

INTEGRATED ALGAE PONDING SYSTEM

Technical Description

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Introduction

For many years sanitation problems in South Africa were due to a lack of knowledge and correct implementation of environmental control. The same problems now come about again due to, not the lack of knowledge, but to the diminishing resources, communities that cannot afford to cover the basic cost of adequate sanitation control, lack of technical service staff, and the political exploitation of the poor and under privileged. In an attempt to rival more technical-intensive operations such as Activated Sludge, EBRU together with the Water Research Commission (WRC) pioneered development of the Integrated Algae Pond System (IAPS).

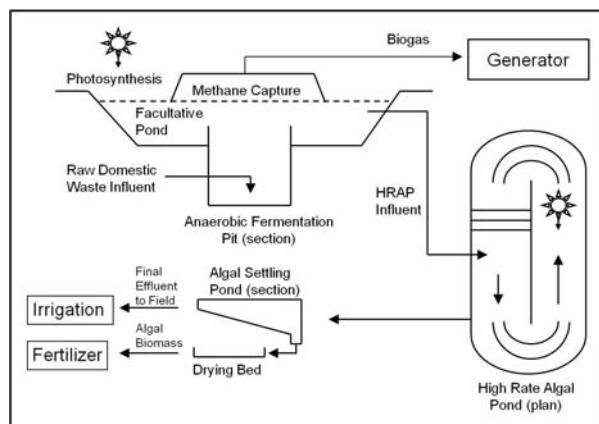
The use of Ponds has become a vital aspect in that they are the most cost effective small- to large-scale reactors available for solar-driven waste treatment, and for the recycling of water, energy and nutrients. IAPS is a derivation of the Pond concept and represents the integration of anaerobic and aerobic biological processes in waste water ponds to effect the treatment process. Microalgae can synthesize high protein biomass at productivities much greater than is possible with land-based agriculture. It is this and related arguments that have been used to strengthen the idea that microalgae utilization would facilitate and improve but lower the cost of producing vital foodstuffs. Likewise, the highly productive microalgae can also be used to treat waste water. In the aerobic treatment of waste water oxygen is required. Oxygen can be introduced into wastewater either by mechanical means (e.g. activated sludge) or by algal photosynthesis. Aeration is the mechanical introduction of atmospheric oxygen into the mixed liquor. This is probably the most energy intensive process in wastewater treatment. To introduce 1 kg of oxygen into the mixed liquor approximately 1 kWh of electricity is required whereas with IAPS, the oxygen is produced photosynthetically from the disassociation of the water molecule by microalgae. This oxygen then becomes readily available to the heterotrophic aerobic bacteria that break down the organic material. Peak dissolved oxygen (DO) has been measured up to 30 mgL⁻¹ in the high rate algal ponds (HRAP). A small amount of electrical energy is required for

microalgae photosynthetic oxygenation and for mixing to maintain the algal cell suspension. This mixing energy is influenced by a number of factors, e.g. raceway size, geometry, surface roughness, velocity, etc. In our experience (EBRU) the optimal gentle mixing velocity lies between 15 and 30 cms⁻¹ and is most efficiently achieved by a rotating paddlewheel. In this system the power requirement for photosynthetic oxygenation lies between 0.075 and 0.15 kWhkg⁻¹ oxygen produced. Also, the paddlewheel mixed HRAP promotes the flocculation of the algae for the rapid settlement and removal of this biomass in the algal settling pond (ASP).

Historical Development of IAPS

Advanced Integrated Wastewater Ponding Systems (AIWPS) was developed over a period of 40 years by Professor William Oswald and his coworkers at the University of California, Berkley, USA.

Following a visit to California by staff of EBRU and, followed up by visits by Dr. Oliver Hart, Professor Oswald was invited to visit South Africa where he lectured to select audiences at various venues on the principles and concepts of AIWPS. These visits resulted in a Water Research Commission (WRC) Project; 'Appropriate low-cost sewage treatment using the advanced algal high rate oxidation pond.' The project commenced in 1994 with technology transfer, design and construction of an IAPS demonstration and research facility at the Environmental Biotechnology Experimental Field Station now, the Institute for Environmental Biotechnology, Rhodes University (EBRU). The first effluent entered the plant at the end of February, 1996.



The rationale behind the project was to demonstrate the technology under South African operating conditions and at the same time to provide an engineering support base in the development of IAPS process applications in the treatment of different wastewaters for use both within and outside of South Africa. A number of such application studies have taken place.

IAPS – A bioprocess technology

Inlet Works (IW) - As with any system of sewage treatment there must be a well designed IW that measures the flow into the plant, preferably with flow recording, adequate screening that caters for the removal of plastic material and a grit or detritus channel in duplicate – one operating, one cleaning. The IW protects the fermentation pit from buildup of inert solids. A standard design as shown in most text books is suitable to precede the IAPS.

Primary Facultative Pond (PFP) - The PFP incorporates the Fermentation Pit (FP), also known as the Anaerobic Digester (AD). The sitting of the FP in the base of the PFP is one of the salient features of the IAPS design. Correct placement overcomes most of the inherent problems experienced with anaerobic lagoons and creates a host of additional benefits. The FP is relatively inexpensive to construct and, as such, can be made much larger with longer Hydraulic Retention Time (HRT). With the longer HRT the need to heat the FP is, if not eliminated, greatly reduced. To reduce the necessity to handle and dispose of large amounts of sludge, the volumetric capacity of the FP is increased over the standard



rate of 0.03 m^3 per capita to 0.45 m^3 per capita which ensures complete breakdown of biodegradable solids. The raw sewage, after

screening, enters at the bottom of the FP, which should be at least 6 m below water level. A “berm” wall protrudes 1.5 m above the PFP floor level and 1.5 m below water level. This makes the PFP 3 m deep in the center. The “berm” wall helps to direct the gas flow and to prevent the intrusion of oxygen rich water into the FP which could disrupt the fermentation process. The upflow velocity in the FP is low, $1.0\text{-}1.5 \text{ md}^{-1}$. This allows the solids to settle and at the same time the parasites (e.g. helminth ova, worms, etc.) will remain in the sludge at the bottom of the FP.

During the fermentation process gases are formed which adhere to the solids in the pit and cause these to float. As the bubbles rise they expand and break away from the solid particles, allowing the solids to resettle to the bottom of the pit. This in turn creates a sludge blanket through which the wastewater must flow. The FP may also provide for the removal of toxic organic compounds and Endocrine Disruptive Chemicals (EDC) although this has not been rigorously tested. Heavy metals will also remain in the FP and are precipitated as metal sulphides.

'Facultative' indicates a pond anaerobic near the bottom, overlain by an anoxic layer, with an oxygen rich algal layer near the surface. The algae at the surface take up, or sequester, the carbon dioxide and nitrogen produced in the anaerobic fermentation. This improves the methane content of the biogas to greater than 80%. At the surface, the oxygen and algae entrap and oxidize malodorous anaerobic gases, preventing them from venting to atmosphere. The surrounding PFP HRT can be designed using a temperature dependant first order decay rate for residual BOD, usually between 15 and 20 days. The construction of the outer PFP is important to reduce short circuiting of the FP overflow to the PFP outlet, which is situated between 0.5 and 1.0 m below the water surface to prevent and/or reduce skimming off of floating material and algae.

Consideration must also be given to water surface erosion protection and the provision of a scum ramp at water level in a down wind direction. Recirculation of oxygen rich algae from the HRAP back to the surface of the PFP is not required. The algae in the HRAP flocculate and, as the PFP surface is not mixed, the algae tend to

settle to the bottom of the PFP. Algal growth in the PFP should be left to develop on its own, which will result in an algal consortium better suited to the PFP surface conditions.

High Rate Algal Ponds (HRAP) - The flow from the PFP goes to the HRAP, where it is subjected to photosynthetic oxidation. The HRAP is a shallow, paddlewheel-driven, continuously mixed raceway, providing profuse algal growth, resulting in a high rate of photosynthesis, elevated pH (up to 11) and dissolved oxygen (DO; up to 3 times saturation), for the heterotrophic bacteria that break down the remaining dissolved organic matter. Most nutrient is assimilated into the algal biomass and at the elevated pH, other mechanisms reduce nutrient load. Phosphate is precipitated and the ammonia in the gas or volatile form is stripped off. Some nitrate is denitrified during early morning anoxic conditions. Nitrogen uptake or the lack of it, as speculated in the literature remains a bit of a problem. At a HRT of 6 days, complete disinfection is accomplished even in winter conditions. The debate as to the mechanisms involved and which is more important continues. With the naturally occurring conditions such as; pH, DO, sunlight, predation and temperature, together with design features; HRT sedimentation and starvation complete disinfection will be achieved.



It is considered that a combination of parameters is essential for optimum disinfection management in the HRAP. Work not done, but expected to show, is that the pond depth can be increased during winter conditions where a longer HRT is required. During winter the algal growth density is less and therefore light penetration greater, allowing for a deeper pond. The inverse is then true for summer conditions. For the most effective treatment EBRU has found that two or

more raceways in series is required.



Pond Mixing - Mixing, or turbulent flow, is essential to maintain optimum conditions for maximum production of microalgae in the pond. Apart from preventing thermal and oxygen stratification, the gentle paddlewheel mixing maintains the surface velocity required to keep the algae and algal flocs in suspension near the surface within the sunlight penetration depth and allow the larger bacterial flocs to use the photosynthetic oxygen and move more slowly along the lower section of the HRAP. In our raceways 50 mms^{-1} is sufficient to achieve destratification and to hold the algae in suspension and eliminate settling. A 50 mms^{-1} channel velocity is very difficult to maintain due to frictional losses, especially in the bends. We have found that a velocity of $200-300 \text{ mms}^{-1}$ is required and that the increased turbulence enhances growth of the biomass. On the downside however, more velocity requires substantially more energy. See Oswald 1988a and the Manning equations for frictional coefficients.



The power installed to drive the paddlewheels is a function of raceway length, wetted area, method of construction and channel velocity. Remember; friction increases as the square of the velocity increases.

For raceway mixing the paddlewheel is, possibly by far, the most efficient means of consistently maintaining channel velocity. The paddlewheel is a pump and as such power must be applied to overcome the static head required to overcome the frictional head loss in the raceway. Design and construction of the volute for the pump (paddlewheel) is of utmost importance. The closer the tolerances, the more efficient the pump becomes. Accurate grouting is required to achieve this efficiency. This is done by forming the radius of the sump with the wheel. By turning the wheel in the concrete before it sets then raising the assembly a few millimeters. This is done by means of jacking bolts, which allows the clearance between the wheel blade and the sump radius. As the static head in front of the paddlewheel is higher than that behind it, the water will tend to slip backwards. To help overcome this, an 8 paddle configuration should be used in the design and construction of the paddlewheel. The other important consideration with an 8 blade wheel is the reduced shock on the drive and mounting assembly, compared to a wheel of fewer blades. Going to more blades becomes impractical and does not significantly increase efficiency. With these close tolerances, foreign objects such as and especially stones become a problem as they find their way into the raceway. To maintain an even velocity around the 180 degree bends it is necessary to include flow rectifiers. Otherwise there is buildup of biomass in the corners due to uneven flows. This buildup will cause increased bacterial growth, resulting in a decline in algal productivity. The biomass also becomes anaerobic. Various methods of flow rectifiers have been tried, teardrops, reverse teardrops, etc. The method that EBRU determined as most successful is the concentric semicircle walls placed 1 m apart. If the raceway is lined, the walls are simply built over of the lining material. Walls do not require any other foundation. Unfortunately, small eddy currents persist behind the centre wall but there is no simple inexpensive method to eliminate these. These however, do not present any major problems.

Algal Settling Tank (AST) - The biomass produced in the HRAP must be removed and this is done easily using an AST. The outflow from

the HRAP, due to paddlewheel mixing, flocculates and settles rapidly in a well designed AST. The settled solids or algae biomass do not decompose and can be kept in the tank for several weeks. The settled biomass is removed to drying beds or to a thickener tank if and when required. This is done by decanting the supernatant and then pumping the slurry out of the holding sump. The accumulation of slurry along the bottom of the tank floor is squeegeed into the slurry sump. A HRT of 0.5 d is sufficient for adequate settling. The residual algae remaining in the supernatant should be removed by other means, depending on sophistication. Algal slurry, typically 2.5 to 4 % is a valuable product and can be easily valorised further into one of many products/applications.

Drying Beds (DB) - If required, a standard and simplified design is sufficient. EBRU uses a coarse gravel support media with geofabric overlay. Multiple beds allow for extended wet periods. The slurry can be stored in the slurry sump in the AST for extended periods, weeks, if necessary.



Resource Utilization (RU)

A waste remains a resource for which a use has not yet been found. The IAPS design allows for the useful recovery of valuable resources e.g. nutrients, biomass, energy and water. This RU could offset much of the cost of wastewater treatment. For example, the FP can be designed to facilitate the capture of methane rich biogas by means of a submerged gas collection hood. The biogas is methane rich because the carbon dioxide and nutrients have been sequestered by the overlaying microbial biomass. To increase biogas production, algae biomass produced in the HRAP

can be recycled back to the FP. Rule of thumb; 1 kg algal biomass will generate methane equivalent to 1 kWh. Energy generated from methane could potentially provide the total electrical requirement for the whole treatment plant and supply a substantial energy input to any national grid. Or, methane could be used directly as a transportation fuel by local communities and for municipal tasks. The algae biomass can also be harvested as a nutrient rich fertilizer, as a foliar feed, as a high protein feed in aquaculture. More sophisticated but easily achieved is the extraction of valuable fine chemicals, oils, pigments, vitamins, and pharmaceutical agents.



An intervention strategy

IAPS is a simple technology with which to upgrade to conventional WSP. It provides an efficient, economic and nuisance-free solution to wastewater treatment. IAPS is inherently simple to construct, operate and maintain with the added potential of resource recovery. IAPS can be designed and built as a modular system and used in various ways to upgrade existing WSP systems. Our design for the upgrade of the Bedford WSP is an example in hand (see attached).

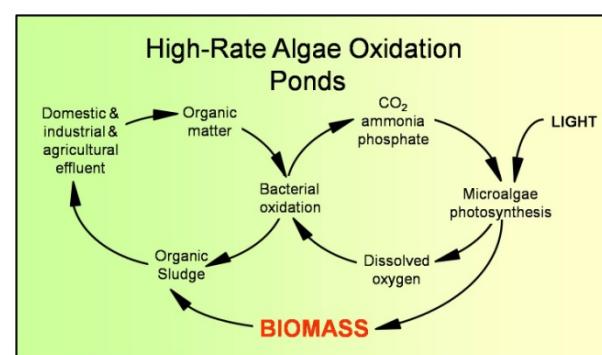
Upgrading poorly performing WWTPs - IAPS can intercept a poor effluent and enhance the quality by taking up nutrients and by

disinfection of the effluent to an acceptable standard for discharge into the environment. The same resource utilization applies.

Other HRAP - The study of the microbial ecology of the saline Waste Stabilization Ponds (WSP) at Mossop Western Leathers Co. in Wellington, South Africa led to the development of the *Spirulina*-HRAP, with a full scale industrial unit erected in Wellington. This unit produced a high quality effluent, and at the same time produced a feed-grade *Spirulina* biomass as a by-product of the treatment process. A *Dunaliella*-HRAP was used to remove organic contamination from saline carbonate brines at the Botswana Ash Co. Sua Pan, Botswana. The *Dunaliella salina* produced in these ponds is a major source of valuable natural β -carotene. The IAPS system demonstrated the effective nutrient and COD removal in the treatment of wine and wine lees wastewaters. Aspects of IAPS have been incorporated into the Algal Sulphate Reducing Ponding Process for Acidic and Metal Wastewater Treatment (ASPAM) Biosure Process, Abattoir, Tannery and others.

Further Reading

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3. Oswald WJ, Green FB. 2005. Apparatus to establish and optimize sedimentation and methane fermentation in primary waste water ponds. United States Patent, US 6923906 B2



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