ENVE 301
Environmental Engineering Unit Operations

CHAPTER: 9

Design of

Rapid mixing (Coagulation)

Slow mixing (Flocculation)

Units

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DESIGN OF RAPID MIXING (COAGULATION) UNITS

Rapid mixing unit : provide complete mixing of the coagulant and raw water.

Destabilization of colloidal particle
Early stages of floc formation
} occur in rapid mixing unit

→ Hydraulic mixing units (see Chp.6)

→ Mechanically mixing units (see Chp.6)

Design Criteria:

G for rapid mix → 700-1000 sec^{-1}

t (detention time) for rapid mixing → 20-60 sec

→ may be single compartment or double compartment

→ Single compartment basins are usually circular or square in plan view

Liquid depth = 1-1,25 x (basin diameter or width) (See Chp.6)

→ Small baffles are desirable to minimize vortexing.(See Chp.6)

DESIGN OF SLOW MIXING (FLOCCULATION) UNITS

Destabilized colloids resulting from coagulation may still settle very slowly

Flocculation is a slow mixing process in which these particles are bought into contact in order to promote their agglomeration.

The objective of flocculation is to provide increase in the number of contacts between coagulated particles by **gentle and prolonged agitation**

Devices used to accomplish mixing required for flocculation $\rightarrow$

- mechanically driven paddles
- baffled channels

Design Criteria :

$$Gt \rightarrow 10 \quad - 10^5$$

$$G \rightarrow 10 - 75 \text{ sec}^{-1} \quad (\text{light / dense floc})$$

$$t = 10 - 30 \text{ min (contact opputinity in the basin)} \quad (\text{small / large floc})$$

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$$t = 10 - 30 \min \ (\text{contact opputinity in the basin}) \quad (\text{small} / \text{large floc})$$

If G is too great → shear forces will prevent the formation of large floc

If G is insufficient → adequate collision will not occur
proper floc will not formed

High G_t → large # of collisions

In the design of flocculation systems; the total number of particle collision is indicated as a function of the product of the velocity gradient and detention time(Gt)

Mixing in an individual flocculator basin → hydraulic flow regime approaching complete mix condition.

Plug-flow conditions are desirable to minimize **short-circuiting** of the flow

Short circuiting → a portion of the incoming flow traverses the chamber in a much shorter time than the nominal detention period

two or more basins in series (TAPERED FLOCCULATION)

promote plug flow through the system (ensure that all particles are exposed to mixing for a significant amount of the total detention time

allows the G value to be decreased from one compartment to next as the average floc size increases.

Tapered Floculation

Flow is subjected to decreasing G values as it passes through the flocculation basin

rapid build up of small dense floc which subsequently aggregates at lower G values into larger , dense, rapid settling floc particles.

High G at the inlet → max. mixing to enhance aggregation — Small, dense flocs

Low G at the outlet→promotes larger flocs by reducing mixing and sheer. — Small dense flocs combine into larger flocs.

Large G , low t → small but dense flocs

Low G , high t → larger but lighter flocs

Good floc :Large and dense

Tapered flocculation:

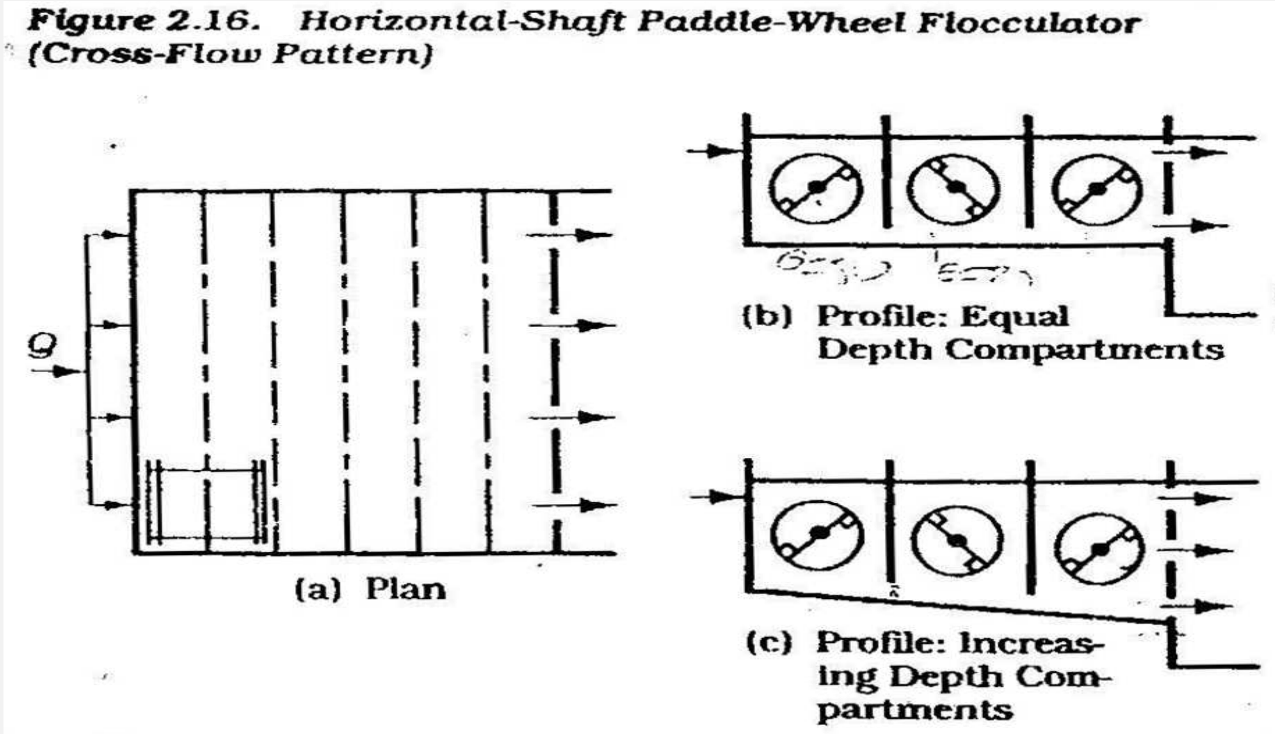
Typical series of G → 80, 40, 20 sec^{-1}

For mechanical mixing flocculators→ Variable speed motors should be provided to change the power input as required with changes in

- Temperature
- Q
- Water quality

The compartments are often separated with a baffle.

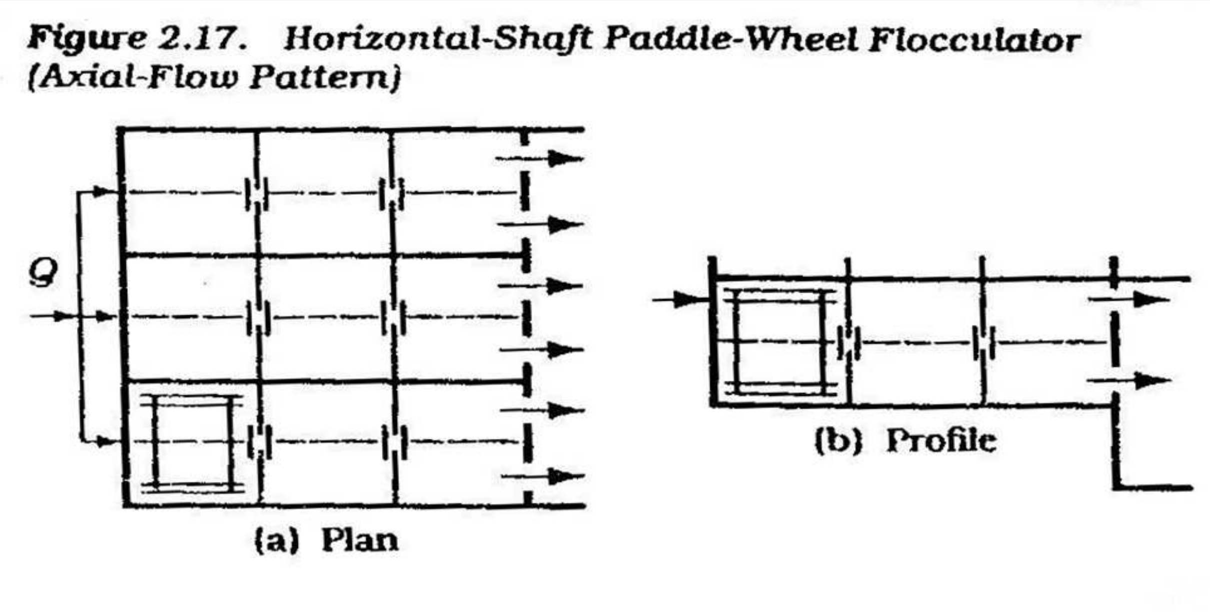
CROSS-FLOW PATTERN (blades are perpendicular to flow)



Tapered flocculation may be provided by varying

- → the paddle size
- → the number of paddles
- → diameter of the paddle wheels on the various horizontal shafts
- → the rotational speed of the various horizontal shafts

AXIAL FLOW PATTERN(Blades are parallel to flow)



Tapered flocculation may be obtained by varying

→ the paddle size
→ number of paddles

on each paddle wheel having a common horizontal shaft.

EXAMPLE (Paddle wheel flocculator design)

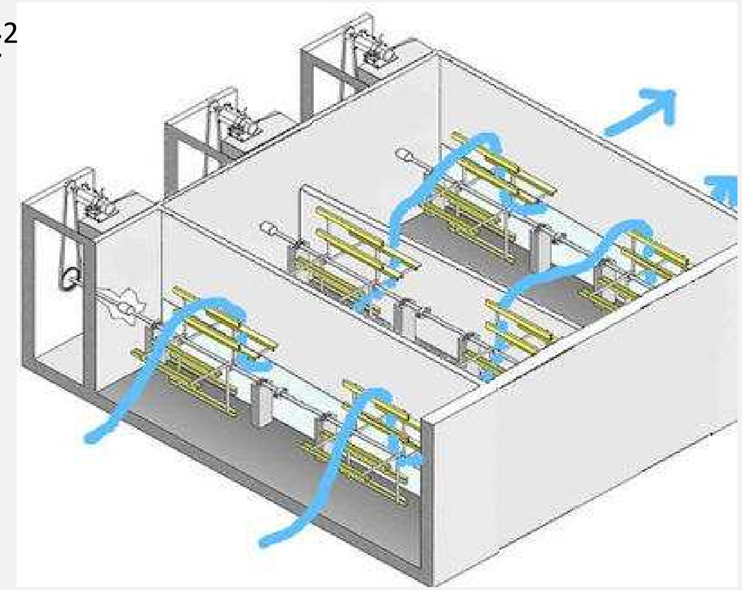
A cross flow horizontal shaft, paddle wheel tapered flocculation basin with 3 compartments square in profile having equal depths are to be designed for a flow of 6.5 MGD. Each horizontal shaft will have 4 paddle wheels and each paddle will have 6 blades each having a width of 6 inch and length of 10 ft. 12in space will be left between each blade.

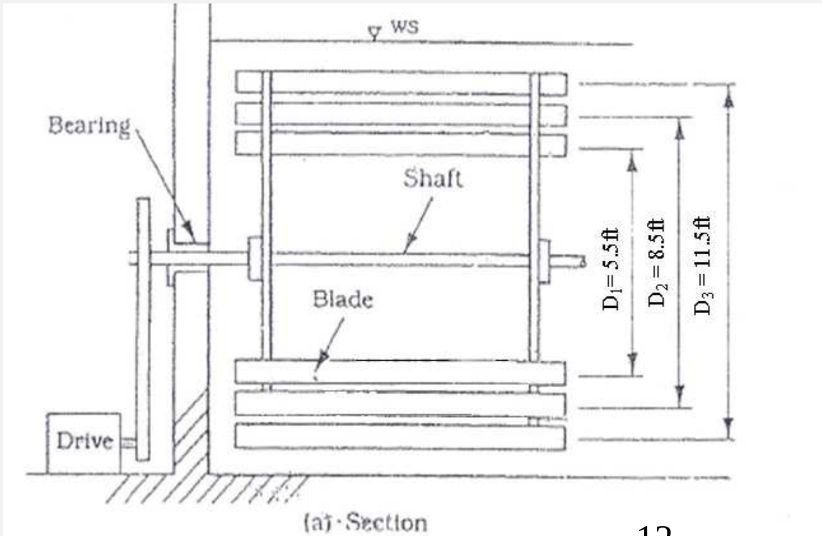
Detention time is 50 min. The G values determined from lab. tests for 3 compartments are; G_1=50 sec^{-1}, G_2=25 sec^{-1}, G_3=15 sec^{-1}. These give an average G value of 30 sec^{-1}. The compartments are to be separated by baffle fences. The basin should be 50ft in width. The speed of blades relative to the water is 3 quarters of the peripheral blade speed. Determine:

a)The Gt value, **b)**The basin dimensions, **c)**The paddle-wheel design, **d)**Power to be imparted to the water in each compartment, **e)**The rotational speed of each horizontal shaft in rpm

$\mu=2.72\times10^{-5}$ lb.sec/ft^2

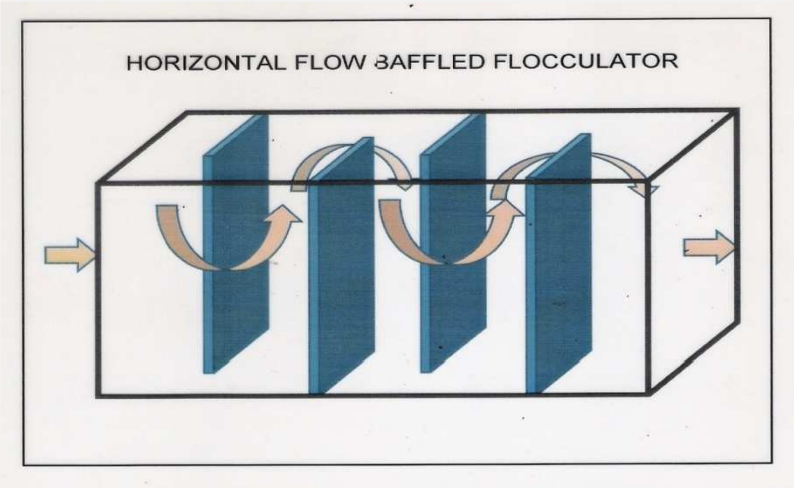
L/W	C_D
5	1.2
20	1.5
∞	1.9

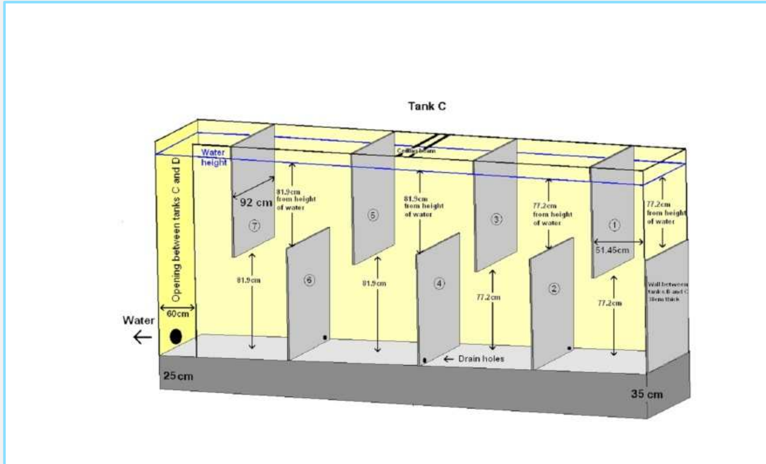




BAFFLED CHANNEL FLOCCULATORS

- Horizontal flow (around the end) Vertical flow (over and under)





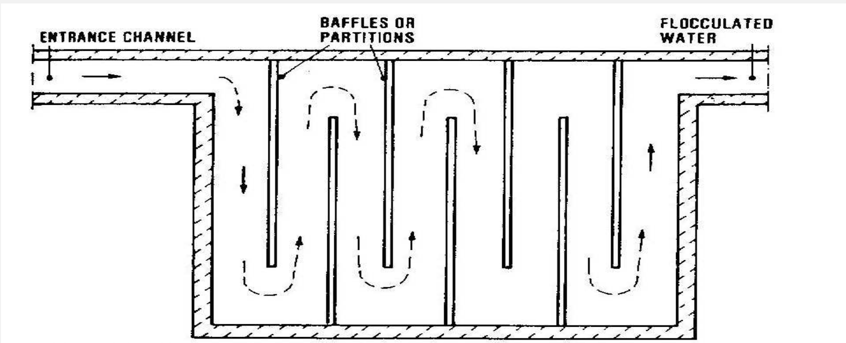


Figure 6.2. Horizontal-flow baffled channel flocculator (plan). *Source:* IRC, 1981b.

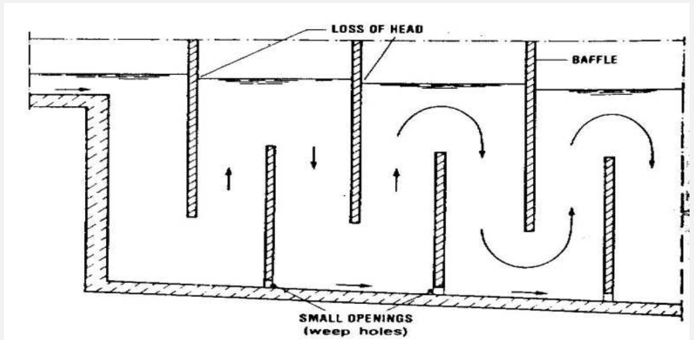


Figure 6.3. Vertical-flow baffled channel flocculator (cross-section). *Source:* IRC, 1981b.

→can be used for large treatment plants ($Q>10000 m^3$/day) where the flowrates can maintain sufficient headlosses in the channels for slow mixing without requiring that baffles be spaced too close together (which would make cleaning difficult)

→A distinct advantage of such flocculators → They operate under plug flow conditions

free from short circuiting problems

The number of baffles needed to achieve a desired velocity gradient:

$$n = \left\{ \left[\frac{2\mu t}{\rho(1.44 + f)} \right] \left[\frac{HLG}{Q} \right]^2 \right\}^{1/3}$$

FOR HORIZONTAL FLOW (around the end) BAFFLED FLOCCULATOR

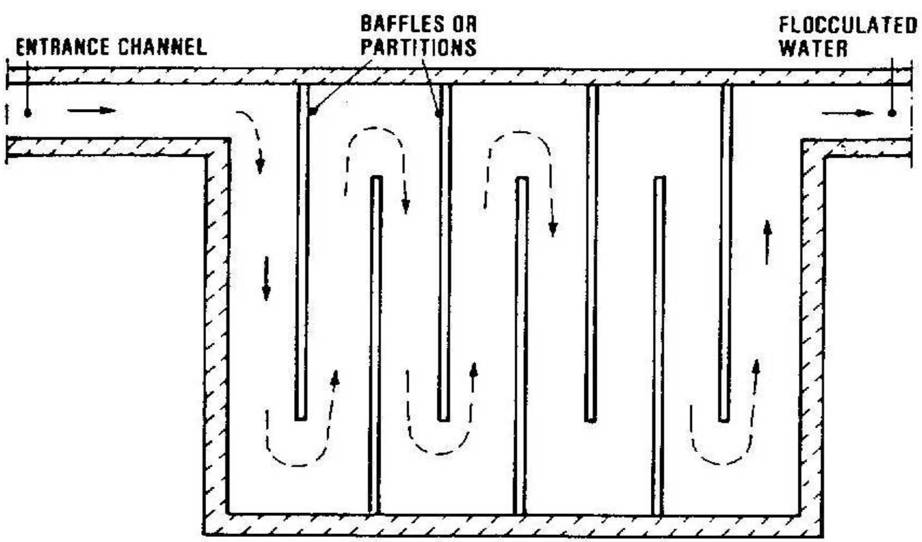


Figure 6.2. Horizontal-flow baffled channel flocculator (plan). *Source:* IRC, 1981b.

n = number of baffles in the basin
H = depth of water in the basin (m)
L = length of the basin (m)
G = velocity gradient (sec^{-1})
Q = flowrate (m^3/sec)
t = time of flocculation (sec)
μ = dynamic viscosity (kg/m.sec)
ρ =density of water (kg/m^3)
f = coefficient of friction of the baffles
w = width of the basin (m)

HEADLOSS AROUND THE BAFFLE IN A CHANNEL can be computed by assuming 180° turn in the direction of flow in a square pipe

$$h=3.2\ (v^2/2g)$$

$$n = \left\{ \left[\frac{2\mu t}{\rho(1.44 + f)} \right] \left[\frac{WLG}{Q} \right]^2 \right\}^{1/3}$$

FOR VERTICAL FLOW (over and under) BAFFLED FLOCCULATOR

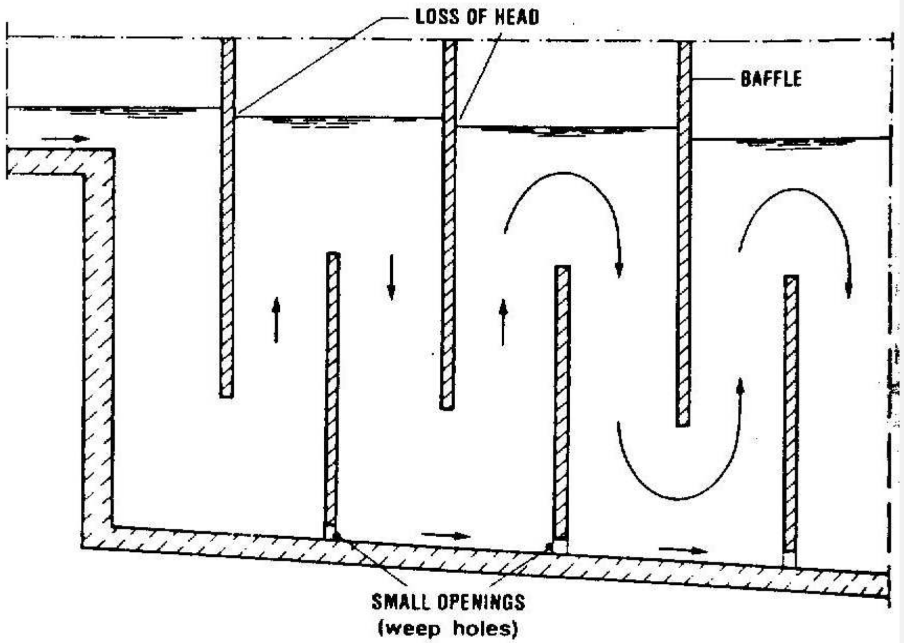


Figure 6.3. Vertical-flow baffled channel flocculator (cross-section). *Source:* IRC, 1981b.

n = number of baffles in the basin
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HEADLOSS AROUND THE BAFFLE IN A CHANNEL can be computed by assuming 180° turn in the direction of flow in a square pipe

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Water velocity in both horizontal flow and vertical flow units generally varies 0.1-0.3 m/sec

Detention time varies from 15-30 min

G = 10-100 sec^{-1}

Other design criteria: Table 6.3 (Okun)

Tapered energy flocculation in baffled channels generally is achieved by varying the spacing of the baffles. That is;

Close spacing of baffles → for high velocity gradients

Wider spacing of baffles → for low velocity gradients

EXAMPLE (Fair, Geyer, Okun p.252)

Design a horizontal flow baffled channel flocculator for a treatment plant of $10000 m^3/day$ capacity. The flocculation basin is to be divided into 3 sections of equal volume, each section having constant velocity gradients of 50, 35, 25 s^{-1}, respectively. The total flocculation time is to be 21 min and the water temperature is 15° C. The timber baffles have a roughness coefficient of 0.3. A common wall is shared between the flocculation sedimentation basins, hence the length of the flocculator is fixed at 10m. A depth of 1m is reasonable for horizontal flow flocculators.

At 15°C $\mu = 1.14 \times 10^{-3}$ kg/msec

$\rho = 1000 \ kg/m^3$