RAPID MIX BASIN DESIGN

Executive Summary

The city of Gatorsville, Florida has decided to construct a surface water treatment plant that will remove arsenic from the groundwater and provide potable water to the city. The population of Gatorsville is 150,000 persons who require a maximum of 120 gallons/person/day of potable water. A rapid mix basin employing alum was designed to fit the city's needs. A type of impeller and corresponding motor were determined, as well as the amount of tanks necessary and their inner dimensions. Inflow and outflow pipes needed to process the required water were chosen and sized. Lastly, reinforced walls were designed to provide a sound structure for the tank to function accordingly. A cost estimate can be found in **Appendix E.**

The rapid mix basin employing alum was designed based on criteria laid out by the city as well as given design specifications. 1st order kinetics was to be assumed and a CSTR (Continuously Stirred Tank Reactor) was to be used. The final alum concentration was to be 80% of the original alum concentration. The city's water temperature to design for was 18°C. Design was also determined based on standard rapid mix basin design criteria;

- Velocity gradient, G, was made to be between 600-1000 s^{-1}
- Tank volumes were kept below $8m^3$
- Design liquid depth was between 1.1-1.6 times the basin width
- Impeller diameter was between 0.3-0.5 times the tank diameter width
- Baffles extended 10% of the tank width

The best design determined to fit the aforementioned criteria resulted in seven 5.70 m^3 rectangular prisms to function as the rapid mix basins. The width of each tank is 1.9 m, the lengths are 1.0 m and the depths are 3.0 m. All dimensions were explicitly determined to meet specifications. The sizes of the basins were determined based on a double bladed Model F 2.24 kW motor with an 80% efficiency rating. The impeller used was a fan turbine with six blades angled at 45°. Two baffles were designed to be placed in the interior of the tank, extending 0.095 meters from the tank wall on the walls of dimension 1.90 m. This equates to the baffles equalling 10% of the tank width. A schematic can be viewed in **Appendix D**.

Pipe type and dimensions were chosen and sized for inflow and outflow of each basin. The pipe material used was concrete with diameter of 0.40 m. Basins were designed to be placed 100 m from the groundwater collection area, equating to a head loss of 0.20 m on a slope of 0.002.

Concrete walls, floors and roofs were sized for adequate thickness and steel reinforcement. A design that was sufficient for all slabs was determined and resulted in a slab thickness of 0.25 m and six Grade 60 #3 bars of steel reinforcement at 30 cm on center for the roof and floor of the tank and 50 cm on center for the walls of the tank. 24 bars of reinforcement were therefore used per tank. A schematic of rebar placement can be found in **Appendix C**.

This design will supply Gatorsville with the 120 gallons/person/day that is required. Moreover, design choices made regarding the motor and impeller will provide for adequate chemical mixing to destabilize the arsenic that currently inhabits the groundwater. Water will remain in the mixing area due to placement of the two baffles.

INTRODUCTION

A. EXPLANATION OF UNIT OPERATIONS

The design process regarding dimensions and instrumentation utilized proceeded as follows;

- A detention time of 50 s was determined based on the given reaction rate of k=0.005 s^{-1} (1^{st} order kinetics) and the stipulation of the final alum concentration is 80% of the initial alum concentration.
- The corresponding velocity gradient, G, to the 50 s detention time was noted as 700 s^{-1}.
- A required volume was determined from the necessary flow rate of 120 gal/person/day for 150,000 people (0.80 m^3/s) as 40.0 m^3.
- Multiple rapid mix basins were deemed necessary to handle the determined volume. The volume capacity of the chosen Double Blade Model F motor (175 RPM, 2.24 kW) was determined to be 6.19 m^3, and subsequently was divided into the required 40.0 m^3 to find the number of tanks necessary. Seven tanks at 5.70 m^3 were deemed adequate. The velocity gradient was recalculated as 729.63 s^{-1}, which safely exceeded the preliminary calculated value of 700 s^{-1}.
- The impeller diameter was then determined based on usage of a 6 bladed fan turbine with blades angled at 45° and an impeller constant, K_T, of 1.65. The impeller diameter equals 0.923 m.
- As per specification, impeller diameter is to be 0.3-0.5 times the width of the basin. A value of 1.90 m was then chosen as the width of the basin.
- The length of the tank was chosen as 1 m and the corresponding depth to provide a volume of 5.70 m^3 was determined to be 3.00 m. The depth was checked to be between 1.1-1.6 times the width of the tank, as per normal design standards.
- Two baffles were chosen as a total 10% of the width, or 0.19 m, to extend 0.095 m into the tank on the two walls of the tank of width equal to 1.90 m.
- Necessary pipe type and dimensions were chosen and calculated by use of the Hazen-Williams equation as 0.40 m for concrete inflow and outflow pipes. Low head loss through the pipe was sought, so tanks are to be placed 100 m from the groundwater collection sight on a slope of 0.002 allowing for a total head loss of 0.10 m.
- Concrete slabs were designed using typical strength and stress equations found in the AASHTO/LRFD Design Manual. The tank walls, roofs, and floors are adequately supported by a slab thickness of 0.25 m.
- Steel Reinforcement was determined as six Grade 60 #3 bars on all slabs on the tanks. For the roofs and floors, bars were placed at 0.30 m on center. For the walls, bars were placed at 0.50 m on center.

Note: Extensive calculations for tank sizing/impeller determination, pipe sizing, and structural calculations can be found in **Appendices A**, **B** and **C**, respectively.

B. Explanation of Treatment Chemicals

The objective of the rapid mix basins that were designed is to employ alum and allow for effective coagulation of the harmful arsenic particles. The final alum concentration was designed to be 80% of the initial alum concentration, meaning the "lost" alum helped destabilize the negative charges of arsenic which will later allow for flocculation, or settling out, of the arsenic from the treated water[3].

Results*

80% Alum Retention, C_0/C_t		0.80	(given)
Reaction Rate, k	(s^{-1})	0.005	(given)
Detention Time, t	(s)	50.00	(determined)
Velocity Gradient, G	(s^{-1})	700.00	(determined)
Gatorsville Population	(person)	150,000	(given)
Flow Rate per person, Q	(gal/person*day)	120.00	(given)
Flow Rate, Q	(m^3/s)	0.80	(determined)
Water Temperature, T	(°C)	18.00	(given)
Dynamic Viscosity of H_2O, μ	(N*s/m^2)	0.001063	(determined)
Model "x" Impeller Efficiency	(%)	80.00	(given)

Table 1: Initial Design Stipulations (given and determined)

Model F Impeller Theoretical Power	(kW)	2.24
Model F Impeller RPM	(rpm)	175.00
Model F Impeller RPS	(rev/s)	2.92
Double Blade Model F Actual Power	(1.8*0.8*kW)	3.23
Impeller Volume Capacity, V_I	(m^3)	6.19
Fan Turbine Model (6 blades @ 45°) Impeller Constant, K_T		1.65
Impeller Diameter, d_I	(m)	0.923

Table 2: Double Blade Model F Impeller w/ Fan Turbine Design Results

Results* Continued

# Tanks to have V < 8m^3		7.00
Volume of each Tank, V_T	(m^3)	5.70
Impeller Diameter, d_I	(m)	0.923
Rectangular Tank Width, w	(m)	1.90
Rectangular Tank Length, l	(m)	1.00
Rectangular Tank Depth, h	(m)	3.00
Baffle Width, w_b	(m)	0.095
Concrete Slab Thickness	(m)	0.25
Grade60 #3 Bars (Walls)		6.00
Grade60 #3 Bars (Roof)		6.00
Grade60 #3 Bars (Floor)		6.00
Inflow/Outflow Pipe Size	(m)	0.40
Pipe Length from Groundwater Collection Area	(m)	100.00
Head Loss Through Pipe, hL	(m)	0.20
Pipe Slope, S		0.002

Table 3: Rectangular Tank and Concrete Pipe Requirements and Design Results

Design Standard Parameter	**Design Standard**	**Proposed Design Verification**
Velocity Gradient, G	$600^{s-1} \rightarrow 1000^{s-1}$	$700s^{-1}$
Tank Volumes, V_T	< 8.0 m^3	5.70 m^3
Liquid Depth/Tank Width	1.1→1.6	1.58
Impeller Diameter/Tank Width	0.3-0.5	0.486
Baffle Width	10% Tank Width	.095 m on each side

Table 4: Proposed Design Verification to Design Standards

*Cost Estimate tables and results can be viewed in **Appendix E**.

Discussion

The main objective of the designed rapid mix tank was to provide a functional atmosphere for coagulation to occur and destabilize the arsenic charges in the groundwater so the arsenic can be easily settled out when they proceed to the flocculation chamber[1,3]. This called for consideration of motor and impeller type, tank dimensions, pipe type and dimensions, and the supporting structure of the tank. The determined design was deemed to answer this objective while staying within standard design considerations.

The Model F Impeller, with a relatively high power of 2.24 kW compared to other models on the market, will utilize its' power (at a standard impeller efficiency of 80%) to rapidly mix the alum with the target negative charges. Futhermore, the double bladed design will increase the power capacity by 1.8, thus providing an even more powerful environment for rapid mixing that will serve to make the final alum concentration 80% of the initial alum concentration.

The fan turbine with six blades at 45° angles will harbor the power of the double bladed Model F impeller while providing for a multi-dimensional mix of particles because of the angled blades. The blade configuration provides for axial flow which imparts shear in the movement of flow[4]. This design will allow for more efficiency in the likelihood of the alum colliding with the negative particles.

Dimensionally, Model F Impellers provided for the largest tanks that would still meet design standards, making 7 tanks an optimal configuration for this design. Other impeller models would have produced more tanks of smaller volume *and* less power.

Necessary pipe sizes to maintain the maximum were determined by use of the Hazen-Williams formulation, which is the most common pipe flow formula[1]. Pipes were chosen as concrete as it's moderate roughness will provide for more interaction of particles.

Lastly, the tank needed to be supported by a sound structure that could withstand worst case scenario conditions. The common building material of reinforced concrete was chosen based on it's strength and availability.

All design choices were conservative, such as providing the citizens with the maximum (120 gal/person/day) flow rate, using the maximum RPM of the Model F Impeller, and designing the structure based on an entirely submerged tank.

CONCLUSION

The continuously stirred tank reactor designed for Gatorsville, Florida is as follows;

- 7 rectangular tanks @ 5.70 m^3 each to provide the necessary flow rate of 120 gal/person/day to the 150,000 persons. Tanks are 1.0 m in length, 1.90 m in width, and 3.00 m in depth to meet design criteria

- Double Bladed Model F Impeller Motor @175 RPM and 2.24kW with a volumetric capacity of 6.19 m^3. Impeller diameters are 0.923 m.

- A fan turbine impeller with 6 blades @ 45° and an impeller constant, K_T, of 1.65 guided the design of the tank dimensions discussed above.

- 0.40 m inflow and outflow concrete pipes. Incoming pipe from the groundwater collection area is 100 m from the basins, resulting in 0.10 m of head loss due to the 0.02 slope.

- 0.25 m thick concrete walls on all tank surfaces. Six GR60 #3 reinforcement steel bars per wall, roof and floor.

This design will provide the needed flow and needed final alum concentration sought.

REFERENCES

1. Hammer, Mark. Water and Wastewater Technology. Prentice-Hall. 5th Ed

2. Munson, Bruce R, Okiishi, Theodore H, and Young, Daniel F. Fundamentals of Fluid Mechanics. New York. John Wiley & Sons, Inc. 2002 4th Ed

3. http://en.wikipedia.org/wiki/Water_purification

4. http://www.mixingsolutions.com/mixing/turbine-impellers.html

APPENDICES

Appendix A: Calculations required for capacity, impeller motor and type, and design standard verifications

Appendix B: Pipe Size Calculations

Appendix C: Structure Design Calculations

Appendix D: Schematic of CSTR Rapid Mix Basin

Appendix E: Cost Estimate and Calculations

APPENDIX A: Calculations required for capacity, impeller motor and type, and design standard verifications.

Given Data

$T := 18 \cdot C$ (Temperature of Water) $k := .005 \cdot s^{-1}$ (Reaction Rate Constant)

$Pop := 150000$ (Gatorsville Population) $Consumption := 120 \frac{gal}{day}$ (Water Consumption/Person)

$Efficiency := .8$ (Mixer Efficiency) $DoubleBlade := 1.8$ (Power factor due to double blade)

$ModelFPower := 2.24kW$ (Mixer Power) $K_T := 1.65$ (Impeller Constant for Fan Turbine)

$C_0 := 1.00$ $C_T := 0.80$ (Final [Alum] is 80% of Initial [Alum]) $ModelFRPM := \frac{175}{60} \cdot s^{-1}$

$\rho := 1000 \frac{kg}{m^3}$ (Density of Water)

Dynamic Viscosity Determination [2]

At 20 C $\mu = 1.002*10^{-3}$ N*s/m2 At 10 C $\mu = 1.307*10^{-3}$ N*s/m2

$$\mu := 1.307 \cdot 10^{-3} N \cdot \frac{s}{m^2} + \frac{(18C - 10C)}{(20C - 10C)} \cdot \left(1.002 \cdot 10^{-3} - 1.307 \cdot 10^{-3}\right) N \cdot \frac{s}{m^2}$$

$$\mu = 1.063 \times 10^{-3} \frac{kg}{m\,s}$$

Flow Rate Conversion

$$Q := Pop \cdot (Consumption) \cdot \left(\frac{1day}{24hr}\right) \cdot \left(\frac{1hr}{60min}\right) \cdot \left(\frac{1ft^3}{7.48gal}\right) \cdot \left(\frac{1m^3}{35.3ft^3}\right)$$

$$Q = 0.789 \frac{m^3}{s}$$

Detention Time Determination

$t := \frac{1}{k} \cdot \left(\frac{C_0}{C_T} - 1\right)$ $t = 50s$ therefore $G := 700 \cdot s^{-1}$ (Velocity Gradient)

Volume Capacity Determination

$V_{Need} := t \cdot Q$ $V_{Need} = 39.45 m^3$ $V := 40.0m^3$

Double Bladed Model F Volume Capacity

$$V_{cap} := \left(\frac{DoubleBlade \cdot Efficiency \cdot ModelFPower}{G^2 \cdot \mu}\right) \qquad V_{cap} = 6.193\,m^3$$

Number of Tanks Required to Satisfy Needed Volume w/ Model F

$$Tanks := \frac{V}{V_{cap}} \qquad Tanks = 6.459$$ therefore $NumberTanks := 7$

Volume of Each Tank Determination

$$VolEach := \frac{V}{NumberTanks} \qquad VolEach = 5.714\,m^3$$ therefore $VolTank := 5.7 \cdot m^3$

Velocity Gradient Check

$$G_{new} := \sqrt{\frac{ModelFPower \cdot DoubleBlade \cdot Efficiency}{VolTank \cdot \mu}} \qquad G_{new} = 729.628\,Hz$$

*(G_{new} is greater thank G - **OK**)*

Impeller Diameter Determination

$$d_{impp} := \left(\frac{DoubleBlade \cdot Efficiency \cdot ModelFPower \cdot 1000 \frac{W}{kW}}{K_T \cdot ModelFRPM \cdot \rho}\right)^{\left(\frac{1}{5}\right)} \qquad d_{imp} := 0.923 \cdot m$$

Tank Width Determination

$$W_T := \frac{d_{imp}}{.4857589} \qquad W_T = 1.9\,m$$

*(The impeller diameter is between 0.3 - 0.5 times the tank width **OK**)*

Tank Depth Determination

$$D_T := \frac{VolTank}{(1 \cdot m) \cdot W_T} \qquad D_T = 3\,m$$

(Note that the length of the tank was chosen as 1.0 m)

$$\frac{D_T}{W_T} = 1.579$$

*(The design liquid depth is between 1.1 - 1.6 times the tank width **OK**)*

APPENDIX B- Pipe Size Determination

$$Q := 150000\cdot(120)\cdot\left(\frac{1}{24}\right)\cdot\left(\frac{1}{60}\right)$$

$Q = 1.25\times 10^{4}$	gal/min	(Flow rate for culmination of all 7 tanks)
$Q_T := \frac{Q}{7}$	gal/min	
$Q_T = 1.786\times 10^{3}$	gal/min	(Flow rate in each tank)
$S := 0.002$	ft/ft	(Typical value for pipe slope)
$C := 130$		(Hazen Williams Coefficient[1])
$D := \left(\frac{Q_T}{.281\cdot C\cdot S^{.54}}\right)^{\frac{1}{2.63}}$	inches	(Hazen Williams Equation)
$D = 15.719$	inches	
$D_{SI} := D\cdot\left(\frac{1}{12}\right)\cdot\left(\frac{1}{3.28048}\right)$	meters	
$D_{SI} = 0.399$	meters	

$PipeDiameter := .400\cdot m$

STRENGTH & CRACK CONTROL CHECK FOR REINFORCED CONCRETE SLAB DESIGN

This MathCAD work sheet provides the derivation of the fundamental equations for strength and stress checks of a rectangular concrete cross section IAW AASHTO Chapter 5

Assumptions:

- -Ignore tensile strength of masonry
- -Plane sections remain plane
- -Perfect bond
- -Stress-strain relationship for steel is elastic perfectly plastic
- -Section is assumed to be at nominal moment capacity when the compressive strain in the extreme fiber reaches 0.003
- -Use rectangular stress block for concrete stress-strain relationships

Notation:

a = depth of equivalent rectangular stress block (in)
A = area of concrete having the same centroid as the principal tensile reinforcement and bounded by the surfaces of the cross-sections and a straight line parallel to the neutral axis, divided by the number of bars or wires (in^2); the thickness of clear concrete cover used to calculate this value shall not be taken to be greater than 2.0 in.
A_b = area of an individual horizontal bar or wire (in^2)
A_s = area of nonprestressed tension reinforcement (in^2)
$A_{s,min}$ = minimum amount of flexural reinforcement (in^2)
$A_{s,max}$ = maximum amount of flexural reinforcement (in^2)
b = width of compression face of member (in)
b_w = width of compression face of member (in)
c = distance from extreme compression fiber to neutral axis (in)
d = distance from extreme compression fiber to centroid of tension reinforcement (in)
d_c = depth of concrete measured from extreme tension fiber to center of bar or wire located closest thereto; the thickness of clear cover used to compute this value shall not be taken to be greater than 2.0 in (in)
E_c = modulus of elasticity of concrete (psi)
E_s = modulus of elasticity of reinforcement (psi)
f'_c = specified compressive strength of concrete (psi)
f_c = calculated stress in the concrete extreme fiber at service loads (ksi)
f_s = calculated stress in reinforcement at service loads (ksi)
f_y = specified yield strength of nonprestressed reinforcement (psi)
I_{cr} = moment of inertia (in^4)
I_{ye} = effective moment of inertia (in^4)
I_g = moment of inertia of gross section (in^4)
jd = distance between internal resultant compressive and tensile forces (in)
kd = depth of compressive stress block (in)
h = overall thickness of member (in)
h_f = flange thickness (in)
Z = crack width parameter (kip/in)
ε_y = yield strain of the reinforcement
ε_s = strain in steel
ε_t = net tensile strain in extreme tension steel at nominal strength
ε_{cu} = compressive strain at crushing of concrete
'eduction factor

$$psi := \frac{lb}{in^2} \qquad kip := 1000lb \qquad ksi := \frac{kip}{in^2}$$

Input

Geometry

$A_s := .66268\cdot in^2$ $d := 9.34144in$ $b := 74.7949in$ $h := 9.84144in$ $d_c := .5\cdot in$ $A := 3.74in^2$

Materials

$f'_c := 4500psi$ $f_y := 60ksi$ $E_s := 29000ksi$ $E_c := 1820\cdot\sqrt{\frac{f'_c}{1000\cdot psi}}\cdot 1000\cdot psi$ $\varepsilon_{cu} := 0.003$

Moments

$M_u := 15.6562\cdot 12kip\cdot in$ $\phi := 0.9$ $M_s := 5.50\cdot 12kip\cdot in$

Crack Control

$Z := 130\frac{kip}{in}$

130 kip/in for Buried exposure
150 kip/in for Severe exposure
175 kip/in for Moderate exposure

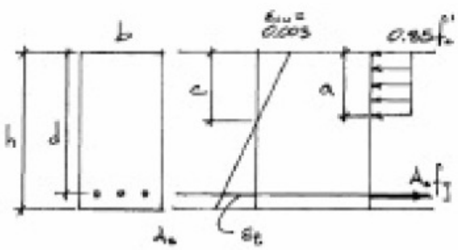
Derivation of Strength Equations

Nominal capacity is defined by the extreme compression fiber strain. Similar triangles gives the following equation for steel strain:

$\frac{\varepsilon_{cu}}{c} = \frac{\varepsilon}{d-c}$ $\varepsilon_t = \frac{d-c}{c}\cdot\varepsilon_{cu}$

Stress Block

$C = 0.85f'_c\cdot b\cdot a$ $a := \frac{A_s\cdot f_y}{0.85f'_c\cdot b}$



Relation between depth of equivalent stress block and depth of N.A. (AASHTO 5.7.2.2)

$$\beta_1 := \begin{cases} 0.85 & \text{if } f'_c < 4000\cdot psi \\ 0.65 & \text{if } f'_c > 8000\cdot psi \\ 0.85 - 0.05\cdot\frac{f'_c - 4000\cdot psi}{1000\cdot psi} & \text{otherwise} \end{cases} \qquad c := \frac{a}{\beta_1}$$

Check if under-reinforced

$$\varepsilon_s := \frac{d-c}{c}\cdot\varepsilon_{cu} \quad \varepsilon_y := \frac{f_y}{E_s} \quad \text{under\_reinforced} := \begin{cases} \text{"Over-Reinforced - analysis invalid"} & \text{if } \varepsilon_s < \varepsilon_y \\ \text{"Under-Reinforced - analysis valid"} & \text{otherwise} \end{cases}$$

Moment Capacity (AASHTO 5.7.3.2.2-1)

$$M_n := A_s\cdot f_y\cdot\left(d - \frac{a}{2}\right)$$

Minimum Reinforcement (AASHTO 5.7.3.3.2)

$$I_g := \frac{b\cdot h^3}{12} \quad f_r := 0.24\cdot\left(\sqrt{\frac{f'_c}{1000\cdot psi}}\cdot 1000\cdot psi\right) \quad M_{cr} := \frac{f_r\cdot I_g}{\frac{h}{2}} \quad M_r := \phi\cdot M_n$$

$$\text{Min\_Check} := \begin{array}{l} \text{return "Min. Reinf. Req. NOT Satisfied" if } M_r < 1.2M_{cr} \wedge M_r < 1.33\cdot M_u \\ \text{return "Min. Reinf. Req. Satisfied" otherwise} \end{array}$$

Maximum Reinforcement (AASHTO 5.7.3.3.1)

$c = 0.42d$ $\quad a = 0.42\cdot d\cdot \beta_1$ $\quad A_s\cdot f_y = 0.85f'_c\cdot b\cdot a$

$$A_{s\_max} := \frac{0.85f'_c\cdot b\cdot 0.42\cdot d\cdot \beta_1}{f_y} \qquad w_{beam} := b\cdot h\cdot\left(0.15\frac{kip}{ft^3}\right) \qquad A_{s\_max} = 0.107\,ft^2$$

Derivation of Working Stress Equations

Equilibrium *Constitutive laws* *Substitute*

$$C = 0.5\cdot k\cdot d\cdot b\cdot f_c \quad T = f_s\cdot A_s \quad f_c = \varepsilon_c\cdot E_c \quad f_s = \varepsilon_s\cdot E_s \quad 0.5\cdot k\cdot d\cdot b\cdot \varepsilon_c\cdot E_c = \varepsilon_s\cdot E_s\cdot A_s \quad \frac{\varepsilon_c}{\varepsilon_s}\cdot\frac{E_s}{E_c} = \frac{0.5k\cdot b\cdot d}{A_s}$$

Define Modular Ratio *Substitute*

$$n_{integer} \equiv 0 \qquad n := \begin{cases} \text{round}\left(\dfrac{E_s}{E_c}\right) & \text{if } n_{integer} > 0 \\ \dfrac{E_s}{E_c} & \text{otherwise} \end{cases} \qquad \frac{1-k}{k}\cdot n = \frac{0.5\cdot k\cdot b\cdot d}{A_s}$$

Define Reinforcing Ratio *Substitute* *Solve* *From geometry*

$$\rho := \frac{A_s}{b\cdot d} \qquad \frac{1-k}{k}\cdot n = \frac{.5k}{\rho} \qquad k := \left(-n\cdot\rho + \sqrt{n^2\cdot\rho^2 + 2\cdot n\cdot\rho}\right) \qquad j\cdot d = d - \frac{k\cdot d}{3} \qquad j := 1 - \frac{1}{3}\cdot k$$

Stress caused by service moment

$$f_c := \frac{2\cdot M_s}{j\cdot k\cdot b\cdot d^2} \qquad f_s := \frac{M_s}{j\cdot d\cdot A_s} \qquad \frac{\varepsilon_c}{k\cdot d} = \frac{\varepsilon_s}{d - k\cdot d} \qquad \frac{\varepsilon_c}{\varepsilon_s} = \frac{k}{1-k}$$

Crack Control (AASHTO 5.7.3.4)

$$f_{s1} := \frac{Z}{\left(d_c\cdot A\right)^{\frac{1}{3}}} \qquad f_{s2} := 0.6\cdot f_y \qquad f_{sa} := \min\left(f_{s1}, f_{s2}\right)$$

$$\text{Crk\_Check} := \left(\begin{cases} \text{"Satisfies Crack Control Requirements"} & \text{if } f_s < f_{sa} \\ \text{"Does Not Satisfy Crack Control"} & \text{otherwise} \end{cases}\right)$$

Moment of inertia

$$I_{cr} := \left[\frac{b\cdot(k\cdot d)^3}{3} + n\cdot A_s\cdot(d - k\cdot d)^2\right] \qquad I_{eff} := \left(\frac{M_{cr}}{M_s}\right)^3\cdot I_g + \left[1 - \left(\frac{M_{cr}}{M_s}\right)^3\right]\cdot I_{cr} \qquad I_e := \begin{cases} I_{eff} & \text{if } I_{eff} < I_g \\ I_g & \text{otherwise} \end{cases}$$

Summary of Results

Moment Capacity

under_reinforced = "Under-Reinforced - analysis valid"

$M_n = 3.072 \times 10^4\,\text{lb ft}$ $\beta_1 = 0.825$ $\phi \cdot M_n = 2.765 \times 10^4\,\text{lb ft}$ $a = 0.012\,\text{ft}$

$E_c = 5.56 \times 10^8\,\frac{\text{lb}}{\text{ft}^2}$ $c = 0.014\,\text{ft}$ $\varepsilon_s = 0.163$

Reinforcement limits

$A_{s\_max} = 0.107\,\text{ft}^2$ $\frac{c}{d} = 0.018$ Min_Check = "Min. Reinf. Req. Satisfied"

Cracking Moment

$f_r = 7.331 \times 10^4\,\frac{\text{lb}}{\text{ft}^2}$ $_{cr} = 5.122 \times 10^4\,\text{lb ft}$

Moments of Inertia

$I_{cr} = 0.018\,\text{ft}^4$ $I_g = 0.287\,\text{ft}^4$ $I_e = 0.287\,\text{ft}^4$

Maximum Stresses

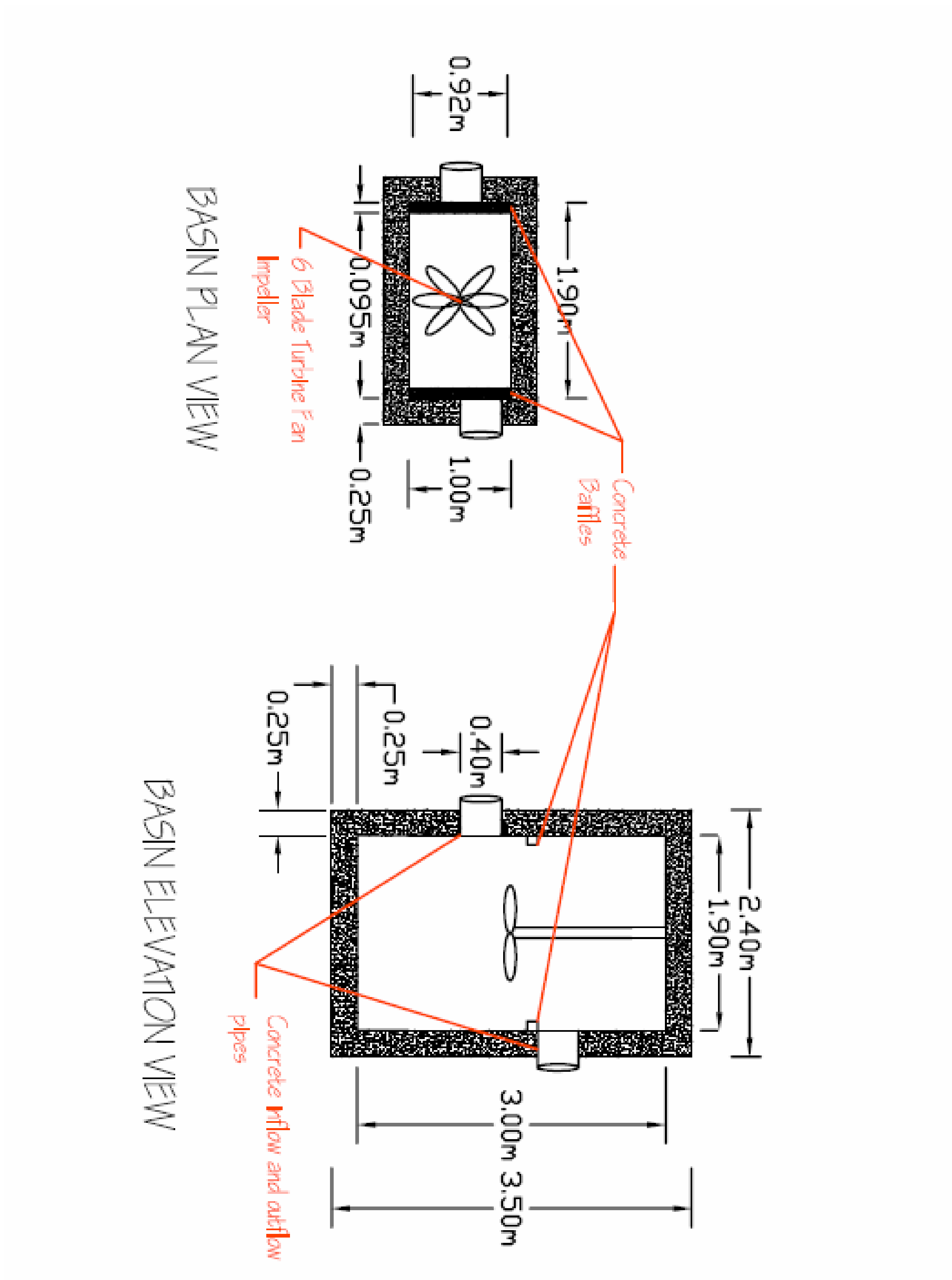
$f_c = 2.691 \times 10^4\,\frac{\text{lb}}{\text{ft}^2}$ $f_s = 1.595 \times 10^6\,\frac{\text{lb}}{\text{ft}^2}$ $k \cdot d = 0.088\,\text{ft}$

Stress Check for Crack Control

$f_{sa} = 5.184 \times 10^6\,\frac{\text{lb}}{\text{ft}^2}$ Crk_Check = "Satisfies Crack Control Requirements"

NOTE: ϕMn is greater than the maximum moment experienced by the floor slab, Mu. ϕMn is also greater than the hydrostatic force (Mu = 24.721 k-ft) experienced by the tank walls, *therefore the same reinforcement and thickness will be utitilzed for the wall design.*

SCHEMATIC OF REINFORCEMENT AND SLAB THICKNESS:

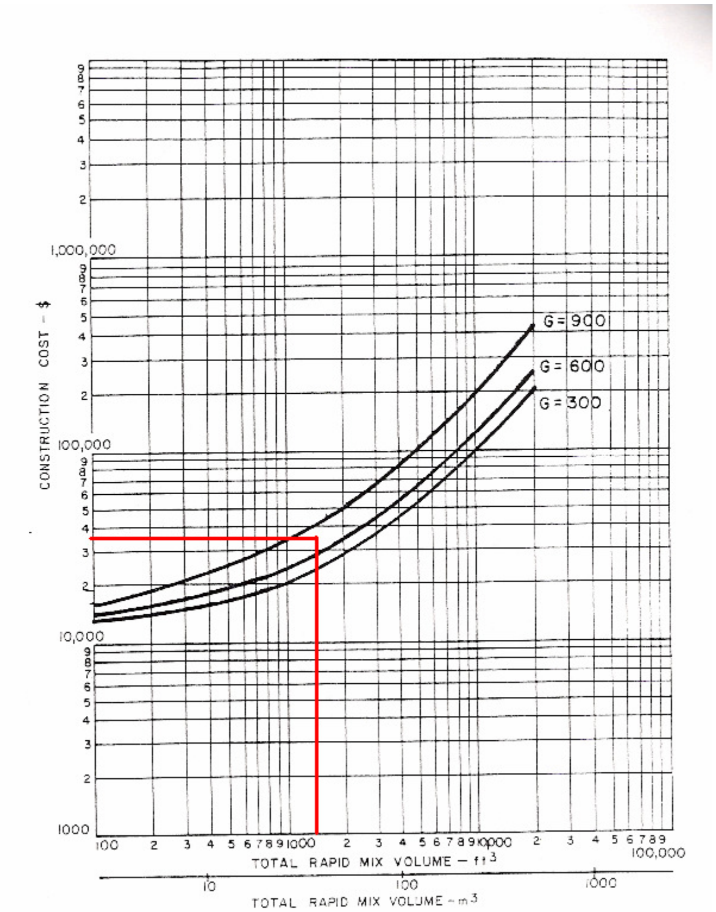

0.92m
1.90m
0.095m
0.25m
1.00m
6 Blade Turbine Fan Impeller
Concrete Baffles
BASIN PLAN VIEW
0.25m
0.25m
0.40m
2.40m
1.90m
3.00m
3.50m
Concrete Inflow and outflow pipes
BASIN ELEVATION VIEW

Cost of Construction and Cost of Maintenance

At G=700s^{-1} the chart below is interpolated with a total volume for 7 tanks:

V=7 * 5.2 m^3=1400 ft^3

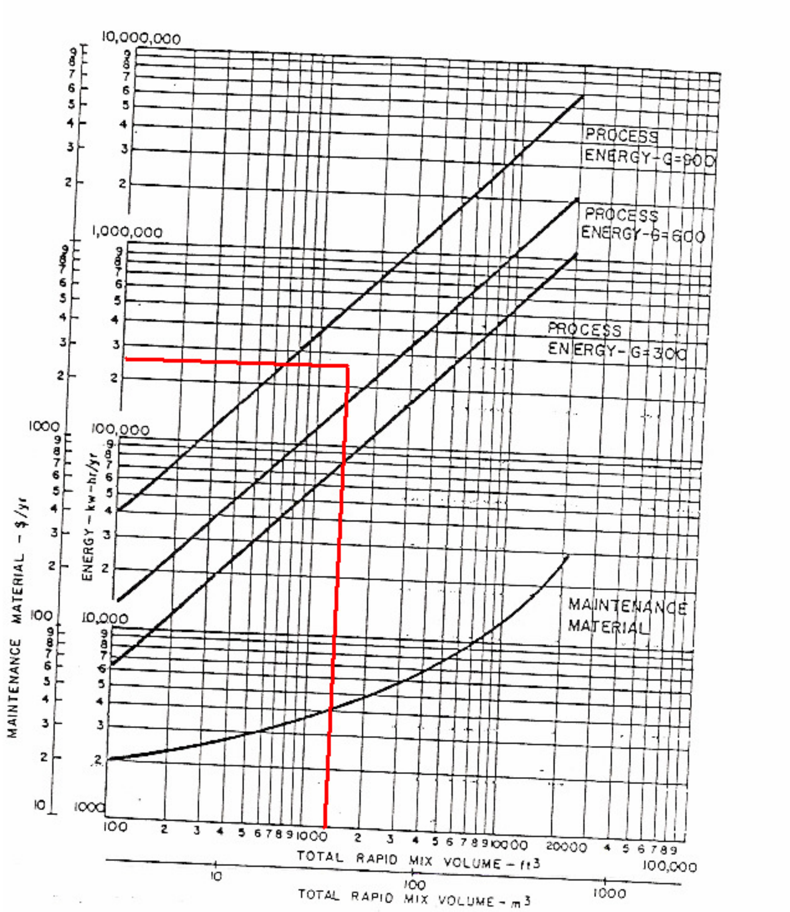
The cost is based on estimates made on charts created in 1978. This gives a construction cost of **$36,000.**



The same is repeated for the maintenance cost.

The energy requirement was estimated to be 260,000 kW-hrs/year. The total maintenance cost was estimated to be **$40 per year**.

APPENDIX E



Since the above cost values were determined from charts developed in 1978, the dollar amount was adjusted based on a conversion factor[5] of 3.10 to account for inflation. The cost of energy[6] per kWh was taken to be $0.10. This gives the final summary of costs adjusted with the appropriate factors:

Cost Type	**Cost**
Construction	$111,600
Energy	$26,000/year
Materials	$124/year

References:
5. US Dollar Inflation Conversion Factors
http://oregonstate.edu/Dept/pol_sci/fac/sahr/cv2003.pdf#search=%22inflation%20conversion%20dollar%22

6. Energy Costs in Florida
http://www.progress-energy.com/aboutenergy/rates/fla_res_rateinsert.pdf#search=%22cost%20of%20energy%20kwh%20florida%22