Disposal of wastewater from Modderfontein Factory: review of the biological nitrogen removal systems

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Abstract

Progress in the treatment of wastewater from Modderfontein Dynamite Factory during the past twenty years is reviewed. Strong effluent is sprayed onto about 2 000 ha of pastures as a nitrogenous fertiliser and the hay is fed to cattle. The effect of the spraying programme on the grass and on the land is discussed. With the expansion of the factory two ponds to denitrify part of the effluent were commissioned, using molasses as a carbon source, but the operating costs are high and every effort is being made to reduce arisings to enable the land to cope satisfactorily with the nitrogen load. Weak effluent is currently discharged to stream but an extensive investigation into its use for growing algae is being undertaken. Following pilot plant work a 1 ha demonstration plant has been commissioned to enable the technical and commercial viability to be determined. It is concluded that the spraying scheme has proved itself as a means of disposal of strong effluent and that the denitrification ponds should only be used to deal with effluent peaks. The use of algae to remove nitrogen from weak effluent is likely to prove technically feasible and less costly than alternative methods. Nitrogen losses from the factory are already very low and further reductions are likely to be too costly to be justified. Applications of the Modderfontein nitrogen removal systems to other industries are feasible.

Introduction

Modderfontein Dynamite Factory was established in 1896 to manufacture explosives for the South African mining industry, then in its infancy. With the growth of the mining industry over the years the production of explosives and the basic chemicals required for explosives and explosives accessories has increased tremendously, and Modderfontein Factory is today the largest commercial explosives factory in the world. The recent increase in the gold price has triggered further demands, some of which will have to be met by newly-established decentralised explosives factories.

Up to the 1930's the nitric acid requirements for the manufacture of explosives at Modderfontein were met by reacting imported Chile saltpetre (sodium nitrate) with sulphuric acid. It was only in 1932 that the country's first synthetic ammonia, nitric acid and ammonium nitrate plants were commissioned. Extensions to these plants were needed to cope with the demands not only for explosives but also for general chemicals and fertilizers, particularly after the end of the second world war. In 1958 the second ammonia plant was constructed, together with nitric acid and ammonium nitrate facilities and a new urea plant. In 1973 it again became necessary to extend the nitrogen production, this time by means of a 1 000 t/d ammonia plant (today still the world's largest ammonia from coal plant) and additional nitric acid, ammonium nitrate and limestone ammonium nitrate plants. In 1978 a second 600 t/d nitric acid plant was commissioned.

In the meantime the explosives and explosives accessories plants also had to be extended almost continually. In 1977 a significant change was made in the manufacture of nitroglycerine which had hitherto been made in a batch process. In the interests of safety a continuous semi-automated process was introduced and today all the nitroglycerine is produced in such plants. The continuous process does however give rise to a larger amount of nitrate in the wastewater than the batch process.

This paper reviews the progress made in the last 20 years in controlling the nitrogen in the wastewater from the factory.

Water Requirements and Early Wastewater Disposal

A series of dams constructed on the stream flowing through the property was sufficient to supply the water requirements of the growing factory until 1928, when it became necessary to purchase water from the Rand Water Board to supplement water drawn from the dams. Today the factory uses about 39 000 m^3/d of Rand Water Board water and 1 500 m^3/d of recovered sewage effluent from Johannesburg's Northern Works, together with 6 000 m^3/d of partly recycled dam water.

There are no records of what was done in the early days with the wastewater from explosives manufacture; it is likely that it was allowed to run to waste on the extensive factory site. With the construction of the chemical plants a collection system was set up, together with evaporation dams for explosives effluents and for chemical effluents. These dams sufficed until 1962.

Early legal requirements

With the passing of the Water Act No. 54 of 1956 the previous emphasis on the use of water for irrigation fell away and the use of water for industrial purposes was recognized, if not exactly encouraged, in a country perennially short of water. The Act provided for standards to be drawn up for discharges to public streams and in 1962 these standards were gazetted. The Act also laid down that permits had to be obtained for the use of water and for the disposal of effluents.

In 1958 the African Explosives and Chemical Industries (AECI) factories at Modderfontein, Somerset West and Umbogintwini started collecting the effluent data called for in the Act. Once the standards were gazetted it was clear that special measures would have to be taken at Modderfontein to meet the requirements of the then Department of Water Affairs in order to obtain the necessary permits.

One of the first measures taken was to engage the National Institute for Water Research (NIWR) of the CSIR on a study of the water usage and wastewater disposal at Modderfontein. Later an AECI team was set up and each plant was critically examined to see whether its effluent could be prevented, reduced or recycled. Remaining effluents were segregated into "weak" and "strong", according to nitrogen concentration, the weak effluent being regarded as suitable for discharge into the stream and the strong requiring treatment.

Treatment of Strong Effluent

Strong effluent, defined as containing more than 100 mg/ℓ of nitrogen, arises partly as the result of spills and leaks of solids and liquids, and partly as the result of the processes used for the manufacture of the products. The initial steps taken were to prevent spillage or leakage where possible and, if feasible, to arrange for the re-use of the materials where such losses could not be prevented. Processes were examined to see whether there was any economic way in which the inherent arisings could be prevented or recycled. This left a residue which had to be catered for and the most urgent task was to develop a scheme for its disposal. Many methods were considered e.g. evaporation, distillation, ion exchange, electrodialysis, only to be discarded on the grounds of high capital and operating costs. As the strong effluent consisted mainly of calcium and ammonium nitrates and sulphates the eventual choice was to use it as a liquid fertilizer to be sprayed on veld and sown pastures. There were two main reasons for accepting this method. Firstly, there were 1 500 ha of suitable ground within the factory area on which effluent could be sprayed and secondly, the company had the expertise and experience in the use of nitrogen on pastures. For more than 30 years AECI's agricultural scientists had led the way in research on the application of fertilizers to veld and sown pastures.

Sown pastures

Past research work had sown that *Eragrostis curvula* (weeping lovegrass) made good response to high levels of nitrogenous fertilizer applied to the soil. Not only did the yield of grass increase, but also the quality was much improved. When growing under natural conditions in the local soil type this grass is considered by farmers to be unpalatable and is little relished by stock, but trials had shown that when fertilized with N and P, it became both palatable and nutritious. A factorial experiment to study the response of *E. curvula* to various levels of N, P, and K applied to the soil had been carried out over 3 growing seasons, with nitrogen dressings 0 to 1 400 kg/ha, phosphorus 0 to 350 kg/ha and potassium 0 to 87,5 kg/ha (Altona, 1957). The results showed no significant increase in herbage yields to applications of P or K alone, although there was a significant response to nitrogen and a highly significant interaction between N and P, but no significant interaction between N and K.

TABLE 1
TYPICAL ANALYSIS OF STRONG EFFLUENT (1963)
(All figures except pH in mg/ℓ)

pH	7,3	Cd	0,003
Nitrate as N	1091	Co	0,56
Ammonia as N	1171	Bi	0,05
SO_4	2293	Fe	1,38
Cl	124	K	14
P	Nil	Mg	75
Na	249	Mn	10
Ca	807	Mo	0,08
Cu	0,2	Sb	0,06
Zn	0,9	Sn	0,2
Pb	0,03	Hg	Nil
F	3,9	As	0,01
CN	0,02	Phenols	Nil
Al	0,02	Cr	0,16

Quantity and quality of effluent

In 1963 the effluent arisings from the factory area carried a nitrogen load of 100 kg/h which meant that the quantity of nitrogen that would have to be sprayed on the land would amount to nearly 900 t/a. As the area readily available for spraying was of the order of 1 500 ha, the quantity of nitrogen to be applied per hectare would be 600 kg, which would be given in 3 dressings of 200 kg per dressing.

A typical analysis of the strong effluent is shown in Table 1.

The effluent farming scheme

Between the years 1963 and 1965, *Eragrostis curvula* was established over an area of 1 000 ha and a further 500 ha of natural veld, where rocky outcrops prevented ploughing and the establishment of sown pastures, was included in the area to be sprayed (Lever, 1966). A few paddocks were planted to *Pennisetum clandestinum* (Kikuyu).

In the disposal scheme as it is presently operated the effluent flows along a furrow from the factory to the retaining dam. A pump at the dam site reticulates the effluent through 15 mm pipes to the spray areas, where portable aluminium pipes are connected to headers and the effluent is sprayed onto the pastures through nozzles that deliver 27 m^3/h.

The grass on the veld is grazed by cattle and the sown pastures are cut for hay which can be sold or fed to the cattle in the dry winter months. Different livestock schemes have been tried over the years but in 1975 it was decided to change over to a permanent breeding herd; Drakensberger cows and bulls were bought and at the same time a stud herd was started. In 1980 the number of cattle stood at 1 560 which included the stud herd of 450.

Effect on grass species

The grass area under effluent spray can be divided into sown pastures, predominantly *Eragrostis curvula* and the natural veld.

At the beginning of the project the dominant species in the veld were *Tristachya hispida*, *Heteropogon contortus*, *Andropogon amplectens*, *Brachiaria serrata*, *Cymbopogon excavatus*, *Elionurus argenteus*, Eragrostis spp., *Themeda triandra* and *Trachypogon spicatus*. Over the years the ground cover has thickened spectacularly but a number of species have disappeared such as *Tristachya hispida*, *Brachiaria serrata*, *Cymbopogon excavatus* and *Elionurus argenteus*. These species belong to the more unpalatable grasses that are not eaten by grazing animals during the dry winter months. The grasses that have responded particularly particularly well to heavy dressings of nitrogen are Eragrostis spp. and Cynodon spp. which have become progressively dominant. These grasses are palatable and well grazed during the winter months and because they now dominate the veld, there is little evidence of selective grazing which is apparent in the veld where no nitrogenous fertilizer has been applied.

The carrying capacity of this veld type (Bakenveld) when unfertilized is one large animal unit per 3 hectares. Because of the poor quality of the veld during the dry winter months the grazing animal cannot obtain enough phosphorus and protein from the grass to maintain its body mass. Mass loss over these months is considerable unless supplementary phosphorus, carbohydrates and protein are fed. Not only has the bulk of herbage produced on the sprayed veld increased during the growing season, but also the quality has improved markedly (Table 2). The carrying capacity of this veld is of the order of 2 large animal

TABLE 2 CHEMICAL ANALYSIS OF HERBAGE				
Veld grazing	**% Crude protein**	**% P**	**% K**	**% Ca**
Veld summer	8,5	0,11	0,92	0,32
Veld winter	3,1	0,06	0,46	0,21
Sprayed veld summer	14,2	0,20	1,66	0,39
Sprayed veld winter	7,3	0,09	0,92	0,29
Eragrostis pastures				
Eragrostis summer	6,3	0,09	1,10	0,45
Eragrostis winter	3,8	0,05	0,35	0,39
Sprayed Eragrostis summer	17,9	0,17	1,28	0,24
Sprayed Eragrostis winter	7,4	0,05	0,21	0,41

units per hectare and body mass is maintained over the dry months with the addition of a salt:phosphate lick and supplementary hay.

The sown pastures under *Eragrostis curvula* must be accepted as being semi-permanent with practical life spans of about 10 years. Towards the end of the period *Cynodon dactylon* rapidly takes over from the weakening Eragrostis and the productivity of the pasture declines as the local variety of Cynodon gives poor herbage yields. The only practical remedy is to plough and reseed with Eragrostis.

In operating the scheme particular care is taken to avoid damaging the grass. Overspraying at any one time, particularly during a dry hot spell in summer, can burn the grass and in extreme cases even kill it. Large quantities of nitrogen if applied in small amounts can be tolerated by Eragrostis without any deleterious effects but a single large application of nitrogen can be fatal. A steady lowering of the pH of the soil can also bring about a concomitant decline in the productivity of the pasture.

TABLE 3
TWO-WAY TABLE OF AIR-DRIED HAY (t/ha)

Wet Season	Eragrostis pastures				Veld			
	P0	P1	P2	Mean	P0	P1	P2	Mean
K0	11,4	12,6	14,3	12,8	2,4	5,0	6,1	4,5
K1	11,3	12,8	13,3	12,5	2,5	6,0	6,7	5,1
K2	10,6	12,6	12,6	11,9	2,4	6,9	5,4	4,2
Mean	11,1	12,7	13,4		2,4	6,0	6,1	

Dry Season	Eragrostis pastures				Veld			
	P0	P1	P2	Mean	P0	P1	P2	Mean
K0	3,7	4,7	5,7	4,7	0,9	1,7	1,7	1,4
K1	4,3	5,9	5,6	5,3	0,9	1,6	1,5	1,3
K2	3,5	5,2	6,0	5,1	0,6	0,8	1,6	1,0
Mean	3,8	5,3	5,8		0,8	1,4	1,6	

P1 – 50 kg P/ha   K1 – 50 kg K/ha
P2 – 100 kg P/ha   K2 – 100 kg K/ha

Herbage yields

Phosphorus and potash factorial experiment

The soils in the Modderfontein area are derived from old granite and are inherently poor in phosphorus but well supplied with potash. As the effect of applying large quantities of nitrogen to the soil would result in a great imbalance of nutrients, a phosphorus and potash experiment was laid down on both veld and Eragrostis to establish the P and K requirements and to confirm previous research results.

The results of air-dried hay yields from a growing season with low rainfall and a season with high rainfall are presented in Table 3 as typical responses of *Eragrostis curvula* and veld to dressings of P and K superimposed on areas sprayed with nitrogenous effluent at 600 kg/ha.

There was a response to P but not to K. The yields also demonstrate the superiority of Eragrostis to veld in its response to the nitrogen applied in the sprayed effluent.

Soil properties

Regular monitoring of the soil has taken place over the 18 years the scheme has been in operation. Initially all the sown pastures and veld were given a dressing of phosphate fertilizer because the P status in the soil was low. Subsequent dressings have been given when the soil P dropped below 30 mg/kg. The pH has fallen over the years and periodic dressings of lime have had to be applied to maintain the pH above 4. In general the soil has not shown any signs of deleterious effects resulting from spraying, such as accumulated salts or a high build up of nitrogen (Table 4), and the grasses of the veld and pastures are healthy and growing vigorously.

TABLE 4
SOIL ANALYSES
(All figures except pH in mg/kg)

Pasture	pH (KCl)	P	K	Na	Ca	N ($NH_3 + NO_3$ as N)
Eragrostis 1963	4,5	4	186	50	355	70
Eragrostis 1980	4,0	32	191	35	280	120
Veld 1963	5,0	6	170	40	370	50
Veld 1980	4,3	30	227	36	295	100

Coping with Expansion

As the output of explosives rose (from approximately 82,5 × 10^6 kg in 1960 to 255 × 10^6 kg in 1980) so the quantity of nitrogen to be sprayed increased. To safeguard the position, the feasibility of extending the original 1 500 ha of land under spray to other areas either inside the 4 000 ha factory site, or outside, was investigated. In due course it was decided to conclude a long term lease on an area of about 600 ha adjoining the factory site. The area to be leased was close to the effluent storage dam and could easily be incorporated in the spraying scheme. The effect of the controlled, intensive spraying and cutting scheme of the leased land has been a marked improvement in the food potential of the cut grass.

Denitrification ponds

With the construction and commissioning of the new ammonia plant in 1973 and the downstream plants, the normal water management principles including further cascade uses to reduce consumption were applied (Moffatt *et al.*, 1978). Even though every effort was made to reduce effluent arisings at source the nitrogen load and concentration continued to increase as the new plants were brought on line.

Various other alternative methods of effluent disposal were therefore investigated. Du Pont of Canada, (Climenhage, 1972) claimed that they were able to remove up to 3 500 kg/d of nitrogen from their wastewater by denitrification. The success of their scheme depended however on the fact that their wastewater contained a built-in carbon source in the form of adipic acid together with byproducts. Their process could not be applied to the Modderfontein strong effluent which contains virtually no carbon and so a specific process had to be developed.

Laboratory and pilot plant work on packed and fluidised beds led to the development of a feasible process (Bosman *et al.*, 1978; Bosman and Hendricks, 1981). Following on this work and after experimental work on small ponds it was decided in 1976 to construct a pair of denitrification ponds to reduce the nitrate content of the effluent. During the commissioning period in 1977 250 t of NO_3-N were denitrified and over the following 3 years the amount denitrified in the ponds rose dramatically: 1978 – 425 t; 1979 – 647 t; 1980 – 732 t.

The source of energy used is molasses and theoretically 7 kg (3,5 kg COD) is required to denitrify 1 kg of N in the form of NO_3. Unfortunately the cost of molasses has increased considerably and it is not always in free supply. The ponds are therefore operated only when effluent arisings are greater than normal.

Other means of reducing the nitrogen load in strong effluent

Before the agricultural scheme was introduced in 1963 other means of removing nitrogen had been evaluated. These included extended solar evaporation ponds, evaporation in various types of evaporator with recovery of salts and water, ion exchange and electro-dialysis. None were as suitable from the capital and operating cost point of view as the farming scheme. At various stages, as nitrogen levels increased, the comparison was repeated, also introducing reverse osmosis, multi-stage distillation etc. but the conclusion remained unaltered. The feasibility of railing only the more concentrated arisings of effluent to localities requiring nitrogen fertilizer was also investigated but the railage proved to be too high when compared with the cost of dry fertilizer.

The most successful way of coping with the increased production and therefore the tendency to produce more effluent has been found to be the application of continuous pressure to reduce spills, liquid and solid and to instal recovery systems. Every effort is made by training and motivation to create an awareness of the problems caused by the nitrogenous effluent and so to reduce effluent production at source, e.g. by using no more gland seal water than necessary, by reducing equipment washing to an absolute minimum, by reducing leaks of ammonium nitrate solution and by sweeping areas around the plants continuously so that fall-out from the prilling towers is not washed into the effluent system by rain. The problem with recovery systems has always been the risk of contamination; contaminated nitric acid or ammonium nitrate cannot be used in explosives manufacture. Clean ammonium nitrate spills are now kept separate from contaminated material and are recovered in an AECI designed recycle evaporator commissioned in 1980. Contaminated ammonium nitrate effluent is recovered by using it to dissolve contaminated solid ammonium nitrate to form a 60-80% solution for sale to fertilizer factories.

Disposal of Weak Effluent

The weak effluent system handles stormwater runoff, cooling tower purges, boiler blowdown, etc., all containing relatively low concentrations of nitrogen. The weak effluent, containing about 100 mg/ℓ of nitrogen, (50 mg/ℓ as ammonia nitrogen and 50 mg/ℓ as nitrate nitrogen), is discharged to stream under a permit granted in 1971. In 1978 the then Department of Water Affairs asked for a reduction of the nitrogen level to 40 mg/ℓ, mainly on the grounds that the nitrogen in the effluent, along with that in discharges from other industries and sewage works, was contributing to the eutrophication of the Hartbeespoort Dam, an impoundment of some 2 000 ha, constructed for irrigation purposes and also used for recreation. In 1979 the company was given a period of three years to investigate reducing the ammonia and nitrate nitrogen in the effluent.

Treatment by means of intensive algal culture

Methods for the removal of nutrients present in low concentrations in sewage effluents have been developed but these are applied only in a limited number of regions in the USA and Europe, largely because of the complexity of the methods or the cost involved. No suitable technology exists however for the removal of the much larger concentrations of nitrogen found in industrial wastewater and so this has had to be developed. Extensive research had already been carried out on various processes for treatment of the strong effluent; this simplified the evaluation of the applicability of such techniques for weak effluent treatment. Biological nitrification (Neytzell-de Wilde, 1975) followed by denitrification (Bosman *et al.*, 1978; Bosman and Hendricks, 1981), ion exchange, ammonia stripping and reverse osmosis were all considered but were found to be expensive when applied to weak effluent.

The cultivation of algae has been shown to be a cost effective method for treating domestic wastewater (Shelef *et al.*, 1978) and was considered to be a sufficiently attractive process for further study because the harvested algal product could possibly be sold as an animal feed to help defray the treatment cost. Additional factors which could favour this process are: availability of large areas of land around the factory, a suitable climate with adequate sunshine and a supply of carbon dioxide from a large coal-based ammonia plant.

Development of algal process

Investigations into algal cultivation began using small (0,25 m^2) outdoor tanks, 2 m^2 "miniponds" and a 120 m^2 pilot pond, to establish and quantify the factors affecting algal growth. Nutrient requirements were established, pond operating parameters were optimised, various pond configurations were evaluated and design data for a larger scale plant were determined (Hendricks and Bosman, 1980; Bosman and Hendricks, 1980). From this work it was concluded that algal mass culture was a potentially suitable method for removing nitrogen from weak effluent and that a high quality protein product could be produced.

The amount of nitrogen removed from the effluent was found to be a function of depth. The shallower the pond the greater the algal concentration per unit vulume and consequently the greater the nitrogen uptake per unit volume. Shallow ponds are however thermally unstable and evaporation is likely to be unacceptably high; a compromise was therefore found to overcome these disadvantages and yet achieve the desired degree of nitrogen removal. A system of ponds of decreasing depths was devised where only the last pond was shallow enough to reduce nitrogen levels to the required value (Bosman and Hendricks, 1980; Hendricks and Norton, 1980). This pond configuration of decreasing depths has many advantages over single pond systems. Water losses caused by evaporation and thermal instability – both normally a problem with shallow pond systems – are minimised. The number of harvesting steps is reduced with a saving in primary dewatering cost. In single or multiple pond systems of one depth the algal concentration will reach a maximum value which will depend on the light available. The growth of this algal crop is generally not sufficient to remove large concentrations of nitrogen except in very shallow ponds, since a harvesting step is required to remove the biomass before further growth and nitrogen removal can occur. In the case of ponds of decreasing depths the need for such a step is eliminated. The system is also very flexible as high culture densities in excess of 500 mg/ℓ can be maintained, even under adverse conditions, and variations in both hydraulic and nitrogen loads can be accommodated.

The next stage in the development programme was to prove the feasibility of the process on a large scale and to produce sufficient quantities of product for animal feeding experiments and product marketing trials. In order to achieve these objectives a demonstration plant was constructed with a pond area covering 1 ha.

Demonstration plant

The plant was designed to treat 10 m^3/h of effluent containing about 50-60 mg/ℓ NH_3-N and 50-60 mg/ℓ NO_3-N.

The expected reduction in nitrogen content of the water is 70 mg/ℓ. Ammonia is the preferred form of nitrogen assimilated by microalgae during active growth. Once all the ammonia has been utilised nitrate uptake occurs after a lag phase. In order to overcome this disadvantage the process consists of two stages, one for ammonia removal and one for nitrate removal. Each stage consists of four ponds and the residence time in each of the ponds varies between 2 and 8 days depending on the pond depth and season.

The first pond in the system is plastic lined and the remaining seven are unlined. The unlined ponds were found to be adequately sealed by the biomass within a few days of start-up. Phosphoric acid is added to the effluent to supply growth requirements and CO_2 addition is achieved by means of inline static mixers and spargers in the ponds (Hendricks and Bosman, 1980). Predators such as Daphnia are effectively controlled by means of wedgewire screens on which they are collected. Daphnia can be processed as food for exotic fish species.

The cultures in the ponds are mixed by means of submerged pumps. The water is pumped into the first pond of each stage and flows by gravity to subsequent ponds. The algae-rich water is pumped to the biomass harvesting plant after ammonia removal in the first stage, and the clarified water is pumped to the second stage for removal of nitrate. The biomass is again harvested and the clarified water discharged.

The harvesting process consists of flocculation of the biomass, followed by flotation, centrifugation and drying. The process produces a high quality algal product with a protein content in excess of 50%, the amino acid composition of which compares favourably with other high protein products such as soya bean or fish meal. The biomass production from the demonstration plant is about 150 kg/d on average but the output will vary seasonally.

Animal feeding trials are under way to confirm the nutritional value of the product and to optimise inclusion of levels of algae in animal rations.

Economics of the algae scheme

The major difficulty is the high capital cost which makes it unlikely that the sale of algae could do much more than cover the operating costs. Even taking a credit for the value of the water would not improve the situation much. The scheme is however less expensive than other methods considered, which could brighten the economic picture a little; furthermore there is the possibility of an element of compensation in the prices of the two main products giving rise to the weak effluent.

Before committing the country to an expenditure of the magnitude of R20-30 million one ought, however, to question the validity of the argument that a reduction in the nitrogen level will in fact lead to reduction in the eutrophication of the Hartbeespoort Dam. Nitrogen is the limiting nutrient but the blue-green algae in the dam are able to fix nitrogen. A similar position holds in Australia (Bliss and Barnes, 1981).

Conclusions

Present status of disposal systems

Over the years the effluent farming system has coped well with the arisings of strong effluent; the fertility of the soil has improved, growth of grass is excellent and under careful supervision the scheme could be maintained indefinitely. The denitrification ponds are easy to start up and provide a means of dealing with peak arisings although at considerable cost (it costs more to liberate 1 ton of nitrogen than it does to fix it in the first instance). The algae demonstration plant is likely to prove a technically feasible means of dealing with the arisings of weak effluent. Its commercial viability under current conditions is in some doubt, though it may well be the least costly way to treat the effluent. With the emphasis on reduction of effluents at source the quantity to be treated may well be reduced.

Nitrogen losses

Under current conditions 1 300 t/d of ammonia is fixed at Modderfontein, most of which is used to make nitric acid, ammonium nitrate, limestone ammonium nitrate and urea. In terms of the daily tonnage of nitrogen handled (fixed + oxidised + converted into other products) which amounts to over 5 000 t/d as N, the nitrogen in the strong effluent is about 2,5 t/d as N and that in the weak effluent is about 3,5 t/d as N. The total of 6 t/d reflects a loss in the conversion of ammonia nitrogen to products of only 0,12%. Taking into account that the strong effluent is used to grow grass and raise cattle the real loss is only 0,07%. Looking at it in another way the 6 t/d lost represents an efficiency of 99,9% which is increased even further when the farming scheme is included.

Other applications

The effluent farming scheme has been seen by many visitors, including officials from the South African Iron and Steel Corporation (Iscor). Following small scale experiments at Vanderbijlpark, Iscor has now launched a similar scheme to deal with the nitrogenous effluents from its Newcastle works. The use of denitrification ponds is applicable to industries wishing to treat effluents containing nitrates but could equally well be used to treat high BOD wastewaters by the addition of nitrates (SA Pat., 1976, US Pat., 1978).

By the year 2000 the world's population is expected to reach 6,35 billion with the increase of 100 million people per year (Cole 1981). Food will become more expensive with aquaculture coming to the fore. Algae will probably be grown on a continuous basis in large plants, some of which may be wastewater based, producing a high protein material for animal feeds. Other algae production plants will be based on added nitrogen fertilizers, and will produce algae for human consumption.

With this scenario in mind the continued operation of the 1 ha demonstration plant at Modderfontein, together with any further large developments, will make an invaluable contribution to knowledge and will serve to provide design data for future large scale plants.

Acknowledgements

The authors thank AECI Limited for permission to publish this paper.

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