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DESIGN CRITERIA OF COARSE MEDIA FLOCCULATOR IN IRON REMOVAL PROCESS

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ABSTRACT : Dimensionless CAMP number and mean velocity gradient are the important parameters for the control of flocculation process. For the best iron removal performance an optimum range of CAMP number and mean velocity gradient have been determined. A comparison between jar test results and performance of the coarse media flocculator verify the applicability of the mathematical expressions (Ahmed, 1995) developed for CAMP number and mean velocity gradient. This paper describes the other design criteria of coarse media flocculator in iron removal process.

KEY WORDS: Iron, flocculation, CAMP number, mean velocity gradient, settling column.

INTRODUCTION

Flocculation of suspended iron particles depends on the number of particles and probability of collision. Collision may result from variable velocity of suspended particles and from micropulsation generated by mixing. The intensity of mixing. can be defined by the variation in the velocity vector of fluid motion, which is described in terms of average velocity gradient G. But if the velocity gradient exceeds the boundary value, floc damage proceeds faster than floc formation. Similarly extended mixing also affects the flocculation process because the flocs already formed may likely be destroyed due to repeated shearing among them. Hence the coagulation criterion developed by CAMP (Fair, Geyer and Okun, 1971), which is the CAMP number G.td, and mean velocity gradient, G, are important parameters for the control of flocculation process. A specific range of values is maintained for a particular condition and should be determined separately for a specific quality of water. In the iron removal process, particularly in the design of coarse media flocculator no such values are known. The mathematical expressions (Ahmed, 1995) developed for CAMP number and mean velocity gradient need to be verified under laboratory conditions to determine their applicability in the design of coarse media flocculator. Moreover, other factors like face velocity, size of coarse media and length of run might affect the iron removal performance and their optimum conditions should be determined for the design of coarse media flocculator.

EXPERIMENTAL PROCEDURES

Preparation of Artificial Iron content water

Laboratory tap water was used as the main source of water for the experiments. To maintain a constant rate of gravity flow, water

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was supplied through a constant head water chamber provided with an overflow pipe. The delivery pipe was provided with an adjustable valve to maintain a desired rate of flow.

Stock solution of iron was prepared by dissolving 100 grams of $FeSo_4, 7H_20$ in 980 ml deionised water. 20 ml of concentrated sulphuric acid was added with deionised water during preparation of stock solution to keep the iron always in solution. From the supply bottle desired portion of iron solution was mixed with iron free tap water through a Peristaltic Pumps to give a resultant iron concentration of around 10 mg/1. To raise the pH value and alkalinity of mixed water, Na_2CO_3 solution of known strength (1 gm/1) was then mixed with it at different proportions with the help of another Peristaltic Pump. The pH value of the final mixed water was monitored through a pH meter with a probe submerged in the mixing chamber.

Environmental Conditions and Analytical Technique

Constant environmental condition and iron concentration were maintained throughout the whole experiment. Feed raw water temperature was 26 to 27°C, alkalinity was around 130 mg/1 as $CaCO_3$ and pH value was 6.9 to 7.0. Iron concentration was around 10 mg/1. The concentration of iron was determined through Atomic Adsorption Spectrophotometer capable of detecting upto 0.01 mg/1 of iron.

Experiments under Continuous flow condition

For continuous study, raw waters containing iron and 75-80 percent saturated with dissolved oxygen was applied at a rate of 200/300/500/1000 ml per minute at the bottom of upflow flocculators (without any nitrogen gas purging). The flocculators were made of 5/10 cm dia and 35/140 cm long PVC pipes packed with average 0.76/1.84 cm dia. gravel. The characteristics of gravel and flocculator have been shown in Table 1 and 2. Instantaneous oxidation of ferrous iron occurs by the dissolved oxygen showing a yellow-reddish colour of water. Flocculation process was followed by a sedimentation chamber arranged in series. The Processes were continued for approximately 100 hours length of run.

Table 1 Characteristics of Gravels

Designated Type	Description	Sphericity (Ψ)	Average dia, d, cm	Shape factor S=6/Ψ	Volume of gravel, cm^3
G_1	Rounded Wornout	0.96	1.84	6.25	2700
G_2	Wornout Sharp	0.88	0.76	6.82	2700

Table 2 Characteristics of Flocculators

Designated Type	Direction of Flow	Diameter of flocculator, ϕ cm	Length of flocculator, L cm	Materials made of	Cross-sectional Area, a, cm^2
F_1	Up flow	10	35	PVC	78.53
F_2	Up flow	5	140	PVC	19.63

Batch Study

Settling ColumnTest-Settling column tests were carried out to study the settleability characteristics of the precipitate in flocculant settling. The flocculant settling study was carried out in a 5 cm. dia, 80 cm long vertical PVC cylinder provided with draw-off side tubes at different levels of the cylinder. Water samples from the effluent of the flocculator were poured into the cylinder every day during the operation period. Then at every 15 minutes interval small portion of water samples were drawn out through the draw-off side tubes and transferred to 20 ml tubes for iron concentration determination. The fraction of iron removed at different depths was then used to construct lines of equal percent removal. The overall percentage removal for any predetermined detention time was then calculated.

Jar Test : A laboratory flocculator consisting of a bank of stirrers with a variable speeed drive was used. Five plastic jars of minimum 1 litre capacity, containing the same amout of aerated and oxidised water of known iron content (around 10 mg/1) were place dunder the vertical shaft paddle stirrer. The water in the jars were stirred for different durations of time with the same impeller velocity to obtain different values of G.

Determination of the characteristics of iron precipitates in the pores of gravel

Loose iron precipitates along with water from the pores of gravel of a clogged flocculator were drained out carefully by gravity in a large measuring cylinder. Then iron precipitates attached to gravel surface were gently washed with clean water and collected in a separate measuring cylinder. In each cases the precipitates were allowed to settle completely and the volume occupied and concentration of iron in the settled sludge were determined.

OPTIMUM RANGE OF CAMP NUMBER

Jar Test:

A conventional Jar Test procedure was used to determine the optimum range of CAMP number for best iron revmoval performance.The following equation (Fair, Geyer and Okun, 1968) was used in determining the useful power input.

Useful power input, $\rho = 5.74 \times 10^{-4} C_D \rho [(1-k')n]^3 r^3 A'$

Where, C_D is the drag co-efficient and ρ is the density of water.

n, r and A' are the number of revolution effective radius arm and area of impeller blade, respectively.

k' =ratio of fluid velocity to Impeller velocity.
The corresponding 'G' Value was calculated from (Weber, 1972)

$$G = \sqrt{\frac{P}{\mu C}} \ldots\ldots\ldots\ldots (1)$$

Where μ = absolute viscosity and C =Volume of water.

For a specific value of 'G', water samples in the jars were stirred for different durations of time (td) to obtain different values of CAMP number. Stirred water was then allowed to settle for 45 minutes and the iron concentrations of the supernatant samples were determined. Percentage of iron removal against different calculated values of CAMP Number have been presented in Figure- 1.

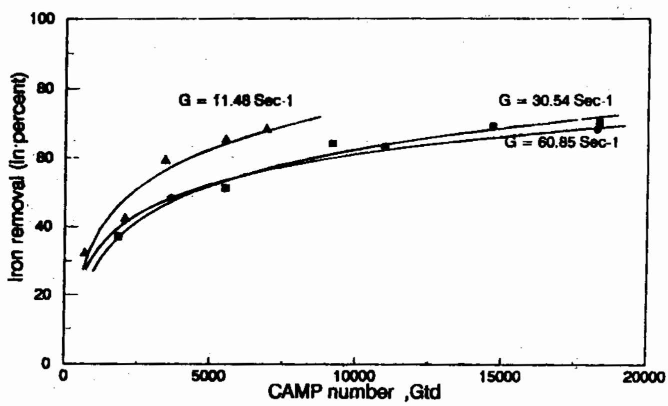

Fig 1. Variation of Iron Removal Efficiency with CAMP Number as a Function of 'G'.

The Results indicate that increased value of CAMP number gives better iron removal performance, but an increased CAMP number beyond about 6000 does not show any appreciable proportional increase in iron removal performance.

Gravel Bed Flocculator

Further studies were carried out with different combinations of gravel sizes, flocculator shapes, and varying the rate of flow of water. Different values of CAMP number were calculated for different G values from the following expression (Ahmed, 1995).

$$G.td = \sqrt{k}\,\frac{(1-f)}{f}\,\frac{S}{d}L \ldots\ldots (2)$$

Where, S = shape factor = $6/\psi$
d = average diameter of gravel
L = length of the flocculator

k = dimensionless coefficient. [Assumes a magnitude close to 5.0 under most conditions of water filtration (Fair, Geyer and Okun, 1968)].

f = porosity. [Typical porosities of granular spherical materials to angular materials vary between 0.38 and 0.43 (Fair, Geyer and Okun, 1968). An average bed porosity of 0.40 has been used in all calculations]

Water samples of the effluent from the flocculator were collected from time to time and settling column tests were carried out. Average iron removal in the flocculation process and subsequently in the settling column after a detention time of 45 minutes were determined. Variation of iron removal with the calculated values of CAMP number (G.td) have been presented in the Figure-2.

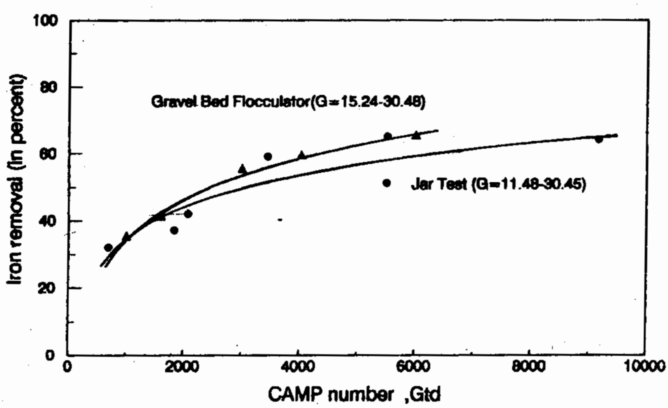

Fig 2. Variation of Iron Removal Efficiency With CAMP Number (Jar Test and Coarse Media Flocculator)

Similar to the batch process, the results indicate that iron removal performance increases with increased value of CAMP number. This also verifies the applicability of the expression developed for CAMP number. In a continuous process of flocculation, this increase in iron removal is more and at a faster rate than in a batch process. This is due to the fact that the whole bed is effective for flocculation process and a portion of precipitated and flocculated iron trap inside the gravel bed flocculator, resulting in a high total removal after settling. The clogging of the pores of the gravel bed cause an increase in head loss and thereby an increase in CAMP number. Comparing Figures-1 and 2, a higher removal can be obtained at a lower value of CAMP number in a gravel bed flocculator and a range of CAMP number between 3000 and 6000 may be considered optimum for the design of coarse media flocculator in the iron removal process.

MEAN VELOCITY GRADIENT (G)

In the jar test procedure, three different values of mean velocity gradient, G, were maintained by varying the number of revolution of impeller blade. Variation of iron removal efficiency with different values of 'G' has been presented in Figure-3. The results indicate that for a given range of CAMP number, lower 'G' values give comparatively better removal performance.

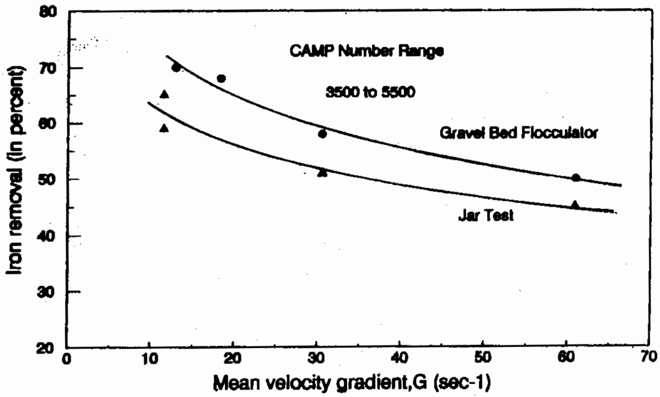

Fig 3. Variation of Iron Removal Efficiency with mean Velocity Gradient, (CAMP number 3500-5500)

In a gravel bed flocculator, according to the following expression (Ahmed, 1995) different values of mean velocity gradient, G, were obtained by varying the face velocity.

$$G = \sqrt{k}\,\frac{Q}{a}\,\frac{(1-f)}{f^2}\,\frac{S}{d} \quad \ldots\ldots\ldots(3)$$

Where, Q = rate of flow of water and
a = cross sectional area of flocculator.

Figure - 3 represents the variation of iron removal efficiency with different values of 'G'. Figure -3, indicates that similar to the batch study results, for a specific range of CAMP number, an increase in mean velocity gradient causes a gradual deterioration in iron removal performance. Therefore longer displacement time, td, through increasing the length of flocculator provides better iron removal performance.

Comparing the batch study and continuous study results it may be concluded that the expression developed for 'G' may be used and a mean velocity gradient range between 10 and 20 sec^{-1} may be considered optimum for the design of coarse media flocculator in the iron removal process.

FACE VELOCITY (Q/a) AND SIZE OF COARSE MEDIA (d)

Since for a particular size and shape of coarse media, face velocity is the main factor that controls the mean velocity gradient, G, the lower the face velocity; the better is the iron removal performance. According to Figure-4, for a range of 'G' values between 10 and 20 Sec^{-1} , and gravel sizes d from 0.75-0.85 cm, face velocity varies for about 0.1 to 0.3 cm/sec. Which is close to the rate of flow usually maintained in rapid sand filters (Davis and Cornwell, 1991).

Since the pores of the bed gradually clogs causing an increase in head loss, the mean velocity gradient, G, which is a function of head loss incurred, will also increase with time. For the same reason the pore volume will also decrease with time causing a decrease in displacement time.

Since for a given face velocity, mean velocity gradient varies inversely with the size of coarse media, the smaller the gravel size the better is the iron removal performance. To avoid rapid clogging, size of coarse media should be selected on the basis of total load of suspended matter, but a size below 5 mm is not recommended (Schulz and Okun, 1984). Size of coarse media can be determined from figure -4 for known values of face velocity and mean velocity gradient. It should be noted that due to the deposition of iron precipitates on the gravel surface, the total effective size of gravel will vary, causing a variation in G and CAMP number.

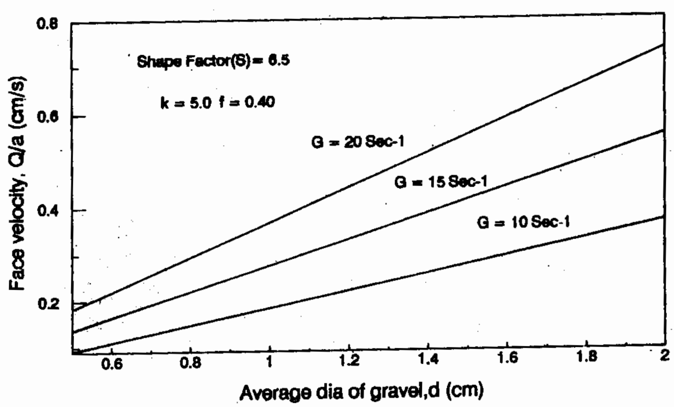

Fig 4. Variation of Face Velocity With Coarse Media Size as a Function of 'G'

LENGTH OF RUN BETWEEN CLEANING OF THE GRAVEL BED.

Since the removal performance varies with the length of run, periodical cleaning of gravel bed would be necessary. The pores of the gravel gradually clogs with iron precipitates. Time required for clogging of pores is a function of iron concentration, Fe, the rate of flow of water, Q. the pore volumes, fV, space occupied by iron precipitates and the removal efficiency of the gravel bed itself, E_f. A portion of the iron precipitates remains attached with the gravel surface and the remaining precipitates occupy spaces within the interstices of gravel. A laboratory investigation was carried out on gravel bed flocculators with gravel sizes from 0.75 cm-1.5 cm and almost clogged with iron precipitates. The characteristics of iron precipitates in the pores of gravel have been presented in the Table-3.

Assuming uniform removal with time, total amout of accumulated iron precipitates within the pores (CF) = load of iron (Li) in mg/hour x length of run (t_L) in hour.

$$t_L = \frac{CF}{Li} = \frac{0.39\ G.td}{G.\ Fe.\ E_f} \qquad \text{.....................(4)}$$

where, CF = Total pore volume (fV) in ml x Concentration of iron ppt. in the pores (1.4 gm /l) [form Table-3]

Li = Rate of flow of water (Q) in ml/sec x Raw water Iron (Fe) Concentration in mg/l x E_f

Therefore, length of run between cleaning can be calculated form the above equation.

Table 3 Characteristics of Iron Precipitates in the poes of gravel

Constituents	% of volume occupied	Nature of precipitates	% of volume occupied	Concentration of Iron in sludge (gm/l)	Avg conc. of Iron in settled sludge, (gm/l)	Conc. of Iron in sludge mixed water (gm/l)
Iron Precipitates (sludge)	24%	Attached to gravel surface	19%	9.70	5.90	1.41
		Loose hydrophobic	81%	9.02		
Water	76%					

CONCLUSION

Although iron removal performance increases with increased value of CAMP number, a range of CAMP number between 3000 and 6000 may be considered optimum for the flocculation of suspended iron particles in the jar test procedure. A higher iron removal can be achieved at a lower value of CAMP number in a gravel bed flocculator. It has also been observed that for a given range of CAMP number (3500-5500), lower mean velocity gradient value (10-20) gives better iron removal performance. A comparison between jar test results and continuous study result indicate that the mathematical expressions developed for CAMP number and mean velocity gradient can be used for the design of coarse media flocculator.

Since face velocity is the main factor that controls the mean velocity gradient, for average 0.75 -0.85 cm diameter of coarse media, a face velocity between 0.1-0.3 cm /sec may be chosen for design purpose. Although smaller coarse media gives better iron removal performance, to avoid rapid clogging the size of coarse meda can be limited to 5 mm.

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