01 Jan 1998

Biological Fixed-Film Systems

Mark W. Fitch
Missouri University of Science and Technology, mfitch@mst.edu

Natalie Pearson

Gene Richards

Joel Gerard Burken
Missouri University of Science and Technology, burken@mst.edu

Lagoons at Pulp and Paper Mills. *Water Sci. Technol.* (G.B.), **35,** 2, 117.
Wentzel, M.C., and Ekama, G.A. (1997) Principles in the Design of Single-Sludge Activated-Sludge Systems for Biological Removal of Carbon, Nitrogen, and Phosphorus. *Water Environ. Res.*, **69,** 1222.
Whyte, L.G.; Bourbonniére, L.; and Greer, C.W. (1997) Biodegradation of Petroleum Hydrocarbons by Psychrotrophic *Pseudomonas* Strains Possessing both Alkane (*alk*) and Naphthalene (*nah*) Catabolic Pathways. *Appl. Environ. Microbiol.*, **63,** 3719.
Williams, C.L.; Mahmood, T.; Corcoran, H.; Zaltzmann, M.E.; and Banerjee, S. (1997) Tracing the Efficiency of Secondary Treatment Systems. *Environ. Sci. Technol.*, **31,** 3288.
Wilson, T.; Carrio, L.; Fillos, J.; and Bailey, W. (1997) Getting More Information with Less Work: Application of the SSV Test to the Operation Activated Sludge Plants. *Proc. 70th Annu. Water Environ. Fed. Conf. Exposition,* Chicago, Ill., **1,** 713.
Winnen, H.; Suidan, M.T.; Scarpino, P.V.; Wrenn, B.; Cicek, N.; Urbain, V.; and Manem, J. (1996) Effectiveness of the Membrane Bioreactor in the Biodegradation of High Molecular-Weight Compounds. *Water Sci. Technol.* (G.B.), **34,** 197.
Woolard, C.R., and Luetters, S.T. (1997) Starvation Response in Biological Treatment Systems. *Proc. 70th Annu. Water Environ. Fed. Conf. Exposition,* Chicago, Ill.
Yang, C.; McKinney, R.; Johnson, L.; Zack, C.; and Koeppen, T. (1997) The Use of a Modified Sequencing Batch Reactor for Organic Carbon and Nitrogen Removal. *Proc. 70th Annu. Water Environ. Fed. Conf. Exposition,* Chicago, Ill., **1,** 569.
Yang, Z.; Suzuki, H.; Sasoki, S.; and Karube, I. (1996) Disposable Sensor for Biochemical Oxygen Demand. *Appl. Microbiol. Biotechnol.*, **46,** 10.
Ydstebo, L., and Bilstad, T. (1997) Experiences with Bio-P and BNR at Low Temperature. *Proc. 70th Annu. Water Environ. Fed. Conf. Exposition,* Chicago, Ill., **1,** 451.
Yoong, E.T.; Lant, P.A.; and Greenfield, P.F. (1997) The Influence of High Phenol Concentration on Microbial Growth. *Water Sci. Technol.* (G.B.), **36,** 2, 75.
Young, J.C. (1997) Fundamentals of Respirometry: Instrument Types and Basis of Operation. *Proc. 51st Ind. Waste Conf., Purdue Univ.,* West Lafayette, Ind., 46.
Yu, H.; Gu, G.; and Song, L. (1997) Posttreatment of Effluent from Coke-Plant Wastewater Treatment System in Sequencing Batch Reactors. *J. Environ. Eng.*, **123,** 305.
Yu, H.Q.; Tay, J.H.; and Wilson, F. (1997) An Alternative Operational Mode for the Sequencing Batch Reactor Process. *J. Environ. Sci. Health,* **A32,** 8, 2169.
Yu, R.F.; Liaw, S.L.; Chang, C.N.; Lu, H.J.; and Cheng, W.Y. (1997) Monitoring and Control Using On-Line ORP on the Continuous-Flow Activated Sludge Batch Reactor System. *Water Sci. Technol.* (G.B.), **35,** 1, 57.
Yuan, Z.; Bogaert, H.; Vanrolleghem, P.; Thoeye, C.; Vansteenkiste, G.; and Verstraete, W. (1997) Control of External Carbon Addition to Predenitrifying Systems. *J. Environ. Eng.*, **123,** 1080.
Yuan, Z.; Vanrolleghem, P.A.; and Vansteenkiste, G.C. (1997) Modeling Error Identification of Activated Sludge Models. *Water Sci. Technol.* (G.B.), **36,** 5, 81.
Zaloum, R., and Abbott, M. (1997) Anaerobic Pretreatment Improves Single Sequencing Batch Reactor Treatment of Landfill Leachates. *Water Sci. Technol.* (G.B.), **35,** 1, 207.
Zarnt, G.; Schräder, T.; and Andreesen, J.R. (1997) Degradation of Tetrahydrofurfuryl Alcohol by *Ralstonia eutropha* Is Initiated by an Inducible Pyrroquinoline Quinone-Dependent Alcohol Dehydrogenase. *Appl. Environ. Microbiol.*, **63,** 4891.
Zhang, M.; Tay, J.H.; Qian, Y.; and Gu, X.S. (1997) Comparison Between Anaerobic-Anoxic-Oxic and Anoxic-Oxic Systems for Coke Plant Wastewater Treatment. *J. Environ. Eng.*, **123,** 876.
Zhao, H.; Hao, O.J.; McAvoy, T.J.; and Chang, C.H. (1997) Modeling Nutrient Dynamics in Sequencing Batch Reactor. *J. Environ. Eng.*, **123,** 311.
Zhou, S.; Vitasovic, C.; McCorquodale, J.A.; Lipke, S.; DeNicola, M.; and Saurer, P. (1997) Improving Performance of Large Rectangular Secondary Clarifiers. *Proc. 70th Annu. Water Environ. Fed. Conf. Exposition,* Chicago, Ill., **1,** 721.
Zilverentant, A.G. (1997) Pilot-Testing, Design and Full-Scale Experience of a Sequencing Batch Reactor System for the Treatment of the Potentially Toxic Waste Water from a Road and Rail Car Cleaning Site. *Water Sci. Technol.* (G.B.), **35,** 1, 259.
Zita, A., and Hermansson, M. (1997) Effects of Bacterial Cell Surface Structures and Hydrophobicity on Attachment to Activated Sludge Flocs. *Appl. Environ. Microbiol.*, **63,** 1168.
Zuckut, S.; Boehnke, B.; and Diering, B. (1997) Case Study: Effective BNR Removal in a Municipal WWTP with Very High Industrial Wastewater Content. *Proc. 70th Annu. Water Environ. Fed. Conf. Exposition,* Chicago, Ill., **1,** 481.

Biological fixed-film systems

Mark W. Fitch, Natalie Pearson, Gene Richards, Joel G. Burken

Biological fixed-film systems offer several advantages when compared to activated-sludge processes, such as handling convenience, little residual sludge, and ease of use in small-scale treatment (Xu, 1997). Another advantage is the capacity to handle shock loads, such as those experienced by a continuous-flow mode treatment of inhibitory organic compounds in landfills and hazardous waste sites (Woolard, 1997). These shock loads caused biofilm stratification and uneven biomass distribution that limited the system ability to treat shock loads. A change to periodic operation of the reactor imposed regular variations in substrate concentrations that resulted in maximum growth rates throughout the film and improved response to shock loading. Similarly, Boller *et al.* (1997) studied the effects of transient NH_4^+-loading rates, transient oxygenation capacities, and short- and long-term organic loading on nitrification performance in pilot experiments using tertiary trickling filters, rotating biological contactors (RBCs), aerated biofilters, and other fixed-bed reactors. It was reported that periodic flow reversal in trickling filter and RBC series and pure oxygen use in biofilters may increase nitrification in tertiary biofilm reactors, whereas biodegradable organics may lower or stop nitrification activity.

Biofilm systems are also used to treat volatile organic chemicals (VOCs), and a brief discussion of pilot studies of VOC removal in fixed-film systems including trickling filters and RBCs was offered by Iranpour and Ludwig (1997). Oesterholt *et al.* (1997) examined pilot-plant biological and chemical treatment options to find the optimal configuration of treatment steps for groundwater treatment at a former gas works remediation site in the Netherlands.

Pilot-plant investigations were performed for five treatment

options for separate treatment of sludge liquor: the biofilm airlift suspension (BAS) reactor, the membrane bioreactor (MBR), the bioreactor without sludge retention, stripping of ammonia, and the MAP/ACFR-process. It was concluded that the optimal choice is site specific (Janus and van der Roest 1997). The production of sludge was the focus of a paper by Kahmark and Unwin (1997), who minimized sludge production in aerobic wastewater treatment through variations in the design of biofilms and suspended-growth reactors in pulp and paper plant wastewaters.

TRICKLING FILTERS

Detailed evaluation of six full-scale, biological-filtration wastewater-treatment works was performed over 2 years in which there were significant changes in wastewater flow rates, composition, and temperature from summer to winter. Key parameters to produce a high-quality nitrified effluent were determined, and detailed design guidelines were developed (Boon *et al.*, 1997). At the pilot scale, an 11-month study of potential pretreatment of industrial wastes with trickling filters was conducted. Of four models tested against the pilot-scale data, a Monod-like, pseudo-mixed-order model gave slightly superior results (Randall *et al.*, 1997). Michalakos *et al.*, 1997) investigated iron removal from potable water with a pilot-scale trickling filter. Iron removal resulted from both physicochemical and biological oxidation, with periodic backwash required to remove the significant quantities of precipitated iron.

Most of the work with trickling filters published in 1997 focused on nitrification and denitrification. Operation and monitoring of two full-scale nitrifying trickling filters was conducted to investigate treatment efficiency and biofilm control strategies. Backwash and predator control strategies proved effective in maintaining treatment levels (Parker *et al.*, 1997). Investigation of full-scale biotowers revealed that upsets in nitrifying efficiency were linked to predatory snails (Palsdottir and Bishop, 1997). A dynamic model describing nitrification and nitratification in trickling was developed and tested in a pilot-scale trickling filter by Vayenas *et al.*, 1997). The model predicted, among other parameters, the concentration profiles of ammonia, nitrite, and nitrate along the filter depth and along the biofilm depth. Wilk (1997) presented models of nitrifying trickling filters based on data from a pilot-plant study and drew several conclusions from a comparison of experimental data and model simulations. Lee (1997) observed that nitrifiers detached from trickling filters enhanced nitrification in downstream suspended-growth systems. Microelectrodes and fluorescently labeled 16s rRNA-targeted oligonucleotide probes were used to examine the stratification of nitrifiers in a trickling filter biofilm. Nitrifiers were found to form a dense layer of cells in the upper part of the biofilm, correlating well with activity profiles (Schramm *et al.*, 1997). Denitrification in a full-scale tertiary filter was studied with varying temperature and methanol dose. Optimal backwashing periods were determined, and denitrification performance was favorable throughout the year (Koch and Siegrist, 1997b). Denitrification rates of 1.0 $kg\text{-}N/m^3 \cdot d$ were observed at 12–15°C, with denitrification rates reduced by backwashing. A yield of 0.4 kg COD_X/kg COD_{MeOH} resulted, with high-quality effluent during winter operation. During summer (20–22°C), nitrite accumulated (Koch and Siegrist, 1997a).

Pilot-plant experiments in Bangkok, Thailand, by Fujii *et al.*, 1997) point to several criteria that make rock-bed filtration techniques applicable to improving polluted canal/klong water. The biological treatability of assimilable organic carbon in drinking water was investigated under oligotrophic conditions. Removal efficiencies with different media were examined and evaluated (Nitisoravut *et al.*, 1997).

ROTATING BIOLOGICAL CONTACTORS

Martin *et al.*, 1997) improved the operations of a full-scale, three-stage RBC plant, having parallel trains used to treat domestic and industrial wastewater. The plant had failed to meet standard secondary effluent limits because of above-normal influent concentration levels (300 mg/L) in the initial stages. Integrating a secondary solids recycling process, the RBC performance improved significantly to obtain an approximate 50% reduction in BOD_5 and 40% reduction in suspended solids effluent concentration levels at a $5 000 cost to the community.

A pilot rotating biological reactor and a pilot sequencing batch reactor (SBR) were compared for the ability to nitrify landfill leachate with an average ammonia nitrogen concentration of 202 mg/L and an average biological oxygen demand (BOD) concentration of 50 mg/L. Rotating biological contactor ammonia removal proved superior to SBR ammonia removal, but neither system effectively removed BOD, chemical oxygen demand (COD), or metal color (Henderson *et al.*, 1997). Denitrification kinetics of a synthetic substrate in a rotating disk biofilm reactor (RDBR) were studied. For predicting efficiency of the RDBR, experimental data reasonably agreed with the model based on zero-order reaction and diffusion inside the biofilm (Boaventura and Rodrigues, 1997). Treatment studies were conducted in a RBC by Radwan and Ramanujam (1997a) using synthetic wastewater prepared with different NH_3-N and COD influent concentrations to develop a single process that simultaneously affects organic removal and nitrification.

Su and Ouyang (1997) added RBC biofilms to A^2/O processes to affect advanced removal efficiency of organic carbon, phosphorus, and nitrogen from municipal wastewater while combining the long solid retention time (SRT) biofilm and the short SRT-suspended activated sludge to yield many practical benefits. Results of a pilot-plant study on the performance of a hybrid small municipal wastewater treatment system consisting of an upgraded RBC and jet mixed separator converted from use as a primary clarifer to RBC pretreatment were presented by Watanabe and Iwasaki (1997).

Another modification of a RBC process was to follow the RBC with a solids contact unit (RBC/SC system). The RBC/SC system was evaluated and modeled for small community usage. The SC phase improving overall removal efficiencies largely due to an average increase in the removal of suspended matter of 26%. Total and soluble COD removal were also increased by 18 and 17%, respectively (d'Antonio *et al.*, 1997). A combined treatment process involving RBCs and subsurface reed beds produced a high-quality effluent in a small treatment plant, with BOD_5, total suspended solids, and total Kjeldahl nitrogen < 10 mg/L (Green *et al.*, 1997).

A four-stage, cross-flow. Laboratory-scale reactor was extensively characterized for the removal of phenol from wastewater, with the effects of temperature, loading, concentration, hydraulic loading, and rotational velocity determined. Phenol was removed with a first-order rate constant of 0.10–0 13 per hour in the temperature range 20.5–27°C, with a temperature coefficient (θ) of 1.04 (Banerjee, 1997). The removal of salt from wastewa-

ter is generally accomplished by a physicochemical process, but Kargi and Uygur (1997) used an RBC that was seeded with the halophile *Halobacter halobium* to remove salt from a synthetic wastewater. An empirical model was developed from the experimental data.

A program of batch, continuous-flow, and field pilot tests was conducted to measure the extent and stability of nitrification in Kraft wastewater. The results during the 11-month run were (a) the RBC demonstrated the capability of consistently and substantially reducing NH^{4+}-N concentration below 1 mg/L, (b) about 1 month was needed to establish effective treatment, and (c) effective treatment was sustained at a maximum hydraulic loading rate of 0.11 $m^3/d \cdot m^2$ (Bryant *et al.*, 1997).

A modified, laboratory-scale RBC, in which the disks were modified by attaching porous netlon sheets to enhance biofilm area and volume, was used for treatability studies of wastewaters containing synthetic 2,4-dichlorophenol (2,4-CP). Radwan and Ramanujam (1997b) discussed the effect of hydraulic loadings and influent concentration on 2,4-CP removal and presented a mathematical model to describe the effects.

Two types of magnetic RBCs (MRBCs), disk and drum systems, were implemented to investigate continuous citric acid fermentation using *Aspergillus niger.* Citric acid was produced at a higher rate in the drum system than in the disk system, and the biofilm maintained its stable activity for about 50 days of continuous operation (Saha and Takahashi, 1997). Sakurai *et al.*, 1997) modeled citric acid production in an RBC based on Monod parameters, diffusion of oxygen in the biofilm, and citric acid production rate equations. Five adjustable parameters were fit to experimental data generated in 12 runs.

Experiments to investigate the microfauna of adhered biofilms treating a simulated petrochemical plant wastewater were conducted in an RBC in relation to organic loadings and the toxicity. A resulting correlation between the wastewater and the distribution and abundance of microfauna can predict the biofilm's biological quality of the activated sludge (Selivanovskaya *et al.*, 1997). A microscopic examination of the microfauna in bacterial samples and sludge from the first and fourth stages of a RBC was performed, with coccoid bacteria predominant in both stages (Venkataraman *et al.*, 1997). In the fourth stage, there were fewer nematodes, algae, and *Chroococcus* but greater numbers of rotifers and *Navicula.* Supplemental aeration of an overloaded RBC resulted in favorable performance and adaptation to differing organic loading rates, with *Beggiatoa* growth completely eliminated (Surampalli and Baumann, 1997). Slime samples from 66 RBCs in 20 U.S. states were examined to establish an indicator organism. The organisms differed in abundance along the RBC stages so organisms were grouped based upon the organism loading preference (Chung and Strom, 1997b).

Studies on the effects of organic loading rates and temperature on BOD and COD removal were conducted by Mathys *et al.*, 1997) to evaluate mill wastewater treatment using a laboratory-scale RBC. Average BOD and COD removals increased with temperature increase, whereas dissolved oxygen (DO) appeared to have no effect on BOD removal, even though some DO levels were low. A different laboratory-scale RBC, operated in Singapore to test the response to equatorial conditions, produced high removal efficiencies, with some first-stage problems associated with the high reaction rates because of high temperatures (Wilson and Lee, 1997). High rates of loading to an RBC treating high-strength, food-processing waste were studied using total organic carbon (TOC) rather than BOD or COD. TOC was found to give excellent correlation between efficiency and input parameters (Wilson, 1997).

BIOFILTRATION AND BIOTRICKLING FILTERS

The fundamentals, design, operation, and process application of biofiltration for VOCs were studied by Swanson and Loehr (1997). Key parameters for design, performance, and operation were given. They noted that, with proper design and operation, VOC removal efficiencies of 95–99% could be achieved. In a commentary on biofilter design, past experiences with full-scale units and design trends were summarized (van Lith *et al.*, 1997). Moisture was identified as the critical parameter in biofiltration design, and cost data were provided. Wani *et al.*, 1997) presented an overview of the historical development and present status of biofiltration, especially as it relates to the removal of odors, VOCs, and air toxics.

The roles of humidity and microbial heat generation were investigated (Gostomski *et al.*, 1997). A moving front of higher temperature and subsequent increased water evaporation was observed, eventually impairing degradation in the compost biofilter. The start-up of biofilters was investigated at the laboratory scale by Deshusses (1997). Within 3–5 days of start-up, 82% of influent methyl ethyl ketone (MEK) was mineralized. Step inputs of 0.5–1 hour of hexane, acetone, 1-propoanol, and/or methyl isobutyl ketone were applied, with apparent sorption to packing material, followed by degradation within 2–5 hours. The step inputs did not affect MEK removal, although concentration profiles indicated substantial inhibition occurring during these inputs.

Zarook, Shaikh, and Ansar (1997a) presented a general transient biofiltration model that incorporates general mixing phenomena, oxygen limitation effects, adsorption phenomena, and general biodegradation reaction kinetics. Results validated with experimental transient data of benzene and toluene demonstrated that transient behavior was predicted well by the model and that the biofilter withstood conditions such as random variations in the inlet concentration and gas flow rate. The transient biofilter model was extended for binary VOC mixtures (Zarook, Shaikh, Ansar, and Baltzis, 1997b). A quasi-steady-state approximation was the basis for the approximate model, but results showed that predictions by the general model were closer to experimental results. The authors also learned that inlet oxygen consumption played a vital role, especially at high VOC concentrations. Baltzis *et al.* (1997) used a different mathematical model to describe treatment of binary VOC contaminated air streams in biofilters. This model accounted for potential kinetic interactions, oxygen availability, and biomass diversification.

A steady-state mathematical model was developed by Abumaizar *et al.* (1997) to describe the kinetics of VOC removal in biofilters that consist of a mixed compost and granulated activated carbon (GAC) medium. The presence of GAC improved BTEX removal efficiencies over a biofilter containing only compost. A mathematical model was defined that describes physical and biological processes occurring in a trickle-bed air biofilter for waste gas treatment, and this model was found to be in agreement with experimental data (Alonso, Suidan, *et al.*, 1997a). Analysis of specific surface area variation effects with bacterial growth led to the conclusion that excessive biomass accumulation has a negative effect on contaminant removal

efficiency, but this problem was corrected by removing the excess biomass with full media fluidization and backwashing of the biofilter.

Experimental results and a mathematical model describing the effect of nutrient supply on the biodegradation of volatile organic compounds in a packed-bed biofilter were presented by Alonso, Zhu, *et al.* (1997b). Nitrate was rate limiting as a growth nutrient rather than as an electron acceptor, and resistance to the transport of nitrate into the biofilm led to nutrient limitations in the biofilm deeper layers. Zhu *et al.*, 1997) utilized diethyl ether as a VOC substrate in trickle-bed filters with pelletized media to investigate the effect of phosphorus on VOC removal in the biofiltration process. The results of this study provided evidence that limiting phosphorus did not significantly affect biofilter performance, unlike reducing nutrient nitrogen concentrations. Hwang *et al.*, (1997) developed a mathematical model of the acetone biofiltration process with the following parameters: diffusion and biodegradation of acetone, diffusion of oxygen in the biofilm, mass transfer resistance in the gas film, and flow pattern of the bulk gas phase. Although the overall acetone-removal process was limited by the oxygen diffusion rate, the acetone concentration profile along the biofilter and the elimination capacity predicted by the model were consistent with experimental results.

Several models of biofiltration of aromatic hydrocarbons were published in 1997. The interactions among the adsorption, microkinetics, mass transfer, and gas flow were mathematically modeled to explain the transient behavior of toluene-degrading biofilters (Tang and Hwang, 1997). Experimental results and the proposed model were in good agreement. A phenomenological model for simulating the removal of toluene, ethylbenzene, and *o*-xylene (TEX) from contaminated air streams by a biofilter was developed and tested by Nguyen *et al.*, (1997). The model produced a suitable approximation with discrepancies within experimental uncertainties. Toluene was treated during a 93-day period in a laboratory-scale biofilter system packed with peat and inoculated with specific flora (*Pseudomonas* sp.) (Bibeau *et al.*, 1997). The biofilter was intermittently humidified with a nutrient solution. Under pseudo-steady-state conditions, a maximum elimination capacity of 70 $g/m^3 \cdot h$ was obtained for an inlet load of 190 $g/m^3 \cdot h$, and elimination capacity data agreed well with predictions of two recognized zero-order kinetic models. Research of toluene biofiltration as a model for less water-soluble gas pollutants was performed by Hwang and Tang (1997). They verified the applicability of a mathematical model describing the biodegradation rate along the biofilter as zero order followed by fractional order to first-order kinetics as toluene concentration decreased, and they concluded that biofiltration of low-solubility compounds should not be operated at low gas residence times. Pedersen and Arvin (1997b) examined toluene removal from a waste gas using a trickling filter, with removal increasing linearly with loading to 70% removal at the maximum loading examined. An analytical model was developed using gas/liquid mass transfer and biological degradation kinetics, with modeled parameters corresponding to previously observed values. The same authors studied the overall liquid mass transfer coefficient (K_La) in a trickling filter for treatment of waste gas containing toluene (Pedersen and Arvin, 1997a). They concluded that the K_La value for the biofilm system was 25–140% larger than the for the support material without biofilm, resulting from improved wetting of the filter surface area and an enlarged mass transfer area. A predictive model to describe degradation of toluene in a flat-plate, vapor-phase reactor was developed by Mirpuri, Sharp, *et al.* (1997b) and shown to accurately predict experimental data. The performance evaluation of a biofilter containing *Exophiala jeanselmei* for the purification of styrene-containing gas was used to develop a mathematical model for pollutant degradation in a biofilm (Cox *et al.*, 1997). Biofilm performance was limited at low styrene concentrations (less than 0.06 g/m^3) with a maximal styrene degradation rate of 62 $g/m^3 \cdot h$, but, at high styrene concentrations, the maximal degradation rate improved to 91 $g/m^3 \cdot h$ by increasing oxygen concentration in the dry gas from 20 to 40%.

Low rates of mass transfer in gas/water systems by low-miscibility pollutants such as styrene may be improved by the addition of dispersed nonpolar organic solvents in the water. A model of the improvement in mass transfer coefficient was developed and validated for toluene and oxygen using FC40, a perflourocarbon, as the dispersent (Cesário *et al.*, 1997). A bench-scale technique was developed and implemented to evaluate mass transfer rate constants (K) and concentration partition coefficients (K_h) for four different packing materials using two vapor-phase contaminants, ethanol and carbon dioxide (Hodge, 1997). Experimental results for these constants were similar to both "batch" and "spike test," indicating accuracy. Water content of the packing material strongly affected K_h values.

A pilot-scale compost biofiltration system, composed of four identical units operated in an upflow mode, was operated at a gasoline soil vapor extraction site for 1 year (Wright *et al.*, 1997). The primary factor affecting performance was bed moisture content, and overall TPH_{gas} removals and BTEX removals exceeded 90% once management of the moisture content improved. The gas resulting from bioventing a hydrocarbon-contaminated soil was treated using a wood bark media biofilter by Origgi *et al.* (1997). The technical, regulatory, and economic feasibility of such biofiltration for off-gases from petroleum processing and soil remediation equipment was investigated by the Petroleum Environmental Research Forum (Leson and Smith, 1997). High removals of aromatic hazardous air pollutants and odors were accomplished at residence times of less than 1 minute, whereas high-percentage removal, especially of light aliphatics, rendered biofiltration noncompetitive. Biofiltration performance and operational reliability depended on filter material selection, moisture control system reliability, and fluctuation level in petroleum hydrocarbon concentrations.

A biological trickling filter for treatment of waste gas was studied to investigate toluene degradation using *Pseudomonas* sp. as the representative degrader (Pedersen *et al.*, 1997). Based on the rRNA content, the *in situ* activity was estimated to be reduced to 20% of the activity of cells grown at maximum conditions in batch culture. Pilot-scale testing on biofiltration of a gaseous stream containing benzene and other aromatics was conducted to investigate operational parameters. First-order rate constants were determined for all compounds tested (Sorial *et al.*, 1997). Immobilized on a perlite-packed trickling air biofilter, a stable microbial consortium grew on nitrobenzene (NB) and released excess nitrogen as ammonia (Oh and Bartha, 1997). Salinity and pH controls were unnecessary because the system operated at pH 8.7 while the biofilter removed 50 g $NB/m^3_{packing} \cdot h$ on a sustained basis.

To overcome the issues associated with excess buildup of biomass in a trickling biofilter, the bed was moved periodically to dislodge excess biomass (Wübker *et al.*, 1997). This moving-bed trickling biofilter was considered to operate similarly to a

chemostat and gave from 56 to 72% removal of toluene as the dilution rate was varied.

A genetically engineered strain of *Burkholderia cepacia* G4, which constitutively expresses toluene *ortho*-monooxygenase, degraded trichloroethylene (TCE) at high rates when grown on phenol in a biofilter (Sun and Wood, 1997). A kinetic study on aerobic degradation of phenol in a *P. putida* biofilter was conducted to carry out a comparison among diffusion, convection, and bioreaction mass velocities along the biofilter fed with air streams contaminated with different levels of phenol (Converti *et al.,* 1997). In contrast to the low residence time result, biomass grew so abundantly at high resonance time that the superficial layers of biofilm were enough to nearly completely transform the phenol.

Dry wastewater sludge (30–40% moisture content) was used as a packing material by Degorce–Dumas *et al.* (1997) in a biofilter treating hydrogen sulfide. Abiotic pilot units showed significant chemical oxidation occurring. High initial bacterial numbers of *Thiobacillus* sp. and neutral pH allowed biotic biofilters to achieve high removal efficiencies, although sulfide concentrations greater than 3 000 mg/m^3 had a negative impact on removal. Peat and BSE biofilters were compared to the wastewater sludge biofilter, and metal leaching from the sludge was also studied. A peat-based medium was used in two sets of biofilters degrading methylamine (Chou and Shiu, 1997). Methylamine was completely converted to ammonia, nitrate, and cell nitrogen in equal ratios at a loading of 3.5 g $nitrogen/m^3_{medium}$. A neutral medium outperformed an acidic medium, with a maximum rate of nitrification of 0.69 g $nitrogen/m^3_{medium} \cdot h$. The variety of choices available for biofilters was addressed in part by Chou and Cheng (1997), who evaluated blends of compost and fillers such as fern chips, wheat bran, or bagasse for suitability as a medium for the biofiltration of MEK. A removal of 100 $g/m^3_{media} \cdot h$ was achieved, and a loading of 50 $g/m^3_{media} \cdot h$ was successfully treated for more than 50 days. Nitrogen was one focus of experiments with two trickling biofilters to degrade diethyl ether with nitrate as the sole nitrogen source (Rihn *et al.,* 1997). The rate of nitrate diffusion into the biofilms was rate limiting and increased oxygen concentrations not affecting removal, so that use of nitrate as a nitrogen source rather than as an electron acceptor was apparently the source of limitation.

To counter increasing nitrification needs, Tarallo *et al.* (1997) conducted extensive pilot-scale testing and evaluation of full-scale, fixed-bed, attached-growth systems and concluded that separation of organics removal and nitrification in staged biofilter reactors, operating at high hydraulic loading rates, results in the most efficient and compact facility. Results from a two-stage upflow biofilter pilot in Northern Virginia for nitrification and case histories of full-scale facilities using multiple biofilter stages for nitrification and total nitrogen removal were presented.

A heterotroph, *Arthrobacter oxydans* CH8, capable of removing NH_3 from a gas stream, was isolated from livestock farming wastewater by immobilization with calcium alginate packed into a filter column. Greater than 97% efficiency was obtained in removing ammonia, and the high maximum removal rate enhanced biofilter use in industrial-scale ammonia gas pollution control (Chung *et al.,* 1997). A biofilter was prepared from polyacrylamide fibrous and porous ceramic supports, seeded with the methylotroph *Methylobacterium extorquens.* During optimized continuous flow cultivation, the bacterial metabolism could be switched from biodegradation of methanol or formaldehyde to utilization of methylamine after a certain adaptation period determined by the induction of enzymes of the *N*-methylglutamate pathway (Doronina *et al.,* 1997).

New wastewater treatment plant (WWTP) legislation in New Zealand, the Resource Management Act, is nonprescriptive in nature, encouraging narrative rather than numeric standards for odor control at the boundaries of wastewater facilities. Macdonald *et al.* (1997) described how odor master plans have been developed for several WWTPs in New Zealand, including biofilter and other odor control methods, odor reduction, or mitigation both through control technologies and through the adequate provision of new or expanded "odor buffer zones."

Because of the severely cold climate at a regional WWTP in Duluth, Minn., all unit process structures are enclosed, causing an odorous off-gas disposal problem. In response, the Western Lake Superior Sanitary District used an open-bed biofilter system to treat 23.6 m^3/s of sulfide-laden exhaust gases, demonstrating the ability of an open-bed biofilter system to effectively treat odorous wastewater plant emissions in the extreme cold of Northern Minnesota (Williams, Boyette, Bergstedt, *et al.,* 1997a; Williams, Boyette, Pomroy, *et al.,* 1997b).

FLUIDIZED BED AND AIRLIFT BIOREACTORS

Zhao and Lan (1997) reviewed 14 references on research progress and trends in fluidized-bed reactors (FBRs) for immobilized microbial cells, including their attributes and applications.

Haldane-inhibition kinetics were used in the development of a model of a fluidized bioparticle, which considers the interactions between intrabiofilm mass transfer and bacterial rate processes. The model predicted that, under some circumstances, a bioparticle effectiveness factor of greater than unity is possible. The bioparticle effectiveness factor was used in conjunction with fluidization correlations to predict the overall efficiency of a fluidized-bed bioreactor in the presence of substrate inhibition (Lai and Shieh, 1997). The complete segregation model, already successfully tested for binary-solid liquid fluidized beds of smooth rigid particles, has been shown by Di Felice *et al.* (1997) to predict solid mixing and segregation in fluidized-bed bioreactors. Brosilow *et al.* (1997) described the NO_3^- and NO_2^- concentration profiles within a denitrifying FBR in a unique, simple model. When compared to experimental data and a more complex model previously proposed in the literature, this simple model fits the experimental data as well as the more complex model.

A nitrifying biofilm reactor removed 7.2 mg Cl/g biomass (volatile solids) per day of organic halogens while treating bleached Kraft pulp mill wastewater. The same wastewater was treated by a denitrifying FBR with no dechlorination but removal of 35% of the TOC content from the wastewater (Kostyal *et al.,* 1997). Lazarova *et al.* (1997) studied nitrification in a gas-lift, circulating-bed reactor, observing substantive nitrification rates at high COD/N-NH_4 ratios. The possibility of nitrifying municipal landfill leachate using suspended-carrier biofilm technology was studied by Welander *et al.* (1997) in three laboratory-scale reactors filled with three different types of carrier media. A maximum nitrification rate of 40 g $(NH_4^+\text{-}N)/m^3$ per reactor hour was obtained at 20°C, a hydraulic retention time of 14 hours, and a carrier filling degree of 10% of reactor time.

Nitrification in BAS reactors was the subject of several publications. Converting ammonium and acetate, a BAS was operated with nitrifying biofilm growth and heterotrophic suspended growth. Van Benthum, van Loosdrecht, and Heijnen (1997a) found that, in the presence of the heterotrophic layers, the maximum specific activity on ammonia of the nitrifying biofilms increased as well as the mass transfer resistance. Two BAS reactors were operated with an ammonium load of 5 kg $N/m^3 \cdot d$ to study the influence of biomass and oxygen concentration on the nitrification process (Garrido, Van Benthum, *et al.*, 1997b). Nitrite buildup at decreased DO content was associated with the microbial growth system as verified by a biofilm model. A nitrifying BAS reactor was operated at an ammonia loading rate of 5 kg $N\text{-}NH_4^+/m^3 \cdot d$, obtaining 99% ammonia conversion. No nitrous oxide production was detected until a formaldehyde addition of 55 mg/L was introduced (Garrido, Campos, *et al.*, 1997a). Ammonium conversion in a BAS reactor was described using a diffusion reaction model (Picioreanu *et al.*, 1997). Operation parameters were varied to check the way to affect the NO_2^- concentration, and oxygen concentration was determined to be the controlling factor. Innovative methods of arranging and operating BAS reactors for nitrification were investigated. It was found that a two-reactor configuration was best suited for pretreatment of normal wastewater and that a one-reactor system could obtain low nitrogen concentrations in the effluent (van Benthum, van Loosdrecht, and Heijnen, 1997b).

The hydraulics of fluidized beds and airlift reactors has been the subject of much interest. A simple model was developed to predict the hydrodynamic behavior of a three-phase internal airlift reactor by Heijnen *et al.* (1997) to treat wastewater using biofilm particles. Gjaltema and coauthors offered a variety of studies on hydraulics in airlift reactors. A variety of support materials was studied for the development of *P. putida* biofilms in an airlift reactor, in which hydrodynamic conditions and particle collisions controlled biofilm formation. A model of growth and detachment was presented, and greater surface roughness was found to promote biofilm accumulation (Gjaltema, van der Marel, *et al.*, 1997a). The effect of particle size was examined in an airlift reactor (Gjaltema, van Loosdrecht, *et al.*, 1997b). Larger particles increased the abrasion rate more than predicted by conventional collision theory, so an empirical relationship was developed. Under nongrowth conditions with the presence of bare carrier particles, the detachment of biomass from suspended biofilm pellets in three-phase internal loop airlift reactors was dominated by the collisions among the particles and pellets and leads to pellet flattening/reduction in volume. The internal structure of the biofilms showed two layers: a cell-dense outer layer and an interior layer with a low biomass density (Gjaltema, Vinke, van Loosdrecht, Heijnen, 1997d). Detachment of biomass from suspended biofilm pellets was interpreted in terms of collision frequency and impact for internal loop airlift bioreactors (Gjaltema, Vinke, van Loosdrecht, Heijnen, 1997c).

A predictive model was developed for the hydraulic behavior such as bed height and overall gas, liquid, and solid holdups of the three-phase FBRs. The model predictions and experimental results agree quantitatively for two-phase and three-phase conditions, and the authors proposed a new correlation for the bed expansion index (Yu and Rittmann, 1997). Schugerl (1997) reviewed the application of three-phase biofluidization in biotechnology discussing aerobic and anaerobic wastewater treatment and the properties of biofilms attached to carriers.

A new reasonably successful method to estimate biomass concentration carried out in a FBR was developed and tested on collected data that combine the Richardson and Zaki law for fluidized-bed expansion, the overall bed voidage definition, and available literature data on biofilm dry density. The method also gave an estimate of the biomass concentration through a nonlinear minimization routine using experimental data of bed height versus fluid superficial velocity (Nicolella, Di Felice, *et al.*, 1997b). Nicolella, Chiarle, *et al.* (1997a) also investigated biofilm detachment in FBRs to identify the different mechanisms involved. Detachment rate strongly increased with fluid velocity while it slightly decreased with liquid shear stress.

A low-strength synthetic wastewater, composed of 1.6–12.6 mg/L 1-naphthalene in tap water and unable to support a viable biomass in a FBR, was successfully treated by adding acclimated cells from an off-line enricher–reactor. This bioaugmentation demonstration offered an alternative for the treatment of dilute wastewater and contaminated groundwater, which are generally considered poor candidates for biological treatment (Ro *et al.*, 1997). Massol–Deya *et al.* (1997) compared community composition, succession, and performance in three FBRs operated to test preemptive colonization and the influence of toluene compared with a mixture of benzene, toluene, and *p*-xylene (BTX) as feeds. The experiment led to convergence of communities from three different starting conditions to the same composition with constancy over several months (Roessink and Eikelboom, 1997). Microbial and protozoa populations were characterized in an airlift bioreactor. Treatment efficiencies and effluent solids concentrations were studied.

A pure culture of *P. putida* was grown as a film on carbon particles in a differential fluidized-bed biofilm reactor (DFBBR). The ratio of effective diffusion coefficients through the active biofilm to that of water varied between 17 and 44% and 9 and 24% for phenol and oxygen, respectively, thus showing a fair agreement with the literature at low biofilm densities (Beyenal *et al.*, 1997). Safferman and Bishop (1997) related the operational mode of an aerobic FBR (AFBR) with the amount of biomass in the media. Results indicated that using the AFBR is favorable for maximizing substrate removal, for minimizing solids production, and for applications that produce only intermittent wastewater flows, such as those found in many industries and hazardous waste remediation systems.

The effect of heavy metal loading on the degradation of naphthalene-2-sulfonic acid (2NS) by immobilized bacteria in biological wastewater treatment in continuously operated airlift-loop reactors was studied by Pack and Hempel (1997). Shock loading with mixtures of cadmium and nickel, or cadmium and zinc, respectively, resulted in increases in inhibition compared to those observed with the single metal, whereas shock loading with mixtures of nickel and zinc caused less 2NS degradation than by the single metal ions. Buchtmann *et al.* (1997) studied quinoline degradation by *Comamonas acidivorans* in FBRs at various dilution rates. Complete quinoline oxidation was observed, and critical dilution rates were determined.

In batch ozonation of wastewater, 3-methylpyridine (MP) and 5-ethyl-2-methylpyridine (EMP) were removed using a low concentration of dissolved ozone in a fluidized-bed biofilm reactor with a mixed culture. Complete mineralization of MP and extensive mineralization of EMP was observed during the whole experiment, but during adaptation of biomass, the ozone requirement decreased from 10 mol/mol of MP oxidized to 4 mol/mol (Stern *et al.*, 1997).

Wastewaters from three integrated newsprint mills have been treated by Broch-Due *et al.* (1997) in a pilot-plant moving bed biofilm reactor (MBBR) in which the biomass adheres to plastic elements moving freely in the stream. The amount of chemicals needed to precipitate the biologically treated wastewater was one-fourth to one-third of that needed for the chemical treatment of the untreated wastewater. Johnson *et al.* (1997) discussed a MBBR pilot test in a recycle paper mill that showed a reduction of soluble BOD of 93% with a 3-hour hydraulic retention time. Rusten *et al.* (1997) concluded that plants using a MBBR operate very reliably.

The Algoma fluidized-bed system represented the first full-scale application of the FBR technology for treatment of coke plant wastewater in North America and the first large-scale FBR system to be installed in Canada. During a 6-week performance assessment, which began approximately 2 weeks after process start-up, the FBRs achieved over 99% phenolics reduction, from the initial concentration of 1 000 mg/L. The biomass concentration, measured as volatile solids, in the FBRs was greater than 15 g/L (Sutton *et al.*, 1997). Another study for a specialized industry was the use and modeling of fluidized bed reactors and stationary bed reactors in the treatment of dairy wastewater. Laboratory-scale columns were used to generate adsorption and biodegradation kinetic coefficients and for model verification (Ravindran *et al.*, 1997).

SUBMERGED BIOFILM REACTORS

Glaser (1997) reviewed the use of slurry reactors to remediate contaminated soils. Knowledge of the structure, population dynamics, nutritional requirements, and metabolic activity of soil biofilms coupled with soil composition/texture was identified as necessary for better management of soil treatment. Feedstock, reactor configurations, and pretreatment and posttreatment phases were cited as important factors to the cost-effective implementation of slurry treatment. A review of the performance and configurations of biological aerated filters (BAFs) at a number of WWTPs was compiled and presented (M'Coy, 1997). The advantages and disadvantages of BAFs were discussed.

Beg and coauthors contributed three studies on upflow packed beds: a methanol-fed nitrifying upflow packed-bed bioreactor suffered fasting conditions of methanol or ammonia, with methanol fasting causing a more pronounced effect (Beg, Hassan, and Chaudry, 1997b). The performance of an aerobic upflow packed-bed biofilm reactor fed glucose was modeled numerically (Beg, Hassan, and Chaudry, 1997a). Finally, the performance of an upflow packed-bed biofilm reactor was analyzed under multisubstrate limitation by considering simultaneous carbon oxidation and nitrification. The concentration profiles within the biofilm reactor revealed that O_2 was a limiting component at the middle of the reactor when methanol and NH_4^+-N inlet concentrations follow sinusoidal variation (Beg, Hassan, and Chaudry, 1997c).

Because space available is often a limiting factor as in the large surface area required for conventional suspended growth processes in wastewater plants for nutrient removal, treatment technologies such as the new attached growth processes have emerged. One of these processes is the Biostyr process, which uses polystyrene granules that have a high specific surface area, resulting in a more compact design (Borregaard, 1997). The influence of substrate concentration on the activity and concentration of nitrifying was tested in upflow aerated filters (Villaverde, Fernandez, *et al.*, 1997a). Effects of nutrition and inhibition were observed, and threshold concentrations of these effects were determined.

A continuous-flow, fixed-biofilm reactor was constructed and operated by Jin and Englande (1997) to optimize carbon tetrachloride biodegradation and compare the efficacy of existing kinetic models describing degradation. An unusal substrate was examined by Macaskie *et al.* (1997), who used growth-decoupled biomineralization to remove uranyl ions in flow-through reactors containing *Citrobacter* cells immobilized as biofilms on Raschig rings. The *Citrobacter* system succesfully removed UO_2^{2+} from acid mine water.

An RBC fixed-film media was submerged 30–50%, which resulted in a more efficient, less expensive system than conventional activated-sludge systems at small WWTPs. When Chevron implemented the submerged biological contactor, results showed COD removal efficiencies greater than 70%, NH_3-N concentrations less than 5 mg/L, and negligible benzene, molecular sulfur, oil and grease, and phenol effluent concentrations (Reynolds *et al.*, 1997). Continuous experiments were carried out at a pilot-plant biological aerated filter and denitrification tank over 18 months. The nitrification–denitrification capability was examined with an emphasis on the cold seasons. Biological oxygen demand and SS removal rate exceeded 95% and T-N removal rate was about 75%. Consequently, this particular denitrification technology is effective in cold climatic regions (Terayama *et al.*, 1997). The influence of pH over nitrification in submerged biofilters was presented by Villaverde, Garcia-Encina, *et al.* (1997b). The pH effect was characterized in terms of activation–deactivation, substrate limitation, and free ammonia inhibition.

MEMBRANE BIOREACTORS

Porous-walled hollow fiber membrane reactors allow oxygen fed on the lumen side to pass directly through the microporous wall to a biofilm attached to the shell side of the membranes (Brindle *et al.*, 1997). Such a MBR process significantly reduces the amount of oxygen vented to the atmosphere, making the use of pure oxygen economically favorable. An MBR system using such microporous hydrophobic hollow fiber membranes for mass transfer of volatile organic compounds (VOCs) from the gas phase to the liquid phase overcame conventional compost biofilter limitations (Ergas and MacGrath, 1997). The reactor design provided a high biomass concentration, a method for wasting biomass, and a method for pH buffer addition, nutrients, cometabolites, and/or other amendments. Toluene removal efficiency was greater than 98% at an inlet concentration of 100 ppm and a gas resistance time of less than 2 seconds. Another porous, gas-permeable polyether imide membrane with asymmetric pore structure was used for the study of the biodegradation in aquatic systems of nonchlorinated dibenzofuran and dibenzo-*p*-dioxin by *Sphingomonas* HH69 and RW1, respectively (Hellge, 1997). The membrane biofilm reactor operated in both sequencing batch and flowing-through mode, achieving high conversion rates into CO by additional feed of acetate and by the addition of microorganisms isolated from lime marshy soil. *Xanthobacter* Py2 seeded on a microporous hydrophobic MBR removed propene from air but required a 20-day start-up time for biomass development (Reij *et al.*, 1997).

A study of "counterdiffusional" methanotrophic biofilms cultivated on gas-permeable membranes and subjected to TCE-

contaminated feed-streams was performed by Clapp *et al.* (1997). A mixed-methanotrophic biofilm cultivated on silicone tubing achieved a steady-state rate of CH_4 utilization per surface area of approximately 13 mmol/m$^2 \cdot$h (in the absence of TCE-loading)—ten times greater than reported for more conventional methanotrophic biofilm reactors. Membrane biofilm reactors were also used to treat chlorinated aromatics (Peys *et al.*, 1997). Modeling and optimization were a focus, with biofilm structure and characteristics found to be important.

Two membrane-attached biofilm systems were characterized and studied by Freitas dos Santos *et al.* (1997): *X. autotrophicus* GJ10 growing on 1,2-dichloroethane and *Pseudomonas* JS150 growing on monochlorobenzene. Excess biofilm thickness was found to be a problem in the system, and control measures were discussed. A steady-state mathematical model was developed to predict axial concentration profiles of a pollutant in such extractive MBRs with experimental verification (Pavasant *et al.*, 1997). The rate-limiting step in the reactor was determined to be the mass-transfer resistance of the pollutant in the biofilm.

A flat MBR (FMBR) converting metal ions into insoluble metal carbonate crystals was developed by Van Roy *et al.* (1997) to remove greater than 99.95% of heavy metals by use of an *Alcaligenes eutrophus* biofilm. An organomineral membrane with immobilized bacteria induced metal precipitation as crystals, allowing direct metal recovery.

IMMOBILIZED CELL BIOREACTORS

A model of the steady-state performance of an immobilized enzyme reactor was developed. The model accounted for external diffusion limitations, reversible Michaelis–Menten kinetics, axial dispersion, and equilibrium constants while predicting relative substrate conversion and yield (Abu-Reesh, 1997).

The model system of a reactor containing immobilized methylotrophic cells of *Candida boidinii* was studied to assess the ability to remove methanol from wastewater. The rate of methanol oxidation to formaldehyde (first stage) was much higher than the limiting rate of oxidation to formic acid (second stage) (Artsukevich and Solomon, 1997).

Using *Escherichia coli* as the basis, heterogeneity in the biomass distribution inside gel-immobilized cell systems was modeled by Lefebvre and Vincent (1997). The study showed that heterogeneity was greatly enhanced when the initial cell concentration increased, the substrate concentration decreased, or the membrane thickness increased. Continously stirred tank type reactors also showed a greater heterogeneity in the immobilized biomass distribution than discontinuous closed reactors in which the cell leakage in the external medium controls the system more. Operational temperature of a biofilm of immobilized *Thiobacillus ferrooxidans* revealed a temperature response in organism activity, indicating the temperature could be used to control the biomass levels in an immobilized cell reactor (Nemanti and Webb, 1997).

The possibility of application of gel-entrapped biomass for high-rate complete nitrogen removal from municipal wastewater was verified using a system that consisted of two stages: an aerobic stage using nitrifying microorganisms immobilized in gel beads and a conventional anoxic stage. Results show that a heterotrophic layer of less than 12 μm on 2-mm diameter gel beads could provide complete nitrogen removal, whereas a larger layer can cause residual nitrogen concentration in the effluent (Libman *et al.*, 1997). Nitrifying bacteria in a cellulose carrier were studied by Matsumara *et al.* (1997). An optimal carrier size of 1 mm with 500-mm pores gave complete ammonia oxidation at a loading rate of 12 kg-N/m$^3_{carrier} \cdot$d at 25°C.

To further the use of immobilized cells in biofilters, Zhou and Bishop (1997) summarized studies on oxygen distribution and diffusivity in k-carrageenan gel beads using oxygen microelectrodes to measure oxygen profiles. Diffusivity constants in k-carrageenan gel beads were estimated at 46.3% of the value in water when the bead was immersed in water and 53.9% that of water when the bead was in air with a thin liquid film surrounding it.

Vogelsang *et al.* (1997) developed a treatment system using gel beads of PVA-SBQ cast by entrapment in calcium-alginate beads before photoinduced cross-linking of the synthetic polymer. The system may be suitable for specially designed full-scale reactors with short hydraulic retention times as well as an additive to existing biofilm or activated-sludge nitrification plants. Methods for encapsulating pollutant-degrading bacteria into microbeads of various materials were also presented. Pentachlorophenol (PCP) degradation experiments with an encapsulated *Sphingomonas* sp. showed degradation rates similar to those for free cells (Hammill and Crawford, 1997).

The methanotroph *Methylocystis* sp. strain M, immobilized in alginate gel beads within a fluidized-bed bioreactor, degraded TCE from groundwater, with 80–90% removal of 0.9–1.6 mg/L of TCE at a 2.56-hour residence time. However, removal depended on feeding with methane and air, with activity declining rapidly after feeding ceased (Shimomura *et al.*, 1997). Various immobilized call bioreactors were investigated to maximize SO_2 reduction in biodesulfurization processes. The columnar reactor with mixed SRB cells that had been allowed to grow into highly stable BIO-SEP polymeric beads exhibited the highest sulfite conversion rates (Selvaraj *et al.*, 1997).

Cellulose triacetate cubes of 1- or 2-cm dimensions were created by Yang *et al.* (1997) and used to treat a synthetic wastewater. With a 9-hour hydraulic retention time, a 96% decrease in soluble COD and a 76–84% decrease in NH_4^+-N were observed at 25°C, with a significantly lower removal of nitrogen at 10°C but similar COD treatment. An economic analysis indicated that this process had a net value comparable to conventional biological processes. Yang (1997) also immobilized nitrifying bacteria and zeolite in alginate beads in a sequencing batch-fluidized bed. The SBR exhibited strong air stripping of ammonia compared to ion exchange with the zeolite or with nitrification as ammonia sank.

Saccharomyces cerevisiae and *Candida shehatae* cells were coimmobilized in a composite structure consisting of a flat agar layer in between two microporous membrane filters. Both organisms displayed growth in the composite structure, and biofilmlike gel areas of high cell density appeared behind the membrane filters during immobilized organism incubations (Lebeau *et al.*, 1997). Martins dos Santos *et al.* (1997) evaluated fracture properties of gel materials rather than tensile tests to estimate mechanical stability. No correlation was found between fracture properties and abrasion rates, but the observations of abrasion indicated that abrasion was likely related to fatigue of the immobilization matrix.

Polyurethane foam was used to evaluate immobilization of the TCE-degrading bacterium *Burkholderia cepacia.* Domingo *et al.* (1997) learned that several parameters such as surfactant type, surfactant amounts, and biomass concentration in the foam

affected cell retention. They concluded that these immobilized cells were metabolically active and could be used for biodegradation.

Laugero *et al.* (1997) focused on the transformation of PCP by *Phanerochaete chrysosporium* I-1512 in relation to pentachloroanisole. Results showed the advantage of an immobilized culture for mineralization of PCP when compared to static cultures. Pentachloroanisole formed only in static cultures, and it underwent limited mineralization. However, formation was catalyzed by the biomass in static cultures of *P. chrysosporium* when experimentation was performed with mycelium and culture supernatant.

BIOLOGICAL GRANULAR ACTIVATED CARBON

Zhao *et al.* (1997) treated groundwater containing benzene, toluene, and *p*-xylene (BTX) with FBRs using nonactivated carbon (FBR) and activated carbon (BAC-FBR) as the biofilm carriers. They found lower effluent BTX and intermediate concentrations in the BAC-FBR system under shock loading because of the metabolic and adsorptive removal mechanisms. Also, according to research by Rajan *et al.* (1997), the GAC-FBR was shown to be a strong candidate for cost-effective treatment of hydrocarbon constituents in contaminated waters at manufactured gas plant sites.

Nishijima *et al.* (1997) found that the bioactivity of attached bacteria was affected by adsorbed substances on GAC when the GAC was kept in an equilibrium condition. An equilibrium model for concurrent biodegradation and adsorption was developed and verified with existing data. When biodegradable contaminants controlled the service life, the service life was 1.2–7 times that of adsorption alone (Erlanson *et al.*, 1997).

Morin and Camper (1997) captured and released carbon fines (CFs) of two size ranges (1.2–50 and 1.2–8 mm) in biofilms and studied their effect using a bench-scale simulated drinking water system. They conclude from their results that the attachment of CFs into a biofilm was size dependent, that the CFs do not protect the biofilm against disinfection, and that the disinfectants induced the detachment of the CFs.

INNOVATIVE REACTORS

There have been many innovative uses of biofilms for wastewater treatment. Bench-scale aerobic biofilm reactors were operated at different recirculation rates and with a variety of high influent waste concentrations. The optimal recirculation rate was determined to be five reactor volumes per hour (Chua and Yu, 1997). Gemeinert *et al.* (1997) investigated open-pore sintered glass ceramics as carrier material for biotechnological use. Carrier body samples produced through this process were tested and evaluated quantitatively as carriers for biofilms for pollutant decomposition in a synthetic model wastewater system.

Guiot (1997) introduced an integrated synchronous aerobic and anaerobic bioreactor for treating liquid wastes, such as pulp and paper wastewater. The new reactor was fitted with an external aerator for injecting a specific amount of an oxygen-containing gas into the waste liquid as it is cycled through the reactor. Moebius and Cordes–Tolle (1997) examined a new approach for treating wastewater from pulp and paper industries: rather than attempting total oxidation of organic matter, they applied partial oxidation to improve biodegradability and eliminated the persistent organics in a subsequent biological treatment by low-loaded biofilm reactors.

A large number of innovative applications of biofilms to achieve nitrification and denitrification have appeared over the last year, with many new proprietary names appearing. A relatively new moving bed biofilm process was evaluated for use in replacing the first stage of the wastewater treatment system at the Exxon Chemicals Baton Rouge Chemicals Plant. The technology is marketed by a Norwegian company, Kaldnes Miljfteknologi AS, and is referred to as the "Kaldnes" or "KMT" process. Testing demonstrated that the process was capable of achieving good organics removal while exhibiting stable operation at relatively high organic loading rates (Ganze *et al.*, 1997). One pilot-plant and two full-scale studies have been carried out seeking the optimal use of the Kaldnes suspended carrier process in the treatment of wastewaters from the forest industry. The wastewater used in all three cases came from secondary fiber mills. The studies revealed that the Kaldnes process as a highly loaded stage (typically 15–25 kg COD/m·d) in series with an activated-sludge stage forms an efficient, stable, and competitive combination process, regarding both investment and operating costs (Dalentoft and Thulin, 1997).

For the first time, a pilot-plant "BIOFOR" fixed-film aerobic biofilm treatment system operates on the principle of an upflow concurrent flow of process. Water and air was utilized for centrate treatment at New York City plants to assuage effluent high nitrogen concerns (Jiye Zhang, 1997). Results of these efforts, together with nitrification rates, chemical usage, air, backwash, and other operational requirements, and problems encountered were thoroughly reported. Koyoama *et al.*, 1997) related an aerobic biofilm method, the Biofiner, as a measure for nitrogen removal enhancement and for treatment capacity enhancement. Le Tallec *et al.* (1997) assessed the effect of influent quality variability on biofilm operation for the Biostyr process used in nitrification/denitrification design at very low ammonia residuals. The nitrification performance of an integrated fixed film activated-sludge (IFAS) process using the Ringlace and Biomatrix looped cord media products was compared to a parallel control system at full scale. The results indicated that proper aeration design and the prevention and treatment of worm blooms were two important issues in the application of the IFAS process (Jones, Sen, *et al.*, 1997a).

Takai *et al.* (1997) found recirculation to be indispensable in promoting nitrification–denitrification activity and volatile fatty acid biodegradation in small-scale anaerobic-aerobic biofilm processes. To nitrify at low ammonia concentrations, rotating membrane disks were used and modeled by Watanabe *et al.* (1997). Continuously fed fixed-film reactors were used to study microbial denitrification to treat highly contaminated aquifers with efficiencies reaching 90–99% nitrate removal when external donor addition was sufficient. Results also revealed a significant relationship between denitrification rates and phosphorus supply (Chevron *et al.*, 1997).

Pilot-scale moving-bed biofilm reactors (MBBRs) were successfully operated in sequencing batch mode for denitrification and in continuous-flow mode for nitrification of primary settled wastewater. The process proved reliable, easy-to-operate, and suitable for application to small WWTPs, either in designing new plants or in upgrading existing overloaded activated-sludge systems (Pastorelli, Andreottola, Canziani, Darriulta, *et al.*, 1997a; Pastorelli, Andreottola, Canziani, Frangipane, *et al.*, 1997b). To reduce land area requirements for waste stabilization

lagoons, baffles were added to promote both plug flow and to generate biofilms, with impressive improvements in performance in terms of removal of COD, NH_3-N, and total nitrogen (Muttamara and Puetpaiboon, 1997). Otterpohl *et al.* (1997) proposed an alternative to wastewater system and centralized aerobic WWTPs in the form of source control systems of resource management that return agricultural material to the soil as fertilizer and treat stormwater at decentralized biofilm systems.

Janssen *et al.* (1997) described the performance of a new sulfide-oxidizing, expanded-bed bioreactor in which the liquid-phase aeration and the sulfide oxidation to elemental sulfur were spatially separated to stimulate well-settleable sulfur sludge, thus avoiding turbulence due to aeration in the bioreactor. Under autotrophic conditions, almost all biomass was immobilized within the sulfur sludge, and, as a result, the maximum sulfide-loading rate more than doubled the conventional "free-cell" suspension. Hyvik *et al.* (1997) created an effective bioreactor having a large density of denitrifying bacteria and a large contact area for removing sulfide from oil-containing water. Sakakibara *et al.* (1997) grew and modeled a denitrifying biofilm in an electrochemical cell to denitrify groundwater also containing sulfate.

Biofilm innovations have also been made in the treatment of organic pollutants. Segar *et al.* (1997) developed a complex kinetic model for the operation of sequencing batch and biofilm reactors that were capable of cometabolizing TCE. The model included terms for multiple-Monod, Haldane, and competitive inhibition kinetics. Biomass kinetic equations accounted for growth, endogenous decay, toxicity, cometabolic activity decay, and reactivation or rejuvenation. Masak *et al.* (1997) isolated acetone and/or ethylene glycol-utilizing bacteria as well as biofilm-forming strains of bacteria with packed columns of zeolite A-calcium particles. High yield strain isolations and long-term physiological adaptations resulted from phased procedure and outlined schemes of column operations.

Kaballo (1997) presented one performance of SBBRs treating wastewater containing the priority organic pollutant *para*-chlorophenol (*p*-CP). The operation mode of a sequencing batch biofilm reactor was optimized when shock loading appeared. A two-layer system was developed by Kao and Borden (1997) to remediate gasoline-contaminated groundwater. Toluene, ethylbenzene, and xylene biodegradation rates were presented, but benzene was not degraded in the system. Chen *et al.* (1997) investigated and modeled removal of organic substances with varying biodegradability in a hybrid reactor, with both suspended and attached growth. Results indicate that the hybrid reactor system increased efficiency, with the biofilm increasing the degradation of compounds resistant to degradation.

De heyder *et al.* (1997) found that biological ethene removal from waste gases was largely affected by the water film thickness covering the biofilm, limiting the ability of the continuous conventional operation of a packed biobed. An alternative reactor concept, the Bio-swing reactor, realized ethene removal by a combination process of adsorption/desorption and biodegradation. Carlson and Silverstein (1997) investigated the effect of ozonation on sorption of aquatic natural organic matter onto biofilms using bench-scale packed-bed reactors. Ozonation simultaneously decreased the molecular size and increased the acidity of natural organic matter (NOM) compounds. The effects counterbalanced each other at an ozone dose of 1:1.

BIOFILMS ON SAND, SOIL, AND SEDIMENTS

Rothfuss *et al.* (1997) determined viable counts and potential activities as a function of depth in the sediment of Lake Constance, Germany. They learned that below 25 cm all viable heterotrophic bacteria were present as spores, and they decreased exponentially with sediment depth and reached below the detection limit (5–55 cells/mL) at 4–6 m in 8 900-year-old sediment, indicating from this observation and other data that bacteria become nonviable in aged sediments.

Soil column experiments studied bacterial growth and transport in porous media under denitrifying conditions, and the results showed that first-order attachment and detachment models described interphase exchange processes between suspended and attached biofilms. Comparison of detachment coefficient values with those calculated from published data suggested that detachment in porous media may increase with microbial growth rate (Clement *et al.*, 1997). Brough *et al.* (1997) created biofilm barriers in laboratory sand columns by introducing activated sludge. Permeability of the sand columns decreased by 28% during batch feed and by 79% in continuous feeding. The permeability decreases were associated with increases in COD removal and colony forming units. The sand columns did not completely clog, and treatment with 1% sodium hypochlorite restored original permeabilities.

An experimental investigation conducted by Essa *et al.* (1997) found a good correlation between decreasing porosity and increasing biofilm thickness in local sands for a range of low film thickness (0.066–0.099 mm). Deleo and Baveye (1997) investigated factors affecting protozoan predation of bacteria clogging laboratory aquifer microcosms. They found that bacteria growing among sand particles as aggregates, large barren surfaces, and the lack of biofilms contributed to evidence that a key mechanism of microbial clogging is pore blockage by these aggregates.

A systematic protocol was developed to determine bioavailability and biokinetics for organic pollutants in soil to enhance *in situ* and on-site bioremediation. Detailed mathematical models were developed for each type of soil reactor (slurry, wafer, and porous tube), and the models were fitted to the cumulative oxygen uptake rates (Govind *et al.*, 1997). Column studies were used to investigate the fate of a representative NAPL, hexadecane, with specific regard to the effect of attached bacteria on the formation of residual saturation and the role of biodegradation and biosurfactants on the removal of residual NAPL. The results revealed that a combination of biodegradation and rhamnolipid treatment could be used to maximize the removal of residual NAPL from porous media (Herman *et al.*, 1997). The biodegradation of a mixture of several creosote-related compounds, *p*-cresol, phenanthrene, fluoriene, and carbazole, was examined in columns containing aquifer sands. The biodegradation of all the compounds was greatly enhanced by the inclusion of *p*-cresol in the substrate mixture (Hosein *et al.*, 1997).

The half-time of biodegradation of the surfactant sodium dodecylsulfate (SDS) by *Pseudomonas* species C12B was reduced twofold by the presence of a riverine sediment that alone gave comparatively negligible SDS biodegradation. The enhancement of surfactant biodegradation by sediment was discussed in the context of the design of biodegradability tests and environmental acceptability (Marchesi *et al.*, 1997). Rates of c-4-bromophenol respiration and assimilation nearly matched in samples taken from a site inhabited by bromophenol-producing

polychaete and from a similar site with very low levels of bromophenol. Respiration showed strong seasonal (temperature) variation, whereas assimilation was more stable. The measured rates indicated that sediment bacteria play an important role in bromophenol degradation (Steward and Lovell, 1997).

Material was collected over a month on plates attached to the bed of a stream highly contaminated by acid mine drainage, and the authors determined that the sediment–water interface is best described as a highly contaminated biofilm. Evidence from previous work suggested that the stream bed was active in iron removal, and the authors also related that the iron flux prediction required biofilm ecology and physiology knowledge as well as physical and chemical data (Boult *et al.*, 1997).

Bioaccumulation of pollutants on biofilms and short-term variations in river sediment compounds were investigated, resulting in the conclusion that sorption processes on biofilms played a vital role during spring and summer months for transport and accumulation for various pollutants. The amount of pollutants sorbed on sediment particles depended on both the particulate bound or dissolved pollutants in the river water and was altered by the changing biofilm conditions (Schorer and Eisele, 1997). A methodology to describe the bacterially facilitated contaminant transport in a subsurface environment using the biofilm theory was developed based on mass balance equations for bacteria and contaminant (Kim and Corapcioglu, 1997). In the experiment, biofilm grew rapidly near the top of the column where the bacteria and contaminant were injected, was detached by increasing fluid shear stress, and reattached downstream. Optimization of physicochemical conditions for biofilm formation on a porous medium in groundwater was performed by Ross *et al.* (1997) to further research the area of plume containment by microbial barriers in fractured rock aquifers.

For the first time, exoenzymes of white rot fungi were demonstrated to be active in nonsterile soil. Also, a method for extracting laccase from soil samples was developed (Lang *et al.*, 1997). Sack and Fritsche (1997) investigated the mineralization of pyrene in sterile and nonsterile soil using the wood-decaying fungi *Kuehneromyces mutabilis* and *Agrocybe aegerita* over 3 months. In comparison with indigenous soil microflora, *K. mutabilis* enhanced pyrene elimination up to 42%.

Methanol-fed postdenitrification was investigated in a succeeding sand filter system originally designed for the retention of suspended solids in the secondary effluent of a municipal two-stage biological WWTP. Biological parameters were determined, and, by avoiding detrimental effects on denitrification efficiency such as accumulation of biomass, support operations were optimized (Lemmer, Zaglauer, and Metzner, 1997a). Bench-scale investigations of particle-removal mechanisms in slow sand filters identified bacterivory as the only significant biologically mediated particle removal mechanism (Weber-Shirk and Dick, 1997).

The toxic effects of bioconcentrated tributyl tin (TBT) compared to those of dissolved TBT inhibited the natural attachment and growth of oyster larvae on bottom surfaces because of the biofilm's bioconcentration of that heavy metal (Labare *et al.*, 1997).

BIOFILM MEASUREMENTS AND CHARACTERIZATION

A multi-imaging procedure using a computer-assisted laser scanning microscope equipped for confocal laser scanning and color video microscopy was used to examine *Crytosporidium parvum* oocysts in agriculture soils, a barnyard sediment, and calf fecal samples (Anguish and Ghiorse, 1997). These enhanced counting, sensitivity, and imagery techniques allowed for efficient location and interpretation of acridine orange-stained, immunostained, and fluorescently stained oocysts in the soil matrix and barnyard sediment, respectively. Confocal scanning laser microscopy (CLSM) was used to observe a compost particle (Chalmers *et al.*, 1997). Significant heterogeneity was observed in the biofilm, contrary to previous reports that assumed homogeneity.

The development of stream biofilms using raw river water as innoculum and a sole nutrient source was studied using a rotating annular biofilm reactor system for cultivation and CLSM for structural examination. The rotating annular biofilm reactor may be a useful tool for morphological studies of complex microbial films, particularly those developing under turbulent flow regimes that are typical from aqueous environmental ecosystems (Neu and Lawrence, 1997).

Stoodley, Yang, *et al.* (1997b) investigated the relationship between local mass transfer coefficients and fluid velocity in heterogeneous biofilms using microelectrodes and CSLM. They correlated local flow velocities with local mass transfer coefficients and found that the Sherwood numbers, Reynolds numbers, and Schmitt numbers were similar to literature values for mass transfer in porous media. Sich and Rijn (1997) studied biofilm formation in denitrifying FBRs (FBD) by scanning electron microscopy (SEM). They discovered a distinct growth pattern of *Pseudomonas*- and *Zoogloea*-like cells and compared these colonizations on sand in a laboratory-scale FDR and on sand grains in a pilot-plant FBR, raising the question that this coexistence might be essential for denitrifying biofilm formation.

Morris *et al.* (1997) used epifluorescence microscopy, SEM, and CLSM to observe biofilms and to rapidly determine the abundance and localization of biofilms on leaves. Nagarkar and Williams (1997) described procedures to quantify tropical, cyanobacteria-rich biofilms in an effort to standardize worldwide comparative studies. They recommended using a combination of SEM techniques for initial species identification and chlorophyll a extraction of rock chips using cold methanol for an indirect estimate of biomass.

A new technique to determine local diffusion coefficients based on microinjection of fluorescent dyes and quantitative analysis of subsequent plume formation using confocal laser microscopy was described by De Beer, Stoodley, Lewandowski, *et al.* (1997b). Diffusion coefficients of fluorescein, TRITC-IgG, and phycoerythrin through intestinal voids were close to theoretical values in water. However, TRITC-IgG did not diffuse in the cell clusters, and the diffusivity of phycoerythrin was impeded by 41% in cell clusters when compared to voids.

A new microscopic array that provides simultaneous measurement with eight oxygen microoptodes is designed for investigating the oxygen distribution in biofilms and aquatic sediments (Holst *et al.*, 1997). The herbicide Me 2-4-(2,4-dichlorophenoxy) phenoxy propionate (diclofop-methyl) and three of its degradation products were identified in a biofilm using tandem mass spectrometry (MS/MS) on samples introduced directly into the ion sources with no further sample preparation. The results indicated that data comparable to those obtained using the hybrid instrument could be achieved using ion traps, despite the complex nature of the biofilm. This was true of mass

spectra and of production MS/MS spectra, which were essential for identification of the individual compounds in these complex mixtures (Kopf *et al.,* 1997).

Biofilms were also analyzed with an epifluorescence microscopephotometer incorporating a new *in vivo* fluorimetric method. This *in vivo* analysis allowed biofilms on artificial substrate to be removed, analyzed, and returned in field or laboratory conditions (Becker *et al.,* 1997).

Battin (1997) applied the fluorescein diacetate hydrolysis technique to estimate esterase activity in stream sediment biofilms in which he investigated the effects of temperature, pH, incubation time, and optimized the assay for low blanks and high fluorescein extraction. Results showed that spatial patterns of esterase activity within stream sediment biofilms correlated with electron transport system activity, bacterial thymidine incorporation, glucosidase activity, and chlorophyll A.

A highly selective liquid membrane nitrite microsensor based on a hydrophobic ion carrier was described that has a hydrophilic coating and increased diameter on the tip. This improved tip protected the sensor membrane from detrimental direct contact with biomass and could be used for profiling biofilms in complex environmental samples and *in situ* (De Beer, Schramm, Santegoeds, and Kuhl, 1997a).

A fiber-optical microsensor recently measured physical and chemical parameters of biofilms and other microbial communities as an alternative to electrochemical microsensors. A microoptode array as well as a method for high-resolution oxygen imaging are related as two ways to investigate the two-dimensional oxygen distribution in heterogeneous living systems (Klimant *et al.,* 1997). The oxygen concentration profile in a *P. putida* biofilm in a flat plate vapor-phase bioreactor treating toluene was determined by microsensor. The outer 87% of the biofilm was apparently inert, with the remainder following zero-order kinetics (Villaverde, Mirpuri, Lewandowski, and Jones, 1997c).

The effect of biofilms on transport within porous media was monitored using a transparent media replica of a sandstone aquifer and image analysis software combined with automated pressure drop measurements (Paulsen *et al.,* 1997).

In a review of wastewater treatment bioreactors, emphasis was placed on recent insights into the population dynamics of biofilms as a result of conventional and molecular techniques (Stams and Oude Elferink, 1997).

Kalmbach, Manz, and Szewzyk (1997a) described the development of bacterial density, phylogentic diversity, and bacterial metabolic activity during the formation of drinking water biofilms through the application of fluorescence-labeled oligonucleotide probes combined with *in situ* reduction of the fluorochrome 5-cyano-2,3-ditolyl tetrazolium chloride (CTC).

A review of methods for *in situ* identification of microorganisms by rRNA probes was offered by Amann *et al.* (1997), who noted that spatial distributions of organisms in biofilms may be determined on a micrometer scale.

Coughlin *et al.* (1997) isolated an azo dye-degrading strain, TBX65, from the mixed liquor of the Mill Creek WWTP in Cincinnati, Ohio. Based on 16S r-RNA probing, they developed a strain-specific fluorescent antibody for the two TBX65 strains, MC1 and MI2. This probe was used to determine the survival and azo dye-degrading ability of these strains in biofilms generated in a rotating drum reactor. Kalmbach, Manz, and Szewzyk (1997b) isolated and characterized new bacteria species affiliated with the *in situ* dominating beta subclass of Proteobacteria in a municipal drinking water distribution system using 16S r-RNA probes. They found that two of eight strains, B6 and B8, were dominant bacteria strains in groundwater and distribution system biofilms, and the other strains were found within various parts of the distribution system.

Taylor *et al.* (1997) simulated a municipal wastewater environment to examine the distribution of total bacterial organisms and phenol-degrading organisms in the biofilm using ethidium bromide dot tests on extracted DNA and radioactively labeled DNA probes, respectively. Except under conditions of stress, concentrations of total bacterial DNA and of DNA from phenol degraders followed a direct relationship with biofilm depth.

Using DNA extracted from a fuel oil-contaminated field site, the enrichment of several genes that encode enzymes responsible for key steps in the degradation of hydrocarbons and one gene specific to rRNA group I of the genus *Pseudomonas* were studied. When toluene, ethylbenzene, xylene, and naphthalene concentrations were related to the extent of hybridization of some of the genes, significant differences were observed between contaminated and noncontaminated sites (Guo *et al.,* 1997).

The *tfdA* gene that encodes an α-ketoglutarate-dependent dioxygenase that catalyzes the initial step in the degradation of 2,4-dichlorophenoxyacetic acid (2,4-D) has been found on plasmids or on the chromosomes of phylogenetically diverse 2,4-D–degrading microorganisms. However, highly similar sequences were found in 76 soil bacteria grown in isolation on nonselective medium (Hogan *et al.,* 1997).

Restriction fragment length profiles of 16S rRNA genes derived from bulk community DNA or bacterial isolates were compared to determine the efficacy of polymerase chain reaction (PCR)-based methods for studying microbial diversity and phylogeny in a deep (188-m) subsurface environment. This study showed that a majority of the cultivated aerobic heterotrophic bacteria in a subsurface sediment could be described by 16S rDNA clones obtained from directly extracted DNA, but that PCR-based methods cannot account for all organisms from a given sample (Chandler *et al.,* 1997). Wintzingerode *et al.* (1997) summarized pitfalls of PCR-based analysis of prokaryotic small-subunit ribosomal RNAs for ecological studies that could lead to an erroneous description on the microbial diversity of a given habitat. The authors covered aspects of this approach such as sample collection, cell lysis, nucleic acid extraction, PCR amplification, separation of amplified DNA, application of nucleic probes, and data analysis.

An inexpensive chemostat apparatus was designed for continuous culture experiments such as biofilm assays. This apparatus enabled the development of highly reproducible biofilm populations at various growth rates (Whiteley *et al.,* 1997). McLean *et al.* (1997) used a cross-feeding assay to determine if *N*-acyl homoserine lactone (AHL) molecules are naturally produced in aquatic biofilms growing on submerged stones. *N*-Acyl homoserine lactone was detected in living biofilms and biofilm extracts, but AHL was not present on rocks lacking a biofilm.

Because they are critical variables in the overall performance of any biofilm system, the concentration boundary layer (CBL) and the hydrodynamic boundary layer (HBL) thicknesses above a biofilm were studied by Bishop *et al.* (1997), and they related these two variables through the use of the Schmidt number relationship. They also found that CBL thickness varied with the bulk liquid flow velocity but the roughness had little effect,

and they also learned that there was minimal relationship between HBL thickness and bulk flow velocity.

Electric fields and pH demonstrating the "bioelectric effect" affected mixed species biofilm structure. The biofilm thickness grown in a how cell was reduced by 74% when the cell was anodic and by 69% when the cell flushed with media of pH 3, respectively (Stoodley, de Beer, *et al.,* 1997a).

The evaluation of a biocide's ability to penetrate varying thicknesses was disclosed by Chen and Swei (1997) using a modular method and device.

Thiothrix sp., sulfide-oxidizing filamentous bacteria, were a principal component of aquatic biofilms causing biofouling in municipal water storage tanks, private wells, and drip irrigation systems in Florida. Brigmon *et al.* (1997) confirmed that specific biological and chemical interactions may induce physical changes, leading to significant biofouling.

Respiratory activity in freshwater biofilms was measured by the dimethylsulfoxide reduction method. Because of its high sensitivity, short experimental duration, and small sediment sample requirements, this method resulted in expedient and extensive measurement under field or laboratory conditions (Grieber, 1997). Specific rates of adenosine triphosphate and oxygen uptake were measured for biofilms and suspensions of *Beneckea natriegens* in an airlift bioreactor, with biofilm rates three to four times lower than those measured in suspension (Gikas and Livingston, 1997).

Hu *et al.* (1997) studied the acclimation of a biofilm in an aerobic submerged biofilter to *N,N*-dimethylformamide (DMF). Easily biodegradable substances prevented this acclimation, with appreciable changes in the quinone profile associated with a change to DMF utilization.

Friese *et al.* (1997) compared the elemental mass fractions of potassium, calcium, chromium, manganese, iron, nickel, copper, zinc, and lead in biofilms taken from stones and from the bulk water phase in the River Elbe and determined that the bulk water phase biofilms had two to three times higher mass fractions for the determined elements.

Results from studying the effect of nutrient composition on a degradative biofilm showed that it has both a significant effect on both architecture and the physicochemistry. When the sole carbon and energy source was changed from 2,4,6-trichlorobenzoic acid to a labile, nonchlorinated carbon source, the biofilms lost their mound structures, and the neutrally charged fluorescent dextrans (cationic when hydrated) bounded to these mounds and to the basal cell layer in 14-day biofilms (Moller *et al.,* 1997). Gisi *et al.* (1997) used biofilms immobilized on glass to degrade the pesticide 4,6-dinitro-*ortho*-cresol (DNOC). Maximal degradation rates were 30 mmol/d (1 reactor volume), were inhibited at DNOC concentrations above 30 mM, and ceased at 340 mM.

Studies by Tan and Qian (1997) confirmed that *Bacillus subtilis* killed by short exposure to high temperatures still retained sufficient enzymatic viability and activity for biooxidation of organisms and can be used for sensing BOD in water and wastewater.

Gschoessl *et al.* (1997) compared observations of ciliated protozoa and metazoa in biofilms with enzymatic analyses and performance data.

The density and structure of the denitrifying bacteria community in a methanol-fed system were investigated (Lemmer, Zaglauer, Neef, *et al.,* 1997b). The authors revealed that distinct taxonomic groups were involved, and some species such as paracocci and hyphomicrobia of the genus *Hyphomicrobium* were sensitive to pH drops in the filter bed, favoring accumulation of nitrous oxide.

The effect of humic acids on mucilage development in periphyton communities was studied using a variety of techniques. Humic acid-treated communities contained 10–57% less mucilage than untreated controls (Wetzel *et al.,* 1997).

GROWTH AND MODELING

Many freshwater organisms that secrete acid polysaccharides of high molecular mass that combat specific environmental stresses and aggregate to form colloids could participate in biofilm formation and natural decontamination of water. A review by Leppard (1997) presented a strategy to combine separation technology, biochemical concepts, and the tools of analytical chemistry. A review by Gagnon *et al.* (1997) assessed the available models describing the utilization of biodegradable organic matter and biofilm growth in distribution systems.

Using nonlinear ordinary differential equations (ODEs) solved by a fourth-order Runge-Kutta algorithm, Wang and Bryers (1997) proposed a dynamic mathematical model to describe bacterial cell adhesion in viscous shear flow that is mediated by ligand bonding, a specific receptor. Various stages of bacterial attachment were pertinent at different stages of biofilm development, and, based on model solutions, a recommendation for a proper time duration for experimental adhesion research is possible.

In a one-dimensional, mixed-culture biofilm model volume expansion caused by microbial growth led to a displacement of biomass toward the biofilm surface. The processes of "transport of solids in biofilm pore volume," and "attachment to and detachment from the solid matrix" were added to a biofilm model that can be used to investigate the transport of solids in the biofilm and the biofilm–solid matrix (Reichert and Wanner, 1997).

Coexistence of *Klebsiella pneumonie* and *P. aeruginosa* was stable in laboratory grown biofilms, although the growth rates were not equal. The authors hypothesized that structural heterogeneity and differing rates of attachment and detachment were responsible for the coexistence (Stewart *et al.,* 1997).

The effects of mercaptoethanol and dithiothreitol on growth of free and attached *Saccharomyces paradoxus* were compared. The resistance of attached cells to mercaptoethanol and dithiothreitol was accompanied by changes in metabolic and biosynthetic activity as well as by changed starvation response. Use of ethylene glycol by the bacterial biofilm indicated that the cell attachment to insoluble supports could allow modulation of the technologically significant properties of microbial cell populations (Jirku *et al.,* 1997).

The nitrifying performance of biofilms formed on polymeric supports was correlated with the hydrophobicity and the surface charge of both bacteria and media. The adhesion of nitrifying bacteria was primarily governed by hydrophobic interactions (Sousa *et al.,* 1997).

To illustrate that bacteria surfaces are highly interactive with their environments, a *P. aeruginosa* model system was used to determine that lipopolysaccharide is vital in the initial attachment of this gram-negative bacteria to interfaces and that its surface changes during biofilm formation. In this model system, gram-negative bacteria also tended to concentrate and package periplasmic components into membrane vesicles that could be

predatory and lyse neighboring bacteria, releasing additional nutrients in the microbial environment (Beveridge *et al.*, 1997).

Using a laboratory-scale system, Biedermann *et al.* (1997) concluded the suitability of polymers for applications as the matrix substance for denitrification in a bioreactor. To assist in the design and evaluation of characterization experiments, a conceptual model of exopolymer production was developed (Nielsen *et al.*, 1997).

A kinetic model was designed for a biofilm reactor fed toluene to degrade TCE by Arcangeli and Arvin (1997b). Toluene above 1 mg/L inhibited TCE degradation, whereas TCE above 50 mg/L inhibited toluene removal. The model showed fair agreement with experimental data, except for when cells were resting, giving a maximal TCE degradation rate, k_X(TCE), of 0.38 ± 0.11 gTCE/$g_X \cdot$ d and a half-saturation constant for TCE, K_S (TCE), of 0.17 ± 0.1 mg/L.

Using modeling and experimentation, the biodegradation of toluene by *P. putida* biofilms in unsaturated systems was described by Holden *et al.* (1997). Their studies showed that the diffusion of toluene to biodegrading bacteria could limit the overall rate of toluene depletion in unsaturated systems.

The effects of prolonged toluene exposure and degradation in bacterial cultures of *P. putida* 54G were investigated in batch suspension cultures, bench-scale, flat-plate biofilm reactors, and bench-scale, packed-column reactors. Results confirm that decreased culturability on toluene media correlated with decreased toluene degradation rate (Jones, Mirpuri, *et al.*, 1997b).

Mirpuri, Jones, *et al.* (1997a) compared ^{14}C-toluene degradation kinetics by biofilm and by planktonic cells of *P. putida* 54G, and they found that specific activities measured for both of these cells were similar based on toluene-degrading cells and total biomass. Although planktonic cell kinetics worked for modeling substrate degradation and bacteria growth in biofilms, the authors suggested that, for superior bioreactor design, cellular activity during biofilm development should be investigated under relevant reactor operation conditions before predictive models for bioreactor systems are developed.

A flat plate biofilm reactor was used to grow a *P. putida* 54G biofilm on toluene vapor, resulting in several trends of long-term exposure to high toluene levels. Data also indicated that more respiring cells and a higher respirator rate occurred at the base of the film, demonstrating physiological deterioration with continued toluene exposure (Villaverde, Mirpuri, Lewandowski, and Jones, 1997d). Villaverde and Fernandez (1997) also evaluated nontoluene-associated respiration (NTAR) within a *P. putida* 54G biofilm growing on toluene as sole external carbon source. The NTAR rate was positively correlated with the fraction of viable stressed and nonrespiring cells within the biofilm, suggesting that some cells grew at the expense of leakage and lysis products coming from injured and dead cells.

Lapaglia and Hartzell (1997) studied *Archaebacteris fulgidus*, an anaerobic marine hyperthermophile, and learned that this organism forms a biofilm in response to environmental stresses such as pH and temperature extremes, high concentrations of metals, and the addition of oxygen, antibiotics, or xenophobics. Their data suggested that cells may produce biofilms as a mechanism for concentrating cells and attaching to surfaces, as a protective barrier, and as a reserve nutrient.

The metal selectivity of *in situ* microcolonies in biofilms of the Elbe River was evaluated using transmission electron microscopy and energy-dispersive x-ray (EDX) analysis (Lundsdorf *et al.*, 1997). Unlike the aluminum ions studied, EDX analysis indicated that electron-dense microcolony surface contained manganese and iron in significant amounts, whereas these two elements were not detected in the intercellular space and cytoplasm.

Biofilm biomass and activity affected by surface channel water or inflowing lateral source water were investigated in the Rhone River during the growing and dormant seasons as well as in hydrodynamic and trophic situations. Source biofilms consumed total organic matter of sediments in each season, and channel biofilms preferably used dissolved organic matter from overlying water, which fluctuates seasonally (Claret and Fontvielle, 1997). In another seasonal stream study, it was found that Mediterranean stream biofilms exposed to summer periods of dry conditions recovered enzymatic activities immediately upon rewetting and increased those activities above predrought levels (Romani and Sabater, 1997). Batchelor *et al.* (1997) investigated recovery speed of cell suspensions and biofilm populations of the ammonia-oxidized *Nitrosomonas europaea* following starvation. For these starved biofilm populations colonizing sand or soil particles in continuous flow, fixed-column reactors, the organisms exhibited no lag phase before nitrite production after 43.2 days of starvation following ammonium resupply. When there was an intermittent substrate supply, the biofilm formation offered an ecological advantage.

Confer and Logan (1997b) wanted to determine if hydrolytic fragments would accumulate in solution during degradation of the model protein bovine serum albumin (BSA; 65 000 amu). They concluded that the involvement of numerous microbial species during protein degradation limits the accumulation of hydrolytic fragments under conditions of typical wastewater treatment systems, thus resulting in little effect on the overall macromolecule degradation kinetics. They also desired to determine whether small (<1 000 amu) and/or intermediate (1 000–10 000 amu) size fragments are released during bacterial degradation of soluble large-molecular-weight (>10 000 amu) model polysaccharides (Confer and Logan, 1997a). They conclude that a large-molecular-weight polysaccharide must undergo perhaps hundreds of hydrolytic reactions before fragments were small enough (<1 000 amu) to be assimilated by bacterial cells.

Daly *et al.*, (1997) examined the mechanisms underlying the protection of pathogens by biofilms. *Escherichia coli*-seeded biofilms were grown at bench scale and studied for the ability of organisms to reproduce under conditions of increasing free chlorine concentrations.

Removal of MS2 virus from primary effluent in a laboratory-scale sintered glass filters both with and without a biological layer was studied. At the constant hydraulic application rate, increasing the dosing frequency from 1 to 48 times per day resulted in an increase in the viral log removal from 0.29–2.3 in the absence of bacteria, and from 0.80–4.6 in the presence of bacteria (Emerick *et al.*, 1997).

Jeppsson (1997) described and exemplified some of the work that has been carried out within the STAMP project at IEA at Lund Institute of Technology within the field of mathematical modeling of wastewater treatment processes, particularly in three main areas: reduced-order models of the activated-sludge process, modeling of biofilm processes including some effects of higher-order organisms, and one-dimensional settler models based on recent new mathematical developments.

Horn and Hempel (1997a) discovered experimentally and by modeling that for autotrophic bacteria a first-order reaction could describe loss of bacteria activity for death and endogenous

respiration processes. The starvation and decay of heterotrophic bacteria were modeled by maintenance, lysis, and death. In another experiment, Horn and Hempel (1997b) investigated autotrophic biofilms to verify and improve a biofilm model. Simulation of the experimental results yielded relationship information on biofilm depth, density of inert volume fraction, growth and decay, and mass transfers coefficients.

The effect of temperature and salinity on colonization by the predatory prokaryote *Bdellovibrio bacteriovirus* was studied by Kelley *et al.* (1997). Natural material (oyster shell) was found to cultivate larger numbers of *B. bacteriovirus* than did glass or polystyrene, and higher temperatures and salinity also promoted colonization.

In laboratory experiments on combined sewer wastewater in Bayreuth, Germany, samples of wastewater and a wastewater/biofilm mixture were incubated with and without NaCl. If NaCl was added before incubation, the wastewater/biofilm mixture emitted 4.8 times more N_2O than did wastewater samples (Clemens and Haas, 1997).

Tanyolic and Beyenal (1997) experimentally verified a theory that predicts the optimal density of a biofilm to yield a maximum substrate consumption rate within the biofilm. Results showed a good correlation between the model prediction and experimental results for biofilm density and substrate consumption rates.

Inert fluorescent microparticles were used as tracers to investigate the dynamics of spatial distribution of particulate components in mixed population biofilms. The dynamics of the inert microbeads in the biofilm was strongly influenced by not only microbial growth but also by the biofilm structure and growth (Okabe *et al.*, 1997).

Acetate removal in a gravity sewer was simulated by continuous-flow biofilm reactor using extreme load situations. Low-loaded biofilms showed very high acetate removal in short-term experiments at high acetate concentrations, whereas high-loaded biofilms revealed lower-rate acetate removal. Results also showed that acetate removal rate level was related to biofilm structure (Raunkjaar *et al.*, 1997). Research on biofilm structures and implications for substrate and nutrient transport into biofilm were reviewed. Biodegradation kinetics in the various growth models were discussed (Bishop, 1997).

When the basic structure of microbial biofilms was reviewed, at least three conceptual models existed. To synthesize the models, Wimpenny and Colasanti (1997b) presented a "unifying" hypothesis, asserting that cellular automata used to model biofilm growth strongly suggested that biofilm structure was determined by substrate concentration. In response, a "more unifying" hypothesis for biofilm structures, an improvement to the proposed Wimpenny and Colasanti (1997a) model, held that the interaction between the substrate gradient (rather than concentration) at the biofilm interface and detachment forces influence the biofilm structure (van Loosdrecht *et al.*, 1997). Wimpenny and Colasanti (1997a) replied, concurring to a degree but remaining convinced that substrate concentration is the most important factor influencing the structure of a biofilm.

Under various flow rates, freshwater *Pseudomonas* biofilms were grown on glass plates in a biofilm, and the microcolony studied exhibited unique interbacterial separation distance distribution. As the flow rates increased, the local orientation order gradually developed into a general order, which eventually disrupted and showed local alignment of cells (Rao *et al.*, 1997).

A new model for rapidly calculating the removal of multiple substrates by different bacterial species growing in a biofilm reactor was presented and verified for a dynamic change in organic loading on a heterotrophic-autotrophic biofilm. The model was an extension to the well-known half-order reaction concept that combines a zero-order kinetic dependency on substrate concentration with diffusion limitation (Rauch and Vanrolleghem, 1997).

Nagaoka (1997) studied mass transfer mechanisms in biofilms under oscillatory conditions and found that substrate uptake rate decreased with the decrease of the Reynolds number of the wave motion according to a power law with a coefficient of 0.6.

For a laboratory-scale, continuous flow fixed-film growth system, the aeration effects on *Beggiatoa* and sulfate removal were understandable in the context of the *Beggiatoa–Desulfovibrio* interaction, diffusion, and uptake rate of substrate. Glucose diffusion and uptake rate may be more rapid; thus, air could not penetrate as efficiently into the sulfide-emitting anaerobic layer inhabited by sulfate-reducing bacteria such as *Desulfovibrio* (Chung and Strom, 1997a).

By exploiting the inherent linearity of the biofilm process under certain conditions, operational criteria for regulating the performance of the biofilm reactors were obtained and their applicability and utility numerically demonstrated (Ojha and Shrivastava, 1997).

Biofilm growth and water quality changes were studied in two pilot-scale sewers. The biofilm thickness, sulfide formation, denitrification, organic matter removal, and phosphorus removal were monitored in relation to wastewater treatment (Aesoy *et al.*, 1997).

A comparison of a methanotrophic biofilm model to experimental data showed that biofilm growth, methane removal, oxygen consumption, product formation, and biofilm detachment were fitted well with the model (Arcangeli and Arvin, 1997a).

ANAEROBIC BIOFILM SYSTEMS

A number of papers were published on anaerobic biofilms. Although not reviewed here, they are listed under a separate heading at the end of the References. Additional citations, review, and comments are contained in the Anaerobic Processes section of this issue.

Natalie Pearson and Gene Richards are graduate students and Mark W. Fitch and Joel G. Burken are assistant professors of civil engineering at the University of Missouri-Rolla. Correspondence should be addressed to Dr. Mark. W. Fitch, Department of Civil Engineering, University of Missouri–Rolla, Rolla, MO 65409-0030.

REFERENCES

Abumaizar, R.J.; Smith, E.H.; and Kocher, W. (1997) Analytical Model of Dual-Media Biofilter for Removal of Organic Air Pollutants, *J. Environ. Eng.*, **123,** 606.

Abu-Reesh, I.M. (1997) Predicting the Performance of Immobilized Enzyme Reactors Using Reversible Michaelis-Menten Kinetics, *Bioprocess. Eng.*, **17,** 131.

Aesoy, A.; Storfjell, M.; Mellgren, L.; Helness, H.; Thorvaldsen, G.; Odegaard, H.; and Bentzen, G. (1997) Comparison of Biofilm Growth and Water Quality Changes in Sewers with Anoxic and Anaerobic (Septic) Conditions, *Water Sci. Technol.* (G.B.) **36,** 1, 303.

Alonso, C.; Suidan, M.T.; Sorial, G.A.; Smith, F.L.; Biswas, P.; Smith, P.J.; and Brenner, R.C. (1997a) Gas Treatment in Trickle-Bed Bio-

filters: Biomass, How Much Is Enough? *Biotechnol. Bioeng.*, **54**, 583.

Alonso, C.; Zhu, X.; Suidan, M.T.; Kim, B.R.; and Kim, B.J. (1997b) Effect of Nitrate on VOC Removal in a Gas Phase Biofilter. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition*, Chicago, Ill.

Amann, R.; Gloeckner, F.-O.; and Neef, A. (1997) Modern Methods in Subsurface Microbiology: In Situ Identification of Microorganisms with Nucleic Acid Probes, *FEMS Microbiol. Rev.*, **20**, 191.

Anguish, L.J., and Ghiorse, W.C. (1997) Computer-Assisted Laser Scanning and Video Microscopy for Analysis of *Cryptosporidium parvum* oocysys in Soil, Sediment, and Feces, *Appl. Environ. Microbiol.*, **63**, 724.

Arcangeli, J., and Arvin, E. (1997a) Modeling of the Growth of a Methanotropic Biofilm, *Water Sci. Technol.* (G.B.), **36**, 1, 199.

Arcangeli, J.-P., and Arvin, E. (1997b) Modeling of the Cometabolic Biodegradation of Trichloroethylene by Toluene-Oxidizing Bacteria in a biofilm System, *Environ. Sci. Technol.*, **31**, 3044.

Artsukevich, I., and Solomon, Z. (1997) Biodegradation of Methanol Waste Water by Immobilized Methylotrophic Yeast, *Meded.—Fac. Landbouwkd. Toegepaste Biol. Wet.* (Ger.), **62**, 1759.

Baltzis, B.C.; Wojdyla, S.M.; and Zarook, S.M. (1997) Modeling Biofiltration of VOC Mixtures under Steady-State Conditions, *J. Environ. Eng.*, **123**, 599.

Banerjee, G. (1997) Treatment of Phenolic Wastewater in RBC Reactor, *Water Res.* (G.B.), **31**, 705.

Batchelor, S.E.; Cooper, M.; Chharbra, S.R.; Glover, L.A.; Stewart, G.S.A.B.; Williams, P.; and Prosser, J.I. (1997) Cell Density-Regulated Recovery of Starved Biofilm Populations of Ammonia-Oxidizing Bacteria, *Appl. Environ. Microbiol.*, **63**, 2281.

Battin, T.J. (1997) Assessment of Fluorescent Diacetate Hydrolysis as a Measure of Total Esterase Activity in Natural Stream Sediment Biofilms, *Sci. Total Environ.*, **198**, 51.

Becker, G.; Holfeld, H.; Hasselrot, A.T.; Fiebig, D.M.; and Menzler, D.A. (1997) Use of Microscopic Photometer to Analyze in Vivo Fluorescence Intensity of Epilithic Microalgae Grown on Artificial Substrata, *Appl. Environ. Microbiol.*, **63**, 1318.

Beg, S.A.; Hassan, M.M.; and Chaudhry, M.A.S. (1997a) Dual Substrate Limitations in Upflow Packed-Bed Biofilm Reactors—a Theoretical Study, *Chem. Eng. Technol.*, **20**, 10.

Beg, S.A.; Hassan, M.M.; and Chaudhry, M.A.S. (1997b) Effect of Fasting Condition on Multi-Substrates Carbon Oxidation and Nitrification System in an Upflow Packed-Bed Biofilm Reactor, *Chem. Eng. Technol.*, **20**, 162.

Beg, S.A.; Hassan, M.M.; and Chaudhry, M.A.S. (1997c) Effect of Sinusoidal Perturbations of Feed Concentration on Multi-Substrate Carbon Oxidation and Nitrification Process in an Upflow Packed-Bed Biofilm Reactor, *Chem. Eng. J.*, **65**, 165.

Beveridge, T.J.; Makin, S.A.; Kadurugamuwa, J.L.; and Li, Z.S. (1997) Interations Between Biofilms and the Environment, *FEMS Microbiol. Rev.*, **20**, 291.

Beyenal, H.; Seker, S.; and Tanyolac (1997) Diffusion Coefficients of Phenol and Oxygen in a Biofilm of *Pseudonomonas putida, AIChE J.*, **43**, 243.

Bibeau, L.; Kiared, K.; Leroux, A.; Brzezinski, R.; Viel, G.; and Heitz, M. (1997) Biological Purification of Exhaust Air Containing Toluene Vapor in a Filter-Bed, *Can. J. Chem. Eng.*, **75**, 921.

Biedermann, J.; Owen, A.J.; Schloe, K.T.F.G.; and Sussmuth, R. (1997) Interaction Between Poly-3-hydroxybutyrate-co-3-hydroxyvalerate and a Denitrifying *Pseudomonas* Strain, *Can. J. Microbiol.*, **43**, 561.

Bishop, P. (1997) Biofilm Structure and Kinetics, *Water Sci. Technol.* (G.B.), **36**, 1, 287.

Bishop, P.L.; Gibbs, J.T.; and Cunningham, B.E. (1997) Relationship Between Concentration and Hydrodynamic Boundry Layers Over Biofilms, *Environ. Technol.*, **18**, 375.

Boaventura, R.A.R., and Rodrigues, A.E. (1997) Denitrification Kinetics in a Rotating Disk Biofilm Reactor, *Chem. Eng. J.*, **65**, 227.

Boller, M.; Tschui, M.; and Gujer, W. (1997) Effects of Transient Nutrient Concentrations in Tertiary Biofilm Reactors, *Water Sci. Technol.* (G.B.), **36**, 1, 101.

Boon, A.; Hemfrey, J.; Boon, K.; and Brown, M. (1997) Recent Developments in the Biological Filtration of Sewage to Produce High-Quality Nitrified Effluents, *J. CIWEM*, **11**, 393.

Borregaard, V.R. (1997) Experience with Nutrient Removal in a Fixed-Film System at Full-Scale Wastewater Treatment Plants, *Water Sci. Technol.* (G.B.), **36**, 1, 129.

Boult, S.; Johnson, N.; and Curtis, C. (1997) Recognition of a Biofilm at the Sediment-Water Interface of an Acid Mine Drainage-Contaminated Stream, and Its Role in Controlling Iron Flux, *Hydological Process.*, **11**, 391.

Brigmon, R.L.; Martin, H.W.; and Aldrich, H.C. (1997) Biofouling of Groundwater Systems by Thiothrix Species, *Curr. Microbiol.*, **35**, 169.

Brindle, K.; Stephenson, T.; and Semmens, M. (1997) Enhanced Biological Treatment Of High Oxygen Demanding Wastewaters By A Membrane Bioreactor Capable Of Bubbleless Oxygen Mass Transfer. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition*, Chicago, Ill.

Broch-Due, A.; Andersen, R.; and Opheim, B. (1997) Treatment of Integrated Newsprint Mill Wastewater in Moving Bed Biofilm Reactors, *Water Sci. Technol.* (G.B.), **35**, 2, 173.

Brosilow, B.J.; Schnitzer, M.; Tarre, S.; and Green, M. (1997) A Simple Model Describing Nitrate and Nitrite Reduction in Fluidized Bed Biological Reactors, *Biotechnol. Bioeng.*, **54**, 543.

Brough, M.J.; Al-Tabbaa, A.; and Robert, M.J. (1997) Active Biofilm Barriers for Waste Containment and Bioremediation: Laboratory Assessment, Paper presented at 4th Int. In Situ On-Site Bioremediation Symp., New Orleans, La.

Bryant, C.W.; Barkley, W.A.; Garrett, M.R.; and Gardner, D.F. (1997) Biological Nitrification of Kraft Wastewater, *Water Sci. Technol.* (G.B.), **35**, 2, 147.

Buchtmann, C.; Kies, U.; Deckwer, W.; and Hecht, V. (1997) Performance of Three Phase Fluidized Bed Reactor for Quinoline Degradation on Various Supports at Steady State and Dynamic Conditions, *Biotechnol. Bioeng.*, **56**, 295.

Carlson, G., and Silverstein, J. (1997) Effect of Ozonation on Sorption of Natural Organic Matter by Biofilm, *Water Res.* (G.B.), **31**, 2467.

Cesário, M.T.; de Wit, H.L.; Tramper, J.; and Beeftink, H.H. (1997) Dispersed Organic Solvent to Enhance the Overall Gas/Water Mass Transfer Coefficient of Apolar Compounds in the Biological Waste-Gas Treatment. Modeling and Evaluation, *Biotechnol. Prog.*, **13**, 399.

Chalmers, J.; Mauras, C.; and Vir, R. (1997) Confocal Microscopic Images of a Compost Particle, *Biotechnol. Prog.*, **13**, 727.

Chandler, D.P.; Shu-Mei, L.; Spadoni, C.M.; Drake, G.R.; Balkwill, D.L.; Fredrickson, J.K.; and Brockman, F.J. (1997) A Molecular Comparson of Culturable Aerobic Heterotrophic Bacteria and 16S rDNA Clones Derived from a Deep Subsurface Sediment, *Microbiol. Ecol.*, **34**,, 131.

Chen, C.-Y., and Swei, W.-J. (1997) Modular Method and Device for the Evaluation of the Ability of Biocide to Penetrate Biofilm, *Biotechnol. Adv.*, **15**, 748.

Chen, G.H.; Huang, J.-C.; and Lo, I.M.C. (1997) Removal of Rate-Limiting Organic Substances in a Hybrid Biological Reactor, *Water Sci. Technol.* (G.B.), **35**, 6, 81.

Chevron, F.; Defives, C.; and Dubourguier, H.C. (1997) Denitrification of High Nitrate and Ammonia Waters Using Fixed-Biofilms Reactors on Natural Supports, *Environ. Technol.*, **18**, 171.

Chou, M.-S., and Cheng, W.-H. (1997) Screening of Biofiltering Material for VOC Treatment, *J. Air Waste Manage. Assoc.*, **47**, 674.

Chou, M.-S., and Shiu, W.-Z. (1997) Bioconversion of Methylamine in Biofilters, *J. Air Waste Manage. Assoc.*, **47**, 58.

Chua, H., and Yu, P.H.F. (1997) Hydrodynamic Characteristics in Aerobic Biofilm Reactor Treating High-Strength Trade Effluent, *Appl. Biochem. Biotechnol.*, **63–65**, 669.

Chung, J.-C., and Strom, P.F. (1997a) Aeration Effects on *Beggiatoa*

in a Laboratory Fixed-Film Growth System, *J. Environ. Sci. Health*, **A32,** 763.

Chung, J.-C., and Strom, P.F. (1997b) Filamentous Bacteria and Protozoa Found in the Rotating Biological Contactor, *J. Environ. Sci. Health*, **32,** 671.

Chung, Y.-C.; Huang, C.; and Tseng, C.-P. (1997) Biotreatment of Ammonia from Air by an Immobilized *Arthrobacter oxydans* CH8 Biofilter, *Biotechnol. Prog.*, **13,** 794.

Clapp, L.; Newman, J.; Ali, F.; and Park, J. (1997) Degradation of TCE Using Methanotrophic Biofilms Cultivated on Gas-Permeable Silicone Membranes. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition*, Chicago, Ill.

Claret, C., and Fontvielle, D. (1997) Characteristics of Biofilm Assemblages in Two Contrasted Hydrodynamic and Trophic Contexts, *Microbial Ecol.*, **34,** 49.

Clemens, J., and Haas, B. (1997) Nitrous Oxide Emissions in Sewer Systems, *Acta Hydrochim. Hydrobiol.* (Ger.), **25,** 96.

Clement, T.P.; Peyton, B.M.; Skeen, R.S.; Jennings, D.A.; and Petersen, J.N. (1997) Microbial Growth and Transport in Porous Media under Denitrification Conditions--Experiments and Simulations, *J. Contaminant Hydrol.*, **24,** 269.

Confer, D., and Logan, B.E. (1997a) Molecular Weight Distribution of Hydroysis Products During the Biodegredation of Model Macromolecules in Suspended and Biofilm Cultures. II. Dextran and Dextrin, *Water Res.* (G.B.), **31,** 2137.

Confer, D.R., and Logan, B.E. (1997b) Molecular Weight Distribution of Hydroysis Products During Biodegredation of Model Macromolecules in Suspended and Biofilm Cultures I. Bovine Serum Albumin, *Water Res.* (G.B.), **31,** 2127.

Converti, A.; Delborghi, M.; and Zilli, M. (1997) Evaluation of Phenol Diffusivity Through *Pseudoomonas putida* Biofilms—Application to the Study of Mass Velocity Distribution on a Biofilter, *Bioprocess. Eng.*, **16,** 105.

Coughlin, M.F.; Kinkle, B.K.; Tepper, A.; and Bishop, B.L. (1997) Characterization of Aerobic Azo Dye-Degrading Bacteria and their Activity in Biofilms, *Water Sci. Technol.* (G.B.), **36,** 1, 215.

Cox, H.H.J.; Moerman, R.E.; Van Baalan, S.; Van Heiningen, W.N.M.; Doddema, H.J., and Harder, W. (1997) Performance of a Styrene-Degrading Biofilter Containing the Yeast *Exophiala jeanselmei*, *Biotechnol. Bioeng.*, **53,** 259.

Dalentoft, E., and Thulin, P. (1997) The Use of the Kaldnes Suspended Carrier Process in Treatment of Wastewaters from the Forest Industry, *Water Sci. Technol.* (G.B.), **35,** 2, 123.

Daly, B.; Betts, W.B.; and O'Neill, J.G. (1997) The Influence of Sodium Hypochlorite Concentration on Retention of *E. coli* in a Gram Positive Biofilm, *Spec. Publ.—R. Soc. Chem.*, **191,** 260.

d'Antonio, G.; Mendia, L.; Pirozzi, F.; and Polese, A. (1997) Rotating Biological Contactor-Solid Contact System for the Treatment of Wastewater from Small Communities, *Water Sci. Technol.* (G.B.), **35,** 6, 109.

De Beer, D.; Schramm, A.; Santegoeds, C.M.; and Kuhl, M. (1997a) A Nitrite Microsensor for Profiling Environmental Biofilms, *Appl. Environ. Microbiol.*, **63,** 973.

De Beer, D.; Stoodley, P.; and Lewandowski, Z. (1997b) Measurement of Local Diffusion Coefficients in Biofilms by Microinjection and Confocal Microscopy, *Biotechnol. Bioeng.*, **53,** 151.

Degorce-Dumas, J.R.; Kowal, S.; and Le Cloirec, P. (1997) Microbial Oxidation of Hydrogen Sulphide in a Biofilter, *Can. J. Microbiol.*, **43,** 264.

De heyder, B.; Van Langenhove, H.; Janssens, I.; and Verstaete, W. (1997) Combined Physical/Biological Treatment of a Waste Gas Containing Ethene, *Meded.—Fac. Landbouwkd. Toegepaste Biol. Wet.*, **62,** 1513.

Deleo, P.C., and Baveye, P. (1997) Factors Affecting Protozoan Predation of Bacteria Clogging Laboratoy Aquifer Microcosms, *Geomicrobiol. J.*, **14,** 127.

Deshusses, M.A. (1997) Transient Behavior of Biofilters: Start-Up, Carbon Balances, and Interactions Between Pollutants, *J. Environ. Eng.*, **123,** 563.

Di Felice, R.; Nicolella, C.; and Rovatti, M. (1997) Mixing and Segregation in Water Fluidized-Bed Bioreactors, *Water Res.* (G.B.), **31,** 2392.

Domingo, J.W.S.; Radway, J.C.; Wilde, E.W.; Hermann, P.; and Hazen, T.C. (1997) Immobilization of *Burholderia cepacia* in Polyurethane-based Foams: Embedding Efficiency and Effect on Bacterial Activity, *J. Ind. Microbiol. Biotechnol.*, **18,** 389.

Doronina, N.V.; Ezhov, V.A.; and Trotsenko, Y.A. (1997) Aerobic Biodegradation of Formaldehyde, Methanol, and Methylamine by Immobilized *Methylobacterium extorquens* Cells, *Appl. Biochem. Microbiol.*, **33,** 138.

Emerick, R.W.; Tchobanoglous, G.; and Darby, J.L. (1997) Use of Sintered Glass as a Medium in Intermittently Dosed Wastewater Filters: Removal and Fate of Virus. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition*, Chicago, Ill.

Ergas, S.J., and MacGrath, M.S. (1997) Membrane Bioreactor for Control of Volatile Organic Compound Emissions, *J. Environ. Eng.*, **123,** 593.

Erlanson, B.; Dvorak, B.; Speitel, G., Jr.; and Lawler, D. (1997) Equilibrium Model for Biodegradation and Adsorption of Mixtures in GAC Columns, *J. Environ. Eng.*, **123,** 469.

Essa, M.H.; Farooq, S.; and Nakhla, G. (1997) Effect of Biofilm on the Physical Properties of Sands Contaminated with Phenol, *J. Environ. Sci. Health*, **32,** 1109.

Freitas dos Santos, L.; Pavasant, P.; Strachan, L.; Pistikopoulos, E.; and Livingston, A. (1997) Membrane Attached Biofilms for Waste Treatment—Fundamentals and Applications, *Pure Appl. Chem.*, **69,** 2459.

Friese, K.; Mages, M.; wendt-Potthoff, K.; Neu, T.R.; and Kramer, J.F. (1997) Determination of Heavy Metals in Biofilms from the River Elbe by Total-Reflection X-Ray Fluorescence Spectrometry, *Spectrochim. Acta Part B-Atomic Spectroscopy*, **52,** 1019.

Fujii, S.; Niwa, C.; Mouri, M.; and Jindal, R. (1997) Pilot-Plant Experiments for Improvement of Polluted Canal/Klong Water by Rock-Bed Filtration, *Water Sci. Technol.* (G.B.), **35,** 83.

Gagnon, G.A.; Ollos, P.J.; and Huck, P.M. (1997) Modeling BOM Utilization and Biofilm Growth in Distribution Systems: Review and Identification of Research Needs, *Aqua (Oxford)*, **46,** 165.

Ganze, C.K.; Cashion, B.S.; Koon, J.H.; Davoren, D.J.; and Donohoe, C. (1997) Moving-Bed Aerobic Treatment of Exxon Baton Rouge Chemical Plant (BRCP) Wastewater. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition*, Chicago, Ill.

Garrido, J.; Campos, J.; Mendez, R.; and Lema, J. (1997a) Nitrous Oxide Production by Nitrifying Biofilms in a Biofilm Airlift Suspension Reactor, *Water Sci. Technol.* (G.B.), **36,** 1, 157.

Garrido, J.M.; Van Benthum, W.A.J.; Van Losdrecht, M.C.M.; and Heijnen, J.J. (1997b) Influence of Dissolved Oxygen Concentration on Nitrite Acumulation in a Biofilm Airlift Suspension Reactor, *Biotechnol. Bioeng.*, **53,** 168.

Gemeinert, M.; Muller, R.; Wihsmann, F.G.; Schroder, F.; and Kliche, H. (1997) Open-Pore Sintered Glass Ceremics as Carrier Material for Biotechnological Use, *Glass Sci. Technol.*, **70,** 278.

Gikas, P., and Livingston, A.G. (1997) Specific ATP and Specific Oxygen Uptake Rate in Immobilized Cell Aggregates: Experimental Results and Theoretical Analysis Using a Structured Model of Immobilized Cell Growth, *Biotechnol. Bioeng.*, **55,** 660.

Gisi, D.; Stukci, G.; and Hanselmann, K. (1997) Biodegradation of the Pesticide 4,6-dintro-ortho-cresol by Microorganisms in Batch Cultures and in Fixed-Bed Column Reactors, *Appl. Microbiol. Biotechnol.*, **47,** 441.

Gjaltema, A.; van der Marel, N.; van Loosdrecht, M.C.M.; and Heijnen, J.J. (1997a) Adhesion and Biofilm Development on Suspended Carriers in Airlft Reactors: Hydrodynamic Conditions Versus Surface Characteristics, *Biotechnol. Bioeng.*, **55,** 880.

Gjaltema, A.; van Loosdrecht, M.C.M.; and Heijnen, J.J. (1997b) Abra-

sion of Suspended Biofilm Pellets in Airlft reactors: Effect of Particle Size, *Biotechnol. Bioeng.*, **55,** 206.
Gjaltema, A.; Vinke, J.; van Loosdrecht, M.; and Heijnen, J. (1997c) Biofilm Abrasion by Particle Collisions in Airlift Reactors, *Water Sci. Technol.* (G.B.), **36,** 1, 221.
Gjaltema, A.; Vinke, J.L.; van Loosdrecht, M.C.M.; and Heijnen, J.J. (1997d) Abrasion of Suspended Biofilm Pellets in Airlift Reactors: Importance of Shape, Strucuture, and Particle Concentrations, *Biotechnol. Bioeng.*, **53,** 88.
Glaser, J.A. (1997) Utilization of Slurry Bioreactors for Contaminated Solids Treatment. An Overview, *Int. In Situ On-Site Biorem. Symp., 4th.*
Gostomski, P.; Sisson, J.; and Cherry, R. (1997) Water Content Dynamics in Biofiltration: The Role of Humidity and Microbial Heat Generation, *J. Air Waste Manage. Assoc.*, **47,** 936.
Govind, R.; Fu, C.; Yan, X.; Gao, C.; and Pfanstiel, S. (1997) Development of Bioavailability and Biokinetics Determination Methods for Organic Pollutants in Soil to Enhance In-Situ and On-Site Bioremediation, *Biotechnol. Prog.*, **13,** 43.
Green, M.B.; Griffin, P.; Jennings, P.G.; and Upton, J.E. (1997) Removal of Nitrogen by the Combination of Mechanical/Biological Treatment and Constructed Reed Beds. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.
Grieber, C. (1997) Dimethysulfoxide (DMSO) Reduction—A New Approach to Determine Microbial Activity in Freshwater Sediments, *J. Microbiol. Meth.*, **29,** 31.
Gschoessl, T.; Michel, I.; Heiter, M.; Nerger, C.; and Rehbein, V. (1997) Microscopic and Enzymatic Investigations on Biofilms of Wastewater Treatment Systems, *Water Sci. Technol.* (G.B.), **36,** 1, 21.
Guiot, S.R. (1997) Anaerobic and Aerobic Integrated System for Biotreatment of Toxic Wastes (Canoxis), *Biotechnol. Adv.*, **15,** 806.
Guo, C.; Sun, W.; Harch, J.B.; and Ogram, A. (1997) Hybridization Analysis of Microbial DNA from Fuel Oil-Contaminated and Noncontaminated Soil, *Microbiol. Ecol.*, **34,** 178.
Hammill, T., and Crawford, R. (1997) Bacterial Microencapsulation with Three Algal Polysaccharides, *Can. J. Microbiol.*, **43,** 1091.
Heijnen, J.J.; Hols, J.; van der Lans, R.G.J.M.; van Leeuwen, H.L.J.M.; Mulder, A.; and Weltevrede, R. (1997) Simple Hydrodynamic Model for the Liquid Circulation Velocity in a Full-Scale Two- and Three-Phase Internal Airlift Reactor Operating in the Gas Recirculating Regime, *Chem. Eng. Sci.* (G.B.), **52,** 2527.
Hellge, S. (1997) Microbial Degredation of Persistent Compounds in Low Concentrations Exemplified with Dibenzofuran and Dibenzo-p-dioxin, *Ber. Wasserguete-Abfallwirtsch., Tech. Univ. Muenchen,* **135,** 1.
Henderson, J.P.; Besler, D.A.; Atwater, J.A.; and Mavinic, D.S. (1997) Treatment of Methanogenic Landfill Leachate to Remove Ammonia Using a Rotating Biological Contactor (RBC) and a Sequencing Batch Reactor (SBR), *Environ. Technol.*, **18,** 687.
Herman, D.C.; Lenhard, R.J.; and Miller, R.M. (1997) Formation and Removal of Hydrocarbon Residual in Porous Media: Effects of Attached Bacteria and Biosurfactants, *Environ. Sci. Technol.*, **31,** 1290.
Hodge, D.S. (1997) Determination of Transfer Rate Constants and Partition Coefficients for Air Phase Biofilters, *J. Environ. Eng.*, **123,** 577.
Hogan, D.A.; Buckley, D.H.; Nakatsu, C.H.; Schmidt, T.M.; and Hausinger, R.P. (1997) Distribution of the *tfdA* Gene in Soil Bacteria that do not Degrade 2,4-Dichlorophenoxyacetic Acid (2,4-D), *Microbiol. Ecol.*, **34,** 90.
Holden, P.A.; Hunt, J.R.; and Firestone, M.K. (1997) Toluene Diffusion and Reaction in Unsaturated *Pseudomonas putida* Biofilms, *Biotechnol. Bioeng.*, **56,** 656.
Holst, G.; Glud, R.N.; Kuhl, M.; and Klimant, I. (1997) A Microbial Array for Fine-Scale Measurement of Oxygen Distribution, *Sensors Actuators B-Chem.*, **38,** 1, 122.
Horn, H., and Hempel, D.C. (1997a) Growth and Decay in an Auto-Heterotrophic Biofilm, *Water Res.* (G.B.), **31,** 2243.
Horn, H., and Hempel, D.C. (1997b) Substrate Utilization and Mass Transfer in an Autotrophic Biofilm System: Experimental Results and Numerical Simulation, *Biotechnol. Bioeng.*, **53,** 363.
Hosein, S.G.; Millette, D.; Butler, B.; and Greer, C.W. (1997) Catabolic Gene Probe Analysis of an Aquifer Microbial Community Degrading Creosote-Related Polycyclic Aromatic and Heterocyclic Compounds, *Microbiol. Ecol.*, **34,** 2, 81.
Hu, H.-Y.; Fujie, K.; Tanaka, H.; Makabe, T.; and Urano, K. (1997) Respiratory Quinone Profile as a Tool for Refractory Chemical Biodegradation Study, *Water Sci. Technol.* (G.B.), **35,** 8, 103.
Hwang, S.-J., and Tang, H.-M. (1997) Kinetic Behavior of the Toluene Biofiltration Process, *J. Air Waste Manage. Assoc.*, **47,** 664.
Hwang, S.-J.; Tang, H.-M.; and Wang, W.-C. (1997) Modeling of Acetone Biofiltration Process, *Environ. Prog.*, **16,** 187.
Hyvik, H.; Eskilt, J.P.; and Hovland, J. (1997) Method for Removing Hydrogen Sulphide from Oil-Containing Water and Equipment Therefor, *Biotechnol. Adv.*, **15,** 734.
Iranpour, R., and Ludwig, K. (1997) VOCs in Fixed Film Processes. I: Pilot Studies. Discussion, *J. Environ. Eng.*, **123,** 818.
Janssen, A.J.H.; Ma, S.C.; Lens, P.; and Lettings, G. (1997) Performance of a Sulfide-Oxidizing Expanded-Bed Reactor Supplied with Dissolved Oxygen, *Biotechnol. Bioeng.*, **53,** 32.
Janus, H.M., and van der Roest, H.F. (1997) Don't Reject the Idea of Treating Reject Water, *Water Sci. Technol.* (G.B.), **35,** 10, 27.
Jeppsson, U. (1997) Modeling the Dynamics of Wastewater Treatment Processes, *Vatten* (Sweden), **53,** 83.
Jin, G., and Englande, A.J., Jr. (1997) Kinetic Study of Carbon Tetrachloride Biodegradation in a Fixed-Biofilm Reactor, *In Situ On-Site Bioremediation Symposium, 4th,* **3,** 25.
Jirku, V.; Masak, J.; and Cejkova, A. (1997) Cell Attachment and its Physiological Role in Environmental Biotechnology, *Meded.—Fac. Landbouwkd. Toegepaste Biol. Wet.*, **62,** 1793.
Jiye Zhang, L.A.C.; Mitchell, A.; and Brewington, L. (1997) Treatment of a High Ammonia Wastestream Using a Biological Aerated Filter. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.
Johnson, C.H.; Schlegel, M.J.; and Vandenberg, C.D. (1997) Treatment of Recycle Paper Mill Wastewater in Moving Bed Biofilm Reactors, *Environ. Conf. Exhib.*, **2,** 999.
Jones, R.; Sen, D.; and Lambert, R. (1997a) Evaluation of Nitrification under Dynamic Loading Conditions in an Integrated Fixed Film Activated Sludge Process with Cord Media. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.
Jones, W.; Mirpuri, R.; Villaverde, S.; Lewandowski, Z.; and Cunningham, A. (1997b) Effect of Bacterial Injury on Toluene Degradation and Respiration Rates in Vapor Phase Bioreactors, *Water Sci. Technol.* (G.B.), **36,** (1) 85.
Kaballo, H.-P. (1997) Shock Loading Management with the Sequencing Batch Film Bioreactor Technology, *Water Sci. Technol.* (G.B.), **35,** 1, 35.
Kahmark, K.A., and Unwin, J.P. (1997) Pulp and Paper Effluent Management, *Water Environ. Res.*, **69,** 641.
Kalmbach, S.; Manz, W.; and Szewzyk, U. (1997a) Dynamics of Biofilm Formation in Drinking Water—Phylogenetic Affiliation and Metabolic Potential of Single Cells Assessed by Fomazan Reduction and In Situ Hybridization, *Fems Microbiol. Ecol.*, **22,** 265.
Kalmbach, S.; Manz, W.; and Szewzyk, U. (1997b) Isolation of New Bacterial Species from Drinking Water Biofilms and Proof of Their In Situ Dominance with Highly Specific 16S rRNA Probes, *Appl. Environ. Microbiol.*, **63,** 4164.
Kao, C., and Borden, R. (1997) Enhanced TEX Biodegradation in Nutrient Briquet-Peat Barrier System, *J. Environ. Eng.*, **123,** 18.
Kargi, F., and Uygur, A. (1997) Biological Treatment of Saline Wastewater in a Rotating Biodisc Contactor by Using Halophilic Organisms, *Bioprocess. Eng.*, **17,** 81.
Kelley, J.I.; Turng, B.F.; Williams, H.N.; and Baar, M.L. (1997) Effects of Temperature, Salinity, and Substrate on the Colonization of

Surfaces In Situ by Aquatic Bdellovibrios, *Appl. Environ. Microbiol.*, **63**, 84.

Kim, S., and Corapcioglu, Y. (1997) Role of Biofilm Growth in Bacteria-Facilitated Contaminant Transport in Porous Media, *Transport Porous Media*, **26**, 161.

Klimant, I.; Kuhl, M.; Glud, R.N.; and Holst, G. (1997) Optical Measurement of Oxygen and Temperature in Microscale-Strategies and Biological Applications, *Sensors Actuators B-Chem.*, **38**, 1, 29.

Koch, G., and Siegrist, H. (1997a) Denitrification with Methanol in Tertiary Filtration, *Water Res.* (G.B.), **31**, 3029.

Koch, G., and Siegrist, H. (1997b) Denitrification with Methanol in Tertiary Filtration at Wastewater Treatment Plant Zurich-Werdholzli, *Water Sci. Technol.* (G.B.), **36**, 1, 165.

Kopf, G.; Headley, J.V.; Peru, K.M.; Johnson, R.C.; Soni, M.H.; and Cooks, R.G. (1997) Comparison of Tandem Mass Spectrometric Techniques Using Ion-Trap and Hybrid Mass Spectrometers for Studies of the Degradation of a Herbicide by Biofilm, *Rapid Commun. Mass Spectrom,* **11**, 24.

Kostyal, E.; Nurmiaho-Lassila, E.-L.; Puhakka, J.A.; and Salkinoja-Salonen, M. (1997) Nitrification, Dentrification, and Dechlorination in Bleached Kraft Pulp Mill Wastewater, *Appl. Microbiol. Biotechnol.*, **47**, 731.

Koyoama, T.; Kataoka, K.; and Imamura, Y. (1997) Chiyoda Biofiner for Enhancement of Wastewater Treatment Capacity—a Measure for Enhancement of Nitrogen Removal and a Measure for Enhancement for Treatment Capacity, *Sangyo to Kankyo* **26**, 73.

Labare, M.L.; Coon, S.L.; Matthias, C.; and Weiner, R.M. (1997) Magnification of Tributyl Tin Toxicity to Oyster Larvae by Bioconcentration in Biofilms of *Shewanella Colwelliana, Appl. Environ. Microbiol.*, **63**, 4107.

Lai, B., and Shieh, W.K. (1997) Substrate Inhibition Kinetics in a Fluidized Bioparticle, *Chem. Eng. J.* (Lausanne), **65**, 117.

Lang, E.; Eler, G.; and Zadrazil, F. (1997) Lignocellulose Decomposition and Porduction of Ligninolytic Enzymes During Interaction of Whie Rot Fungi with Soil Microorganisms, *Microbiol. Ecol.*, **34**, 1.

Lapaglia, C., and Hartzell, P.L. (1997) Stress-Induced Production of Biofilm in the Hyperthermophile Archaeoglobus, *Appl. Environ. Microbiol.*, **63**, 3158.

Laugero, C.; Mougin, C.; Sigoillot, J.-C.; Moukha, S.; and Asther, M. (1997) Comparison of Static and Agitated Immobilized Cultures of *Phanerochaete chrysosporium* for the Degredation of Pentachlorophenol and Its Metebolite Pentachloroanisole, *Can. J. Microbiol.*, **43**, 378.

Lazarova, V.; Nogueira, R.; Manem, J.; and Melo, L. (1997) Control of Nitrification Efficiency in a New Biofilm Reactor, *Water Sci. Technol.* (G.B.), **36**, 1, 31.

Lebeau, T.; Jouenne, T.; and Junter, G.A. (1997) Simultaneous Fermentation of Glucose and Xylose by Pure and Mixed Cultures of *Saccharomyces cerevisiae* and *Candida shehatae* immobilized in a Two-Chambered Bioreactor, *Enzyme Microbiol. Technol.*, **21**, 265.

Lee, C.-Y. (1997) Suspended-Growth Nitrification Bioaugmented by Detached Nitrifiers in Combined Processes, *Zhongguo Huanjing Gongcheng Xuekan,* **7**, 1, 35.

Lefebvre, J., and Vincent, J.-C. (1997) Control of the Biomass Heterogeneity in Immobilized Cell Systems. Influence of Initial Cell and Substrate Concentrations, Structure, Thickness, and Type of Bioreactors, *Enzyme Microbiol. Technol.*, **20**, 536.

Lemmer, H.; Zaglauer, A.; and Metzner, G. (1997a) Denitrification in a Methanol-Fed. Fixed-Bed Reactor. Part 1: Physico-Chemical and Biological Characterization, *Water Res.* (G.B.), **31**, 1897.

Lemmer, H.; Zaglauer, A.; Neef, A.; Meir, H.; and Amann, R. (1997b) Denitrification in a Methanol-Fed. Fixed-Bed Reactor. Part 2: Composition and Ecology of the Bacterial Community in the Biofilms, *Water Res.* (G.B.), **31**, 1903.

Leppard, G.G. (1997) Colloidal Organic Fibrils of Acid Polysaccharides in Surface Waters: Electron-optical Characteristics, Activities and Chemical Estimates of Abundance, *Colloids Surf.*, **120**, 1.

Leson, G., and Smith, B.J. (1997) Petroleum Environmental Research Forum Field Study on Biofilters for Control of Volatile Hydrocarbons, *J. Environ. Eng.*, **123**, 556.

Le Tallec, X.; Zeghal, S.; Videl, A.; and Lesouef, A. (1997) Effect of Influent Quality Variability on Biofilter Operation, *Water Sci. Technol.* (G.B.), **36**, 1, 111.

Libman, V.; Eliosov, B.; and Argaman, Y. (1997) Feasibility Study of Complete Nitrogen Removal from Municipal Wastewater by Consequent Nitfrification--Denitrification. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition*, Chicago, Ill.

Lundsdorf, H.; Brummer, I.; Timmis, K.N.; and Wagnerdobler, I. (1997) Metal Selectivity of an In Situ Microcolonies in Biofilms of the Elbe River, *J. Bacteriol.*, **179**, 31.

Macaskie, L.E. (1997) Bioaccumulation of Heavy Metals, and Application to the Remediation of Acid Mine Drainage Water Containing Uranium, *Res. Microbiol.*, **148**, 528.

Macdonald, G.J.; Steven, B.; Freeman, T.J.; Archer, H.E.; and Steven, B. (1997) Air Discharge Permitting And Odour Control For New Zealand Wastewater Plants. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

Marchesi, J.; Graham, F.W.; Nicholas, J.R.; and House, W.A. (1997) Effect of River Sediment on the Biodegradation Kinetics of Surfactant and Non-Surfactant Compounds, *Microbiol. Ecol.*, **23**, 55.

Martin, R.J.; Surampalli, R.Y.; and Berge, D. (1997) Improving the Performance of Rotating Biological Contactors by Recirculating Secondary Clarifier Solids—A Case Study. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

Martins dos Santos, V.A.P.; Leenen, E.J.T.M.; Rippoll, M.M.; van der Sluis, C.; van Vliet, T.; Tramper, J.; and Wijffels, R.H. (1997) Relevance of Rheological Properties of Gel Beads for their Mechanical Stability in Bioreactors, *Biotechnol. Bioeng.*, **56**, 517.

Masak, J.; Cejkova, A.; and Jirku, V. (1997) Isolation of Acetone/Ethylene Glycol Utilizing and Biofilm Forming Strains of Bacteria, *J. Microbiol. Meth.*, **30**, 133.

Massol-Deya, A.; Weller, R.; Rios-Hernandez, L.; Zhou, J.Z.; Hickey, R.F.; and Tiedje, J.M. (1997) Succession and Convergence of Biofilm Communities in Fixed-Film Reactors Treating Aromatic Hydrocarbons in Groundwater, *Appl. Environ. Microbiol.*, **63**, 270.

Mathys, R.G.; Branion, R.M.R.; Lo, K.V.; Anderson, K.B.; Leyen, P.; and Louie, D. (1997) CTMP Wastewater Treatment Using a Rotating Biological Contactor, *Water Qual. Res. J. Can.*, **32**, 771.

Matsumura, M.; Yamamoto, T.; Wang, P.-C.; Shinabe, K.; and Yasuda, K. (1997) Rapid Nitrification with Immobilized Cell Using Macro-Porous Cellulose Carrier, *Water Res.* (G.B.), **31**, 1027.

McLean, R.J.C.; Whiteley, M.; Stickler, D.J.; and Fuqua, W.C. (1997) Evidence of Autoinducer Activity in Naturally Occuring Biofilms, *FEMS Microbiol. Lett.*, **154**, 259.

M'Coy, W. (1997) Biological Aerated Filters: A New Alternative. *Water Environ. Technol.*, **9**, 2, 39.

Michalakos, G.D.; Nieva, J.M.; Vayenas, D.V.; and Lyberatos, G. (1997) Removal of Iron from Potable Water Using a Trickling Filter, *Water Res.* (G.B.), **31**, 991.

Mirpuri, R.; Jones, W.; and Bryers, J.D. (1997a) Toluene Degrading Kinetics for Planktonic and Biofilm-Grown Cells of *Pseudomonas putida* 54G, *Biotechnol. Bioeng.*, **53**, 535.

Mirpuri, R.; Sharp, W.; Villaverde, S.; Jones, W.; Lewandowski, Z.; and Cunningham, A. (1997b) Predictive Model for Toluene Degradation and Microbial Phenotypic Profiles in Flat Plate Vapor Phase Bioreactor, *J. Environ. Eng.*, **123**, 586.

Moebius, C.H., and Cordes–Tolle, M. (1997) Enhanced Biodegradability by Oxidative and Radiative Wastewater Treatment, *Water Sci. Technol.* (G.B.), **35**, 2, 245.

Moller, S.; Korber, D.R.; Wolffaardt, G.M.; Molin, S.; and Caldwell, D.E. (1997) Impact of Nutrient Composition on a Degredative Biofilm Communtiy, *Appl. Environ. Microbiol.*, **63**, 2432.

Morin, P., and Camper, A.K. (1997) Attachment and Fate of Carbon Fines in Simulated Drinking Water Distribution System Biofilms, *Water Res.* (G.B.), **31**, 399.

Morris, C.E.; Monier, J.M.; and Jacques, M.A. (1997) Methods for Observing Microbial Biofilms Directly on Leaf Surfaces and Recovering Them for Isolation of Culturable Microorganisms, *Appl. Environ. Microbiol.*, **63**, 1570.

Muttamara, S., and Puetpaiboon, U. (1997) Roles of Baffles in Waste Stabilization Ponds, *Water Sci. Technol.* (G.B.), **35**, 8, 275.

Nagaoka, H. (1997) Mass Transfer Mechanism in Biofilms Under Oscillatory Flow Conditions, *Water Sci. Technol.* (G.B.), **36**, 1, 329.

Nagarkar, S., and Williams, G.A. (1997) Comparative Techniques to Quantify Cyanobacteria Dominated Epilithic Biofilms on Tropical Rocky Shores, *Mar. Ecol.-Prog. Ser.*, **154**, 281.

Nemanti, M., and Webb, C. (1997) Does Immobilization of *Thiobacillus ferrooxidans* Really Decrease the Effect of Temperature on its Activity? *Biotechnol. Lett.*, **19**, 39.

Neu, T.R., and Lawrence, J.R. (1997) Development and Structure of Microbial Biofilms in River Water Studied by Confocal Laser Scanning Microscopy, *Microbiol. Ecol.*, **24**, 11.

Nguyen, H.D.; Sato, C.; Wu, J.; and Douglass, R.W. (1997) Modeling Biofiltration of Gas Streams Containing TEX Components, *J. Environ. Eng.*, **123**, 615.

Nicolella, C.; Chiarle, S.; Di Felice, R.; and Rovatti, M. (1997a) Mechanisms of Biofilm Detachment in Fluidized Bed Reactors, *Water Sci. Technol.* (G.B.), **36**, 1, 229.

Nicolella, C.; Di Felice, R.; and Rovatti, M. (1997b) Biomass Concentration in Fluidized Bed Biological Reactors, *Water Res.* (G.B.), **31**, 936.

Nielsen, P.H.; Jahn, A.; and Palmgren, R. (1997) Conceptual Model for Production and Composition of Exopolymers in Biofilms, *Water Sci. Technol.* (G.B.), **36**, 1, 11.

Nishijima, W.; Akama, T.; Shoto, E.; and Okada, M. (1997) Effects of Adsorbed Substances on BiOactivity of Attached Bacteria on Granular Activated Carbon, *Water Sci. Technol.* (G.B.), **35**, 8, 203.

Nitisoravut, S.; Wu, J.; Reasoner, D.; and Chao, A. (1997) Columnar Biological Treatability of AOC Under Oligotrophic Conditions, *J. Environ. Eng.*, **123**, 290.

Oesterholt, F.I.H.M.; Pluim, M.P.; and De Vries, P.W. (1997) Groundwater Treatment at the Former Gas Works Remediation Site "Griftpark" in Utrecht, the Netherlands. Results of the Semi-Permanent Testing Facility, *Water Sci. Technol.* (G.B.), **35**, 10, 165.

Oh, Y.-S., and Bartha, R. (1997) Removal of Nitrobenzene Vapors by a Trickling Air Biofilter, *J. Ind. Microbiol. Biotechnol.*, **18**, 293.

Ojha, C.S.P., and Shrivastava, R. (1997) Identification of Linearity in the Biofilm Process and its Operational Utility, *Biotechnol. Bioeng.*, **53**, 253.

Okabe, S.; Yasuda, T.; and Watanbe, Y. (1997) Uptake and Release of Inert Fluorescence Particles by Mixed Population Biofilms, *Biotechnol. Bioeng.*, **53**, 459.

Origgi, G.; Colombo, M.; Palma, F.D.; Rivolta, M.; Rossi, P.; and Andreoni, V. (1997) Bioventing of Hydrocarbon-Contaminated Soil and Biofiltration of the Off-Gas: Results of a Field Scale Investigation, *J. Environ. Sci. Health*, **A32**, 2289.

Otterpohl, R.; Grottker, M.; and Lange, J. (1997) Sustainable Water and Waste Management in Urban Areas, *Water Sci. Technol.* (G.B.), **35**, 9, 121.

Pack, H., and Hempel, D.C. (1997) Effect of Mixtures of Heavy Metals on the Biological Treatment of Sewages Containing Naphthalenesulfonic Acid, *Acta Hydrochim. Hydrobiol.* (Ger.), **25**, 6, 306.

Palsdottir, G., and Bishop, P. (1997) Nitrifying Biotower Upsets Due to Snails and Their Control, *Water Sci. Technol.* (G.B.), **36**, 1, 247.

Parker, D.; Jacobs, T.; Bower, E.; Stowe, D.; and Farmer, G. (1997) Maximizing Trickling Filter Nitrification Rates through Biofilm Control: Research Review and Full-Scale Application, *Water Sci. Technol.* (G.B.), **36**, 1, 255.

Pastorelli, G.; Andreottola, G.; Canziani, R.; Darriulta, C.; de Fraja Frangipane, E., and Rozzi, A. (1997a) Organic Carbon and Nitrogen Removal in Moving-Bed Biofilm Reactors, *Water Sci. Technol.* (G.B.), **35**, 6, 91.

Pastorelli, G.; Andreottola, G.; Canziani, R.; de Fraja Frangipane, E.; De Pascalis, F.; Gurrieri, G.; and Rozzi, A. (1997b) Pilot-Plant Experiments with Moving-Bed Biofilm Reactors, *Water Sci. Technol.* (G.B.), **36**, 1, 43.

Paulsen, J.E.; Oppen, E.; and Bakke, R. (1997) Biofilm Morphology in Porous Media, a Study with Microscopic and Image Techniques, *Water Sci. Technol.* (G.B.), **36**, 1, 1.

Pavasant, P.; Pistikoulus, E.N.; and Livingston, A.G. (1997) Prediction of Axial Concentration Profiles in an Extractive Membrane Bioreactor and Experimental Verification, *J. Membrane Sci.*, **130**, 85.

Pedersen, A.R., and Arvin, E. (1997a) Effect of Biofilm Growth on the Gas-Liquid Mass Transfer in a Trickling Filter for Waste Gas Treatment, *Water Res.* (G.B.), **31**, 1963.

Pedersen, A.R., and Arvin, E. (1997b) Toluene Removal in a Biofilm Reactor for Waste Gas Treatment, *Water Sci. Technol.* (G.B.), **36**, 1, 69.

Pedersen, A.R.; Moller, S.; Molin, S.; and Arvin, E. (1997) Activity of Toluene-Degrading *Pseudomonas putida* in the Early Growth Phase of a Biofilm for Waste Gas Treatment, *Biotechnol. Bioeng.*, **54**, 131.

Peys, K.; Diels, L.; Leysen, R.; and Vandecasteele, C. (1997) Development of a Membrane Biofilm Reactor for the Degradation of Chlorinated Aromatics, *Water Sci. Technol.* (G.B.), **36**, 1, 205.

Picioreanu, C.; van Loosdrecht, M.; and Heijnen, J. (1997) Modeling the Effect of Oxygen Concentration on Nitrite Accumulation in a Biofilm Airlift Suspension Reactor, *Water Sci. Technol.* (G.B.), **36**, 1, 147.

Radwan, K.H., and Ramanujam, T.K. (1997a) Influence of COD/NH3-N Ratio on Organic Removal and Nitrification Using a Modified RBC, *Bioprocess. Eng.*, **16**, 77.

Radwan, K.H., and Ramanujam, T.K. (1997b) Studies on Organic Removal of 2,4-Dichlorophenol Wastewaters Using a Modified RBC, *Bioprocess. Eng.*, **16**, 219.

Rajan, R.V.; Seybold, A.S.L.; Hickey, R.F.; and Hayes, T. (1997) MGP Groundwater Treatment with High Rate Fixed-film Biological Systems, *In Situ On-Site Bioremediation Symposium, 4th*, **3**, 451.

Randall, A.; Sullivan, J.; Dietz, J.; and Randall, C. (1997) Industrial Pretreatment: Trickling Filter Performance and Design, *J. Environ. Eng.*, **123**, 1072.

Rao, T.S.; Kesavamoorthy, R.; and Rao, C.B. (1997) Influence of Flow on Ordering Characteristics of a Bacterial Biofilm, *Curr. Sci.* (India), **73**, 1, 69.

Rauch, W., and Vanrolleghem, P. (1997) A Simple Dynamic Multispecies Biofilm Model Which Considers Diffusion and Degradation of Multiple Substrates, *Meded.—Fac. Landbouwkd. Toegepaste Biol. Wet.*, **62**, 1649.

Raunkjaar, K.; Nielsen, P.H.; and Hvitvedjacobsen, T. (1997) Acetone Removal in Sewer Biofilms under Aerobic Conditions, *Water Res.* (G.B.), **31**, 2727.

Ravindran, V.; Kim, S.; Badriyha, B.; and Pirbazari, M. (1997) Predictive Modeling for Bioactive Fluidized Bed and Stationary Bed Reactors: Application to Dairy Wastewater, *Environ. Technol.*, **18**, 861.

Reichert, P., and Wanner, O. (1997) Movement of Solids in Biofilms: Significance of Liquid Phase Transport, *Water Sci. Technol.* (G.B.), **36**, 1, 321.

Reij, M.J.; Hamann, E.K.; and Hartmans, S. (1997) Biofiltration of Air Containing Low Concentrations of Propene Using a Membrane Bioreactor, *Biotechnol. Prog.*, **13**, 380.

Reynolds, S.L.; Kalluri, R.; and Schultz, T.E. (1997) Down Under. Submerged System Provides Better Biological Treatment, *Ind. Wastewater*, **5**, 5, 43.

Rihn, M.J.; Zhu, X.; Suidan, M.T.; Kim, B.J.; and Kim, B.R. (1997) The Effect of Nitrate on VOC Removal in Trickle-Bed Biofilters, *Water Res.* (G.B.), **31**, 2997.

Ro, K.S.; Babcock, R.W.; and Stenstrom, M.K. (1997) Demonstration of Bioaugmentation in a Fluidized-Bed Process Treating 1-Naphthylamine, *Water Res.* (G.B.), **31**, 1687.

Roessink, R., and Eikelboom, D. (1997) Characterization of Suspended

Solids In/Out Airlift Biofilm-Reactors, *Water Sci. Technol.* (G.B.), **36,** 1, 237.

Romani, A.M., and Sabater, S. (1997) Metabolism Recovery of a Stromatolitic Biofilm after Drought in a mediterranean Stream, *Arch. Hydrobiol.*, **140,** 261.

Ross, N.; Deschenger, L.; and Clement, B. (1997) Physico-chemical Optimization of Biofilm Development in Fractured Rock Aquifer Conditions, *In Situ On-Site Bioremediation Symposium, 4th,* **4,** 227.

Rothfuss, F.; Bender, M.; and Conrad, R. (1997) Survival and Activity of Bacteria in a Deep, Aged Lake Sediment (Lake Constance), *Microbiol. Ecol.*, **33,** 69.

Rusten, B.; Kolkinn, O.; and Odegaard, H. (1997) Moving Bed Biofilm Reactors and Chemical Precipitation for High Efficiency Treatment of Wastewater from Small Communities, *Water Sci. Technol.* (G.B.), **35,** 6, 71.

Sack, U., and Fritsche, W. (1997) Enhancement of Pyrene Mineralization in Soil by Wood-Decaying Fungi, *Microbiol. Ecol.*, **22,** 1, 77.

Safferman, S.I., and Bishop, P.L. (1997) Operating Strategies for Aerobic Fluidized Bed Reactors, *J. Haz. Mater.*, **54,** 241.

Saha, M.L., and Takahashi, F. (1997) Continuous Citric Acid Fermentation by Magnetic Rotating Biological Contactors Using *Aspergillus niger, J. Ferment. Bioeng.*, **84,** 244.

Sakakibara, Y.; Araki, K.; Watanabe, T.; and Kuroda, M. (1997) Denitrification and Neutralization Performance of an Electrochemically Activated Biofilm Reactor Used to Treat Nitrate-Contaminated Groundwater, *Water Sci. Technol.* (G.B.), **36,** 1, 61.

Sakurai, A.; Imai, H.; Takenaka, Y.; and Sakakibara, M. (1997) Simulation of Citric Acid Production by Rotating Disk Contactor, *Biotechnol. Bioeng.*, **56,** 689.

Schorer, M., and Eisele, M. (1997) Accumulation of Inorganic and Organic Pollutants by Biofilms in the Aquatic Environment, *Water Air Soil Pollut.*, **99,** 1, 651.

Schramm, A.; Larsen, L.; Revsbech, N.; and Amann, R. (1997) Structure and Function of a Nitrifying Biofilm as Determined by Microelectrodes and Fluorescent Oligonucleotide Probes, *Water Sci. Technol.* (G.B.), **36,** 1, 263.

Schugerl, K. (1997) Three-Phase-Biofluidization—Application of Three-Phase Fluidization in the Biotechnology—A Review, *Chem. Eng. Sci.*, 3661.

Segar, R.L., Jr.; Kalia, P.; and Dvorak, B.I. (1997) Simulation of Sequencing Batch and Biofilm Reactors for Trichloroethene (TCE) Cometabolism, *Int. In Situ On-Site Biorem. Symp., 4th.*

Selivanovskaya, S.Y.; Petrov, A.M.; Egorova, K.V.; and Naumova, R.P. (1997) Protozoan and Metazoan Communities Treating a Simulated Petrochemical Industry Wastewater in a Rotating Disc Biological Reactor, *World J. Microbiol. Biotechnol.*, **13,** 511.

Selvaraj, P.; Little, M.; and Kaufman, E. (1997) Biodesulfurization of Flue Gases and Other Sulfate/Sulfite Waste Streams Using Immobilized Mixed Sulfate-Reducing Bacteria, *Biotechnol. Prog.*, **13,** 583.

Shimomura, T.; Suda, F.; Uchiyama, H.; and Yagi, O. (1997) Biodegradation of Trichloroethylene by *Methylocystis* sp. strain M Immobilized in Gel Beads in a Fluidized-Bed Bioreactor, *Water Res.* (G.B.), **31,** 2383.

Sich, H., and Rijn, J.V. (1997) Scanning Electron Microscopy of Biofilm Formation in Denitrifying, Fluidized Bed Reactors, *Water Res.* (G.B.), **31,** 733.

Sorial, G.; Smith, F.; Suidan, M.; Pandit, A.; Biswas, P.; and Brenner, R. (1997) Evaluation of Trickle Bed Air Biofilter Performance for BTEX Removal, *J. Environ. Eng.*, **123,** 530.

Sousa, M.; Azeredo, J.; Feijo, J.; and Oliveira, R. (1997) Polymeric Supports for the Adhesion of a Consortium of Autotrophic Nitrifying Bacteria, *Biotechnol. Technol.*, **11,** 10, 751.

Stams, A.J.M., and Oude Elferink, S.J.W.H. (1997) Understanding and Advancing Wastewater Treatment, *Curr. Opin. Biotechnol.*, **8,** 328.

Stern, M.; Heinzle, E.; Kut, O.M.; and Hungerbuehler, K. (1997) Removal of Substituted Pyridines by Combined Ozonation/Fluidized Bed Biofilm, *Water Sci. Technol.* (G.B.), **35,** 4, 329.

Steward, C.C., and Lovell, C.R. (1997) Respiration and Assimilation of 4-Bromophenol by Estuarine Sediment Bacteria, *Microbiol. Ecol.*, **33,** 198.

Stewart, P.S.; Camper, A.K.; Handran, S.D.; and Huang, C.T. (1997) Spatial Distribution and Coexistence of *Klebsiella pneumonie* and *Pseudomonas aeruginosa* in Biofilms, *Microbial Ecol.*, **33,** 2.

Stoodley, P.; de Beer, D.; and Lappinscott, H.M. (1997a) Influence of Electric Fields and PH on Biofilm Structure as Related to the Bioelectric Effect, *Antimicrob. Agents Chemotherapy,* **41,** 1876.

Stoodley, P.; Yang, S.N.; Lappinscott, H.; and Lewandowski, Z. (1997b) Relationship between Mass Transfer Coefficient and Liquid Folw Velocity in Heterogenous Biofilming Using Microelectrodes and Cofocal Microscopy, *Biotechnol. Bioeng.*, **56,** 681.

Su, J.-L., and Ouyang, C.-F. (1997) Advanced Biological Enhanced Nutrient Removal Processes by the addition of Rotating Biological Contactors, *Water Sci. Technol.* (G.B.), **35,** 8, 153.

Sun, A.K., and Wood, T.K. (1997) Trichloroethylene Mineralization in a Fixed-Film Bioreactor Using a Pure Culture Expressing Constitutively Toluene ortho-Monooxygenase, *Biotechnol. Bioeng.*, **55,** 674.

Surampalli, R.Y., and Baumann, E.R. (1997) Role of Supplemental Aeration in Improving Overloaded First-Stage RBC Performance, *Water Air Soil Pollut.*, **98,** 1, 1.

Sutton, P.M.; Hurvid, J.; and Hoeksema, M. (1997) Biological Fluidized Bed Treatment of Wastewater From Byproduct Coking Operations: Full Scale Case History. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

Swanson, W.J., and Loehr, R. (1997) Biofiltration: Fundamentals, Design and Operations Principles, and Applications, *J. Environ. Eng.*, **123,** 538.

Takai, T.; Hirata, A.; Yamauchi, K.; and Inamori, Y. (1997) Effects of Temperature and Volatile Fatty Acids on Nitrification-Denitrification Activity in Small-Scale Anaerobic-Aerobic Recirculation Biofilm Process, *Water Sci. Technol.* (G.B.), **35,** 6, 101.

Tan, T.C., and Qian, Z. (1997) Dead Bacillus Subtilis Cells for Sensing Biochemical Oxygen Demand of Waters and Wastewaters, *Sens. Actuators,* **B40,** 1, 65.

Tang, H., and Hwang, S. (1997) Transient Behavior of the Biofilters for Toluene Removal, *J. Air Waste Manage. Assoc.*, **47,** 1142.

Tanyolic, A., and Beyenal, H. (1997) Prediction of Average Biofilm Density and Performance of a Spherical Bioparticle under Substrate Inhibition, *Biotechnol. Bioeng.*, **56,** 319.

Tarallo, S.; Ballard, P.T.; Pujol, R.; and Bucher, H.M. (1997) Upgrading Wastewater Treatment Plants for Nitrification Using a Two-Stage Upflow Biofiltration Process. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

Taylor, D.G.; Breen, A.; and Bishop, P.L. (1997) Determination of Phenol-Degrader Distribution in Biofilms Using Gene Probes, *Water Res.* (G.B.), **31,** 119.

Terayama, Y.; Nishimura, T.; Isono, M.; and Hosoya, M. (1997) Feasibility Study on Nitrogen Removal Process by Biological Aerated Filter. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

van Benthum, W.; van Loosdrecht, M.; and Heijnen, J. (1997a) Control of Heterotrophic Layer Formation n Nitrifying Biofilms in a Biofilm Airlift Suspension Reactor, *Biotechnol. Bioeng.*, **53,** 397.

van Benthum, W.; van Loosdrecht, M.; and Heijnen, J. (1997b) Process Design for Nitrogen Removal Using Nitrifying Biofilm and Denitrifying Suspended Growth in a Biofilm Airlift Suspension Reactor, *Water Sci. Technol.* (G.B.), **36,** 1, 119.

van Lith, C.; Leson, G.; and Michelsen, R. (1997) Evaluating Design Options for Biofilters, *J. Air Waste Manage. Assoc.*, **47,** 37.

van Loosdrecht, M.C.M.; Picioreanu, C.; and Heijnen, J.J. (1997) A More Unifying Hypothesis for Biofilm Structures, *FEMS Microbiol. Ecol.*, **24,** 181.

Van Roy, S.; Peys, K.; Dresselaers, T.; and Diels, L. (1997) The Use of an *Alcaligenes eutrophus* Biofilm in a Membrane Bioreactor for Heavy Metal Recovery, *Res. Microbiol.*, **148,** 526.

Vayenas, D.V.; Pavlou, S.; and Lyberatos, G. (1997) Development of

a Dynamic Model Describing Nitrification and Nitratification in Trickling Filters, *Water Res.* (G.B.), **31,** 1135.

Venkataraman, R.; Ramanujam, T.K.; and Jagannath, S. (1997) Identification of Micro Organisms in the Biological Slime Layer of Rotating Biological Contactors, *Bioprocess. Eng.,* **17,** 323.

Villaverde, S., and Fernandez, M.T. (1997) Non-Toluene-Associated Respiration in a *Pseudodomonas putida* 54G Biofilm Grown on Toluene in a Flat-Plate Vapor Phase Bioreactor, *Appl. Microbiol. Biotechnol.,* **48,** 357.

Villaverde, S.; Fernandez, M.T.; Urena, M.T.; and Fdz-Polanco, F. (1997a) Influence of Substrate Concentration on the Growth and Activity of Nitrifying Biofilm in a Submerged Biofilter, *Environ. Technol.,* **18,** 921.

Villaverde, S.; Garcia-Encina, P.A.; and Fdz-Polanco, F. (1997b) Influence of pH Over Nitrifying Biofilm Activity in Submerged Biofilters, *Water Res.* (G.B.), **31,** 1180.

Villaverde, S.; Mirpuri, R.; Lewandowski, Z.; and Jones, W.L. (1997c) Study of Toluene Degradation Kinetics in a Flat Plate Vapor Phase Bioreactor Using Oxygen Microsensors, *Water Sci. Technol.* (G.B.), **36,** 1, 77.

Villaverde, S.; Mirpuri, R.G.; Lewandowski, Z.; and Jones, W. (1997d) Physiological and Chemical Gradients in a *Pseudomonas putida* 54G Biofilm Degrading Toluene in a Flat Plate Vapor Phase Bioreactor, *Biotechnol. Bioeng.,* **56,** 361.

Vogelsgang, C.; Husby, A.; and Ostgaardo, K. (1997) Functional Stability of Termperature-Compensated Nitrificatoin in Domestic Wastewater Treatment Obtained with PVA-SBQ/Alginate Gel Entrapment, *Water Res.* (G.B.), **31,** 1659.

Wang, G.T.Y., and Bryers, J.D. (1997) A Dynamic Model for Receptor-Mediated Specific Adhesion of Bacteria under Uniform Shear Flow, *Biofouling,* **11,** 227.

Wani, A.H.; Branion, R.M.R.; and Lau, A.K. (1997) Biofiltration: A Promising and Cost-Effective Control Technology for Odors, VOCs and Air Toxics, *J. Environ. Health,* **32,** 2027.

Watanabe, Y.; Kimura, K.; Okabe, S.; Ozawa, G.; and Ohkuma, N. (1997) Novel Biofilm-Membrane Reactor for Ammonia Oxidation at Low Concentrations, *Water Sci. Technol.* (G.B.), **36,** 1, 51.

Watanabe, Y., and Iwasaki, Y. (1997) Performance of Hybrid Small Wastewater Treatement System Consisting of Jet Mixed Separator and Rotating Biological Contactor, *Water Sci. Technol.* (G.B.), **35,** 6, 63.

Weber-Shirk, M., and Dick, R. (1997) Biological Mechanisms in Slow Sand Filters, *J. Am. Water Works Assoc.,* **89,** 72.

Welander, U.H.; Henrysson, T.; and Welander, T. (1997) Nitrification of Landfill Leachate Using Suspended-Carrier Biofilm Technolgy, *Water Res.* (G.B.), **31,** 2351.

Wetzel, R.G.; Ward, A.K.; and Stock, M. (1997) Effects of Natural Dissolved Organic Matter on Mucilaginous Matrixes of Biofilm Communities, *Arch. Hydrobiol.,* **139,** 289.

Whiteley, M.; Brown, E.; and Mclean, R.J.C. (1997) An Inexpensive Chemostat Apparatus for the Study of Microbial Biofilms, *J. Microbiol. Meth.,* **30,** 125.

Wilk, T. (1997) Modeling Nitrifying Trickling Filters, *Vatten* (Swed.), **53,** 1, 33.

Williams, T.O.; Boyette, R.A.; Bergstedt, L.; Hamel, K.C.; Johnson, S.; and Parrella, A. (1997a) Wastewater Treatment Plant Odor Control Using a Biofiltration System in Duluth, Minnesota. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

Williams, T.O.; Boyette, R.A.; Pomroy, J.; and Berger, D. (1997b) Central Contra Costa Sanitary District Uses Biofiltration to Control Biosolids Thickening Odors. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

Wilson, F. (1997) Total Organic Carbon as a Predictor of Biological Wastewater Treatment Efficiency and Kinetic Reaction Rates, *Water Sci. Technol.* (G.B.), **35,** 8, 119.

Wilson, F., and Lee, W.M. (1997) Rotating Biological Contactors for Wastewater Treatment in an Equatorial Climate, *Water Sci. Technol.* (G.B.), **35,** 8, 177.

Wimpenny, J.W.T., and Colasanti, R. (1997a) A More Unifying Hypothesis for Biofilm Structures—a Reply, *FEMS Microbiol. Ecol.,* **24,** 185.

Wimpenny, J.W.T., and Colasanti, R. (1997b) A Unifying Hypothesis for the Structure of Microbial Biofilms Based on Cellular Automation Models, *FEMS Microbiol. Ecol.,* **22,** 1.

Wintzingerode, F.V.; Gobel, U.B.; and Stackebrandt, E. (1997) Determination of Microbial Diversity in Environmental Samples: Pitfalls of PCR-Based rRNA Analysis, *FEMS Microbiol. Rev.,* **21,** 213.

Woolard, C.R. (1997) Advantages of Periodically Operated Biofilm Reactors for the Treatment of Highly Variable Wastewater, *Water Sci. Technol.* (G.B.), **35,** 1, 199.

Wright, W.F.; Schroeder, E.D.; Chang, D.P.Y.; and Romstad, K. (1997) Performance of a Pilot-Scale Compost Biofilter Treating Gasoline Vapor, *J. Environ. Eng.,* **123,** 547.

Wübker, S.-M.; Laurenzis, A.; Werner, U.; and Friedrich, C. (1997) Controlled Biomass Formation and Kinetics of Toluene Degradation in a Bioscrubber and in a Reactor with a Periodically Moved Trickle-Bed, *Biotechnol. Bioeng.,* **55,** 686.

Xu, Y. (1997) Microbial Characteristics and Performance of Biofilm System, *Shangai Huanjing Kexue,* **16,** 3, 20.

Yang, L. (1997) Investigation of Nitrification by Co-Immobilized Nitrifying Bacteria and Zeolite in a Batchwise Fluidized Bed, *Water Sci. Technol.* (G.B.), **35,** 8, 169.

Yang, P.Y.; Zhang, Z.Q.; and Jeong, B.G. (1997) Simultaneous Removal of Carbon and Nitrogen Using an Entrapped-Mixed-Microbial-Cell Process, *Water Res.* (G.B.), **31,** 2617.

Yu, H., and Rittmann, B.E. (1997) Predicting Bed Expansion and Phase Holdups for Three-Phase Fluidized-Bed Reactors with and without Biofilm, *Water Res.* (G.B.), **31,** 2604.

Zarook, S.M.; Shaikh, A.A.; and Ansar, Z. (1997a) Development, Experimental Validation and Dynamic Analysis of a General Transient Biofilter Model, *Chem. Eng. Sci.,* **52,** 759.

Zarook, S.M.; Shaikh, A.A.; Ansar, Z.; and Baltzis, B.C. (1997b) Biofiltration of Volatile Organic Compound (VOC) Mixtures under Transient Conditions, *Chem. Eng. Sci.,* **52,** 4135.

Zhao, X., and Lan, S. (1997) Research Progress in Fluidized Bed Reactor for Immobilized Microbial Cell, *Huanjing Kexue,* **18,** 1, 83.

Zhao, X.; Doh, K.; Criddle, C.S.; and Voice, T.C. (1997) Accumulation of Metabolic Intermediates During Shock Loads in Biological Fluidized Bed Reactors, *J. Environ. Eng.,* **123,** 1185.

Zhou, Q., and Bishop, P. (1997) Determination of Oxygen Profiles and Diffusivity in Encapsulated Biomass k-Carrageenan Gel Beads, *Water Sci. Technol.* (G.B.), **36,** 1, 271.

Zhu, X.; Suidan, M.T.; Sorial, G.A.; Kim, B.J.; and Kim, B.R. (1997) Role of Phosphorus in Trickle-Bed Biofilters. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

Anaerobic Biofilms

Agarwal, L.K.; Ohashi, Y.; Mochida, E.; Okui, H.; Ueki, Y.; Harada, H.; and Ohashi, A. (1997) Treatment of Raw Sewage in a Temperate Climate Using a UASB Reactor and the Hanging Sponge Cubes Process, *Water Sci. Technol.* (G.B.), **36,** 6, 433.

Andersson, K., and Rosen, M. (1997) Biological Reduction of Hexavalent Chromium in a Leachate from Vargon Alloys, *Vatten* (Swed.), **53,** 3, 245.

Araujo, J.C., and Campos, J.R. (1997) Characterization and Development of Biofilms by Scanning Electron Microscopy and Biomass Quantification. Paper presented at Ano. Reuniões Nacionais Microbiologica Aplicar. Meio Ambiente, Sao Paulo, Braz.

Banik, G.C.; Ellis, T.G.; and Dague, R.R. (1997) Structure and Methanogenic Activity of Granules from an ASBR Treating Dilute Wastewater at Low Temperatures, *Water Sci. Technol.* (G.B.), **36,** 6, 149.

Baumann, U., and Muller, M.T. (1997) Determination of Anaerobic Biodegradability with a Simple Continuous Fixed-Bed Reactor, *Water Res.* (G.B.), **31,** 1513.

Bjornsson, L.; Mattiasson, B.; and Welander, T. (1997) Supports Made

from Recycled Glass as Anaerobic Packed Bed Treatment of High-Strength Wastewaters, *Resour. Environ. Biotechnol.*, **1,** 243.

Brigmon, R.L.; Martin, H.W.; and Aldrich, H.C. (1997) Biofouling of Groundwater Systems by Thiothrix Species, *Curr. Microbiol.,* **35,** 169.

Chaudhry, M.A.S., and Beg, S.A. (1997) Modeling of Simultaneous Methanogenesis and Denitrification in an Upflow Packed-Bed Biofilm Reactor, *J. Chem. Technol. Biotechnol.*, **70,** 267.

Chen, K.; Lin, Y.; and Houng, J. (1997) Performance of a Continuous Stirred Tank Reactor with Immobilized Denitrifiers and Methanogens, *Water Environ. Res.*, **69,** 233.

Chiou, J.H.Y.; Alatriste-Mondragon, F.; Wilkie, J.A.; Hesselmann, R.X.P.; and Stenstrom, M.K. (1997) Anoxic Biological Transformation and Mineralization of RDX. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

Chirwa, E.M.N., and Wang, Y.-T. (1997a) Chromium(VI) Reduction by *Pseudomonas fluorescens* LB300 in Fixed-Film Bioreactor, *J. Environ. Eng.*, **123,** 760.

Chirwa, E.M.N., and Wang, Y.-T. (1997b) Hexavalent Chromium Reduction by Bacillus sp. in a Packed-Bed Bioreactor, *Environ. Sci. Technol.*, **31,** 1446.

Chua, H.; Hu, W.F.; Yu, P.H.F.; and Cheung, M.W.L. (1997) Responses of an Anaerobic Fixed-Film Reactor to Hydraulic Shock Loadings, *Bioresour. Technol.*, **61,** 79.

Daraktchiev, R.; Beschkov, V.; Kolev, M.; and Aleksanddrova, T. (1997) Bioreactor with a Semi-Fixed Packing: Anaerobic Lactose to Lactic Acid Fermentation, *Bioprocess. Eng.*, **13,** 25.

Domenech, P.L., and Flotats, X. (1997) A Simplified Mathematical Model for an Upflow Anaerobic Fixed Film Reactor Under Transient Loading, *Hung. J. Ind. Chem.* (Spain), **25,** 4, 315.

Eisenbeis, M.; Bauer-Kreisel, P.; and Scholz-Muramatsu, H. (1997) Studies on the Dechlorination of Tetrachloroethene to cis-1,2-Dichloroethene by *Dehalospirillum multivorans* in Biofilms, *Water Sci. Technol.* (G.B.), **36,** 1, 191.

Fang, H.H.P., and Chan, O.-C. (1997) Toxicity of Phenol Towards Anaerobic Biogranules, *Water Res.* (G.B.), **31,** 2229.

Friese, K.; Mages, M.; Wendt-Potthoff, K.; Neu, T.R.; and Kramer, J.F. (1997) Determination of Heavy Metals in Biofilms from the River Elbe by Total-Reflection X-Ray Fluorescence Spectrometry, *Spectrochim. Acta Part B-Atomic Spectroscopy,* **52,** 1019.

Frigon, J.-C.; Bisaillon, J.-G.; Paquette, G.; and Beaudet, R. (1997) Anaerobic Treatment of a Municipal Landfill Leachate, *Can. J. Microbiol.*, **43,** 937.

Gisi, D.; Stukci, G.; and Hanselmann, K. (1997) Biodegradation of the Pesticide 4,6-dintro-ortho-cresol by Microorganisms in Batch Cultures and in Fixed-Bed Column Reactors, *Appl. Microbiol. Biotechnol.*, **47,** 441.

Gupta, N.; Gupta, S.K.; and Ramachandran, K.B. (1997) Modelling and Simulation of Anaerobic Stratified Biofilm for Methane Production and Predictions of Multiple Steady States, *Chem. Eng. J.*, **65,** 37.

Guwy, A.J.; Hawkes, F.R.; Hawkes, D.L.; and Rozzi, A.G. (1997) Hydrogen Production in a High Rate Fluidised Bed Anaerobic Digester, *Water Res.* (G.B.), **31,** 1291.

Hirl, P.J., and Irvine, R.L. (1997a) Electron Donor Requirement to Support Sustained PCE Dechlorination in Periodically Operated Bioreactors. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

Hirl, P.J., and Irvine, R.L. (1997b) Reductive Dechlorination of Perchloroethylene Using Anaerobic Sequencing Batch Biofilm Reactors (AnSBBR), *Water Sci. Technol.* (G.B.), **35,** 1, 49.

Holst, T.C.; Truc, A.; and Pujol, R. (1997) Anaerobic Fluidized Beds: Ten Years of Industrial Experience, *Water Sci. Technol.* (G.B.), **36,** 6, 415.

Huang, J.-S., and Jih, C.-G. (1997) Deep-Biofilm Kinetics of Substrate Utilization in Anaerobic Filters, *Water Res.* (G.B.), **31,** 2309.

Janning, K.; Mesterton, K.; and Harreemoes, P. (1997) Hydrolysis and Degradation of Filtrated Organic Particulates in a Biofilm Reactor under Anoxic and Anaerobic Conditions, *Water Sci. Technol.* (G.B.), **36,** 1, 279.

Jianrong, Z.; Jicui, H.; and Xiasheng, G. (1997) The Bacterial Numeration and an Observation of a New Syntrophic Association for Granular Sludge, *Water Sci. Technol.* (G.B.), **36,** 6, 133.

Johansen, S.S.; Arvin, E.; Mosbaek, H.; and Hansen, A.B. (1997) Degradation Pathway of Quinolines in a Biofilm System under Denitrifying Conditions, *Environ. Toxicol. Chem.*, **16,** 1821.

Jones, L.R.; Watson-Craik, I.A.; and Senior, E. (1997) Image Analysis for the Study of the Development of Anaerobic Biofilms on Material Characteristic of Landfilled Refuse, *Water Sci. Technol.* (G.B.), **36,** 6, 485.

Khodadoust, A.P.; Wagner, J.A.; Suidan, M.T.; and Brenner, R.C. (1997) Anaerobic Treatment of PCP in Fluidized-Bed GAC Bioreactors, *Water Res.* (G.B.), **31,** 1776.

Kolmert, A.; Henrysson, T.; Hallberg, R.; and Mattiasson, B. (1997) Optimization of Sulfide Production in an Anaerobic Continuous Biofilm Process with Sulfate-Reducing Bacteria, *Biotechnol. Lett.*, **19,** 971.

Lens, P.; Hulsoff Pol, L.; Lettinga, G.; and van As, H. (1997) Use of 1H NMR Study of Water Transport Processes in Sulfidogenic Granular Sludge, *Water Sci. Technol.* (G.B.), **36,** 6, 157.

Lu, C.; Li, H.-C.; Lee, L.Y.; and Lin, M.-R. (1997a) Effects of Disk Rotational Speed and Submergence on the Performance of an Anaerobic Rotating Biological Contactor, *Environ. Int.*, **23,** 253.

Lu, C.; Lin, M.R.; Li, H.C.; and Lee, L.Y. (1997b) Temperature Effects on the Performance of an Anaerobic Rotating Biological Contactor, *Environ. Technol.*, **18,** 711.

Martienssen, M., and Schöps, R. (1997) Biological Treatment of Leachate from Solid Waste Landfill Sites—Alterations in the Bacterial Community During the Denitrification Process, *Water Res.* (G.B.), **31,** 1164.

Mihopoulos, P.G.; Sayles, G.S.; Suidan, M.T.; Rauch, C.; and Shah, J. (1997) Anaerobic Bioventing of Tetrachloroethylene in the Unsaturated Zone. *Proc. Water Environ. Fed. 70th Annu. Conf. Exposition,* Chicago, Ill.

Natarajan, M.R.; Nye, J.; Wu, W.-M.; Wang, H.; and Jain, M.K. (1997) Reductive Dechlorination of PCB-Contaminated Sediments by Anaerobic Microbial Granules, *Biotechnol. Bioeng.*, **55,** 182.

Nishimura, S., and Yoda, M. (1997) Removal of Hydrogen Sulfide from an Anaerobic Biogas Using a Bio-Scrubber, *Water Sci. Technol.* (G.B.), **36,** 6, 349.

Pereboom, J.H.F. (1997) Strength Characterisation of Microbial Granules, *Water Sci. Technol.* (G.B.), **36,** 6, 141.

Perez, M.; Romero, L.; and Sales, D. (1997a) Performance of Fixed-Film Reactors for Anaerobic Treatment of Wine-Distillery Wastewaters: Effect of the Influent pH Conditions, *Chem. Biochem. Eng. Q.*, **11,** 133.

Perez, M.; Romero, L.I.; Nebot, E.; and Sales, D. (1997b) Colonisation of a Porous Sintered-Glass Support in Anaerobic Thermophillic Bioreactors, *Bioresour. Technol.*, **59,** 2, 177.

Pérez, M.; Romero, L.I.; and Sales, D. (1997) Thermophilic Anaerobic Degradation of Distillery Wastewater in Continuous-Flow Fluidized Bed Bioreactors, *Biotechnol. Prog.*, **13,** 33.

Premier, G.C.; Dinsdale, R.; Guwy, A.J.; Hawkes, F.R.; Hawkes, D.L.; and Wilcox, S.J. (1997) Simple Black Box Models Predicting Potential Control Parameters During Disturbances to a Fluidised Bed Anaerobic Reactor, *Water Sci. Technol.* (G.B.), **36,** 6, 229.

Raihan, S.; Ahmed, N.; Macaskie, L.E.; and Lloyd, J.R. (1997) Immobilisation of Whole Bacterial Cells for Anaerobic Biotransformation, *Appl. Microbiol. Biotechnol.*, **47,** 352.

Schwarz, A.; Mosche, M.; Wittenberg, A.; Jordening, H.-J.; Buchholz, K., and Reuss, M. (1997) Mathematical Modelling and Simulation of an Industrial Scale Fluidized Bed Reactor for Anaerobic Wastewater Treatment—Scale Up Effect on pH-Gradients, *Water Sci. Technol.* (G.B.), **36,** 6, 219.

Sujana, P., and Ramanujam, T.K. (1997) Studies on Sago Wastewater

Treatment Using Anaerobic Rotating Biological Contactor, *Bioprocess. Eng.*, **16,** 163.
Tan, T.C., and Qian, Z. (1997) Dead Bacillus Subtilis Cells for Sensing Biochemical Oxygen Demand of Waters and Wastewaters, *Sens. Actuators,* **B40,** 65.
Tartakovsky, B., and Guiot, S.R. (1997) Modeling and Analysis of Layered Stationary Anaerobic Granular Biofilms, *Biotechnol. Bioeng.*, **54,** 122.
Timur, H., and Özturk, I. (1997) Anaerobic Treatment of Leachate Using Sequencing Batch Reactor and Hybrid Bed Filter, *Water Sci. Technol.* (G.B.), **36,** 6, 501.
Turan, M., and Özturk, I. (1997) Comparative Evaluation of Longitudinal Dispersion of Liquid in Non-Biological and Anaerobic Fixed Film Reactors, *Environ. Technol.*, **18,** 45.
Van den Heuvel, J.; Verschuren, P.; and Ottengraf, S. (1997a) Acceleration of Mass Transfer in Loop Reactors, *Water Sci. Technol.* (G.B.), **36,** 1, 311.
Van den Heuvel, J.C.; Beuling, E.E.; Van Dusschoten, D.; Roosenschoon, O.L.; and Verschuren, P.G. (1997b) Convective Flow in Methanogenic Granules, *Water Sci. Technol.* (G.B.), **36,** 6, 311.
van Houten, R.T.; Yun, S.Y.; and Lettinga, G. (1997) Thermophilic Sulphate and Sulphite Reduction in Lab-Scale Gas-Lift Reactors Using H_2 and CO_2 as Energy and Carbon Source, *Biotechnol. Bioeng.*, **55,** 807.
Van Lier, J.B.; Rebac, S.; Lens, P.; Van Bijen, F.; Oude Elferink, S.J.W.H.; Stams, A.J.M.; and Lettinga, G. (1997) Anaerobic Treatment of a Partly Acidified Wastewater in a Two-Stage Expanded Granular Sludge Bed (EGSB) System at 8°C, *Water Sci. Technol.* (G.B.), **36,** 6, 317.
Wilson, G.J.; Khoudadoust, A.P.; Suidan, M.T.; and Brenner, R.C. (1997) Anaerobic/Aerobic Biodegradation of Pentachlorophenol Using GAC Fluidized Bed Reactors—Optimization of the Empty Bed Contact Time, *Water Sci. Technol.* (G.B.), **36,** 6, 107.
Yeh, A.C.; Lu, C.; and Lin, M.-R. (1997) Performance of an Anaerobic Rotating Biological Contractor: Effects of Flow Rate and Influent Organic Strength, *Water Res.* (G.B.), **31,** 1251.
Yeoh, B.G. (1997) Two-Phase Anaerobic Treatment of Cane-Molasses Alcohol Stillage, *Water Sci. Technol.* (G.B.), **36,** 6, 441.
Yoda, M., and Nishimura, S. (1997) Controlling Granular Sludge Flotation in UASB Reactors, *Water Sci. Technol.* (G.B.), **36,** 6, 165.
Zaiat, M.; Vieira, L.G.T.; and Foresti, E. (1997) Spatial and Temporal Variations of Monitoring Performance Parameters in Horizontal-Flow Anaerobic Immobilized Sludge (HAIS) Reactor Treating Synthetic Substrate, *Water Res.* (G.B.), **31,** 1760.
Zellner, G.; Macario, A.J.L.; and de Macario, E.C. (1997) A study of Three Anaerobic Methanogenic Bioreactors Reveals that Syntrophs are Diverse and Different From r Organisms, *FEMS Microbiol. Ecol.*, **22,** 295.
Zhang, J.; Li, L.; and Feng, X. (1997) Study on Characteristics of Activated Sludge for Anaerobic Attached Microbial Film Expanded Bed Process, *Huanjing Kexue,* **18,** 1, 42.

Anaerobic processes

Rumana Riffat, M. Wahid Sajjad,
Somchai Dararat

MICROBIOLOGY

Strain Isolation. A hydrogen-producing anaerobic bacterium, *Clostridium butyricum* strain SC-E1, was isolated from soybean meal and studied under vacuum and nonvacuum systems. The maximal hydrogen production potential by the bacteria ranged from 1.3 to 2.2 mol H_2/mol glucose, which was less than 50% of theoretical values (Kataoka *et al.*, 1997). The ability of a sulfate-reducing bacterium, *Desulfovibrio desulfuricans,* to reduce molybdenum(VI) and molybdenum(IV) in anaerobic environments was investigated (Tucker *et al.*, 1997). The organism was observed to be useful for removing soluble molybdenum from water. The anaerobic bacterial strain *Desulfomonile tiedjei* was introduced in soil slurry microcosms supplemented with acetate and formate as cosubstrates and was able to achieve dechlorination of 2.5 mM of 3-chlorobenzoate within 12 days (El Fantroussi *et al.*, 1997). A DNA extraction and purification method was also presented. Godon *et al.* (1997) analyzed the bacterial community structure of a fluidized bed reactor fed by vinasses and established three 16S rDNA clone libraries of *Bacteria, Archaea,* and *Procarya.*

The enzymes from anaerobic fungi, that is, *Piromyces* sp. strain E2 and *Neocallimastix patriciarum* strain N2, effectively converted up to 2% (w/v) microcrystalline cellulose (Avicel) to glucose and surpassed their commercial counterparts (Celluclast and Novozym) in batch degradation of 2% (w/v) Avicel (Dijkerman *et al.*, 1997). The anaerobic bacterium *Dehalospirillum multivorans* was applied to a biofilm reactor at 20°C for reductive dechlorination of tetrachloroethylene (PCE) via trichloroethylene (TCE) to *cis*-1,2-dichloroethene (DCE) (Eisenbeis *et al.*, 1997). Tetrachloroethylene was converted to TCE at a rate of 55 nmol/min per mg protein and TCE to DCE at 90 nmol/min per mg protein. Two facultative anaerobic bacterial cultures isolated from yeast extract (inoculated with textile dye discharge effluent) were capable of growth and decolorization at elevated temperatures up to 60°C (Banat *et al.*, 1997). Both cultures have potential industrial applications in treating textile dye effluent discharged at elevated temperatures. Fumarate was formed as an intermediate before benzylsuccinate when toluene was mineralized under anaerobic conditions by strain PRTOL1, a toluene-mineralizing and sulfate-reducing bacterium (Beller and Spormann, 1997). A critical analysis was presented of the applicability of modified strains of indigenous microorganisms and the adaptation of mixed cultures in the degradation of toxic and recalcitrant xenobiotics under anaerobic, anoxic, or aerobic conditions (Torres-Bustillos *et al.*, 1997).

Two thermophilic anaerobic bacterial consortia, ALK-1 and LLNL-1, were developed from the water of ARCO'S Kuparuk oil field of Alaska and the subsurface water at the Lawrence Livermore National Laboratory gasoline spill site, at 60°C (Chen and Taylor, 1997). Both consortia were able to degrade and grow on benzene, toluene, ethylbenzene, and xylene (BTEX) compounds at 45–75°C. Oil recovery efficiencies from 9.3 to 22.1% of the water flood residual oil saturation were achieved from both lime-free and lime-containing, oil-bearing sandstone cores with strain BNP29 isolated from northern German oil reservoirs at depths of 866–1520 m (Yakimov *et al.*, 1997). To determine the molecular basis for anaerobic degradation of benzoate and related compounds, genes were cloned and analyzed from the phototrophic bacterium *Rhodopseudomonas palustris* (Egland *et al.*, 1997). A cluster of 24 genes was identified. Anaerobic conversion of furfural to furfuryl alcohol was