{CH})^{1/3}=(95.24\ m^3)^{1/3}$

$X=4.57\ m$

The width, length, and depth of each chamber is 4.57 m respectively.

A single basin has depth and width equal to 4.57 m respectively, and length equals to three times the length of each chamber plus the thickness of the two baffle walls 3(4.57m)+2(0.15m)=14.01 m.

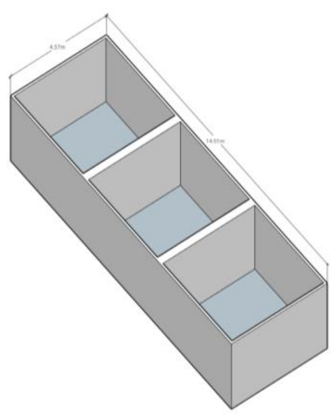


Figure 1-3 Conceptual drawing for one of the 8 flocculation basins

3. JTQ-F MIXER MODEL NUMBER

$P_{M1}=P_{CH.A}/0.8$

$P_{M1}=1.1003kW/0.8$

$P_{M1}=1.25\ kW$

Assuming 80% efficiency, model **JTQ-F200** provides **1.50 kW**, which satisfies the power input needed for **Chamber A**

$P_{M2}=P_{CH.B}/0.8$

$P_{M2}=0.56$ kW

Model **JTQ-F75**, which provides **0.56 kW**, is selected for **Chamber B**

$P_{M3}=P_{CH.C}/0.8$

$P_{M3}=0.14$ kW

Model **JTQ-F25**, which provides **0.18 kW**, is selected for **Chamber C**

4. DIAMETER OF IMPELLER IN M

Equal impeller diameter is going to be used for each chamber to optimize maintenance. Vertical turbine mixing with axial-flow impeller in a mixing basin is recommended over the other types of flocculators because they impart nearly constant G throughout the tank. (Davis p6-41). Use a propeller, pitch of 1, blades 3 type.

5. ROTATIONAL SPEED OF IMPELLER IN RPM

Using Rushton's equation the rotational speed of each camber is calculated:

$$n = \sqrt[3]{\frac{P}{N_p\,(D_i)^5\rho}}$$

Where N_p for axial impeller is equal to 0.32

And P is 80% of rated power of selected mixer.

Trial of allowed rotational speeds from 0.017 rps to 0.75 rps where made to find a common diameter for the impellers. Checking for geometric constraints using Table. 2:

Table. 5 Evaluation of the different axial impeller diameters using different rotational speeds.

When P_M=	1254.25	557.44	139.36
When P_M=	1254.25	557.44	139.36
Rotational speed (rps) n-range Trial	**0.60**	**0.45**	**0.30**
Diameter of the Impeller Di=	**1.79**	**1.80**	**1.74**
Impeller constant Np=	0.32	0.32	0.32

Calculating the average diameter from the three values obtains, the impeller diameter was set to **1.78 m**

Table. 6 Flocculation System design parameters obtained from calculations

<table>
<tr><td>Total Number of Basins</td><td colspan="4">8</td></tr>
<tr><td>Dimensions of each basin in m</td><td colspan="4">W=4.57
L=14.01
D=4.57</td></tr>
<tr><td></td><td colspan="2">Chamber A</td><td>Chamber B</td><td>Chamber C</td></tr>
<tr><td>Velocity gradient in s⁻¹</td><td colspan="2">90</td><td>60</td><td>30</td></tr>
<tr><td>Water input required in kW</td><td colspan="2">1.00</td><td>0.45</td><td>0.11</td></tr>
<tr><td>Power input imparted to water in kW</td><td colspan="2">1.50</td><td>0.76</td><td>0.18</td></tr>
<tr><td rowspan="3">Chamber dimensions in m</td><td>W=</td><td>4.57</td><td>4.57</td><td>4.57</td></tr>
<tr><td>L=</td><td>4.57</td><td>4.57</td><td>4.57</td></tr>
<tr><td>D=</td><td>4.57</td><td>4.57</td><td>4.57</td></tr>
<tr><td>JTQ-F mixer model</td><td colspan="2">200</td><td>75</td><td>25</td></tr>
<tr><td>Diameter of the impeller in m</td><td colspan="2">1.78</td><td>1.78</td><td>1.78</td></tr>
<tr><td>Rotational speed of impeller in rps</td><td colspan="2">0.60</td><td>0.45</td><td>0.30</td></tr>
</table>

(III) SEDIMENTATION TANK

The design flow rate is

$Q=1m^3/s=86400m^3/d=86.4/3.785MGD=22.8MGD$

For horizontal flow, the recommended basin configuration are long rectangular tanks, Type I (Davis, p10-21). The typical design criteria for horizontal-flow rectangular sedimentation basins in water treatment plants with flow rate greater than 40000 m^3/d are documented in the following figure:

Parameter	Typical range of values	Comment
Inlet zone		
Distance to diffuser wall	2 m	
Diffuser hole diameter	0.10–0.20 m	
Settling zone		
Overflow rate	40–70 $m^3/d \cdot m^2$	See Table 10-2
Side water depth (SWD)	3–5 m	
Length	30 m	Wind constraint
	60 m	Chain-and-flight
	≥80–90 m	Traveling bridge
Width	0.3 m increments	Chain-and-flight
	6 m maximum per train	Chain-and-flight
	24 m maximum = 3 trains per drive	Chain-and-flight
	30 m maximum	Traveling bridge
L:W	4:1 to 6:1	≥6:1 preferred
L:D	15:1	Minimum
Velocity	0.005–0.018 m/s	Horizontal, mean
Reynolds number	< 20,000	
Froude number	$> 10^{-5}$	
Outlet zone		
Launder length	1/3–1/2 length of basin	Evenly spaced
Launder weir loading	140–320 $m^3/d \cdot m$	See Table 10-3
Sludge zone		
Depth	0.6–1 m	Equipment dependent
Slope	1:600	Mechanical cleaning
Sludge collector speed	0.3–0.9 m/min	

Sources: AWWA, 1990; Davis and Cornwell, 2008; Kawamura, 2000; MWH, 2005; Willis, 2005.

Figure .1 Typical design criteria for horizontal-flow rectangular sedimentation basins (David, p10-29)

From FE manual, page 193

v_0= Overflow rate= $Q/A_{surface}$

V_0=critical settling velocity
$A_{surface}$= surface area, plan view
$A_{surface}$=$Length_{basin}$*$Width_{basin}$
v_h=Horizontal velocity=Q/A_x
Hydraulic residence time=ϴ=V/Q
V=tank volume= $Length_{basin}$*$Width_{basin}$*$Depth_{basin}$
ϴ=4hr
V_0= 40-70 $m^3/d.m^2$ → use 70 $m^3/d.m^2$
Vh≤ 0.5fpm≤ 219.47m/d
V= ϴ(Q)
V=14400m^3
$A_{surface}$=(86400 m^3/d)/ (70 $m^3/d.m^2$)
$\boxed{A_{surface} = 1234.43\ m^2}$

From FE manual, page 193 for rectangular clarifier tank, and Figure. 1
L:W= 5:1
L:D= 15:1 minimum
$A_{surface}$=$Length_{basin}$*$Width_{basin}$=L*(L/5)=L^2/5
$Length_{basin}$= $(5*A_{surface})^{1/2}$=$(5*1234.43m^2)^{1/2}$
$Length_{basin}$=78.56m
$Witdh_{basin}$=15.71 m
$Detph_{basin}$=6.83m

By setting the V_0=70 $m^3/d.m^2$ and ϴ=4h hours, the length of the basin was found to be to 78.56m , for open sedimentation tanks greater than 30 m in length, Reynold's number must be less than 20000 to avoid turbulence.
Horizontal flow velocities must be controlled to avoid undue turbulence, back mixing, and scour of particles from the sludge.

The Reynolds number is determined as

$$R = \frac{v_f R_h}{\vartheta}$$

v_f=0.02 m/s
R_h = (Across-sectional/Wetted Perimeter)= 0.119 m
ϑ=Kinematic Viscosity= 1.3007*10^6 m^2/s
R=1830.52 < 20000

The sedimentation tank depth is usually increased by about 0.6 m to provide freeboard to act as a wind barrier.
To meet redundancy, two sedimentation tank will be constructed.

Table. 6 Sedimentation tank dimensions and requirements.

Overflow rate	**70 $m^3/d.m^2$**
Side water depth	**5.24+0.6m(freeboard)=5.84m**
Length	**78.56m**
Width	**15.71m**
Horizontal velocity	**0.02m/s**

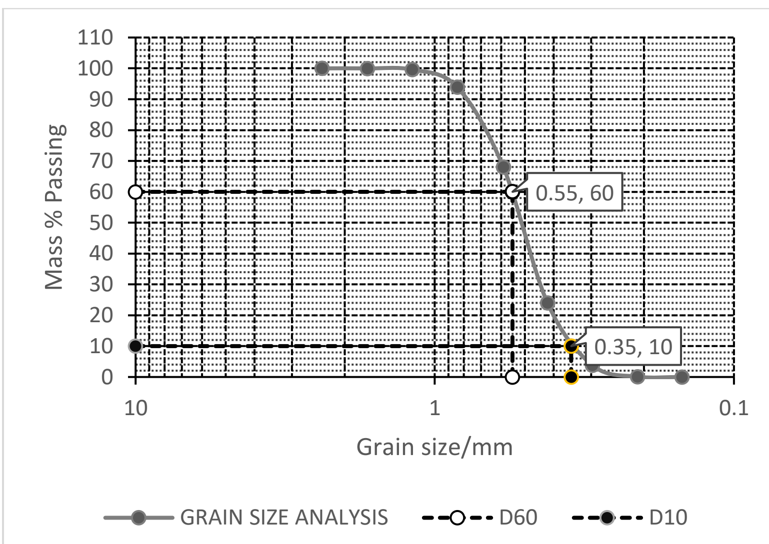
Reynolds number	**1830.52**
Launder length	**L/2=39.28**
Sludge depth	**1m**
Slope	**1:600**

(IV) GRAIN SIZE ANALYSIS

Analysis of the bid made by The Orondo Sand and Gravel Company for sand filter supply

Table. 7. The Orondo Sand and Gravel sand analysis data.

U.S Standard Sive No.	Sieve Size	Mass % Retained	Mass Passing Larger Sieve	Mass % passing
8	2.38	0.00	100.00	100.00
12	1.68	0.01	100.00	99.99
16	1.19	0.39	99.99	99.60
20	0.84	5.70	99.60	93.90
30	0.59	25.90	93.90	68.00
40	0.42	44.00	68.00	24.00
50	0.30	20.20	24.00	3.80
70	0.21	3.70	3.80	0.10
100	0.15	0.10	0.10	0.00



Graph. 1 Graph of sand sieve analysis to determine effective size and uniformity coefficient for Orondo's sand.

Eff. Size=D_{10}=**0.35mm**	
Unif. Coef.=D_{60}/D_{10}=0.55/0.35=**1.57**	

Request for bids

0.40≤Eff. Size≤0.60 **0.35mm**≤0.40
1.4≤Unif. Coef.≤1.6 1.4≤**1.57**.≤1.6
Orodon's sand bid is rejected since it doesn't meet the Efficient Size requirement.

(V) RAPID SAND FILTRATION

Depth(D)=0.75m
Filter loading=160m^3/d-m^2
Sand specific gravity=2.60
Shape factor=0.90
Stratified bed porosity=0.5
Water temperature=10̊C
Solving for Reynolds number, drag coefficient,

$$R = \frac{\varphi d v_a}{v}$$

φ=Shape factor
v_a=Filtration velocity
v=Kinematic viscosity of water at 10̊C
d=size of opening

$$C_d = \left(\frac{24}{R}\right) + \left(\frac{3}{R^{1/2}}\right) + 0.34 \ \ for\ 0.5 < R < 104$$

$$C_d = \frac{24}{R} \quad when\ R < 0.5$$

Where
C_d=Drag coefficient
And fraction of product of drag coefficient and fractional mass retained divided by de size of opening.

$$\frac{(C_d)(f)}{d}$$

Where
f=mass % retained by sieve

Table 8. Data for the frictional head loss through filter (h_L)

U.S Standard Sieve No.	Size of opening, mm	Size of opening, d, m	Mass % Retained, f	Reynolds number, R	Drag coefficient, CD	(CD)(f)/d
8. - 12	2.000	0.00200	0.000	2.56	11.58	0
12. - 16	1.410	0.00141	0.400	1.81	15.86	45
16 - 20	1.000	0.00100	13.100	1.28	21.72	2845
20 - 30	0.710	0.00071	54.500	0.91	29.87	22925
30 - 40	0.500	0.00050	30.200	0.64	41.55	25095
40 - 50	0.350	0.00035	1.785	0.45	53.51	2729
50 - 70	0.250	0.00025	0.015	0.32	74.92	45
					∑((C_D)(f))/d=	**53685**

Head loss Rose equation for multisized media through filter (h_L) (Davis, p11-13)

$$h_L = \frac{1.067(V_a)^2}{(\varphi)(g)(\varepsilon)^4}\sum\frac{(C_d)(f)}{d}$$

Where

ε=Stratied bed porosity

g=gravity

h_L=0.27m

Calculated head loss is less than 0.6m (Davis, p11-16), therefore it meets maximum recommended value.

Calculating the depth of the expanded bed (D_e),

$$D_e = (1-\varepsilon)(\mathrm{D})\sum\frac{f}{(1-\varepsilon_e)} =$$

Where

ε_e=porosity of expanded bed

$$\varepsilon_e = (\frac{v_b}{v_s})^{0.2247R^{0.1}}$$

And,

v_b=velocity of backwash (m/s)=0.75m/s at specific gravity =2.60 and D_{60}=0.55 (Davis p 11-29)

v_s=settling velocity (m/s)

Table 9. Calculation of Expanded Bed for Rapid Sand Filtration

U.S Standard Sieve No.	Size of opening, mm	Particle Diameter, d, m	Est. settling velocity, vs, m/s	Est. Reynolds number, R	Drag coefficient, CD	Calc. settling velocity, vs, m/s	Fraction Retained, f	Calc. Reynolds number, R	Expanded porosity Exponent	Expanded porosity, εe	$\frac{f}{(1-\varepsilon_e)}$
8. - 12	2.000	0.00200	0.300	415	0.55	0.277	0.000	426	0.41	0.279	0.00
12. - 16	1.410	0.00141	0.200	195	0.68	0.209	0.004	226	0.39	0.337	0.01

16 - 20	1.000	0.00100	0.150	104	0.87	0.155	0.131	120	0.36	0.401	0.22
20 - 30	0.710	0.00071	0.100	49	1.26	0.109	0.545	59	0.34	0.481	1.05
30 - 40	0.500	0.00050	0.070	24	1.94	0.073	0.302	28	0.31	0.574	0.71
40 - 50	0.350	0.00035	0.050	12	3.18	0.048	0.018	13	0.29	0.677	0.06
50 - 70	0.250	0.00025	0.030	5	6.28	0.029	0.000	6	0.27	0.800	0.00
						Sum =	1.000			Sum =	2.04

Expanded Bed Depth	**De=**	0.76	m
Expansion ratio	**De/D=**	1.02	
	De-D=	0.01	m

Six filters will filtrate the incoming flow, with a total number of cells equals to 12, 2 cells per filter.

Table 10. Rapid Mix Filtration Dimensions

Head Loss for the clean bed	0.27	m
Maximum backwash rate	0.75	m/min
Height of backwash troughs above sand	0.01	m
Number of filters	6	
Area of filter	90	m^2
Number of cell	12	
Width of each cell	5	m
Length of each cell	11.97	m

The recommended elevation of the backwash is 0.31 m above the depth of sand, (0.75m), Adding a factor of safety of 0.18 m, yields a total depth of 1.24 m

(VI) LIME-SODA ASH SOFTENING

Target final hardness=100mg/L as $CaCO_3$
Lime purity=87%
Soda ash purity=97%
S.Gravity of dry solids=2.2
Raw water analysis

Ca^{2+}=180.0mg/L as $CaCO_3$
Mg^{2+}=25.0mg/L as $CaCO_3$
HCO^{3-}=Alk=170.0mg/L as $CaCO_3$
CO_2=5.0mg/L as $CaCO_3$

When Mg^{2+} ion concentration is less than 40 mg/L as $CaCO_3$, Lime dosage is calculated as follow,

Lime dosage (meq/L) = (CO2) + (AlK) + (Excess)
Cost of Lime/yr. = (Lime dosage*Flow Rate/%Purity)/ (Cost/Mass) = ($/year)
Soda Ash dosage=NCH
Since Mg2+<40 mg/L as CaCO3, addition of 20 mg/L as CaCO3 excess (0.4 meq/L)

Table 11. Softening Process Dosage and Cost.

		meq/L	kg/m^3	$/Year
Lime Dosage		3.9	0.11	3.96E+07
Cost of Lime/Year				
Soda Ash Dosage		0.7	0.04	1.21E+07
Cost of Lime/Year				
Total Chemical Cost				5.16E+07
		meq/L	mg/L as $CaCO_3$	
Final Hardness		0.6	30	

Final hardness is very low, use of split flow of raw water is recommended. This would save capital costs by using smaller tanks and operating costs by reducing chemical usage as well as the amount of sludge that has to be disposed.

The fractional amount of the split is calculated using equation 7-25 (Davis)

$$x = \frac{M_{g_f} - M_{g_i}}{M_{g_r} - M_{g_i}}$$

Where
M_{gf}=final magnesium concentration mg/L as $CaCO_3$= 40
M_{gi}=magnesium concentration from first stage mg/L as $CaCO_3$=10
M_{gr}=raw water magnesium concentration mg/L as $CaCO_3$=25

X=2:1

The daily sludge volume is calculated using equation

Volume of daily sludge=(Mass of solids/0.05)(2.2)

Where the mass of solid is equal to,

Mass of solids=Dry solids/Density of dry solids

Dry solids are the precipitates formed during the softening process, calcium carbonate and magnesium hydroxide. Since the magnesium ions presents are too low, and softening is not required, only the calcium carbonate becomes precipitate or sludge.

Lime Dose	0.11	kg/m^3
Soda Dose	0.04	kg/m^3
Annual Chemical Cost	5.16E+07	$/Year
Daily Sludge Volume	648	m^3/day

Daily volume of sludge produced assuming that it is collected as 5% solids. Calculations show

	meq/L	kg/m^3	kg	m^3/day
Solid $CaCO_3$(s)	7.5			
Dry Solids		0.375		
Mass of Solids			0.0001705	
Volume of Sludge per day				648

<u>Re-carbonization requirements</u>

LSI=pH-pHs

Assuming pH=10.5 at the end of softening process, and Ka=$3.05*10^{-11}$ at 10°C
pCa^{2+}=2.74
pAlk=2.47
TSS=375mg/L
Correction factor=2.5775 using interpolation (Davis, p7-35)

LSI=10.5-(2.74+2.47+2.58)=2.71

LSI > 0, then the solution is supersaturated and $CaCO_3$ will precipitate.
Calculating the carbonate concentration from second dissociation constant,

$[CO_3^{2-}]=0.0384[HCO_3^-]$
pCa^{2+} should be equal to 5.28 for LSI=0

$[CO_3^{2-}]$=0.00013 mol/L

Dose of CO_2 to convert carbonate to bicarbonate
Assuming CO_2= H_2CO_3, and that one mole of CO_2 produces 2 moles of HCO_3^-,

Dose of CO_2=11.453 mg/L

(VII) Desinfection

Use chlorine for primary disinfection, since the water treated is groundwater, and only viruses might be present.

Disinfectant	Chlorine	
Target Pathogen	Viruses	
Required Log Removal	2	
Treatment Credits	2	
Ct value at 10C and pH=7	3	
C (Chlorine Concentration)	1	mg/L
Superior baffling	0.7	(t_{10}/t_0)

Table 13. Disinfection Chamber information

t_{10}=	Ct/C=	3.00	min
t_0=	t10/0.7=	4.29	min

Volume=	$Q*t_0$=		257.14	m^3
Length=	40	(W)	51.57	m
Height=	3	(W)	3.87	m
Volume=	120	(W^3)		
Width=			1.29	m
Number of Tanks	2			

Two disinfection chamber will be implemented for redundancy, each chamber will have the dimension listed in Table 13. Each chamber will use superior baffling and the 51.57 m of length required will be accommodated along the serpentine tank.

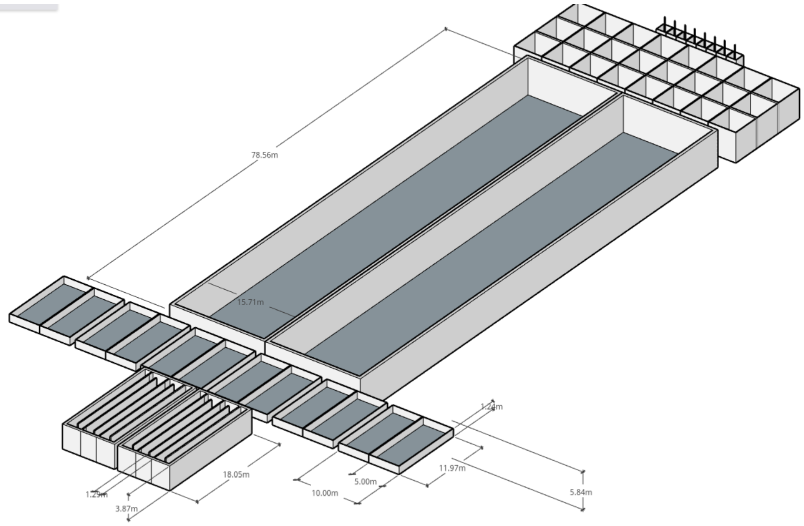


Figure 1.4 Conceptual Drawing of the Complete Treatment process.

Work Cited

- Davis, Mackenzie Leo. Water and Wastewater Engineering Design Principles and Practice. Indian Ed. New York: McGraw-Hill, 2010. Print.
- FE Reference Handbook, 9.3 Version for Computer-Based Testing. 2015, Third Printing.