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DESIGN CRITERIA ASSESSMENT FOR THE AERATION TANK IN THE ACTIVATED SLUDGE PROCESS

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تقنين الاسس التصميميه لاحواض التهويه المستخدمه في طريقة الحماه المنشطه

لقد انشئت فى مصر حديثا العديد من محطات معالجة مياه الصرف الصحى التى تعمل بطريقة الحماه المنشطه في العديد من المدن وبعض القرى . ويعتمد الحجم التصميمى لخزانات التهويه في محطات معالجة مياه الصرف الصحى بطريقة الحماه المنشطه على معاملات الحركه التى تتأثر كثيرا بخواص مياه الصرف الصحى وتغير الاحمال العضويه ووجود مياه صرف صناعى . ولقد اعتمد تصميم حجم خزانات التهويه الموجوده بتلك المحطات التى انشئت فى مصر على معاملات الحركه الموجوده فى المراجع والدراسات التى تمت فى البلدان الاخرى .

لذلك فقد تم تشغيل جهاز معملى يمثل نموذج مصغر لمحطات معالجة مياه الصرف الصحى التى تعمل بطريقة الحماه المنشطه وذلك لايجاد معاملات الحركه لمياه الصرف الصحى المصريه ، وقد تم فى هذا البحث ايجاد معاملات الحركه لمياه الصرف الصحى لكل من مدينة المنصوره وقرية ميت مزاح .

ولقد اوضحت تلك الدراسه الاتى : -

١ - يتاثر الحجم التصميمى لخزان التهويه كثيرا بقيم معاملات الحركه والنموذج المستخدم فى التصميم .
٢ - الحجم التصميمى لخزان التهويه باستخدام نماذج لورنس ومكارتى وكنكانون وستوفر تقريبا متساوى .
٣ - الحجم التصميمى لخزان التهويه باستخدام نماذج ايكنفلدر يكون كبيرا اذا ماقورن بالنماذج الاخرى .

ABSTRACT

In Egypt, the use of activated sludge process for treating domestic wastewater has been started recently. Several of activated sludge plants have been constructed in cities and villages. The kinetic coefficients used in sizing of the aeration tanks for these plants were taken the same as in the developed countries although the climatic conditions, load variation, presence of industrial wastewater and wastewater characteristics in Egypt differ than that in developed countries.

A continuous flow activated sludge pilot plant was operated in El-Mansoura University Sanitary Engineering Laboratory to determine the kinetic coefficients for El-Mansoura city and Meet-Mazah village wastewater. The results indicated that the aeration tank design volume greatly influenced by wastewater kinetic coefficients and model used in the design. The aeration tank design volumes according to Lawrence and McCarty's model and Kincannon and Stover's model are almost equal. On the other hand the design volumes according to Eckenfelder's model and Eckenfelder's modified model are very high compared to other models. In all cases, it is recommended to run a pilot plant to determine the wastewater kinetics for accurate sizing of aeration tanks.

KEYWORDS

Wastewater treatment, domestic wastewater, activated sludge process, kinetic coefficients, aeration tank.

NOMENCLATURE

Q = flow rate, l/d
V = aeration tank volume, l
t = aeration tank detention time, d
Q_w = wasted sludge flow rate, l/d
S_i = influent substrate concentration, mg/l
S = effluent soluble substrate concentration, mg/l
X = mixed liquor volatile suspended solids concentration, mg/l
X_e = effluent volatile suspended solids concentration, mg/l
X_w = wasted sludge volatile suspended solids concentration, mg/l
a = sludge recycle ratio
U = specific substrate utilization rate, 1/d
θ_c = sludge residence time (SRT), d
F:M = food to microorganism ratio
Y = yield coefficient, mg/mg
K_d = decay coefficient, 1/d
K_e = Eckenfelder's model coefficient, $l.mg^{-1}.d^{-1}$
K_e' = Eckenfelder's modified model coefficient, 1/d
K_m = Mckinney's model coefficient, 1/d
K = Lawrence and McCarty maximum substrate utilization rate, 1/d
K_s = Lawrence and McCarty saturation rate, mg/l
u = biomass growth rate, 1/d
u_{max} = Gaudy maximum biomass growth rate, 1/d
K_s' = Gaudy saturation rate, mg/l
r_{su} = substrate utilization rate, $mg.l^{-1}.d^{-1}$
U_{max} = maximum substrate utilization rate, 1/d
K_B = substrate loading at which substrate utilization rate is one-half the maximum rate, 1/d

INTRODUCTION

The activated sludge process has gained growing acceptance as a biological method for wastewater treatment since its discovery at the beginning of this century. The design of the activated sludge plants in the past has been based on empirical criteria. Design approaches have been based upon detention time, volumetric loading, and rational method. Modern approaches to design of the activated sludge process treating demostic wastewater employ mathematical process models depiciting the relationships among factors affecting the kinetics of wastewater treatment. Each model contains kinetic coefficients that are usually determined from bench scale or pilot plant studies. Most models are developed by writing material balances describing the mass rate of change in substrate and in microorganisms.

Various kinetic models for sizing the activated sludge treatment plants have been developed. The most important models are: Eckenfelder's model, Eckenfelder's modified model, Mcklnney's model, Lawrence and McCarty's model, Gaudy's model, and Stover and Kincannon's model. These models are discussed and applied in this research.

All models are based on the fact that the mass rate of substrate change in the reactor is equal to the rate of change in substrate concentration multiplied by the volume of the rector. This rate is dependent on the inflow of substrate, the rate at which substrate flow out of the reactor and the rate at which substrate is utilized for growth of the microorganisms in the reactor. The difference between the above mention models is relying on the rate of substrate utilization assumption. The substrate utilization rate for all models used in this research is presented in Table (1).[5,7,8,9]

Eckenfelder's modified model is applicable to variable influent substrate conditions, its application in industrial waste treatment has become popular.[4] Lawrence and McCarty's model is by far the most useful model .Although its applicability in transient conditions has been questioned.[2] Its use in steady state is well justified and generally accepted.[3]

Table (1) Substrate utilization rate formulas.[5,7,8,9]

Model	Formula
Eckenfelder	$K_e\ X\ S$
Eckenfelder modified	$K_e \frac{XS}{S_i}$
Mckinney	$K_m\ S$
Lawrence and McCarty	$\frac{K\ X\ S}{K_s + S}$
Gaudy	$\frac{u_{max}\ X\ S}{Y\ (K_s + S)}$
Kincannon and Stover	$\frac{U_{max}\ X\ \frac{QSi}{Xt}}{K_B + \frac{QSi}{Xt}}$

Gaudy's model differes from all other model in its practical engineering approach, since Gaudy wrote the materials balance around the reactor rather than the entire system. Accordingly, Gaudy's model provides a direct consideration for returned sludge ratio and returned sludge volatile suspended solids in the design of the activated sludge reactor.[6,7]

The kinetic coefficients for each model can be determined by using steady state conditions results from pilot plant or bench scale operation and plotting the following linear relationships which can be obtained from each model.[7,8,9]

1. Eckenfelder's model:

$$U = K_e\ S \qquad (1)$$

2. Eckenfelder's modified model:

$$S_i\ U = K_e\ S \qquad (2)$$

3. Mckinney's model:

$$K_m = ((S_i - S) - 1) / t \qquad (3)$$

4. Lawrence and McCarty's model:

$$\frac{1}{U} = \frac{K_s}{K} \cdot \frac{1}{S} + \frac{1}{K} \qquad (4)$$

5. Gaudy's model:

$$\frac{1}{u} = \frac{K_s}{u_{max}} \cdot \frac{1}{S} + \frac{1}{u_{max}} \qquad (5)$$

6. Kincannon and Stover's model:

$$\frac{1}{U} = \frac{K_B}{U_{max}} \cdot \frac{1}{(F:M)} + \frac{1}{U_{max}} \qquad (6)$$

Yield coefficient (Y) and decay coefficient (K_d) can be determined by plotting the reciprocal of mean cell residence time ($1/\theta_c$) versus the specific substrate utilization rate (U). The coefficients Y and K_d are the slope and the intercept values of the result line respectively.[7,8,9]

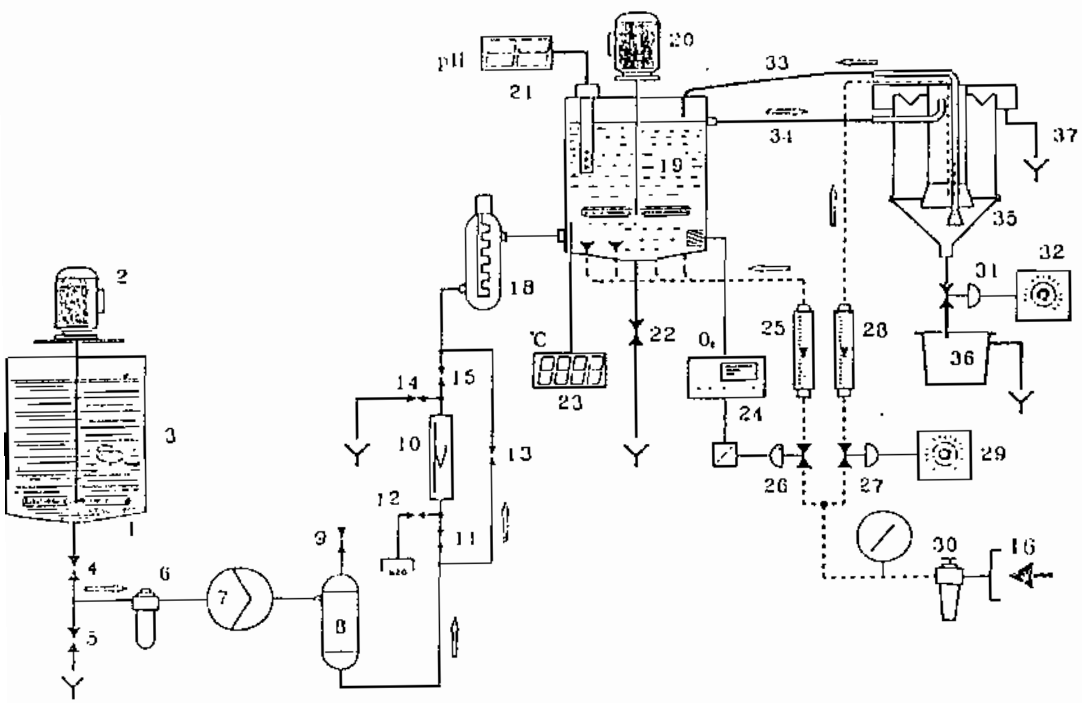
The main objective of all these models is to size the aeration tank rather than explaining the fundamentals of the activated sludge process. The aeration tank volume calculated from each model is presented in Table (2).[5,7,8,9]

Table (2) Aeration tank design volume.[5,7,8,9]

Model	Formula
Eckenfelder	$\frac{Q\ (S_i - S)}{K_e\ S\ X}$
Eckenfelder modified	$\frac{Q\ S_i (S_i - S)}{K_e\ S\ X}$
Mckinney	$\frac{Q\ (S_i - S)}{K_m\ S}$
Lawrence and McCarty	$\frac{Q\ \theta_c\ Y\ (S_i - S)}{(1+K_d\ \theta_c)\ X}$
Gaudy	$\frac{QY\ [S_i - (1+a)S] + aQX_r}{K_d\ X} - \frac{(1+a)Q}{K_d}$
Kincannon and Stover	$\frac{Q\ S_i/X}{\left(\frac{U_{max}\ S_i}{S_i - S}\right) - K_B}$

MATERIALS AND METHODS

A schematic flow diagram for a continuously flow activated sludge pilot plant used in this study is shown in Figure (1). The pilot plant was IC 130D activated sludge sewage treatment pilot plant from Didacta company-Italy and it consists of 150 liters feed tank, filter, feed pump, damper, flowmeter, heater, 33 liters aeration tank, sedimentation tank, electrical panel and air compressor. The aeration tank was aerated by air diffusers and mechanical stirrer. Temperature and dissolved oxygen were controlled automatically at 20°C and 2 mg/l respectively.



1 - FEEDING TANK - 150 l in capacity
2 - FIXED SPEED STIRRER: 100 rpm 0,13 HP
3 - LOW LEVEL INDICATOR
4 - ON-OFF FEED VALVE
5 - FEED DELIVERY VALVE
6 - FEED FILTER
7 - FEED RATE BATCHING PUMP: 0:10 l/h
8 - DAMPER, 1.5 l in capacity
9 - BACK VENT
10 - FEED FLOWMETER: 60 l/h f.s
11 - ON-OFF FLOWMETER VALVE
12 - FLOWMETER WASHING VALVE
13 - BY-PASS VALVE
14 - FLOWMETER WASHING DRAINAGE VALVE
15 - ON-OFF FLOWMETER VALVE
16 - AIR COMPRESSOR
17 - FLOWMETER PROVIDED WITH DIGITAL ODOMETER
18 FEED HEATER; 2000 W
19 - OXIDATION TANK, about 33 l in capacity
20 - VARIABLE SPEED STIRRER, 200 W
21 - DIGITAL PHMETER
22 - OXIDATION TANK DRAINAGE VALVE
23 - DIGITAL TEMPERATURE INDICATOR-REGULATOR
24 - DISSOLVED OXYGEN DIGITAL GOVERNOR
25 - FLOWMETER TO SHOW THE AIR RATE OF FLOW THE OXYGENATION TANK, 500 lt/f.s.
26 - ON-OFF VALVE FOR THE AIR FLOW TO THE OXIDATION TANK
27 - ON-OFF VALVE FOR THE AIR-LIFT AIR FLOW
28 - AIR-LIFT AIR FLOWMETER, 500 l/h f.s
29 - SLUDGE RECIRCULATION DIGITAL TIMER
30 - COMING AIR PRESSURE REDUCER
31 - OVER FLOW SLUDGE DRAINAGE VALVE
32 - OVER FLOW SLUDGE DRAINAGE DIGITAL TIMER
33 - SLUDGE RECIRCULATION LINE
34 - RECIRCULATION SLUDGES SAMPLING VALVE
35 - STATIC SETTLER
36 - CONDITIONED WATER OUTLET (SETTLER OVERFALL)
37 - OXIDATION TANK SAMPLING VALVE
38 - VALVE TO CONTROL THE AIR RATE OF FLOW TO THE OXIDATION TANK
39 - VALVE TO CONTROL THE AIR RATE OF FLOW TO RECIRCULATE THE SLUDGES

Figure (1) Schematic flow diagram for the activated sludge pilot plant

The pilot plant was operated to determined the kinetic coefficients for two types of wastewater. The first type was representing a city (El-Mansoura) and was taken from Weet El-Mansoura Wastewater Pump Station. The second type was representing a village (Meet-Mazah) and was taken from Meet-Mazah Wastewater Pump Station. The average characteristics for El-Mansoura city and Meet-Mazah village wastewater are listed in Table (3).

Table (3) Average characteristics for El-Mansoura city and Meet-Mazah village wastewater.

No.	Description	El-Mansoura Wastewater	Meet-Mazah Wastewater
1	Biochemical Oxygen Demand, 5 days, mg/l	260	780
2	Chemical Oxygen Demand, mg/l	375	1280
3	Total Dissolved Solids, mg/l	590	680
4	Suspended Solids, mg/l	225	430
5	Sulphate, mg/l	60	35
6	Phosphate, mg/l	11	19
7	Ammonia, mg/l	19	38
8	Chloride, mg/l	170	200

The pilot plant was operated using El-Mansoura City wastewater and was operated firstly for the growth of microorganism . The source of microorganism was the influent raw wastewater. After the mixed liquor volatile suspended solids in the aeration tank had reached the maximum required value, the pilot plant was operated at six different steady state conditions corresponding to sludge residence time of 9.3, 7.5, 6.0, 4.9, 4.1 and 3.5 days. The pilot plant was operated for twelve days at each steady state condition and the sludge residence time was controlled by the amount of sludge wastage. The sludge was wasted once a day.

The pilot plant was operated using Meet-Mazah wastewater by adding seed obtained from Meet El-Kholy Village Wastewater Treatment Plant. After adding the seed, the pilot plant allowed to acclimate for two weeks. Then, the pilot plant was operated at four different steady state conditions corresponding to a sludge residence time of 9.8, 8.2, 5.4, and 4.5 days. The pilot plant was operated for twelve days at each steady state condition.

Influent BOD_5 and COD, Effluent soluble BOD_5 and COD, mixed liquor volatile suspended solids, returned and wasted sludge volatile suspended solids and effluent volatile suspended solids were determined daily. All analyses followed the procedures described in Standard Methods.[1]

RESULTS AND DISCUSSION

The kinetic coefficients for El-Mansoura city and Meet Mazah village wastewater were determined using steady state conditions results . The kinetic coefficients for El-Mansoura city and Meet-Mazah village wastewater for BOD_5 and COD basis are listed in Table (4).

Table (4) Kinetic coefficients for El-Mansoura city and Meet-Mazah village wastewater.

coefficient	basis	El-Mansoura		Meet-Mazah	
		BOD basis	COD basis	BOD basis	COD basis
Y	mg/mg	0.578	0.434	0.633	0.458
K_d	1/d	0.065	0.079	0.152	0.200
K_e	1/mg.d	0.046	0.0118	0.0067	0.0026
$\bar{K}_e$	1/d	12.20	4.599	5.15	3.276
K	1/d	3.142	1.598	0.924	1.100
K_s	mg/l	57.61	56.90	29.74	40.45
u_{max}	1/d	1.844	0.960	0.646	0.599
$\bar{K}_s$	mg/l	94.[illegible]1	93.15	36.56	55.91
K_B	1/d	12.10	5.318	6.041	3.612
U	1/d	12.08	5.417	6.253	4.089

The resulting aeration tank volumes using El-Mansoura city wastewater kinetic coefficients and equations in Table (2) are listed in Table (5) for BOD_5 of 260 mg/l and COD of 375 mg/l, flow rate of 10000 m^3/d, and required values of effluent soluble BOD_5 and COD of 7 mg/l and 25 mg/l respectively. In order to compare volumes directly, values for X , X_u ,a were taken 2500 mg/l, 8500 mg/l and 0.40 respectively. In Eckenfelder's model and modified model, the design volume based on COD is higher than that based on BOD_5 . In McKinney, Lawrence and McCarty, Gaudy and Kincannon and Stover models the design volume based on BOD_5 is higher than the design volume based on COD. In Eckenfelder's model and modified model, the difference between the design volume based on COD and that based on BOD_5 are higher by 51% and 48% for both models respectively. In Lawrence and McCarty and Kincannon and Stover models, their is no difference almost between the two design models. The maximum calculated design volume was 4746 m^3 according to Eckenfelder's model based on COD. While the minimum design volume was 2314 m^3 according to McKinney's model based on COD for the same wastewater quantity and quality.

Table (5) Aeration tank design volumes for different models based on El-Mansoura city wastewater kinetic coefficients.

No.	Model	Design volume,m3	
		based on BOD	based on COD
1	Eckenfelder	3143	4746
2	Eckenfelder modified	3081	4565
3	Mckinney	2775	2314
4	Lawrence and McCarty	2975	2868
5	Gaudy	2745	2425
6	Kincannon and Stover	3268	3087

The resulting aeration tank volumes determined from Meet-Mazah village wastewater kinetic coefficients and equations in Table (2) are listed in Table (6). The Meet-Mazah village wastewater BOD_5 was 780 mg/l. The COD was 1280 mg/l. The flow rate considered for design was 10000 m^3/d. The effluent characteristics required values of soluble BOD_5 and COD were 25 mg/l and 63 mg/l respectively. In order to compare volumes directiy, values for X , X_u , a were taken 4300 mg/l, 14500 mg/l and 0.40 respectively.

Table (6) Aeration tank design volumes for different models based on Meet-Mazah village wastewater kinetic coefficients.

No.	Model	Design volume, m3	
		based on BOD	based on COD
1	Eckenfelder	10530	16953
2	Eckenfelder modified	13188	17531
3	Mckinney	2629	2280
4	Lawrence and McCarty	4165	4280
5	Gaudy	4085	3786
6	Kincannon and Stover	4328	4322

From the above table, Eckenfelder's and Eckenfelder's modified model design volume based on COD is higher than that based on BOD_5. In McKinney's and Gaudy's model , the design volume based on BOD_5 is higher than that based on COD. For Lawrence and McCarty's model and Kincannon and Stover's model, the design volume based on BOD_5 is approximately the same as that based on COD. In Eckenfelder's model and Eckenfelder's modified model, the difference between the design volume based on COD, and the design volume based on BOD_5 and are 61% and 33% respectively. The maximum calculated design volume is 17531 m^3 using Eckenfelder's modified model on COD basis. While the minimum design volume is 2280 m^3 using McKinney's model on COD basis.

CONCLUSIONS

According to the results obtained from this study, the following conclusions can be drawn :

1. The aeration tank design volume greatly influenced by wastewater kinetic coefficients and model used in the design.
2. The aeration tank design volumes according to Lawrence and McCarty's model and Kincannon and Stover's model are almost equal.
3. The aeration tank design volume according to McKinney's model is the minimum design volume.
4. The aeration tank design volumes according to Eckenfelder's model and Eckenfelder's modified model are very high if they are compared to the aeration tank design volume of other models.
5. It is important to run experimental works as that explained herein for designing activated sludge process for rural areas in order to determine process kinetic coefficients.

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