FINAL SETTLER PERFORMANCE AS A BIO-REACTOR IN ACTIVATED SLUDGE PROCESS

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Abstract

Pilot plant study showed that there is a relationship between the HRT in aeration tank and the % removal of soluble COD in the final settler if DO is not a limiting function. It was found that the % removal of soluble COD in final settler increased from 13 at HRT in aeration tank of 12 hours to 45 at HRT of 4 hours. Mathematical model was also presented in order to predict the soluble COD utilization in final settler.

Keywords: Activated sludge, Final settler, Biological activity.

1. Introduction

Activated sludge wastewater treatment plants can be considered as a large complex system with inputs which are not always predictable, and with strong interactions among process units. Most activated sludge plants operate in a dynamically changing environment; it is common to observe large variations in wastewater flow rate, concentration, and composition.

Generally, in activated sludge process, final settler must perform 2 functions: clarification to produce high quality effluent and thickening of settled solids in the under-flow. Sudden increases in flow rate into activated sludge treatment plants will reduce the hydraulic retention time in aeration tanks and also will cause high concentrations of both solids and soluble organics to be transported into the final settler. Experimental evidence has established that such increases in flow rate result in increases in the concentration of effluent solids, but not necessary in the concentration of soluble organics [1,2]. Such finding could support the hypothesis that the final settler serves as a bio-reactor if enough dissolved oxygen is available. Unfortunately, very little information can be found in the literature concerning the role of the final settler in removing organics. Because there is no consensus in the literature concerning the biological activity of the final settler, an attempt was made in this study to: first, investigate such role of final settler under several flow rates; second, to propose and adopt a mathematical model to represent and predict such phenomena.

2. Experimental Procedure

In order to investigate the role of final settler in removing soluble organics under several flow rates, laboratory experiments were performed.

2. 1. Pilot Plant

The experimental work was conducted on a laboratory pilot plant. The pilot plant under study was fabricated and located at the Sanitary Engineering Laboratory of the Faculty of Engineering, Alexandria University. As shown in Fig. 1, the pilot plant is consisted of a feed tank of 1.0 m^3 volume, followed by the activated sludge unit. This unit is consisted of a plexiglas completely mixed reactor of 40 liter volume. The aeration was provided using 2 air diffusers which were connected to an air compressor with a plastic tube. The aeration tank is followed by a final settler with surface area of 0.16 m^2 and 20 liter volume. The system was provided with 2 peristaltic pumps, the first pump (p1) to feed the synthetic wastewater to the aeration tank, the second pump (p2) to return the sludge from the final settler to the aeration tank. Synthetic Wastewater feed solution was used as the substrate to the pilot plant. The synthetic wastewater was prepared according to Battistone [3].

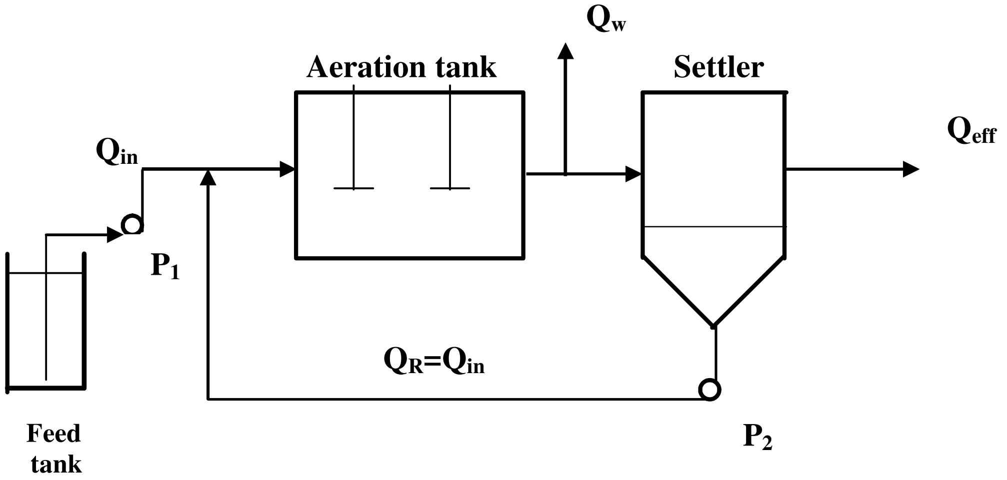

Fig. 1. Activated sludge pilot plant

The stock solution was prepared as follows: Dissolve 40 g/l of glucose; 11.65 g/l of $Na.3Po_4.12H_2O$; and 8.8 g/l $(NH_4)2SO_4$ in one liter of tap water. The synthetic wastewater can be prepared by diluting the stock solution with tap water (1:100). The synthet wastewater was daily prepared fresh.

Start-Up

The start-up of the activated sludge pilot plant was conducted as follows:

1. The activated sludge pilot plant was seeded with sludge taken from Kafr El Dawar Wastewater Treatment Plant. The sludge seed was aerated and completely mixed before applying to the pilot plant.
2. The synthetic wastewater was fed to the reactor at rate of 120 l/d and return activated sludge was also 120 l/d. The system was operated for 2 weeks to reach steady state, reaching the steady-state was indicated by the improvement and stabilization of the effluent quality.
3. After reaching steady-state, sludge was wasted periodically from the aeration tank to reach the projected solids retention time (SRT).

Experimental Plan

After the initial start up period, the activated sludge pilot plant was operated at several hydraulic retention times (HRT) [4, 6, 8, 10, and 12 hours]. Each change in HRT was followed by a period of approximately 1 week before the next change in HRT occurred. Except HRT all other operating conditions were kept constant. The SRT was kept constant at 10 days; the dissolved oxygen (DO) in the aeration tank was maintained within 2-4 mg/l. The duration of each run was about 3 weeks. During this study, an extensive sampling program was conducted to determine the quality of treated wastewater during each run. The pilot plant was run 24 hr/day, 7 days/week, but data were collected regularly 5 days/week.

Sampling and Analysis

Samples were taken from influent, before final settler, and final effluent. Grab samples were taken 4 times per day for analysis, then the average of each day was calculated, the average of each run was also recorded. Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Mixed Liquor Suspended Solids (MLSS) and Mixed Liquor Volatile Suspended Solids (MLVSS) were determined in accordance with the American Standards Methods for the examination of Water and Wastewater (4). Soluble COD was determined using 0.45 μm filters, any material passing through those filters was considered to be soluble. The filtrate contained organic matter attributable to colloidal and dissolved compounds but is referred to herein as soluble COD. The DO was measured in the final settler at 10 cm from water surface.

3. Results and Discussion

Investigation of the effect of particular variables on the performance of an activated sludge unit requires that the system should be operated at steady-state. The unit operated during this study approximately met the steady-state conditions.

In order to invistigate the effect of HRT in aeration tank on soluble organic removal on final settler, all operating parameters were kept constant except HRT was varied according to the experimental plan. SRT was maintained constant at 10 days; constant recycle ratio of 100 % was also maintained. The data depicting the average performance of the pilot plant for each HRT are presented in Table 1.

From Table 1 it is clear that increasing the HRT in aeration tank improves the removal efficiency of both COD and BOD. The COD and BOD removal percentages increased from 78.8 and 79.5 at HRT of 4 hrs. to 88.4 and 89.3 respectively at HRT of 12 hrs. Any decrease in the HRT resulted in increasing effluent organic concentration and also resulted in increasing effluent suspended solids concentration due to washout conditions. The question here is how the final settler will perform when it receives high concentrations of soluble organic during short HRT. In order to experimentally answer this question, soluble COD was measured before and after the final settler under different HRT in the aeration tank.

Table 1. The average performance of the activated sludge pilot plant under different HRT

Influent	Flow Rate l/d	120	80	60	48	40
	HRT hr	4	6	8	10	12
	Temperature °C	19-20	19-20	19-20	19-20	19-20
	pH	6.66	6.64	6.54	6.6	6.6
	COD mg/l	531	532	540	565	534
	BOD mg/l	425	420	477	470	450
Aeration Tank	MLSS mg/l	2150	2568	3086	3095	2700
	MLVSS mg/l	1762	2105	2530	2537	2190
	F/M	0.9	0.5	0.32	0.26	0.24
Final Effluent	COD mg/l	112	105	90	79	62
	BOD mg/l	87	75	70	59	48
	SS mg/l	118	87	53	32	28
Removal Efficiency	COD %	78.8	80.3	83.3	86.0	88.4
	BOD %	79.5	82.1	85.3	87.5	89.3

Figure 2 presents the relationship between HRT in aeration tank and the % of soluble COD removal in final settler. By examining this Figure it can be realized that decreasing HRT in aeration tank results in higher soluble COD to be transported from aeration tank to final settler. This also results in increasing the % of soluble COD removal in final settler. From Table 2, the soluble COD removal in final settler increased from 13% at HRT in aeration tank of 12 hour to 45% at HRT of 4 hours.

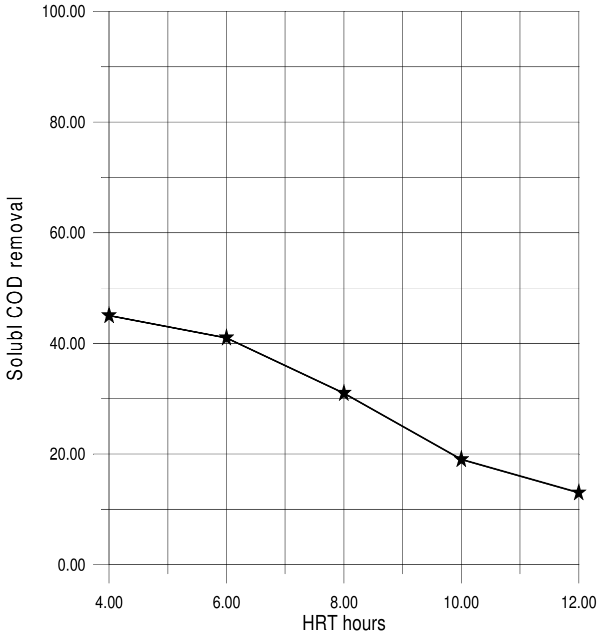

Fig. 2. Relation between HRT and soluble COD removal

Table. 2. The performance of the final settler under different HRT in aeration tank

HRT (hr)	4	6	8	10	12
Influent COD conc. Mg/L	531	532	540	565	534
Reactor DO mg/L	2-4	2-4	2-4	2-4	2-4
Before Soluble Settler COD mg/L	118	110	84	69	52
Final Settler DO mg/L	1.50	1.00	0.75	1.00	0.75
Effluent Soluble COD mg/L	70	65	58	56	45
% Soluble COD removal in final settler	45	41	31	19	13

The DO in the aeration tank was maintained within the desired limits (2-3 mg/L), the DO in final settler varied but never fell below 0.75 mg/L.

According to these results it can be concluded that the final settler can act as a bio-reactor when it receives high concentration of soluble COD due to short HRT in aeration tank, this role of final settler should be considered especially during hydraulic shock loading such as rainstorms.

4. Final Settler Model

An attempt was made in this study to develop a comprehensive settler model which can predict the biological activity of the final settler. This was not an easy task because most models assume that the process which occurs in the final settler is merely one of physical character, i.e. no reaction takes place.

In general, the proposed model was developed by adopting submodels taken from the literature; these submodels were modified where necessary. The proposed model assumes that the settler is divided into a number of equally sized layers (10 layers), the model works into 2 steps: first, solids concentration in each layer is predicted according to a dynamic settler model, second, in order to predict the soluble organic utilization in the final settler, each layer is assumed to act as a biological reactor and is modeled according to modified version of the IAWQ model [5]. Aerobic growth of biomass results in soluble organic removal, while hydrolysis of particulate organics produces soluble organics. The difference is the soluble organic concentration in each layer. No doubt that, dissolved oxygen concentration in each layer has direct effect on the rate of organic utilization; this is why it must be included in material balance equations in the full version of the model.

In order to predict solids concentration in each layer a settler dynamic model was employed. In this model the settler is divided into n equally sized layers. Feed enters the feed layer (f), and wastewater flows either up into the top zone to leave as effluent or down into the bottom to be thickened and leave as returned activated sludge. Solids settling velocity is originally calculated from the Vesilind Eq. [6]:

$$Vs = Vo \exp(-b_1.X) \qquad (1)$$

where:

Vs = settling velocity $(m.d^{-1})$
Vo = max. settling velocity $(m.d^{-1})$
b1 = empirical parameter $(m^3.g^{-1})$
X = solids concentration $(m^3 \cdot g^{-1})$

For the solid components, the general mass equation is:

$$\frac{dX}{dt} = \frac{Q}{V}(X_{in}-X) + \frac{A}{V}(V_s.X_{above} - V_s.X) \qquad (2)$$

where:

Q = flow rate $(m^3.d^{-1})$
V = layer volume (m^3)
X_{in} = inlet solids concentration $(g.m^{-3})$
A = settler surface area (m^2)
V_s = settling velocity $(m.d^{-1})$
X_{above} = solids concentration in the layer above $(g.\ m^{-3})$

Q has the value for the effluent flow above the feed point, the value of the total flow at the feed point, and the value of the returned activated sludge plus wastage sludge below the feed point. Above the feed point the inlet concentrations are those for the entering mixed liquor.

At the top of the settling tank there are no solids to enter from air, so the value of Vs X above is zero. At the base of the settler the tank floor prevents further settling, so that the value of V_s X is zero. The settling velocity Vs is calculated as a function of the solids concentration as given by the Vesilind equation.

This model is reported as under predicting the effluent solids, this is why the Tackacs modification [7] was considered in the proposed model. The settling velocity according to the modification is:

$$V_s = \min(Vmax, Vo[e^{-b1.x} - e^{-b2.x}]), \qquad (3)$$

where:

Vmax= maximum practical settling velocity $(m.d^{-1})$
V_o = maximum theoretical settling velocity $(m.d^{-1})$
b_1, b_2 = empirical parameters
X = solids concentrations $(g.m^{-3})$

where the solids are partitioned into two fractions, settleable and non-settleable. Only the settleable fraction is used in calculating the settling velocity. Limits are placed on the settling flux to mini mimic the effects of a minimum settling flux. For any zone within the tank the settling flux is specified by the equation:

$$(V_s.X)_{out} = \min([V_s.X]_{zone}, [V_s.X]_{below}) \qquad (4)$$

The simple method of solving equation (4) is to produce a graph of the Vo $(\exp[-b_1X]-\exp[-b_2X])$ term and use the graph to locate the concentrations of X that give the Vmax values. The model has the parameters: Vmax, Vo, b1, and b2. Values of these parameters can be calculated as proposed by Rachwel et al. [8]:

$$Vo = 9.32 - 0.039\ SSVI_{3.5} \qquad (5)$$

$$b_l = (0.269 + 0.00122\ SSVI3.5)*10^{-3} \qquad (6)$$

where

Vo = maximum theoretical settling velocity (mh^{-1})
b_l = empirical parameter $(l.mg^{-1})$
$SSVI_{3.5}$= stirred sludge volume index at MLSS of 3.5g/l $(ml.g^{-1})$

$$Vmax = (10.9+o.18\ SSVI_{3.5})\ \exp(-0.016\ SSVI_{3.5}) \qquad (7)$$

$$b_2 = (0.016+0.0027\ SSVI_{3.5}) * 10^{-3} \qquad (8)$$

where:

$Vmax$= maximum practical settling velocity $(m\ .h^{-1})$
b_2 = empirical parameter $(l.mg^{-1})$

The model at this stage can predict solids concentration in each layer. However, the soluble organic utilization in the settler still cannot be predicted. In order to incorporate the biological activity of final settler it was assumed that each layer of the settler acts as a complete mix reactor and was modeled according to the modified version of the IAWQ model [5]. The material balance for soluble substrate in settler layers is as follows:

Feed layer (f)

$$Vf.\frac{dS_{sf}}{dt} = (Qe+Qr)S_{sin} - Qe.S_{sf} - Qr.\ S_{sf} + rS_{sf}.Vf \qquad (9)$$

where:

Vf = feed layer volume (m^3)
S_{sf} = soluble substrate concentration in feed layer $(g.m^{-3})$
S_{sin}= soluble substrate concentration from aeration tank $(g.m^{-3})$
rS_{sf}= soluble substrate process rate

The soluble substrate process rate in each layer is the difference between soluble substrate utilized by bacteria and soluble substrate produced by hydrolysis:

$$rS_{sf}(\text{utilized}) = -\frac{1}{Y_B}.\hat{\mu}_B.\frac{S_{sf}}{K_s + S_{sf}}.\frac{S_{of}}{K_o + S_{of}}X_{B1} \qquad (10)$$

$$rS_{sf}(\text{produced}) = \frac{K_H(X_{sf})}{K_x + (X_{sf}/X_{Bf})}.\frac{S_{of}}{K_o + S_{of}} \qquad (11)$$

$$rS_{sf} = rS_{sf}(\text{utilized}) + rS_{sf}(\text{produced}) \quad (12)$$

where:

Y_B= growth yield	(g^{-1})
$\hat{\mu}_B$ = maximum biomass specific growth rate	(d^{-1})
K_s= biomass half saturation coefficient	($g.m^{-3}$)
Y_{Bf}= active biomass concentration in feed layer	($g.m^{-3}$)
K_o= oxygen half saturation coefficient	($g.m^{-3}$)
S_of= oxygen concentration in feed layer	($g.m^{-3)}$
K_H= maximum hydrolysis rate	(d^{-1})
K_x= hydrolysis half saturation coefficient	($g.m^{-3}$)
Y_{sf}= slowly biodegradable substrate in feed layer	($g.m^{-3}$)

Layers above feed layer (i)

$$Vi.\frac{dSsi}{dt} = Qe.S_{si} + 1 - Qe.S_{si} + rS_{si}.Vi \quad (13)$$

where:

$$rS_{si}\ (\text{utilized}) = -\frac{1}{Y_B}.\hat{\mu}_B\ \frac{Ssi}{Ks + Ssi}\cdot\frac{Soi}{Ko + Soi}\cdot X_{Bi} \quad (14)$$

$$rS_{si}\ (\text{produced}) = -\frac{K_H(X_{si})}{K_x + (X_{si}/X_{Bi})}\cdot\frac{S_{oi}}{K_o + S_{oi}} \quad (15)$$

$$rS_{si} = rS_{si}(\text{utilited}) + rS_{si}(\text{produced}) \quad (16)$$

Ssi = soluble substrate concentration in layer i	($g.m^{-3}$)

Layers under feed layer (j)

$$V_j\frac{dS_{si}}{dt} = Qr.S_{sj-1}Qr.S_{sj} + rS_{sj}.\ \ V_j \quad (17)$$

where:

$$RS_{sj}(\ \text{utilized}) = -\frac{1}{Y_B}.\ \hat{\mu}_B\ .\ \frac{S_{sj}}{K_s + Ssj}.\ \frac{S_{oj}}{K_o + S_{oj}}.\ X_{BJ} \quad (18)$$

$$rS_{sj}\ (\text{produced}) = \frac{K_H(X_{sj})}{K_x + (X_{sJ}/X_{BJ})}.\ \frac{S_{oJ}}{K_o + S_{oJ}} \quad (19)$$

$$rS_{si} = rS_{si}(\text{utilized}) + rS_{sJ}(\text{produced}) \quad (20)$$

S_{sj} = soluble substrate concentration is layer j (g.m^{-3})

It must be indicated that this work will be extended in order to perform model verification, using computer simulation and experimental data.

5. Conclusions

- The pilot plant results showed that the final settler in activated sludge process acts as a bio-reactor, when it receives high concentrations of soluble organics and DO is not a limiting factor.
- Results of pilot plant study also showed that decreasing HRT in aeration tank causes an increase in the % removal of soluble COD in the final settler.
- A comprehensive settler model was presented in to simulate the biological activity of final settler. The proposed model was developed by adopting submodels taken from the literature; these submodels were modified where necessary. Every effort was made to keep the model as simple as possible without reducing its accuracy.

Nomenclature

A	Settler surface area
b_1	Empirical parameter
b_2	Empirical parameter
BOD	Biochemical oxygen demand
CO	Chemical oxygen demand
DO	Dissolved oxygen
f	Feed layer
HRT	Hydraulic retention time
i	Layer i
j	Layer j
K_H	Maximum hydrolysis rate
K_o	Oxygen half saturation coefficient
K_s	Biomass half saturation coefficient
K_x	Hydrolysis half saturation coefficient
MLSS	Mixed liquor suspended solids
MMLVSS	Mixed volatile suspended solids
Q	Flow rate
Qe	Effluent flow rates
Qr	Recycle flow rate
rS_s	Soluble substrate reaction rate
S_s	Soluble substrate
S_{sin}	Soluble substrate from aeration tank
SS	Suspended solids
S_o	Soluble oxygen
$SSVI_{3.5}$	Stirred sludge volume index at MLSS of 3.5 g/l
SRT	Solids retention time
IAWQ	International Association on Water Quality
V	Layer volume
V_o	Maximum theoretical settling velocity

V_{max}	Maximum practical settling velocity
V_s	Settling velocity
X	Solids concentration
X_{above}	Solids conc. in the layer above
X	Active biomass
X_s	Slowly biodegradable substrate
Y_B	Growth yield
$\hat{\mu}_B$	Maximum biomass specific growth rate

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