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Algae-blanket phenomenon inside flat-bottom clarifier

Moharram Fouad[a,*], Shaban Hassan[b]

[a]*Public Works Department, Faculty of Engineering,Mansoura University, Mansoura, Egypt, email: m123f12317@yahoo.com, moharramf2001@yahoo.com(M. Fouad)*
[b]*Faculty of Engineering, Zawia University, Zawia, Libya, email: shubanhassan2012@yahoo.com (S. Hassan)*

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ABSTRACT

Algae-blanket phenomenon has been observed inside a large-scale flat-bottom clarifier for water treatment. This phenomenon occurred after running the reactor under high concentration of algae (10^9 cells/l) for a long time especially in hot climate regions. Under that high algae concentration, pre-chlorination doses up to 4.0 mg/l was not sufficient to prevent algae accumulation inside the sludge blanket layer. So, a gradual accumulation of algae (such as *Chlorella*, *Melosira*, and *Pediastrum*) occurred inside the sludge blanket, converting the whole blanket, to algae blanket after a specific period. So, this phenomenon depends on the algae concentration of the raw water, pre-chlorination dose, and the environmental conditions. As soon as the algal blanket is formed, the clarifier's performance is affected negatively. Algae blanket depletes all chlorine in the upper layer above it resulting in an accumulation of green weeds in that layer, as well as decreases the removal efficiency of the clarifier drastically. Finally, total failure of the clarifiers occurs after a few days associated with filter clogging. However, laboratory experiments confirmed this phenomenon and recommended that daily shock dose using chlorine with a concentration of 6.0 mg/l for one hour can prevent algae accumulation inside the sludge blanket layer.

Keywords: Water treatment; Flat-bottom clarifier; Sludge blanket; Algae; Chlorine dose

1. Introduction

Generally, high concentrations of algae (10^6–10^9 cells/l) cause many problems and increase the consumption of disinfectants in many plants [1]. High concentrations of algae cause many other problems such as color, odor, taste and toxins compounds as well as reduces the efficiency of water treatment and increases clogging of filters [2–4]. Finally, the presence of algae in sediments leads to changes in sludge characteristics and increases the difficulty in its removal [5].

As confirmed by several researchers, removal of algae by conventional sedimentation is not easy [5–7]. Although algae and clay colloids have the same sizes which range up to 1.0 microns, but the density of algae (1.2 g/cm^3) is generally less than that of clay (2.6 g/cm^3) [6]. Further, compared to clay colloids, algae consume a large amount of alum [7,8]. In addition, large algae cells fall slower than smaller algae cells [9,10] in contrast to solids. Large algae cells (more than 1.0 microns) may need several hour to settled [9,10]. Although high temperature increases the efficiency of sedimentation for most particles due to the decrease in fluid viscosity, but temperature has a negative effect on the removal efficiency of algal cells [11,12]. At high temperature, most algae cells swell and release large quantities of gases that reduce the coagulation of these cells [6]. Conversely, at low temperatures, better algal removal is achieved as production of gases due to algae photosynthesis is decreased, but low temperature decrease the efficiency of the sediment particles due to the decrease in fluid viscosity. So, algae removal is improved at temperatures of 10°C and below, but solid removal is improved only at temperatures of 20°C and above [13–16].

Generally, the flat-bottom clarifier is an important version of sludge blanket clarifier that, combining flocculation and sedimentation in one unit. This clarifier is equipped with surface sludge cones for excess sludge removal.

*Corresponding author.

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Compared to conventional sedimentation tank, this clarifier is more efficient, with high surface loading and less space requirement. Flat-bottom clarifier has good potential in upgrading sedimentation tanks, especially for algae removal [17,18]. The blanket is formed within the clarifier surface as water is pumped through the bottom of the clarifier and flows upwards. Then removal of colloid stakes place by a combination of flocculation, and straining of water through the blanket. The performance of the flat bottom clarifier depends on the raw water quality, coagulant concentration, temperature and up flow velocity. Typical retention time and surface loading of this clarifier are of 80–100 min and 60–80 $m^3/m^2/d$, respectively.

In hot regions, most water treatment plants using initial chlorine dose up to 4.0 mg/l to overcome algae accumulation. So, under retention time of 90 and 180 min for flat-bottom clarifier and conventional settler respectively, the product of chlorine concentration and the contact time (CT value) will be 360 and 720 mg min/l respectively. So under same initial chlorine dose, the CT value is lower in the flat-bottom clarifier compared to the conventional settler, that means algae destruction in the flat-bottom clarifier is less than that in the conventional settler.

Although flat bottom clarifier is a good solution for algae removal especially under low level of algae [16,17], the performance of sludge blanket under high level of algae is not clear and its removal efficiency could not be found. Under small value of CT and high algae concentration, algae cells can grow and accumulate inside the blanket. The accumulation of algae inside the blanket layer may cause many changes in the clarifier performance such as, increase the thickness of the sludge layer and the irregularity of its upper surface. With more increase of the algal cell inside the blanket, much algal cells may emerge out from the sludge blanket to the effluent water.

The aim of the present research is to study the behavior of a sludge blanket under high concentration of algae. Under high concentration of algae, much concentration of live algae will be accumulated in the blanket converting it to algae blanket phenomena. So, the main objective of this study was to observe algae-blanket phenomenon in flat-bottom clarifier and monitor all its consequences on the performance of this clarifier. Further, this study aims to evaluate the performance of, flat-bottom-chaffier, with respect to removal efficiency of turbidity and algae, during the conversion of the blanket from sludge-blanket into an algae-blanket.

2. Experimental work

Data of this study was collected from the field and confirmed using laboratory scale set up, as explained below.

For reliable results, long-term data were collected from several plants which located in northern Egypt having flat-bottom clarifiers treating natural surface water for drinking water (discharges of 50,000–100,000 m^3/d). The data were observed for flat bottom clarifier has a length of 36 m and width of 16 m as well as water depth of 4 m located in Ibshan, Kafr El-Sheikh, Egypt. Fig. 1a shows a schematic diagram of the flat-bottom clarifier with discharges of 35,000 m^3/d. A typical retention time of 85 min and surface loading of 67.5 $m^3/m^2/d$ are used to treat high turbid water (turbidity = 30–40 NTU and algae concentration up to billion cell/lit).

Daily samples were taken from the influent, effluent, as well as along the tank depth for one year operation. Fur-

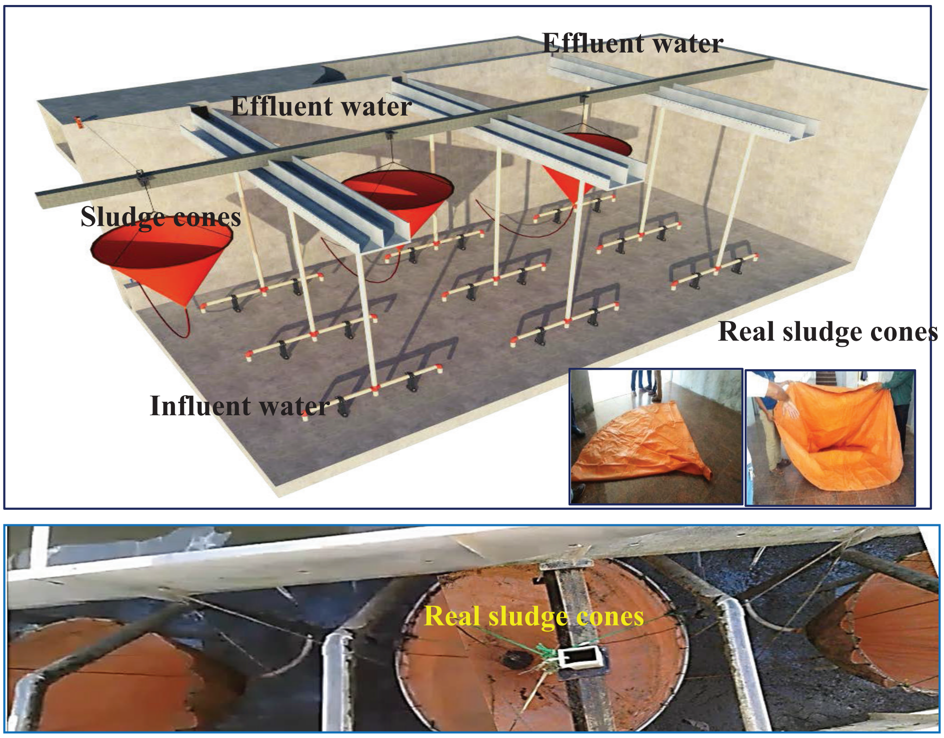

Fig. 1a. Schematic diagram of a typical large scale flat-bottom.

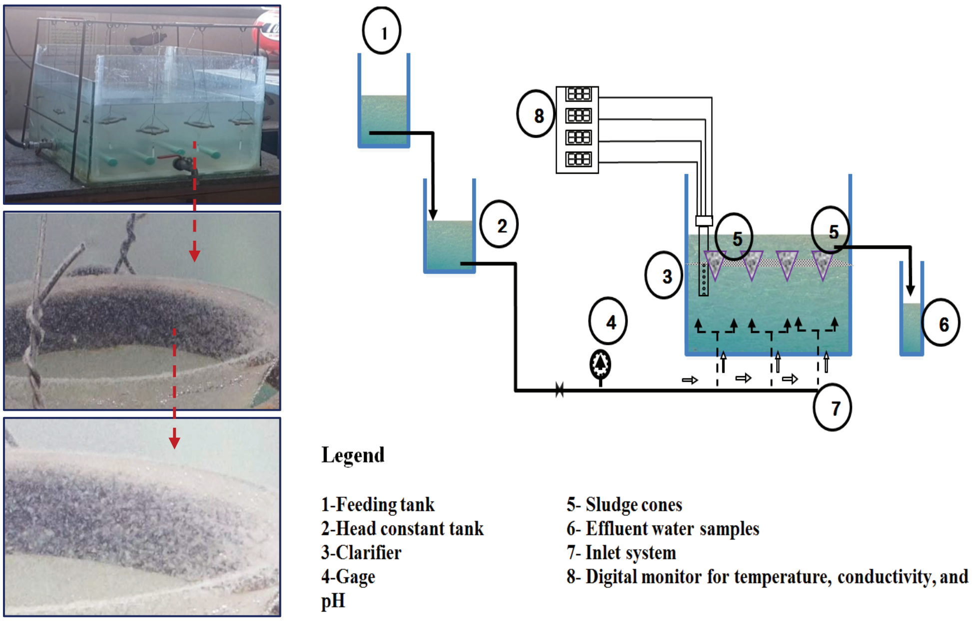

Fig. 1b. Schematic diagram of the experimental set up.

ther, samples were collected from the sludge blanket of these flat-bottom clarifiers. These samples were examined for removal efficiency of turbidity and algae as well as take-off residual chlorine. The removal efficiency was estimated as (influent – effluent)/influent × 100. Further, each sample from the effluent was examined for residual chlorine and the dissolved oxygen. Temperature, pH, and conductivity, were also continuously monitored. Samples from the sludge blanket were periodically examined to get the algae/solid ratio. Algae/solid ratio was determined by weight as well as zeta potential. The ratio of algae was determent as the weight of the organic matter after ignition at 550°C. Daily algae concentration and characterization were measured and observed in the clarifier and in the effluent water. Finally, the top level of the blanket and its thickness were approximately estimated as well as Zeta potential was observed.

2.1. Laboratory data

To supplement the field findings, laboratory experimental were carried out inside the laboratory using small scale set up under continuous conditions. Fig. 1b illustrates the flow diagram and schematic of the bench scale set up that used in the present study. The laboratory clarifier consisted of a glass basin. The glass basin was 60 cm in length, 50 cm in width and 40 cm in height to accommodate a volume of 120 l. Digital monitor was connected to measure total dissolved solids (TDS), conductivity, temperature, and pH. Natural algae and powdered clay were used as two sources of algae and turbidity respectively. The pH and oxygenation levels were controlled at 7.0 and 7.0 mg/L, respectively. In each case, the source of turbidity was started with clay only, then the clay content was gradually reduced and the algae content was gradually increased up to 10^9 cells/l. The experiment was also conducted at different ratio of solid/algae in the blanket. Real algae were collected from the field and supplemented to the blanket of the set up. The primary characteristics of first synthetic raw water from clay powdered was as follows: NTU = 80, pH ≈ 7.0, DO ≈ 7.0, temperature ≈ 25–30°C, without any algae. However, the primary characteristics of synthetic raw water from algae were as follows: NTU = 80, algae concentration up billion cell/ l, temperature ≈ 25–30°C, DO ≈ 7.0. In each case, the source of turbidity was started with clay only, then the clay content was gradually reduced and the algae content was gradually increased up to 10^9 cells/l. The experiment was also conducted at different ratio of solid/algae in the blanket. Comparison chlorine dosing regarding the different ratios of solid/algae in the blanket. Initial choline doses of 0.5, 1.5, 2.0, 4.0, and 6 was added to the raw water.

The main aim of the experimental runs was to observe the movability of solids and algae cells with the effluent water after passing from the blanket. Further, to estimate the effect of the initial chlorine dose and the contact time on algae removal under high algae concentration of 10^9 cell/l and to confirm the observed results from the field. Finally, laboratory data estimated the effect of CT-value on the algae removal in laboratory at high algae concentration of 10^9 cell/l and under different ratio of solid/algae in the blanket. All parameters were measured according to the Standard Methods for the Examination of Water and Wastewater as described by Fouad and Hassan [19].

3. Results and discussion

The results of this study were divided into two parts which are field observation and laboratory experiments.

3.1. Field results

Under medium concentration of algae less than 10^6 cell/l, field observations of several clarifiers confirm that flat bottom clarifier works well which is confirmed also by Fouad and Hassan, [19]. Under that algae concentration, a little accumulation of algae was trapped inside the blanket that did not reduce its efficiency. The trapped algae were easily disposed from the tank surface to the sludge-cones with an efficiency of 95% and solids kept predominated in the blanket.

Under medium concentration of algae between 10^6 and 10^9 cell/l, several clarifiers under similar operational conditions have showed a significant reduction in the efficiency especially for algae removal. At that algae concentration, algae and solids were mutually predominated inside the blanket (at night solids predominate and at day solids predominate) yielding algae-solid blanket. Algae-solid blanket showed bad performance for solid and turbidity removal less than 85% and 70% respectively. The rate at which the blanket is converted from solid to algae and vice versa was a function of algae concentration, chlorine dose and the solids concentration in the raw water as well as the environmental conditions.

Under high algae concentration (10^9 cell/l), algae start to accumulate significantly inside the blanket, especially near the sludge-cones that used for sludge collection as shown in Fig. 2. After continuous operation for about 14 days, under high algae concentration, algae constituting about 60% of the weight of the blanket and predominated in the blanket

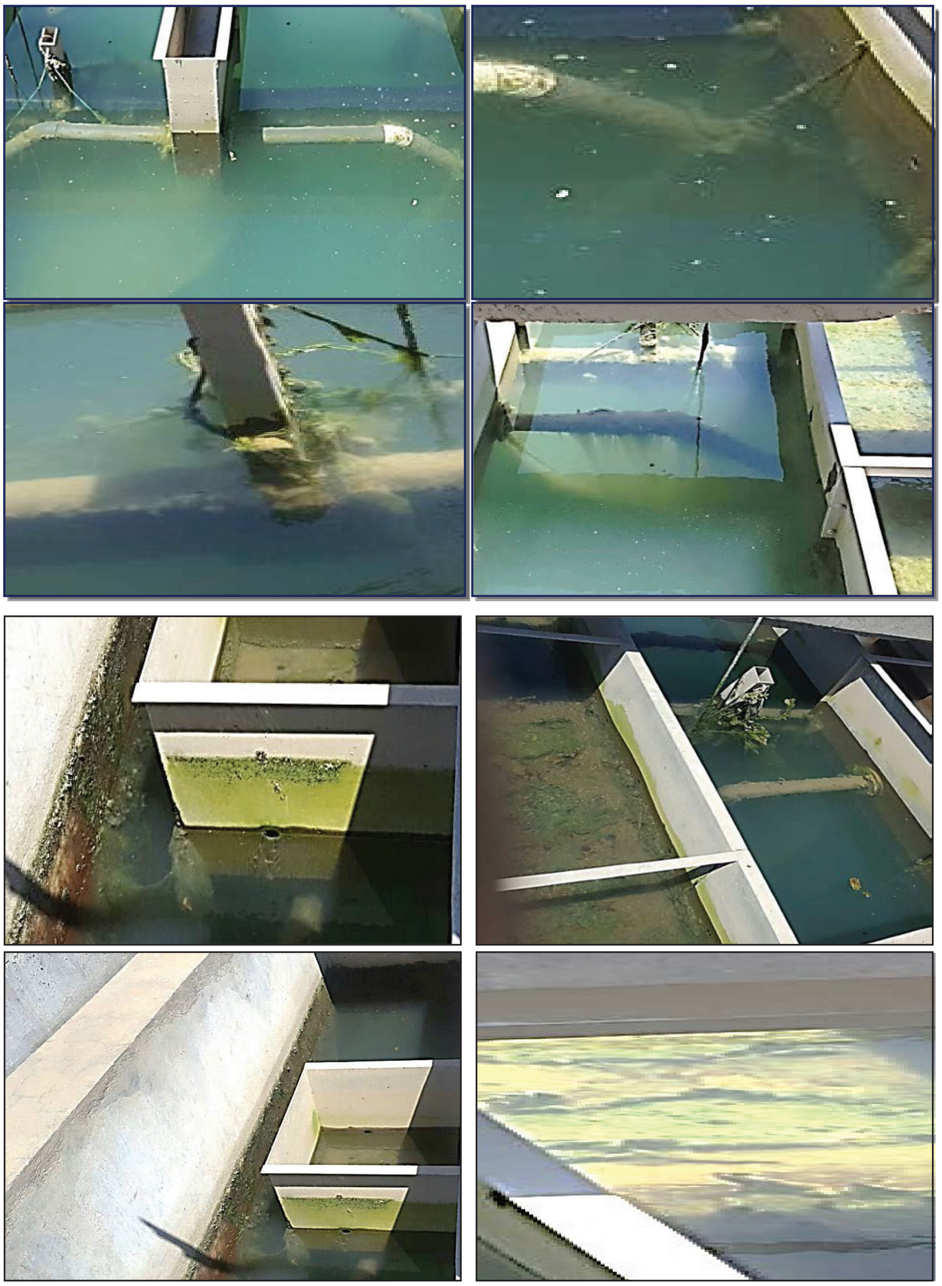

Fig. 2. Shape and color of the water during operation and after lowering the water level during the algae blanket.

instead of the solids. At those conditions, algae cause depletion of all chlorine inside the blanket associated with much accumulation of green weeds in the upper layer of the tank. Pre-chlorination dose up to 4.0 mg/l, was not sufficient to prevent the accumulation of algae (such as *Chlorella*, *Melosira*, and *Pediastrum*) and green weeds inside and above the blanket.

Fig. 3a shows sample collection from the blanket while Fig. 3b shows some algae types that were found in the blanket. Fig. 3c shows the accumulation of algae on the filter surface and the failure due to filter clogging that happened through few days.

Figs. 4a and 4b show the schematic diagram a typical large scale flat-bottom clarifier, and the concentration of the residual chlorine at different levels before and after converting the blanket into algae-blanket. It is clear that before the algae dominate in the blanket, pre-chlorination dose of 4.0 mg/l, was able to produce effluent water with residual chlorine of 1.4 mg/l. Only the residual chorine is reduced from 3.2 to 1.4 mg/l from the tank bottom to the tank surface when running the clarifier under sludge blanket layer (Fig. 4b). Further, there is no depletion of chlorine due to passing the water through the sludge blanket layer. Conversely, after increasing the algae in the blanket, the residual chlorine in the effluent was reduced gradually, under the same pre-chlorination dose. Finally, after the algae reach-

Fig. 3c. Algae accumulation on the filter surface at 2 pm.

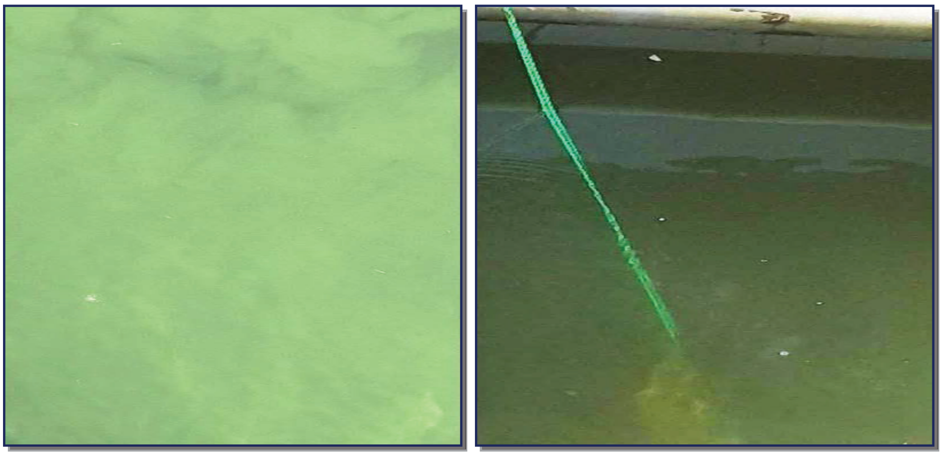

Fig. 3a. Collection of samples from during operation under algae blanket.

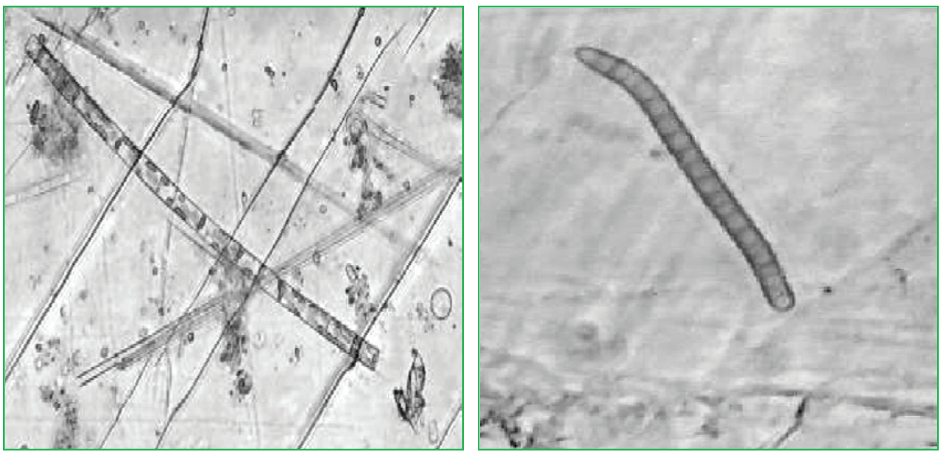

Fig. 3b. Algae types inside algae blanket (Chlorella–Melosira–Pediastrum).

Fig. 3d. Algae on the filter surface at 2 pm during algae blanket.

ing about 60% in the blanket,the residual chlorine vanished (Fig. 4c) inside the blanket and in the effluent water. Further, Fig. 5a summarizes the residue chlorine values of the effluent along the depth of the flat bottom under each case of sludge blanket and algae blanket. Fig. 5b shows the effect of increasing the algae in sludge blanket on the residue chlorine of the effluent. It is clear that the residue chlorine is decreased from 1.45 to 0.0 during the algae accumulation in the blanket up to 60%.

The turbidity and algae removal was also observed during the algae accumulation in the blanket. Fig. 6a shows the average removal of algae and turbidity with the increase in the amount of algae in the blanket layer. Fig. 6a indicates that the flat bottom clarifier achieves removal effluent of 98% for both algae and turbidity in the absence of algae in the blanket. Then the removal is gradually decreased to 60%, 5% for turbidity and algae to removal respectively after the algae reaching about 60% in the blanket .It was useful to state that, the val-

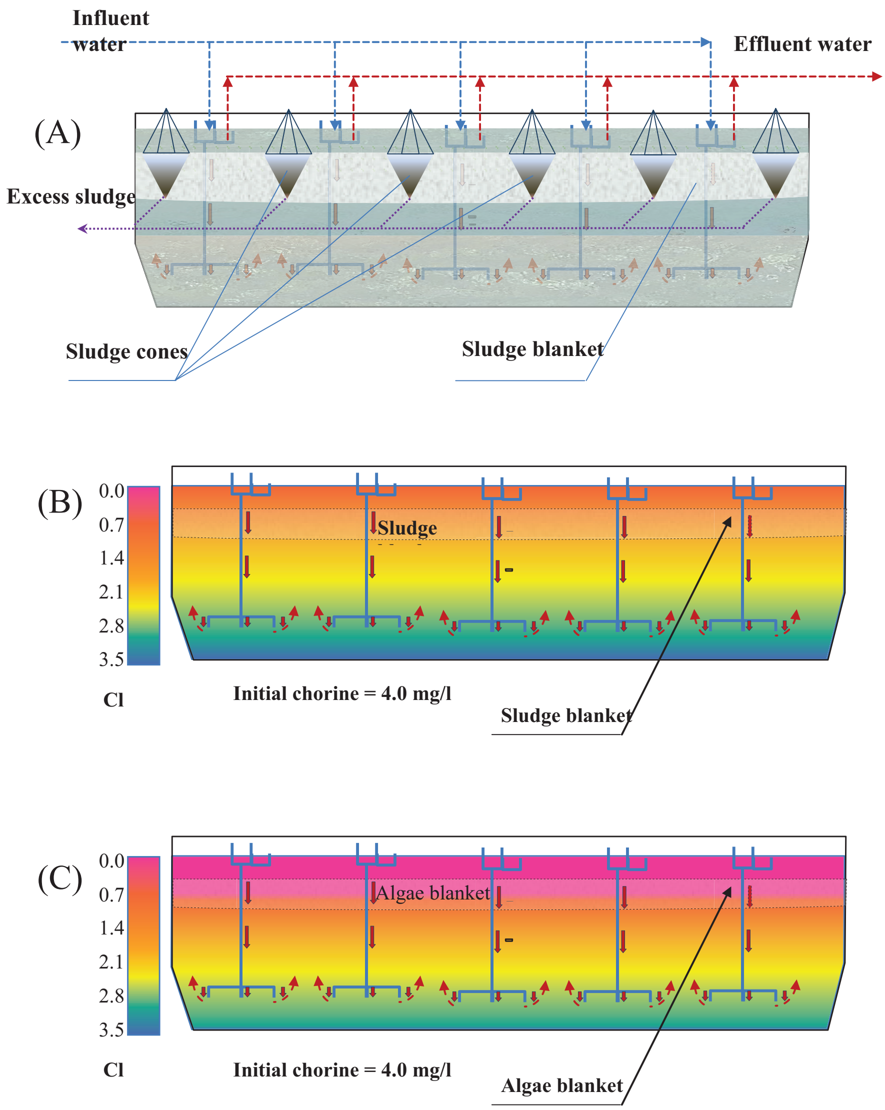

Fig. 4. (A) Schematic diagram of the large scale flat-bottom clarifier, (B) Residual chlorine concentration during operation under sludge blanket, and (C) Residual chlorine concentration during operation under algae blanket.

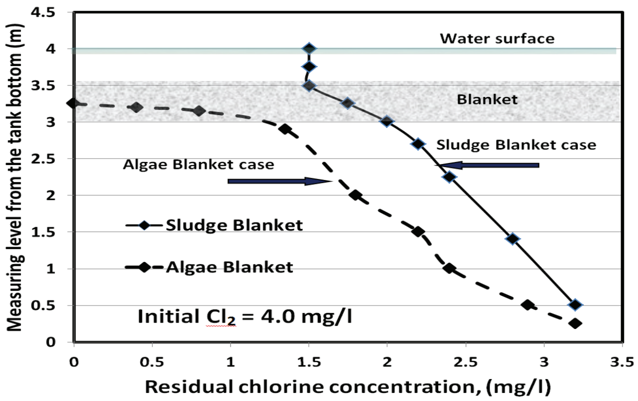

Fig. 5. a. Residual chlorine concentration at different depths at 2.0 PM (in case of algae blanket and sludge blanket)(flied data).

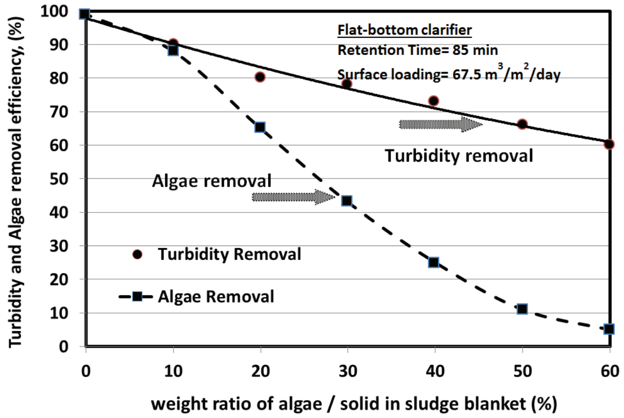

Fig. 6. a. The effect of weight-ratio of algae/solid in sludge blanket on the turbidity and algae removal against (flied data).

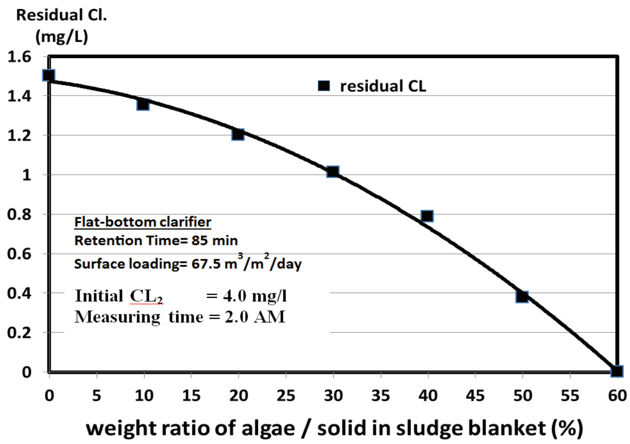

Fig. 5. b. The effect of weight-ratio of algae/solid in sludge blanket on the residue chlorine of the effluent (flied data).

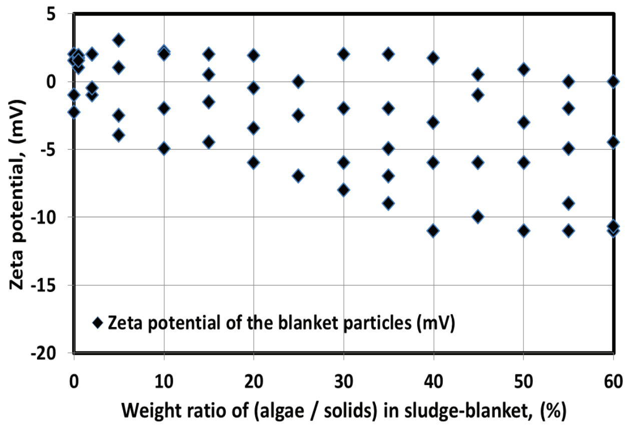

Fig. 6. b. The effect of weight-ratio of algae/solid in sludge blanket on Zera-potential of the blanket particles (flied data).

ues of zeta potential were increased drastically with the increase of the algae in the blanket (Fig. 6b). Zeta potential was nearly zero at the absence of algae in the blanket then it come up to about –12 Mv after the algae reaching about 60% in the blanket.

The above results can be interpreted easily; most algae have a density ranging from 1.0 to 1.2 as confirmed by Oliver et al. [20], Hu [21], and Gerde et al. [22].Therefore, most algae cells start to accumulate on the upper part of the blanket. Then increasing the water temperature and dissolved oxygen during the daylight increase both the blanket depth, level its and its irregularity which enforce huge amount of algae to leave the blanket with the effluent water. So, after the algae constituted about 60%, the blanket thickness was increased about 125–150% from its original depth with an increase in its irregularity, as well as rising in its top level to the water surface. Further, depletion of most chlorine from the water surface and caused a clear fluctuation of oxygen values and the removal efficiency between the day and night in the same tank causing a rapid failure of the clarifier. At that failure phase, a rapid reduction in the removal efficiency was observed and the clarifier showed its worst performance at daylight. At daylight much of algae were continuously escaping from the clarifier to the filter, i.e. at noon, the clarifier delivered much amount of algae, causing rapid filter clogging as depicted in Fig. 2.

To support the above results, the dissolved oxygen (DO) concentration and the algae removal of the effluent were observed throughout the day after algae-blanket phenomena. It was found that DO values were changed inside same tank from 6.75 to 8.55 mg/l at night and daylight respectively (Fig. 7). During daylight, light and temperature excites the algae to produce high DO values, which forces the algae to overcome the optimal alum dose and helping these algae to float near the tank surface, thus reduces the removal efficiency of such tanks. It was found also that optimum alum doses were not the same under different DO values and not suitable for DO values between 6.75 to 8.55 mg/l. Fig. 7 shows also that maximum DO values are found at 14:00. At that time the removal efficiency of the algae comes down to the minimum value and much algae escape from the clarifier surface to the filter. These results are confirmed by several researchers, such as Gates and McDermott [23] and Wu et al. [24] who stated that most types of algae move with the water stream towards the surface of the tank regardless of the type of algae (floatable or submersible) at high DO level. At night time, positive removal

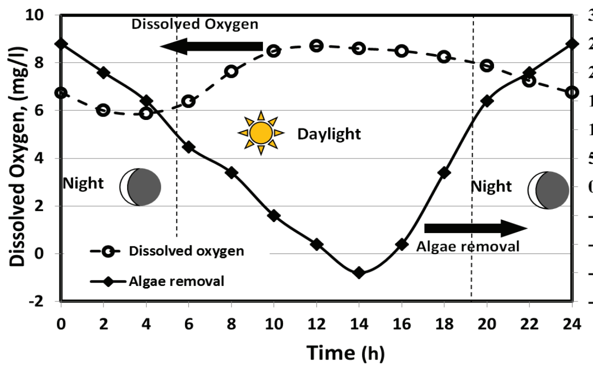

Fig. 7. Dissolved oxygen concentration and algae removal of the effluent waters throughout the day after algae-blanket.

efficiency of algae is observed due to the lower oxygen concentration and the good flocculation of algae cells.

3.2. Laboratory results

According to Figs. 7a and 7b,the laboratory experimental reveal that, under high concentration of algae (10^9 cells) pre-chlorination dose less than 2.0 mg/l is not enough to damage all algae cells. Under retention time less than 150 min, pre-chlorination dose more than 4.0 mg/l is required. Further full damage of high concentration of algae (10^9 cells) requires pre-chlorination dose less than 6.0 mg/l, especially under short retention time of 90 min as a typical retention time in the flat-bottom clarifier. Laboratory results recommend also that the water is required to be diverted during and right after, the performing of a chlorine shock as the TDS value is increased about 150% of its usual values.

4. Conclusion

Field data confirm that flat-bottom clarifier works well when algae vanish within the blanket. Conversely, increasing the algae in the blanket decreases the removal efficiency of the clarifier. Finally, when the algae predominate in the blanket, it increases the blanket depth and decreases its density, as well as increase zeta potential of the algae cell which leads to escape much algae and solids as well as depletion of most chlorine from the water. So the flat-bottom clarifier is not suitable to treat that water of high concentration of algae (10^9 cells/l), especially for a long periods. Under that high algae concentration, pre-chlorination dose up to 4.0 mg/l is not sufficient to prevent live algae accumulation inside the sludge blanket layer. Consequently, few days is enough to produce algae blanket phenomena which leads to total failure of the clarifiers as well as filter clogging. Algae blanket also depletes all chlorine in the upper water surface, resulting in an accumulation of green weeds in that layer. Laboratory experiments confirmed that chlorine shock dose with a concentration of 6.0 mg/l for one hour can prevent algae accumulation inside the sludge blanket layer. However, the water is required to be diverted during and right after, the performing of a chlorine shock as the TDS value is increased about 150% of its usual values.

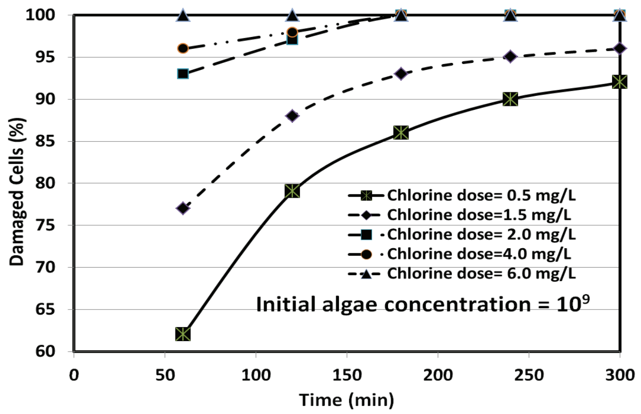

Fig. 8. a. Effect of initial chlorine dose and contact time on the algae removal in laboratory scale at algae concentration of 10^9 cell/lit (lab. data).

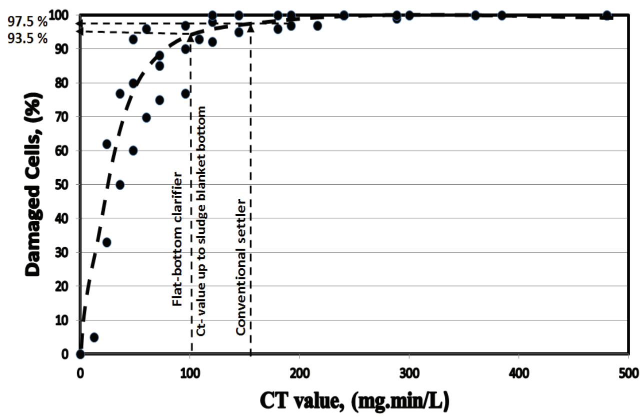

Fig. 8. b. Effect of CT-value on the algae removal in laboratory at algae concentration of 10^9 cell/L.

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