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Risk Reduction Engineering Laboratory Cincinnati, OH 45268

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EPA

Project Summary

Technology Assessment of the Biological Aerated Filter

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The innovative and alternative technology provisions of the Clean Water Act of 1977 (PL 95-219) provide financial incentives to communities for using wastewater treatment alternatives that reduce costs or energy consumption when compared with those for conventional systems. Some of these technologies have only recently been developed and are not in widespread use in this country. To increase awareness of the potential benefits of such alternatives and to encourage their implementation where applicable, several assessments of promising new treatment technologies have been conducted.

The technology assessment summarized here describes a recently developed biological wastewater treatment concept called the biological aerated filter (BAF)/ Biocarbone process* and addresses performance and operational characteristics, design approaches used by the two vendors of the process, and potential applications of that process. Recommendations are provided where further definition of process performance response to environmental conditions is believed warranted. Similarities and differences of the BAF/Biocarbone process are briefly compared with those of conventional activated sludge systems. An alternative design method proposed by the author based on operating and performance data from several French Biocarbone systems is also presented.

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

The BAF is a trademarked wastewater treatment process marketed in the United States and most of Canada by Eimco Process Equipment Company (Eimco) of Salt Lake City, UT. Original research and development of the technology belongs to the French company Omnium de Traitements et de Valorisation (OTV) that directly or indirectly markets their equivalent Biocarbone process elsewhere, but primarily in Europe. A number of process patents, dating back to 1978, have been granted both in Europe and North America.

Process Description

The BAF/Biocarbone process consists of a granular media bed, usually of vitrified clay particles with a specific gravity of approximately 1.6, through which pretreated wastewater (minimum acceptable pretreatment is primary clarification) is passed in a downward gravity flow pattern similar to either a downflow water filter or a downflow tertiary wastewater filter. The media bed is supported by an underdrain plate that incorporates plastic nozzles for collecting the treated wastewater and for distributing backwash water and air. The process air supplied to the media (via a distribution header assembly located 8 to 10 in. [20 to 25 cm] above the underdrain plate) results in aerobic biological growth on the media. The filtering action of the media obviates the need for a separate final clarification step.

*Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This process, therefore, provides both biological stabilization of organic matter and suspended solids removal in a single vessel. As a consequence, the space requirements of this technology can be substantially less than for more conventional secondary treatment systems.

Accumulated solids stored in the media and excess biological growth sheared from the media are backwashed and removed from the bed on a predetermined schedule, typically once a day, or on the basis of headloss buildup. The backwash solids can be separately thickened or returned to the plant headworks for cothickening with the primary sludge.

When treating primary effluent, the BAF/Biocarbone process can be designed to achieve carbonaceous BOD removal only or carbonaceous BOD removal and nitrification by selecting appropriate loading rates. The process can also be designed to achieve advanced secondary treatment removals of BOD and suspended solids as well as nitrification with either primary or secondary effluent feed.

Plan and section views of a typical BAF/Biocarbone unit are presented in Figure 1. A typical process flow diagram for a complete BAF/Biocarbone treatment train is shown in Figure 2.

Background Performance Data

Pollutant Removal

OTV, through years of conducting pilot- and full-scale Biocarbone plant evaluations, has developed reliable correlations between applied pollutant and/or hydraulic loading rates and effluent quality or percent pollutant removal.

One of these generalized correlations extracted from an OTV brochure is depicted in Figure 3 for two types of media, activated carbon and biodamine (vitrified clay particles). Influent waste-

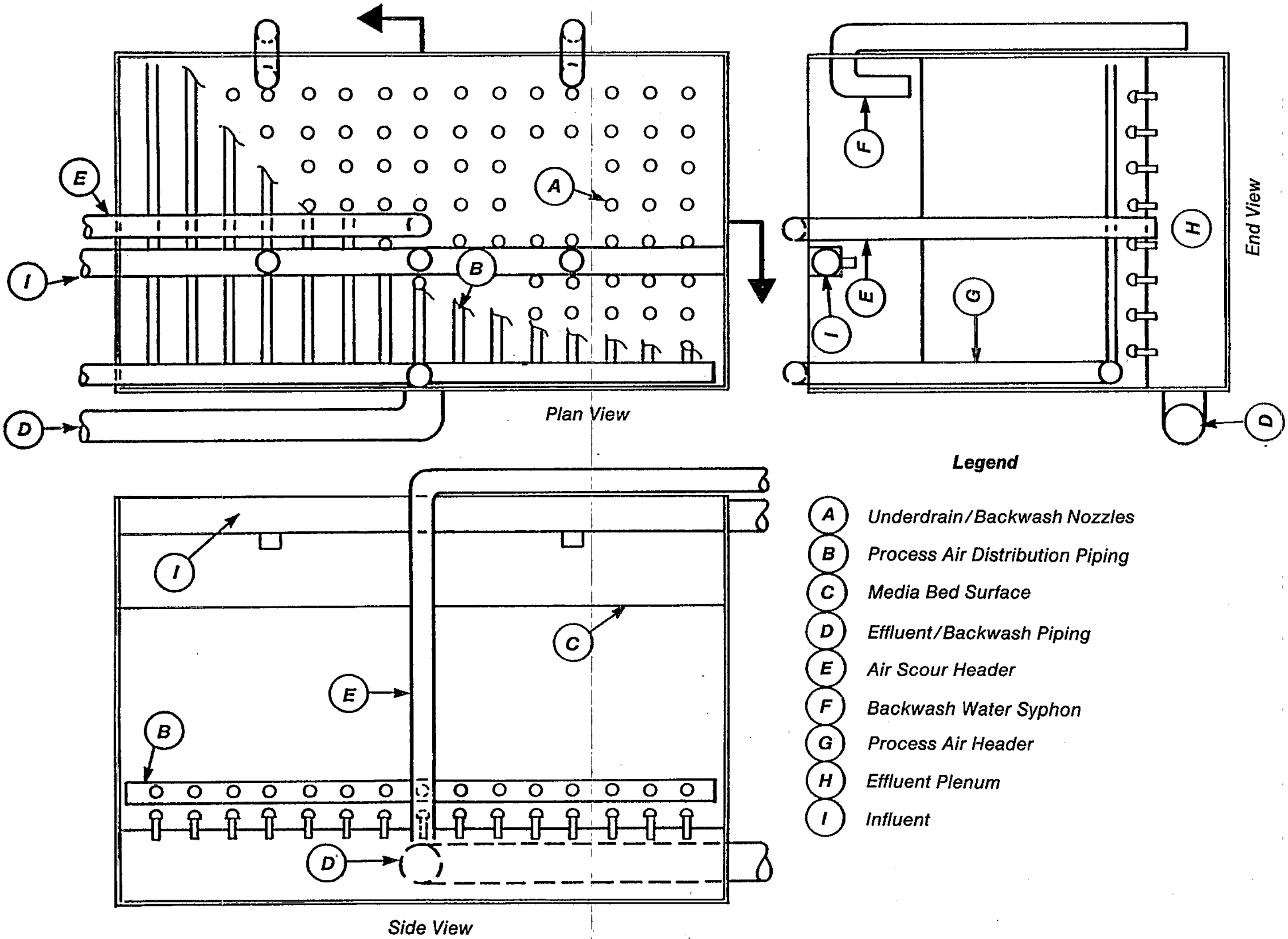

Figure 1. Plan and side views of a BAF/Biocarbone module.

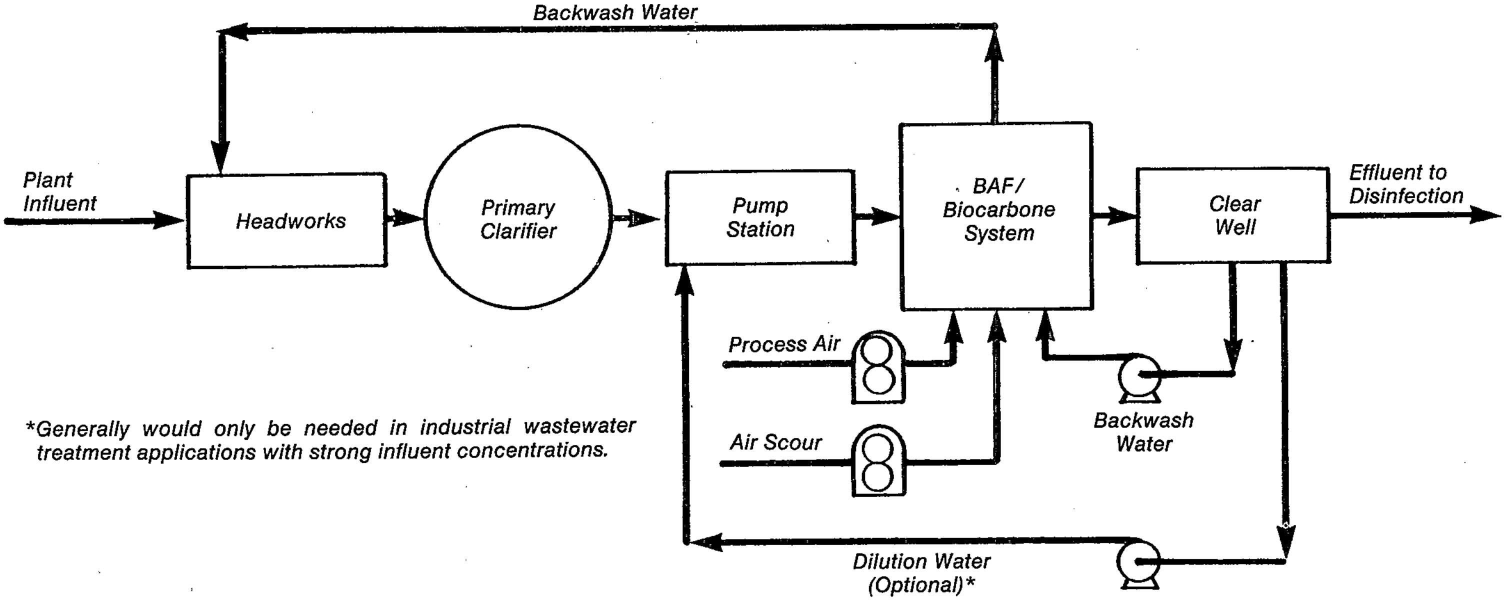

Figure 2. *Typical BAF/Biocarbone system process flow diagram.*

water characteristics from which the correlations were developed include:

Parameter	Range, mg/L
BOD_5	50–150
COD	100–300
TSS	50–150
TKN	15–30
NH_4-N	10–25

Effluent quality from a Biocarbone unit, based on the above influent characteristics, is graphically depicted in Figure 4.

Pilot plant studies by OTV indicated that ammonium nitrogen (NH_4-N) removal is governed, in part, by the organic loading to the Biocarbone unit. As indicated in Figure 5, an organic loading of greater than approximately 0.19 to 0.22 lb COD/ft^3/day (3.0 to 3.5 kg/m^3/day) produces incipient inhibition of NH_4-N oxidation, and the inhibition becomes substantially more pronounced once the organic loading exceeds 0.25 to 0.28 lb COD/ft^3/day (4.0 to 4.5 kg/m^3/day). The above loading condition is of concern mainly when primary effluent must be nitrified in conjunction with removing carbonaceous BOD. Nitrification of secondary effluent, on the other hand, is governed mainly by the TKN loading to a Biocarbone unit. Between nitrogen loadings of 0.010 and 0.037 lb TKN/ft^3/day (0.16 and 0.59 kg/m^3/day), NH_4-N removal decreases at a relatively linear rate, from about 90% to 84%. Loadings above about 0.037 lb TKN/ft^3/day (0.59 kg/m^3/day) result in substantially reduced NH_4-N removal rates.

Pilot plant studies also provided data on the temperature dependence of NH_4-N oxidation. Based on NH_4-N oxidation in secondary effluent, OTV reported removal rates to approximate the following:

Temperature		NH_4-N Removal Rate	
0°F	0°C	lb/ft^3/day	kg/m^3/day
54	12	0.024	0.39
64	18	0.031	0.50
75	24	0.037	0.60

Media Characteristics

The original media OTV used in their Biocarbone process was granular activated carbon. This material had the desirable characteristics of a porous surface with a high surface-to-volume ratio for enhancing biomass attachment and a low specific gravity to allow for ease of air scouring and backwashing, but it was found too expensive. Subsequently, two new media were developed, both kiln-fired clay particles. Biodamine is an angular shaped media that is subject to a slight degree of abrasion during media placement and backwashing operations. Biodagene is a spherical shaped media that is less subject to abrasion. Both have a bulk dry density of about 50 lb/ft^3 (800 kg/m^3). Eimco has developed an angular media that appears to be a kiln-fired shale. This media also has a bulk dry density of approximately 50 lb/ft^3 (800 kg/m^3).

Media gradation is one of the more important variables responsible for the performance of the BAF/Biocarbone process. Gradation not only affects effluent BOD and TSS concentrations but also governs the rate of headloss buildup and the associated time interval between backwashings. An OTV approximation of effluent quality as a function of media gradation is as follows:

Media Gradation		Effluent Quality, mg/L	
in.	mm	BOD_5	TSS
0.079–0.157	2–4	10	10
0.118–0.236	3–6	20	20
0.157–0.325	4–8	30	30

Media in the smaller size ranges require more frequent backwashing than larger media sizes subjected to the same loading rate. In general, media in the 0.079 to 0.157 in. (2 to 4 mm) range should be considered where stringent effluent residuals are required, lower loading rates are economically feasible, and wastewaters contain

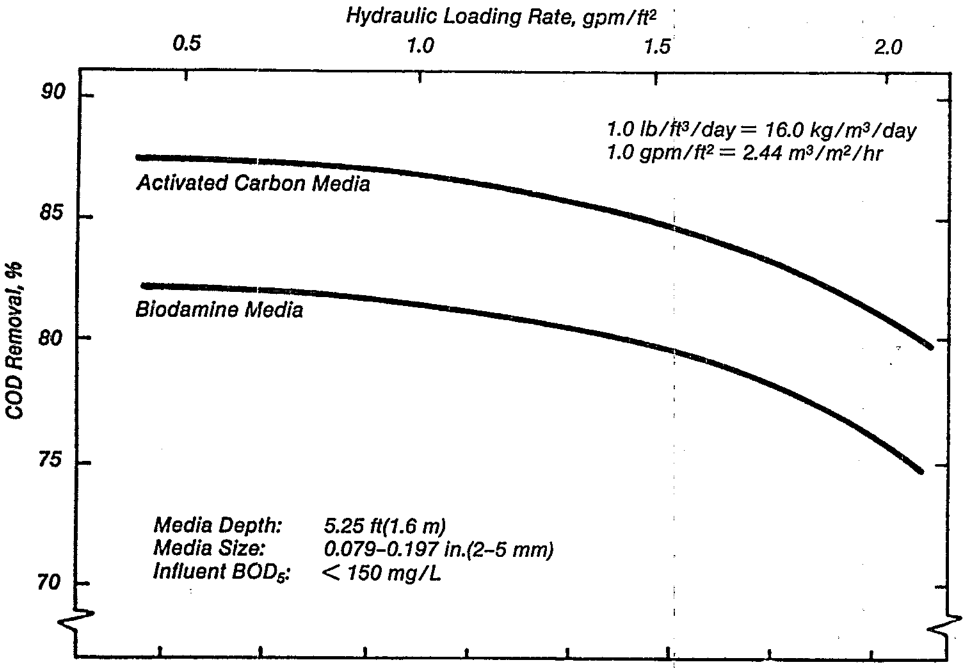

Figure 3. *COD removal as functions of influent COD loading rate and influent hydraulic loading rate for two different media.*

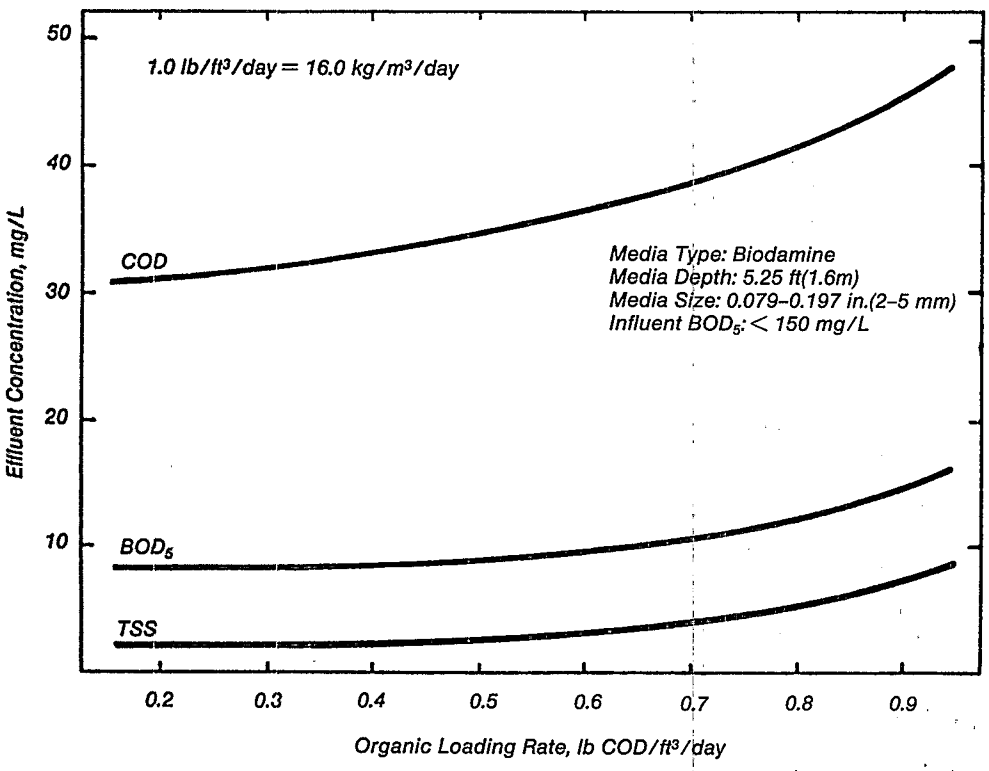

Figure 4. *Effluent quality as a function of influent COD loading rate.*

a high soluble BOD fraction. Wastewaters with a high TSS concentration may not be compatible with a media gradation of 0.079 to 0.157 in. (2 to 4 mm) because of the short run time between backwashings that could be incurred. Selecting BAF/Biocarbone media gradation for a given system influent loading may involve a tradeoff decision of attaining advanced secondary effluent quality with frequent backwashing (e.g., several times per day) versus attaining just secondary effluent quality with relatively infrequent backwashing (e.g., once a day).

Media gradation also defines capacity of a bed to store accumulated solids, which include a combination of suspended solids captured in the filtration process plus biomass produced from the assimilation and oxidation of carbonaceous and nitrogenous matter. An approximation of solids storage capacity, as a function of media gradation, developed from OTV pilot plant studies and confirmed at full-scale operational facilities is as follows:

Media Gradation		Solids Storage Capacity	
in.	*mm*	*lb/ft³*	*kg/m³*
0.079–0.157	2–4	0.06–0.09	1.0–1.5
0.118–0.236	3–6	0.14–0.17	2.2–2.7
0.157–0.315	4–8	0.19–0.22	3.0–3.5

In a BAF demonstration study at Salt Lake City, UT, sponsored by the U.S. Environmental Protection Agency (EPA), media with a size range of approximately 0.098 to 0.256 in. (2.5 to 6.5 mm) were used. Data indicated that the solids storage capacity of these media averaged about 0.16 lb/ft³ (2.6 kg/m³).

Solids Production

The solids production rate in the BAF/Biocarbone process is a function of, among other factors, the quantities of soluble BOD, nonbiodegradable TSS, NH_4-N, and TKN removed. OTV initially used the historic solids production approximation of 0.7 to 0.8 lb solids/lb total BOD_5 removed (kg/kg). A larger data base acquired from both pilot- and full-scale facilities yielded the following two modifications by OTV to their historic solids production value:

$$\text{Solids Production Rate} = \frac{0.4\ \text{lb (kg)}}{\text{lb (kg) soluble BOD}_5\ \text{removed}} + \frac{1.0\ \text{lb (kg)}}{\text{lb (kg) insoluble BOD}_5\ \text{removed}} \quad (1)$$

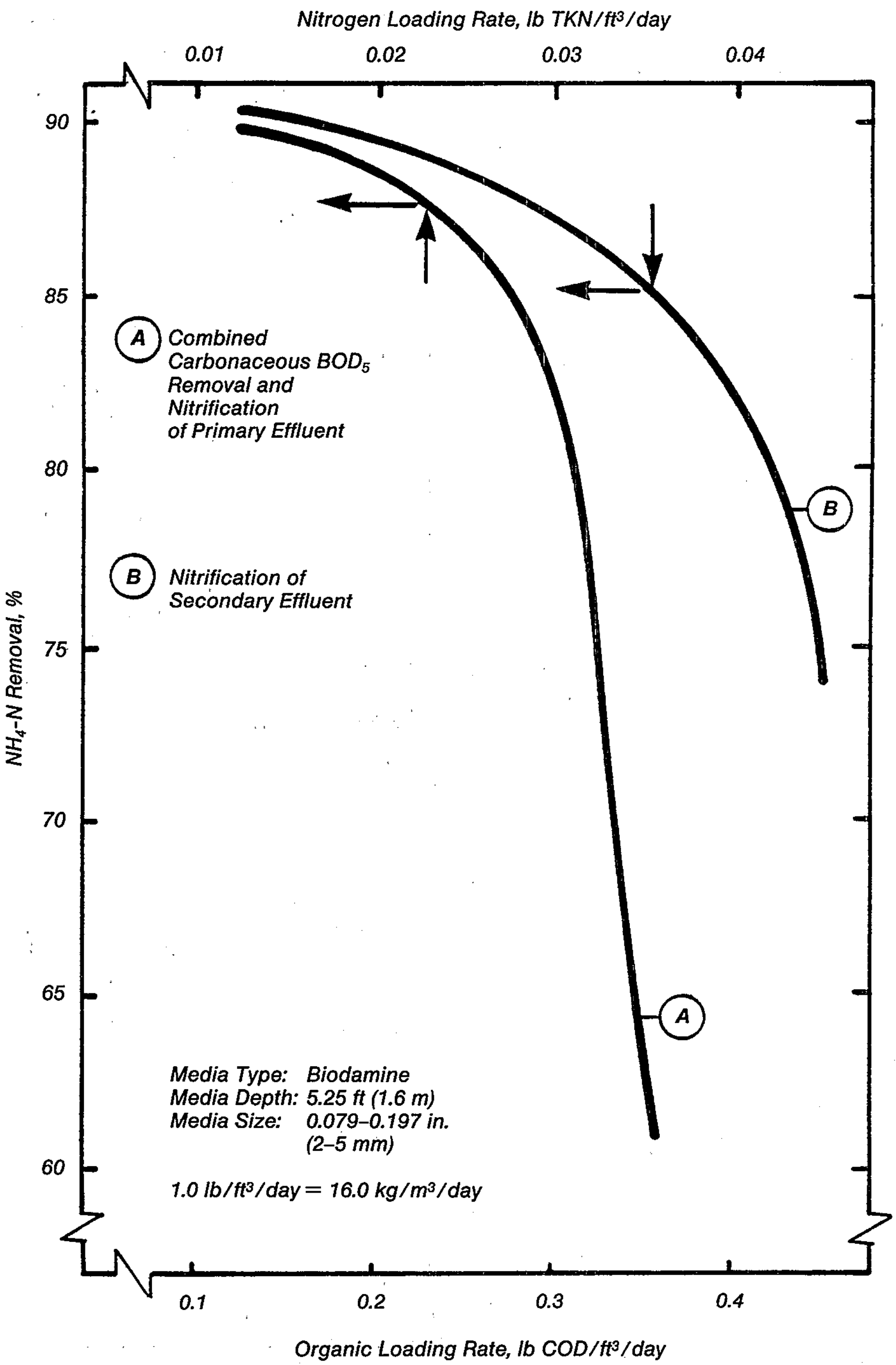

Figure 5. *NH_4-N removal as functions of influent COD and TKN loading rates.*

Solids Production Rate =

$$\frac{0.4 \text{ lb (kg)}}{\text{lb (kg) soluble } BOD_5 \text{ removed}} + \frac{0.65 \text{ lb (kg)}}{\text{lb (kg) TSS removed}} \quad (2)$$

Either of the above predicted models may be used to approximate the net solids production rate according to OTV.

Backwashing

The BAF/Biocarbone system must be backwashed, normally once a day, to ensure a specific volumetric throughput rate of wastewater. From numerous pilot plant studies, OTV established a need for up to seven consecutive sets of air scours and backwashes to clean the media bed. The seven consecutive sets constitute one backwash sequence. Air scour and backwash water rates and total volumes used at several full-scale French facilities are summarized below:

Parameter	Range of Values
Air Scour	
Rate, ft^3 (m^3) air/ft^3 (m^3) media/min	*0.43–0.52*
Total Volume, ft^3 (m^3) air/ft^3 (m^3) media	*5.14–6.25*
Backwash Water	
Rate, ft^3 (m^3) water/ft^3 (m^3) media/min	*0.33–0.35*
Total Volume, ft^3 (m^3) water/ft^3 (m^3) media	*2.50*

The EPA BAF demonstration project used essentially these same air scour and backwash water rates and volumes as do facilities that Eimco has recently installed.

Performance of Existing Facilities

North American Facilities

A 0.25-mgd (946-m^3/day) Eimco facility has been installed at Lake Wildwood, GA. Primary effluent is being treated with the goal of achieving a nitrified secondary effluent containing 6 to 8 mg/L NH_4-N. This facility is operating at, or slightly above, design flow. Another Eimco operational facility is located at Wallace, NC. Design flow is 0.60 mgd (2,271 m^3/day), and the system is polishing the effluent from an existing trickling filter plant to effect additional BOD and TSS removals as well as to achieve an NH_4-N concentration of 2 mg/L. Eimco's 0.60-mgd (2,271-m^3/day) facility at Madison, FL, is polishing effluent from an existing activated sludge system to provide supplemental BOD and TSS removals and nitrification to effluent residuals of less than 5 mg/L NH_4-N. At the present time, limited performance data have been reported for these facilities. A 0.75-mgd (2,839-m^3/day) facility is being constructed at St. George, SC, and a 2.2-mgd (8,327-m^3/day) facility is also under construction at Oneonta, AL. These latter two facilities will be used to polish and nitrify lagoon effluent.

The aforementioned EPA demonstration project at Salt Lake City, UT, operated from January 1983 to February 1985, also used an Eimco system. The system was operated to demonstrate the applicability of this European technology to treat U.S. strength wastewaters and to formulate any needed design or operational modifications to ensure a specific effluent quality. One of the system's two cells was operated to amass information on carbonaceous BOD removal with nitrification; the other cell was operated to generate information on carbonaceous BOD removal with nitrification. Data on the performance of this pilot plant are reported in detail in the June 1988 issue of the ASCE Journal of Environmental Engineering ("Biological Aerated Filter Evaluation" by H.D. Stensel et al.).

French Facilities

OTV has designed, constructed, and operated a number of Biocarbone facilities throughout France.

The location of these operational facilities, the type of wastewater being treated, and their design population equivalents are summarized in Table 1.

In addition to the above, a four-celled 323-ft^2 (30-m^2) pilot plant has been operated by OTV at the Colombes treatment plant to optimize system design criteria and operating conditions for future reference when the City of Paris is required to install wastewater nitrification facilities.

On-site visits were made to four of the French facilities: Soissons, Grasse, Valbonne, and Colombes. The Colombes pilot plant was nitrifying activated sludge treatment plant effluent at the time of the visit. Available operating and performance data for Soissons, Grasse, and Colombes are summarized in Tables 2 and 3, respectively. Detailed operating and performance data were not available for Valbonne.

The system at Soissons was the first full-scale facility built by OTV. A circular design with 10 truncated, pie-shaped units was selected, with the center of the structure functioning as the clear well for storing the treated wastewater used for backwashing the units.

The Grasse Biocarbone system, which began operation in April 1983, is similar in appearance to the circular Soissons facility. Wastewater being treated at this facility during the 1984 site visits was primarily from perfumeries located in the City. As more of the City's collection system is installed, the contribution of domestic wastewater is expected to increase from the 35% to 40% level noted at the time of the site visit.

The Colombes pilot system during the 1984 site visits was composed of four independent 81-ft^2 (7.5-m^2) cells. As previously mentioned, this system was being operated as an experimental facility to amass design and operational information for future City of Paris secondary effluent nitrification facilities.

The Valbonne system was designed to achieve nitrification and partial denitrification along with carbonaceous BOD_5 removal. Three units are operated in an aerobic state to nitrify, and one unit is operated in an anoxic state to denitrify.

The Valbonne facility was placed in operation in October 1982. Between that time and the site visits in 1984, on the average, only one to two effluent samples per month had been analyzed for randomly selected pollutant parameters. The available data, though limited, indicated the facility had consistently achieved high removals of BOD_5, TSS, and NH_4-N with effluent residuals in the ranges of 5 to 10 mg/L for BOD_5 and TSS and 1 to 5 mg/L for NH_4-N.

Table 1. *Basic Information on Existing Biocarbone Facilities*

Location	Type of Wastewater	Design Population Equivalent
Le Havre	Secondary Effluent	5,000
Valbonne	Municipal	16,000
Hochfelden	Industrial (Brewery)	25,000
Soissons	Municipal-Industiral (Slaughterhouse)	40,000
Grasse	Municipal-Industrial (Perfumery)	52,000
Le Touquet	Municipal	53,000
Sanary-Bandol	Municipal	35,000
Luneville	Municipal	33,000

Table 2. *Operating Data for Soissons, Grasse, and Colombes*

Parameter	Facility Location: Soissons	Grasse	Colombes
Operating Period	11/82–6/84	1/84–5/84	7 months
Avg. Inf. Flow			
mgd	0.91	1.00	—
m^3/day	3,460	3,790	—
Avg. Hydraulic Loading			
gpm/ft^2	0.28	0.48	0.75
m^3/m^2/day	0.69	1.17	1.84
Avg. BOD_5 Loading			
lb/ft^3/day	0.11	—	—
kg/m^3/day	1.74	—	—
Avg. COD Loading			
lb/ft^3/day	0.20	0.47	—
kg/m^3/day	3.22	7.51	—
Avg. NH_4-N Loading			
lb/ft^3/day	0.02	—	—
kg/m^3/day	0.32	—	—
Avg. Empty Bed Contact Time (min)	156	—	—
Wastewater Temperature, °F (°C)			
Avg.	57 (13.7)	—	58 (14.7)
Range	46–69 (8–20.5)	—	53–65 (11.5–8.5)
Backwash Water Flow (% of Inf. Flow)			
Avg.	33.2	22.2	—
Range	17.5–63.3	19.3–27.4	—

Table 3. *Performance Data for Soissons, Grasse, and Colombes*

Parameter	Facility Location: Soissons	Grasse	Colombes
Avg. BOD_5 (mg/L)			
Influent	298	—	29*
Primary Effluent	161	—	—
Final Effluent	10	—	4
Avg. COD (mg/L)			
Influent	616	1,243+	—
Primary Effluent	299	825	—
Final Effluent	61	177	—
Avg. TSS (mg/L)			
Influent	281	382+	35*
Primary Effluent	111	85	—
Final Effluent	10	25	6
Avg. NH_4-N (mg/L)			
Influent	36	—	25.7*
Primary Effluent	30	—	—
Final Effluent	12/8‡	—	7.7

**System influent is secondary effluent.*
+Includes backwash water pollutant load.
‡Average of 12 mg/L for all wastewater temperatures; average of 8 mg/L for wastewater temperatures above 54° F (12° C).

Design Approaches

Based on findings from their own research and development, the OTV and Eimco staffs developed generalized approaches to facility design. These extensive design protocols are presented in the full report.

After examining OTV's and Eimco's design approaches and analyzing available full-scale system performance data, the author formulated an alternative design approach. A review of certain of OTV's and Eimco's system performance functions, which were primarily based on pollutant mass loadings, coupled with performance data from the Soissons and Colombes full-scale facilities indicated complementary mathematical equations that potentially allowed for prediction of actual effluent quality.

At Soissons, where the feed to the Biocarbone system was primary effluent, the following mathematical relationships were developed for predicting effluent BOD_5, TSS, and NH_4-N:

Effluent BOD_5, mg/L =

$$\frac{\text{Influent BOD}_5\text{, mg/L}}{0.13\ (\text{EBCT})} \qquad (3)$$

Effluent TSS, mg/L =

$$\frac{\text{Influent TSS, mg/L}}{0.09\ (\text{EBCT})} \qquad (4)$$

Effluent NH_4-N, mg/L =

$$\frac{\text{Influent NH}_4\text{-N, mg/L (Effluent BOD}_5\text{, mg/L)}^{0.5}}{0.064\ (\text{EBCT})} \qquad (5)$$

where EBCT is the empty bed contact time in minutes.

A similar set of analyses was undertaken on the performance of the Colombes pilot plant facility, where the system feed was secondary effluent. Effluent BOD_5 and TSS concentrations from the pilot plant facility were independent of influent wastewater quality as well as independent of EBCT. Ammonium nitrogen removal was best described by the mathematical expression:

Effluent NH_4-N, mg/L =

$$\frac{\text{Influent NH}_4\text{-N, mg/L}}{0.060\ (\text{EBCT})} \qquad (6)$$

Predicted values have been compared with actual values for effluent BOD_5 at Soissons (Table 4). Similar tables for the other effluent pollutant concentrations are given in the full report.

Technology Application

North American and French systems performance data indicate that the BAF/Biocarbone process is capable of yielding an effluent of secondary treatment or advanced secondary treatment quality. As evidenced by performance of the EPA demonstration facility at Salt Lake City, UT, an effluent containing approximately 25 to 30 mg/L each of BOD_5 and TSS can be achieved at an EBCT of about 45 min when treating a dilute, primary clarified domestic wastewater. Data from the Soissons, France, facility indicated that a stronger primary clarified municipal wastewater can be treated to yield an effluent containing less than 10 mg/L each of BOD_5, TSS, and NH_4-N at an EBCT

Table 4. *Predicted versus Actual Effluent BOD_5 Concentrations for the Soissons Facility*

Month	Wastewater Temp., °C	EBCT, min	Influent BOD_5, mg/L	Effluent BOD_5, mg/L	Predicted Effluent BOD_5, mg/L
11	12.8	93	195	30	16
12/82	10.0	79	182	17	18
1/83	10.0	86	162	12	14
2	8.0	104	136	12	10
3	10.7	98	184	13	14
4	11.0	79	186	12	18
5	13.8	104	169	10	13
6	17.5	149	147	8	8
7	19.5	184	139	8	6
8	20.5	195	137	6	5
9	17.7	177	135	7	6
10	16.0	223	175	7	6
11	14.5	213	256	9	9
12/83	12.2	222	185	7	6
1/84	10.0	173	141	8	6
2	11.0	189	180	6	7
3	11.5	217	140	7	5
4	13.0	232	57	6	2
5	15.8	155	147	6	7
6	18.0	148	150	6	8

of approximately 140 min. The process can also be used for polishing secondary effluent, as evidenced by the Colombes, France, facility data that produced an effluent containing an average of 4 mg/L BOD_5 and 6 mg/L TSS and achieved an average NH_4-N removal of 18 mg/L at an EBCT of about 60 min.

To illustrate the application of the BAF/Biocarbone process, two example designs are developed in the full report to upgrade an existing 1.0-mgd (3,785-m^3/day) primary clarification system to (1) a secondary treatment system at similar capacity and (2) an advanced secondary treatment system of similar capacity using the BAF/Biocarbone process. In the first case, the goal is to achieve effluent BOD_5 and TSS concentrations of 30 mg/L or less. Nitrification is not a process requirement in the second case, effluent goals are 4 mg/L for BOD_5, 6 mg/L for TSS, and less than 7 mg/L for NH_4-N. Estimates of capital costs and average daily power requirements are developed for these two example designs.

The full report was submitted in fulfillment of Contract No. 68-03-1821 by James M. Montgomery, Consulting Engineers, Inc., under the sponsorhip of the U. S. Environmental Protection Agency.

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***Richard C. Brenner** is the EPA Project Officer (see below).*
The complete report, entitled "Technology Assessment of the Biological Aerated Filter," (Order No. PB90-188 806/AS; Cost: $23.00, subject to change) will be available only from:
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