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BIOLOGICAL REMOVAL OF ALGAE IN AN INTEGRATED POND SYSTEM

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ABSTRACT

A system of oxidation ponds in series with a biological trickling filter is described. It was known that this arrangement was incapable of reducing effectively the levels of algae present in the pond liquid even though nitrification was effected because of autotrophic conditions prevailing in the trickling filters. This very low trophic level explained the lack of adsorptive capacity present.

By shortcircuiting less than 10 percent of the effluent from a fully loaded primary facultative oxidation pond to the trickling filter, the autotrophuc nature or the film in the trickling filter was sufficiently shifted towards a heterotrophic state that had sufficient adsorptive capacity to retain the majority of the algae.

It is concluded that the algae, although being absorbed, stay alive on the film and do not contribute significantly to the carbonaceous load on the trickling filter. Further more the algae, although secluded from all sunlight, actually partake in the purification process, producing an effluent which, unlike a normal humus tank effluent, is surprisingly sparkling clear. This significant observation appears to be in line with laboratory findings by others who, when they artificially immobilised certain species of algae and passed water over them, concluded that the algae retained the potential to remove certain compounds from the water. Conglomerates of biologically flocculated dark-green algae are scoured off the film (or sloughed off as part of the film) and, having been photosynthetically inactive for some days, tend not to float, but settle very rapidly.

A very significantly aspect of this development is the great potential it has for practical application in developing countries. The algae sloughed off the media are easily thickened and available for ultimate recovery from the water phase without the addition of chemicals.

KEYWORDS

Algae; algae immobilisation; algae removal; anaerobic pond-reactor; autotrophic; bioflocculation; facultative; heterotrophic; oxidation ponds; Petro process; trickling filters.

INTRODUCTION

As a wastewater treatment facility oxidation ponds constitute an ``appropriate technology" in developing countries. In developed countries they are seldom considered a full-grown technological alternative to either activated sludge or trickling filters. These latter processes were developed in industrialised countries of the West with cool climates where they have served both urban and rural communities well. Even today the time and effort invested in further research and development of especially the activated sludge process is not only impressive but also very worthwhile. The advances made in the understanding and application of biological of biological nutrient removal and kinetic modelling to mention but two aspects stem from these endeavours in a number of countries.

The role that climate has on the subordinate role that ponds play in certain leading countries is logical. The use of ponds employed as continuous flow-through complete wastewater treatment processes which dependably produce an effluent of tertiary quality is largely restricted to areas where the visible solar energy input is above 100 gram-calories per cm^2 per day 90 percent of the time and where freezing conditions do not persist at any time. However, in South Africa for one, an oxidation pond effluent is not looked upon as an effluent of tertiary quality.

It is worth noting that the above-mentioned climated conditions prevail in over 60% of the earth's habitable land surface which happens to include most of the developing countries where ponds would be particularly attractive. South Africa falls within this climatic zone and oxidation ponds are indeed indigenous to this country. However, here also there have been spectacular advances since the first system was developed in Cape Town as a temporary pragmatic solution to an environmental hazard in ca 1956 (Abbott, 1963). These very large ponds served their purpose well and filled the breach for two decades before an activated sludge facility complete with a first-generation biological phosphorus removal capability and a capacity of 150 Ml/d replaced it in 1976.

It is ironical that while the Cape Town ponds were to be phased out similar ponds based on the very same design concept were inroduced at Tel Aviv, again to fill a breach and to overcome an urgent envrionmental hazard (Folkman *et al*, 1975). These ponds are also now being phased out because of the large area of land occuppied and the quest for an effluent of superior quality suitable for infiltration and extraction for agricultural reuse.

In South Africa an effluent standard based on what a trickling filter can achieve but which pond effluents cannot meet is applicable to all wastewater discharges. Exemptions from this requirement are granted but conditonally and only for very samll operations ($\leq$ 800 m^3/d). These concessions effectively had a stifling effect and for many years no further research and development work was undertaken.

In France where there is a perennial flow in the rivers the situation with regard to effluent standards is very different. Here a more lenient standard, one especially designed for pond effluents, applies (Vuillot and Boutin, 1987), see Table 1. This standard recognises that the COD brought about by algal cells need not necessarily constitute pollution. However, there is that same danger that designers may become complacent and that research and development would not be sufficiently encouraged.

Table 1. Oxidation ponds: effluent quality requirements

	Oxidation Pond Effluent Quality Requirement (mg/ℓ)		South African General Standards (mg/ℓ)
	France	USA	
Biochemical Oxygen Demand	< 40	< 45	< 10*
Oxygen Absorbed (4 hours)			< 10
Chemical Oxygen Demand			< 75
Suspended Solids	< 120	< 80	< 25
NH_4 - N	-		< 10

* South Africa has no BOD standard but the stipulated OA or COD maxima effectively stipulate a BOD maximum of approximately 10 mg/ℓ.

Note that in France even these relaxed quality requirements can be temporarily exceeded in summer.

INTEGRATED POND SYSTEM

The present interest in devising an integrated pond system that will overcome the apparent inability to produce an effluent of high quality will be welcomed in developing countries. Wherever circumstances permit their use, oxidation ponds offer very substantial advantages, both economical and operational. In South Africa in 1973 Vosloo (1976) introduced the concept of an integrated pond system to exploit its advantages but also to overcome the apparent inability of ponds in isolation to produce a superior effluent. To this end he devised a line-up of an oxidation pond system followed by a trickling filter and humus tank (Fig. 1). This enabled him to omit primary sedimentation tanks, sludge digesters and sludge drying beds. At Elliot, Cape Province, one such installation is still operative today. Unfortunately the trickling filters were incapable of removing substantial amounts of algae and although the ammonias were satisfactorily nitrified the CODs and suspended solids remained unacceptably high (Table 2). Chlorophyll reduction were mostly negligible (Table 3).

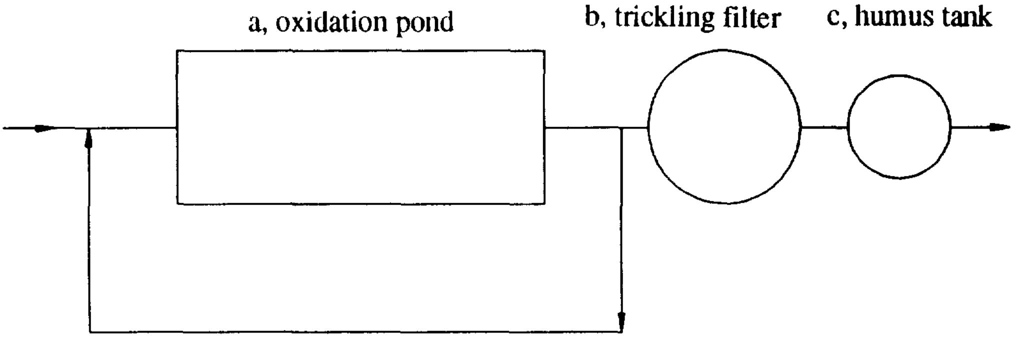

Figure 1. Early South African effort to integrate oxidation ponds and trickling filters.

Some 10 years ago, Oswald followed a similar approach in California. His efforts were similarly unsuccessful. The algae passed through the biological trickling filter virtually unabated (Oswald, 1993).

As a yardstick of the effect that algae in suspension have on the COD of a pond effluent the following equation could be used as a rough approximation:

100 μg/l of chlorophyll α give rise to 5.6 mg COD/l

ALGAE REMOVAL

When a relatively new facultative oxidation pond system at Kanyamazane in Kangwane designed to serve a community of 20,000 had to be replaced in 1976 because of its substandard effluent quality the first author endeavoured not to abolish the ponds but convert them into an integrated pond system. However, being aware of Vosloo's aforementioned lack of success because of the inability of the biological film on the filter media treating oxidation pond effluent to adsorb algae he designed an adjustable facility which would allow the operator to increase the percentage of readily available organic matter present in the feed to be biological trickling filters. The revised flow diagram is shown in Figure 2A and some performance results subsequently obtained in Table 4 (Meiring, 1993).

TABLE 2 : Elliot Analytical Results Snap Sample 11 February 1993*

Parameter (mg/ℓ)	Sampling Point		
	Applied on filter	**Underflow from filter**	**Removal Percentage**
COD	190	138	27%
OA	28.2	21.3	25%
DOC	84	45	46%
SS	102	52	50%
NH_4 - N	27.2	6.3	77%
Kjeldahl N	35.3	14.8	58%
NO_3 - N	0.2	22.2	-

* (Meiring, 1993).

Table 3. Algal reduction obtained in trickling filter treating oxidation pond effluent (11 February 1993)*

Cells/mℓ	Influent	Effluent	Removal
Blue-green Algae (Spirulina)	22 518	10 039	55%
Green Algae	161 174	67 696	58%
Euglenophyta	860	287	67%
Chlorophyl α	332 μg/ℓ	343 μg/ℓ	0

* (Meiring, 1993).

The biological filter installation at Kanyamazane consists of two trickling filters in parallel. This therefore facilitated experimental work in which a much larger flow could be directed towards one of the trickling filters than to the other one. Suprisingly there did not seem to be much difference between the performance of the highly and lightly loaded trickling filters (Table 5).

Similarly unexpected performace results were also obtained at an integrated pond installation built subsequently at Letlhabile, Transvaal, in 1982. Here the basic flow diagram was somewhat different (Fig. 2B). Again an uneven split of the inflow to the two trickling filters was brought about, and again the performance of the highly and lightly loaded filters were surprisingly similar. It was to be expected that the slime layer on the surface of the biological filter bed would be green since it was exposed to solar irradiation and algae grown quite profusely on the surface, but at Kanyamazane and Letlhabile, when algae were being removed by the filters, the slime had an opaque greenish colour at levels well below the surface where no irradiatioin took place. This colouring of the slime layer was obviously caused by planktonic algae adsorbed onto the slime by microbial activity.

The colour of the humus sludge sloughed off the media or scoured off the film had a peculiar dark green colour and at the same time, the humus tank effluent had exceptional clarity which was superior to that normally associated with the pinpoint floc usually present in humus tank effluents. Associated with this clarity was the formation of well defined clusters of flocculated humus in the triclimg filter underflow. The clusters settled rapidly. Suspended solids concentrations of below 5 mg/l were generally achieved.

PRETREATMENT IN FACULTATIVE OR ANAEROBIC PONDS

Augmentation of the supply of readily available organic matter to stimulate the growth of heterotrophic organisms on the slime layer in the trickling filters as described above was instituted at both Kanyamazane and Letlhabile, in the one instance in a system employing a facultative primary pond with high-rate recirculation and in the other instance in one employing an anaerobic promary pond with low-rate recirculation.

At Kanyamazane it was found that only 10 percent of the outflow from the facultative primary pond was enough to introduce a marked adsorptive capacity in the slime layer in the trickling filters.

The performance of both facultative oxidation ponds and anaerobic stabilisation ponds is dependent on good anaerobic degradation taking place on the floor. Anaerobic biodegradation in either system can therefore be greatly enhanced by improving bacteriological activity in the bottom layers of both these pond types.

TABLE 4: Kanyamazane: Performance of Integrated Pond System (11-08-1992)

Cells/mℓ	T.F Influent	T.F. Effluent	T.F. Removal	HTE mg/ℓ	Overall Removal
Blue-green algae	140 600	25 020	82%	28 340	80%
Green algae	46 600	4 350	91%	6 080	87%
Euglenophyta	59 200	2 110	96%	1 380	98%
Chlorophyll α (μg/ℓ)	859	65	92.4%	89	90%
DOC (mg/ℓ)	28	9.4	66%	9.3	67%
COD	103	57	45%	43	52%
COD (filtered)	76	44	42%	45	41%
OA	14.9	8.6	42%	6.6	56%
TKN	18.1	0	100%	0	100%
TKN (filtered)	13.2	0	100%	0	100%
NO_3 - N	-	15.6	-	15.6	-
Suspended Solids	45	25	45%	0	100%
Alkalinity	160	50	-	50	-

TABLE 5: Kanyamazane: Performance of highly and lightly loaded Trickling Filters (23 August 1993)

Analyses mg/ℓ	Final Pond Effluent	Filter Inflow	Filter 1 Underflow (3 Q)	Filter 2 Underflow (1 Q)
Suspended solids	46	42	23.0	28
COD	150	150	96	80
COD (filter)	-	-	36	28
OA 4 hours	12	13	9	9,5
Kjeldahl-N	28	19.5	5,6	5,6
NH_3 - N	24	18.5	4.0	3.8
NO_3 - N	0.3	3.2	26	31
Chlorophyll α ($\mu g/\ell$)	155	118	21.5	21.5
Phaeophyton α ($\mu g/\ell$)	0	0	38.4	35.3

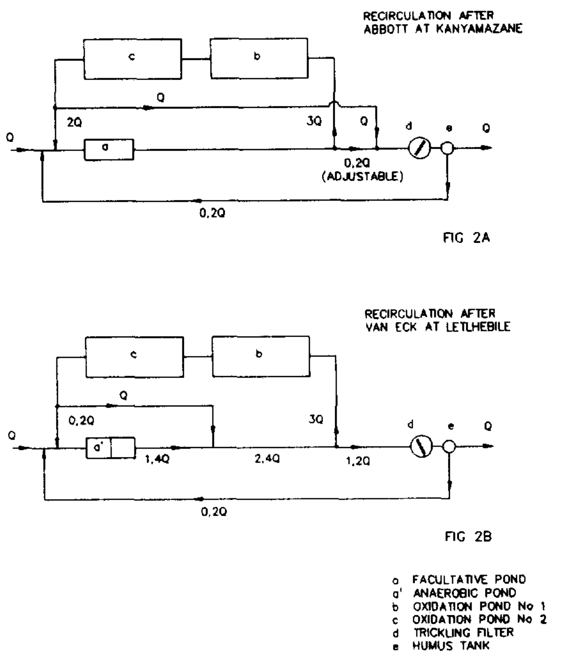

Figure 2. Integrated oxidation pond systems with two different modes of recirculation

The value of a fermentation pit (Oswald, 1991) for the bottom inlet to discharge into, simulating to some extent the flow pattern in an upflow anaerobic sludge blanket digester (UASB), is substantial. It follows that the incoming raw sewage and recycled algae-rich oxidation pond effluent should not enter the pond in the same pipe if on the one hand optimum conditions are required for anaerobic breakdown of organic matter present in the raw sewage on the bottom and on the other hand optimum conditions are sought to ensure an overlay of algae water (Fig. 4). The pond-reactor built at Swakopmund in Namibia is illustrated in Fig. 3 (Meiring and Hoffman, 1994).

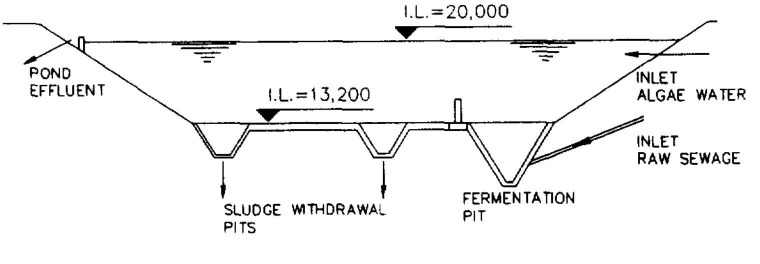

Figure 3. Swakopmund – anaerobic pond reactor.

DISCUSSION

It would appear that the efficient removal of algae by attachment on the film of a trickling filter (TF) receiving a well stabilised oxidation pond effluent can only be accomplished if a certain minimum amount of heterotrophic nourishment comprising readily available organic matter is added to the pond effluent. By supplementing and changing the sustenance available to the biological film, its nature is changed from virtually purely autotrophic to one which is also heterotrophic. It thus obtains the adsorptive capacity which enables it to retain algae present in the pond effluent passing over it.

Associated with the adsorptive capability and greatly improved efficiency of the trickling filters imparted in this way the following significant observations were made.

a) There seems to be little difference in the performance of highly and lighlty loaded filter, loading being expressed in terms of the carbonaceous oxygen demand which to a large extent is brought about by the algae present in the final pond effluent applied on the filters.

b) The biological film attached on the media had an opaque green colour even well below the surface where no photosynthesis was possible. This colouring was obviously caused by algae adsorbed onto the biological film.

c) The underflow from the trickling filters contained humus material but this matter consisted of columinous well defined clusters of a dark green appearance. They settled well. A microscopic investigation revealed a mass of flocculated algae attached onto the film and high chlorophyll α readings in the humus tank underflow were recorded, but also some phaeophytin α.

d) The supernatant was very clear with a clarity typical of the effluent from an activated sludge facility.

Earlier on when looking for an explanation for the effective removal of algae at Letlhabile it was suggested that by passing algal water through a pond covered with scum and therefore secluded from solar irradiatioin the algae would loose its vitality rendering it more amenable to adsorption on the film of a trickling filter. Tests were conducted using chlorophyll α and phaeophytin α as a yardstick to determine the effect of darkness on the longevity of algae. It was concluded that within a perion of 8 days it had only little effect, and therefore from the evidence available it seems that most of the algae attached to the biological film in the trickling filtrer stay alive until they are sloughed off, either in flocculated form as an algae conglomerate, or as part of the film after the mean cell residence time (MCRT), the duration of which still has to be established. The MCRT may fall between 5 and 15 days. It is recognised that the MCRT will be determined by the nutritious value of the substrate applied on the trickling filters. It would also appear that the coherent clusters of sludge present in the trickling filter underflow having been exposed to the dark for a relatively long period are photosynthetically dormant and therefore, having no minute gas bubbles attached to them, show no tendency to float.

Pilot plant work in Kuwait in 1989 (Banat *et al.* 1990) on wastewater treatment and algal productivity in an integrated pond system has certain aspects in common with the present full-scale studies. Again a facultative primary pond was used but, instead of employing biological immobilisation, in complete darkness, of algae on the film of a biological trickling filter, an open-air high-rate algal pond was used as the secondary operational unit. This facilitated the removal of the algae which flocculated and settled fast in separation ponds. Work by Hall (1985) is quoted which relates this phenomenon to the combination of algal and bacterial extracellular polymers forming flocs during the continuous gentle mixing.

De la Noüe *et al.* (1992) reported on work in a way which is relevant to the present development of adsorption, build-up and biological immobilisation of algae on the zoögleal slime in a trickliing filter. Chevalier and de la Noüe in 1985 immobilised two species of *Scenedesmus* in k-carrageenan beads to remove nutrients from wastewater. The growth curves of immobilzed cells of *Chlorella vulgaris* in sodium alginate could be used for sewage treatment, at least at the laboratory scale.

From the clarity of the supernatant in the trickling filter underflow it would seem that bioflocculation is in this respect also playing a significant role.

CONCLUSION

An integrated pond system has been developed which invloves oxidation ponds is series with trickling filters but in a way that renders the biological film on the trickling filter partly heterotrophic. It this enables the film to adsorb and retain in large numbers algae, which otherwise would pass over it quite freely. The algae are not only retained but also form a coherent mass which attaches itself to the film; from here it is sloughed off, either as a separate algal conglomerate or as an integrated part of the film.

Although the algae in the pond effluent make a large contribution to the theoretical chemical carbon load imposed on the trickling filter, this parameter can be misleading in this context beacuse the algae only respire and do not constitute dead material or readily available organic matter which imposes a relatively large biochemical oxygen demand. The effective load on the trickling filter is therefore substantially less than would otherwise be presumed. Indeed, the performance of a ``heavily'' loaded filter does not differ much from that of a ``lighlty'' loaded filter. It is postulated that the algae, whilst forming part of the biological film attached to the filter media, contribute to the overall process of biological purification taking place in the trickling filter. The algae attached to the film act as heterotrophs and also seem to produce a coagulant which adds to the removal of suspended matter in the wastewater and explains the sparking appearance of the final product.

Not enough data is available as yet to put forward optimised design parameters for all aspects of the process. However, much attention must be given to the design of the primary facultative pond which should ideally make use of the upflow anaerobic sludge blanket concept.

The system involved the Petro process which is the acronym for Pond Enhanced Treatment and Operation. The process should satisfy the protagonists of the idea of recovering nutritious matter from sewage, and ties in with work done by others to immobilise algae artificially. The prospect of easy harvesting of algae without the addition of chemicals is most attractive. The concept requires optimization, but should find frequent application in developing and developed countries alike.

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