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Flocculator Design for a Water Treatment Plant in a Rural Community with a River or Stream Water Source around Maiduguri Area, Borno State, Nigeria

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ABSTRACT: *Flocculator, a major component of water treatment plant is required for attaining the International Standard for a potable drinking water is hereby design for rural domestic water supply. This is for an estimated population of 260,000 people with an average consumption rate of 0.057 mgd (million gallons daily). The dimension of the flocculator is 2m x 2m x 2.5m i.e. 10m^{3}in volume with a power input of 0.0036kw and detention time of 54.36min.Provision is also made for future expansion in the event of an increase in the communities' population. The sinuous channels principle used aided in minimal power requirement for the system.*

Key words: flocculator, sinuous channel, head loss, velocity gradient

I. INTRODUCTION

The use of gentle stirring in water, which floc has formed to induce the particles to coalesce and grow is known as flocculation. The bigger and denser the floc particles, the quicker are the rate of settlement.

The source of power for flocculating devices are mechanical and pneumatically. Generally speaking, seldom used in large plants, even though they possess quite useful features [2].When the dosed water carrying floc finally passes into the flocculator through the inlet port, a certain rolling motion is inevitable, which can be accentuated by baffles in Horizontal flow basin or in an upward flow basin by the sludge blanket. [1]

However in many basins there is ample evidence that better results can be obtained if mixing and flocculation can be intensified. In recent years much research has been done on both and sound theoretical rules have been laid down.

There are methods of theoretical approach, the mixing and flocculation can be carried out either by mechanical means in specially built chambers or in suitable baffled channel or interconnected chambers. The latter methods requires no mechanical equipment but lacks flexibility, because the system can be designed for maximum efficiency only at one rate of flow and at one temperature, where-as the speed of mechanical paddles can be adjusted to suit the variations of flow, temperature and silt conditions. However, the cost added to the complexity of mechanical equipment introduces additional complications to be avoided in a developing country, and in practice a sinuous inlet channel preceded by violent mixing generally provides a reasonable effective solution [1].

If the pipe or channel through WHICH the incoming water enters the basin is so dimensioned as to ensure a velocity > 1m/s, and if the channel or directed at an end wall so that the flow is forced to reverse abruptly through 180^o, any coagulant introduced into the water before that sudden reversal will be adequately mixed and floc will form almost instantaneously.

Unlike the absolute necessity for thorough mixing, the need for flocculation as a separate process may or may not be essential much depends on the nature of the suspended solids, for rivers carrying coarse and heavy sediment the main problem is to prevent the silt settling and blocking the inlet channels before it reaches the basin [1]. Shallow depth settling may present operational difficulties in developing countries, so separate flocculators are mostly found before conventional horizontal flow basins where colloids are a problem and the complication of additional machinery may be avoided by having the flocculating action imparted to the water by the gently rolling motion resulting from passing water along a sinuous channel. In practice a channel providing a velocity of flow of about 0.3m/s with cross-walls ensuring 12-20 changes of direction though 180^o (with well rounded corners), has often proved to be very effective, The emphasis must be placed on the comparative smoothness of flow required. Under no circumstances should velocity or turbulence be such as to break up the floc.

II. THEORETICAL APPROACH:

The stirring of water creates difference of velocity and therefore velocity gradients. The average temporal mean velocity gradient in a shearing fluid is denoted by G. For baffled basins or sinuous channels: -

$G = (\frac{\rho g h}{\mu T})^{1/2}$……………………. (1)

Also $T = \frac{\rho g h}{\mu G}$ …………………. (2)

Where,
G is the velocity gradient, s^{-1}
ρg is the weight of water per unit volume
h is the head loss due to friction, m
μ Is the dynamic viscosity
T is the detention time, s.
For mechanical agitation, the velocity gradient relation G is given by;

$G = (\frac{P}{\mu V})^{1/2}$……………………. (3)

Where,
P is the power consumption, W
V is the volume of fluid, m^3
The total number of particle oscillation is proportional to GT, and is greater when there is a degree of turbulence as opposed to general rotation. It has been observed that in many of the more successful mixing and flocculating basins which are mechanically stirred the GT values are as shown in tables (1 & 2) below. Increase in contact time above 120 seconds achieves little, and excessive G values can be harmful [1].

Table: 1 Recommended GT Values for Flash Mixers [1]

Contact time T,s	Velocity Gradient G,s^{-1}	GT
20	1000	20,000
30	900	27,000
40	75	30,000
41-120	700	30,000

Table 2: Recommended GT Values for Flocculation [1]

Type	Velocity Gradient G,s^{-1}	GT
Turbidity or colour removal (without solids recirculation	20-100	20,000-150,000
Turbidity or colour removal (with solids recirculation)	75-75	25,000-200,000
Softeners (solid contact reactors)	30-200	200,000-250,000
Softener (ultra-high solid)	250-300	300,000-400,000

III. SINOUS CHANNELS

The permissible loading on a sinuous channel at any given value of GT is (from eqn. 2.0)

$\frac{Q}{V} = (\frac{Q\rho g h}{\mu V})^{1/2} / GT = (\frac{Qgh}{\upsilon V})^{1/2} / GT$…….. (5)

Where,
Q is the rate of flow, m^3/s
V is the channel volume, m^3
g is the acceleration due to gravity (9.81 m/s^2)
υ is the kinematic viscosity of the water, m^2/s
The useful power input is

$P = Q\rho gh$………………………….. (6)

where P is the power watts for each meter of head lost, the useful power input is 9.8 x 10^3 watts per m^3/s, in practice, head losses are commonly 0.15-0.6m, velocities 0.15-0.5m/s and detention times 10.60min.
For channel with baffles (over and under or round the bend), the extra loss of head in the channel (in addition to normal channel friction) is,

$h = \frac{nV_1^2 + (n-1)V_2^2}{2g}$…………………..……… (4)

Where,
h is the addition head loss, m

n is the number of baffles
v_1 is the velocity between the baffles, m/s
v_2 is the velocity at the baffles slots, m/s
To approximate the total channel friction can be obtained by calculation using a Hazen Williams discharge coefficient c= 50 [5].

IV. FLOCCULATOR DESIGN

Since, the design is for a rural settlement, which should avoid excessive use of power and at lower cost, the flocculator should be a sinuous flow baffled channel type.
The number of baffles (n) is chosen to be 7, (over and under) [3] with an entry velocity V_1 = 0.36m/s (Velocity of water from mixer) [3] and a velocity between baffles V_2 = 0.5m/s.
The detention time in the channel is given by equation 2

$$T=\frac{\rho g h}{\mu G^2}$$

For turbidity or colour removal without recirculation G is taken to be $23s^{-1}$ (table 2). The head loss due to friction (hf) is given by Haizen Williams eqn with c = 50

$$hf = (\frac{1.594}{C})^{1.85} \times \frac{L}{d^{4.87}} \times Q^{1.85}$$

Where L is the length of pipe which is 2m
d is the pipe diameter which is 0.1m
$Q = 0.003m^3/s$

$$hf = (\frac{1.594}{50})^{1.85} \times \frac{L}{0.1^{4.87}} \times 0.003^{1.85}$$

hf = 0.0054m
ρg and μ at 35°C are $9.747x10^3 N/m^2$ and $0.7255x10^3 Ns/m^2$ respectively(Appendix II)
Addition head loss in the channel is given by equation 4,

$$h = \frac{nV1^2 + (n-1)V2^2}{2g}$$

$$h = \frac{7 \times 0.36^2 + (7-1)0.5^2}{2 \times 9.81}$$

h = 0.123m
∴Total head loss = head loss due to friction + additional head loss.
Total head loss = 0.123 + 0.0054 = 0.1284m
Thus substituting values of head loss, ρg and μ in equation (2),

The detention time $T = \frac{9.747 \times 10^3 \times 0.1284}{0.7255 \times 10^{-3} \times 23^2}$ = 361sec = 54.35min

Thus from flow rate $Q = \frac{\text{volume discharged}}{\text{time}}$

$$Q = \frac{V}{T}$$

$V = 0.003 \times 3261 = 9.8m^3 \cong 10m^3$
The dimension of the flocculator is 2m x 2m x 2.5m; hence the useful power inputs given by equation (6)
P = ρgQh
$P = 9.747 \times 10^3 \times 0.003 \times 0.1230$
P = 3.6watts = 0.0036Kw
The permissible loading Q/V is given by equation (1)
$Q/V = \frac{0.003}{10} = 0.03s^{-1}$ and the GT value is thus, GT = 23 X 3261 = 75003.
This is within the recommended range as given in table 2.
The floor of the flocculator slopes from entry by 10% of the height. Thus 10% of 2m = 0.2, hence the height at entry = 2-0.2which is equals to 1.8m.

Thickness of the baffles are chosen to be 50mm, there are 3 upper baffles spaced 587.5mm apart and each 1.2m deep. The upper and lower baffles should lap by 0.4m (400mm) as shown in the diagram appendix I.
The flocculator basin is to be built with bricks and the surface is plastered to a smooth finish, the floor of the basin is of concrete. Since the flocculator is accompanied by a settlement basin, almost all floc formed will settle at the settlement basin and the remaining that settled at the flocculator is to be hand cleaned monthly.
The top of the flocculator is to be left open so as to assist further disinfection by ultraviolet radiation. The outlet diameter of the flocculator is to be the same with the inlet, i.e. 0.1m

V. CONCLUTION

For future expansion of the treatment plant due to increased water demand or population increase as pre-determined based on data of the 1963 census report, this expansion will be based on the population figure projected to that year. The provision for expansion has already been provided in the design and the addition of more chambers such as in the flocculator and settlement basins may be found necessary. The filter has been designed to last the life span of the project.

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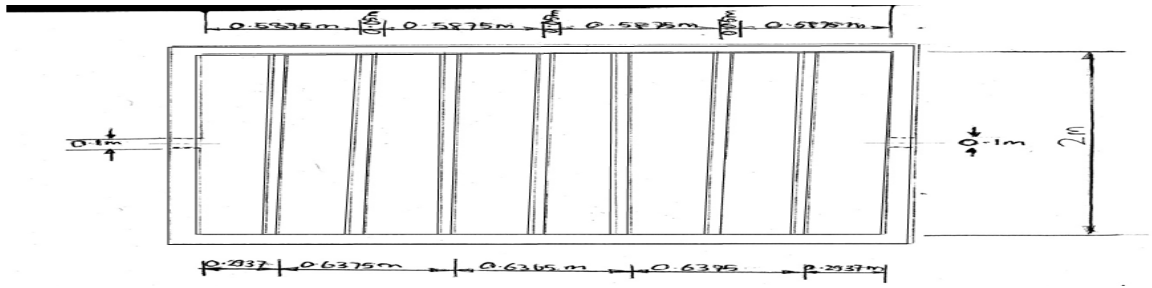
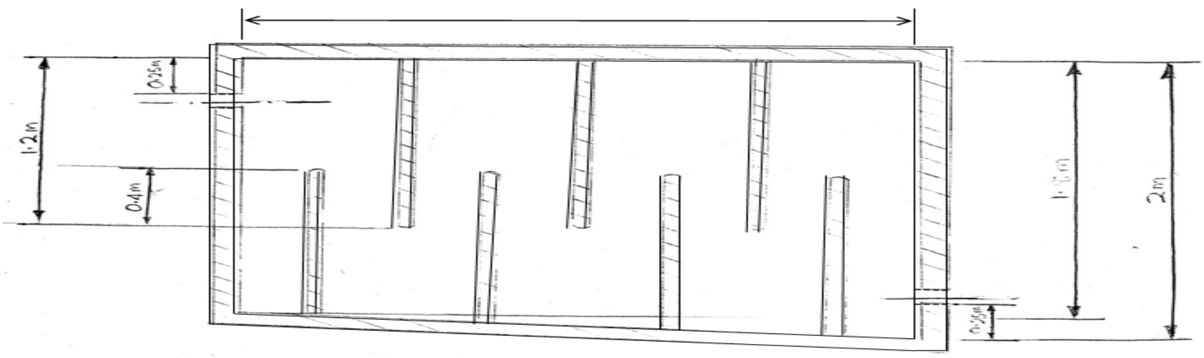
APPENDIXI



FLOCULLATOR PLAN VIEW

2.5m



FLOCCULATOR SECTIONAL FRONT VIEW

APPENDIX II

Table A-2a Physical properties of water in English units

Temperature , °F	Specific weight lb. ft³	Density ρ Slugs ft./	Viscosity μx10³, lb. sec ft²	Kine-matic viscosity υ x 10³ ft²/sec	Heat of vapor-ization, Btu.lb	Vapor pressure p Pascal	Vapor pressure head *p* h ft.	Bulk modulus of elasticity E_tx 10³ Pascal
32	' 62.42	1.940	3.746	1.931	1075.5	0.09	0.20	293
40	62.43	1.940	3.229	1.664	1071.0	0.12	0.28	294
50	62.41	1.940	2.735	1.4 10	1065.3	0.18	0.41	305
60	62.37	1.938	2.359	1.217	1059.7	0.20	0.59	311
70	62.30	1.936	2.050	1.059	1054.0	0.36	0.84	320
80	62.22	1.934	1.799	0.930	104 8.4	0.51	1.17	322
90	62.1 1	1.931	1.595	0 826	1042.7	0.70	I .61	323
100	62. 00	1.927	1.424	0.739	1037.1	0.95	2.19	327
110	61.86	1.923	1.284	0.667	1031.4	1.27	2.95	331
120	61.71	1.918	1.163	0.609	1025.6	1.69	3.91	333
130	61.55	1.913	1.069	0.558	1019.8	2.22	5.13	334
140	61 38	1.908	0.981	0.514	1014.()	2.89	6.62	330
150	61 20	1.902	0 905	0.476	1008.1	3.72	8.58	328
160	61.00	1.896	0.838	0.412	1002.2	4.74	10.95	326
170	60.80	1.890	0.780	0.413	996.2	5.99	13.83	322
180	60. 58	1.883	0.726	0 385	990.2	7.51	17.33	318
190	60. 36	1.876	0.678	0.362	984.1	9.34	21.55	313
200	60.12	1 868	0.637	0 341	977.9	11.52	26.59	308
212	59.83	1.860	0.593	0.319	970.3	14.70	33.90	300

Table A - 2 A Physical properties of water in SI units

Tem pera ture, °C	Specific weight **kN m³**	Density ρ **kg m³**	Viscosity μx10³ **N sec m²**	Kine-matic viscosity υ x 10³ **m² sec**	Heat of vapor-ization **J gm.**	Vapor pressure p **kN m\ abs**	Vapor pressure head *p* m	Bulk modulus of elasticity E_t x 10-6 kN m:
0	9.805	999.8	1.781	1.785	2500.3	0.61	0.06	2.02
5	9.807	1000.0	1 518	1.519	2488. 6	0.87	0.09	2.**06**
10	9.804	999.7	1.307	1.306	2476.9	1.23	0.12	2.10
15	9.798	999.1	1.139	1.139	2465.1	1.70	0.17	2.15
20	9.789	998.2	1.002	1.1003	2453.0	2.34	0.25	2.18
25	9.777	997.0		0.893	244 1.3	3.17	0.33	2.22
30	9.764	995.7	0.798	0.800	24 29.6	4 24	0.44	2.25
40	9.730	992.2	0.653	0.658	2405.7	7.38	0.76	2.28
50	9.689	988.0	0.547	0.553	2381.8	12.33	1.26	2.29
60	9.642	983.2	0.466	0474 ,	2357.6	19.92	• 2.03	2.28
70	9.589	977.8	0.404	0.413	2333.3	31.16	3.20	2.25
80	9.530	971.8	0.354	0.364	2308.2	47.34	4.96	2.20
90	9.466	965.3	0 315	.0.326	2282.6	70.10	7.18	2.14
10	9.399	958.4	0.282	0.294	2256.7	101.33	10.33	2.07