Flocculation

Lecture No. 5

1. Purpose

- Flocculation is the gentle mixing phase that follows the rapid dispersion of coagulant by the flash mixing unit.
- The purpose of flocculation is to accelerate the pace at which the particles collide, causing the agglomeration of electrolytically destabilized particles into setteable and filterable sizes
- The aggregation of particulate matter is a 2-step process
    - The coagulant is added and reduces the interparticle forces; this is coagulation.
    - The particles then collide and enmesh into larger particles, floc; this is flocculation.

2. Considerations

- Raw Water Quality and Flocculation Characteristics. Flocculation characteristics can be evaluated by a jar test. Repeatability of the results must be demonstrated. F3.2.4-1. P.106. The residual turbidity is directly proportional to alum dosage, but not always. Note the effects of alum on kaolinite, topsoil and diatomaceous earth. The initial reaction is a decrease in turbidity, but if too much alum is added, the turbidity increases.
- Finished Water Quality Goals. Less than .5TU.
- Example:

    Given: A bentonite soil.
    Find: What dosage of alum is effective and what is the resulting turbidity.
    From F3.2.4-1, p.106
    An **alum dosage of 45 mg/l** appears effective. Lesser dosage give markedly poorer results; increased dosages do not markedly effect the turbidity removal
    The **residual turbidity at an alum dosage is about 5 NTUs**.

3. Type and Selection Guide

- Flocculation can be provided by either mechanical mixers or baffles
- F3.2.4-3, p. 111 show the most common types of units. The mixing system include:

Mechanical Mixing.

- Vertical shaft with turbine or propeller type blades
- Paddle type with either horizontal or vertical shafts
- Proprietary units such as Walking Beam

Baffled Channel Basins.

- Horizontally baffled channels
- Vertically baffled channels

Others including: Reactor Clarifier Proprietary Systems, Contact Flocculation and Diffused Air Agitation

- Selection Criteria: Selection of the flocculation process should be based on the following criteria:
  - treatment process: conventional, direct, softening or sludge conditioning
  - raw water: turbidity, color, TDS
  - Flocculation characteristics in response to mixing characteristics. For example: if the floc is hard, more rigorous mixing intensity can be applied.
- The order of preference is:
  - vertical shaft flocculators in properly compartmentalized, horizontal tanks.
  - paddle flocculators in properly compartmentalized, horizontal tanks.
  - baffled channel flocculation for constant flow rate plants

4. Discussion of Alternatives

- Mechanical Mixing System. The mixer should have the following characteristics:
  - Must delivered the required G value which may vary by compartment.
  - The shear must be low at the edge of the blades.
  - Low maintenance and operation.

Regardless of the type of flocculator, tapered mixing across the tank is important. The initial mixing is rigorous, but as the floc grows in size, a more gentle, less disruptive regime is in order.

Vertical shaft flocculators are usually the first choice for the following reasons:

- minimal maintenance
- operational flexibility
- very little head loss across the tank
- easy control of mixing intensity

- Baffled Channel System. Requires a moderate head loss across the tank. Suitable for developing countries that may not be able to afford a mechanical system.

5. Design Criteria(T 3.2.4-2, p.121)

- The general design criteria for a basic rectangular flocculation tank are as follows:

Energy input: Gt=10,000 to 100,000, t $=5x10^{4}$ s average, G=30 s^{-1} average, 10-70 range
DT: 20-30 minutes at Qmax.
Depth: 10-15’
Stages: 3-4 common, 2-6 range

- Among the first considerations are the selection of the mode of mixing and the physical relationship between the flocculators and clarifiers. Subsequent decisions include: the number of tanks, number of mixing stages and their energy level and baffling type

- Design usually based on:
  - DT
  - mixing energy level
- The energy level is the G value or velocity gradient as defined by Camp:

$$G = \left[\frac{P}{\mu V}\right]^{.5}, \text{ units p.117}$$

Given: P= 850J/s, and the space influenced by the flocculator 4x6x6m. The temperature is 15°C.
Find:
1.)G
2.)What size motor is 850J/s, assume e=70%

1.) G
From App.6, p.632 @15°C, $\mu=1.17\text{x}10^{-3}$ $N.s/m^2$, N=Newton = $kg.m/s^2$, the units of μ are kg/m.s
V = 4x6x6m
$V = 144m^3$
$$G = \left[\frac{P}{\mu V}\right]^{.5} = \left[\frac{850J/s}{1.17\text{x}10^{-3}kg/m.s \text{ x } 144m^3}\right]^{.5}$$
$G = 71s^{-1}$

2.)How many hp is 850J/s
1kW=1000J/s
850J/s x (1kW / 1000J/s) = .85kw
1hp = .746kw
.85kw x (1hp/.746kW) = 1.14hp
Motor size = 1.14/e = 1.14/.7
Motor size = 1.63hp

The velocity gradient indicates the contacts that are being made. The gradients are produced by hydraulic or mechanical mixing.

- The number of particle contacts is:

$$N = n_1 n_2 (G/6)(d_1 + d_2)^3 \text{ units p.117}$$

N is the number of contacts between n_1 and n_2 particles. Therefore, the rate of flocculation increases with the number and size of the particles and with the power input but decreases with the viscosity of the fluid.

- The mean velocity gradient for baffled systems is:

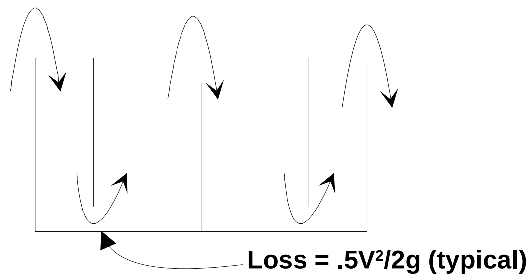
$$G = \left(\frac{gh}{\nu t}\right)^{.5} = \left(\frac{\delta h}{\mu t}\right)^{.5}, \text{ units p.117}$$

in which δ is the specific weight, $62.4lb/ft^3$ and
μ=absolute viscosity, $2.73\text{x}10^{-5}$ $lb.s/ft^2$ @50°F

The gradient increases with the head loss across the tank and decrease when the viscosity and time increase. In plane English, the more turns and curves the more the mixing; the thicker the liquid and the longer it takes, the less the mixing.

Example:

Given: Rectangular basin, L=W=4', D=4.5', Q=8.7MGD, Water @50°F, μ=absolute viscosity, $2.73\text{x}10^{-5}$ $lb.s/ft^2$



Find: G
t=V̶/Q=4’ x 4’ x 4.5’ / 8.7MGDx1.547cfs/MGD = 72/13.46
t= 5.35s
h total = no of baffles x loss per baffle
v=Q/A = 13.46/(4x1) Note the entire distance is 4’, but there are 4 compartments, therefore each compartment is 4/4=1’wide.
v=3.37fps
h = head loss per baffle, see graphic $=.5v^2/2g = .5(3.37)^2/(2x32.2)$
h = head loss per baffle = .0882ft
head total = 3 baffles x .0882ft
head total = .264ft

$$G = \left(\frac{\delta h}{\mu t}\right)^{.5} = \left(\frac{62.4 \text{ x } .264}{2.73\text{x}10^{-5} \text{ lb.s/ft}^2 \text{ x } 5.35\text{st}}\right)^{.5}$$

G = 336.3 fps/ft

- For mechanical systems with paddles:

$$G = (C_D A v^3/2\nu V̶)^{.5} \text{ units p.117}$$

C_D is a shape factor, use 1.8 (p.117). A is the cross sectional area of the paddles. G is increases as the area of the paddle increases, the velocity of the paddle increase and G decreases and the fluid gets thicker or the volume of the tank increases. A very important consideration is that v, the relative velocity of the paddle with respect to the fluid is from .5-.75 of the peripheral velocity of the paddle.

Given: If $G = (C_D A v^3/2\nu V̶)^{.5}$ and $G = \left[\frac{P}{\mu V̶}\right]^{.5}$
Find: A power equation
$(C_D A v^3/2\nu V̶)^{.5} = \left[\frac{P}{\mu V̶}\right]^{.5}$ square both sides
$P = \mu V̶ \text{ x } C_D A v^3/2\nu V̶$, $\mu\nu=\rho$
$\mathbf{P = C_D A \rho v^3/2}$
Given: The outside blade of a paddle wheel is rotating at 4rpm. The distance from the center of the shaft to the outside of the paddle element (a piece of wood, perhaps a 6”x10’) is 7’.
Find:
1.) What is the peripheral speed of the outside blade
2.) Estimate the blade velocity relative to the water.

1.) What is the peripheral speed of the outside blade
v = rps x πD/revolution = 4rev/min x 1min/60s x π(7ftx2), 7’ is a radius
v = 2.93fps

2.) Estimate the blade velocity relative to the water.
v, the relative velocity of the paddle with respect to the fluid is from .5-.75 of the peripheral velocity of the paddle.
v'= 2.93fps x .5
v' = 1.47fps
v'= 2.93fps x .75
v' = 2.20fps, use .75 unless otherwise stated

- The number of stages used in design is determined by:
    - Type of subsequent treatment unit.
    - Raw water.
    - Short circuiting and types of baffles
    - Local conditions
- Vertical Shaft Flocculators. D/T>35, where D is the diameter of the blade and T is the tank diameter. The maximum flow induced by the mixing blade should be less than 8fps in the first stage and less than 2fps in the last stage. When properly produced, the floc should have the characteristics and appearance of snow flakes.
- Horizontal Shaft Flocculators. The advantage of the horizontal shaft is that one shaft can operate a number of agitators and thereby reduce the number of drive units but if a drive fails, more agitators will be put out of business. Basic design criteria include:

- The total paddle area should be 10-25% of the tank cross-sectional area. If the paddles are too big, they will rotate the water causing a reduction in eddies and turbulence.
- Each arm should have a minimum of 3 paddles, so that dead space especially near the shaft will be eliminated.
- The peripheral speed of the paddles should be between .5 and 3.3fps.
- The G value should be $50s^{-1}$ and then be reduced to 10 or $5s^{-1}$ in the last stage

- Baffled Walls. Each baffle should have orifices that 4-6 inches in diameter uniformly distributed across the vertical surface and a velocity of 1.2-1.8 fps should be produced in each hole at maximum flow. The baffle is placed perpendicular to the flow. The top of the baffle is slightly submerged, 1/2 inch, to allow scum to flow over the top. The orifice formula is $Q=CA(2gh)^{.5}$, C=.8, see p.118.

Given: The total orifice area available is $20ft^2$. Q=50MGD
Find:
1.) total number of orifices
2.) orifice velocity
3.) headloss through the orifice

1.) total number of orifices
4-6" in diameter, use 5"

$A = \frac{\pi}{4}D^2 = .785 \times (5/12)^2$

$A = .136ft^2$

number or orifices = total area/orifice area = $20ft^2$ / $.136ft^2$/orifice
number or orifices = 147 orifices

2.) orifice velocity
v=Q/A = 50MGD x 1.547cfs/MGD / $20ft^2$

v=3.87 fps, Note: this is too high, should be from 1.2-1.8fps

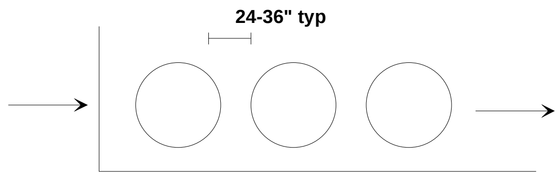
3.) headloss through the orifice
$Q=CA(2gh)^{.5}$
$50MGD \times 1.547cfs/MGD = .8 \times .136ft^2 (2 \times 32.2 \times h)^{.5}$
$4.84 = (64.4h)^{.5}$
23.39 = 64.4h
h = .36ft

6. Operation and Maintenance

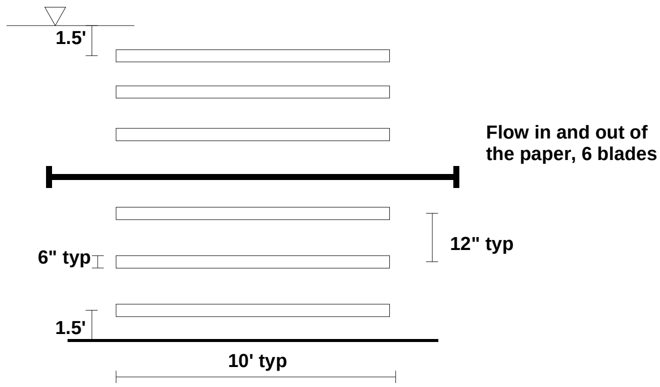
- Three basic operational procedures:
  - check the size of the floc
  - removal of the scum from the water surface
  - algae control

7. Example

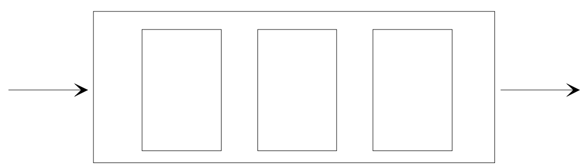
Given: A flocculation basin. Q=12MGD, horizontal shaft, paddle wheel. The mean $G=25s^{-1}$ @ 50°F. t=45min. The Gt must be between 50,000-100,000. Use 3 stages of equal depth in which the G's decrease: 45,20,10. L=.5W, L=3H. The paddles are to be made of redwood, 10'x6". The outside blade is to be 1.5' from the floor of the tank as well as from the top of the water surface. Use 6 blades/wheel and maintain a clear spacing of 12" between blades. Adjacent wheels are to maintain a clear spacing of 24-36" between blades. The wall clearance is to be between 12-18". C_D=1.50 for the paddles. Use the power equations $P=.97C_DAv^3$ and $P=\mu \forall G^2$.



Profile



Section



Plan

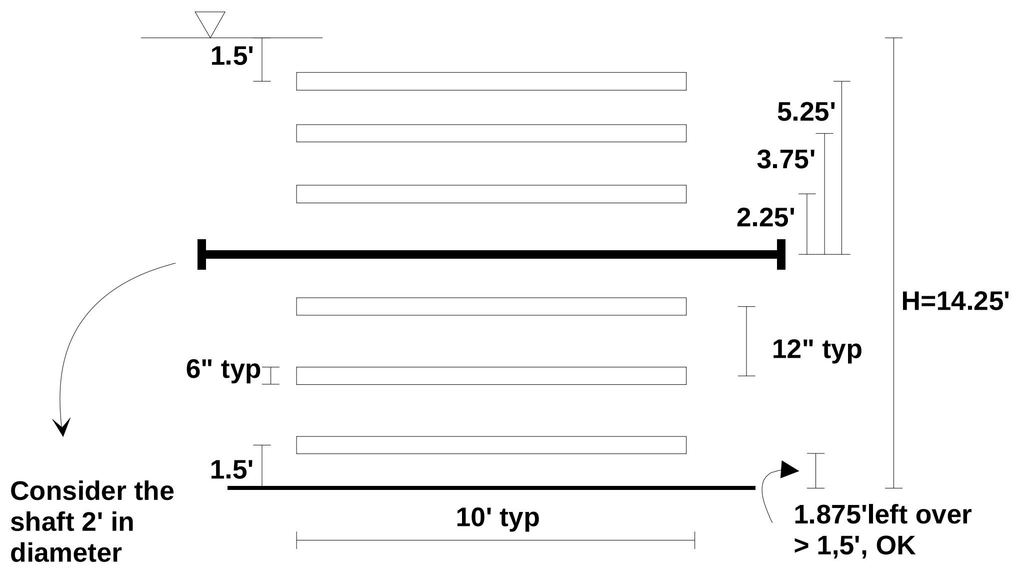
Find:
1.) Basin dimensions
2.) Design the paddle wheel
3.) Calculate the P for each compartment and the rotational speed of the paddles, provide for a 1:4 turndown.

1.) Basin dimensions
~~V~~ = Qt = 12MGD x 45 minutes x 1.547cfs/MGD x 60s/minute
~~V~~ = 50,122.8ft^3
L=.5W, L=3H, W=2L=6H
~~V~~ = WLH = 3H x 6H x H
~~V~~ = $18H^3$
$18H^3$ = 50,122.8ft^3
H = 14.07’ use 14’-3”
W = 6H = 6(14.07)
W = 84.4’ use 85’-0”
L = 3H = 3(14’-3”)
L = 42’-9”
new ~~V~~ = WLH = (14.25)(85.0)(42.75)
~~V~~ = 51,780.9 ft^3
H = 14’-3”
W = 85’-0”
L = 42’-9”

2.)Paddle wheel

Calculate the numbers of individual 10’ wheels across the 85’ width.
Since the blades are 10’x6”, the width is 10’. The width of the tank is 85’, 85/10≈8 wheels, but there are clearances involved, so try 7 wheels.
Let the clear space between the wheels be s, s/2 at the walls, therefore, let s=clearance.
7s + 7(10) = 85
s = 2.14’ which is between 24-36”, so 7 wheels is OK.

Check maximum blade area;
Max blade area = 20% x cross-sectional area = .20HW = .20(85)(14.25)
Max blade area = 242.25ft^2
Calculate actual blade area
Try 6 blades per wheel, given but typical.
A = wheels/tank width x blades/wheel x blade area
A = 7 wheels x 6 blades/wheel x (6”/12 x 10’)
A = 210ft^2 < Max blade area = 242.25ft^2 ∴ OK



Starting from shaft at the center and working down
1'(shaft) + 1'(clearance) +6/12 /2(1/2board) = 2.25'
2.25' + 6/12 /2(1/2 board) + 1' (clearance) +6/12 /2 =3.75'
3.75 +6/12 /2(1/2 board) + 1' (clearance) +6/12 /2 =5.25'

3.) P, power

$t = \forall/Q = 51{,}780.9ft^3/12\times10^6 gpd \times \frac{7.48\ gal}{ft^3} \times 1440$ minutes/day

t = 46.48 minutes
Gt = 25s^{-1} x 46.48 minutes x 60s/minute
Gt = 69,720 between 50,000-100,000 ∴ OK

velocity of the water,v = 75% of the maximum peripheral velocity
The distance traveled is πD or 2πr per revolution, rev/s x πD/rev = πD/sec
v = .75 x 2πr x R(revolutions per second)
v_1(first compartment) = .75 x 2π(5.25’) x R
v_1(first compartment) = 24.74R
v_2(second compartment) = .75 x 2π(3.75) x R
v_2(second compartment) = 17.67R
v_3(third compartment) = .75 x 2π(2.25’) x R
v_3(third compartment) = 10.60R

$P=.97C_DAv^3 =.97C_DA_1v_1^3 +.97C_DA_2v_2^3 + .97C_DA_3v_3^3 = .97C_DA(v_1^3 + v_2^3 + v_3^3)$, $A_1=A_2=A_3$
P = .97(1.50)(.5'x10'board dim.)(2 boards,1up,1down)$[24.74^3+17.67^3+10.61^3]R^3$
$P=317{,}976R^3$

first compartment
$P=\mu ¥G^2$ = μ= 2.73x10^{-5} lb.s/ft^2 x 51,780.9 ft^3 /3(3 compartments)x 45^2
P=950.7 ft.lb/s x 1hp/550ft.lb/s
P_1=1.73hp
950.7 ft.lb/s / 7wheels = $317{,}976R^3$
R = .075 rps
RPM(max) = .075 rps x 60s/min
RPM(max) = 4.50rpm
RPM(min @ 1:4 turndown) = 4.50rpm/4
RPM(min @ 1:4 turndown) = 1.13rpm

Peripheral speed of outside blade
v = circumference x RPM
v_1 (actual v as opposed to 75%) = R x 2πr
v_1 = .075 x 2π(5.25)
v_1 = 2.47fps

second compartment
$P=\mu ¥G^2$ = μ= 2.73x10^{-5} lb.s/ft^2 x 51,780.9 ft^3 /3(3 compartments)x 20^2
P=187.8 ft.lb/s x 1hp/550ft.lb/s
P_2=.34hp
187.8 ft.lb/s / 7wheels = $317{,}976R^3$
R = .044 rps
RPM(max) = .044 rps x 60s/min
RPM(max) = 2.64rpm
RPM(min @ 1:4 turndown) = 2.64rpm/4
RPM(min @ 1:4 turndown) = .66rpm

third compartment
$P=\mu ¥G^2$ = μ= 2.73x10^{-5} lb.s/ft^2 x 51,780.9 ft^3 /3(3 compartments)x 10^2
P=46.95 ft.lb/s x 1hp/550ft.lb/s
P_3=.085 hp
46.95 ft.lb/s / 7wheels = $317{,}976R^3$
R = .0276 rps
RPM(max) = .0276 rps x 60s/min
RPM(max) = 1.66 rpm
RPM(min @ 1:4 turndown) = 1.66 rpm/4
RPM(min @ 1:4 turndown) = .42 rpm

Go over example problems in book, p.123

HOMEWORK No. 5, Flocculation
Read Chapter 3 pp. 104-139
Problems:

5A. Given: Diatomaceous earth
Find: What dosage of alum is effective and what is the resulting turbidity.

5B. Given: The power delivered by a tank is 1.5hp, $G=35s^{-1}$, T=30°C.
Find: What are the required tank dimensions if L=W and the depth =15', 1hp=550ft.lb/s

5C. Given: See F.3.2.4-10. The boards are 6"x10's except the diagonals which are 11'long and the vertical members which are 7' long. The channel x-section is 11' wide by 12' deep.
Find: The total paddle area should be 10-25% of the tank cross-sectional area.
Has the criterion been met?

5D. Given: A baffled tank. $G=60s^{-1}$, the kinematic viscosity,ν, is $.898x10^{-6}$ m^2/s, 25°C. and $Q=3m^3/s$. There are 30 turns. The head loss at the turn is $h=Kv^2/2g$, where K=1.5, p.125. t=10min
Find:
1.) total head loss
2.) The velocity at each turn, slit.

5E. Given: A cross-flow, horizontal shaft, paddle-wheel flocculation basis is to be designed for a flow of 25,000 m^3/day with a mean G of $30s^{-1}$ @ 10°C(μ=1.307 centipoise, 1centipoise=$10^{-3}N\text{-}s^2/kg\text{-}m$) and a t=50 minutes. Assume L=3W and W=D. The Gt should be between 50,000-100,00. Tapered flocculation is to be provided and three compartments of equal depth in series are to be used. The G values determined from laboratory tests are: $G_1=50s^{-1}$, $G_2=25s^{-1}$ and $G_3=15s^{-1}$. These give an average of $30s^{-1}$. The compartments are to be separated by slotted, redwood baffle fences and the floor of the basin is level. The basin should be 15m in width to adjoin the settling basin. The speed of the blades relative to the water is 3/4 of the peripheral blade speed. Assume 6 pieces of wood per paddle, 3 up, 3 down: $D_1=1.70m$, $D_2=2.60m$, $D_3=3.50m$, four assemblies (groups of 6 pieced of wood) per shaft. Each piece of wood is 15cm wide and 3m long. Use the power equations: $P=C_D A\rho v^3/2$ and $P=\mu \forall G^2$, in which $C_D=1.50$, $\rho=999.7kg/m^3$.
Find:
1.) Gt and $\forall$
2.) Basin dimensions
3.) Design the paddle wheels
4.) P in each compartment
5.) Rotational speed of each horizontal shaft in rpm
6.) The peripheral speed of the outside paddle blades in m/s

5F. Given: Design the flocculators for your project.