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ADVANCED INTEGRATED WASTEWATER POND SYSTEMS

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ABSTRACT

By incorporating special environments for methane fermentation and photosynthetic oxygenation, advanced integrated ponding systems attain high degrees of primary and secondary treatment and significant degrees of tertiary and quaternary treatment of sewage and organic industrial wastes. When properly designed in appropriate locations, the systems virtually eliminate sludge disposal, minimize power use, require less land than conventional ponds, and are much more reliable and economical than mechanical systems of equal capacity.

INTRODUCTION

As is well known to Environmental Engineers, wastewater treatment to the secondary degree involves removal and digestion of settleable and floatable organic solids (primary treatment) followed by removal and digestion of microbial solids produced during aeration of the primary effluent (secondary treatment). Such treatment traditionally has been done in reinforced concrete and/or steel structures with materials moved by motorized pumps and aeration provided by mechanical means. Sometimes for economy and simplicity in small communities, ponds are used to replace mechanical systems. The greatest advantages of ponds are their simplicity, economy, and reliability; their greatest drawbacks are their high land use, their potential for odor, and their tendency to eutrophy or fill in with sludge and to become less effective with age. Our research, devoted to maintaining the advantages of ponds while mitigating their drawbacks, has led to the development of Advanced Integrated Wastewater Pond Systems (AIWPS). These require much less capital, energy, operation and maintenance than mechanical systems and require less land, produce less odor, and fill in or age much more slowly than ordinary ponds. In this paper I wish to introduce AIWPS as a system worthy of consideration for many waste treatment applications. Due to space limitations, however, only a brief description of AIWPS design and performance can be made herein. More detailed information is available in the dissertations teaching syllabi, papers, and engineering reports quoted in the reference section (Oswald, 1990).

THE SYSTEM

In their most effective, reliable and economical form AIWPS consist of a series of at least four ponds, each designed to best perform one or more of the

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basic treatment processes (see Figure 1). First is a Facultative pond with an aerobic surface and an extremely anoxic internal pit for sedimentation and fermentation. Anaerobic microbes in the pit are protected by surrounding walls or berms from the intrusion of cold surface water containing dissolved oxygen. Raw sewage is introduced directly into the pits where sedimentation and methane fermentation occur. Overflow velocity in the pits is maintained so low (see Figure 2) that suspended solids removal approaches 100% and biochemical oxygen demand (BOD) removal approaches 70%. The overflow velocities of one or two meters per day are less than the settling velocities of helminth ova and parasite cysts so most of these remain in the pit and consequently are permanently removed from the effluent.

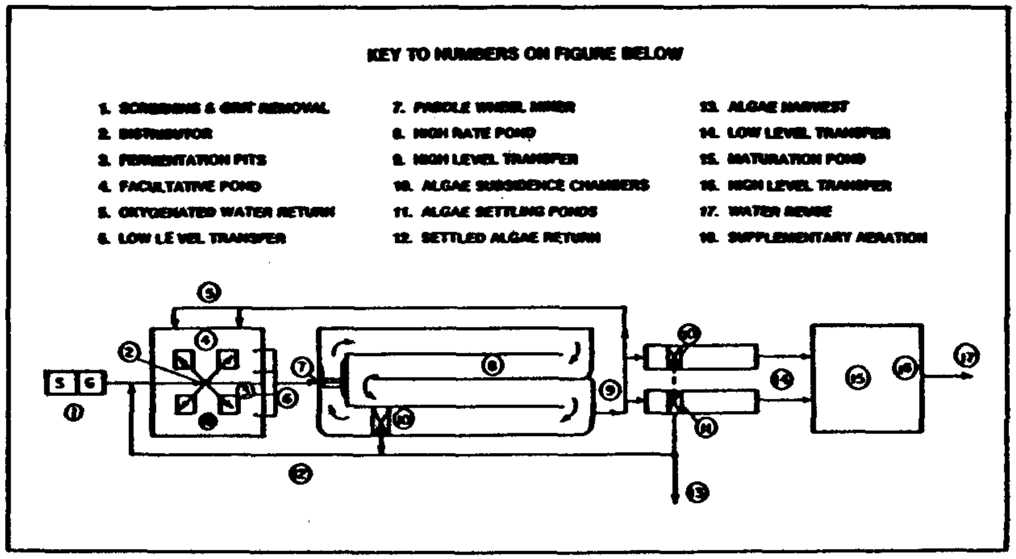

Figure 1. An Advanced Integrated Wastewater Ponding System (Schematic)

Another potential benefit of anoxic pits is conversion of chlorinated hydrocarbons to forms that may be biodegradable in an aerobic environment (Bouer and McCarty, 1983). Due to the large pit volume and its reducing environment, settled solids ferment there to a point where only ash remains, hence sludge removal is seldom if ever required. In the case of St. Helena, California (the first AIWPS) sludge removal has not been required for over 25 years. A second AIWPS at Hollister, California, evidences little sludge build up after twelve years.

The second pond of an AIWPS series is a paddle wheel mixed shallow raceway called a High Rate Pond. In such a pond microalgae grow profusely releasing oxygen from water by photosynthesis. This oxygen is immediately available to bacteria to oxidize most of the soluble and biodegradable BOD remaining in the effluent from the facultative pond. Algae produced during paddle wheel mixing are highly settleable (see Table 1) (Eisenberg, 1981) and, after algal removal by sedimentation, or dissolved air flotation (Krofta and Wang, 1984), the remaining water has a BOD that is generally less than 20 mg/liter. Recirculation of algae-bearing water from the High Rate Pond to the Facultative Pond provides an oxygen rich cap on the facultative pond. This oxygen quickly oxidizes reduced gases emerging from the fermentation pit thus mitigating odors.

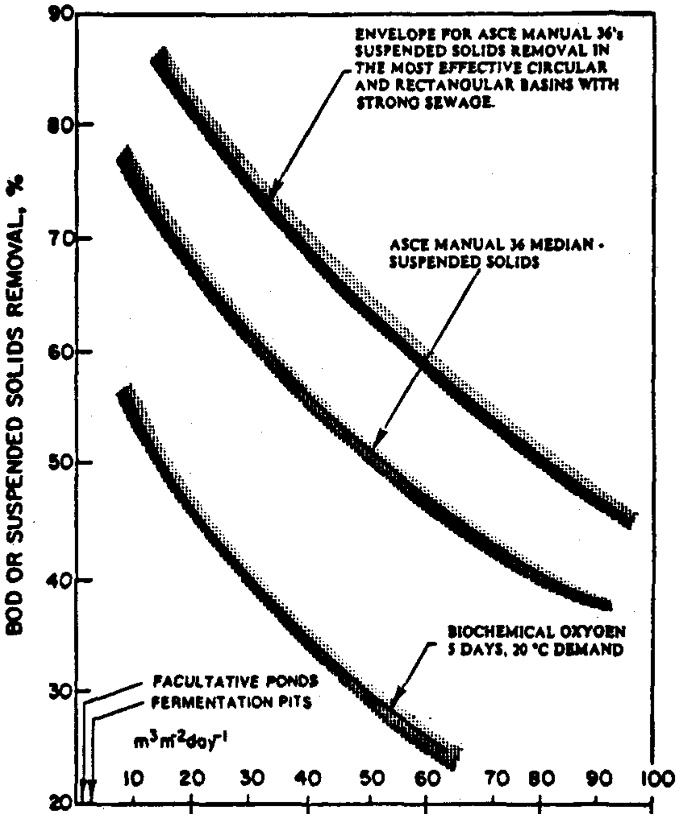

Figure 2. ASCE Guidelines For Sedimentation Tank Performance Showing AIWPS Overflow Rates

TABLE 1

SEDIMENTATION OF ALGAL-BACTERIAL SOLIDS FROM A PADDLE WHEEL MIXED HIGH RATE POND. *

	Milligrams Per Liter Ash-Free Dry Weight		
MONTH	HIGH RATE POND EFFLUENT	SETTLING CONE SUPERNATANT	PERCENT SETTLED
JAN	115	10	91
FEB	220	15	93
MAR	150	20	87
APR	240	45	81
MAY	283	20	93
JUN	320	35	89
JUL	300	20	93
AUG	230	30	87
SEP	220	15	93
OCT	120	15	95
NOV	125	5	96
DEC	95	10	89
MEAN			90.6
STD. DEV.			4.2

* 24 Hrs. Sedimentation
After Eisenberg (1981)

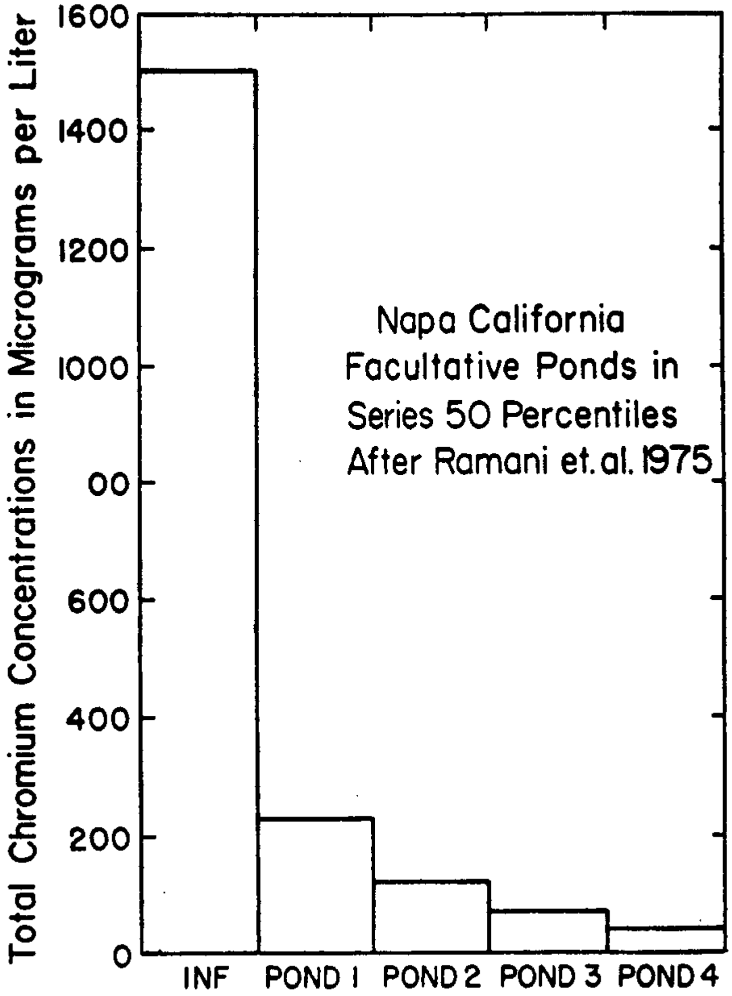

Figure 3. Total Chromium Removal Due To Algal Growth and Sedimentation In Wastewater Ponds

Algae in the recycled waters tend to adsorb any heavy metals that may be present in the incoming waste and to settle in the facultative pond, thus removing most of the adsorbed metals from the facultative pond effluent (see Figure 3) (Ramani and Oswald, 1975).

The third pond of the AIWPS series provides for sedimentation of algae in the effluent of the high rate pond. As noted above a paddle wheel mixed high rate pond tends to select for algae that are settleable when not in a mixing field (Nurdogan, 1988; Hall, 1989). Algae which settle tend to hibernate and thus do not immediately decompose or produce nuisance. In fact if two settling ponds in parallel are used, one or the other can be drained and dried every three or four years to remove concentrated algal sludges. Dried algal sludge is rich in nitrogen, phosphorus, and potash and hence is an excellent fertilizer for fast growing plants (Metting and Pyne, 1986). There is little chance that dried algae would contain infectious organisms but to be safe it should only be used on ornamentals and crops not eaten raw (California state, 1978; Gunnerson et al., 1984).

Waters emerging from the settling ponds are sufficiently low in BOD and suspended solids to percolate readily into the ground or to be used for irrigation. They will, however, likely contain an MPN greater than 1000 per 100 ml and hence may require additional storage prior to use. The fourth pond of an AIWPS often called a Maturation pond has the dual purpose of added disinfection and storage for irrigation. The use of pond effluents for irrigation is more fully discussed elsewhere (Oswald, 1989; Pahren, 1985; Sheikh and Cooper, 1984). A recent publication by the World Health Organization outlines major concerns and safety factors related to the use of wastewater for irrigation (Shuval, 1989). According to Shuval and others the major danger in developing countries is transmission of helminth ova. This is virtually precluded by the use of four ponds in series. Added to the need for four ponds in series should be an admonition against short circuiting which can only be avoided by alternating surface and submerged intakes in pipes transferring water from one pond to another.

TABLE 2

PERFORMANCE OF ADVANCED INTEGRATED WASTEWATER PONDS

ST. HELENA (Annual Means) (1)

PARAMETER	UNITS	STATION **					Percent Removed
		1	2	3	4	5	
Res Tm *	DAYS	0	20	10	5	INDEF	. .
BOD	Mg/l	223	17	9	6	7	97
COD	Mg/l	438	124	74	58	32	93
TOTAL C	Mg/l	215	144	88	69	50	77
TOTAL N	Mg/l	40	16	13	6	4	90
TOTAL P	Mg/l	14	13	12	8	5	64

(1) After Meron 1970

HOLLISTER (Annual Means) (2)

PARAMETER	UNITS	STATION **					Percent Removed
		1	2	3	4	5	
Res Tm *	DAYS	0	32	10	7	• • • •	. .
BOD	Mg/l	194	43	7	7	. .	96
T V S	Mg/l	604	393	341	347	. .	42
MPN (3)	100 ML	10 E8	10 E6	10 E5	10 E4	. .	99.999

(2) After Mosquera (1966)

(3) E. Coli

* Approximate (Residence Time Varies With Season)

** Station Key 1= Influent Sewage
2= Faculative Pond
3= High Rate Pond
4= Settling Pond
5= Maturation Pond

*** Hollisters Settling Pond Effluent Is Discharged To Natural Gravel Percolation Beds. There Is No Surface Effluent

PERFORMANCE

Table 2 presents performance data from the AIWPS at St. Helena (Meron, 1970) and Hollister (Mosquera, 1988). It is clear from these data that the major fraction of BOD removal occurs in the facultative ponds and, from the St. Helena data, that a major fraction of the total nitrogen is removed in the facultative pond. Hollister's high volatile dissolved solids originate from a paper reclamation plant and those solids remaining beyond the facultative and high rate pond are clearly refractory to both anaerobic and aerobic degradation. The high rate ponds do not remove a great deal of BOD but contribute oxygenation to the facultative ponds and aid in removal of nitrogen, phosphorus and carbon. Following algal removal the degree of pollutant removal in AIWPS is equivalent to that of mechanical secondary plants, with the added benefit of significant nitrogen and carbon removal (Table 2, St. Helena), removal of heavy metals (Figure 3) and a degree of fail safe disinfection (Table 2, Hollister) (also see Sarikaya and Sartei, 1987).

DISCUSSION

Neither Hollister nor St. Helena are complete AIWPS because they lack paddle wheel mixing in the high rate pond. Also residence times in the high rate ponds are excessive, exceeding the time required to accumulate sufficient solar energy to release sufficient photosynthetic oxygen to meet the BOD. The high rate pond in Hollister is mixed with screw pumps and in St. Helena with propellar pumps. Both are a waste of energy compared with paddle wheels. The data in Table 1 is from paddle wheel mixed experimental 1/4 acre (0.1 hectare) ponds at Richmond, and indicates the excellent natural algal removal that results from gentle mixing. The interrelationship between paddle wheel mixing and algae sedimentation was first noted in high rate pond studies in the Philippines (Oswald et al., 1978) and was confirmed in extensive subsequent studies at Richmond (Eisenberg, 1981). Both Nurdogan (1988) and Hall (1989) have studied the reasons for improvement in algal sedimentation following paddle wheel mixing. Nurdogan has found a natural selection for larger algae which settle in a quiescent field and Hall has emphasized the natural filaments produced by algae and their tendency to cause agglomeration of cells with consequent improved sedimentation. Both phenomena appear to be important in natural separation. Neither is related to the phenomenon of auto flocculation that occurs due to high pH in poorly mixed ponds resulting in precipitation of calcium carbonate, magnesium hydroxide, and calcium phosphate. This type of precipitation, as well as thermal stratification, is prevented by continuous mixing at a linear velocity of about 1/2 foot per second (15 cm per sec) (Oswald, 1978).

The energy required to paddle wheel mix a shallow pond at a velocity of 1/2 foot per second is only about 5 kwhrs per hectare per day and results in the release from water of more than 100 kg of dissolved oxygen per hectare per day--that is 20 kg of oxygen per kilowatt hour (kwhr). This should be compared with mechanical aeration which normally transfers one kilogram of oxygen per kwhr (Smith, 1973). The energy savings is thus more than 10 fold.

The phenomena that occur in the fermentation pits of facultative ponds are somewhat unique and deserve consideration. Quiescent sedimentation is only the first reaction. Apparently then, in the intensely anoxic volume in a pit, surfaces of all sorts of solid particles that settle from raw sewage become populated by acid forming and methane producing bacteria. As gas is released on their surfaces, the solid particles become buoyant and tend to rise due to the attached gas bubbles. If the pits are sufficiently deep (5-6 meters), the gas bubbles expand as they rise and usually will break away from their attachment to the particles before they reach the aerobic surface waters. The bubbles then emerge and the particles with their adhering anoxic bacteria are free to again settle down through the slowly rising bed of influent sewage. In this way the entire raw sewage flow is passed through a volume of intense anoxic activity where both insoluble and soluble organic matter is adsorbed and converted to carbon dioxide, water, methane and nitrogen gas. The positive action in deep AFP pits is very similar to that of the well known ingenious upflow anaerobic sludge blanket (UASB) reactors (Switzenbaum, 1985) without some of UASB's problems. Like Imhoff tanks, when pretreatment and maintenance, even for a short time, are neglected, UASBs are prone to clogging with rags, plastic bags and with compacted sludge or grit, and hence require rigorous management including fail safe pretreatment, frequent sludge removal and other maintenance. In the case AIWPS, sludge removal is not often required, clogging is impossible and maintenance is minimal. Thus the main principles and advantages of UASB reactors are realized in advanced facultative ponds with few of the disadvantages and with lower costs.

The helminth ova removal projected for fermentation pits is of particular interest in developing countries where millions of children are weakened by parasites and consequently fall prey to childhood diseases.

The economy of AIWPS results from a number of factors beyond operation and maintenance. For example, consider the cost of reactor volume; reinforced concrete reactors such as settling tanks and digesters are likely to cost $350 U.S. (1990) to $700 U.S. (1990) per m^3. On the other hand, formed earth reactors are likely to cost less than $5 U.S. (1990) per m^3--a hundred-fold less. By using earthwork ponds, large reactor volumes can be created very economically. The microbes involved in treatment are, of course, unaware of the cost of their reactor and, provided the environment is suitable and constant, perform as well in earthwork ponds as they would in the most elaborate digesters. Also since they cost so little, earthwork digesters (fermentation pits) can be made large enough to permit complete digestion and thus the elimination of day by day sludge handling for many years.

CONCLUSION

Development of economical and reliable AIWPS is timely because of the problems small communities now have with financing their treatment systems. The past trend, under government and state subsidies, has been toward complex and expensive mechanical treatment plants, many of which work poorly and are difficult to operate reliably in small communities and developing countries. Now, most government and state subsidies for sewage treatment are being decreased or terminated and economy is becoming a major criterion in the selection or upgrading of a community's wastewater treatment system. Based on our experience at St. Helena and Hollister, AIWPS, when properly designed, are not only economical and effective, but also attractive and nuisance free. For communities in the sunny part of the world, AIWPS can provide a new opportunity to have adequate, simple, reliable and nuisance free waste water treatment with significant opportunities for reclamation and environmental enhancement and at a price most communities should be able to afford.

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