Biological Filtration of Industrial Effluent Water: A Successful Case Study

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ABSTRACT

The production of 100,000 tonnes per year of synthetic rutile from the processing of ilmenite, coal and copperas (iron sulphate) produces 200 cubic metres per hour of effluent water. A 2.0 hectare biological filter, comprising natural and man-made wetlands, has been built into the last stage of the effluent water treatment system. It is an area of shallow water (<30cm), densely vegetated with indigenous aquatic plants.

Normal effluent water meets stringent quality limits with respect to pH and heavy metals. However, equipment failure and operating errors can allow partially treated effluent to flow out of the final storage dam. In these cases, pH can range from 2.5 to 10.8, with high Fe, Mn, Zn and other metal contents.

The biological filter accepts all liquid discharges from the final storage dam. It has a residence period of 10-12 hours and a flow length of approximately 1400m. After 16 months of operation, its effective pH buffering and metal removal capacities have been proven to last for more than 4 days.

The effectiveness of the biological filter is beyond dispute, although the mechanisms involved are not well understood. It is an efficient, low cost emergency back-up to the engineered water treatment systems but, like any filter, it may need to be cleaned during its lifetime.

The use of biological filters in effluent water treatment systems is strongly recommended to provide a natural back-up in case of human or mechanical/chemical system failure.

INTRODUCTION

Detailed planning for the construction of a synthetic rutile (SR) plant was commenced by Westralian Sands Limited in 1982. To meet legislative requirements of the Environmental Protection Act, an environmental impact study was initiated in late 1982 and published in April 1985. Construction of the plant began in July 1985 and operations began in December 1986. It was through the environmental assessment process that the concept of a biological filter for the treatment of water discharge from an industrial plant was first developed.

The production of synthetic rutile from ilmenite includes the generation of acidic liquid with low pH and high base metal contents and the creation of kiln gas scrubber liquid with moderately low pH and a high sulphate content. Other plant liquids are more benign, but high suspended solids and dissolved ammonium chloride contents occur.

Although an engineered water treatment system was incorporated into the SR plant, the concept of enlarging a small wetland area, manually introducing aquatic plants and directing processed effluent water through this biological filter, was investigated. This paper describes the physical and botanical characteristics of the resulting wetland and outlines its operational history.

LOCATION AND CLIMATE

The SR plant is located near Capel, Western Australia, some 200 km south of the State capital, Perth. The plant site occupies former farming land that had been disturbed by mining operations due to the presence of adjoining deposits of ilmenite, zircon, rutile, leucoxene and monazite. The plant lies upon a complex sand and clay-sand sequence of Quaternary age. Surface and deeper aquifers are of high quality and able to produce large volumes of potable water. Surface watercourses mainly flow in winter, when salinities are low, but some summer flow of brackish quality water occurs. Many farms depend on underground supplies for their stock water, while recreation and conservation values are high for the larger, local watercourses. For these reasons, protection of existing water qualities was an essential requirement for the operation of the SR plant.

The Capel area enjoys a Mediterranean climate of wet, cool winters and dry, warm to hot summers. Rainfall averages 847 mm/annum while evaporation annually averages 1516mm. Average winter temperatures range from 8°C to 20°C, while average summer temperatures vary from 13°C to 27°C..

CONCEPTUAL DESIGN

The use of freshwater wetlands for the removal of nutrients from sewerage and other liquid effluents is well known (1) (2) (3) (4). Although not previously applied to industrial effluent, there seemed no reason why pH and base metal control could not be accomplished in the same manner as for nutrients such as phosphorous and nitrogen.

Studies were carried out at the University of Western Australia (5) (6) to test whether the aquatic plants growing in a small ($<$0.3 ha) natural wetland were capable of reducing pH and metal contents. Pot trials showed that pH buffering was readily accomplished, for example, reductions of 1 to 2 pH units for alkaline waters for up to 27 days. Reduction of metal contents also occurred, but this was thought to be more a physical response to the increase in pH than to any biologically induced uptake of metals by macrophytes or algae.

After detailed evaluation of these laboratory tests, the land surrounding the small natural wetlands was surveyed and its sub-soil profile examined. It was found that approximately 1.0 hectare of land adjoining the existing wetland could be excavated so as to produce contours conducive to a through-flow of effluent water. A narrow 1000 metre drain, originally intended to be an earth-lined channel for removal of the cleaned effluent water, was found to be readily excavated to a 3 to 4 metre width. Finally, the entire area proposed for the construction of the biological filter was underlain by an impervious layer of clay or sandy clay, thereby protecting underlying freshwater aquifers from contamination in the event that the biological filter concept should fail or prove ineffective.

Conceptually, therefore, it was resolved that:

1) within economic and topographic constraints, as large an area of biological filter would be created
2) the site would be densely planted with aquatic vegetation indigenous to the local area
3) biological interaction with the through-flowing effluent water would be kept as high as possible, by maintaining shallow water depths and by oxygenating the flowing water via shallow weirs or baffles running across the width of the biological filter

at selected sites.

DESCRIPTION OF PHYSICAL AND BOTANICAL COMPONENTS

Figure 1 shows that the biological filter has two parts. The U-shaped area immediately down-stream from the solution storage dam (where lime treatment of the mixed liquid effluents causes pH to rise to pre-determined levels with consequent precipitation of metals) covers some 16,000 square metres. It has a central wall of clay in order to direct water flow over the longest possible route through the filter, while five baffles cause agitation and hence oxygenation of the flowing water. Each baffle is made from compacted gravel-bearing clay, an earlier sandy structure proving too incoherent to prevent being washed away.

The second part of the filter is the enlarged drain with a basal width of some 4 metres. The water flows through two culverts and over a V-notch flow-measuring structure, all of which cause turbulence and increase dissolved oxygen levels.

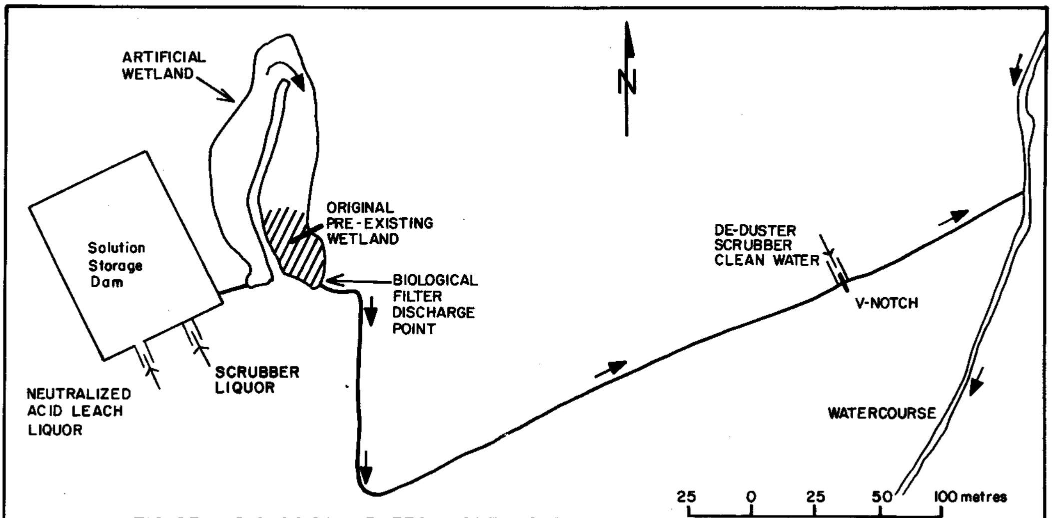

FIGURE I. BIOLOGICAL FILTER, NORTH CAPEL.

Within the pre-existing natural wetland, the following species were (and still remain) dominant (listed in decreasing order of abundance):

Isolepis prolifera - Budding Clubrush
Juncus articulatus
Paspalum dilatatum.

Within the remainder of the U-shaped artificial wetland, all plants were brought in from nearby natural wetlands. A back-hoe excavator loaded 0.5 square metre clumps of vegetation onto trucks which spread their loads onto the dry bed of the wetland prior to plant construction.

Fifteen months after commencement of operations of the SR plant, the following species are dominant:

Paspalum dilatatum
Paspalum distichum - Salt Water Couch
Eleocharis acuta - Common Spike-Rush
Juncus palladis - Pale Rush
Juncus panciflorius - Loose Flower Rush
Cyperus polystachyos

Within the drain section, Juncus varieties and Typha sp. (Bullrush) predominate but, due to a combination of factors including faster water flow in places, only about 60% is vegetated, compared with more than 80% in the U-section.

The effectiveness of the biological filter is believed to depend on a number of biological and physical features. These include the denseness of vegetative growth; the oxygenation of the flowing water; maintenance of a shallow average water depth (approximately 30cm); a climate favourable to the growth of the plant species; water temperatures that are slightly enhanced (2 to 5^{o} C) due to the addition of heated gas cleaning scrubber water from the SR plant; the presence of soil characteristics favourable to the growth of macrophytes; and as yet undetermined conditions that encourage algal growth in certain, restricted sections of the filter.

Research studies have been initiated to explain which of the above features are of greater or lesser importance. However, one of the perceived strengths of this biological filter is its botanical species diversity and the mosaic nature of the vegetation distribution within its U-shaped and drain sections.

The total cost of construction of the biological filter is estimated at A$40,000. University research trials were an additional $4,000, while ancilliary costs have amounted to less than $15,000.

OPERATIONAL HISTORY

Before construction of the biological filter was completed, the reduction kiln within the SR plant required pre-heating. Diesel oil was burnt in it for some 10 days and a pH 3.0 liquid with high levels of suspended carbon particles was produced from the gas cleaning scrubber. From the instant that this water was introduced into the biological filter, natural processes operated to raise the pH to above 6.0 and to allow the carbon particles to be trapped within the dense beds of vegetation.

In the 15 months since start-up, there have been occasional operational problems associated with human error or equipment failure. Figures 2 and 3 indicate the effectiveness of the biological filter on such occasions (7). In July 1987, the pH of the solution storage dam discharge liquid varied from 2.2 to 4.0. Buffering within the biological filter maintained the pH above 5.0 for the six days of this equipment failure, with pH levels above 6.0 being common. In late March/early April 1987, major problems occurred in the acid neutralization plant and pH 3.2 to 4.4 liquid entered the biological filter for over 9 days. For the first 4 days, the filter raised pH levels to over 6.4 before its buffering capacity was exceeded.

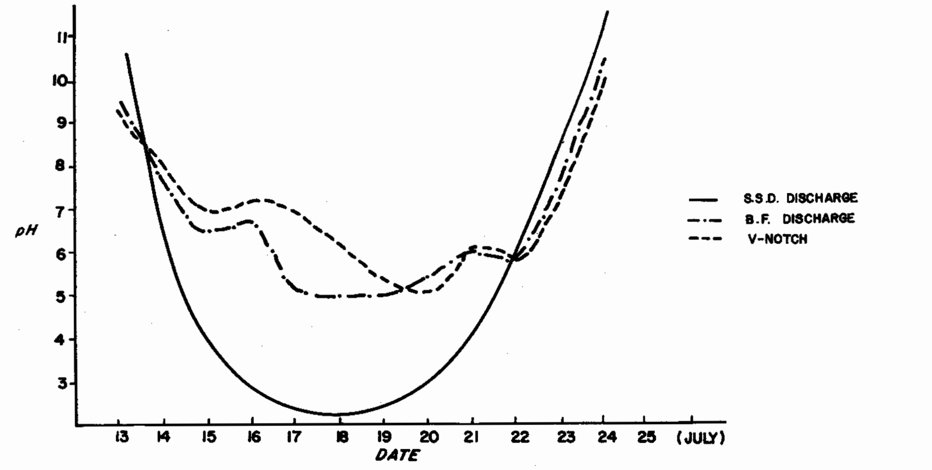

FIGURE 2. pH VARIATION 13/07/87 - 24/07/87.

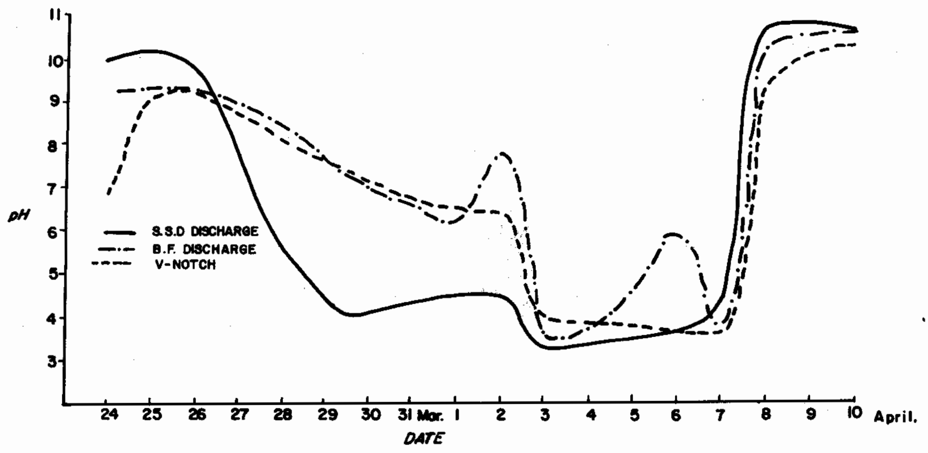

FIGURE 3. pH VARIATION 24/03/87 - 10/04/87.

On other occasions, short-term (2 day) reductions in pH from the solution storage dam have seen no change in pH of final discharge water.

Water quality other than pH was also improved by passage through the biological filter. For the five month period ending 31/07/87, there occurred:

39% reduction in T.D.S.
78% reduction in dissolved Fe
43% reduction in dissolved Mn
21% reduction in dissolved SO_4

Typical water quality after leaving the biological filter is:

pH 6.8	P <0.1mg/l
TDS 1200 mg/l	Cu <0.01mg/l
SO_4 580mg/l	Cr <0.01mg/l
Zn 0.04mg/l	Ni <0.05mg/l
Fe 0.4 mg/l	Pb <0.05mg/l
Mn 2.0mg/l	
Temperature 22°C	
Suspended Solids 20mg/l	Flow 204m^3/hr

FUTURE INVESTIGATIONS

Like any manufactured filter, the biological filter may eventually lose its effectiveness due to the metal uptake capacity of plants and soils being saturated. In this situation, the filter will need cleaning or replacement and, at an estimated cost of less than A$10,000, the existing filter vegetation and soils will be removed and replaced.

Ongoing monitoring will indicate when, if ever, the time for cleaning or replacement is reached. Research is also being carried out on the various mechanisms responsible for the effectiveness of the filter and it is expected that future results will indicate which plant species are most appropriate, what soil characteristics are most desirable and so on.

CONCLUSIONS

For industrial plants that are able to install biological filters at the end of their waste water stream, the use of these cheap, effective emergency back-ups to the standard engineered water cleaning systems is strongly recommended. The list of variables to be considered prior to the construction of a biological filter is large and the resulting filter must be engineered to suit the local conditions of climate and water quality etc.

To date, the filter has proved efficient and effective within the confines of its buffering period (4 to 6 days). The recreation and conservation values of down-stream watercourses have been protected and the filter represents a cost effective investment component of the SR plant.

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