Preliminary Studies on the Treatment of Canning Factory Effluent With An Integrated Bacterial-Algal-Fish System*

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Abstract

Laboratory experiments were done to determine whether an integrated bacterial-algal-fish unit could be employed for water reclamation and fish production utilizing canning factory effluent. The effluent with a mean pH of 4,5, BOD of 528 mg ℓ^{-1} and COD of 3 116 mg ℓ^{-1} was fermented at 37°C for 24 h, led through photosynthetic bacterial and algal units and finally fed to fish. At a retention time of 8 days in each unit the COD dropped by 98% and the pH increased to 7,8. Water from the algal unit complied with South African standards for drinking water regarding BOD, COD, PO_4-P and NH_4-N. *Oreochromis mossambicus* efficiently filtered suspended unicellular algae from the water. Uptake rate per 100 g living fish mass increased from 50 mg (dry mass) algae per h at 10 mg algae per ℓ to 600 mg h^{-1} at 80 mg ℓ^{-1}. At low feeding rates up to 98% of the algae were ingested and 70% assimilated but no or negative growth occurred. At higher feeding rates a lower percentage was ingested and assimilated but growth occurred.

Introduction

Organic waste from feedlot systems, breweries, canning factories etc. is becoming a source of environmental pollution in South Africa and will become increasingly so with the rapid expansion of these activities and greater demands on our already limited water resources. Treatment of effluent to remove these organic wastes by conventional methods is expensive. Studies done in various parts of the world have shown that part of this cost can be recovered by employing a treatment process that incorporates fish to utilize the organic waste either directly or indirectly (Allen, 1970). Authors such as Kobayashi and Tchan (1973) have shown that photosynthetic bacteria can be utilized to treat industrial waste solutions of high BOD value and the same process was employed in the present study to convert the organic waste into fish food.

This paper describes the results of preliminary laboratory studies which are aimed at determining whether

- photosynthetic bacteria can utilize canning factory effluent as a nutrient source, and if so, whether this will reduce the organic loading;
- algae can be produced on the residue from the photosynthetic bacteria and whether this will further reduce the organic loading; and
- fish can be used to harvest the algae in suspension and how effective the conversion is.

Materials and Methods

Effluent obtained from the Langeberg Canning Factory at Ashton was fermented in aspirator bottles at 37°C for 24 h which resulted in the production of fatty acids. Photosynthetic bacteria were grown on the fatty acid rich product and algae on the effluent from the photosynthetic bacterial unit. The photosynthetic bacteria and algae were grown under artificial light in round open plastic containers which were filled to the 8 ℓ level. The contents of both was mixed continuously with the aid of magnetic stirrers. One litre of algae were harvested and one litre of fermented effluent added daily giving a retention time of 8 days. The chemical oxygen demand (COD), biological oxygen demand (BOD), chlorophyll *a*, total suspended solids, PO_4, and NH_4 were determined every second day according to Standard Methods (1965).

Algae obtained from open algal culture units of the Institute for Environmental Sciences were used for the experiments with fish. Two algal feeding fish species namely Mocambique tilapia (*Oreochromis mossambicus*) and silver carp (*Hypophthalmichthys molitrix*) were obtained from the Lowveld Fisheries Research Station at Marble Hall. Preliminary studies were done with both species but because tilapia adapted better to laboratory conditions and were easier to handle the results described are restricted to this species.

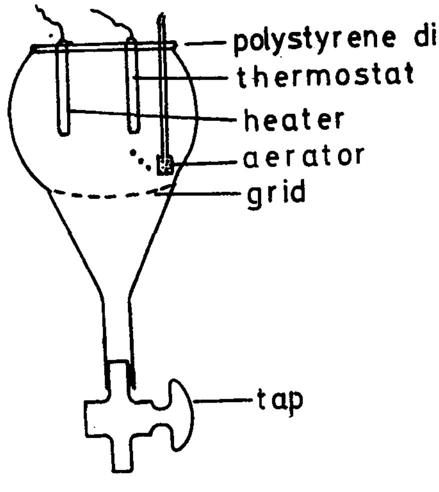

Figure 1
A diagram of the container used for feeding trials

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The fish were kept in round 15 ℓ perspex bowls attached to a 20 cm glass funnel with a tap at the bottom (Fig. 1). A plastic grid was placed in the mouth of the funnel and the top of the bowl was closed with a polystyrene disc from which a thermostat and heater were suspended. The temperature was maintained at 22 – 25°C. Chlorinated tap water was used. Because the faeces sank down to the bottom of the funnel these could be collected by opening the tap at required intervals. The amount of algae in the bowl or suspension extracted was determined by subsampling. The subsample (usually 100 mℓ) was filtered through 0,47 μ pre-wetted, dried and weighed membrane filters which were then dried and weighed again to determine the dry mass of the subsample.

Both *Chlorella* and *Scenedesmus* were available from local experimental algal culture units but because *Chlorella* tended to sink down to the bottoms of the aquaria only *Scenedesmus* was used for the feeding trials. Aeration and the movement of fish helped to keep the *Scenedesmus* in suspension and observation showed that settling was negligibly small.

To determine filtering rates a quantity of algae was added to the aquarium with a known mass of fish and the algal concentration determined at hourly intervals. These experiments extended from 08h00 to 16h00 and the aquaria were cleaned daily. The fish were weighed at weekly intervals.

The trials on assimilation and conversion rates extended over several days. The fish were fed 5 ℓ of a known density of algal suspension at 08h00, 12h00 and 16h00 giving a retention time of approximately 1 day. Faeces were collected during these three periods. The fish were weighed at approximately weekly intervals or more frequently if deaths occurred.

Before each series of trials the fish were acclimatized for a period of one to six weeks until they seemed to feed rapidly. Handling and the unnatural conditions obviously affected the results.

Results

Treatment of effluent (Table 1)

The mean COD of the effluent was 3 116 mg ℓ^{-1}, it dropped to 225 in the photosynthetic bacterial unit and to as low as 60 in the algal unit. Ninety four per cent of the COD was therefore removed in the first and 98% in the second step. The relatively high COD value obtained on 16/7/81 was probably due to the poor algal growth during this period. Addition of PO_4 and NH_4 improved the algal growth with a resultant reduction in COD. For the rest of the experimental period algal growth remained good without the addition of nutrients.

The mean BOD value in the effluent of 528 mg ℓ^{-1} was reduced to 170 in the photosynthetic bacterial and 41 in the algal unit, giving a mean BOD removal of *ca.* 92%.

The mean total suspended solids (TSS) value changed from 1,3 g ℓ^{-1} in the effluent to 1,8 g ℓ^{-1} in the photosynthetic bacterial unit and 0,09 g ℓ^{-1} in the algal unit.

The mean Chl *a* value in the algal unit was 673 μg ℓ^{-1}. More work will have to be done on the factors affecting algal growth in this system. The data in Table 1 do not suggest a shortage of NH_4 and PO_4. The pH of the effluent increased from 4,5 in the effluent to 7,8 in the photosynthetic bacterial unit.

Filtration rate of algae by fish

Observations showed that both species of fish rapidly filtered suspended *Scenedesmus, Chlorella* and photosynthetic bacteria from the water. Figure 2 shows the rate at which tilapia removed suspended *Scenedesmus*. Although the rate was reduced at low algal densities, removal continued to densities of as low as 2,5 mg ℓ^{-1}. A 100 g of tilapia is capable of cleaning 15 ℓ of water with an initial concentration of 70 mg ℓ^{-1} within a period of 5 to 7 h.

TABLE 1
CHANGE IN THE QUALITY OF CANNING FACTORY EFFLUENT AFTER FERMENTATION AT 37°C FOR 24 h AND TREATMENT IN PHOTOSYNTHETIC BACTERIAL AND ALGAL UNITS AT RETENTION TIMES OF 8 DAYS AND TEMPERATURES OF 20—24°C

Day	Fermentation unit BOD mg ℓ^{-1}	Fermentation unit COD mg ℓ^{-1}	Phot. Bact. System BOD mg ℓ^{-1}	Phot. Bact. System COD mg ℓ^{-1}	Algal System BOD mg ℓ^{-1}	Algal System COD mg ℓ^{-1}	% Removal BOD	% Removal COD
1	520	2 610	50	77	20	76	96	97
3	530	2 611	50	38	40	38	93	99
10	515	2 995	180	192	30	38	94	99
12	518	3 379	250	345	10	38	98	99
14	540	3 379	190	230	10	38	98	99
19	555	3 456	280	499	100	115	82	97
21	515	3 379	190	192	76	77	85	98

Day	Fermentation unit TSS g ℓ^{-1}	Fermentation unit Chl a μg ℓ^{-1}	Fermentation unit NH_4 mg ℓ^{-1}	Fermentation unit PO_4 mg ℓ^{-1}	Phot. Bact. System TSS g ℓ^{-1}	Phot. Bact. System Chl a μg ℓ^{-1}	Phot. Bact. System NH_4 mg ℓ^{-1}	Phot. Bact. System PO_4 mg ℓ^{-1}	Algal System TSS g ℓ^{-1}	Algal System Chl a μg ℓ^{-1}	Algal System NH_4 mg ℓ^{-1}	Algal System PO_4 mg ℓ^{-1}
1	1,2	–	1,8	0,50	1,8	–	8,1	0,82	0,09	859	1,6	0,81
3	1,2		1,8	0,67	1,9	–	1,5	0,82	–	790	1,5	0,89
10	1,2	–	1,5	0,78	2,0	–	3,1	0,83	0,10	859	1,9	0,90
12	0,9	-	1,5	0,76	0,4	-	2,8	0,77	0,16	695	1,2	0,60
14	1,2		1,1	0,82	2,3	–	1,2	0,82	0,05	695	1,2	0,65
19	1,2	-	1,8	0,80	2,2	–	1,1	0,92	0,03	10	1,4	0,85
21	2,0		1,9	0,60	2,0	-	2,4	0,63	0,09	803	0,9	0,80

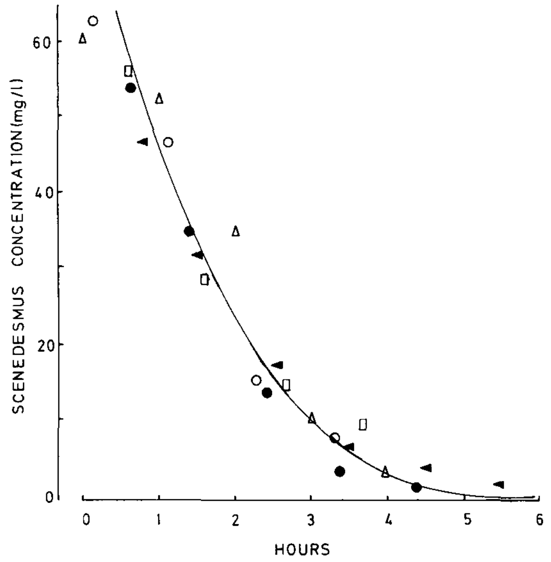

Figure 2
Rate of Scenedesmus *removal by 6,3 g ℓ ⁻¹* Oreochromis mossambicus *at 22—25 °C in five different feeding trials (each symbol represents a different feeding trial). The line was fitted by hand*

Figure 3 shows that filtration rate decreases with a decrease in algal concentration from 0,6% (dry mass) of body mass (wet) per h at a concentration of 80 mg ℓ^{-1} to less than 0,1% at concentrations below 10 mg ℓ^{-1}. A linear regression line fitted to the data is described by the equation: intake rate (% of body mass per h) = 0,0497 + 6,4284 x algal concentration (g ℓ^{-1}) (r + 0,7554). Scattering of the points is probably increased by natural feeding rhythms and the effect of unnatural experimental conditions.

The percentage suspended solids removed from the water within an 8 h feeding period varied depending on the feeding rate and frequency (Fig. 4). At low feeding rates they removed as much as 98% of the suspended solids. At a feeding rate of 1,4

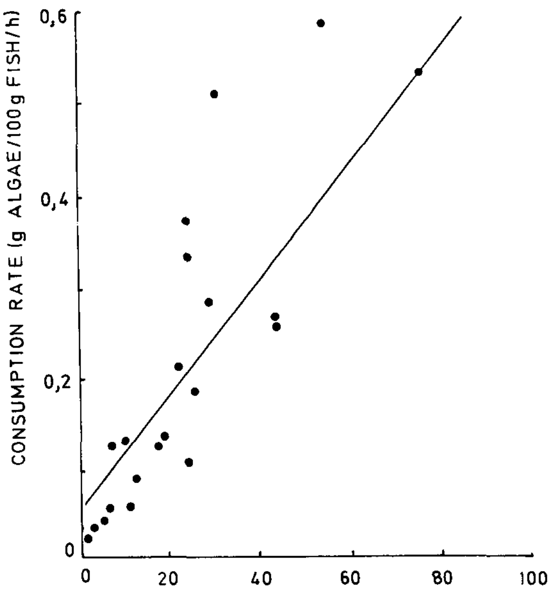

Figure 3
Relationship between the concentration of Scenedesmus *and its consumption rate by* Oreochromis mossambicus *in 15 ℓ tanks at 22—25 °C*

— 1,8% (dry) of body mass they removed 1% of body mass within the first 3 h. Even with two feedings (08h00 and 13h00) of ≃ 1% of body mass each, they removed over 90% of the algae within the trial period.

Assimilation and conversion rates of algae by fish

Only three preliminary experiments extending over periods of 8, 4 and 5 days respectively have been done. During the first trial tilapia consumed on average 1,9% (dry mass) *Scenedesmus* of wet body mass per day of which 43% was assimilated and 6,1 % converted into fish flesh (dry). During the second trial 1,2% of body mass was consumed, and 69,7% assimilated but negative growth occurred. In the third period they consumed 3,0% of body mass, assimilated 59,8% but only converted 4,3% into fish.

Discussion

It was found that photosynthetic bacteria can utilize fermented canning factory effluent as a nutrient source and so remove most of the organic load. Algae grew well in series with the photosynthetic bacteria, but unknown factors might cause growth inhibition. This requires further investigation. Outflow from the algal unit complied with South African standards for drinking water regarding BOD, COD, PO_4-P and NH_4-N (Hattingh, 1977).

Locally available algal-feeding fish were capable of filtering up to 98% of suspended solids from the water. Although *O. mossambicus* grew on algae, the results were variable and more work will have to be done to eliminate possible experimentation errors, the influence of unnatural conditions and the effect of mating behaviour which took place in these trials.

In three preliminary trials tilapia assimilated between 43 and 70% of *Scenedesmus* ingested. The conversion ratio varied from negative to 6,1%. Mironova (1974 and 1975), who fed the same species on dried unicellular algae found assimilation rates of 24—25% and conversion ratios of 1,9 and 11,4%. Pandian and Raghuraman (1972) fed *O. mossambicus* on tubifex and found the conversion ratio to be between 24 and 28%. According to Bowen (undated) this species assimilates 56% of the organic content of detrital aggregate consumed. In other cichlids Moriarty, C.M. and Moriarty (1973) and Moriarty, D.J.W. and Moriarty (1973) found that *Sarotherodon niloticus* assimilates from 43—60% of phytoplankton ingested. According to the last mentioned author the maximum possible assimilation efficiency could not be higher than 80% due to the nature of the food. Gophen (1980) reported that *S. galilaeum* fry assimilated 67% of suspended algae. He found no growth when this fish fed on chlorophytes at a daily rate of 0,45% of body mass and a conversion efficiency of 17% when they consumed 2% of body mass *Peridium* per day.

The results obtained during this preliminary study therefore fit in with the above published data and from this one can make preliminary predictions on the efficiency of tilapia in an effluent treatment system. The fish unit will have two objectives, namely water purification and protein production. If the fish is fed suspended algae at a low rate they could remove 98% of the suspended matter and probably assimilate between 70 and 80% of this. It should be possible to design a fish holding system that separates the faeces, which drop to the bottom, from the main water column and in this way virtually all the organic matter could be removed. However, under these conditions the fish will not be able to consume sufficient algae for

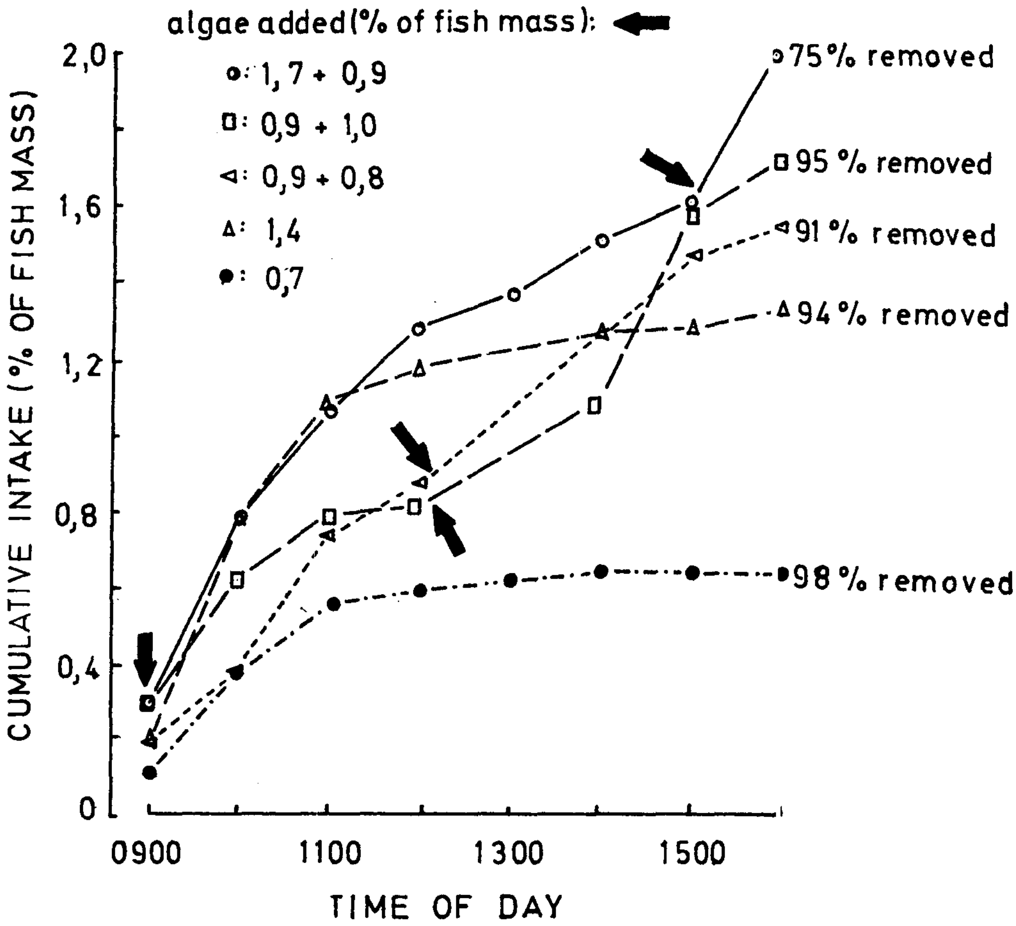

Figure 4
The rate of Scenedesmus *removal by* Oreochromis mossambicus *at different feeding levels in 15 ℓ aquaria with 6 g live fish per ℓ*

maintenance and growth, and no growth will probably occur. As the feeding rate is increased fish growth will take place but the percentage organic matter removed will drop. The fish part of the system can be simplified by feeding the algae to a combination of algal feeding and benthic feeding fish in earthern ponds. The benthic feeding fish such as carp or labeo will then feed directly on the faeces which will aid further breakdown. Microbiological decomposers will speed up this process and should also serve as an additional food source to both fish groups.

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