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Project Summary

Capital and O&M Cost Estimates for Attached Growth Biological Wastewater Treatment Processes

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Data for projecting process capabilities of attached growth biological wastewater treatment systems and procedures for making design calculations are presented in this report. Carbonaceous oxidation (secondary treatment) and single-stage nitrification design examples are given. Information for estimating average construction costs and operation and maintenance (O&M) requirements are presented for typical wastewater treatment plants ranging in size from 1 to 100 mgd capacity.

Estimated average construction costs and O&M requirements for individual unit processes are related graphically to appropriate single parameters for each component. Construction costs are broken down into labor and materials components to enable the costs to be inflated using readily available Bureau of Labor Statistics Wholesale Price Indices. O&M requirements are given for labor, energy, and maintenance materials and supplies so that appropriate current, local unit costs can be used to estimate annual costs.

The data in this report provide a means for estimating anticipated average performance and costs for facilities, but they should not be substituted for detailed assessment of local conditions or recognition of changing design requirements.

This Project Summary was developed by EPA's Risk Reduction Engineering Laboratory, Cincinnati, OH, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

This report represents recommended design procedures, reviews performance design procedures, reviews performance capabilities, and presents cost estimating guidelines for municipal wastewater treatment plants incorporating attached growth biological processes for secondary treatment. Attached growth treatment processes are based on the development of biological growth on a media surface, either by passing wastewater over stationary media or by moving media through a wastewater bath. Attached growth processes are most commonly exemplified by the trickling filter. The rock media trickling filter has been recognized and used since 1898. There are nearly 4,000 municipal trickling filter wastewater treatment plans in the United States.

Objectives

The objectives of this report are to develop suggested design procedures for attached growth biological treatment processes, assess the accuracy of those procedures, and present guidelines for estimating capital costs and O&M requirements.

Commonly used design procedures for biological treatment processes are empirical in nature, based on experienced results. Available design procedures are reviewed to assess their utility in assisting the engineer in predicting attached growth performance.

Once a design has been developed and the proposed facilities sized, estimating capital costs and O&M requirements must be considered. Capital costs include the cost of construction; engineering, legal, and administrative services; land; and interest during construction. This report emphasizes the development of construction costs. Other costs, except land, may be related to construction costs. Land is a variable that cannot be typified. General information for plant construction costs has been available for some time; however, this information is often presented for an overall system, rather than in terms of unit processes. The variability of combinations of several unit processes limits the use of these data. By separating plant costs into categories of unit processes, historical cost data from existing plants may be applied to similar processes in project planning.

Attached Growth Processes Considered

Four attached growth processes are examined in the report, including rock media trickling filters, plastic media trickling filters, rotating biological contactors, and trickling filter/solids contact, which is an attached growth process enhanced by a coupled-suspended growth process. The six process alternatives analyzed in the study are listed in Table 1. These processes are generally incorporated into liquid stream system designs that include pretreatment via screening and grit removal, primary and final sedimentation, sludge pumping, recirculation pumping, and effluent disinfection. Sludge handling selection varies depending on local economic considerations.

- *Rock media trickling filters* are a simple, single-stage treatment process. Rock media varies in diameter from 1 to 4 in. and are designed with depths of 3 to 10 ft. Wastewater is continuously sprayed over the stationary media, which supports biological growth. Treated wastewater is collected in a underdrain system where it is recycled and/or directed to the final settler. Biological growth sloughs from the media resulting in the need for final sedimentation. Rock media filters are usually employed for secondary treatment (carbonaceous removal) only.

- *Plastic media trickling filters* were introduced to overcome the limitations of rock media. Plastic media trickling filters may be designed much deeper (commonly 21 ft deep) than rock filters since the media is very light. Corrugated sheet modules are delivered in bundles that are then cut to size and placed in the media towers. Plastic rings, on the other hand, are dumped, making installation simple.

  Recirculation is typically taken directly from the trickling filter underflow, although some designs recycle the final sedimentation tank underflow. Plastic media have been used for both carbonaceous removal and nitrification.

- *Rotating biological contactors (RBC's)* were developed in Europe and introduced in the United States in the 1970's. The media, which supports biological growth, is generally 12 ft in diameter and rotated through a bath of wastewater. The media is alternately exposed to the liquid and to the atmosphere. RBC effluent is typically not recirculated. Originally, the media was designed as a series of closely-spaced, parallel, flat discs with a specific surface area of 20 to 25 ft^2/ft^3. The newer lattice-structured media
offers about 50% more specific su
area than the disc-type constru
The lattice-structured media, and
lesser extent the disc structure
fragile and should be protected
direct exposure to sun, wind,
weather. Therefore, the medi
enclosed in either superstructu
individual shaft covers. Media r
can be provided by either mech
drives or air motivation. RBC's m
used for either *secondary treatm*
secondary treatment plus nitrifi
applications.

- *Trickling filter/solids contact (TF*
a development that enhance
reliability of the trickling filt
incorporating suspended g
treatment in the process. There
been other "coupled" att
growth/suspended growth proc
that have been used in an atte
offset the disadvantages ass
with the two processes. Wit
processes there can be
variations in relative organic
rates, locations and quantit
recycle, and process arrangem
a consequence, there were an
process alternatives under the
category of "coupled tri
filter/suspended growth" proce
TF/SC variation represents
processes in this report.

  The TF/SC process uses the
filter (TF) as the primary me
remove organics and a ver
hydraulic retention time aeratio
(SC) to polish that tricklin
effluent. Where the treatme
effluent quality needs only
secondary treatment stand
conventional final sedimentatio
is used. Where higher quality
standards are required,
sedimentation basin with a flo
center well is used. The TF/SC
is not used for nitrification.
nitrification is required, the
segment must be larger
process is no longer categori
TF/SC process.

***Table 1.** Biological Treatment Process Alternatives*

Treatment Process	*Carbonaceous Removal Only*	*Single-Stage Carb. Rem Nitrification*
Rock Media Trickling Filter	*x*	
Plastic Media Trickling Filter	*x*	*x*
RBC's	*x*	*x*
Trickling Filter/Solids Contact	*x*	

ocedure

three-step approach was used to nduct the work of this study. The first p was to develop design criteria for atment plant liquid and solids handling it processes applicable to attached wth treatment systems. To thoroughly aluate a complete treatment system ernative, it is necessary to consider the sign and costs of ancillary treatment its, such as solids handling processes d functional parts of the total project. tailed construction costs and O&M uirements for typical additional unit ocesses and functional units that mplete the system alternatives are luded.

The second step was to collect, alyze, and formulate the construction st and O&M requirements for each unit ocess. Comparative cost information is esented for certain design odifications, e.g., alternative solids ocessing equipment.

The third step was to develop flow agrams for each of the systems. pical flow schemes meeting the state rformance requirements have been cluded.

The attached growth processes timated have been sized to correspond design flows ranging from 1 to 100 gd. Within this range, six nominal plant pacities have been evaluated: 1, 5, 10, , 50, and 100 mgd.

The following unit process costs have en included in the complete final port:

aw wastewater pumping
hlorine feed & storage facilities
erated grit removal & flow measurement
O_2 storage & feed equipment
rimary treatment screens
lotation sludge thickeners
edimentation basins
ludge handling tanks
Sludge pumping stations
Anaerobic digesters
Trickling filters
Filter presses
Rotating biological contactors
Centrifuges
Inplant & recycle pumping stations
Multiple hearth incinerators
Aeration basins
Sludge & ash lagoons
Mechanical aeration equipment
Land spreading of sludge
Blowers
Sand drying beds
Diffused air aeration equipment
Sludge composting
Effluent filtration
Pipeline transport
Chlorine contact basins
Truck transport

The costs have been presented in two forms. The construction cost components have been itemized for several sizes of the unit process so they can be updated according to the inflation rates for the individual components. The total updated costs (September 1987) are also presented graphically so they can be used for any size treatment system. Total annual costs (September 1987) for the different size plants and treatment options are summarized.

These costs, presented in terms of $/1,000 gal wastewater treated, are the sum of a plant's annual O&M costs and its capital costs amortized for 20 yr at 10% divided by the total quantity of wastewater treatment annually.

The most cost-effective treatment method is indicated in Table 2. RBC's are estimated to be the most economical attached growth process for carbonaceous oxidation and for single-stage nitrification. The estimated costs for the TF/SC process are essentially the same as for the RBC process above 10 mgd. The relative ranking of these costs for estimating purposes should be tempered by site-specific conditions and by engineering judgment. The use of these cost estimating procedures results in project estimates that are very close to the experienced costs to as much as 30% different than experienced costs. The relative accuracy, comparing competing alternatives should be within 10%.

Design Approaches

Performance data from operating systems are used to evaluate the various methods for designing attached growth processes. This is particularly important since design must be based on achieving specific effluent quality. The design approaches for removal in rock and plastic media trickling filters and RBC's are evaluated first, followed by performance evaluation and the design approach for the TF/SC process

Attached growth processes are characterized by a decreasing concentration of organics passing over a film of attached bacterial growth. Organic and oxygen fluxes from the carriage water to the growth are proportional to their concentrations. The surface area is the major parameter in attached growth process evaluation if the organic loading rate is not so high that either the rate of organic assimilation by bacteria or the rate of oxygen transfer would limit the removal rate. Greater surface area per unit volume will support more bacterial growth and provide more contact opportunities between organics and bacteria. However, there are many complicating factors that obviate the effect of media surface area. These factors have relegated attached growth process design to empirical relationships that are of limited usefulness.

ble 2. *Summary of Total Annual Costs for Plants Utilizing Attached Growth Treatment Processes*

	Annual Cost Summary, $/1000 gal					
	Plant Size, mgd					
Process	*1*	*5*	*10*	*25*	*50*	*100*
arbonaceous Oxidation						
ock Media	*3.86*	*2.59*	*2.32*	*1.88*	*1.67*	*1.60*
lastic Media	*2.93*	*1.74*	*1.41*	*1.20*	*0.97*	*0.94*
BC's	*2.53*	*1.48*	*1.22*	*0.99*	*0.82*	*0.77*
F/SC	*3.09*	*1.69*	*1.38*	*1.02*	*0.85*	*0.79*
ingle-Stage Nitrification						
lastic Media	*3.28*	*2.07*	*1.80*	*1.44*	*1.18*	*1.17*
BC's	*2.65*	*1.62*	*1.40*	*1.12*	*0.94*	*0.94*

Empirical models based on statistical curve fitting of data to variations in operating conditions and physical facilities are most commonly used by design engineers. The actual phenomenon involved in organics removal may or may not be understood from the resulting statistical model. These empirical models yield varying results that do not reflect the true removal phenomenon. It is important to realize this limitation and restrict the application of the empirical models to the range of operating conditions and wastewater characteristics for which they have been developed.

Techniques classified as rational approaches better describe the removal mechanisms, but they also present difficulty in application. The Williamson and McCarty biofilm model represents the rational approach, although it is rather complex and may be beyond general use by design engineers. This model considers many factors that describe substrate utilization by biofilms. Basically, it predicts soluble substrate removal based on limitations of oxygen and substrate diffusion through the liquid and the biofilm into the bacteria. It also considers the simultaneous effects of biochemical reactions. The biofilm surface area is a key design parameter.

Empirical Models

Empirical predictive design techniques for trickling filters have been presented by several investigators. The complete project report for this study describes several empirical models including the National Research Council (NRC), Galler and Gotaas, modified Velz, and the rational model of Williamson and McCarty.

A variation of the basic Velz equation is presented in this summary report:

$$\mathrm{In}\left[\frac{\mathrm{BOD}_5\,\mathrm{out}}{\mathrm{BOD}_5\,\mathrm{in}}\right] = K\left[\frac{D}{695\,Q/A}\right]^n \qquad (1)$$

$$= K\left[\frac{V}{695\,Q}\right]^n$$

where: K = coefficient related to media volume $\mathrm{gpm}^n/(\mathrm{ft}^3)^n$

Q = flow rate to the filter including recirculation, mgd

A = filter surface area, ft^2

D = filter depth, ft

n = hydraulic coefficient

v = filter volume. 1,000 ft^3

The variation in K with varying media wetting rates (applied hydraulic loading to plan surface area of trickling filter) is predicted by the following equation for rock media trickling filters:

$$K = 0.25 + (1n\, q_w)/20 \qquad (2)$$

where: q_w = media wetting rate, $\mathrm{gpm/ft}^2$

Model Evaluation

The designer is faced with selecting a media volume for which the effluent criteria may be attained with a reasonable degree of confidence. In the following discussion, data are presented for existing attached growth systems. The Velz model generally is used to predict effluent soluble BOD_5 from the trickling filter. Sometimes it is used with influent soluble BOD_5. Since influent BOD_5 is hydrolyzed quickly, the author believes it is inappropriate to use influent soluble BOD_5. The model has been applied in this report to predict effluent total BOD_5 after the final clarifier. The model might be more precise if used to predict effluent soluble BOD_5 and if effluent insoluble BOD_5 were estimated, but the precision of the model is not adequate to justify such refinements.

Tables 3, 4, and 5 present field data and predicted results for rock media, fabricated media, and RBC systems, respectively. Variables used in the equations to predict performance are given in Table 6.

It is noteworthy that the K values in Equation 1 for rock media trickling filters approach those of plastic media at higher wetting rates:

Wetting Rate (q_w), $\mathrm{gpm/ft}^2$	K, $\mathrm{gpm}^{0.5}/\mathrm{ft}^{1.5}$
0.1	0.15
0.2	0.18
0.3	0.20
0.4	0.22

An "n" value of 0.5 has been used in these comparisons. The performance of plastic media trickling filters was predicted using a K of 0.21 $\mathrm{gpm}^{0.5}/\mathrm{ft}^{1.5}$ for wetting rates varying from 0.5 to 2.27 $\mathrm{gpm/ft}^2$. The probable reason that the specific surface area of plastic media is not more effectively utilized at conventional organic loading rates in comparison to rock media is oxygen diffusion limitations. The treatment efficiency achieved with both typ media will be determined b availability of oxygen and effectiveness of the media to aera wastewater.

Richards and Reinhardt invest different configurations of plastic using variable depths with the media volume and found performance improved with dept media specific surface areas used i investigation did not vary. Their fi indicated that the 45° and 60° cro configurations performed bette either the vertical configuration or r dump media. When they evaluate plant data, they found an "n" of best mimic performance of soluble removal. They used an "n" of compare field data.

Rotating Media Biological Contractor (RBC's)

The design approaches propo RBC manufacturers are primarily on "rational" models. One such ap is summarized in the gra relationship between effective surface area (expressed as flow of surface area) and effluent BOD_5 shown in Figure 1. relationship indicates benefits fro media with high specific surfac The design approach shown in F is based on soluble BOD_5 in the and effluent. Unfortunately, the soluble BOD_5 portion is highly For example, the following hav reported for soluble BOD_5 in effluents:

Plant	Soluble BO
Pewaukee, WI	66
Seattle, WA	31-50 (41 a
Tucson, AR	50-71 (56 a

The use of influent soluble assumes that insoluble BOD_5 is by some mechanism other than b stabilization. Some insoluble may be incorporated in biologi and removed by sedimentation, will be hydrolyzed and meta Therefore, a design approach based on only soluble organic lo a liberal one. Since hyd particulate organics as well as organics are available substr design (substrate removal a empirical approach, or other) s based on total influent substrate.

To provide a design approach more onsistent with stationary media attached owth processes and to enable realistic valuation of the available data, Equation has been applied to the RBC process. vailable data for mechanically driven sc and lattice-type RBC systems have een evaluated using this approach and ere summarized earlier in Table 4. ese data represent both full-scale and lot-plant installations.

Because lattice media have greater urface area per unit volume than disc edia, an analysis of the data was also erformed relating BOD_5 removal to edia surface area according to the llowing equation:

$$\ln\left[\frac{BOD_5\,out}{BOD_5\,in}\right] = -K_s(A_sV/695Q)^{1/2} \quad (3)$$

The performance data in Table 4 have een evaluated in terms of k_s, the efficient related to media surface area, $pm^n/(ft^2)^n$. Figure 2 represents a robability distribution plot of the alculated k_s values that imply that media pecific surface area is a more significant arameter for the design of RBC process erformance than media volume. Using a ${}_s$ value of 0.062 $gpm^{0.5}/ft$ and media densities of 20 ft^2/ft^3 for the disc media and 30 ft^2/ft^3 for the lattice media, the standard error of estimate would be 5 mg/L.

Trickling Filter/Solids Contact

The inability to accurately predict trickling filter process performance and the need for uniformly reliable effluent quality have led to the development of a variety of combined trickling filter-suspended growth systems. The TF/SC process is one of the coupled processes consisting of a trickling filter followed by an aeration basin. The trickling filter is lightly loaded, usually 20 to 50 lb BOD_5/1,000 ft^3/day. The aeration basin detention time may be 10 min to as long as 1 hr.

The TF/SC process relies on the trickling filter to stabilize the majority of the organics while the aeration basin completes the stabilization of the organics and conglomerates the solids into a settleable floc.

The evaluation of coupled processes is complicated by the difficulty in separating the removal occurring in the individual process units. The data presented by most investigators are not complete; therefore, a thorough evaluation is not possible. The design and evaluation procedures used in this report are based on the following:

- *Assume the trickling filter performs in* the same manner that it would when operating alone.
- The trickling filer soluble BOD will exert a synthesis oxygen demand of 0.5 lb O_2/lb soluble BOD_5 synthesized.
- The endogenous oxygen demand will be 1.2 lb O_2/lb insoluble BOD_5 or synthesized cellular material.

An example of the application of these concepts is presented in Table 7 for the field data collected for the Corvallis, OR, TF/SC plant. The Corvallis plant consists of a trickling filter followed by a solids contact aeration basin of 0.02 mil gal volume. The final report describes temperature consideration, nitrification design equations, and example design illustrations.

Conclusions

This report is a consolidated volume describing the methodology involved in designing attached growth biological wastewater treatment processes to achieve carbonaceous oxidation

able 3. *Comparison of Predicated vs. Measured Effluent BOD_5 Using Rock Media Trickling Filter Data*

Plant Location	Depth, ft	R	Q/A, mgd/ac	W/V, lb BOD_5/1,000 ft^3/day	BOD_5, mg/L In	BOD_5, mg/L Out	Predicted Effluent BOD_5, mg/L, from Equation 1
Aurora, IL	6.0	--	2.1	4.4	70	14	20
Dayton, OH	7.5	--	3.5	12	138	33	34
Druham, NC	7.0	--	1.9	13	261	68	66
Madison, WI	10.0	--	2.4	6.4	138	33	27
Richard, TX	6.5	--	3.9	13.3	118	20	32
Plainfield, NJ	6.0	0.6	2.4	25	76	13	15
Great Neck, NY	4.0	1.0	7.8	20	117	20	32
Oklahoma City, OK	6.0	1.0	16.3	78	300	66	78
Freemont, OH	3.3	1.5	19.0	41	95	21	32
Storm Lake, IA	8.0	2.1	21.5	62	381	61	63
Richland, WA	4.5	2.8	19.6	44	118	20	25
Visal, CA	3.2	3.1	20.8	53	185	24	49
Chapel Hill, NC	4.25	2.0	16.3	19	77	44	19
Dallas, TX	7.5	0.5	5.6	21.4	225	37	45
Bridgeport, MI	6.0	1.2	20.6	29	99	42	26
Cass City, MI	6.0	1.3	10.0	23	151	33	30
Charlotte, MI	6.0	--	7.7	29	119	63	39
illsdale, MI	6.0	--	3.6	10	91	32	26
apeer, MI	5.8	0.3	13.5	22	65	23	21
tate Prison, MI	8.0	0.1	3.8	13	153	17	34
assar, MI	5.6	1.7	9.2	6	59	29	11
nglewood, CO	4.4	1.0	14.8	60	158	46	49
orvallis, OR	8.0	2.4	24.6	16	86	32	32
orvallis, OR	8.0	0.5	24.6	19	49	31	18

Table 4. *Comparison of Predicted vs. Measured Effluent BOD_5 Using Plastic Media Trickling Filter Data*

Plant Location	Media	Depth, ft	q, gpm/ft²	Rate, gpm/ft²	BOD_5, mg/L		Predict Effluent B mg/L fr Equatio
					In	Out	
Indianapolis, IN	Plastic	21.5	2.0	2.0	112	57	56
Stockton, CA	Plastic	21.5	0.28	0.71	240	40	38
Akron, OH	Plastic dumped	25.5	0.36	0.75	120	20	18
Buena Vista, MI	Plastic	20.0	0.46	1.20	54	21	14
Bay City, MI	Plastic	21.5	0.90	1.1	79	18	28
Essexville, MI	Plastic	21.5	0.75	1.50	23	11	7
Greenville, MI	Plastic	21.5	0.46	0.50	62	15	15
Rockwood, MI	Plastic	22.0	0.32	0.97	61	23	10
[1] Indio, CA	Plastic	33.0	0.27	--	62	72	46
[2] Linden Rochelle, NJ	Plastic	21.5	1.10	2.77	100	50	40
[3]	Plastic	20.0	1.4	1.4	78	29	36
[3]	Plastic	10.0	0.6	0.06	76	41	42

[1] Drury, D. D., Carmota, III, J., and Degadillo, A., "Evaluation of High Density Cross Flow Media for Rehabilitating an Existing Trickling Filter," J 58(5):364, May 1986.

[2] Fillos, J., Nierstedt, R., and Donahur, R., "Full Scale Evaluation of Plastic Media Roughing Filters," Presented at 57th Annual WPCF Confere New Orleans, LA, October 1984.

[3] Richards, T. and Reinhart, D., "Evaluation of Plastic Media in Trickling Filters," JWPCF, 58(7):774, July 1986

Table 5. *Comparison of Predicted vs. Measured Effluent BOD_5 Attached Growth Model Using RBC Data**

Plant Location	Media	Volume, ft³	Q, gpm	BOD_5, mg/L		Predic Effluent E mg/L fr Equatio
				In	Out	
Pewaukee, WI	Disc	197	8.3	172	33	38
Pewaukee, WI	Disc	10,450	235.0	119	20	15
Edgewater, NJ	Lattice	6,110	333.0	133	38	35
Gladstone, MI	Disc	196	10.4	100	32	26
Gladstone, MI	Lattice	16,300	550.0	106	20	20
Woodland, WA	Lattice	2,413	104.0	175	28	40
Kirksville, MO	Lattice	63,100	904.0	164	15	12
Georgetown, KY	Lattice	25,240	765.0	150	21	25
Brainerd, MN	Lattice	40.715	950.0	80	17	20

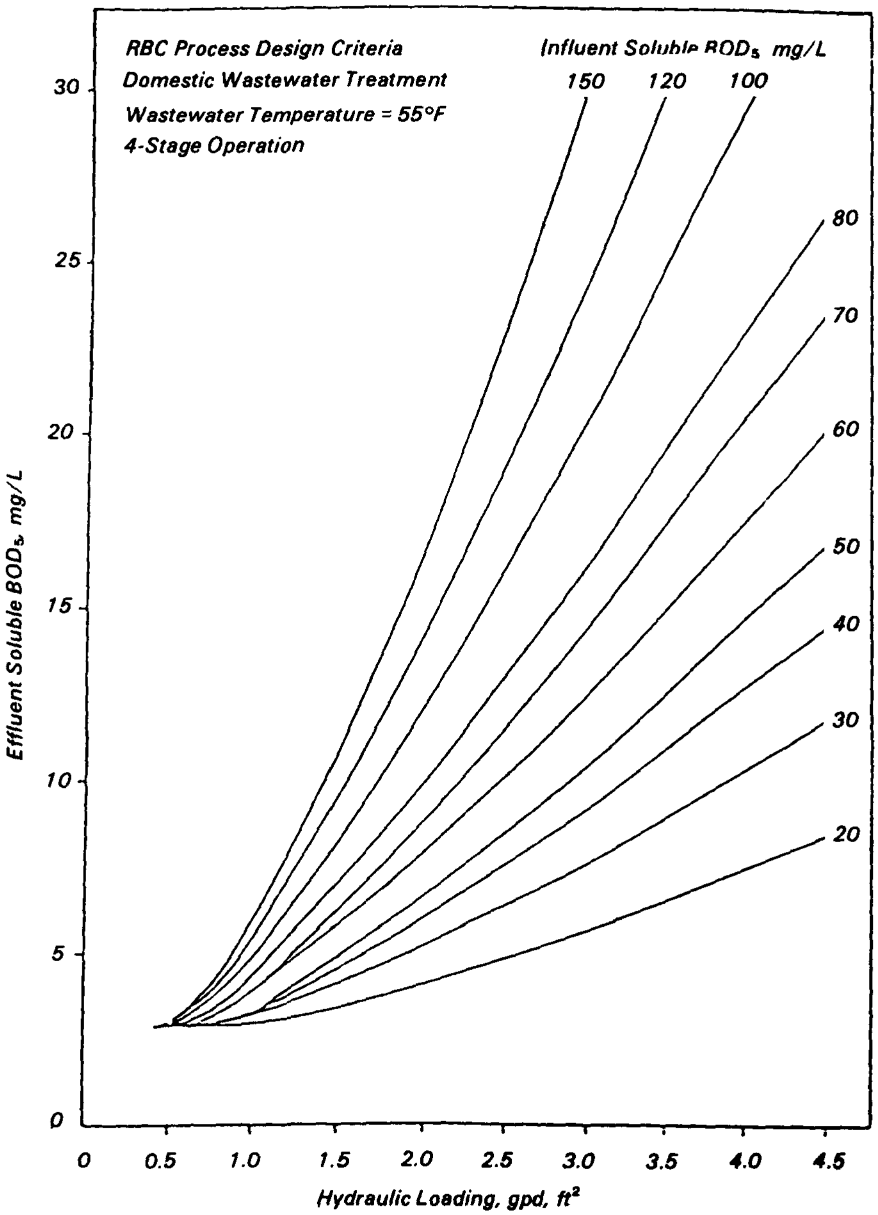
*Lehman, P. J., 'Start-up and Operating Characteristics of an RBC Facility in a Cold Climate," JWPCF, 55(10):1233, October 1983.

Table 6. *Variables Used for Models Evaluation*

Modified Velz Parameters	Rock Media	Plastic Media	RBC's
n	0.5	0.5	0.5
K (Equation 1)	(Equation 2)	0.21	0.308

(secondary treatment) and nitrification of domestic wastewater. The theoretical considerations given to design are reviewed, and detailed examples using the most accurate approaches are presented. Cost analyses were facilitated by using a computer; however, the procedures are straightforward and can easily be done manually.

Several mathematical models have been used to design attached growth systems. None are particularly accurate in predicting process performa some are quite complicat carbonaceous removal, the Velz is as accurate as any and conveniently applied to all growth processes. The Velz equ



igure 1. Manufacturer's design approach for RBC's.

e applied to rock media, plastic or ppropriate modifications.

Total plant capital and O&M costs have een estimated for various size facilities sing attached growth biological ocesses for secondary treatment arbonaceous oxidation) and for nitrification in the final report. RBC's are estimated to be the most economical attached growth process for carbonaceous oxidation and for single-stage nitrification. The estimated costs for the TF/SC process are essentially the same as for the RCB process above 10 mgd. The relative ranking of these costs for estimating purposes should be tempered by site-specific conditions and engineering judgment.

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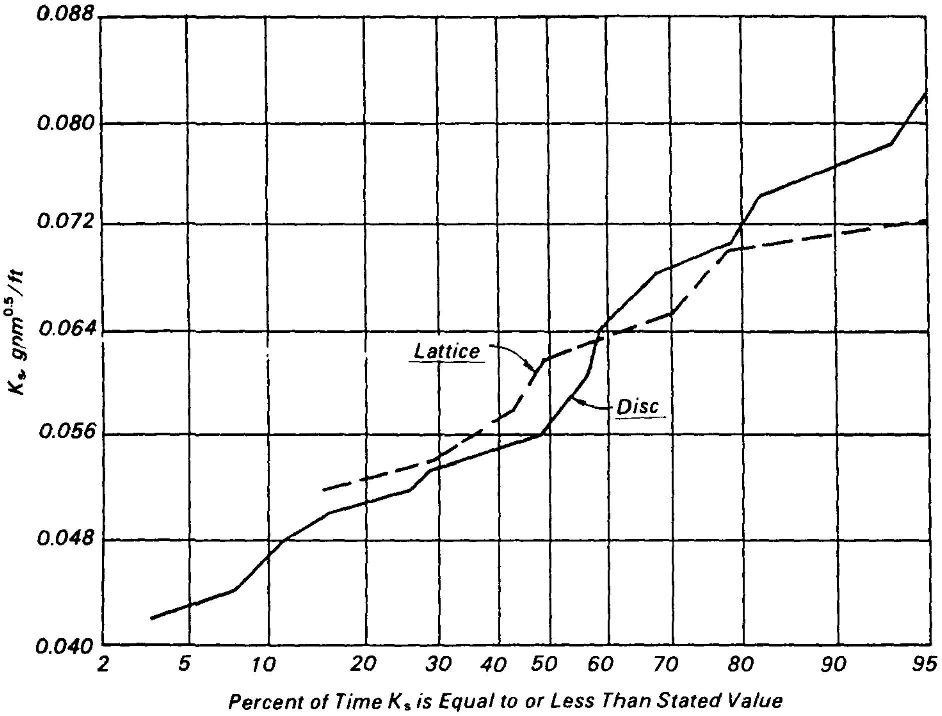

Figure 2. Probability of RBC performance based on media surface area

able 7. Evaluation of TF/SC Process

orvallis TF/SC Plant (1983-1984)

Month	Apr.	May	June	July	Aug.	Sept.	Oct,	Nov.	Dec.	Jan.	Feb.	Mar.
Q, mgd	12.2	7 4	7.3	6.2	6.2	5.7	5.6	15.2	17.9	13.4	16.6	12.7
Temp., °C	15	18	20	20	22	22	21	17	14	14	13	13
Influent												
BOD_5, mg/L	66	90	87	78	72	94	114	56	35	49	56	48
TSS, mg/L	75	82	74	68	63	68	66	56	58	56	64	64
TF Effluent												
BOD_5, mg/L	25	34	32	28	29	39	38	33	26	26	22	22
$SBOD_5$, mg/L	6	5	6	5	5	8	8	6	4	4	3	3
TSS, mg/L	63	72	61	60	57	59	56	55	59	54	59	58
C_r, mg/L	13,075	8,091	8,180	6,345	5,437	5,415	10,293	13,703	16,139	17,170	16,523	15,353
C_a, mg/L	3,110	2,150	1,940	1,768	1,557	1,675	2,948	3,571	4,218	4,777	4,832	4,982
Q_r, mgd[1]	3.8	2.7	2.3	2.4	2.5	2.6	2.2	5.4	6.3	5.2	6.9	6.1
Solids												
Aeration, lb[2]	520	360	324	295	260	280	490	595	703	797	806	830
Reaeration, lb[3]	2,180	1,350	1,364	1,060	907	903	1,720	2,285	2,690	2,870	2,760	2,560
Clarifier, lb[4]	17,300	7,600	6,450	5,280	4,700	4,800	8,040	25,560	35,520	30,800	39,390	32,550
Total, lb	20,000	9,310	8,138	6.635	5,867	5,983	10,250	28,340	38,913	34,464	42,956	35,940
SRT, day[5]	3.1	2.1	2.2	1.9	1.8	1.9	3.3	4.0	4.5	5.5	4.8	5.3
BOD_5/TSS Ratio[6]	0.3	0.4	0.4	0.4	0.4	0.53	0.54	0.5	0.36	0.42	0.32	0.33
Oxygen Demand, lb/day												
Synthesis[7]	90	71	91	69	74	112	108	106	63	58	44	41
Endogenous Aeration[8]	63	72	75	68	69	98	164	139	107	127	91	97
Endogenous Reaeration[9]	266	270	154	244	240	170	572	534	368	457	312	299
Oxygen Demand, mg/L/hr												
O_2 Demand Aeration[10]	38	36	42	34	36	53	68	61	43	46	34	35
O_2 Demand Reaeration[11]	67	68	39	61	60	43	143	134	92	114	78	75

[1] $Q_r = Q_i (C_a/(C_r - C_a))$

[2] Aeration lb solids = $C_a \times V_a \times 8.34 = C_a \times 0.02 \times 8.34$

[3] Reaeration lb solids = $C_rV_r \times 8.34 = C_r \times 0.02 \times 5.34$

[4] Clarifier lb solids = $(Q_i + Q_r)\, C_a \times 8.34/24$, assuming 1-hr time to achieve C_r

[5] Total lb solids/(Q in x TF TSS out x 8.34)

[6] BOD_5/TSS ratio = (TF BOD_5 out - TF $SBOD_5$ out)/TF TSS out

[7] Synthesis Oxygen, 0.5 x TF $SBOD_5$ out x 24 x V_a x 8.34 $\left[\dfrac{K_sK_t}{K_sK_t \quad ta+1}\right]$

[8] Endogenous Oxygen, Aeration, lb/d = $1.2\, C_a \times 8.34 \times (BOD_5/TSS\ ratio)\, K_eK_tV_a$

[9] Endogenous Oxygen, Reaeration, lb/d = $1.2\, C_r \times 8.34 \times (BOD_5/TSS\ ratio)\, K_eK_tV_r$

[10] Oxygen Demand Aeration, mg/L/hr = (Synthesis + Endogenous Aeration)/(V_a x 8.34 x 24)

[11] Oxygen Demand Reaeration, mg/L/hr = (Endogenous Aeratin)/(V_r x 8.34 x 24)

Where: Q_r = RAS flow mgd
Q_i = In flow mgd
C_a = MLSS, mg/L
C_r = RAS concentration, mg/L
V_a = Aeration basin volume, mil gal
V_r = Reaeration basin volume, mil gal
TF SS out = trickling filter effluent suspended solids, mg/L
TT BOD out = trickling filter effluent BOD_5, mg/L
TF SBOD out = trickling filter effluent soluble BOD_5, mg/L
K_S = 15 hr^{-1} @ 20°C
K_e = 0.02 hr^{-1} @ 20°C
K_t = 1.072 (T-20)
t = aeration detention time, hr

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The complete report, entitled "Capital and O&M Cost Estimates for Attached Growth Biological Wastewater Treatment Processes," (Order No. PB 89-148 324/AS; Cost: $36.95, subject to change) will be available only from:

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