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Performance of Pulsator Clarifier (Low Turbidity)

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Abstract

Experimental and theoretical investigations are presented on flocculation process in pulsator clarifier. Experimental system was designed to study the factors that affecting the performance of pulsator clarifier. These factors were water level in vacuum chamber which range from 60 to 150 cm , rising time of water in vacuum chamber which having times of 20,30 & 40 seconds , and sludge blanket height which having heights of 20,30 & 40 cm .The turbidity and pH of raw water used were 200 NTU and 8.13 respectively. According to the jar test, the alum dose required for this turbidity was 20 mg/l .The performance parameters of pulsator clarifier such as , turbidity ,total solids TS , shear rate , volume concentration of sludge blanket and the flocculation criteria were studied. It was observed that by decreasing the water level in vacuum tube and by increasing the rising time and sludge blanket height , low turbidity of output water attained . Moreover, flocculation criteria value GCt was within the optimum range values (100-500) .A theoretical models was applied for total solids TS of output water .The difference between experimental and theoretical data was ranged between (11-24)% of mean deviation at water level range of (125-150)cm and sludge blanket height 20 cm.

Keywords: water treatment, flocculation, pulsator clarifier, low turbidity.

Introduction

Coagulation, flocculation and settling processes in the field of water treatment have received extensive attention during the past century. Theoretical and experimental studies of these processes became increasingly important because of their widespread applications in industry. Water treatment involves physical, chemical and biological processes that transform raw water into drinking water. Clarification is one of these processes, which includes the removal of excessive color or turbidity of raw water to produce clear uncolored water. Generally, clarification of turbid water includes coagulation, flocculation and settling processes [1].

Clarification process is achieved in settling basins. These settling basins can be classified according to the direction of flow through the basin into three main types; horizontal flow basins, upward flow basins and spiral flow basins [2]. Each type of these basins may be classified into several categories.Generally, coagulation is the first step in complete clarification process that includes the neutralization of the electrostatic charges on colloidal particles. It is achieved in a rapid mixing tank with adding inorganic or organic coagulants. The second step in clarification is flocculation , which is the agglomeration of neutralized suspended solids as a result of particle-particle collisions. The third step in clarification process is the sedimentation of flocs formed in second step. These steps are achieved in all basin types except that at upward flow basins the sedimentationis replaced by fluidization process.

Pulsator clarifier is a simple type of upward flow tank which its effectiveness depends on a sludge blanket . It is the most widely used clarifier in the world because of it is highly reliable and flexible . It also combines the merit of having a flat bottom with the operating simplicity of the hopper-bottomed tank [3].In pulsator clarifier, the water flows upward through the sludge blanket in a cycling or pulsating flow. During surging flow, the bed expands uniformly. During subsiding flow, the bed settles uniformly, as it would in a liquid at rest. As a result of pulsating flow, the blanket remains homogeneous throughout, with no stratification, facilitating continuous, effective contact between water and sludge [2].

Flocculation rate is one of the most important characteristics in the operation of pulsator clarifier .This rate is influenced by a number of physical parameters and operating conditions . Sludge blanket height, upflow velocity of coagulated water, volume concentration of sludge blanket and physical properties of flocs . All these factors are highly interactive and control the pulsator clarifier performance.Numerous investigation show that , flocculation criteria GCt (The product of shear rate , volume concentration of sludge blanket and residence time) gives an indication for the best flocculation conditions in sludge blanket clarifier [4-7]. Also, Flocculation criteria is a basic factor in the design of any sludge blanket clarifiers type [1, 6, 8].

Steady fluidization is one of the most important characteristics of Pulsator clarifier , which represent the balance between the varying upward flow velocity of coagulated water and the hindered settling velocity of the fluidized bed .Many authors suggested empirical correlation that relate the upward velocity with the individual settling velocity and volume concentration of flocs [9-11].

Despite the pulsator clarifier is the most widely used in the world in many water treatment stations, no theoretical and experimental analysis have been reported yet in the literature to describe the operation of pulsator clarifier. Numerous investigators describe experimentally and theoretically the operation in horizontal flow and spiral flow clarifier [12-16].

Most of the experimental and theoretical investigations that have been reported on flocculation process in upward flow clarifiers were for hopper-bottomed sludge blanket clarifier and accelerator type solid contact clarifier [17, 18]. However, the information about the factors that affect the operation of pulsator clarifier is not adequate. Therefore, in order to obtain a general predictive model for the performance of pulsator clarifier , there is a need for better understanding of the role of the physical, design and operating parameters. Thus, the aim of the present study can be reported as follow:

1. To study the effect of important factors on the performance of pulsator clarifier.
2. To apply theoretical model which are capable of predicting total solids of output water in pulsator clarifier, and test the applied model experimentally.

Experimental Work

Experimental rig

The laboratory apparatus that was constructed and utilized to perform this study was shown in Fig. 1. It composed from a tank of 10 liter capacity used as storage tank in which the prepared turbid water was placed. In order to keep the column content at a uniform state, a high speed centrifugal pump was used to circulate the content.

Coagulation process was achieved in 1 liter beaker by mixing the prepared turbid water with required alum dose. The mixing speed was 70 rpm and the detention time was 1 min. Prepared turbid water and alum solution were fed to the beaker by two stage dosing pump.

Pulsation system consists of a vacuum pump, on-off valve and flasher timer. The pulsation system enables the admission of coagulated water into the vacuum tube intermittently. The vacuum tube was connected from the bottom to the flocculation basin by a L-shape tube through one way check valve and connected from top to the vacuum pump and on-off valve. The coagulated water enter the vacuum tube (from the coagulation unit) in a point 0.5 m below the top of vacuum tube. A vacuum pump was used to create a vacuum in the vacuum tube. If timer switch on the vent valve (open vent valve) the water enter the vacuum tube and rise to level ranges between (0.6-1.5 m) above the level of water in flocculation basin. When the timer switches off the vent valve (closed vent valve) the accumulated water in the vacuum tube drains rapidly into the distribution system and passes through the sludge blanket in flocculation basin. After each drain cycle, the vent valve is opened, allowing the action of the vacuum pump to refill the tube.

Coagulated water was introduced into flocculation basin through a perforated plastic tube of 1.27 cm diameter. The pipe contains four holes with a diameter of 2 mm for all experiments.

The Flocculation basin is a rectangular tall tank which was constructed from flat glass sheet connected from bottom to the perforated tube. The bottom of the basin consists of an inverted triangular section with a triangle angle 63°. This triangular bottom geometry was used to bring the settling large flocs under the effect of high rate of water from the holes of distributor pipe. This geometry was designed to minimize the occurrence of dead spaces at the bottom of the basin. Flocculation basin contains a blanket of sludge formed previously. Flocculation occurs within this blanket when coagulated water passes through this blanket. The passing of coagulated water through sludge blanket lead to expansion of this blanket. As the blanket expand, the excess sludge flows into a sludge concentrator across a weir of different heights (20, 30 and 40 cm).

Preparation of solutions

The river water clay has been brought from the adjacent region of Tigris river at Al-Sarafia location. The clay was treated in order to remove any undesirable particles (e.g sand). The treated clay and river water were mixed with tap water to obtain a clay suspension with

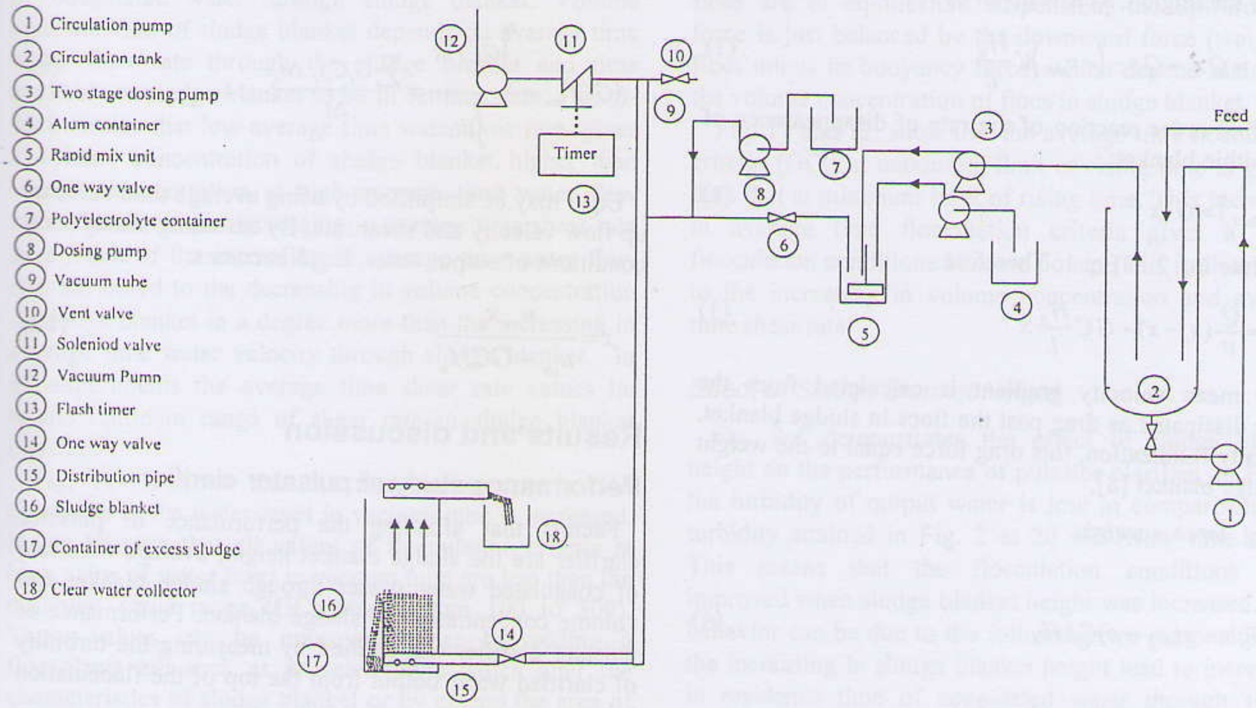

Fig. 1 Schematic diagram of the experimental apparatus

certain concentration. To obtain a certain turbidity level, a certain quantity of clay suspension was added to circulation column which was filled with 10 liter of water.

A 1 wt% Alum solution was prepared by dissolving (10 g) of Alum into 990 ml of distilled water and with stirring. Each 1 ml of solution was equivalent to (10 mg) of alum per liter or (10 ppm).

Measurements and testing

Turbidity meter type (Hach 2001A turbidmeter), with measurement units NTU, was used to measure the turbidity of the water.

Jar test was used also to determine the optimal dose of coagulant and flocculant aid. It consists of six beakers which are simultaneously stirred by a paddle agitator in each so that conditions in each beaker are identical. (0.8) liter of turbid water was placed in each beaker (1 liter capacity). Floc tester with six mixers and lighting source (manufactured by HLIC company England) was used to achieve jar test . The agitation speed was controlled by speed controller with 10 different mixing speed.

Experimental procedure

The experimental steps that were conducted in the pulsator clarifier system were as follows:

1. The vacuum pump was turned on, and the flasher timer was adjusted to provide the desired water level in vacuum tube and rising time. The range of the water level was from 0.6 to 1.5 m. the range of the rising time was from 20 to 40 sec.
2. When the system reached a stable pulse flow, the sludge blanket was formed by operating the system with very high turbidity raw water. After certain time, the sludge blanket reaches the weir level. Then, the system was operated with raw water of (200 NTU, pH of 8.13) as turbidity using 20 ppm as alum dose. The range of the sludge blanket height was from 20 to 40 cm.
3. After one hour, more than one sample of output water was taken to measure the turbidity and total solids of water produced.
4. When the system turned off, the volume concentration of sludge blanket was measured.

Mathematical Model

Removal of primary particles is the main output variable that describes the model of pulsator clarifier. The basic principle that followed to derive the model of pulsator clarifier is that, the total solid of incoming water be equal to the excess sludge that is removed. Assuming particles entering the basin in the dosed water stream is primary floc particles. The removal of these flocs by flocculation in sludge blanket can be simulated as continuous stirred tank reactor CSTR [18]. The mass balance for single CSTR is given by:

$$V\frac{dx}{dt} = Qx_i - Qx - \left(-r_{floc}\right)V\frac{H_b}{L} \tag{1}$$

For a first order reaction of the rate of disappearance of flocs within blanket:

$$\left(-r_{flocs}\right) = G\ x \tag{2}$$

Substitute Eq. 2 in Eq. 1. Therefore:

$$\frac{dx}{dt} = \frac{Q}{V}(x_i - x) - GC\frac{H_b}{L}x \tag{3}$$

The mean velocity gradient is calculated from the power dissipated as drag past the flocs in sludge blanket. At steady fluidization, this drag force equal to the weight of sludge blanket [8].

$$drag\ \ force = weight$$

and

$$Weight = g(\rho_s - \rho)CAH_b \tag{4}$$

also

$$Power\ dissipated = drag\ force \times velocity$$

$$P = g(\rho_s - \rho)CAH_b u \tag{5}$$

finally

$$G = \sqrt{\frac{P}{V\mu}}$$

and therefore

$$G = \sqrt{\frac{g(\rho_s - \rho)Cu}{\mu}} \tag{6}$$

Eq. 6 shows that velocity gradient depend on the volume concentration of the sludge blanket and upward flow velocity of coagulated water. Since upward flow velocity changes with time, also velocity gradient changes with time. Therefore, velocity gradient and upward flow velocity with must be expressed as average time values.

$$G_{av} = \frac{\int_o^{\Delta t} G\,dt}{\int_o^{\Delta t} dt} = \frac{\sum Gi\,\Delta t_i}{\Delta t} \tag{7}$$

$$u_{av} = \frac{\int_o^{\Delta t} u\,dt}{\int_o^{\Delta t} dt} = \frac{\sum u_i\,\Delta t}{\Delta t} \tag{8}$$

also

$$(GCt)_{av} = \frac{\int_0^{\Delta t} GCt\,dt}{\int_0^{\Delta t} dt} = \frac{\sum G_i C_i t_i\ \Delta t_i}{\Delta t} \tag{9}$$

Eq. 3 may be simplified by using average time value of up flow velocity and shear rate. By assuming steady state conditions of output water, Eq. 3 becomes:

$$x = \frac{u_{av} x_i}{u_{av} + GCH_b} \tag{10}$$

Results and discussion

Performance study of pulsator clarifier

Factors that affecting the performance of pulsator clarifier are the sludge blanket height, average time rate of coagulated water passes through sludge blanket and volume concentration of sludge blanket. Performance of pulsator clarifier was studied by measuring the turbidity of clarified water output from the top of the flocculation basin.

In order to get a better understanding of the effect of the above factors on the performance of pulsator clarifier, it is important to relate the operating conditions in pulsator clarifier to the average shear rate or velocity gradient (G), volume concentration of the sludge blanket (C) and average time flocculation criteria (GCt). There are optimum values for shear rate, volume concentration of sludge blanket and flocculation criteria. These optimum values are: shear rate less than 5 S^{-1}, typical volume concentration (0.15) and flocculation criteria ranges between 100 – 500.

Effect of average time rate

The average time rate of coagulated water through sludge blanket depends on the water level in the vacuum tube. At maximum level of water in vacuum tube, the flow rate of coagulated water achieves a maximum value and gradually decreases until the level of water in vacuum tube becomes at the same level as that of the flocculation basin.

Fig. 2-4, shows that the turbidity of output water increases as the level of coagulated water in vacuum tube is increased. This behavior can be due to the decrease in residence time as the flow rate of coagulated water is increased.

Fig. 5-7, shows that the average time shear rate decreases as the level of coagulated water in vacuum tube is increased. Average time shear rate in pulstor clarifier was calculated using Eq. 6 and 7. It is clear from Eq. 6, shear rate is proportional directly to the product of volume concentration of sludge blanket and the velocity of coagulated water through sludge blanket. Volume concentration of sludge blanket depends on average time water flow rate through the sludge blanket and time available to sludge blanket to be in settling state. Fig. 8-10 indicates that low average time water flow rate gives a volume concentration of sludge blanket higher than volume concentration at high average time water flow rate. Therefore, the decreasing in average time shear rate as a result of the increasing in average time water flow rate attributed to the decreasing in volume concentration of sludge blanket in a degree more than the increasing in average time water velocity through sludge blanket. In all experiments the average time shear rate values lie within optimum range of shear rate in sludge blanket clarifier.

Fig. 11-13 shows that the flocculation criteria GCt decreases as the water level in vacuum tube is increased. It can be seen that all values of flocculation criteria at high value of water level in vacuum tube are less than the optimum value range (GCt ranges from 100 to 500). These values can be improved either by adding a flocculants aid such as polyelectrolyte which alter the characteristics of sludge blanket or by extend the area of the basin.

Effect of Rising Time

In practice, rising time is the time required to fill the vacuum chamber but in our experimental scheme , rising time was taken to be the time interval between the end of pulse flow and starting of pulse flow.

Fig. 2 and 3 show that the effect of rising time on the performance of pulsator clarifier. Turbidity of output water at minimum limit of rising time was higher than that at maximum limit of rising time. This can be due to the increasing in volume concentration of sludge blanket where the sludge blanket was leaved to settle for additional period of time. Fig. 8 and 9 indicate the increasing in volume concentration of sludge blanket as a result of the increasing in rising time. The increasing in volume concentration of sludge blanket improves the efficiency of flocculation process which happens within sludge blanket. This was attributed to the increasing in probability of collision between primary flocs present in coagulated water and secondary flocs present in sludge blanket.

The increasing in volume concentration of sludge blanket affect the average time shear rate values. Fig. 5 and 6 show that the average time shear rate at minimum rising time is lower than that at maximum rising time. The direct effect of volume concentration of sludge blanket on the shear rate attributed to that shear rate or mean velocity gradient is provided by the power dissipated in fluid drag past the fluidized flocs. If the flocs are in equilibrium suspension, the upward drag force is just balanced by the downward force (weight of flocs minus its buoyancy force) which depend mainly on the volume concentration of flocs in sludge blanket.

Fig. 11 and 12 show that the average time flocculation criteria (GCt) at maximum limit of rising time is greater than that at minimum limit of rising time. This increasing in average time flocculation criteria gives a better flocculation conditions in some points. This is clearly due to the increasing in volume concentration and average time shear rate.

Effect of Sludge Blanket Height

Fig. 2-4 demonstrates the effect of sludge blanket height on the performance of pulsator clarifier. In Fig. 4, the turbidity of output water is low in comparison with turbidity attained in Fig. 2 at 20 sec rising time curve. This means that the flocculation conditions were improved when sludge blanket height was increased. This behavior can be due to the following two reasons. Firstly the increasing in sludge blanket height lead to increasing in residence time of coagulated water through sludge blanket. Consequently, the probability of primary particles to be flocculated on secondary particles is increased. The Secondly, the increasing in volume concentration of Sludge blanket as a result of the increase in sludge blanket height itself. This may be note in Fig. 8-10 by comparing the curves at 20 sec rising time in these figures.

Fig. 5-7 show that the average time shear rate increases as the sludge blanket height is increased. Again this is due to the increasing in volume concentration of sludge blanket. Fig. 11-13 show that the average time flocculation criteria increase as the sludge blanket height is increased. This can be due to the increase in the average time shear rate, volume concentration and residence time of coagulated water passing through sludge blanket.

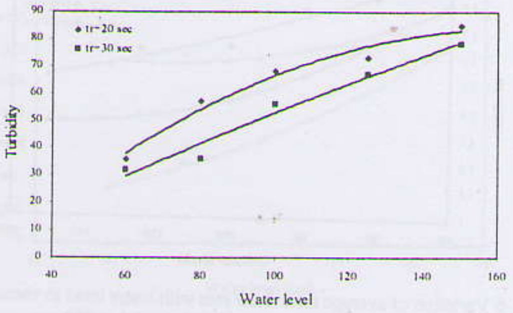

Fig. 2 Turbidity of output water vs water level in vacuum tube at different rising time and blanket height of 20 cm

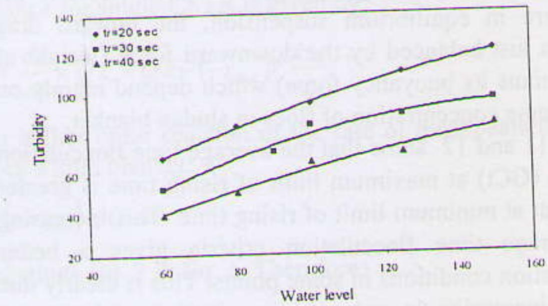

Fig. 3 Turbidity of output water vs water level in vacuum tube at different rising time and blanket height of 30 cm

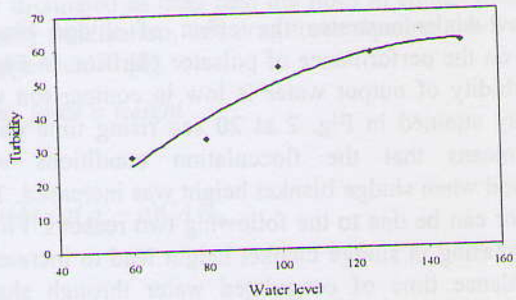

Fig. 4 Turbidity of output water vs water level in vacuum tube at 40 s rising time and blanket height of 40 cm

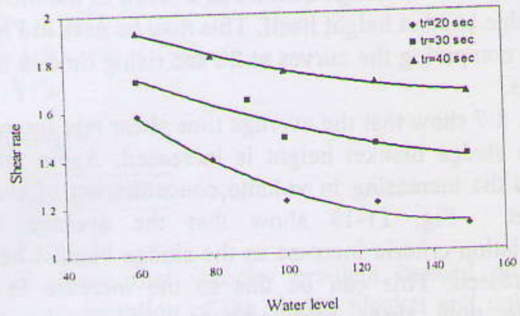

Fig. 5 Variation of average time shear rate with water level in vacuum tube at different rising time and blanket height of 20 cm

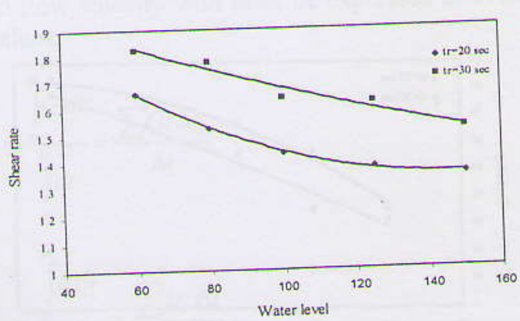

Fig. 6 Variation of average time shear rate with water level in vacuum tube at different rising time and blanket height of 30 cm

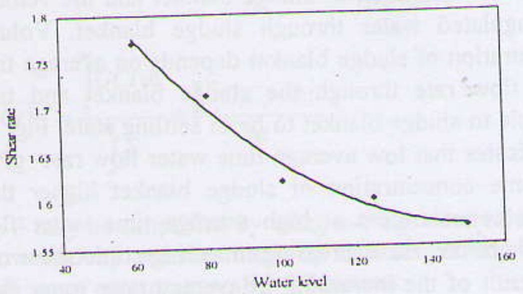

Fig. 7 Variation of average time shear rate with water level in vacuum tube at rising time of 20 s and blanket height of 40 cm

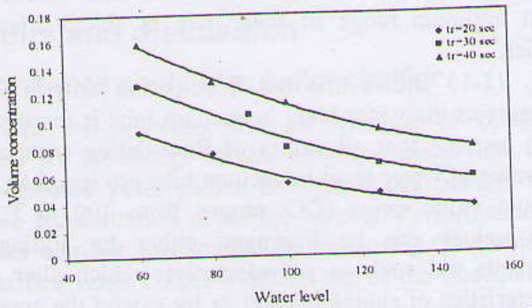

Fig. 8 Volume concentration of output water versus water level in vacuum tube at different rising time and blanket height of 20 cm

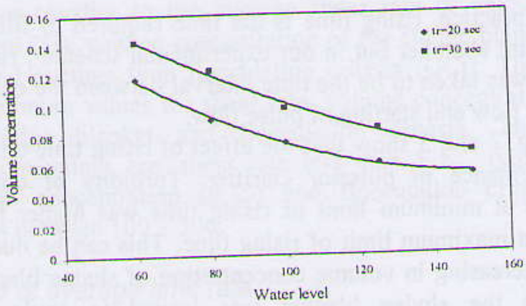

Fig. 9 Volume concentration of output water versus water level in vacuum tube at different rising time and blanket height of 30 cm

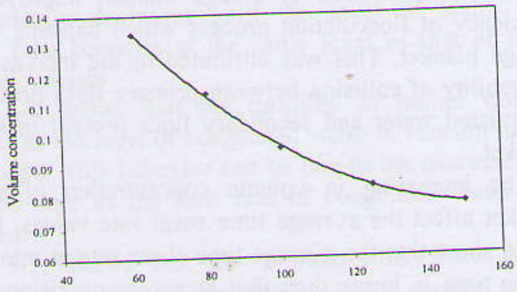

Fig. 10 Volume concentration of average time shear rate with water level in vacuum tube at rising time of 20 s and blanket height of 40 cm

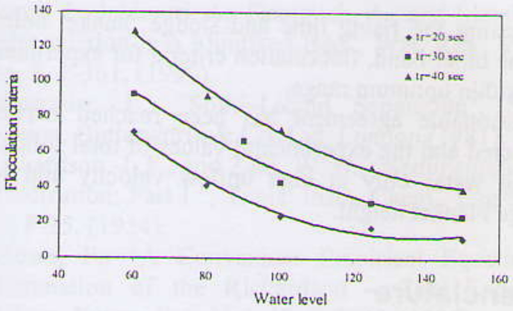

Fig. 11 Variation of average time flocculation criteria with water level in vacuum tube at different rising time and blanket height of 20 cm

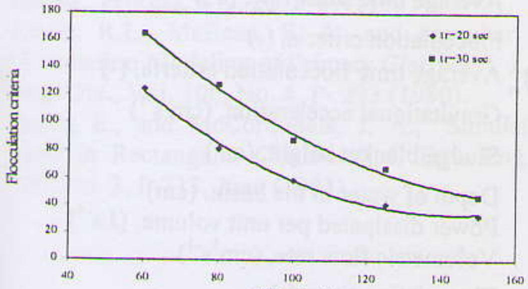

Fig. 12 Variation of average time flocculation criteria with water level in vacuum tube at different rising time and blanket height of 30 cm

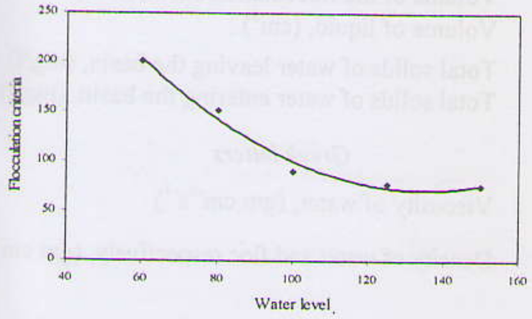

Fig. 13 Variation of average time flocculation criteria with water level in vacuum tube at rising time of 20 sec and blanket height of 40 cm

Mathematical model results

The removal of primary particles was simulated as a continuous stirred tank reactor CSTR. The mass balance for a single CSTR can be represented by Eq. 3. This equation takes into account the removal of particles by flocculation in the basin. By using the average time value of upflow velocity and shear rate and by assuming a steady state conditions of output water, Eq. 3 may be reduced to Eq. 10. The total solid of output water was calculated using Eq. 10 at different water level in vacuum tube, rising time and sludge blanket height. Fig. 14-19 shows the comparison between total solids attained in experiments and total solids calculated from Eq. 10. It can be seen that all results have the same behavior in both experiment and theory, but the degree of agreement differs from condition to another.

It can be concluded that the results of the theoretical model are in reasonable agreement with present experimental data for the entire range of rising time only at 20 cm sludge blanket height and high water level in vacuum tube (125–150) cm. The difference between the mathematical data and present experimental data was ranged between (11-24)% of mean deviation. At low water level in vacuum tube and sludge blanket height more than 20 cm the mathematical model exhibit a large deviation from present experimental data.

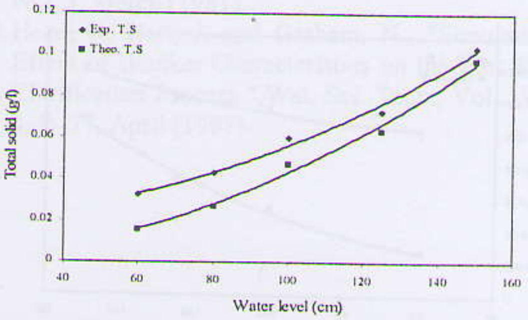

Fig. 14 Comparison of experimental and theoretical total solids of output water at rising time of 20 s and blanket height of 20 cm

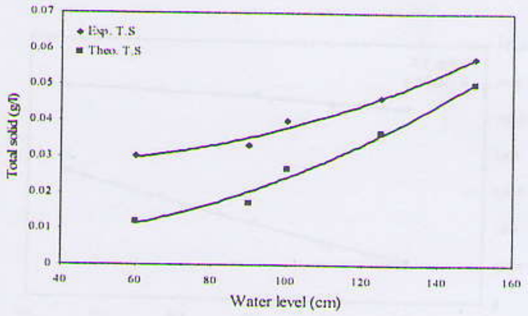

Fig. 15 Comparison of experimental and theoretical total solids of output water at rising time of 30 s and blanket height of 20 cm

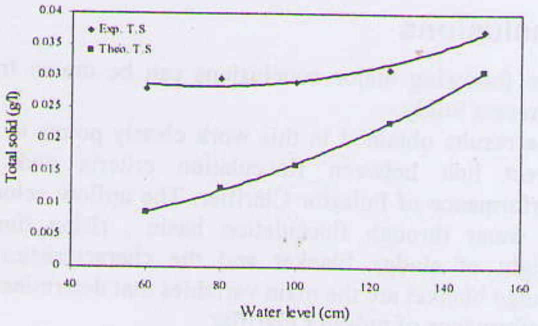

Fig. 16 Comparison of experimental and theoretical total solids of output water at rising time of 40 s and blanket height of 20 cm

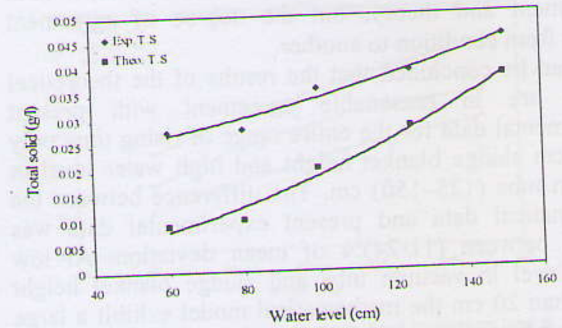

Fig. 17 Comparison of experimental and theoretical total solids of output water at rising time of 20 s and blanket height of 30 cm

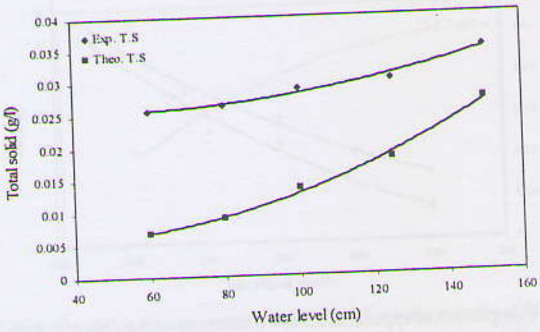

Fig. 18 Comparison of experimental and theoretical total solids of output water at rising time of 30 s and blanket height of 30 cm

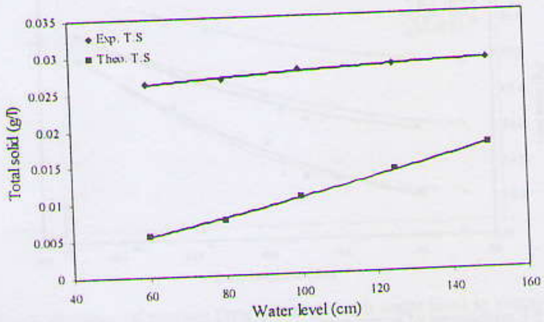

Fig. 19 Comparison of experimental and theoretical total solids of output water at rising time of 20 s and blanket height of 40 cm

Conclusions

The following major conclusions can be drawn from the Present Study:-

1. The results obtained in this work clearly points to the direct link between flocculation criteria and the performance of Pulsator Clarifier. The upflow velocity of water through flocculation basin , rising time , height of sludge blanket and the characteristics of sludge blanket are the main variables that determine the performance of pulsator clarifier
2. It is concluded that, the flocculation criteria decrease with increasing the upflow velocity of water and with decreasing the rising time and sludge blanket height. On the other hand, flocculation criteria for experiments lies within optimum range.
3. A reasonable agreement has been reached between predicted and the experimental values of total solids of output water only at high upflow velocity and low sludge blanket height.

Nomenclature

A	Cross sectional area of the basin, (cm^2)
C	Volume concentration of sludge blanket, (-)
G	Shear rate, (s^{-1})
G_{av}	Average time shear rate, (s^{-1})
GCt	Flocculation criteria, (-)
$(GCt)_{av}$	Average time flocculation criteria, (-)
g	Gravitational acceleration, (cm s^{-1})
H_b	Sludge blanket height, (cm)
L	Depth of water in the basin, (cm)
P	Power dissipated per unit volume, (J.s^{-1})
Q	Volumetric flow rate, (cm^{3}s^{-1})
t	Flocculation time, (s)
u	Water velocity through flocculation basin, (cm s^{-1})
u_{av}	Average time upflow velocity of water through basin, (cm s^{-1})
V	Volume of the flocculation basin, (cm^3)
V_l	Volume of liquid, (cm^3)
x	Total solids of water leaving the basin, (mg/l)
x_i	Total solids of water entering the basin, (mg/l)

Greek letters

μ	Viscosity of water, (gm cm^{-1}s^{-1})
ρ, ρ_s	Density of water and floc respectively, (gm cm^{-3})

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