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METHANE FERMENTATION, SUBMERGED GAS COLLECTION, AND THE FATE OF CARBON IN ADVANCED INTEGRATED WASTEWATER POND SYSTEMS

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ABSTRACT

There are several basic reasons for concern regarding the fate of carbonaceous material in waste stabilization ponds: accumulation of solids; performance and useful life of the pond system; and, the control of methane emissions. In conventional ponds methane fermentation is minimal, and carbon-rich organic matter is integrated by bacteria and microalgae which grow and settle. The integration of carbon decreases pond volume and treatment capacity and causes the ponds to age prematurely, to produce odor, and to require frequent sludge removal; and, any methane produced escapes to the atmosphere. However, if carbon-rich organics are efficiently converted to methane or to harvested microalgae, the pond system will continue to treat wastewater effectively for an extended period of time. Advanced Integrated Wastewater Pond Systems (AIWPSs) developed at the University of California fully utilize methane fermentation and microalgal cultivation to treat wastewater and to reclaim energy and nutrients. First generation AIWPSs have provided reliable municipal sewage treatment at St. Helena and Hollister, California, for 28 and 16 years, respectively, without the need for sludge removal. However, these first generation systems lack the facilities to recover and utilize the carbon-rich treatment byproducts of methane and algal biomass. The recovery of methane using a submerged gas collector was demonstrated using a second generation AIWPS prototype at the University of California, Berkeley, and the optimization of in-pond methane fermentation, the growth of microalgae in High Rate Ponds, and the harvest of microalgae by sedimentation and dissolved air flotation were studied. Preliminary data are presented to quantify the fate of carbon in the second generation AIWPS prototype and to estimate the fate of carbon in a full-scale, 200 MLD second generation AIWPS treating municipal sewage. In the experimental system, 17% of the influent organic carbon was recovered as methane, and an average of 6 g C/m^2/d were assimilated into harvestable algal biomass. In a full-scale second generation AIWPS in a climate comparable to Richmond, California, located at 37° N latitude, these values would be significantly higher — as much as 30% of the influent organic carbon would be recovered as methane and as much as 10 g C/m^2/d would be assimilated by microalgae. These efficiencies would increase further in warmer climates with more abundant sunlight.

KEYWORDS

Advanced Integrated Wastewater Pond Systems; Advanced Facultative Ponds; algal High Rate Ponds; algae harvesting; carbon sequestration; dissolved air flotation; greenhouse gases; in-pond digesters; methane fermentation; microalgae.

NOMENCLATURE

a	=	specific interfacial surface area, cm^{-1}
c	=	concentration of aqueous methane, mg/l
c_s	=	concentration of aqueous methane at equilibrium with gas phase, mg/l
K_L	=	coefficient of mass transfer based on liquid phase resistance, cm/s
d	=	bubble diameter, cm
D_L	=	diffusivity of a gas in the liquid phase, cm^2/s
μ_L	=	liquid viscosity, g/cm/s
ρ_L	=	water density, g/cm^3
ρ_G	=	gas density, g/cm^3
g	=	gravitational constant, cm/s^2
Q_G	=	volumetric gas flow, cm^3/s
V	=	digester volume, cm^3
θ	=	residence time of bubbles in digester, s

INTRODUCTION

Increasing atmospheric concentrations of carbon dioxide, methane, and other radiatively active trace gases and their impact on global climate change have increased the importance of waste management processes that efficiently convert carbon to methane and microalgal biomass. Methane is a valuable renewable energy resource, and microalgae are a valuable source of protein-rich animal and fish feed and of nitrogen-rich fertilizer. When the value of energy exceeds the value of the fixed nutrients, the harvested algal biomass may be used for additional fermentation substrate to increase the methane yield of the system. Annual methane emissions from domestic sewage treatment have been estimated at 25 Tg as CH_4 (25×10^{12} g as CH_4), approximately 7% of global anthropogenic methane emissions (Houghton, 1992). An equal or greater volume of methane is estimated to evolve from wastes generated in animal agriculture. Municipal sewage, food processing wastes, and the wastes from confined animal facilities have been successfully treated in Advanced Integrated Wastewater Pond Systems developed at the University of California. First generation AIWPSs at St. Helena and Hollister, California, have operated reliably for 28 and 16 years, respectively, without the need for sludge removal. However, these first generation systems lack the facilities to recover and utilize methane and algal biomass.

Our present studies concern the development of submerged gas collectors, the further optimization of in-pond methane fermentation, and a preliminary estimation of the fate of carbon in AIWPSs. Studies were conducted at the University of California, Berkeley, Environmental Engineering and Health Sciences Laboratory in Richmond, California, using a second generation AIWPS prototype during an initial two-year operation period, 1992–1993. The companion essay in this same volume (Green *et al.*, 1995) discusses methane-fueled electrical generation and the electrical energy balance in second generation AIWPSs and provides additional description of the design and operation of the second generation AIWPS prototype at Richmond.

Carbon is transformed in AIWPSs through two important mechanisms: methane fermentation and biological assimilation by microalgae. The conversion of waste organic solids to methane, nitrogen gas, and carbon dioxide via methane fermentation and the assimilation of organic and inorganic carbon to algal biomass via photosynthesis provide the basis for primary, secondary, and tertiary treatment in AIWPSs. More recently designed second generation AIWPSs incorporate the recovery and utilization of methane and algal biomass and provide a final effluent that may be safely reused. They also significantly improve the performance

efficiency and economy of first generation AIWPSs. Conventionally designed waste stabilization ponds and more energy intensive mechanical wastewater treatment processes, such as activated sludge and extended aeration systems, tend to integrate carbon and to generate large volumes of sludge. In wastewater ponds sludge accumulation results in the loss of reactor volume and treatment capacity, an increase in odors, and frequent de-sludging which adds significantly to operational and externality costs. In activated sludge and extended aeration systems, typically several times more expensive to build and operate than are AIWPSs, sludge handling and disposal is a daily requirement and a significant cost.

Methane fermentation has long been recognized as one of the most efficient ways to manage and reclaim waste organic matter, and this fundamental biological process has influenced the design of AIWPS for several decades (Oswald *et al.*, 1963; Oswald *et al.*, 1994). Methane fermentation is optimized in the first element of an AIWPS, called an Advanced Facultative Pond (AFP). AFPs are uniquely designed to foster three distinct microbial consortia: a deep anaerobic strata is overlain by a deep facultative strata which is overlain by an aerobic surface strata. Fermentation pits or in-pond digesters located in the bottom of AFPs are protected against the intrusion of dissolved oxygen. After screening, flow measurement, or other pretreatments, all of the influent wastewater is discharged into the bottom of these internal digesters. A low upflow velocity, usually less than 2 m/d, insures the efficient sedimentation and fermentation of volatile settleable solids to methane, nitrogen gas, and carbon dioxide; nitrogen gas is produced via heterotrophic nitrification denitrification (Verstraete and Alexander, 1973). One of the prerequisites for stable methane fermentation is the absence of dissolved oxygen. In many primary waste ponds, the influent is introduced at or near the surface in the presence of oxygen. Stable methanogenesis is further inhibited from dissolved oxygen being circulated from the pond surface down into the anaerobic bottom by wind-induced vertical mixing. If methane fermentation is inhibited, acetogenic digestion will dominate, and more carbon will be integrated in the form of bacterial biomass than will be exported in the form of methane. In an AIWPS, because the digesters are located within deep facultative ponds, the emerging biogas is scrubbed as it rises through the overlying water column increasing the methane concentration by well over 50% (from 51% CH_4 in the digester to 86% CH_4 at the pond surface). Most of the carbon dioxide is redissolved near the surface where it is utilized by microalgae.

The second mechanism by which carbon is transformed and exported in AIWPSs is biological assimilation by microalgae grown in the second element of an AIWPS, an algal High Rate Pond (HRP). HRPs are designed to promote the symbiosis between microalgae and aerobic bacteria, each utilizing the major metabolic products of the other. BOD is oxidized by aerobic bacteria utilizing photosynthetic oxygen produced by microalgae which in turn utilize carbon dioxide and plant nutrients released through bacterial oxidation. The cultivation of algae is uncontrolled in conventional waste stabilization ponds, but in AIWPSs the growth of microalgae is optimized in paddle wheel mixed HRPs. Algal cell concentrations are matched with influent BOD to provide efficient photosynthetic oxygen production and nutrient assimilation. The gentle mixing and flocculation provided by paddle wheels selects for microalgal species such as *Scenedesmus* and *Micractinium* that settle easily in Algae Settling Ponds (ASP). Complete removal of algae is accomplished by dissolved air flotation (DAF) followed by filtration depending on effluent requirements; although, residual algae in the effluent of ASPs is beneficial in agricultural irrigation and in many receiving waters. Algal biomass harvested by sedimentation without chemical addition may be used as a protein-rich animal or fish feed, a nitrogen-rich fertilizer. Algal biomass harvested by DAF with the use of alum as a coagulant may be recycled as additional fermentation substrate to increase the methane yield.

Previous studies of biogas emissions and collection in wastewater ponds

The collection of methane-rich biogas at various depths within the water column of waste stabilization ponds has been used by our group as a method for studying anaerobic digestion, methane fermentation, and general pond performance since the early 1960s (Oswald *et al.*, 1963; Uziel, 1978; Von Hippel and Oswald, 1985). The results from each of these studies indicate that the composition of biogas emanating from the bottom sludges in waste ponds is high in methane and nitrogen gas and low in carbon dioxide in contrast to the composition of biogas produced in separate sludge digesters which is typically 30% to 35% carbon dioxide

and less than 5% nitrogen. As the biogas emerges through the overlying water column, carbon dioxide is converted to bicarbonate alkalinity and a portion is utilized by microalgae in the AFP.

During the 1980s interest in renewable energy technologies hastened the development of large-scale biogas collection devices. Several animal waste ponds were retrofitted with floating plastic covers to collect biogas (Oswald and Swanson, 1981; Safley and Westerman, 1992). Given their exposure to the elements, surface covers are vulnerable to high winds, heavy rains, UV degradation, and vandalism. We have developed submerged gas collectors to avoid the difficulties experienced with surface gas collectors.

METHODS

Beginning in 1989, the 0.1-hectare facultative pond built at Richmond, in 1963 for primary treatment of municipal sewage was modified in order to study the optimization of methane fermentation and to demonstrate the feasibility of collecting methane using a submerged gas collector. Over the next several years two in-pond digesters each with submerged gas collectors were installed and operated over a range of loading rates. The inverted conical shape of the first submerged gas collector shown in Fig. 1 resembles the shape of the small experimental gas collector used by Bronson and the later conceptual design for a submerged gas collector shown in Fig. 2 (Oswald *et al.*, 1963; Oswald, 1985). The first submerged gas collector was fabricated using a scrim-reinforced plastic liner. Twelve panels were seamed with nylon thread and nylon webbing for reinforcement. The bottom of each seam strap was attached with 10 mm Dacron rope to eye bolts set in the top of the digester wall, and the top of each seam strap was buckled around the styrofoam flotation collar. Gas emerging from the digester was focused through the central opening between the flotation collar and the support column and was collected at the surface in a rigid circular PVC cap also aligned by the support column. The gas collector positioned above the second digester, a rectangular wedge-shaped pit installed in 1993, was attached to the surrounding wooden berm wall by 10 mm Dacron rope passing through grommets in the outside hem of the canopy and eye bolts set near the base of the berm wall. The gas canopy was elevated toward the central aperture by two ridge beams extending from the berm end walls to the aperture and there attached to the bridge.

Start-up of the second generation AIWPS prototype at Richmond, including two 0.1 hectare algal High Rate Ponds (HRPs) and three algae settling basins, began in October 1991. Standard water quality parameters including total and soluble BOD_5, TSS, VSS, total Kjeldahl nitrogen, organic nitrogen, ammonia nitrogen, total phosphorus, soluble reactive phosphorus, total and fecal coliforms, temperature, pH, DO, total organic and inorganic carbon, and alkalinity were measured in the influent and effluent of each element of the AIWPS on a twice weekly basis over a two year period. Biogas was metered continuously and samples were collected at various depths and analyzed using gas chromatography. The AIWPS prototype at Richmond received 100 m^3/d of domestic sewage. A Krofta DAF Supracell SPC 4 was used to remove residual algae from the settling basin effluent. The Richmond prototype was taken out of operation in the fall of 1992 in order to install a second digester, submerged gas collector, and access bridge. Operation and monitoring of the Richmond prototype resumed in the fall of 1993.

Gas production and composition, digester sludge mass, and water quality data collected in 1992 and 1993 were used to estimate the fate of carbon in the second generation AIWPS prototype at Richmond, and in a full-scale AIWPS treating 200 MLD in a similar climate. Digester loading rates of 0.03 to 0.20 kg $VSS/m^3/d$ were tested during this period with the greatest methane production levels achieved at the lowest loading rates. Using a Dohrmann DC-80 total organic carbon (TOC) analyzer in 1993, inorganic carbon (IC) and organic carbon (OC) concentrations were measured directly in each element of the prototype and a correlation was developed between BOD_5 and OC. A preliminary carbon balance was estimated using the 1992 digester loading rate of 0.03 kg $VSS/m^3/d$, the correlation of BOD_5 to OC, and alkalinity data. For samples taken from the sludge layer, a correlation was developed between VS and OC. The carbon content of the collected gas was measured using gas chromatography (GC).

RESULTS

The Fate of Carbon in the Second Generation AIWPS Prototype at Richmond. The best methane yield achieved was 0.2 m^3/kg VSS introduced (STP), and the average methane concentration of the recovered biogas was 86%. The OC entering the Richmond digesters was approximately 60% particulate and 40% soluble based on filtered and unfiltered BOD. The OC entering the digesters was either converted to methane and carbon dioxide, accumulated as sludge in the digesters, or transferred into the overlying AFP. The municipal sewage entering the digesters had an average BOD_5 and VSS concentration of 233 mg/l and 182 mg/l, respectively. During the period of optimal organic loading and highest methane yields (1992), the digester had a hydraulic residence time (HRT) of 6.3 days and a 1.6 m/d overflow rate. Soluble BOD concentrations in digester effluent samples were used to estimate the OC concentration in digester effluent. IC entering the digester was assumed to pass through the digester unchanged. The dissolution of the CO_2 fraction of the biogas into the water column was calculated by performing a carbon mass balance on the digester. Mass balancing indicated that neither methane nor carbon dioxide achieved equilibrium with the digester supernatant. The composition of biogas sampled inside the digester and the mass transfer coefficient for bubbles passing through water were used to estimate the dissolution of methane. The flux of methane into the aqueous phase was calculated by:

$$\frac{dc}{dt}=K_L a(c-c_s) \tag{1}$$

An estimate of c_s was determined with average hydrostatic pressure and average composition of biogas collected at several depths in the digester. The aqueous concentration of methane was assumed to be zero in order to conservatively estimate the methane flux into the aqueous phase. The coefficient of mass transfer for methane was estimated using an empirical formula from Calderbrook and Moo-Young (1961).

$$\frac{K_L}{D_L}=0.42\left(\frac{\mu_L}{\rho_L D_L}\right)^{0.5}\left[\frac{\rho_L(\rho_L-\rho_G)g}{\mu_L^2}\right]^{0.33} \tag{2}$$

An estimate of the specific interfacial area was based on bubble diameter and gas flow rate (AWWA, 1990). Bubble residence time, θ, was estimated using Stokes law. Bubble diameter was visually estimated.

$$a=\frac{(no.bubbles)\times(area/bubble)}{digester\ volume}=\frac{6Q_G\theta}{Vd} \tag{3}$$

The biogas collected by the submerged gas collector had an average composition by volume of 86% methane, 13% nitrogen, and less than 1% carbon dioxide as shown in Fig. 3. Samples collected and analyzed from stationary gas collectors inside each digester showed a much lower concentration of methane (51%) and higher concentrations of nitrogen (42%) and carbon dioxide (7%). As expected, the carbon dioxide content of the biogas collected within the digesters was higher than that collected at the surface quantifying biogas scrubbing in the overlying water column.

Equations (1) through (3) were used to estimate the mass of methane that dissolved from biogas bubbles into the digester water column. For a 6.3-day hydraulic residence time in the digester, the concentration of methane in the aqueous phase was estimated to be 0.2 mg/l. Dissolved carbon gases were apparently leaving the digester in the effluent at the rate of 1 g/d as aqueous methane and according to mass balance, 550 g/d as aqueous carbonate species. Although the two species have similar mass transfer coefficients and methane is the dominant biogas component, the high solubility of carbon dioxide resulted in a calculated flux of this species into the aqueous phase that is 100 times greater than the flux of methane.

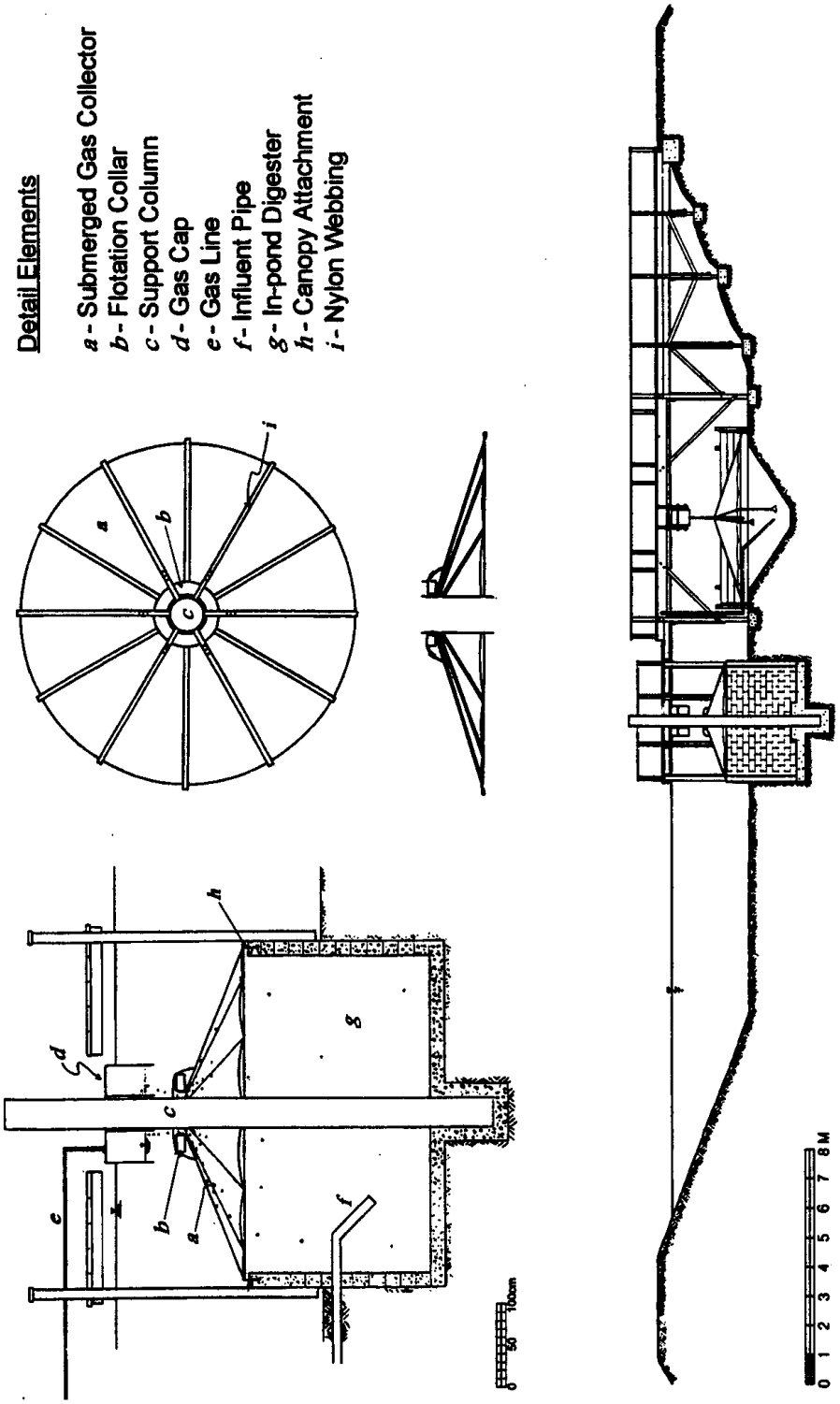

Figure 1. Cross section of the Advanced Facultative Pond showing both digesters, submerged gas collectors, sampling platform and bridge with details of the first digester, and submerged gas collector.

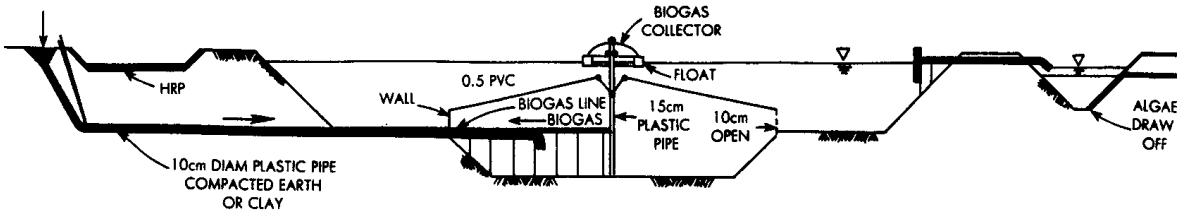

Figure 2. Cross section of an integrated in-pond biogas disgester with gas capture, facultative pond and high rate pond sized for village of 400 population equivalent.

Figure 4 shows the estimated partitioning of influent organic carbon in the Richmond in-pond digester. Approximately 17% of the influent OC mass was converted to methane and 99% of that was recovered by the submerged gas collector. The majority of influent OC (61%) was converted to IC by bacteria.

Sludge accumulation accounted for 9% of the influent carbon and would be less in a mature, well established digester. Sludge generally accumulates in new systems, but eventually the rate of sludge digestion equilibrates with the rate of sludge deposition. The original Richmond in-pond digester was in operation for only one year when the accumulated sludge was measured.

The Fate of Carbon in a 200 MLD Second Generation AIWPS. During 1992, when the first Richmond digester was loaded at the rate of 0.032 kg/m^3/d, 29% of the volatile solids that settled in the digester were destroyed and methane was produced at a rate of 0.20 m^3/kg VSS introduced. Digester sludge temperature averaged 20 °C during this period. In a full-scale second generation AIWPS, in-pond digestion is expected to result in 50% VS destruction as is common in separate sludge digesters (Metcalf and Eddy, 1991; Wander Associates, 1993). The methane yield used in the carbon balance shown in Fig. 5 was (50%/29%)(0.20 m^3/kg VSS introduced) or 0.34 m^3/kg VSS introduced.

In a full-scale second generation AIWPS it was assumed that 80% of the algal biomass recirculated from the HRP to the AFP settled and that its organic carbon content was converted to methane with the same yield as achieved from the volatile solids retained in the digester. It was assumed that the remaining 20% of the recirculated algal biomass was returned to the HRP in the AFP effluent. The sedimentation and fermentation of new algal biomass grown in the AFP was assumed to be negligible.

HRPs with 3 to 4 day hydraulic residence times (HRTs)in a climate similar to that of Richmond typically produce an annual average of 12 g VSS/m^2/d of algal biomass. Algal biomass is typically 50% carbon (Oswald, 1988). Therefore the annual average carbon assimilation in a HRP would be 6 g/m^2/d. Due to the lack of scale at Richmond, (e.g. more HRP area than required by the AFP) both of the 0.1-hectare HRPs were operated with 7 to 14 day HRTs. The algal-bacterial biomass retained in the HRPs was surveyed and analyzed for volatile solids content at the end of 1992. Algal accumulation in the HRP of a second generation AIWPS treating 200 MLD was assumed to be 1/3 the accumulation observed at Richmond due to shorter HRTs (3 to 7 days) and better hydraulic design and performance.

A solids mass balance on the Richmond HRPs indicated an influx of carbon dioxide from the atmosphere of 2.6 g/m^2/d. This flux was assumed for the HRP of the 200 MLD AIWPS. The existence of a carbon dioxide flux is reasonable since the pH of the HRPs usually reached 9 by mid-morning and 10 by early afternoon. High pH indicates low IC concentrations that promote the dissolution of carbon dioxide from the atmosphere into the water.

Effluent from the Richmond HRPs passed through concrete settling basins where algae settled and were harvested. Influent and effluent concentrations to these units were monitored for BOD_5 and solids. The 50% average solids removal found at Richmond, was used to estimate the carbon removal in the 200 MLD AIWPS. The 200 MLD tertiary treatment plant at Stockton, California, utilizes DAF and dual media

filtration to remove algae from oxidation pond effluent. The average effluent solids concentration of 8 mg/L from the Stockton plant was used to estimate the organic carbon content of the final effluent of the 200 MLD AIWPS.

Figure 5 shows liquid and gaseous flows of carbon through a hypothetical 200 MLD AIWPS located in northern California (latitude 37°). The sewage influent conveys 19 metric tons per day of OC (t OC/d) into the system. Thirty-six percent of this (6.8 t C/day) is expected to be converted to methane and collected for utilization. The HRPs receive 13 t OC/d from the AFP effluent, and 7.4 t OC/d is recirculated back from the HRP to the AFP. Primary solids and algae from recirculation are expected to accumulate in the AFP at a rate of approximately 5 t OC/d.

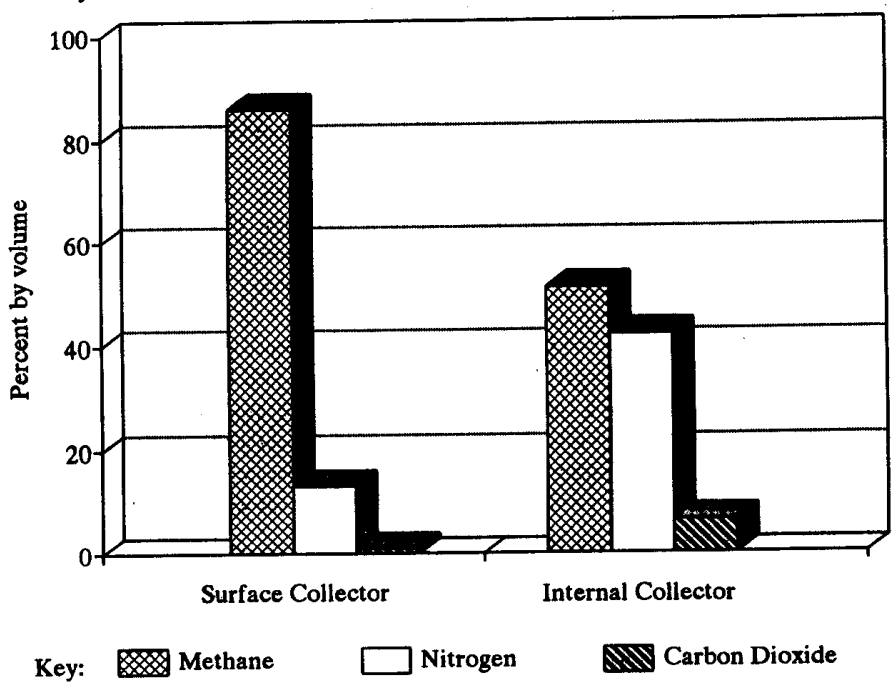

Figure 3. Mean composition of biogas collected in main surface collector 3.9 m above the digester floor and in the internal collector 0.9 m above the digester floor at Richmond AIWPS May–September 1992.

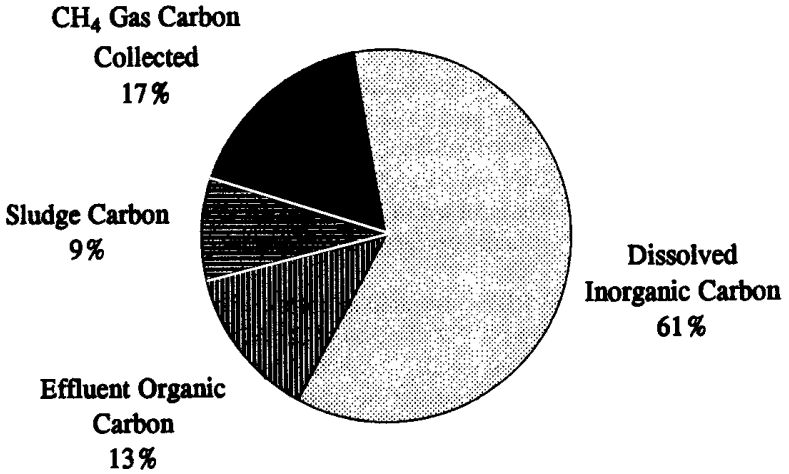

Figure 4. Initial partitioning of influent organic carbon in the digester of the Richmond AIWPS during 1992. Less than 1% of the influent organic carbon was converted to dissolved methane or collected as carbon dioxide gas.

This rate is equivalent to about 0.01 m^3/person/year which is 3 to 8 times less than the accumulation found in anaerobic ponds (Gloyna, 1971). Influent to the algae settling ponds contains 22 t OC/d in the form of algal-bacterial biomass. Inorganic carbon decreases from 13 t/d in the HRP influent to 3.0 t/d in the effluent and recirculation flows due to the assimilation of 9.6 t/d in the form of algal OC. This drop in IC occurs despite approximately 7.4 t CO_2 carbon entering the HRPs, equivalent to 2.6 g/m^2/d. With typical ratios of 6.3:1 for C:N and 50:1 for C:P in algal biomass, the fixation of 9.6 t IC/d in the HRPs corresponds to the fixation of 1.5 t/d soluble N and 0.2 t/d soluble P into biomass. This fixed mass is in excess of algae in the HRP influent. The algal-bacterial biomass is estimated to deposit on the floor of the HRP at a rate of 0.4 t/d organic carbon. In the settling basins, 11 t/d of OC in algal biomass is removed by sedimentation on average. The algal slurry of 3% to 4% solids should be removed from settling ponds periodically to maintain low effluent nutrient concentrations. Most of the 11 t OC/d remaining after the settling basins would be removed by a DAF unit leaving approximately 0.8 t OC/d in the effluent. The total harvest of fixed carbon would be 22 t/d which if returned to the in-pond digester would allow recovery of some of this fixed carbon as methane.

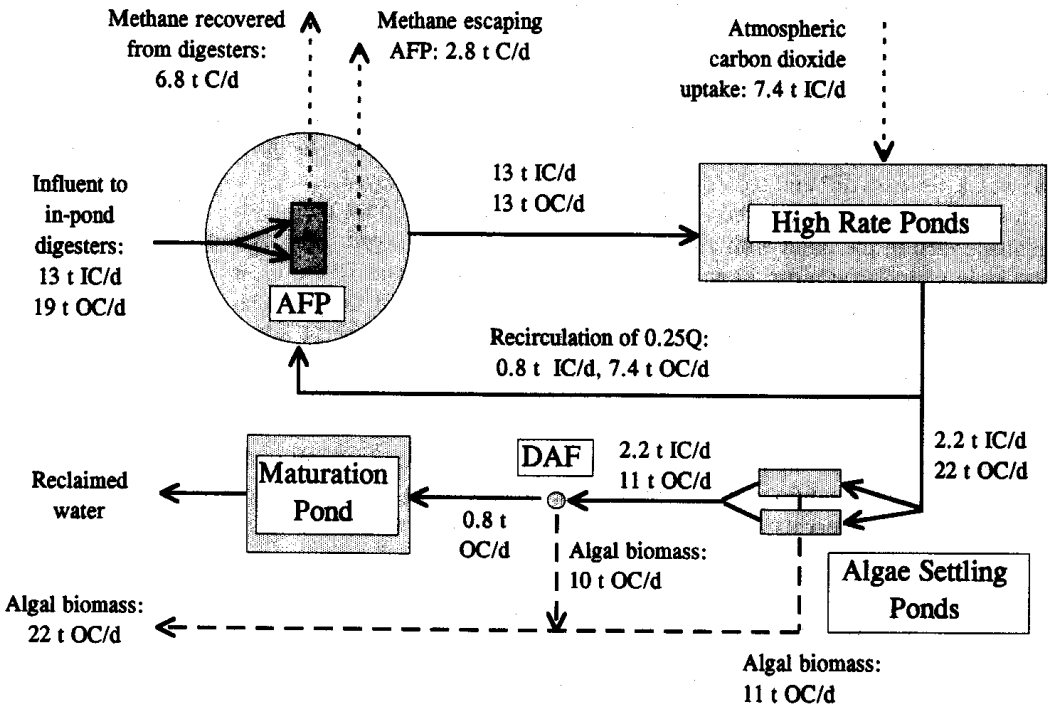

Figure 5. Carbon partitioning projected for a 200 MLD second generation AIWPS. All values in metric tons per day of organic carbon (t OC/d) or inorganic carbon (t IC/d). Dissolved air flotation (DAF) results based on tertiary treatment plant data at Stockton, California (Anderson, 1994). Advanced Facultative Pond (AFP) algae residual is approximately 5 t OC/d. High rate Pond residual is < 1 t OC/d.

DISCUSSION

The sequence of testing digester loadings and the limited availability of a TOC analyzer have required the use of correlations and estimations of carbon mass flows in the Richmond AIWPS. With the approximate optimal digester loading now determined and a TOC analyzer available, a more complete carbon balance can be performed. In addition to direct measurement of carbon in liquid, biomass, and gas samples with a TOC analyzer and GC, methodologies have been developed to measure directly several carbon paths that in the past required calculation. These methods are presented below.

Dissolved methane. To confirm that aqueous methane concentrations in the digesters and AFP are low, water samples will be taken at various depths in the water column in the digesters and in the ponds themselves. The sample bottle design will allow the bottle to be sealed at the depth of sampling preventing any dissolved gases from coming out of solution at the surface. In the laboratory, some water will be displaced with helium gas to create a headspace in the bottle. It will then be shaken for 24 hours and the headspace sampled and analyzed by GC for methane, nitrogen, oxygen, carbon dioxide. Henry's Law will be used to determine the original dissolved gas concentrations.

Gaseous methane and carbon dioxide leaving the AFP. The quantity of gases escaping the surface of the AFP, the HRPs, and the ASPs will be estimated with several 30-cm diameter gas collectors placed at the surface of the ponds and near the sludge layer. The collectors will be designed to isolate the collected gas from the pond water to prevent gas diffusion into the water between sampling. The rate of biogas production is proportional to the rate of sludge destruction, but the destruction rate is difficult to determine in situ. Instead, gas production in the near-sludge collectors will be correlated to mass of volatile solids and temperature in the sludge below the collector. The scrubbing of carbon dioxide will be correlated to water depth. Surveys of sludge depth and volatile solids content throughout the pond will allow extrapolation of gas release by the ponds.

Atmospheric carbon dioxide influx. Carbon dioxide may also enter the ponds from the atmosphere during the daily periods of algae-induced high pH and low IC concentration in surface water. Wind-driven mixing and the exposed surface of the HRP paddle wheels will also contribute to the diffusion of carbon dioxide into the water. In the AFP and the ASPs, the rate of CO_2 diffusion will be estimated by isolating the surface water from biogas sources of carbon dioxide in a transparent cylinder with a closed bottom. The cylinder will be suspended in the pond with a majority of its length submerged. The cylinder will extend below the euphotic zone which is at most 50 cm in the AFP and the HRPs and 70 cm in the ASPs. The placement of the cylinder in the pond will allow factors such as wind speed and temperature to be accounted for in the testing. By measuring the total carbon concentration every 4 hours for 24 hours, the atmospheric influx of CO_2 will be determined. Periodic tests will allow pond-wide carbon dioxide influx and mass transfer coefficients to be estimated.

In the HRPs, the losses of algal biomass to sedimentation should be small compared to the other flows of carbon. Under this condition, the difference in total carbon mass in the HRP influent and effluent determined at 4 hour intervals over the course of a day will indicate the carbon dioxide flux into the pond and the period in which the flux occurs.

SUMMARY

The fate of carbon in waste stabilization ponds may be used to evaluate the performance and to predict the useful life of the ponding system. Carbon is transformed through the mechanisms of methane fermentation and microalgal assimilation in an AIWPS. With the recovery and utilization of methane and algal biomass in second generation AIWPSs, additional environmental benefits are achieved. A significant anthropogenic emission of methane can be mitigated; greenhouse gas emissions associated with more energy intensive wastewater treatment processes can be reduced; and, CO_2 produced from the combustion (e.g. utilization) of methane can be largely recycled through algal assimilation.

ACKNOWLEDGEMENTS

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