Salinity, Sanitation and Sustainability:
A Study in Environmental Biotechnology and
Integrated Wastewater Beneficiation in South Africa

Volume 3

INTEGRATED ALGAL PONDING SYSTEMS AND THE TREATMENT OF DOMESTIC AND INDUSTRIAL WASTEWATERS

Part 2: Abattoir Wastewaters

Report to the Water Research Commission
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Report to the Water Research Commisson Project K5/658, 'Algal High Rate Oxidation Ponding for the Treatment of Abattoir Effluents'

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FOREWORD

The work presented in this series covers a decade of concerted research into critical sustainability issues in the water-scarce Southern African situation. The provision of safe and adequate drinking water and sanitation services to all our people remains a challenge. Pervasive salination from a range of mining, industrial and agricultural activities threatens the quality of our water resources. Simultaneously, the complex ecological needs of the aquatic environment are being understood with ever-increasing clarity.

Significant progress has been made in meeting some of these challenges. In the years since the democratic elections of 1994, millions of previously unserviced South Africans have been supplied with safe drinking water and sanitation services. The problem of increasing salinity of our water resources, with its direct economic impacts and future threat to sustainability, is being addressed at policy and implementation levels, for example by reduction-at-source measures. The ecological needs of the aquatic environment have been recognised by the provision in our water law of a prioritised ecological reserve, to be managed by the catchment management agencies being formed.

Such promising developments notwithstanding, ultimately sustainable resolution of these issues depends crucially also on acquiring appropriate and affordable technologies that provide physical solutions to our water-related challenges. It is in this context that the research described in this series deserves special commendation for the highly innovative biotechnological linkage developed between the treatment of saline wastewaters on one hand and domestic sewage and sludges on the other.

In the novel approach followed, salinity and sanitation issues are each viewed essentially as a resource base (rather than simply as "waste problems") in a suite of integrated process schemes which can be variously manipulated to deliver products of treated water, recovered nutrients and metals, and algal biomass. The paradigm is consequently changed from one of "managing problems" to one of "engineering opportunities", with the potential of offering a major contribution towards the management of water and sanitation in the RSA - some applications have already been taken to full scale implementation, for example in the accelerated digestion of sewage sludge. Significantly, the achievements of this research add weight to biotechnology as "the" technology of the 21st century.

So, as we approach the World Summit on Sustainable Development, we can reflect on the provisions of Agenda 21 adopted after the Earth Summit some 10 years ago, and note that in this time we have ourselves in various ways "done something" about our own situation. And we can therefore point with a justifiable sense of pride and achievement to the body of work presented here as being "Made in South Africa", at a time when social, environmental, political and economic calls are being made to all of Africa to stand up in the continental and global communities of nations.

My deep thanks and appreciation go to the Water Research Commission for the foresight in funding this work, and, in particular, to Prof Peter Rose and his research team at Rhodes University, for the vision, purposefulness, innovation and application with which this work has been conceived and executed.

Minister of Water Affairs and Forestry
Pretoria
31 July 2002

PREFACE

This report is one of a series of twelve Water Research Commission studies undertaken by the Environmental Biotechnology Group at Rhodes University, on biotechnology and integration in the management of saline and sanitation wastewater systems. Environmental problems in these areas are reckoned to be responsible for six of the seven priority pollution issues undermining the sustainable development project in Southern Africa. While both salinity and sanitation have separately been the subject of quite extensive investigation, relatively little has been reported on the potential linkage of these systems in meeting sustainable development objectives.

At the time these studies commenced, in 1990, focus on the operationalisation of the sustainability idea had identified ‘integrated waste resource management’ as a key requirement for progress towards ‘closed systems’ production. Here human activities, and the associated technological environment, would be detached as far as possible from the bio-physical environment related to natural systems. Waste recovery, recycle and reuse had emerged as major strategies for achieving the radical shift to new technologies which would enable societies to live off nature’s income, rather than consuming its capital. Waste beneficiation (a term still more common in the traditional resources sector, and referring to operations that add value by transforming raw material into finished products), was seen as a means of placing treatment operations on an economic footing, with value added in the form of products and services accrued in the waste management operation.

To meet the time-scale of the sustainability agenda, the breakthroughs in technology required would have to be initiated now to guarantee their availability in the next 2 to 4 decades. This led to widespread use of technology-push approaches in sustainable technologies research.

The principal aim of this programme was thus to investigate potential in environmental biotechnology for the development of technological enablement in the linkage of saline and sanitation wastewater management. This involved initial studies in the biology of organic saline wastewater impoundments, and an evaluation of the recovery of nutrient values in these wastes in the form of high-value bio-products produced by halophilic micro-organisms. Integrated Algal Ponding Systems were investigated as a ‘core technology’ in delivering these objectives.

A critical path research methodology was used to identify technological constraints in the organic saline wastewater treatment operation and served to prioritise the research inputs required to underpin bioprocess development. Studies in the microbial ecology and environmental biotechnology of these systems provided the basis for bio-process innovation, and the subsequent development of treatment processes to full-scale engineered applications.

This series includes an introductory volume which provides an overview of the twelve-year programme to date. The reports are listed inside the front cover, and each study in the series is identified by a ‘racing flamingo’ number, which also appears on the outside cover. This relates to the appearance of a large flock of flamingoes, which took up residence on tannery wastewater ponds following the installation of the *Spirulina*-based Integrated Algal Ponding System developed in the initial studies in this series. The development of the ‘Salinity, Sanitation and Sustainability’ programme is outlined below in Figure P1, and shows studies in the integrated algal ponding of saline, and domestic and industrial wastewaters, leading to the Rhodes BioSURE Process®, which provides linkage in the treatment of sulphate saline wastewaters and sewage sludge disposal.

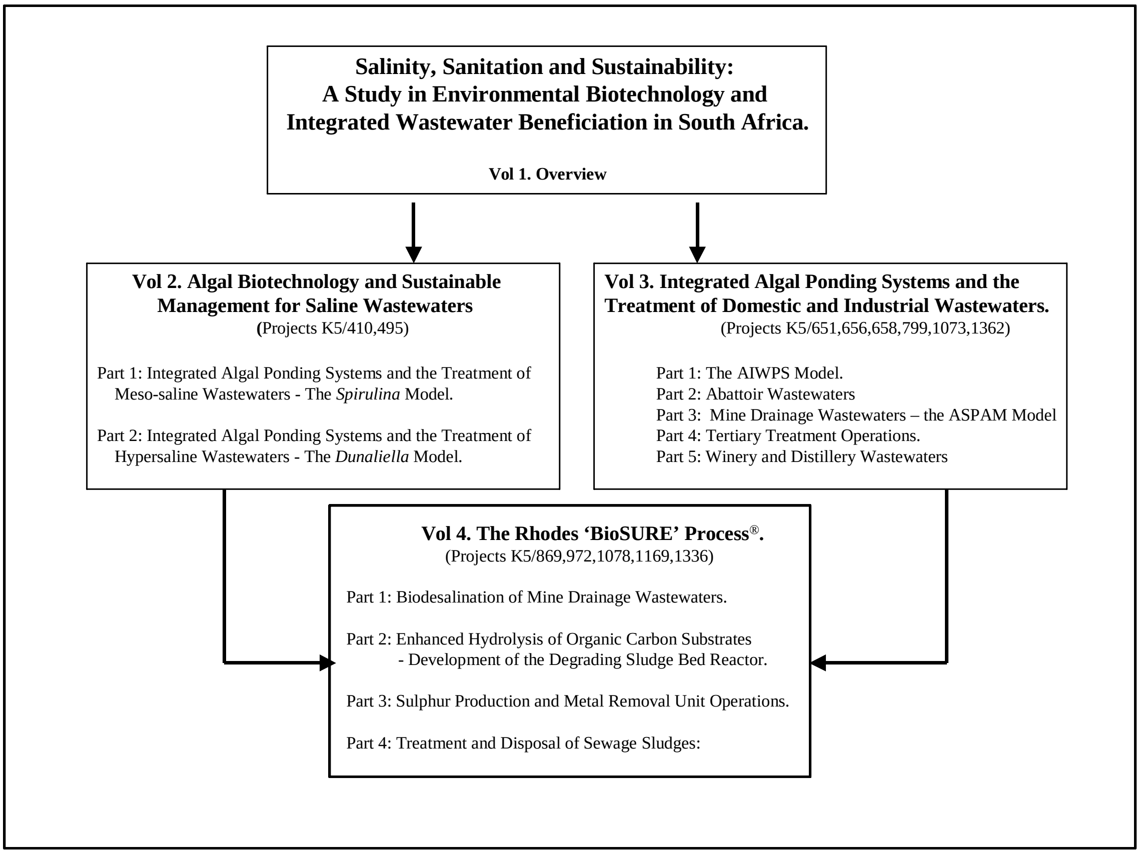

Figure P1. Research projects undertaken as components of the Water Research Commission study 'Salinity, Sanitation and Sustainability'.

A large number of people have assisted generously in many ways in the development of these studies, and are thanked under Acknowledgments. The support of former Water Research Commission Executive Director, Dr Piet Odendaal, is noted in particular. His vision of research needs in water resource sustainability, in the period leading to the Rio Earth Summit in 1992, not only contributed to this study, but also initiated early contributions to sustainable development research in water and sanitation service provision to developing communities. His inputs, together with Research Managers Dr Oliver Hart, Mr Zola Ngcakani, and Mr Greg Steenveld, have made substantial contributions to the development of the ideas investigated in these studies. The contribution and enthusiasm of my post-graduate research students is beyond measure.

Peter Rose
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EXECUTIVE SUMMARY

1. BACKGROUND

The abattoir industry had been identified in the Water Research Commission (WRC) NATSURV study as one of the 14 priority industries in South Africa consuming large quantities of potable quality water and generating high-strength wastewaters (SRK, 1989a&b). The need for water treatment technology development was identified for this sector, and a more recent shift from controlled slaughtering at large central abattoirs, to decentralised small abattoirs, has placed an increasing emphasis on low-cost water treatment technologies.

In 1990 the WRC commenced its support for the development of algal biotechnology-based solutions for the treatment of industrial wastewaters in South Africa, being researched by the Environmental Biotechnology Group (EBG) at Rhodes University, Grahamstown. These studies had investigated 'integrated waste resource management' approaches to water resource sustainability and, by linking value-adding functions to the effluent treatment process, had provided a technological basis for the beneficiation of these wastes. Waste beneficiation in the form of algal bioproducts from the treatment operation serves to convert wastes into resources and thereby promotes 'closed system' management objectives.

The development of an Integrated Algal Ponding System (IAPS) application in the treatment of tannery wastewater was investigated in WRC Projects K5/410 and K5/495 (Appendix 1), which had resulted in the development of an algal-based process linking wastewater treatment and the production of high-value *Spirulina* biomass.

Early in the WRC IAPS applications programme it was recognised that progress in the development of algal-based wastewater treatment applications in South Africa, would require a matching investment in the development of the engineering skills necessary for their construction and operation under local conditions. In this regard the Advanced Integrated Wastewater Ponding Systems (AIWPS) design, developed by Prof William Oswald over nearly 40 years, at the Sanitary Engineering and Environmental Health Research Laboratory Richmond Field Station, University of California, Berkley, USA, was identified as representing one of the most intensively engineered and developed of IAPS-type applications (Oswald, 1988 a&b; 1995). This process application had been principally focussed on sewage treatment and has been found to be particularly attractive in low-cost community development projects. Numerous plants operated successfully in both the USA and developing countries (see Notation for clarification of terminology used).

Following reciprocal visits by Professor Rose and WRC Research Manager Dr Hart, and Professor Oswald, a WRC-sponsored technology transfer project was initiated, Project K5/651: 'Appropriate low-cost sewage treatment using the advanced algal high rate oxidation pond', which commenced in 1994 (Appendix 1). In this project an AIWPS Plant would be constructed at the Rhodes University Environmental Biotechnology Experimental Field Station, at the Grahamstown Disposal Works

(GDW), where IAPS research and process demonstration would be undertaken.

While the projects outlined above were underway, it was decided to commence investigations into the extension of the technology in a number of associated areas requiring development of low-cost wastewater treatment, including abattoir wastewaters. The programme of studies in IAPS applications which followed are noted in Appendix 1.

2. OBJECTIVES

The WRC Project K5/658, ‘Algal high rate oxidation ponding for the treatment of abattoir effluents’ reports the development of an IAPS approach to abattoir wastewater treatment.

The following research objectives were identified:

1. A laboratory study to evaluate the function of the Algal High Rate Oxidation Ponding process applied to the treatment of abattoir effluents (previously demonstrated in treating high protein tannery effluents and sewage);

2. Scale-up evaluation of rate functions for the process in a 5 m^2 outdoor pilot plant facility under semi-laboratory conditions. Both total combined effluent and the polishing of partly treated effluents would be evaluated;

3. Construction of a 500 m^2 demonstration facility at the Cato Ridge Abattoir.

3. RESULTS

The overall objectives of the WRC Project K5/658 were accomplished. Laboratory studies were scaled up from flask to a bench-scale pilot plant investigation, and these results were used to inform the design of the IAPS pilot plant constructed on-site at Cato Ridge Abattoir (Table 1). Although numerous problems combined to constrain the pilot plant study, nevertheless, data from some ten months of steady state operation of the pilot plant were collected. These showed an effective treatment operation, producing an effluent suitable for discharge to a maturation pond or to the municipal sewer. Although the General Standard for discharge to the environment was not reached, it was apparent from the study that this could be well within the reach of the system. Phosphate and nitrogen removal in the High Rate Algal Pond (HRAP), as a tertiary treatment operation, has been the subject of a follow-up WRC study in Projects K5/799 and K5/1073 (Appendix 1). Application of these nutrient removal findings, in the operation of the abattoir IAPS application, would contribute to the process meeting the discharge standard (Figure 1).

Following the experience of IAPS treatment of high organic load, high-protein tannery wastewaters in Wellington (Project K5/495), it was again demonstrated that ammonia toxicity provides an important regulatory function in the process. The impact of ammonia toxicity on the performance of the Fermentation Pit located within the Primary Facultative Pond (PFP) is a potential problem with abattoir wastewaters, and acidification with slow-down of anaerobic digestion in this compartment retards the overall loading rate to the system. This situation could be corrected with either lime addition or recirculation of alkaline HRAP water to the Fermentation Pit. Follow-up studies should include the investigation of these possibilities.

Table 1. Summary of parameters used in the process design for the plant constructed at Cato Ridge Abattoir.

Flow rate:	$42m^3.day^{-1}$
Organic loading average	COD $4600mg.L^{-1}$
Fermentation Pit	
Hydraulic retention time:	5.5 days
Depth:	4 m
Surface area:	$57.8m^2$
Upflow velocity:	$0.7m.day^{-1}$
Primary Facultative Pond	
Dimension water surface:	32m x 27m
Surface area:	$864m^2$
Depth	2.3m
Volume:	$1541m^3$
Hydraulic retention time:	36.7 days
High Rate Oxidation Pond	
Dimension:	86m long 12m wide
Surface area:	$1000m^2$
Water depth:	24.5cm
Volume:	$245m^3$
Hydraulic retention time:	5.8 days
Linear velocity:	23cm $second^{-1}$

Figure 1. The HRAP unit operation of the IAPS pilot plant constructed at the Cato Ridge Abattoir.

4. CONCLUSIONS AND RECOMMENDATIONS

The study has clearly demonstrated the potential advantage of the IAPS approach in the treatment of wastewaters from small and medium-sized abattoirs, and abattoirs located at sites remote from sewer discharge.

The following conclusions and recommendations emerged from the study:

1 While preliminary results show the IAPS approach to abattoir wastewater treatment may be applied with some confidence, and a good quality wastewater may be produced, a conservative approach to design should be followed, in particular with respect to sizing of the system;

2 A longer-term operation of the pilot study would be desireable to further optimise the operational performance of the system, and to derive more accurate criteria for the successful design of these systems;

3 Nutrient removal studies undertaken in the sewage treatment study should be applied to the IAPS in abattoir wastewater treatment to improve the quality of final treated water;

4 Ammonia toxicity and acidification of the Fermentation Pit should be subjected to more critical study, and the use of alkaline HRAP recycle water to control acidification should be further investigated;

5 Studies should be undertaken on the recovery of algal biomass from the HRAP unit, and value-adding opportunities investigated as component operations in an ‘integrated waste resource management’ approach to the beneficiation of abattoir wastewaters.

ACKNOWLEDGMENTS

The authors wish to express their thanks and appreciation to:

- Prof William Oswald without whose pioneering work in the field over many years, and kind and generous support for algal ponding studies in this group, none of this would have been possible. Also his colleague Dr Bailey Green who made valuable contributions in a number of ways;

- The Water Research Commission for finance and support throughout the project;

- ABAKOR (later Multilog) for making available and preparing the site for the pilot plant. Also for their input in kind, such as workshop facilities, provision of pipes, pumps, electricity etc. for the operation of the plant;

- LIRI and Mr Roger Rowswell for design inputs and support;

- Mr Kobus Eloff, Manager of Cato ridge abattoir for his enthusiasm and continuous support of the project;

- Mr Peter Ford, Engineer at Cato Ridge abattoir for his input in terms of the design and construction of the pilot plant;

- Ms Fiona MacTavish (later Mrs Alexander) chief analyst, Cato Ridge laboratory, for the execution of all analytical results and data compiling;

- The project team consisting of:

Professor P D Rose	Project Leader
Mr J R Müller	Project Leader
Dr O O Hart	Researcher
Ms V Shipin	Researcher
Mr B Maart	Researcher

- All those who served or were observers on the Steering Committee, as detailed below, for their able guidance, support and encouragement throughout the research period:

Mr Z Ngcakani	Water Research Commission (Chairman)
Dr T C Erasmus	Water Research Commission
Dr S A Mitchel	Water Research Commission
Mr A C Fritz	Water Research Commission
Dr H M Saayman	Water Research Commission
Professor J R Duncan	Rhodes University
Professor P D Rose	Rhodes University
Dr O O Hart	Rhodes University
Mr J R Müller	Abakor
Mr K Eloff	Abakor
Mr P D Ford	Abakor

Ms F G B MacTavish	Abakor
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Mr G D Hefer	Department of Water Affairs & Forestry
Professor W A Pretorius	University of Pretoria
Professor C A Buckley	University of Natal
Mr I P van Heerden	BBR Enviro Systems
Mr R Rowswell	LIRI

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ABBREVIATIONS

AIWPS	Advanced Integrated Wastewater Ponding Systems
ASP	Algal Settling Pond
BOD	Biological oxygen demand
cal	Calorie
Chl a	Chlorophyll a
COD	Chemical oxygen demand
cm	centimetres
DO	Dissolved oxygen
EBG	Environmental Biotechnology Group
FP	Fermentation Pit
GDW	Grahamstown Disposal Works
g	Gram
ha	Hectare
HRAP	High Rate Algal Ponds
HROP	High Rate Oxidation Pond
HRT	Hydraulic retention time
hp	horsepower
IAPS	Integrated Algal Ponding Systems
L	Litre
m	Metres
MPN	Mean Probable Number
PFP	Primary Facultative Pond
SS	Suspended solids
TDS	Total dissolved solids
TKN	Total Kjeldal nitrogen
t	Time
VFA	Volatile fatty acids
WRC	Water Research Commission
WSP	Waste Stabilisation Pond
WRCU	Water Related Cattle Unit

DESIGN PARAMETER ABBREVIATIONS

A	Surface area
A_{FP}	Area of FP
A_{HRAP}	Area HRAP
$A_{PFP\ mid}$	Mid-depth area PFP
$A_{PFP\ ws}$	Area PFP at water surface
A_{SU}	Area settling unit.
BOD_{ult}	Ultimate BOD
C_c	Concentration algal cells
C_L	Channel length
DA_{ADB}	Daily area requirement of ADB
d_{FP}	Depth fermentation pit
d_{HRAP}	Depth HRAP

d_L	Depth light penetration
d_{max}	Maximum depth
F	Photosynthetic efficiency
h	Heat of combustion of algae
I_{HRAP}	Influent BOD_{ult} to HRAP
I_{SU}	Length settling unit
L_{HRAP}	Loading rate to HRAP
L_o	Organic loading rate
L_{PFP}	Organic load to PFP
PE	Person equivalent
Q	Design flow
Q_{ctr}	Control flow
Q_{HRAP}	Flow to HRAP
Q_{max}	Maximum flow
Q_{Twc}	Worst case total flow
r_{FP}	Radius of fermentation pit
r_{mid}	Mid-depth radius
S	Solar energy flux
TA_{ASB}	Total area ASB
V_{as}	Volume algal slurry
V_{FP}	Volume FP
$V_{overflow}$	Overflow velocity
V_{PFP}	Volume PFP
V_{SU}	Volume settling unit
V_{upflow}	Upflow velocity
W_{SU}	Width settling unit
π	3.1416
θ	Optimal HRT
θ_{FP}	HRT in FP
θ_{min}	Minimum HRT
θ_{PFP}	HRT in PFP

NOTATION

A wide range of terms have been used over the years by different authors to describe various configurations of ponding systems used in wastewater treatment and in algal biotechnology applications. This has created a certain confusion in the literature, and to avoid possible further confusion the following usage has been followed in this study:

- ❑ The term Advanced Integrated Wastewater Ponding System (AIWPS) refers to a specific trade-marked process application design. This ownership of name has been respected and care has been taken throughout not to use the term in a generic sense to cover the many forms of integrated ponding systems involving the use of algal photosynthesis. The term Algal Integrated Ponding Systems (AIPS), and Integrated Algal High Rate Oxidation Ponding Process (IAHROP), which was used in this sense in the earlier part of this study to describe the hybrid algal ponding systems, the development of which was under consideration in this programme, has been changed to Integrated Algal Ponding Systems (IAPS) to avoid confusion;

- ❑ The IAPS is used here to refer generically to combinations of ponding system unit operations involving an algal component in their operation;

- ❑ The term High Rate Algal Pond (HRAP) has been used here and replaces High Rate Oxidation Pond (HROP) used in some literature references, as it is not necessarily inclusive of the algal component;

- ❑ The terms algae or micro-algae are used for convenience in the more traditional sense, broadly covering both the eucaryotic algae as well as the cyanobacteria.

1 INTRODUCTION

1.1 ABATTOIR WASTEWATERS

The abattoir sector, serving both the red and the white meat industries in South Africa, was identified in the Water Research Commission (WRC) NATSURV study, as one of 14 water-intensive industries where water usage and effluent discharge presented problems of national significance and concern (SRK, 1989 a&b). Following a nation-wide audit of these water-intensive industries involved in the NATSURV programme, a series of industry-specific guides to water and wastewater management were published by the WRC. Two of these related to the abattoir industry, and dealt with both the red meat and poultry abattoirs (SRK, 1989 a&b, 1990). It was noted that the use of significant quantities of high-quality water for processing purposes, and the discharge of high strength organic effluents, may have severe impacts on both the environment and the infrastructure required for sewage treatment.

It was estimated in 1992 that the abattoir industry consumed about 7 million $m^3.year^{-1}$ of high-grade potable water, and discharged an effluent of approximately 6 million $m^3.year^{-1}$ to municipal sewers (SRK, 1998). With an organic load in abattoir wastewaters of 4 - 6 $g.L^{-1}$ COD, after screening and fat removal, one water-related cattle unit (WRCU) produces an average 4.6 kg COD. An abattoir processing 1000 cattle $units.day^{-1}$ will discharge a load to the treatment works equivalent to a population of around 46 000 people.

In identifying the pollution problems associated with abattoirs, including the consumption of high quality water in large volumes, the NATSURV reports identified the need in South Africa for the development of a comprehensive effluent management strategy for the industry. Among the principle recommendations was that this strategy should aim at progressively implementing low-cost and low-technology methods for improving the overall quality of the effluent. In addition to good housekeeping practice attention should also be addressed to the final treatment approaches, applied on-site at the abattoir, to ensure a substantial improvement in the quality of the effluent prior to discharge to the municipal treatment works, or directly to the public water system.

In addition to the above, more recent developments have also seen a profound shift in stock slaughtering trends. With the deregulation of the meat industry commencing in the early 1990s, controlled slaughtering at large centralised abattoirs has been replaced, to some extent, by small regional abattoirs slaughtering between 10-100 cattle $units.day^{-1}$. Apart from the dispersion of the abattoir pollution problem, this trend has placed additional burdens on already over-loaded small domestic sewage treatment works, not designed to accept high strength wastewaters. In some cases these may be located beyond the range of any wastewater treatment works at all. This situation has placed further pressure on the need for the development of low-cost appropriate technology to deal with the wastewater treatment needs of the medium to small-sized abattoir.

The WRC project reported here deals with the investigation of Integrated Algal Ponding Systems (IAPS) as a low-cost approach in the treatment of abattoir wastewaters.

1.2 INTEGRATED ALGAL PONDING SYSTEMS

In 1990 the WRC commenced its support for the development of algal biotechnology-based solutions for the treatment of industrial effluents in South Africa, being researched at that time by the Environmental Biotechnology Group (EBG) at Rhodes University, Grahamstown. Advances had been demonstrated in the development of IAPS technology in low-cost saline wastewater treatment, linked to the recovery of algal bioproducts such as β-carotene and *Spirulina* sp. biomass, in 'integrated waste resource management' and waste beneficiation strategies (WRC projects K5/410 and K5/495, Appendix 1). Process development resulted in the construction of a full-scale IAPS plant treating tannery wastewaters at the Mossop-Western Leathers tannery in Wellington, South Africa. The need was identified to effect the transfer of currently best available technology world-wide on the design, construction and operation of IAPS-type processes, with specific application as appropriate technology, low-cost systems for small and developing communities.

Early in the WRC IAPS applications programme, it was recognised that progress in the development of algal-based wastewater treatment applications in South Africa, would require a matching investment in the development of the engineering skills necessary for their construction and operation under local conditions. In this regard the Advanced Integrated Wastewater Ponding Systems (AIWPS) design, developed by Prof William Oswald over nearly 40 years, at the Sanitary Engineering and Environmental Health Research Laboratory Richmond Field Station, University of California, Berkley, USA, was identified as representing one of the most intensively engineered and developed of IAPS-type applications (Oswald, 1988 a&b; 1995). This process application had been principally focussed on sewage treatment and has been found to be particularly attractive in low-cost community development projects. Numerous plants operated successfully in both the USA and developing countries (see Notation for clarification of terminology used).

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1.3 ADVANCE INTEGRATED WASTEWATER PONDING SYSTEMS

The AIWPS system utilises the integration of anaerobic and aerobic biological processes in wastewater ponds to effect the waste water treatment process. Ponds not only provide low-cost reactors, at least an order of magnitude cheaper than concrete structures (Oswald, 1995), but algal photosynthesis yields large quantities of oxygen to support bacterial breakdown of the organic components. Shelef (1987) has noted that these systems epitomise the principles of water and nutrient recycling and close the cycle of waste to primary biomass more rapidly than any other outdoor process; converting organic wastes into an algal biomass rich in protein, while stripping out nutrients. Furthermore, all this is accomplished without mechanical aeration but capitalising only on solar energy and, following algal harvesting, producing a high quality effluent not surpassed in quality by other biological or physico-chemical wastewater treatment processes.

1.3.1 The System

The AIWPS design, in terms of its unit processes operations, is similar to those of conventional wastewater treatment plants. These involve primary sedimentation, flotation, fermentation, aeration, secondary sedimentation, nutrient removal, storage, and final disposal. The methods by which these unit processes are fostered are, however, unique to AIWPS (Figure 1.1).

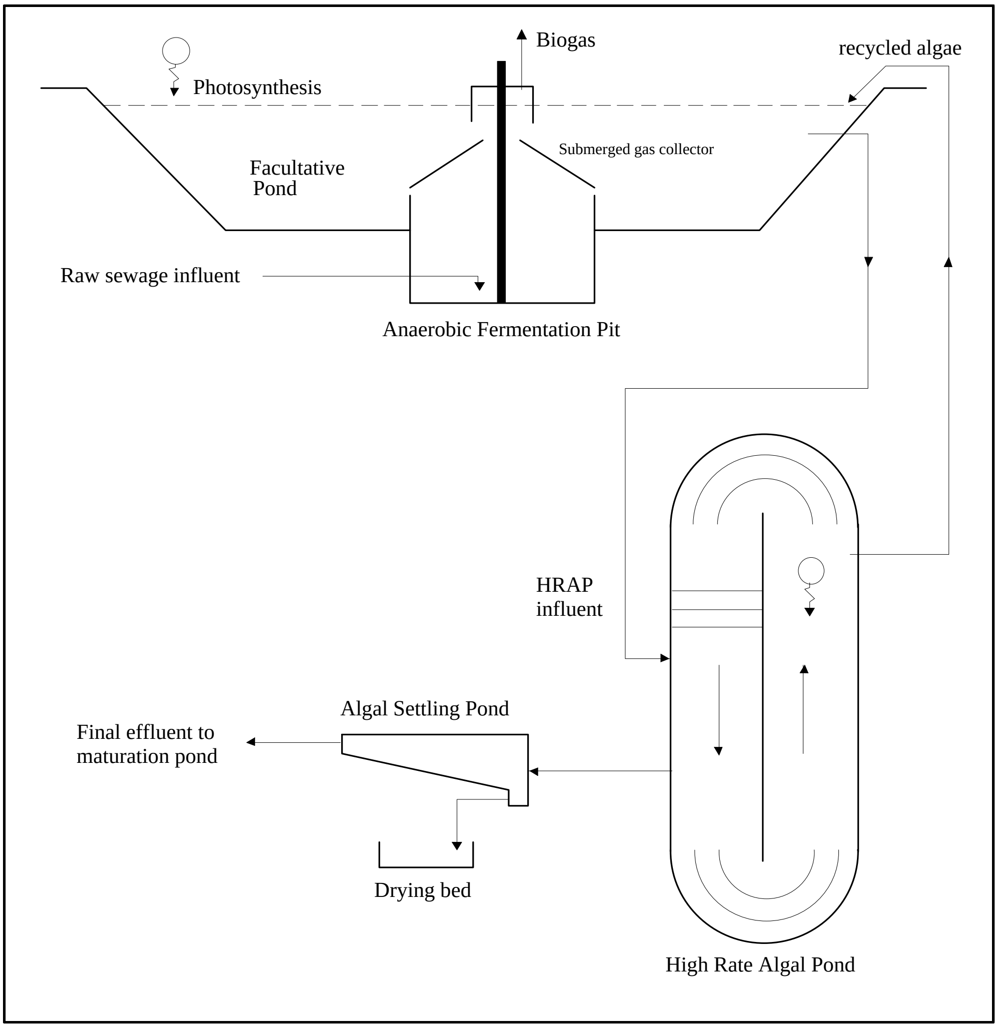

Figure 1.1 Schematic diagram of the Advanced Integrated Algal Ponding Systems design constructed at the Rhodes University Environmental Biotechnology Experimental Field Station.

The system is composed of a four-pond series and for a full discussion of development, concept and design of the AIWPS see Oswald (1988a&b; 1991; 1995).

1.3.2 Primary Facultative Pond

The first of the four-pond series is the Primary Facultative Pond (PFP), in which the anaerobic bottom zone is overlayed with surface aerobic waters, creating thereby two functionally separate compartments in the pond. A chronic problem with conventional Waste Stabilisation Ponds (WSP) has been that during windy periods inversions and water mixing occurs, which carries oxygenated waters into the anaerobic zone, and inhibits the anaerobic digestion processes. Fermentation pits (FP) are constructed in the base of the PFP in which solids sedimentation and anaerobic processes take place, and these are designed with a surrounding berm or wall to prevent the intrusion of oxygenated water.

Raw waste is introduced near the bottom of these pits and, since they are deep (+/- 4 m), most of the settleable solids remain within the pits. Overflow velocity is designed to be low enough (less than $2 m.day^{-1}$) so that most helminth ova and other parasites also remain in the pit. Particulate solids are lifted by bubbles of biogas which form on and in them, but as these rise the bubbles expand and break away leaving the solids to resettle. The result is that solids accumulate within the pits creating an anaerobic sludge blanket through which all of the wastewater must flow.

Carbon dioxide in the biogas becomes available to support algal growth in the upper layers of the PFP, and the generation of photosynthetic oxygen provides, in part, for the aerobic function of this compartment. The upper aerobic layer is also responsible for particularly effective entrapment and oxidation of odour causing compounds. The low-odour characteristics of these systems has enabled their construction in close proximity to urban developments, and has focussed interest in strategies where smaller dispersed wastewater treatment plants replace large centrally located treatment works.

To deal with floatables, PFP are designed with down-wind concrete scum ramps where floatable trash can be cast up by the wind to dry. These substances are largely inert, light in weight and low in odour. They can be collected periodically with a loader for burial or disposal as a solid waste. Since overflowing PFP are constant in depth, bank erosion is best controlled with a paved water line.

Depth is regulated in the PFP by the level of the invert of the outlet pipe. The inlet of this pipe should be located about 1m below the surface to avoid transfer of floatables into the secondary pond.

1.3.3 High Rate Algal Pond

The High Rate Algal Pond (HRAP) provides the most effective design for the second unit operation of the AIWPS. This paddle-mixed raceway requires short retention times of 3-5 days, and produces much more dissolved oxygen than a conventional secondary facultative pond. Algae in HRAP form stable flocs, which settle readily, and > 80% of the algal cells present in the system may be removed in a short residence time Algal Settling Pond (ASP). This biomass has a low respiration rate and may remain concentrated in bottom of the ASP for a period of weeks without releasing significant amounts of nutrients.

Algal photosynthesis in the HRAP tends to raise the pH of the treated waters, and a pH of 9.2 for 24 hours will provide a 100% kill of *E.coli* and most pathogenic bacteria and viruses. It is not uncommon for the HRAP to reach pH levels of 9.5 to 10 during the day, so a high rate of disinfection is normally achieved.

Because a surplus of dissolved oxygen is produced in the HRAP, usually several times the applied Biological Oxygen Demand (BOD), some of this partly-treated effluent is used to overlay the PFP with warm oxygen-rich water. This absorbs odour-causing compounds generated in the FP, and assures the presence of oxygen producing algae in the surface waters of the PFP.

1.3.4 Algal Settling Pond

As indicated above, the HRAP should be followed by an ASP or some other method of removing algae. If the water from the HRAP is to be used for irrigation, algae need not be removed, but settling and storage should be sufficient to achieve a bacterial Mean Probable Number (MPN) $<10^3$ which is sufficient for irrigation waters.

Harvesting and removal of the algal biomass component of the treated water is required prior to discharge into public water bodies, although the algae may be beneficial to the food chain in the local ecosystem. There is little evidence that this biomass is harmful in moving waters. As uses for waste-grown algae become established, such as its use in animal feeds, fatty acid, plant hormone and pigment extraction, the potential exists for adding value to the treatment process and providing an incentive for an ‘integrated waste resource management’ and waste beneficiation approach in wastewater treatment.

Although natural sedimentation of algae from a paddle-wheel-mixed HRAP is sufficient to remove >80% of the algae, if higher degrees of removal are required mechanical harvesting is indicated. In the Grahamstown AIWPS, the settled algae from the ASP is pumped onto underdrained sand beds for drying and harvesting for evaluation purposes.

1.3.5 Maturation Pond

Where AIWPS-treated waters are to be discharged under conditions leading to possible human contact, storage for 10 to 20 days in a deep maturation pond may be used instead of chlorination, and will provide adequate reduction of the bacterial count. The maturation ponds provide valuable wetland environments and are often occupied by wild water fowl, and many other forms of wildlife. These may, however, also impart high but innocuous MPN loads to maturation pond effluents.

2 STUDIES IN ABATTOIR EFFLUENT TREATMENT

2.1 INTRODUCTION

Following the developments described above, including the construction of full-scale IAPS systems for algal ponding-based treatments of tannery wastewaters, and an AIWPS for domestic sewage, the Rhodes University EBG and Abakor Ltd undertook the joint development of the technology applied to abattoir wastewater treatment. At that time (mid-1990s), Abakor owned and controlled 10 abattoirs, and with 40% of the commercial slaughter in South Africa, constituted the largest single operator in the industry. Together with Mr Jerrard Müller, GM Technical at Abakor, the EBG proposed a project for the development of IAPS applications in abattoir wastewater treatment. The Project K5/658 “Algal High Rate Oxidation Ponding Treatment of Abattoir Effluents” was awarded initially as a two-year project to commence in 1995.

The research objectives to be undertaken in this project were identified as follows:

1. A laboratory study to evaluate the function of the Algal High Rate Oxidation Ponding process applied to the treatment of abattoir effluents (previously demonstrated in treating high protein tannery effluents and sewage);

2. Scale-up evaluation of rate functions for the process in a 5 m^2 outdoor pilot plant facility under semi-laboratory conditions. Both total combined effluent and the polishing of partly treated effluents will be evaluated;

3. Construction of a 500 m^2 demonstration facility at Cato Ridge Abattoir.

The principal anticipated research product from the study was identified as low-cost treatment for abattoir effluents. The target group included large, medium and small-sized country abattoirs. The application of the technology was directed at low-cost treatment method for abattoir effluents, with the conversion of waste into an algal product of value.

2.2 RESEARCH APPROACH

While the AIWPS application in sewage treatment had been described by Oswald (1988a), with well-engineered design principles reported for their construction and operation (Oswald, 1988b), little had been reported on the use of the AIWPS process or IAPS generally in the treatment of abattoir wastewaters. The IAPS application developed for the treatment of tannery effluents (WRC Report K5/495) had, nevertheless, demonstrated the treatment of a high-organic load and high-protein wastewater, with the recovery of *Spirulina* biomass as a value-added product of the treatment process. Micro-algal growth rates in these high-organic wastewaters were found to substantially exceed those in control inorganic autotrophic media. Ammonia toxicity, and its control in the use of alkalinity generated within the system by photosynthetic activity, were identified as the important issues to be addressed in this study.

Given the above, and the lack of specific design criteria for the abattoir wastewater application, it was decided to adopt an experimental approach to process development. Flask studies would be undertaken in the first instance to determine whether the algal-based approach could be addressed, and to identify the problems likely to be encountered in the scale-up exercise. Following flask studies, a small bench-scale model system would be designed and operated to confirm the flask studies, and to provide some indication of size requirements for the pilot-plant construction on-site at an abattoir.

It was identified, at the outset, that the pilot plant would need to be designed to be operated in a flexible manner, providing for a wide range of loading rates and volumetric flows through the system. This should provide the opportunity to establish steady state operating conditions and hence the derivation of reliable criteria for the design of the system for abattoir wastewater treatment.

The laboratory and bench-scale model studies were carried out at the Rhodes University Leather Industries Research Institute (LIRI), and the pilot plant was constructed at Cato Ridge Abattoir. This abattoir provided a useful site for the development, given the production of large volumes of wastewater discharging to a conventional treatment works, and the presence of a fairly large balancing dam which could be converted to a PFP at relatively low cost.

2.3 ANALYTICAL METHODS

All analytical procedures relating to results reported in this study were from Standard Methods (APHA, 1989).

3 LABORATORY STUDIES AND PILOT PLANT DESIGN

3.1 FLASK STUDIES

As noted above, laboratory experimental work was undertaken as a first approach to confirming the growth and performance of micro-algae in a number of different abattoir wastewaters samples. A *Spirulina* sp. culture (provisionally identified as *S. platensis*) was sourced from the tannery wastewater treatment IAPS system operating in Wellington, and 500 mL flask studies were set up using abattoir wastewaters sourced from the Port Elizabeth Abattoir. A range of concentrations of wastewaters was used, growth was measured as increase in chlorophyll a (chl a), and treatment performance as reduction in COD achieved over the treatment period.

Although growth did not commence immediately, and did not occur in the undiluted raw wastewaters, it was shown that the *Spirulina* culture could be acclimatised to grow in dilutions of raw abattoir wastewaters over a period of time. It was also shown that adapted cultures could be introduced successfully into increasing concentrations of the wastewaters. Luxurious growth was observed in the adapted cultures, and although carbon fixation productivity values were not monitored, the observation of enhanced growth of this strain in the high protein wastewater was observed in common with the tannery wastewaters experience reported in K5/495 (Rose *et al.*, 2002 a).

3.2 LABORATORY BENCH-SCALE IAPS

Based on these provisional findings, it was decided to proceed to evaluate the IAPS-based treatment for abattoir wastewaters in a laboratory bench-scale model system based on the AIWPS conceptual design. A 270 L two-part ponding system was designed incorporating anaerobic and facultative pretreatment in a primary pond reactor (total volume 170 L, and incorporating an anaerobic pit volume 1 L), and two HRAP units (volume 50 L each) as the secondary stage. Design details for the bench-scale unit are recorded in Appendices 2 and 3, and photograph of the units is provided in Figure 3.1.

Wastewater was also obtained from the Port Elizabeth Abattoir for the bench-scale pilot plant studies. The analyses shown in Table 3.1 are average values for abattoir effluent from the Port Elizabeth Abattoir, which were used for calculation purposes throughout the subsequent bench-scale studies. The plant was set-up and operated in the LIRI laboratories in Grahamstown.

The *Spirulina* culture from the flask studies was acclimatised to the raw abattoir wastewater in the HRAP over a period of 50 days. Although in the integrated system, with the unit operations placed in series, the HRAP would not see raw wastewater, it was considered important to evaluate a worst-case condition in operating the system directly on untreated raw wastewater. The feed rate of raw wastewater was increased from 0.5% to 3.3% HRAP volume.day^{-1} (1.3-3.0 L.day^{-1}). Maximum system hydraulic retention time attained was 30 day (9 L.d^{-1}). The highest algal density obtained in the HRAP was 1650 mg.L^{-1} chl a.

At the same time as the *Spirulina* culture in the HRAP was being acclimatised using the raw wastewater feed, an anaerobic culture was established using sludges from the anaerobic digesters at the GDW. Following the acclimatisation and culture establishment phase, the FP in the PFP was innoculated and feeding with raw abattoir wastewater commenced. Once filled, the PFP overflow was fed to the HRAP.

Table 3.1 Analysis of abattoir effluent sourced from the Port Elizabeth Abattoir. Values in mg. L^{-1} unless otherwise stated.

Parameter	
pH	7.0
Conductivity ($mS.m^{-1}$)	406
Salinity (%)	<0.1
Chemical Oxygen Demand (COD)	6443
Settleable Solids ($mL.L^{-1}$)	114
Total Solids (TS)	9328
Total Inorganic solids (TIS)	2361
Total Volatile Solids (TVS)	7021
Suspended Solids (SS)	5091
Volatile suspended Solids (VSS)	4548
Inorganic Suspended Solids (ISS)	593
Total Dissolved Solids (TDS)	4290
Dissolved Volatile Solids (TDVS)	2472
Dissolved Inorganic Solids (TDIS)	1818
Alkalinity:	
Hydroxide as $CaCO_3$	0
Carbonate as $CaCO_3$	0
Bicarbonate as $CaCO_3$	1484
Total Kjeldahl Nitrogen (TKN)	504
Free and Saline Ammonia as N	168
Sulphide as S	110
Sulfate as SO_4^2	533
Chloride as C1	406
Chromium as Cr	<1
Phosphorus as P_20_5	16
Calcium as Ca	30
Sodium as Na	220

The combined maximum COD reduction obtained in the FP and PFP was 67% (i.e a decrease in COD from an average 6773 to 2126 $mg.L^{-1}$). Further COD reductions were effected in the downstream HRAP with the final filtered (non-algal) COD in the HRAP reduced to 310$mg.L^{-1}$. Total COD removal of 91 - 94% was achieved for the full system under stable operating conditions. The COD of influent was reduced from 6443 $mg.L^{-1}$ to between 399 and 597 $mg.L^{-1}$.

Total ammonia removal of 88% was achieved across the system. A reduction in the ammonia influent of 168 $mg.L^{-1}$ to 19 $mg.L^{-1}$ in the effluent was achieved. Although ammonia removal was efficient it was evident that, as reported for the tannery system (Rose *et al.* 2002a), ammonia toxicity to algal growth provided the principal factor controlling the overall performance of the system. In order to generate oxygenic conditions in the upper layer of the PFP, and to prevent the release of obnoxious odours, a 10% recycle of oxygenated and algae-laden HRAP water was pumped back to the surface of the facultative pond daily.

Figure 3.1 Oleg Shipin examines HRAP components of the laboratory bench-scale pilot plant used to investigate IAPS-based treatment of abattoir wastewaters..

3.3 PILOT PLANT DESIGN

Since no reliable design criteria were available for the use of an IAPS approach to abattoir wastewater treatment, the performance of the bench-scale unit was used as a preliminary indicator of functionality. These results, together with the experience gained in the tannery effluent treatment study (Rose *et al*., 2002a), and the AIWPS Demonstration Plant in Grahamstown (Rose *et al*., 2002b), led to the decision to use aspects of the AIWPS design criteria published by Prof Oswald for the treatment of sewage wastewaters (Oswald, 1988a), in the design of the IAPS pilot plant to be constructed on-site at Cato Ridge Abattoir.

The sizing of the system was dependent in part on the nature of the site available at the Cato Ridge Abattoir wastewater treatment plant. A balancing dam was available to be used as the PFP and, as excavation would have been one of the major costs of plant construction, it was decided that the remainder of the pilot plant should be sized around this unit. The sizing of the unit was also based on the need to be able to operate it quite flexibly over a wide range of loading rates and hydraulic retention times (HRT). The aim of the piloting exercise was to follow an empirical approach in plant operation, and on establishing reliable steady state operating conditions, to then derive the input values required to inform the rational design approach required for the reliable use of these systems in the abattoir wastewater treatment application.

The design was therefore based on first principles as published by Prof Oswald (Oswald, 1988b;1994) and average analysis values for the wastewaters produced at Cato Ridge Abattoir as follows:

3.3.1 The ratio of FP to PFP HRT should not be less than 2:20 days. Given an HRT of 3 days in the Grahamstown AIWPS, it was decided to use a 3:20 day ratio for FP: PFP

HRT.

3.3.2 A pond will be 100% anaerobic when the loading rate is 673 kg BOD_{ULT} ha^{-1}. day^{-1}. To equate load to 673 kg BOD_{ULT} ha^{-1} day^{-1} the following formula was used:

$$\text{Load} = (d/\theta)\ BOD_{ULT} \qquad (1)$$

(where d is depth in metre, θ = HRT in days and BOD_{ULT} in $mg.L^{-1}$).

3.3.3 The FP depth should be 4 metres to allow gas and sludge to separate. The lip around the pit should extend upward for at least 1 metre to prevent wind driven vertical circulation in the pond from dropping cold oxygen-bearing water into the pit.

3.3.4 A well designed PFP with an FP will remove around 60% of the influent BOD_{ULT}, leaving only 40% to be dealt with in the HRAP.

3.3.5 The optimal hydraulic time (θ) in the HRAP (days) can be calculated by the following equation:

$$hC_c = S\ AF\ \theta \qquad (2)$$

Where, h is the heat of combustion of algae in $cal.mg^{-1}$ (taken as 5.5 $cal.mg^{-1}$), S is the solar energy flux expressed in $cal.mg^{-2}.day^{-1}$, and taken as 300 $cal.mg^{-2}.day^{-1}$ for Cato Ridge. C_c is the infuent to the HRAP in $mgL^{-1}BOD_{ULT,}$ A is the area occupied by 1 litre in the HRAP expressed in cm^2, and F is the photosynthetic efficiency of algae taken as 3.5%.

3.3.6 In order to oxidize the influent organic load, the concentration of algal cells (C_c) in a HRAP expressed in $mg.L^{-1}$ is normally set equal to the influent BOD. This rule of thumb includes a safety factor as algae produce net oxygen through photosynthesis in an amount between 1.6 and 1.9 their cell dry weight mass. Using an empirically derived formula, the depth of light penetration (d_L) expressed in centimetres can be determined by dividing 6,000 by the influent BOD:

$$d_L = 6000/mg.L^{-1}BOD_{ULT} \qquad (3)$$

The depth of light penetration is normally 2/3 of the optimal HRAP depth, so the optimal depth of the HRAP (d_{HRAP}) will be:

$$d_{HRAP} = 3/2 \times d_L \qquad (4)$$

3.4 PRIMARY FACULTATIVE POND

The existing balancing dam was constructed as a PFP with size 32 m x 27 m = 864 m^2, and with a depth of 2.3 m.

With an inner slope of 1:1.6 the area of the PFP at mid level will be 29 m x 23 m = 667 m^2 say 670 m^2.

With a depth of 2.3 m the volume of the PFP will be 670 x 2.3 = 1541 m^3.

With a ratio of FP:PFP of 3:20, the volume of FP would be:

$$V_{FP} = \frac{1541 \times 3}{20} = 231\ m^3$$

Specified depth of FP (d_{FP}) = 4 m
At a volume of 231 m^3 and a depth of 4 m the area of the FP (A_{FP}) will be:

$$A_{FP} = V_{FP}/d_{FP} = 231\ m^3/4\ m$$
$$= 57.8\ m^2$$ with a circular FP.

The radius of the FP (r_{FP}) will be:
$r_{FP} = (A_{FP}/3.14)^{½} = 4.3$ m and the diameter will be 8.6 m

3.5 FERMENTATION PIT

The average effluent COD from the balancing dam at Cato Ridge Abattoir over the months October to December 1993 was 4600 $mg.L^{-1}$. The COD: BOD_{ULT} ratio of the effluent was found to be 5:1. Therefore the BOD_{ULT} of the effluent from the balancing dam will be 4600/15 = 920 $mg.L^{-1}$. This figure is used for design purposes as specified in formula (1) in 3.3.2 above namely:

$$Load = (d_{FP} /\theta)\ BOD_{ULT}.$$
ie. $673 = (4/\theta)\ 920$

$$\theta = \frac{4 \times 920}{673} = 5.5 \text{ days}$$

The HRT of FP (θ_{FP}) = 5.5 days
The volume of FP (V_{FP}) = 231 m^3
Flow rate Q to FP will be:

$$Q = \frac{V_{FP}}{\theta_{FP}} = \frac{231}{5.5}\ m^3 = 42\ m^3.d^{-1}$$

3.6 HIGH RATE ALGAL POND

The HRAP is designed on the basis of organic loading and solar energy flux. Empirical formulae for these calculations are found in Oswald (1994).

From 3.5 above the BOD_{ULT} loading to the pilot plant is 920 $mg.L^{-1}$. Assuming a removal in the PFP and FP of 60%, as in 3.3.4 above, the HRAP influent BOD_{ULT} (I_{HRAP}) will be:

$$I_{HRAP} = 0.4 \times 920\ mg.L^{-1}\ BOD_{ULT} = 368\ mg.L^{-1}\ BOD_{ULT}$$

The depth of the light penetration from formula (3) above will be:

$$d_L = 6000/mg\ BOD_{ULT}$$

= 6000/368 = 16.3 cm

The optimal depth of the HRAP from formula (4) will be:

d_{HRAP} = 3/2 x d_L

= 3/2 x 16.3 = 24.5 cm

The optimal hydraulic time (θ) in the HRAP will, according to formula (2) be:

θ = hC_c/SAF = (5.5 $cal.mg^{-1}$ x 368 $mg.L^{-1}$)/ (300 $cal.cm^{-2}.day^{-1}$ x $1000cm^3$/24.5 cm x 0.035

θ = 5.8 days

The overflow velocity ($V_{OVERFLOW}$) is calculated:

$V_{overflow} = d_{HRAP}/\theta$...(5)

$V_{overflow} = d_{HRAP}/\theta$ = 0.245/5.8 days = 0.0422 $m.day^{-1}$

Therefore, the organic loading rate for the HRAP (L_{HRAP}) will be:

L_{HRAP} = 0.0422 $m.day^{-1}$ x 368 $mg.L^{-1}.BOD_{ULT}$

= 15,5 $gBOD_{ULT}$ $.m^{-2}.day^{-1}$

This organic load would require 15.5 g oxygen.$m^2.day^{-1}$. Assuming that algae produce 1.6 times their dry weight cell mass of dissolved oxygen, the necessary concentration of algae will be:

C_c = 15.5 $g0_2.m^{-2}.day^{-1}$/ 1.6

= 9.7 $gm^{-2}.day^{-1}$

At a flow rate of $42m^3d^{-1}$ the area required for the HRAP (A_{HRAP}) will be:

$A_{HRAP} = Q_{HRAP} / V_{overflow}$ = 42 $m^3.day^{-1}$/0.0422 $m.day^{-1}$

= 995 m^2 say 1000 m^2

Assuming a channel width of 6m the area of the two bends would be 3.14 x 6^2 = 113 m^2

Surface area of straight channels 1000 - 113. = 887 m^2

Length of straight channels 887/12 = 73.92 m say 74 m

Total length of HRAP = 74 + 6 + 6 = 86 m

3.7 SUMMARY OF DESIGN PARAMETERS

3.7.1	Flow rate:	42 $m^3.day^{-1}$
	Organic loading average COD	4600 $mg.L^{-1}$
3.7.2	Fermentation Pit	
	Hydraulic retention time:	5.5 days
	Depth:	4 m
	Surface area:	57.8 m^2
	Upflow velocity:	0.7 $m.day^{-1}$
3.7.3	Primary Facultative Pond	
	Dimension water surface:	32 m x 27 m
	Surface area:	864 m^2
	Depth	2.3 m
	Volume:	1541 m^3
	Hydraulic retention time:	36.7 days
3.7.4	High Rate Oxidation Pond	
	Dimension:	86 m long 12 m wide
	Surface area:	1000 m^2
	Water depth:	24.5 cm
	Volume:	245 m^3
	Hydraulic retention time:	5.8 days
	Linear velocity:	23 $cm.second^{-1}$

4 CONSTRUCTION, COMMISSIONING AND OPERATION

4.1 CONSTRUCTION

The design of the pilot plant at Cato Ridge Abattoir had been determined by two fixed parameters, namely an anticipated COD value of 4 600 $mg.L^{-1}$ as influent raw feed to the pilot plant, and a PFP size of 900 m^2, determined by the balancing dam available on-site for this purpose. While the conceptual design outlined above was adhered to as closely as possible during the construction period, the HRAP was enlarged slightly by lengthening it from 86 m to 94 m, and it was operated at a depth of 30 cm instead of 24.5 cm as specified (Appendices 4 and 5).

Construction work on-site was beset by numerous problems, and the need to use the existing balancing dam for the construction of the PFP was ultimately to be the cause of considerable delay. Work commenced on the project in October 1994, and was completed by the end of August 1995 (Figures 4.1 and 4.2). The HRAP construction had been completed in early 1995 and was commissioned directly. Until the PFP became operational, and normal feed to the HRAP could commence, it was operated using a feed made up as 80% unchlorinated treated effluent from the Cato Ridge disposal works and 20% supernatant liquor from the anaerobic digesters at this plant.

Construction of the PFP was disrupted due to heavy unseasonal rainfall, and filling of the PFP commenced in September 1995. Due to the failure of the structural works, and a leak in the wall of the PFP, which then had to be gunnite-sealed, commissioning of the pond only commenced during March 1996. During May 1996 further leaking of the PFP was observed and the pond was again drained, dried and the entire inside surface gunnite-sealed. The construction of the PFP was finally completed during October 1996 and commissioning of the full system was able to proceed.

Figure 4.1 The Fermentation Pit and Facultative Pond of the IAPS abattoir wastewater treatment plant was constructed in a pre-existing balancing dam available on-site at the Cato Ridge Abattoir.

Figure 4.2 The High Rate Algal Pond unit operation of the IAPS pilot plant constructed at the Cato Ridge Abattoir.

4.2 COMMISSIONING

Start-up procedures for the PFP commenced during October 1996, and the unit overflowed in early November 1996 providing the first feed from the PFP directly to the HRAP. Start-up procedures used were as follows:

1 The FP was filled with raw influent from the balancing tank to 750 mm below the top of the FP wall;

2 HRAP effluent was simultaneously added to the PFP to keep the water level inside and outside the FP wall equal (weep holes were provided through the FP wall at ground level to prevent the FP wall collapsing);

.

3 As a start-up seed 50 m^3 of sludge from the abattoir's anaerobic digester was added to the FP;

4 Operation of the HRAP was maintained with the feed make-up from the Cato Ridge treatment works until the FP overflowed;

5 When the water level in the PFP reached the top of the FP wall feeding of raw effluent from the Cato Ridge screened wastewater balancing dam commenced at an initial rate of 10% design flow rate, i.e. 4.2 $m^3.d^{-1}$;

6 Simultaneously with the feed to the FP, the PFP was supplemented with HRAP effluent until the PFP overflowed;

7 The daily feed rate to the FP was to be increased in stages by 10% incremental steps until the design flow rate of 42 $m^3.d^{-1}$ was reached. The rate of increase was to be determined by treatment performance results;

8. Once the PFP had overflowed HRAP recycle to the PFP commenced.

4.3. OPERATION AND MONITORING

The following operating and monitoring procedures were laid out for the daily management of the pilot plant study, which was undertaken by Abakor staff.

4.3.1 Operating Parameters

- ❑ Raw effluent inflow: 4.2 $m^3.day^{-1}$ increasing to 42 $m^3.day^{-1}$
- ❑ HRAP velocity of mixing: 23 $cm.second^{-1}$
- ❑ HRAP depth of water: 30 cm
- ❑ HRAP volume at 30cm depth:330 m^3
- ❑ Recirculation HRAP to PFP: 10% of HRAP $volume.day^{-1}$ = 33$m^3.day^{-1}$
  (Recirculate for 10 hrs, preferably from 8:00 to 18:00 ie 3.3 $m^3.h^{-1}$)

4.3.2 Analytical Procedures

A comprehensive schedule of analysis and daily plant records required for the operation of the pilot plant was provided and is presented in Table 4.1.

Table 4.1 Chart for daily analysis requirements used for the monitoring and management of the Cato Ridge Pilot Plant.

Determinant	Sampling points 1	2	3	4	5	Frequency
pH	✓	✓	✓	✓	✓	08:00 12:00 16:00
Cond.	✓			✓		8hr composite
Settleable solids	✓			✓		08:00 12:00 16:00
TDIS	✓			✓		8hr composite
DO		✓	✓	✓		08:00 12:00 18:00
COD	✓	✓		✓		8hr composite
NH_3	✓	✓		✓		08:00 12:00
NO_3		✓		✓		8hr composite
Cl	✓			✓		8hr composite
SO_4	✓			✓		8hr composite
P	✓		✓	✓		8hr composite
Chlorophyll a		✓		✓		12:00
Total volatile suspended solids					✓	Twice a week
Total volatile dissolved solids					✓	Twice a week

Five points in the system were identified from which samples were to be drawn for chemical analysis:

1. Raw water
2. Fermentation pit
3. PFP outflow
4. HRAP recycle
5. Final HRAP effluent

4.3.3 Plant Records

A daily spread sheet for each day of the week was provided to simplify the recording of parameters such as temperature, pH, dissolved oxygen, flow measurement, rainfall etc.

The following flow measurement points were used:

1. Q_1 - raw water
2. Q_2 - PFP effluent
3. Q_3 - HRAP recycle
4. Q_4 - final effluent

5 PILOT PLANT PERFORMANCE

Following the commissioning and start-up of the pilot Plant at Cato Ridge Abattoir, the feed rate to the FP in the PFP was increased from 4.2 $m^3.d^{-1}$, in incremental steps of 10% of daily feed volume, until steady state operation was achieved. Even though the COD in the raw effluent feed to the system (1 787 $mg.L^{-1}$) was around half that anticipated in the plant design (4 600 $mg.L^{-1}$, determined for the 1993 operating year), it was found, over a period of pilot plant operation, that steady state was achieved at a flow of only 20 $m^3.d^{-1}$. Plant malfunction, probably due to elevated ammonia levels, was observed where feed rates were elevated above 20 $m^3.day^{-1}$. The average analysis for the Cato Ridge Abattoir wastewater fed to the pilot plant over the study period is recorded in Table 5.1

Table 5.1 Average analysis for the Cato Ridge Abattoir settled raw wastewater fed to the pilot plant over the study period.

Parameter	$mg.L^{-1}$
Chemical Oxygen Demand	2 389
Ammonia	75
Chlorides	299
Phosphate as P	25
Suspended solids	968
Total Dissolved solids	960

The pilot plant was operated at approximate steady state from January 1997 to end October 1997, when operations ceased due to staff problems at Abakor. Although the project was now nearly a year into extended time, and only 10 months of stable operating data had been acquired, funding had been exhausted and it proved impossible to restart the plant and extend the evaluation period. The analytical results are recorded below, and the performance of the pilot plant is discussed mainly in terms of reductions achieved across the system in COD, phosphate and ammonia concentrations, and in the alkalising function of algal growth in the HRAP.

5.1 ORGANIC LOAD REDUCTION

The daily COD throughput in the pilot plant is recorded in Figure 5.1 for 186 individual days over the ten month study period. A very wide variation in the feed COD was observed ranging from 390 $mg.L^{-1}$ to 7 200 $mg.L^{-1}$, with an average of 2 389 $mg.L^{-1}$. The reason for this was that grab samples were taken despite the instruction as per Table 4.1, that composite samples were to be drawn. This situation also applied for phosphate and ammonia levels. The average monthly figures for raw feed to the pilot plant are given in Table 5.2.

The comparative performance of the pilot plant in organic load reduction over a ten month period is reported in Figure 5.1. Although there is a marked variation in the FP feed and PFP effluent, the final HRAP filtered effluent shows a remarkably stable COD removal performance. This indicates a stable buffer capacity in the system and is due, in part at least, to the reduced influent COD compared to the original design values.

Table 5.2 shows a fairly constant reduction in COD throughout the year across the whole system, while COD removal in the PFP is lowered during the winter months it appears to recover during the early summer months.

Table 5.2 Monthly average COD reduction achieved across the IAPS pilot plant at Cato Ridge Abattoir.

Month 1997	Feed mg/L	PFP mg/L	% Red	HRAP (filtered) mg/L	% Red
Jan	2598	270	89.61	125	95.19
Feb	2700	220	91.85	147	94.56
Mar	1968	297	84.91	136	93.09
Apr	1912	439	77.04	124	93.52
May	2508	990	60.53	157	93.74
Jun	2190	1258	42.56	171	92.19
Jul	1743	985	45.04	207	88.12
Aug	2182	770	64.77	161	92.62
Sept	2812	1118	60.24	131	95.34
Oct	3280	1344	59.02	128	96.10
Average	2389	769	67.81	149	93.76

The 67.8% reduction in COD achieved through the PFP is somewhat higher than the 60% rule- of-thumb value normally accepted for sewage treatment. The average COD reduction across all stages of the pilot plant was 93.8%, which may be considered excellent.

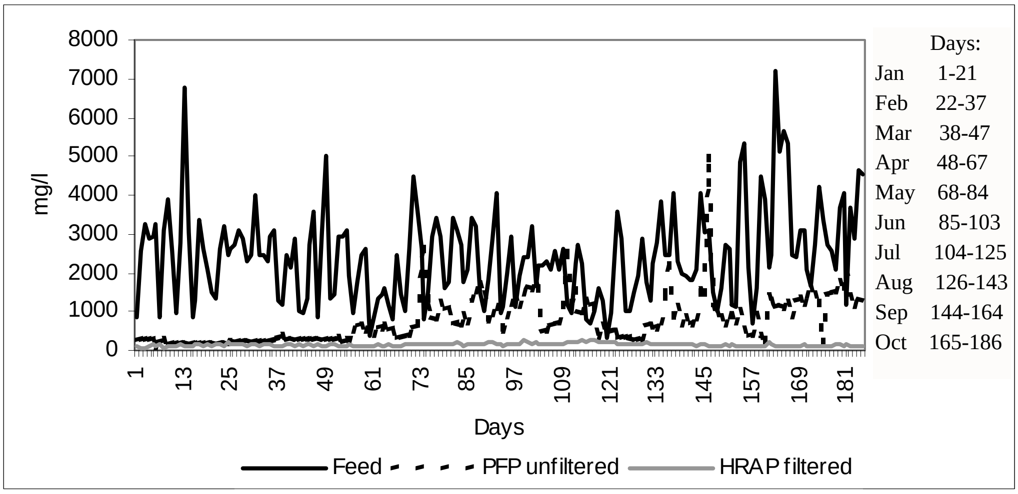

Figure 5.1 Reduction in the COD load of abattoir wastewater fed to the IAPS pilot plant at the Cato Ridge Abattoir for the 10 month study period.

Based on the actual volumetric loading rate to the system of 20 $m^3.day^{-1}$, an influent COD load to the HRAP of 769 $mg.L^{-1}$ (average), and a depth of 30 cm in the HRAP, the optimal HRT (θ) in days according to the formula was:

$$\theta = (5.5 \text{ x } 769/5)(300 \text{ x } 1000/30\ 0.035)$$
$$= \frac{845.9}{350}$$
$$= 2.4 \text{ days}$$

From the formula 5 above the overflow velocity was:

$$V_{OVERFLOW} = 0.3 \text{ m}/2.4 \text{ days} = 0.125 \text{ m.day}^{-1}$$

The organic loading rate to the HRAP therefore was:

$$L_{HRAP} = 0.125 \text{ mg.day}^{-1} \text{ x } 769/5 \text{ mg.L}^{-1} \text{ BOD}_{ULT} = 19.2 \text{ BOD}_{ULT.} \text{ m}^{-2}\text{.day}^{-1}$$

Although the BOD_{ULT} loading rate to the HRAP was set at 15.5mg $m^{-2}.day^{-1}$ in the pilot plant design, the final actual loading rate of 19.2 $BOD_{ULT.}m^{-2}.day^{-1}$ achieved is comparable to the loading rate of 19.1 g BOD_{ULT} .$m^{-2}.day^{-1}$ in the Grahamstown AIWPS Plant. This indicates that the HRAP was neither overloaded nor underloaded at the adjusted 20 $m^3.day^{-1}$ raw feed to the system.

5.2 PHOSPHATE REMOVAL

Performance for phosphate removal over the ten month period is reported in Figures 5.2 and 5.3. The minimum and maximum phosphate in the raw influent was 9.0 $mg.L^{-1}$ and 336 $mg.L^{-1}$ respectively with an average of 20.8 $mg.L^{-1}$ (Table 5.3). These results show a marked decrease in phosphate removal through the cold winter months of May to July in the PFP. Removal in the HRAP, however, remained fairly constant over the 10 month study period.

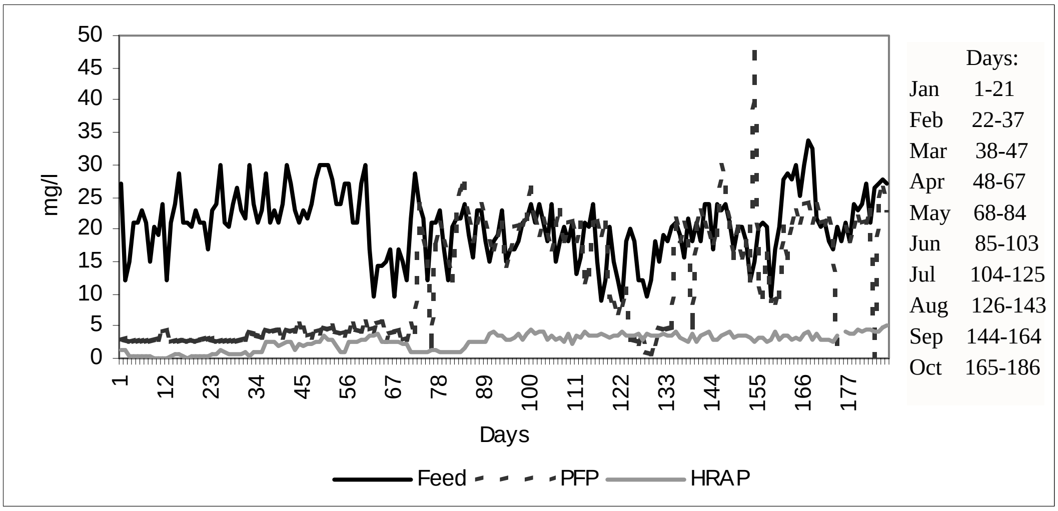

Figure 5.2 Reduction in phosphate levels in abattoir wastewater fed to the IAPS pilot plant at the Cato Ridge Abattoir for the 10 month study period.

It is probable that elevated pH in the HRAP, due to the photosynthetic alkalising function, was responsible for the precipitation of calcium phosphate, rather than the operation of a biological phosphate removal process. Although particularly high pH values were not apparent from the values recorded for the system shown in Table 5.4, it must be borne in mind that the pH readings were taken only at 08:00, despite a request that these be read at 08:00, 12:00 and 16:00. The reported values nevertheless provide an indication that reasonably high pH levels would have been reached by mid-day in the HRAP unit.

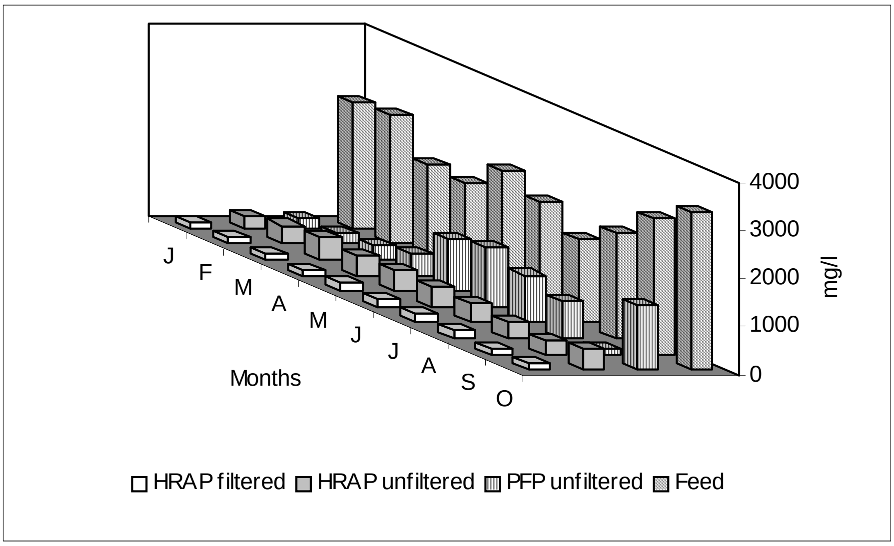

Figure 5.3 Removal of phosphate from abattoir wastewater fed to the IAPS pilot plant at the Cato Ridge Abattoir reported as monthly averages for the 10 month study period.

Table 5.3 Monthly average PO_4/P reduction shown for the individual unit operations and across the IAPS system.

Month	Feed	PFP		HRAP (filtered)		System
1997	mg/L	mg/L	% Red	mg/L	% Red	% Red
Jan	20.5	2.9	85.85	0.3	89.7	98.5
Feb	23.6	3.1	86.86	0.9	71.0	96.2
Mar	24.0	4.1	82.92	2.1	48.8	91.3
Apr	22.1	4.5	79.64	2.7	40.0	87.8
May	19.6	13.9	29.08	1.3	90.7	93.4
Jun	19.6	20.1	-2.55	3.3	83.6	83.2
Jul	17.0	18.0	-5.88	3.3	81.7	80.6
Aug	17.7	10.8	39.98	3.5	67.6	80.3
Sept	20.7	18.5	10.63	3.2	82.7	84.6
Oct	23.6	19.8	16.10	3.8	80.8	83.9
Average	20.8	11.6	44.23	2.4	73.6	73.6

The influent pH during the 10 month period remained fairly constant, ranging from a minimum of 6.1 to a maximum of 6.6, with one exception of 7.6 during September (see Table 5.4). The elevated pH of the PFP effluent could be due to the high recirculation volumes from the HRAP, but the minima of pH of 6.0 to 6.2 indicate that the FP itself probably became acidic during the colder months.

5.3 AMMONIA REMOVAL

The performance for ammonia removal over the ten month period is shown in Figures 5.4 and 5.5, and the monthly average removal values are reported in Table 5.5. The minimum and maximum ammonia levels in the feed to the pilot plant over this period were 25 $mg.L^{-1}$ and 144 $mg.L^{-1}$ respectively. However, the monthly averages show a rather consistent value around 72 $mg.L^{-1}$ NH_4.

Table 5.4 pH values for the pilot plant at Cato Ridge Abattoir for the ten month operating period.

	Feed			PFP Effluent			HRAP Effluent		
	Av	Max	Min	Av	Max	Min	Av	Max	Min
Jan	6.6	6.8	6.7	8.6	9.7	7.4	9.3	9.8	8.5
Feb	6.5	6.6	6.4	7.7	8.8	6.8	8.7	9.4	7.2
Mar	6.5	6.6	6.3	7.0	7.3	6.6	7.9	8.7	7.6
Apr	6.4	6.6	6.3	7.1	9.8	6.3	7.9	9.6	7.2
May	6.4	6.5	6.1	6.6	6.9	6.2	9.0	10.8	7.4
Jun	6.4	6.5	6.2	6.6	6.8	6.4	7.5	8.7	7.2
Jul	6.4	6.7	6.3	6.9	8.8	6.5	7.3	8.2	6.8
Aug	6.3	6.4	6.1	7.0	10.3	6.0	6.9	7.6	6.6
Sep	6.4	7.6	6.1	7.2	8.6	6.2	7.3	8.1	6.6
Oct	6.4	6.6	6.3	6.5	6.9	6.2	7.1	7.4	6.9

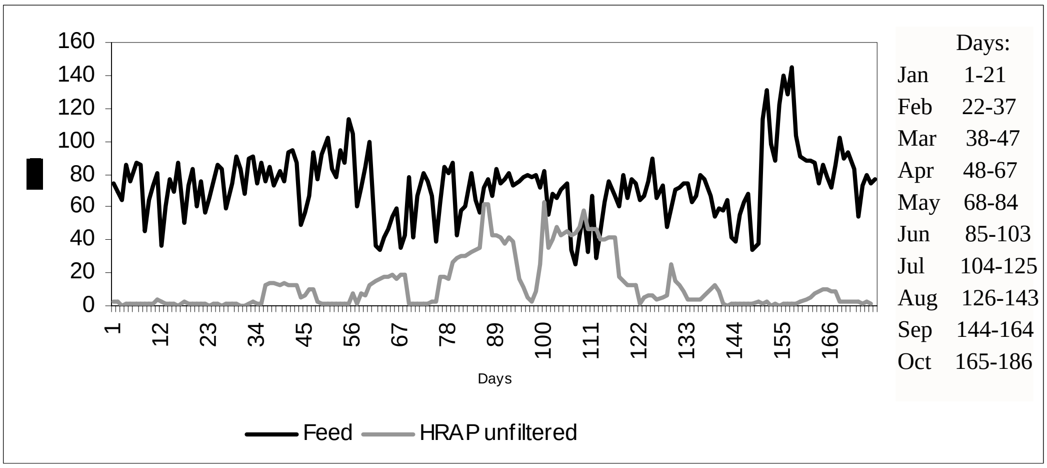

Figure 5.4 Ammonia removal in abattoir wastewater fed to the IAPS pilot plant at the Cato Ridge Abattoir for the 10 month study period.

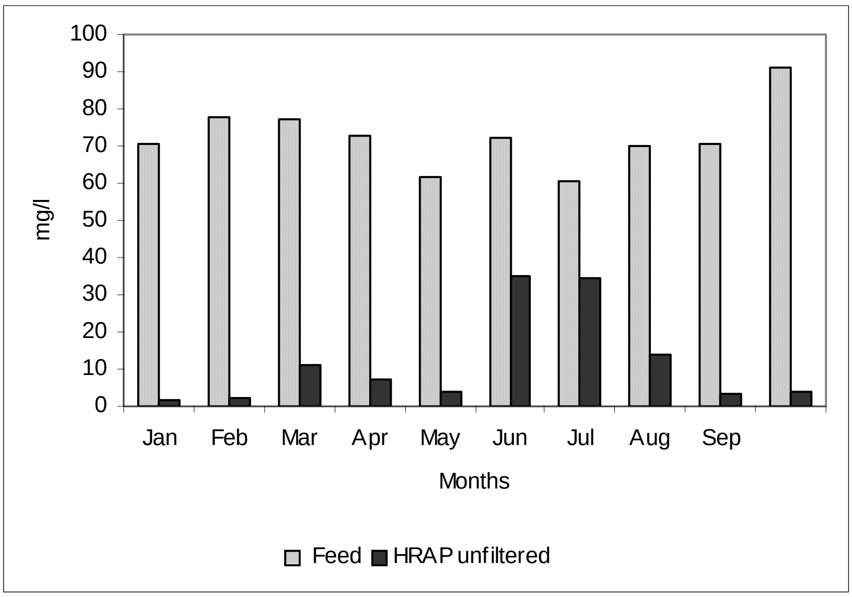

Figure 5.5 Removal of ammonia from abattoir wastewater fed to the IAPS pilot plant at the Cato Ridge Abattoir reported as monthly averages for the 10 month study period.

The overall percentage reduction in ammonia levels across the system was 84% , with the poor ammonia reduction through the HRAP during June and July probably due to temperature-related effects on algal photosynthesis, and hence the alkalising efficiency of the system. Ignoring the 47.5% reduction in ammonia for June and July the average ammonia reduction would be 92%, which is more in line with COD and phosphate removals achieved across the system. Although nitrate levels were not recorded, it is evident that the principle cause of ammonia removal was probably stripping at elevated pH levels.

Table 5.5 Monthly average ammonia reduction values for the pilot plant at Cato Ridge Abattoir for the ten month operating period.

Month 1997	Feed mg/ℓ	HRAP (unfiltered) mg/ℓ	% Red
Jan	70.4	1.5	97.86
Feb	77.7	2.4	96.91
Mar	77.0	10.9	85.84
Apr	72.8	7.4	89.84
May	61.7	3.7	94.00
Jun	71.8	34.8	51.53
Jul	60.6	34.3	43.40
Aug	69.8	13.8	80.23
Sept	70.4	3.3	95.31
Oct	91.2	4.0	95.61
Average	72.3	11.6	83.96

6 CONCLUSIONS

The overall objectives of the WRC Project K5/658 were accomplished. Laboratory studies were scaled up from flasks to a bench-scale pilot plant, and these results were used to inform the design of an IAPS pilot plant constructed on-site at Cato Ridge Abattoir. Although numerous problems combined to constrain the pilot plant study, nevertheless, data from some ten months of steady state operation of the pilot plant were collected. These showed an effective treatment operation, producing an effluent suitable for discharge to a maturation pond or to the municipal sewer. Although the General Standard for discharge to the environment was not quite attained, it was apparent that this could be well within the reach of the system. Phosphate and nitrogen removal in the HRAP, as a tertiary treatment operation, had been the subject of a subsequent WRC study in Projects K5/799 and K5/1073. Follow-up investigation of the abattoir IAPS application should include an investigation of this development.

Following the experience of IAPS treatment of high protein tannery wastewaters in Wellington, it was again demonstrated that ammonia toxicity provides an important regulatory function in the process. The impact on the FP performance is probably most severe, especially after the algal culture is established in the HRAP, and acidification here retards the overall load rate to the system. This could be corrected with lime addition or recirculation of alkaline HRAP water to the FP. This should also be investigated in follow-up studies.

Useful indicators for the design of an IAPS approach to abattoir wastewater have emerged from the study, and have lent heavily on the design criteria published by Oswald (1988b;1994) for the AIWPS. Until further process optimisation studies can be undertaken, this study has broadly indicated that, although high-strength proteinaceous abattoir wastewaters may be successfully treated by IAPS, the loading rate should be approximately 25% of the accepted design values.

The study has clearly demonstrated the potential advantage of the IAPS approach in the treatment of wastewaters from small and medium-sized abattoirs, and abattoirs located at sites remote from sewer discharge.

The overall performance of the Cato Ridge IAPS pilot plant treating 20 $m^3.day^{-1}$ abattoir wastewater is shown in Table 6.1

Table 6.1 Overall treatment performance of the Cato Ridge IAPS pilot plant.

Parameter $mg.L^{-1}$	Digester Feed	HRAP Effluent (Filtered)	Change
pH	6.4	7.9	+ 1.5
COD	2389	149	- 93 %
Phosphate as P	20.8	2.4	- 88.5 %
Ammonia as NH_3	72.3	11.6	- 84.0 %

The following sizing criteria may be applied to the design of an IAPS plant treating 20 $m^3.day^{-1}$ abattoir wastewater with the characteristics reported in Table 5.1:

1 Fermentation Pit

Hydraulic retention time:	5.5 days (fixed)
Depth:	4 m (fixed)
Surface area:	578 m^2 (for 20 $m^3.day^{-1}$)
Upflow velocity	0.7 $m.day^{-1}$ (to be not more than 1.5 $m.day^{-1}$)

2 Primary Facultative Pond

Depth:	not < 2.5m
Volume:	FP:PFP = 3:20

3 High Rate Algal Pond

Surface Area :	$1000m^2$ (for 20 $m^3.day^{-1}$)
Water depth:	30cm
Linear velocity:	23 to 30 $cm.second^{-1}$

7 RECOMMENDATIONS

The following recommendations have emerged from this study:

1 While preliminary results show the IAPS approach to abattoir wastewater treatment may be applied with some confidence, and a good quality wastewater may be produced, a conservative approach to design should be followed, in particular with respect to sizing of the system;

2 A longer-term operation of the pilot study would be desireable to further optimise the operational performance of the system, and to derive more accurate criteria for the successful design of these systems;

3 Nutrient removal studies undertaken in the sewage treatment study should be applied to the IAPS in abattoir wastewater treatment to improve the quality of final treated water;

4 Ammonia toxicity and acidification of the Fermentation Pit should be subjected to more critical study, and the use of alkaline HRAP recycle water to control acidification should be further investigated;

5 Studies should be undertaken on the recovery of algal biomass from the HRAP unit, and value-adding opportunities investigated as component operations in an 'integrated waste resource management' approach to the beneficiation of abattoir wastewaters.

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Rose, P.D., Hart, O.O., Shipin, O. and Ellis, P.J. 2002b. Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa. Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part1: The AIWPS Model. WRC Project K5/651, Water Research Commission, Pretoria.

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9 APPENDICES

APPENDIX 1

WRC STUDY 'SALINITY SANITATION AND SUSTAINABILITY' - PROJECT REPORTS

The WRC study which has been summarised here, developed out of a number of closely interrelated studies, undertaken for the WRC by the Rhodes University Environmental Biotechnology Group, over a 10 year period. The detailed findings associated with this work will be published separately as individual project reports. The following lists the WRC reports which cover the various investigations dealt with in the programme. The individual WRC projects under which the various studies were undertaken are listed separately below:

Report 1

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 1. Overview

Report 2

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 2. Integrated Algal Ponding Systems and the Treatment of Saline Wastewaters.
Part1: Meso-saline Wastewaters - The *Spirulina* Model.

(Project K5/495: A Biotechnological approach to the removal of organics from saline effluents - Part 1.)

Report 3

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 2. Integrated Algal Ponding Systems and the Treatment of Saline Organic Wastewaters.
Part 2: Hyper-saline Wastewaters - The *Dunaliella* Model.

(Project K5/495: A biotechnological approach to the removal of organics from saline effluents - Part 2.)

Report 4

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part1: The AIWPS Model.

(Project K5/651: Appropriate low-cost sewage treatment using the integrated algal high rate oxidation ponding process.)

Report 5

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 2: Abattoir Wastewaters.

(Project K5/658: Algal high rate oxidation ponding for the treatment of abattoir effluents.)

Report 6

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters.
Part 3: Mine Drainage Wastewaters - The ASPAM Model.

(Project K5/656: Appropriate low-cost treatment of sewage reticulated in saline water using the algal high rate oxidation ponding system.)

Report 7

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters.
Part 4: System Performance and Tertiary Treatment Operations.

(Project K5/799: Development and monitoring of integrated algal high rate oxidation pond technology for low-cost treatment of sewage and industrial effluents;
Project K5/1073: Extension of applications and optimisation of operational performance of algal integrated ponding systems technology in appropriate low-cost treatment of industrial and domestic wastewaters.
Project K5/1362: Development and technology transfer of IAPS applications in upgrading water quality for small wastewater and drinking water treatment systems.)

Report 8

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters.
Part 5: Winery and Distillery Wastewaters.

(Project K5/1073: Extension of applications and optimisation of operational performance of algal integrated ponding systems technology in appropriate low-cost treatment of industrial and domestic wastewaters.)

Report 9

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®.
Part 1: Biodesalination of Mine Drainage Wastewaters.

(Project K5/869: Biological sulphate desalination and heavy metal precipitation in industrial and mining effluents using the IAPS.)

Report 10

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®.
Part 2: Enhanced Hydrolysis of Organic Carbon Substrates - Development of the Recycling Sludge Bed Reactor.

(Project K5/972: Process development and system optimisation of the integrated algal trench reactor process for sulphate biodesalination and heavy metal precipitation in mining and industrial effluents.)

Report 11

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®.
Part 3: Sulphur Production and Metal Removal Unit Operations.

(Project K5/1078: Development and piloting of the integrated biodesalination process for sulphate and heavy metal removal from mine drainage water incorporating co-disposal of industrial and domestic effluents;
Project K5/1336: Scale-UP development of the Rhodes BioSURE Process® for sewage sludge solubilisation and disposal.)

Report 12

Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®.
Part 4: Treatment and Disposal of Sewage Sludges:

(Project K5/1169: Intermediate scale-up evaluation of the Rhodes Process for hydrolysis and solubilisation of sewage sludges in a sulphate reducing bacterial system.)

PROJECTS

The following lists the WRC Projects under which the studies in this series have been undertaken, and also the relevant reports in which the detailed results have been documented:

Project K5/410

A Biotechnological approach to the removal of organics from saline effluents.

Report: 1. Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 1. Overview.

Project K5/495

A Biotechnological approach to the removal of organics from saline effluents.

Report: 2. Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 2. Integrated Algal Ponding Systems and the Treatment of Saline Wastewaters. Part1: Meso-saline Wastewaters - The *Spirulina* Model.

Report: 3. Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 2. Integrated Algal Ponding Systems and the Treatment of Saline Organic Wastewaters. Part 2: Hyper-saline Wastewaters - The *Dunaliella* Model.

Project K5/651

Appropriate low-cost sewage treatment using the integrated algal high rate oxidation ponding process.

Report 4: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part1: The AIWPS Model.

Project K5/656

Appropriate low-cost treatment of sewage reticulated in saline water using the algal high rate oxidation ponding system**.**

Report 6: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.

Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 3: Mine Drainage Wastewaters - The ASPAM Model.

Project K5/658

Algal high rate oxidation ponding for the treatment of abattoir effluents.

Report 5: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 2: Abattoir Wastewaters.

Project K5/799

Development and monitoring of integrated algal high rate oxidation pond technology for low-cost treatment of sewage and industrial effluents.

Report 7: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 4: System Performance and Tertiary Treatment Operations.

Project K5/869

Biological sulphate desalination and heavy metal precipitation in industrial and mining effluents using the IAPS.

Report 9: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®. Part 1: Biodesalination of Mine Drainage Wastewaters.

Project K5/972

Process development and system optimisation of the integrated algal trench reactor process for sulphate biodesalination and heavy metal precipitation in mining and industrial effluents.

Report 10: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®. Part 2: Enhanced Hydrolysis of Organic Carbon Substrates - Development of the Recycling Sludge Bed Reactor.

Project K5/1073

Extension of applications and optimisation of operational performance of algal integrated ponding systems technology in appropriate low-cost treatment of industrial and domestic wastewaters.

Report 7: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 4: System Performance and Tertiary Treatment Operations.

Report 8: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 5: Winery and Distillery Watewaters.

Project K5/1078

Development and piloting of the integrated biodesalination process for sulphate and heavy metal removal from mine drainage water incorporating co-disposal of industrial and domestic effluents.

Report 11: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®. Part 3: Sulphur Production and Metal Removal Unit Operations.

Project K5/1169

Intermediate scale-up evaluation of the Rhodes Process for hydrolysis and solubilisation of sewage sludges in a sulphate reducing bacterial system.

Report 12: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®. Part 4: Treatment and Disposal of Sewage Sludges.

Project K5/1336

Scale-up development of the Rhodes BioSURE Process® for sewage sludge solubilisation and disposal.

Report 11: Salinity, Sanitation and Sustainability: A Study in Environmental

Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 4. The Rhodes BioSURE Process®. Part 3: Sulphur Production and Metal Removal Unit Operations.

Project K5/1362

Development and technology transfer of IAPS applications in upgrading water quality for small wastewater and drinking water treatment systems.

Report 7: Salinity, Sanitation and Sustainability: A Study in Environmental Biotechnology and Integrated Wastewater Beneficiation in South Africa.
Volume 3. Integrated Algal Ponding Systems and the Treatment of Domestic and Industrial Wastewaters. Part 4: System Performance and Tertiary Treatment Operations.

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APPENDICES 2 - 5

(See attached drawings)

2. Design detail and drawing for the Primary Facultative Pond of the laboratory bench-scale IAPS pilot plant.

3. Design detail and drawing for the High Rate Algal Pond of the laboratory bench-scale IAPS pilot plant.

4. Design detail and drawing for the Primary Facultative Pond of the IAPS pilot plant constructed at Cato Ridge Abattoir.

5. Design detail and drawing for the High Rate Algal Pond of the IAPS pilot plant constructed at Cato Ridge Abattoir.

APPENDIX 6 TECHNOLOGY TRANSFER ACTIONS

The IAPS pilot plant at Cato Ridge was one of a number of application studies undertaken in South Africa at this time by the WRC, and these are outlined in Appendix 1. Numerous people visited the Cato Ridge site including a technical tour party.

The technical tour of inspection of developments in the WRC study relating to IAPS Technology in South Africa was undertaken 24 - 26 January, 1996. Members of the Technical Committee included: Prof C.T. Johnson (Chairman WRC); Mr P.E. Odendaal (Executive Director WRC); Mr D.S. van der Merwe (Deputy Director WRC); Mr Z. Ngcakani (Research Manager WRC); Mr J.R. Muller (Abakor); Dr A. Jarvis (Sasol Co.); Dr O.O. Hart (Rhodes University); Prof P.D. Rose (Rhodes University).

Sites visited included:

1. SASOL β-carotene production technical scale plant in Upington.
2. WRC/Mossop Western Leathers commercial scale IAPS plant in Wellington.
3. WRC demonstration plant IAPS sewage treatment in Grahamstown.
4. WRC/Abakor demonstration IAPS plant at Cato Ridge Abattoir.
5. De Beers pilot plant for treatment of diamond wastes at De Beers Diamond Research Laboratory, Johannesburg.

Figure A1. Technical tour party which undertook the inspection of WRC AIPS project installations. From left to right Prof P.D. Rose (Rhodes University); Mr D.S. van der Merwe (Deputy Director WRC); Mr Z. Ngcakani (Research Manager WRC); Prof C.T. Johnson (Chairman WRC); Mr J.R. Muller (Abakor); (Pilot); Dr O.O. Hart (Rhodes University); Dr A. Jarvis (Sasol Co.); Mr P.E. Odendaal (Executive Director WRC).