APPROACHES TO ABBATOIR EFFLUENT TREATMENT

JR Müller

WRC Report No. KV 166/05

Water Research Commission

APPROACHES TO ABBATOIR EFFLUENT TREATMENT

Report to the
Water Research Commission

Compiled by

JR MüLLER

WRC Report: KV 166 /05
ISBN No: 1-77005-351-4

SEPTEMBER 2005

This Report is obtainable from:

Water Research Commission
Private Bag X03
Gezina
0031

This report emanates from two research projects entitled:

K5/652: Research into the Purification of Abattoir Effluent by means of a Protein Recovery Process

and

K5/778: Total recycling of Effluent from the Protein Recovery Process Appropriate to the Red Meat and Poultry Abattoir Industries

Compiled by

JR MüLLER
JR Müller & Associates
Consulting Engineers
PO Box 36361
0102 MENLO PARK
PRETORIA SOUTH AFRICA

FOREWORD

The abattoir industry is internationally renowned to be one of the biggest polluters due to large quantities of solid waste being generated as well as the production of large volumes of heavily polluted effluent or waste water.

Previous research (Water Research Commission) has shown that abattoirs are historically known to use large quantities of potable water for continuous cleansing during the slaughter operation, for cleansing of stock pens, for washing down of carcasses and for transportation of solid waste.

Water is still a relatively inexpensive commodity in South Africa thereby adding to the disinterest in respect of water conservation.

Research by the Water Research Commission has shown that water management is closely monitored by larger abattoirs with less control as abattoir capacity decreases. Water consumption for large abattoirs range between 0.8 kl/cattle unit* (cu) and 1.8 kl/cu for large abattoirs, and 3.0kl/cu to 6.0kl/cu for small abattoirs.
(*The term <u>cattle unit</u> (CU) is defined as 1 CU = 1 head of cattle = 6 sheep = 2 pigs.).

Obviously, larger abattoirs have the advantage of well-trained management teams and records of income/expenditure. Smaller abattoirs tend to utilize the services of a trained health official to act as "jack of all trades" in managing the plant. It is therefore easier to convince management of large abattoirs about the impact of their pollution, whilst in smaller plants, managers tend to be overly concerned about carcass quality and little or no attention is paid in respect of water and effluent.

Apart from being users of high volumes of water, the generated waste water or effluent carries high loads of pollution ranging from stock pen manure to paunch content, blood, fats, urine and finally cleansing and sterilizing chemicals.

Pollutant loads vary considerably. It has been found that the pollution strength of large abattoir effluent is in the region of 1 800 mg/l. COD, while the COD of effluent from smaller abattoirs generally range in the region of 4 500 mg/l to 6 000mg/l COD, whilst COD values of 20 000mg/l have been recorded.

The ten largest abattoirs in South Africa were owned by Abakor, who slaughtered approximately 50% of the national requirements for the domestic South African market. The abattoir with the largest slaughter capacity, Johannesburg Abattoir, had a capacity of 2 000 cattle and 8 000 sheep per day. The abattoir used in the region of 2.0 Ml to 2.5 Ml of fresh water daily.

The abattoir had an effluent pre-treatment plant which did a very basic screening and fat removal before entering a balancing tank and being discharged to the local authority. The cost of discharging into the municipal sewer system was based on volume and permanganate value of the effluent. The final cost was in the region of R4 million per year.

K5/652: RESEARCH INTO THE PURIFICATION OF ABATTOIR EFFLUENT BY MEANS OF A PROTEIN RECOVERY PROCESS

In evaluating treatment methods and costs, it was decided that environmentally friendly and cost effective methods would be the preferred treatment systems. It was further decided that the introduction of specially cultivated bacteria was to be avoided as they would obviously influence the robustness of the system. Naturally occurring bacteria were utilized as the core functionaries of the treatment system. These bacteria had to be selected to conform to criteria such as:

1. ROBUSTNESS:

- The ability to accommodate shock-loads of high intensity of elements i.e. blood, fat, chemical cleansing, etc.
- Ability to withstand temperature differentials (summer, winter)
- Re-generation ability
- Ability to hibernate during low flow or even no-flow periods such as long weekends and plant shut-down.

2. REDUCING POLLUTION LOAD TO ACCEPTABLE LEVELS:

- Ability to continuously provide acceptable end results.
- Ability to adapt to change of feed quality

3. HARVESTABILITY OF BACTERIA:

Bacteria had to have the properties of being easily disseminated from their environment, i.e. ease of dewatering, ease of further compression.

Handing characteristics: Bacteria had to be:

- pumpable
- transportable
- dewaterable without clogging of mechanical devices such as pumps, pipe lines and dewatering screens.

Product had to be capable of being dried and sterilized in rendering equipment.

4. PHYSICAL PROPERTIES:

- End product had to have relatively high protein content, being digestible by animals.
- Physical properties had to closely resemble the properties of blood meal or carcass meal.

On advice of Professor WA Pretorius, of the Department of Water Reclamation Engineering of the University of Pretoria, single cell protein systems were investigated.

The first trials were executed on bench scale in the laboratories of Professor Pretorius, and after a trial period of approximately 12 months, it was decided to implement pilot scale studies.

With the financial aid of the Protein Advisory Committee, a pilot plant was erected at Kimberley abattoir. This plant was operated for approximately 12 months, during which period scale-up problems were addressed. At this stage the Water Research Commission entered the scene, and they lauded the process as "commendable".

The facts are that the process:

1. is biological
2. is environmentally friendly
3. cleans the effluent
4. reduces the pollutants to an environmentally friendly, re-usable and saleable end-product.

In the instance of Johannesburg abattoir the financial impact was a major achievement:

1. The bill for discharging effluent into the Municipal sewerage system was reduced by R4 million per annum.
2. The income from the sale-able protein was R1 million per annum.
3. The capital expenditure to retrofit the protein recovery system was R1.75 million.

K5/778: TOTAL RECYCLING OF EFFLUENT FROM THE PROTEIN RECOVERY PROCESS APPROPRIATE TO THE RED MEAT AND POULTRY ABATTOIR INDUSTRIES

The effluent emanating from the single cell protein (or protein recovery) process was of such a high quality that the logical conclusion was to purify the water back to potable standard.

The veterinary hygiene authorities found this idea totally frightening. It was therefore decided to upgrade the water, but initially only utilize this water in limited areas such as cleaning of stock-pens until sufficient records of the quality and sustainability of the recycled water had been acquired. The further treatment entailed:

1. sedimentation
2. ozonation
3. chlorination

ACKNOWLEDGEMENTS

This report consolidates research which emanated from two projects funded by the Water Research Commission entitled:

K5/652: Research into the Purification of Abattoir Effluent by means of a Protein Recovery Process

and

K5/778: Total recycling of Effluent from the Protein Recovery Process Appropriate to the Red Meat and Poultry Abattoir Industries

Members of the Steering Committee responsible for guiding the projects were:

J R Müller	Project Leader
A Parau	Project Assistant
W A Pretorius	University of Pretoria
G H de Villiers	Burger Pretorius & Partners Consulting Engineers
E Anderson	Anderson Vogt & Partners, Consulting Engineers

In addition to the funding by the Water Research Commission, the contribution of ideas by the members of the Steering Committee as well as the considerable contribution in kind by ABACOR LTD and the cooperation of ABACOR staff members, for the implementation of a pilot system, is gratefully acknowledged.

TABLE OF CONTENTS

Page.

1. ABATTOIR EFFLUENT TREATMENT AND PROTEIN PRODUCTION: FULL SCALE APPLICATION (WRC Project K5/652)

Page

2. RECLAMATION OF WASTEWATER FOR DIRECT RE-USE IN AN ABATTOIR (WRC Project K5/778)

LIST OF FIGURES

Page.

PROJECT 652

PROJECT 778

LIST OF TABLES

Page

PROJECT 652

PROJECT 778

APPENDIX

ABATTOIR EFFLUENT TREATMENT AND PROTEIN PRODUCTION:

FULL SCALE APPLICATION

WRC Project No K5/652

EXECUTIVE SUMMARY.

A modified SBR (Sequential Batch Reactor) process was evaluated on full scale for the pre-treatment of abattoir effluent and for protein production that could be utilized as an animal feed supplement. Successful pre-treatment was achieved with unfiltered COD removals in excess of 90% from a raw COD ranging between 4 000 and 6 000 mg/l to a filtered COD of less than 200 mg/l. The process adapted readily to variations in effluent volumes, flow rate and duration, and was to a large extent self-regulating. The peak oxygen supply, and therefore power requirements, was reduced by incorporating an anoxic phase during the fill period. The biomass produced had a CP (crude protein) value of circa 40% and was successfully utilized as a supplement to carcass meal for animal feed. An economic feasibility study showed a net income from additional protein sales compared to operating expenses and a major saving on effluent tariffs payable to the Local Authority, recovering all capital expenditure within the first three months of operation. Comparisons of the results achieved with that of a previously completed pilot plant, showed differences, emphasizing the importance and risk involved in scaling up.

This document is also intended for the use at basic level by management and plant operators to determine the operational practical skills and requirements to operate such a similar plant.

1. INTRODUCTION

1.1 Objectives

The purpose of this project is the transfer and application of technology that has been developed on bench scale format at the University of Pretoria and later tested on pilot scale at the Kimberley abattoir of Abakor.

1.2 Research Products / Results

The effluent of abattoirs contain relatively high pollution loads, which is difficult and expensive to treat with known processes. By means of the cultivation of a Single Cell Protein, a useable protein source of animal feed was developed.

The cultivation of single cell protein has, as far as is generally known, not yet been utilized for the treatment of abattoir effluent. This process was researched and demonstrated by Prof W A Pretorius in the laboratory of the Department of Water Reclamation Engineering at the University of Pretoria.

Based on this information, a pilot plant was erected during 1988 at the Kimberley abattoir, under the auspices of the former Protein Advisory Committee.

This report is based on the final transfer of technology on a full scale basis at Abakor's Johannesburg abattoir. This abattoir was chosen as the infrastructure for a basic pre-treatment plant as well as a By Products rendering and sterilising plant were already in operation. The effluent pre-treatment plant could easily be converted to the required configuration for a modified SBR plant with relatively low capital cost.

Abattoirs, which have By-Products Rendering plants within economical transport distance, will be able to benefit from this process.

1.3 Motivation

One of the largest problems at abattoirs is the complexity and cost related to the treatment / purification of their effluents. The Water Research Commission has already financed research projects based on physical / chemical techniques to treat abattoir effluent.

By utilising the proposed process of the cultivation of single cell protein the following objectives were achieved:

a) Purification of abattoir effluent by means of a natural, robust, environmentally friendly, biological process

b) The production, recovery and manufacturing of a valuable protein product. This protein was successfully utilized as an admixture to existing carcass and blood meal. Depending on the circumstances, it can be utilised as a natural protein source in animal feedstock.

c) The reduction of the high intensity pollution load on existing municipal effluent treatment plants and resultant lower effluent tariffs payable. The potential pollution load of a large (Grade A: ± 2 000 cu/day) abattoir's effluent is equivalent to approximately 325 000 domestic population units. If this load can be minimised, the capacity of a municipal treatment works can be extended.

d) Saving in protein imports and valuable foreign capital.

2. METHODOLOGY

From the upgrading of pilot scale to full operational scale, the following parameters had to be researched/ tested in more detail to determine the effect on the full scale operation:

- Aeration frequencies and rates
- Flocculant dosing
- Operational conditions during non-slaughter days/ periods
- Balancing of peak flows/ loads and excessive fat discharge loads.
- Recirculation rates
- Methods of handling and further processing of the protein sludge dependant on the physical properties.

The project commenced in January 1994. The building work modifications were completed in 16 months due to the fact that the abattoir was fully operational and construction access could only be obtained during very limited periods. Commissioning, stabilisation and optimisation of the process as well as the required test runs before converting to a full time operation was programmed to coincide with the construction period.

ABAKOR granted the capital for the required structural changes and process changes to facilitate the transfer of the technology.

2.1 Background

- The abattoir industry in South Africa produces approximately 6 million kl of effluent per year with a chemical oxygen demand (COD) of 30 000 tons (WRC, 1990; Cowan, 1994).
- Most of the effluent ends up in a municipal sewer network resulting in high tariffs payable to the local authority for the receipt and treatment thereof.
- Furthermore, the design capacities of the receiving municipal treatment plants are reduced due to these high organic loads.

- Larger abattoirs are therefore forced to seek ***economically viable alternatives for effluent treatment*** and to consider the recovery of possible by-products (van der Westhuizen and Pretorius, 1996) as well as the possible reuse of tertiary treated effluent (Cowan, 1994; Roux and Pretorius, 1997).
- Physico-chemical treatment of abattoir effluent for the recovery of high quality reusable water has successfully been tested on pilot plant scale (Roux and Pretorius; 1997; WRC, 1998).
- Biological pre-treatment is also possible with the potential of protein recovery/production as a saleable by-product (Waslien and Steinkraus, 1980; Van Niekerk, 1985; Couillard and Zhu, 1993).

2.1.1 Pilot Plant Study:

- De Villiers and Pretorius reported the successful biological pre-treatment of abattoir effluent in a 60 m^3 pilot plant. The study evaluated a modified sequencing batch reactor process (SBR) that was easy to operate and adapted readily to changes in raw effluent composition.
- A biomass was produced with a low sludge volume index (SVI: 50 -75 ml/g) that could be used as a supplement to carcass meal for animal feed. The biomass had a crude protein value (CP) of between 27 and 37 percent, which was cell residence time dependent.

2.1.2 Full Scale transfer:

- Subsequent to the pilot plant study, the process was implemented on full scale at an abattoir (Johannesburg – Abakor) with a slaughter capacity of 2000 cattle units (i.e. 1800 cattle and 8 000sheep) per day, resulting in an effluent volume of ± 2 200 kl/d (1,1 kl/cu). The evaluation of the full scale implementation is reported here. The aim of the study was to assess on full scale, the modified SBR process for pre-treatment of the abattoir effluent and to evaluate the feasibility of the full scale application.

2.2 Materials and Methods

2.2.1 Modified Sequencing Batch Reactor (SBR) Process. The modified SBR process (de Villiers and Pretorius), is defined as a SBR (Irvine and Busch, 1979) with external settler. Flow equalisation takes place within the reactor which is operated as a SBR, except for settlement which takes place in the external settler. Feed to the reactor is intermittent and idle time is applied. It can also be described as a continuous stirred tank reactor with changing water level and cell recycle (Grady and Lim, 1980).

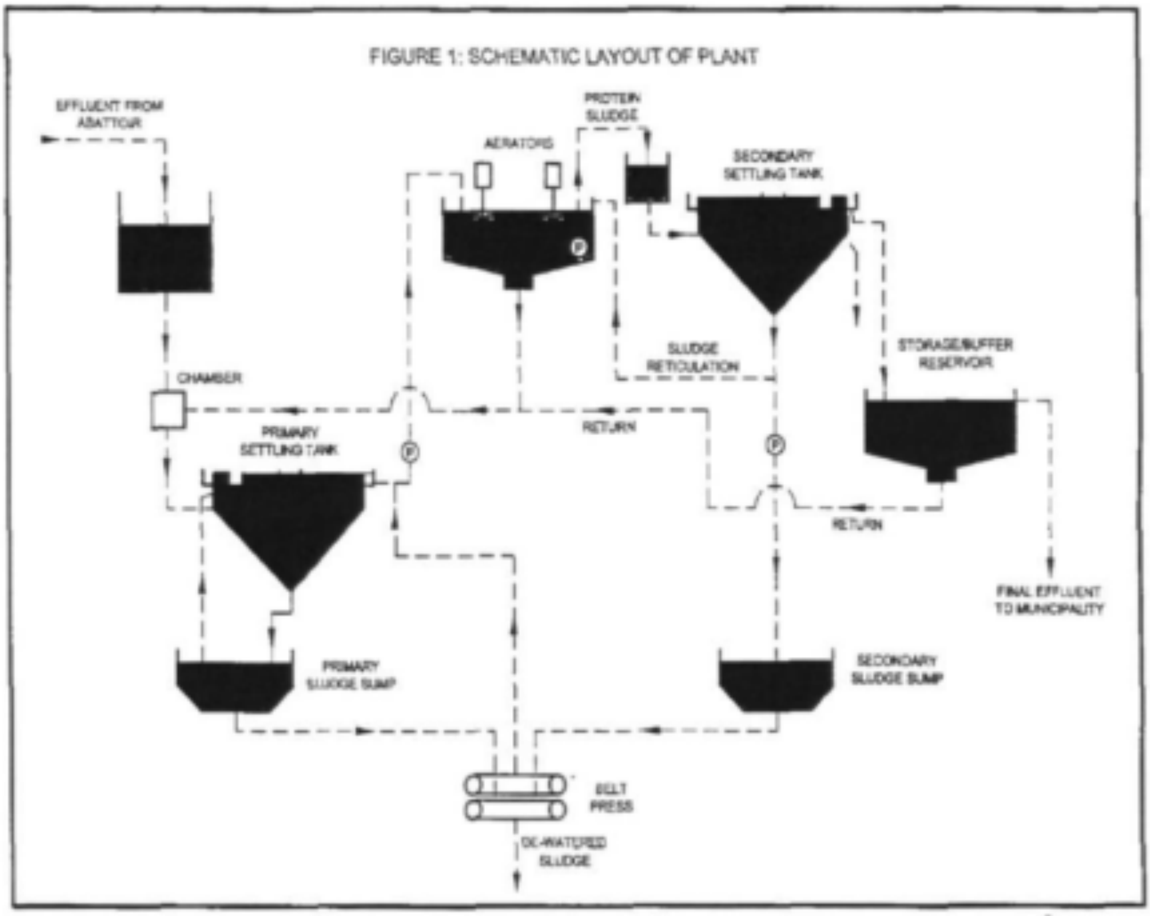


Fig 1. Full scale plant.

Existing structures were utilised and adapted to suit. A circular reactor, 46 meter in diameter and 3,5 meter deep, with floating mechanical aerators was used. A single secondary settling tank was used, 20 meter in diameter, with the feed pumped (reactor pump) from the reactor and the recycle gravitated back. The recycle flow was controlled by a telescopic valve.

The final effluent was stored in a holding tank for overnight discharge into the Municipal sewer system.

Substrate. Substrate included all the industrial (non-domestic) streams: process, offal, lairages and by-products. Screening of the different streams (Table 1) and fat removal were implemented as primary treatment. Effluent generation depended on the number of animals slaughtered, with weekends normally being non-slaughter days.

TABLE 1
SCREEN TYPE AND APERTURE

Effluent Source	Screen Type	Aperture (mm)
Process & By-products	Inclined - Fixed	0,8
Offal	Wine Press	3.0
Lairages (Stock Pens)	Rotary	1.6

2.2.2 Operation. The plant was operated as a modified SBR system with ***Fill, React, Draw and Idle within the reactor, but with Settle in the settling tank*** (Irvine and Busch, 1979). The React period was defined to be the period from the beginning of Fill to the beginning of Idle.

The reactor pump was reactor water level controlled, with low level "off" and a higher level "on", and flow rate such (less than inflow) that partial flow equalisation could take place within the reactor. Biomass was wasted from the settler underflow on slaughter days and dewatered on a filter press.

Aeration was decreased on non-slaughter days and controlled on slaughter days such that an anoxic period was partially induced during Fill, similar to the pilot plant operation. The aerators were controlled by timers, set for typical operation. The dissolved oxygen (DO) concentration was controlled to levels below 3 mg/l.

2.2.3 Test Runs. Two test runs were completed, Test Run 1 and 2 with cell residence times of approximately 5 and 8 days respectively, while keeping other parameters constant.

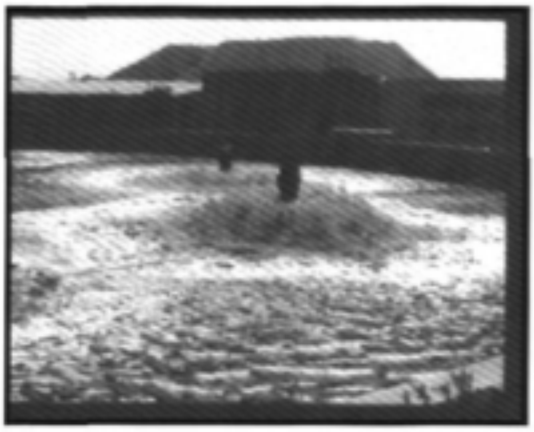


Fig. 2 Sequential Batch Reactor (SBR)

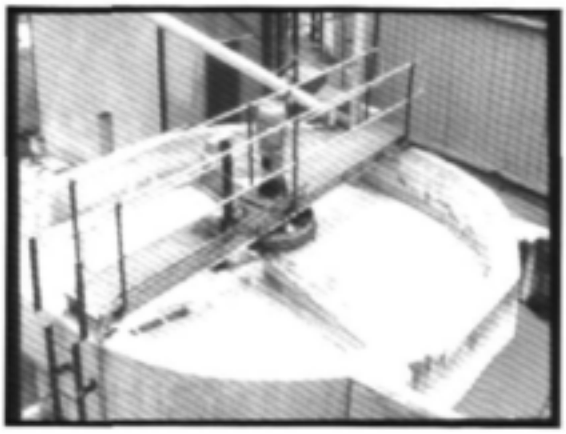


Fig. 3 Fat Removal

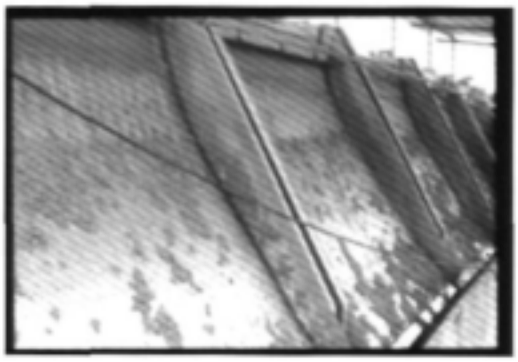


Fig. 4 Inclined Screen

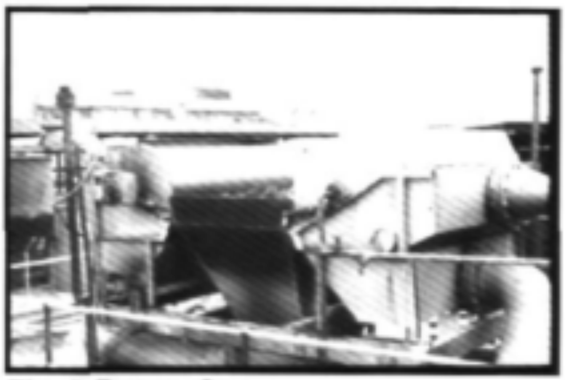


Fig. 5 Rotary Screen

Fig. 6 Primary Sedimentation

Fig 7. Aeration

3. *MONITORING AND ANALYSIS*

The slaughter numbers, water consumption, effluent volume, aerators in use and reactor temperature were measured and recorded daily. DO and mixed liquor suspended solids (MLSS) were monitored on-line and recorded on a computer. Daily samples were taken of:

- primary treated substrate,
- final treated effluent, and
- mixed liquor.

These were analysed for:

- total suspended solids (TSS),
- chemical oxygen demand (COD), and
- mixed liquor for MLSS.

The settler underflow concentration and the SVI were determined daily. All analysis was done as per Standard Methods (1980) except where otherwise stated. The process was allowed at least three cell residence times to stabilise before a complete set of analysis was done and a mass balance completed for the test day of each test run. Biomass samples were occasionally analysed for crude protein (CP), determined from the total organic nitrogen, and observed for filamentous organism characterisation (FOC) by phase contrast microscopic observation (Jenkins et al., 1986). FOC was reported on a scale from 1 (none) to 6 (excessive).

4. RESULTS AND DISCUSSION

4.1 Start-up. The reactor was filled with primary treated substrate, the recycle flow rate and the control levels for the reactor pump was set and aeration commenced.

A fat layer developed on the reactor water level and soon impacted on the operation of the plant. The reactor had to be cleaned out, uncovering a serious build-up of suspended matter and grit. This led to a stepped-up and more efficient housekeeping programme within the abattoir, especially on fat removal at the by-products plant. (Grit removal and primary settling with scum removal was also incorporated). The primary sludge was dewatered on the filter press.

Build-up of fats or suspended matter was never experienced in the pilot plant study. The study was, however, done at another abattoir **with effluent from the stock-pens and by-product plant excluded.** The build-up of suspended matter in the reactor was attributed to a higher TSS in the substrate, ranging from 1,5 g/l to 3,5 g/l, compared to the pilot plant study of 1,1 to 2,1 g/l, and to different aeration systems; (coarse bubble for the pilot plant, versus floating mechanical for the full scale)

This experience emphasizes the importance of completing pilot plant work on the actual effluent planned for application, and the preference of using similar equipment.

4.2 Modified SBR operation. The operating cycle for both test runs were typically as shown in Table 2.

The operation could be varied by adjusting:

- the reactor pump and recycle flow rates,
- the reactor pump control level settings, and
- the number of aerators operating at any time on a weeklycycle.

TABLE 2 TYPICAL OPERATING CYCLE		
Mode	**Time: start to stop**	**Duration (hours)**
Fill	07:00 –16:00	9
React	07:00 –19:00	12
Draw	08:00 – 19:00	11
Settle	08:00 – 19:00	11
Idle	19:00 – 07:00	12

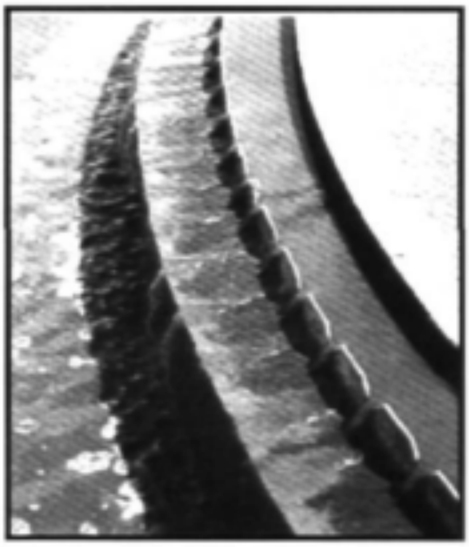


Fig. 8 Primary Sedimentation

Fig. 9 Secondary Sedimentation

Fig.10 Filter Press

These variables made it possible to adjust the operation to accommodate variation in effluent volume, flow rate and duration. The extent of flow equalisation could be controlled and different DO patterns induced. Once set for a typical operation, the system was self-regulating by self adjustment of the duration of the Fill and the Settle periods due to the flow equalisation in the reactor and the return to the same staffing point for the consecutive daily cycle to start.

The process stabilised at a MLSS of 3500 and 4900 mg/l with standard deviations of 300 and 400 mg/l (ca 8%), for Test Run 1 and 2, respectively. The process can therefore be described as stable, in a steady cyclic state, although it is a semi batch process.

4.3 **Treatment efficiency**. The results in Table 3 are the results for the two test days after stabilisation. Overall unfiltered COD and TSS removal was in excess of 90 and 95%, respectively. The filtered COD for the final treated effluent was less than 200 mg/l, approximately 5% of the primary settled COD (4000), and can therefore be assumed to be mainly non biodegradable. This is similar to what was achieved in the pilot plant study. The TSS in the effluent was lower, compared to over 100 mg/l for the pilot plant, resulting in a higher unfiltered COD removal on full scale.

TABLE 3
TREATMENT EFFICIENCY: TEST DAYS
Test day results

Test run no.	Parameter	Substrate mg/l	Primary settled		Secondary settled	
			Effluent (mg/l)	Removal %	Effluent (mg/l)	Removal % **
1	TSS	1 785	998	44	58	97
	COD*	4 660	3 486	25	280	94
2	TSS	3 048	1 386	55	45	99
	COD*	5 859	3 434	41	245	96

* Unfiltered
** Overall removal

The results from the test days compared well with the daily analysis during the stabilisation periods.

4.4 Aeration and DO. Aeration was kept constant during slaughter days. The DO decreased to nil during Fill, simulating the pilot plant trails but generally with a longer duration. This operation decreased the peak oxygen supply and the corresponding peak power requirements. It also decreased the SVI during the pilot plant study, but was not evaluated during these trials. The required aeration power increased with increase in cell residence times, as can be expected. Refer to Table 4.

4.5 Biomass characteristics and protein production The SVI values were higher than expected, compared to the pilot plant, but did not impair settling. The higher values may be due to the longer anoxic period applied (Lakay et al., 1999). FOC varied between 1 (few) and 2 (some). Granules of circa *0,5* mm diameter were noticed (Beun et al., 1999; Dangcong et al., 1999).

The shorter cell residence times increased the biomass production as expected. Biomass production was however approximately 100% more than what was experienced during the pilot plant results, which is difficult to explain. The CP is slightly higher and did not increase with longer cell residence times. The cell residence time can however not be used as a variable in this case due to a combined primary and secondary sludge. An even shorter cell residence time seems attractive for increasing feasibility by increasing protein production and decreasing aeration cost, but could not be evaluated due to a limitation in sludge handling capacity. The combined sludge contained 8% crude fibre (AOAC, 1984) by dry weight which originated from the TSS in the substrate.

The biomass was gravity thickened to circa 20 g/l, mixed with primary sludge and a polymer and dewatered. The dewatered dry solids concentration was circa 30%. Combined sludge production was in the order of 1,2 to 1,3 kg per cattle unit.

4.6 Economic feasibility. A financial feasibility study was completed showing that all expenses were recovered within the first year of operation through protein sales and effluent tariff savings. The results for the running concern are given in Table 4. A net income was generated from protein sales but the main financial benefit was the saving in effluent tariffs due to pre-treatment of the effluent. The feasibility accepts that a by-products plant exists for product handling and that the protein produced is used as a supplement with carcass meal as an animal feed protein source.

TABLE 4 (1994)
FEASIBILITY ON OPERATING EXPENSES, INCOME AND SAVINGS PER YEAR.

Operating expenses	- R 646 000
Income (Protein sales)	+ R 965 000
Net income	+ R 319 000
Effluent tariff savings	+ R 3 780 000
Annual income and savings	+ R 4 099 000

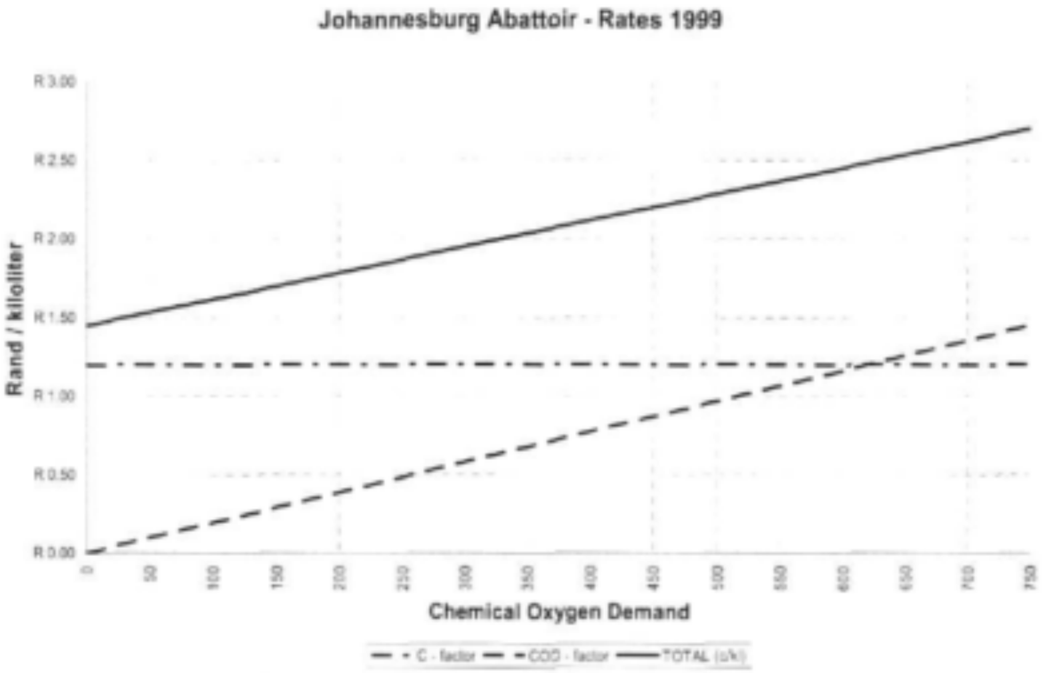
5. CONCLUSIONS

The modified SBR process was successfully implemented from pilot scale to full scale. Differing results were achieved, posting a warning for differences that might be achieved during plant scale-up operations.

The modified SBR process was easy to operate and adapted readily to changes in raw effluent generation. Self-regulating and stable production as well as successful pre-treatment was achieved. The process is ideal for treatment of effluent generated batch wise and with a variable volume. Special attention should however be given to floatable material that is easily confined and concentrated in the reactor.

Biomass with a relatively good settle-ability was produced and could be used as a supplement to carcass meal for animal feed. Protein production and feasibility can probably be increased by decreasing the cell residence time to less than *5* days.

The process proved to be feasible with a net income (on operating) from protein sales on the condition of an existing by-products plant for product handling and product addition to another main protein source. It is also clear that the main financial benefit is the saving in effluent tariffs due to pre-treatment of the effluent.



C Factor Chemical Oxygen Demand (COD) Factor TOTAL (c/kl)

Figure 11 : **Johannesburg City Council - Effluent Rates 1999**

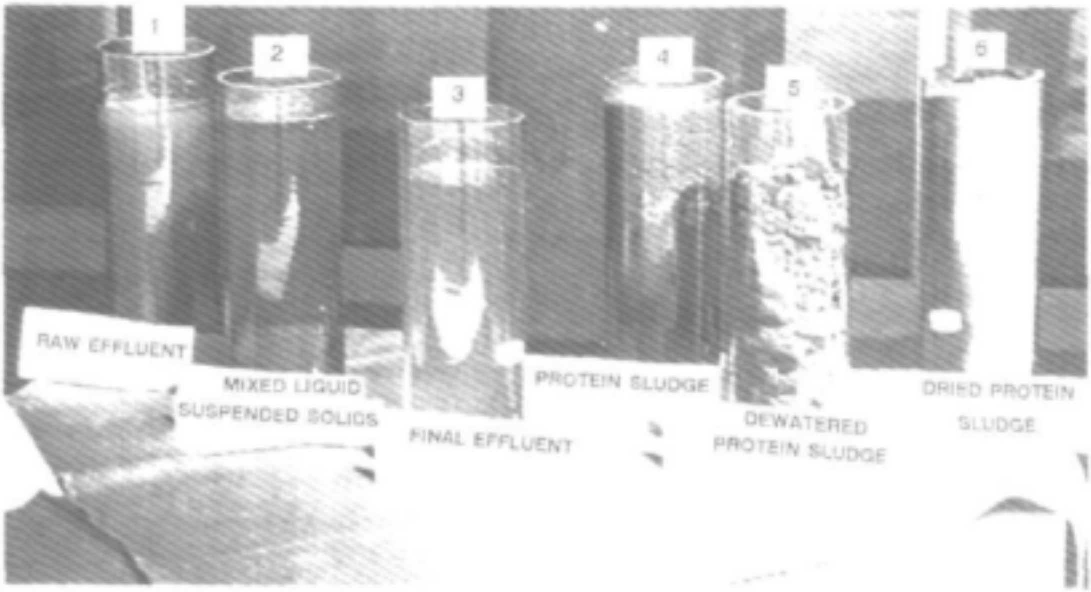


Figure 12: **Samples:**

1. Raw Effluent. 2. Mixed Liquid Suspended Solids 3. Final Effluent
1. Protein Sludge 5. Dewatered Protein Sludge 6. Dried Protein Sludge

6. REFERENCES

AOAC (1984) *OfJicial methods of analysis,* 14~ edn, Association of Official Analytical Chemists, Virginia, USA.

BEUN JJ, HENDLKS, A VAN LOOSDRECHT MCM, MORGENROTH E, WJLDERER PA and HEIJNEN JJ (1999) Aerobic granulation in a sequencing batch reactor. *Wat. Res.* 33(10) 2283 - 2290.

COUILLARD D and ZHU 5 (1993) Thermophilic aerobic process for the treatment of slaughterhouse effluents with protein recovery. *Environm. Poll. 79(2) 121 - 126.*

COWAN J (1994) Using membranes to treat abattoir effluents. *Chemical Tech.* **Feb. (1994)** 7 - 9.

DANGCONG P, BERNET N, DELGENES J and MOLETTA R (1999) Aerobic granular sludge - a case report. *Wat. Res.* 33(3) 890 - 893.

DE VILLIERS GH and PRETORIUS WA (accepted) Abattoir effluent treatment and Protein production. IWA 1St World Congress: Paris, France 3 - 7 July 2000.

GRADY CPL and LIM HC (1980) Continuous stirred tank reactors. In: *Biological Wastewater Treatment, Theory and Application.* Marcel Dekker Inc., New York.

IRVINE RL and BUSCH AW (1979) Sequencing batch biological reactors - an overview. *Joumal Wat. Control Fed. 51(2)* 235 - 243.

JENKINS D, RICHARD MG and DAJGGER GT (1986) *Manual on the causes and control of activated sludge bulking and Jbaming.* Water Research Commission, Pretoria, RSA.

LAKAY MI, HULSMAN A, KETLEY DA, WARBURTON CA, DE VILLIERS ME, CASEY TG, WENTZEL MC and EKAMA GA (1999) Filamentous organism bulking in nutrient removal activated sludge systems. Paper 7: Exploratory experimental investigations. Water SA 25(4) 383-396.

ROUX A and PRETORIUS WA (1997) Renovation of wastewater for direct reuse in an abattoir. Water SA 23(4) 323 - 331.

STANDARD METHODS (1980) *Standard Methods for the Examination of Water and Wastewater* tb
(15 edn.) American Public Health Association. American Water Works Association. Water Environment Federation. Washington DC, USA.

VAN DER WESTHUIIZEN TH and PRETORIUS WA (1996) Production of valuable products from organic waste streams. *Wat. Sci. Tech.* 33(8) 31 - 38.

VAN NIEKERK GJJ (1985) *Gebruik van 'n enkelladingreaktor vir die biologiese voorsuiwering van abattoiruitvloeisels.* MSc thesis, Water Utilisation Division, Department of Chemical Engineering, University of Pretoria, South Africa.

WASLIEN CI and STEINKRAUS KH (1980) The Potential of Microbial Cells as Protein for Man. Bio Science 30(6) 397 - 398.

WRC (1990) *A guide to water and wastewater management in the red meat abattoir industry.* Report IT 45/90, Water Research Commission, Pretoria, RSA.

WRC (1998) *The transfer of waste-water management technology to the meat processing industry.* Report 239/1/98, Water Research Commission, Pretoria, RSA.

RECLAMATION OF WASTEWATER FROM THE PROTEIN RECOVERY PROCESS FOR DIRECT RE-USE IN AN ABATTOIR

WRC Project No K5/778

EXECUTIVE SUMMARY

Tertiary treatment methods were tested on secondary effluent from an abattoir biological wastewater treatment plant with the purpose of reclaiming it for reuse in an abattoir. The colour, dissolved organic matter (DOM), odour, bacteria, viruses and other pollutants, were removed to such an extent that the water would comply with standards for *water of insignificant health risk* (Department of Health). The treatment process sequence utilized, was coagulation with a polymer blend, separation, ozonation, filtration and activated carbon filtration. The development of biologically activated carbon (BAC) in practice was accepted as inevitable and desirable for optimum water quality. A deciding factor in the selection of an appropriate treatment process was that the final water would also have acceptable non-corrosive properties.

1. INTRODUCTION

Because of present and projected water shortages in South Africa (Department van Water Affairs, 1984) the Johannesburg abattoir was considering minimising their freshwater consumption. The abattoir industry is generally accepted as a sector with abnormally high water consumption per carcass produced. Johannesburg abattoir, the former largest in the country, with a capacity of slaughtering 1 800 cattle/day and 8 000 sheep/day consumed an average of 2 200 kl of fresh potable water daily. This relates to ± 1,8 kl/cattle unit (cu) whilst smaller abattoirs use between 3.0 kl/cu and 4.0 kl/cu. The cost of fresh water the time of the report, totalled R6.15/kl.

The water demand was firstly significantly reduced by optimising water usage in the abattoir. The next phase was to reclaim and reuse the effluent.

In effecting an acceptable process for the treatment of process effluent water, savings were achieved in the reduction of costs of fresh water purchased as well as the reduction of the cost of effluent discharged. Adding the treatment cost of the recycled water still proved to be an economically viable proposition. The environmental advantage of using 2 500 kl/month less water was a bonus, which cannot be discounted in financial terms. The total cost saving was approximately R 5 million/year.

The Johannesburg Abattoir employs a biological purification process to treat its wastewater. This reduces the municipal effluent disposal charges and renders the raw effluent to a state to conform to the minimum requirements of the Municipal by-laws to ensure that their minimum tariff is charged for disposal. An added advantage is that single cell organisms for which an economic application exists, are harvested. This secondary treatment process removes 90% - 95% of all the organic matter from the primary effluent (Pretorius *et al.*, 1995). The secondary effluent contains colour, suspended matter and micro-organisms that make it unsuitable for direct reuse. It was determined experimentally that further treatment by tertiary processes could reclaim it to an acceptable quality for selected applications in the abattoir i.e. washing of lairages, truck washing, washing of offal and irrigation.

1.1 Water quality required

Less than half of the average water demand (Van Heerden, 1995) in an abattoir is applied to processes that bring it into direct contact with products for human consumption. The balance of the water demand could be satisfied with effluent that has been renovated to comply with certain minimum health, aesthetic and economic criteria (Cowan and Steenveld, 1990).

The South African Department of Health proposed a three-tiered drinking water quality guideline (Pieterse, 1989) which sets these limits. This guideline grades water quality in

(i) no health risk,

(ii) insignificant health risk, and

(iii) *low health risk*

categories depending on frequency of use. The renovated water could be of *insignificant health risk* quality, while water complying with *no health risk* quality should be supplied to the rest of the abattoir.

The Department of Health guideline stipulates permissible levels of indicator organisms, which can be reached with disinfection (White, 1992).

Dissolved organic matter (DOM) present in water to be disinfected can seriously hamper disinfection efficiency, increase disinfectant demand (Rogers *et al.*, 1987) and lead to the formation of carcinogenic chlorinated organics (Vik *et al.*, 1985). DOM can also be the cause of colour, odour and re-growth of organisms in a distribution system (Funke. 1969). DOM should therefore be removed to levels specified by the Departmental guideline for health and aesthetic reasons. (Krenkel and Novotny, 1980)

Economic criteria require that maintenance costs should be minimised (Cowan and Steenveld, 1990). Corrosion and aggression on equipment and pipes can be controlled by maintaining a calcium carbonate precipitation potential and limiting chloride and sulphate ions (Benefield *et al.* 1982).

Although the recycled water was to be utilized in the "insignificant risk" areas, it was decided to treat the water to "drinking water" Standard – SABS 241-1984 (superceded by SABS 241-1999)

1.2 Present water quality

Most suspended solids and biodegradable organic matter (DOM) are removed during the single cell production process (Pretorius *et al*,. 1995). The DOM in this secondary effluent would be similar (Rebhun *et al*.. 1969) to that found in secondary treated domestic effluents. This DOM is detectable by colour, taste and odour and the composition and characteristics are similar (Narkis and Rebhun, 1983) to DOM found in coloured surface water steams. On average 45 % of DOM in secondary treated domestic sewage would be humic matter (Manka *et al.*, 1974) whereas in surface water, about 50% would be humic matter (Sierka *et al.*, 1989). Humic matter is characterized (Christman and

Ghassemi, 1966) by an unsaturated structure which is the cause of colour.

1.3 Possible treatment alternatives

Because of the possible effect of DOM on the health and aesthetic quality of the re-used water, the removal of DOM was identified as a priority. Humic matter makes up the bulk of the DOM. The various methods of removal of humic matter are:

a) chemical coagulation and separation (Edzwald *et al.*, 1977: Grozes *et al.*, 1995);

b) oxidation (Edwards *et al.*, 1994);

c) adsorption onto activated carbon (Weber and Jodellah, 1985; Sierka *et al.*, 1989):

d) membrane processes like reverse osmosis, ultra- and nanofiltraton (Juby and Botha, 1994: Tan and Amy. 1991); and

e) combinations of these (Weber and Jodellah, 1985).

Coagulation is a popular treatment method and its effectiveness has been proved in coloured surface water (Christman and Ghassemi, 1966). Ozonation in combination with activated carbon (Harrington and DiGiano. 1989) as well as biologically activated carbon is a cost effective treatment alternative (Juby and Botha, 1994: DiGiano *et al.*, 1982). Juby and Botha (1994) have found nanofiltration effective for both colour and organic matter removal, but it is a more expensive treatment alternative (Tan and Am. 1991).

Coagulation of humic matter generally involves complexing and precipitation with a polymer (Edzwald *et al.*, 1987). Metal salts form polymeric hydrolysis intermediates when added to water (Semmens and Field, 1980). Organic poly-electrolytes (Dempsey *et al.*, 1985) and pre-formed metal polymers such as poly-aluminium chloride (Edwards *et al.*, 1994; Grozes *et al.*, 1995) can have a greater charge neutralisation capacity than these hydrolysis intermediates. Commercial blends of poly-metal compounds and organic poly-electrolytes can combine the effect of higher charge densities and optimum length for very effective contaminant removal in specific waters (Kerdachi *et al.*, 1994).

Humic matter stability in water is due to negative charge density (Manka *et al.*. 1974) provided by unprotonated phenol and carboxylic functional groups (Sierka *et al.*, 1989). This charge density is reduced when the pH is reduced (Kuo and Amy, 1988). The stability of the humic matter is reduced, reducing effective coagulant dosage at pH of around 5 (Qureshi and Malmberg, 1985: Amirtharajah *et al.*, 1993). However, decreasing the pH below 4.5 would result in charge reversa1 (Stephenson and Duff, 1996) and increasing stability

Removal of DOM by complete oxidation to CO_2 with prolonged ozonation (Constantine. 1982; Chang and Singer. 1991) would generally be uneconomical. Oxidation with lower ozone dosages decreases the degree of unsaturation of the humic matter (Owen *et al.*, 1995; Kuo and Amy, 1988) by oxidising the double bonds in chromophores and destroying colour. Smaller entities with aldehyde, ketone and carboxylic acid functional groups (Eaton. 1995; Sierka *et al.*, 1989) are the products of this reaction. Turbidity is often increased after ozonation. This can be due to humic matter that adsorbs on and stabilises colloidal matter being oxidised and removed (Edwards *et al*,. 1994).

These products of ozonation are generally more biodegradable than humic matter and would lead to bio-growth on granular activated carbon (Symons. 1980). Optimal use of ozone and activated carbon for removal of organic matter would be in combining an ozonation step to remove colour and increase bio-degradability, and fixed bed activated carbon adsorption on which biological activation is promoted (Constantine, 1982).

2. OBJECTIVES

The purpose of this research was to establish which combination of tertiary treatment processes would produce a stable, re-usable water of *insignificant health risk* quality from the secondary treated wastewater from an abattoir.

In order to achieve this, the following objectives were formulated:

A comparison of the effectiveness of colour removal by:

- Different chemical coagulants at different pH.
- Coagulation followed by various combinations of tertiary treatment processes

The final water produced by these treatment processes would be checked for compliance with the *insignificant health risk* quality guideline and guidelines for corrosion control.

3. METHOD

3.1 Sample collection and testing

Twenty-five litre samples of secondary effluent from Johannesburg Abattoir were collected every second to third day during the experimental period. The samples were preserved at 4 ^{0}C between test runs, but allowed to reach ambient temperatures before any experiments were performed. The samples were shaken before aliquots for experimental procedures were drawn. Each sample of raw water was tested for total dissolved solids (TDS). chloride, sulphate, total alkalinity, total hardness, turbidity, colour, dissolved organic carbon (DOC), and total heterotrophic plate counts were performed.

3.2 Comparison of coagulants for colour removal

Initially a range of metal salt and poly-electrolyte coagulant blends were screened for their ability to remove colour. Of these, aluminium sulphate ($A1_2(SO_4)_3$. $18H_20$). ferric chloride ($FeCl_3.6H_2O$) and a poly-aluminium chloride and polyamine blend (PACI-Blend - NCP: Chloorkop) gave the best results. These were used for comparison of colour removal. Testing consisted of varying the chemical dosage without adjusting pH, and varying pH while keeping dosages constant.

For the varying pH testing. pH was adjusted with 5 N H_2SO_4 or 0.25 N NaOH solutions prior to coagulant addition and recorded after flocculation. Loewenthal *et al.* (1986) advised that the individual concentrations of chloride and sulphate concentrations should not exceed 50 mg/l each to limit corrosion. Polyamine products often have a health limitation for use in drinking water (Mallevaille *et al.,* 1984). Comparing the colour removal at varying pH was therefore performed at:

- 100 mg/l $Al_2(S0_4)_3$ $18H_20$ to limit increase in sulphate concentration to 43 mg/l
- 120 mg/l ferric chloride to limit increase in chloride concentration to 47 mg/l
- 60 mg/l PACI-Blend due to a health limitation on dosing of 66 mg/l

To identify the coagulant that gave consistently the best results for colour removal at these dosages, the mean and standard deviation (Wine. 1964) was calculated for percentage removal obtained at constant pH for aluminium sulphate (100 mg/l), ferric chloride (120 mg/l) and PACI-Blend (60 mg/l).

Coagulation was performed with the jar test method as recommended by (Dental *et al.,* 1988) and (Lai *et al.*. 1975). The best results were obtained by rapid mixing for 2 min at 295 r/min (G-value of $199.5s^{-1}$) after coagulant addition, followed by 20 min at 50 r/min (G-value of $12.6s^{1}$). 500 ml samples to 1 000 ml round glass beakers were used and the G-values were obtained using calibration of G in round beakers by Botha *(1995)*. After 20 min settling, samples of supernatant was drawn for pH and colour measurement.

3.3 Corrosivity

Stabilisation dosage requirements were calculated for coagulant dosages and ph, using the Stasoft computer programme (Loewenthal *et al.,* 1988). According to the Larson index: $\underline{Cl + SO_4\quad}$ corrosivity (Loewenthal *et al.,*1986) was calculated using the theoretical alkalinity given by Stasoft in each case. Loewenthal *et al.* (1986) recommended that this value should be less than 0.2.

3.4 Ozonation

Ozone was generated with a LN 103 ozone generator (Ozonia, Switzerland) with oxygen as a feed gas. The ozone generator was calibrated by bubbling ozone through a diffuser at the bottom of a 75 mm diameter contact column containing 1 litre of a 2% potassium iodide (KI) solution. Ozone dosage was varied according to the time of ozonation at a constant voltage and gas flow. After each time period, the KI solution was transferred and titrated to a clear endpoint using 0.1 N sodium thiosulphate ($Na_2S_20_3.5H_20$) with starch as indicator as was described by Toerien. (1988) and Razumovski and Zaikov (1984), thereby measuring the amount of ozone transferred during each time interval. The ozone production rate was determined from these data.

The ozone demand of water (National Institute for Water Research, 1981) is defined as the amount of ozone consumed before an ozone residual is observed for a given time period. The readily oxidisable organic matter in water will deplete ozone (Venosa and Meckes, 1983: Rice and Bollyky, 1981) and constitute this demand. Since the unsaturated bonds on humic matter would be preferred sites for ozone attack, the demand would also represent the amount of ozone needed for colour removal (Grasso and Weber. 1988). Ozone demand was determined by applying ozone to distilled water and the sample at increasing dosages and measuring the ozone in the off-gas by the same method described above. The ozone demand of the sample and contact system would be the mass of ozone applied minus the mass of ozone in off-gas per litre of sample.

The relationship between ozone absorbed and colour removal was determined by measuring the percentage colour removal with increasing applied ozone dose. Absorbed ozone was determined in the same manner as described for ozone demand.

Table 2 shows applied ozone dosages employed to obtain these relationships:

Table 2: Ozone combinations

Sample	Applied Ozone Dosage	Relationship
Distilled Water	0 - 80 mg/l	Reference curve
Secondary effluent	0 – 80 mg/l	Ozone demand curve
Flocculated Secondary effluent	0 – 60 mg/l	Ozone demand curve
Secondary effluent	0 –020 mg/l	Ozone demand curve

3.5 Activated carbon adsorption for colour removal

Granules of activated carbon type PHO 12/40 was supplied by Montan (Johannesburg) were added to 150 ml aliquots of treated secondary effluent water and shaken over a period of 12 hours to compare the effect of ozonation on the removal of colour by adsorption. Quantities added are shown in Table 3.

Table 3: Activated carbon adsorption for colour removal

Sample	Activated Carbon Added
Flocculated Secondary effluent	50 – 1 000 mg/150 ml
Flocculated and Ozonated Secondary effluent	50 – 1 000 mg/150 ml

3.6 Comparison to guideline

The most effective treatment sequence was performed on a sample of secondary effluent and the product water quality after each treatment step was analysed for TDS, chloride, sulphate, alkalinity, hardness, pH, turbidity, colour and DOC. These were compared to the guidelines for health, aesthetic and economic criteria.

3.7 Analysis methods

- Organic matter removal with coagulation was measured by colour removal as was mentioned by Edwards and Amirtharajah (1985) and Van Breemen *et al.(1979)*. This relationship between colour and COD removal was confirmed in this study.
- DOC was measured by the Rand Water Board Scientific Services.
- Samples were corrected to pH 7 and centrifuged before colour measurement (Crowther and Evans. 1981) with a Merck Spectroquant photometer SQ I18 (E.Merck, Darmstadt). relating it to Hazen units. TDS was determined gravimetrically on the centrifuged samples (Standard Methods. 1989)
- Samples were filtered through Whatman 4 filter papers before turbidity measurements. The nephelometric turbidity (Dental *et al.*, 1988) was measured with a Hach turbiditymeter model 2100 A (Hach. USA.).
- Total hardness was determined as in Standard Methods (1989) method no 2340C, alkalinity by method 2320, chloride with method 4500-Cl B and standard plate count with method 9215 B.

4. RESULTS AND DISCUSSION

4.1 Sample Collection and Testing

The secondary effluent quality is compared to water *of no* and *insignificant health risk*

The TDS, chloride, sulphate, hardness and pH of the secondary effluent water were all within the limits of water quality of *insignificant health risk* (Pieterse. 1989). The chloride concentration is double the recommended 50 mg/l and the Larson index was calculated to average around 0.43, which is higher than the recommended 0.2 (Loewenthal *et al.*, 1986). The turbidity was mostly within the limit as well, apart from days when anaerobic conditions developed in the secondary clarifier. Turbidity levels up to 29 NTU were recorded. These conditions can be prevented with better operation of the biological plant. The colour, dissolved organic carbon (DOC) and microbiological quality (total heterotrophic plate count) of the secondary effluent did not comply with the requirement for water of *insignificant health risk.*

4.2 Comparison of coagulants for colour removal

4.2.1 Varying dosage

The three best coagulants were compared for colour removal at different dosages. No adjustments for pH were made.

Dosages of 120 mg/ PACl-Blend gave far superior colour removal (± *68%)* than similar dosages of alum and ferric chloride *(± 30%)*. To obtain 68% colour removal with alum and ferric chloride dosages of 400 mg/l are needed. At these dosages pH was reduced to 6.

Large increases in colour removal was obtained with small increases in PAC1-

Blend addition, while increase in colour removal was more gradual with alum and ferric chloride. The fact that these two coagulants gave similar removal of colour was confirmed by plotting the percentage removals by alum and ferric chloride at selected dosages against each other. A straight line with gradient of 1 was obtained with r^2=0.97.

The amount of coagulant added would be proportional to the amount of reaction sites on the organic matter (Amirtharajah *et al.,* 1993, Vik *et* al., 1985). The charge density provided by the polyaluminium chloride and polyamine blend. PACl-Blend, is high (Dempsey *et al.*, 1985), therefore less is needed to reach the optimum charge addition than with ferric chloride or alum. Secondly, different fractions of the humic matter could be more amenable to removal by different coagulants (Randtke and McCarty. 1979). A blend like PACl-Blend could therefore be more effective for colour removal. The pH was reduced when ferric chloride and alum were used due to depletion of hydroxide to form hydrolysis intermediates and hydroxide precipitate (Hong-Xiao and Stumm, 1987). This reduction in pH could play a role in the increase in colour removal obtained at higher dosages of metal salts.

Corrosion requirements limit the dosages of alum and ferric chloride to 100 mg/l and 120 mg/l respectively and health requirements limits the PACl-Blend addition to 60 mg/l. The mean and standard deviation **(a)** for removals obtained at these dosages at pH 7.6 was calculated and is reported in Table *5*.

Table 5: Mean and standard deviation of colour removal with 3 coagulants

Alum at 100 mg/l	Mean - 26.2% **a** -3.8 %
Ferric chloride at 120 mg/l	Mean - 25.5 % **a**- 13.2 %
PACl-Blend at 60 mg/l	Mean - 3 7.6 % **a** - 2.7 %

PACl-Blend at 60 mg/l gave better colour removal than alum at 100 mg/l and ferric chloride at 120 mg/l. The difference between colour removal obtained with alum and ferric chloride is marginal. The length and charge distribution of the hydrolysis intermediates-metal species formed with metal coagulants (Stephenson and Duff, 1996) would be determined by pH and would not necessarily always be consistent or optimum. This wou1d explain high variability in results obtained with colour removal with ferric chloride.

4.2.2 Varying pH

The influence of pH on the efficiency of colour removal is compared for the three coagulants at constant dosages. Better removal was obtained with 60 mg/l PACl-Blend than with 100 mg/l alum or 120 mg/l ferric chloride at all pH values. Similar removal efficiencies were again obtained with alum and ferric chloride. Colour removal was at least 20% higher at pH of around 5 than at pH 7.6 for all three coagulants. Optimum removal under pH conditions of around 5 was found by several authors like Edzwald *et al.*,(1977), Narkis and Rebhun *(1983)* and Christman and Ghassemi (1966) and is explained by the destabilising effect of reducing pH on organic matter (Kuo and Amy,1988).

4.2.3 *Corrosivity*

The Larson index increases from 0.49 to 0.5 with the dosage of 60 mg/l PACl-Blend. The Larson index, after restabilisation with lime, of water treated with 400 mg/l ferric chloride is 1.4 and 400 mg/l alum is 1.1. Dosages of alum and ferric chloride to these levels is not recommended.

The buffer capacity of the secondary effluent is high (alkalinity-Table 4) and adds to the stability of the humic matter (Moyers and Wu. 1985). The amount of hydrochloric or sulphuric acid added to obtain a pH of 5 in the secondary effluent increased the chloride or sulphate ion concentrations to 300 mg/l and 400 mg/l respectively. This would increase the Larson index of the water to 0.75. The adjustment of pH to 5 for optimum colour removal is not recommended.

At 60 mg/l PACl-Blend the water still contains 62.4% of the original colour and organic matter and needs to be treated with further processes before it will comply with the *insignificant health risk* standard.

4.2.4 *Ozonation*

An average of 5.86 mg ozone/minute was generated with the ozone generator at 0.5 A and 0.7 bar oxygen pressure. This value was used to determine applied ozone dosage for ozone demand and colour removal.

4.3.5 *Ozone Demand*

The ozone demand of secondary effluent and secondary effluent coagulated with 60 mg/l PACl-Blend can be seen in Fig. 3.

The influence of the amount of dead space in the ozone transfer system on the apparent ozone absorbed by the water is represented by the first straight line portion where all three curves coincide. The ozone demand was about 8 mg/l (A) for secondary effluent and 5.5 mg/l (B) for flocculated water as shown in Fig. 3. Coagulation would reduce ozone dose. Another advantage is that it may absorb variations in raw water quality, avoiding continual adjustment of ozone dose.

4.2.6 Ozone absorbed and colour removal: Relationship

The reduction of colour from secondary effluent with ozone was non-linear (Juby and Botha. 1994), with significant reductions at low ozone dosages. The removal values were fitted to a power curve with the following formula:

$y = 23.6\,x^{0.43}\quad r^2 = 0.989.$

Fitting the colour removal efficiency to a theoretical formula would enable predictions to be made on the ozone dose necessary should the colour in the secondary effluent vary. The colour reduction rate decreases with higher dosages until a certain refractory fraction of colour will remain (Tan and Amy. 1991).

4.2.7 Colour removal with adsorption on activated carbon

The colour removal in the flocculated sample was increased from 40% to 64% by the maximum activated carbon added. The carbon probably reached its adsorption capacity for the coloured humic matter around the dosage of 400mg/150m1. Colour removal from the ozonated water was increased from 77% to 81% by the maximum activated carbon added. The gradient of this curve shows adsorption capacity for colour from this water is very low. PHO 12/40 is a coconut based activated carbon with a small pore size and low capacity for adsorption of humic matter.

Colour removal could possibly be improved using a peat-, wood-, or bitumen-coal based activated carbon (Nel, 1996).

4.2.8 Comparative Removal

Coagulation with 60 mg/l, PACl-Blend, ozonation at 5.5 mg/l followed by filtration and contacting activated carbon at 6.7 mg/l for 12 h was performed on a sample of secondary effluent. The influence of each treatment step on the water quality is compared to guideline values in Table 6.

Table 5: The water quality produced by the selected treatment processes, to guidelines for *insignificant health risk* and corrosion

	Guideline values	Secondary Effluent	PACl-Blend 60 mg/l & settle	Ozonation 5.5 mg/l & filter	Activated Carbon
TDS – mg/l	2 000	664	664	664	664
Alkalinity–mg/l CaCO3		300	300	300	300
Larson – index	0.2	0.49	0.5	0.5	0.5
Chloride – mg/l	600	110	112	112	112
Sulphate	600	35	35	35	35
Hardness – mg/l CaCO3	200	120	120	120	120
pH	5.5-9.3	7.65	7.65	7.8	7.5
Turbidity – NTU	5	5.2	3.6	1.9	1.9
Colour – Hazen	20	176	110	41	33
DOC – mg/l	10	91	76	50	38
Standard plate count cfu/100ml	1 000	2 000 000	1 000 000	50 000	N/A

The TDS. alkalinity, hardness and sulphate concentrations was not altered during any of the treatment processes. A slight increase in chloride ion concentration was due to the addition of PACl-Blend which releases a small amount of counter ions.

Although the Larson index is still outside specification. the treatment process had not increased it significantly (by only 0.01).

The dosage of 60 mg/l PACl-Blend reduced turbidity from 5.2 NTU to *3.6* NTU (by 30%). Small pin flocs appeared in the coagulated sample after ozonation. This could be due to colloidal matter losing their stability due to oxidation of absorbed humic matter (Grasso and Weber. 198& Edwards et *al.*, 1994). It could also be due to polymerisation of organic matter which could bridge between colloidal particles (Chang and Singer. 1991). After filtration removed the pin flocs. the turbidity was improved from 3.6 NTU to 1.9 NTU. Therefore, filtration should be performed after ozonation.

DOC was reduced by 16 % to 76 mg/l by coagulation. Ozonation and filtration reduced the DOC by 29% to 50 mg/l. This removal is probably due to destabilisation of organic colloids, pin floc formation and subsequent removal with filtration and not to complete oxidation to CO_2. McCarthy and Smith (1974) and Edwards *et al.* (1994) reported that significant fractions of organic matter would be removed only when very high ozone dosages and long reaction periods are employed.

DOC removal with activated carbon adsorption was measured for the maximum dosage. The DOC was reduced to 38 mg/l (by another 13% to 58%). The total DOC removal with this dosage of activated carbon was 61% when coagulated but un-osonated water was used. This clearly shows that the products of oxidation of humic matter (low molecular weight and polar) are not adsorbed well (Symons. 1980). These smaller entities may be more biodegradable than humic matter (Weber. 1984).

The biodegradability of the organic matter and the development of BAC was not examined in this study, but the dosage ratio in this experiment of about 0.8 mg 0_3/mg DOC may have to be increased to the recommended 1-2 mg Ozone/mg TOC which was reported. (Juby and Botha. 1994: Goel *et al.*, 1995) to be necessary to increase biodegradability of humic matter.

Fig. 1 Bank of Carbon Filters

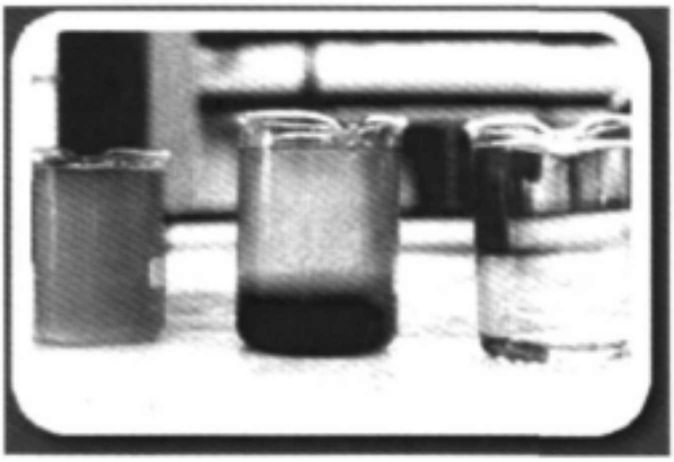


Fig 2. Colour Variation from Raw Effluent to Final Treated Water

Increasing the biodegradability of the DOC may theoretically promote the formation of BAC which could theoretically increase DOC removal (Juby and Botha, 1994).

Colour was reduced to 110 Hazen with coagulation. Ozonation reduced this colour to 41 Hazen and adsorption to 33 Hazen. This is still higher than the recommended 20 Hazen. Colour may be reduced further if BAC develops.

Bacteria reduction was 50% after flocculation and 95.26% after ozonation. Ozonation was not employed as a disinfecting step. Bacteria levels could increase in the final water if BAC develops. A terminal disinfectant step is necessary.

5. CONCLUSION

Comparison between aluminium sulphate, ferric chloride and PACl-Blend as coagulants for colour removal showed that PACl-Blend resulted in a better colour removal at half the dosages of the other two coagulants.

Furthermore, PACl -Blend does not impact on the pH of the water and releases significantly less amounts of counter ions than alum and ferric chloride. The colour removal could be doubled by increasing the dosage of the PACl-blend to 120 mg/l which is outside the health limit. Coagulation with PACl-Blend at 60 mg/l and settlement should be an initial treatment step. Either ferric chloride or alum could be used as a second choice since their performance was similar.

Reducing the coagulating pH from 7.6 to 5 increased colour removal by 20% at the same dosages of coagulant. The buffer capacity of the secondary effluent was very high and high acid dosages were needed to achieve this pH reduction. This increased the chloride and sulphate ion concentration to 3 or 4 times the recommended values for corrosion control. Adjusting the pH to optimise coagulation is not advisable.

Ozonation and filtration improved colour and organic matter removal to levels attained by very high dosages of coagulants or better. The relationship defined in this study could be used in practice to adjust ozone dosages for variations in colour of the secondary effluent. DOM was also reduced after filtration. The chemical quality of the water was not affected by ozonation. Ozonation and filtration should be included in the treatment sequence to reduce colour and organic material and increase the biodegradability of the DOM

Activated carbon adsorption was slightly less effective in DOM removal after ozonation than after just flocculation. However, colour removal was better with the ozonation step included. DOM levels could possibly be reduced to within the guideline values if BAC is allowed to develop.

6. RECOMMENDATIONS

The tertiary treatment recommended to renovate the secondary effluent from Johannesburg abattoir to comply with water quality of *insignificant health risk* should consist of:

- Coagulation with 60 mg/l PACl-Blend and flocculation at ambient pH.
- Settlement.
- Ozonation at *5.5* mg/l (or higher to increase biodegradability).
- Filtration.
- Activated carbon adsorption with provision for biologically activated carbon to develop.
- Disinfection.

Further research:
The formation of BAC after ozonation and the efficiency of removal of DOC and colour should be investigated.

The ammonia concentration was low during these experiments, but is known to vary and could impact adversely on chlorination. The efficiency of post chlorination for disinfection should be investigated due to the very high chlorine demand.

7. K5/778 APPENDIX

The following results were obtained from the tertiary effluent treatment plant built at the Johannesburg Abattoir as a result of the investigative work reported in this publication: This plant consists of coagulation and settling, followed by ozonation, sand filtration, activated carbon filtration and chlorination.

Table 1: Average values of parameters analysed for on samples from the effluent reclamation plant at the Johannesburg Abattoir from 7 January 1997 to 14 May 1997

Parameter	Secondary effluent	Coagulation Ferric chloride & settling	Ozone	Sand filtration	Activated Carbon filtration	Final Water
Conductivity (mS/m)	82					122
Ammonia (mg/l)						38
Chloride (mg/l)						270
pH	7.2					7.3
Turbidity (NTU)		37.8	20	9.9	12.9	2.3
Colour (Hazen)		56	48	42		38
DOC (mg/l)	32	27	19.5	18	15.8	18.2
UV Absorbance @254 nm	1.45	0.94	0.73	0.56	0.41	0.307
Plate count (cfu/100ml)					5 800 – $4.3\text{X}10^5$	60 – 3 000

8. REFERENCES

Amirtharajah. A Dennett. K A and Studstill, A (1993) Ferric chloride coagulation for removal of dissolved organic matter and trihalomethane precursors. *Water Sd. Technol.* 27,11:113-121

Benefield, L D, Judkins, J F and Weand, B L (1982) *Process chemistry for water and wastewater treatment*, Englewood Cliffs:Prentice-Hall, Inc.

Botha. J (1995) Department of Chemical and Environmental Engineering, University of Pretoria: Personal Communication.

Chang. S D and Singer. P C (1991) The impact of ozonation on particle stability and the removal of TOC and THM precursors. *J Am. Water Works Assoc. 83.3:71-79.*

Christman. R F and Ghassemi. M (1966) Chemical nature of organic colour in water. *J Am. Water Works Assoc.* 58,6:723-741.

Constantine. A (1982) Advanced water treatment for colour and organics removal. *J Am. Water Works Assoc* 74,6:310-3 13..

Cowan, J A C and Steenveld, G N (1990) *A guide to water and waste-water management in the red-meat abattoir industry,* Pretoria:Water Research Commission.

Crowther. J and Evans, J (1981) Estimation of color in Hazen units by spectrophotometry. *J Am. Water Works Assoc.* 73.5:497-502.

Dempsey. B A . Sheu. H . Tanzeer Ahmed, I M and Mentink, J (1985) Polyaluminium chloride and alum coagulation of clav-fulvic acid suspensions *J Am. Water Works Assoc.* 77,3:74-80.

Dental, S K, Resta. J J, Shetty, P V and Bober, T A (1988) Selecting coagulant, filtration and sludge conditioning aids. *J Am. Water Works Assoc.* 80: 72-84.

Die Departement van Waterwese (1984) *Bestuur van die waterhulpbronne van die Republiek van Suid Afrika* Pretoria: Die Departement van Waterwese.

DiGiano, F A. McShane, S F and Lorenzo, M F (1982) *Effect of ozonation on the biodegradability and adsorbability of specific organics to be removed in the 'biologically activated carbon (BAG) process.* Water

Resources Centre. University of Massachusetts: Massachusetts: 10-17.

Eaton. A (1995) Measuring UN-absorbing organics: a standard method *J Am. Water Works Assoc.* 87,2:86-90.

Edwards. G A and Amirtharajah. A (1985) Removing Color caused by humic acids *J Am. Water Works Assoc.* 77,3:50-57.

Edwards. M . Benjamin M M and Tobiason, I E (1994) Effects of ozonation on coagulation of NOM using polymer alone and polymer/metal salt mixtures *J Am. Water Works Assoc.* 86,1:105-116.

Edzwald. J K. Becker, W C and Tambini. S 1 (1987) Organics, polymers and performance in direct filtration. *J Environ. Eng,* 113,1:167-185.

Edzwald, J K, Haff, J D and Boak, I W (1977) Polymer coagulation of humic acid waters. *J . Environ. Engng. Div. ASGE,* 103:989-1000.

Funke. J W (1969) *A guide to water conservation and water reclamation in industry.* Pretoria:Council for Scientific and Industrial Research.

Goel, S . Hozalski. R M and Bouwer, E 1 (1995) Biodegradation of NOM: effect of NOM source and ozone dose. *J. Am. Water Works Assoc.* 87.1:90-105.
Grasso. D and Weber, W I Jr (1988) Ozone-induced particle destabilisation. *J Am. Water Works Assoc.* 80,8:73-81.
Grozes. G . White, P and Marshall, M (1995) Enhanced coagulation:Its effect on NOM removal and chemical costs. *J Am. Water Works Assoc.* 87,1:78-89.

Harrington. G W and DiGiano. F A (1989) Adsorption equilibria of natural organic matter after ozonation. *J.Am. Water Works Assoc.* 8 1,6: 93-101.

Hong-Xiao. I and Stumm. W (1987) The coagulating behaviors of Fe(III) polymeric species - II. *Water Res* 21,1: 123-128.

Jodellah, A M and Weber, Jr, W 1 (1985) Controlling trihalomethane formation potential by chemical treatment and adsorption. *J Am. Water Works Assoc.*

Juby, G J G and Botha, G R (1994) *Removal of colour from Cape waters using ozonation and membrane filtration.* Pretoria:Water Research Commission. 445/1/94.

Kerdachi. D A. Smith. B N and Hardouin. D (1994) The use of blended polyamine/polyaluimnium chloride as a primary coagulant for Durban's water supply. *Chemical Technology* Feb, 1994:19-21.

Kisla. T and McKelvey, R D (1978) Color removal from softwood kraft pulp bleach plant effluent by polyamines. *Environ.* Sci. *Technol.* 12,2:207-211.

Krenkel. P A and Novotny. V (1980) *Water quality management,* New York:Academic Press: 112-155.

Kuo, C J and Amy. G L (1988) Factors affecting coagulation with aluminium sulfate - 11. *Water Res.* 22,7: 863-872.

Lai. R J Hudson Jr. H E and Singley, J F (1975) Velocity gradient calibration of jar-test equipment. *J Am. Water Works Assoc.* 67: 553-557.

Loewenthal. R E, Ekama, G A and Marais, G v R (1988) *Stasoft: An interactive computer program for softening and stabilisation of municipal waters,* Pretoria:Water Research Commission. 2 **nd** edn.

Loewenthal, R E , Wiechers. H N S and Marais. G v R (1986) *Softening and stabilization of municipal waters,* Pretoria:Water Research Commission.

Mallevaille, I. Bruchet. A and Fiessinger, F (1984) How safe are organic polymers in water treatment? *J Am. Water Works Assoc.* 76,6:87-93

Manka, I. Rebhun, M. Mandelbaum, A and Bortinger, A (1974) Characterization of organics in secondary effluents. *Environ. Sci. Technol.* 8.12:1017-1020.

McCarthy. J J and Smith. C H (1974) A review of ozone and its application to domestic wastewater treatment. *J Am. Water Works Assoc.* 66,12:718-725.

Moyers. B and Wu, I S (1985) Removal of organic precursors by permanganate oxidation and alum coagulation. *Water Res.* 19, 3:309-3 14.

Narkis, N and Rebhun. M (1983) Inhibition of flocculation processes in systems containing organic matter. *J of the Water Pollut. Control Fed.* 55.7:947-955.

National Institute for Water Research (1981). *Manual for water renovation and reclamation,* Pretoria: Water Research Commission 2 ~ edn

Nel, P (1996) Montan Chemicals. Wadeville. Personal communication.

Owen, D M, Amy, G L, Chowdhury, Z K, Paode, R, McCoy, G and Viscosil, K (1995) NOM characterization and treatability. *J Am. Water Works Assoc.* 87,1:46-63.

Pieterse. M J (1989) Drinking-water quality criteria with special reference to the South African experience. *Water SA.* 15,3:169-177.

Pretorius. W A. Roux. A and Van der Merwe, G D (1995) *Johannesburg abattoir uitvloeisel: Opgradering van uitvloeisel vir hergebruik.* (UnPub).

Qureshi. N and Malmberg, R H (1985) Reducing aluminium residuals is finished water. *J Am. Water Works Assoc.* 77. 10:101-108,.

Randtke. S J and McCarty. P L (1979) Removal of soluble secondary effluent organics. *J Environ. Engng. Div.ASCE.* 105.4:727-743.

Razumovski. S D and Zaikov, G E (1984) *Ozone and its reactions with organic compounds,* Amsterdam:Elsevier.

Rebhun M, Narkis, N and Wachs, A M (1969) Effect of polyelectrolyte in conjunction with bentonite clay on contaminants removal from secondary effluents. *Water Res.* 3:345-355.

Rice. R G and Bollyky, L 1 (1981) Fundamental aspects of ozone technology. In: *Ozone treatment of water for cooling applications,* edited by Rice, R G Virginia: The International Ozone Association: 1-20.

Roux A and Pretorius W A (1997). Renovation of Wastewater for direct reuse in an abattoir. *Water SA, October 1997, Vol 23, No 4, p. 323.*

Rogers. S E , Peterson, D L and Lauer, W C (1987) Organic contaminants removal for potable reuse. *Journal of the Water Pollut. Control Fed* 59,7:722-731.

Semmens, I M and Field, T K (1980) Coagulation: Experiences in organics removal. *J Am. Water Works Assoc.* 72,8:476483.

Sierka, R A, Amy, G L and Renna, 1 (1989) Molecular weight characterisation of color constituents and subsequent removal by ozone and activated carbon adsorption. *Proceedings. 9th Ozone world congress, 1989, New York. Vol 1. Ozone in water treatment. New York:* 1-14.

Standard methods for the examination of water and wastewater (1989) American Public Health Association, American Water Works Association and Water Pollution Control Federation. Washington: American Public Health Association. Ed. 17.

Stephenson, K F and Duff. S I B (1996) Coagulation and precipitation of a mechanical pulping effluent -I: Removal of carbon, colour and turbidity *Water Res.* 30,4:781-792.

Symons. J M (1980) Ozone chlorine dioxide and chloramines as alternatives to chlorine disinfection of drinking water. In: *Ozone and chlorine dioxide technology for disinfection of drinking water,* edited b~' Katz, 1. Noyes Data Corporation.

Tan, L and Amy. G L (1991) Comparing ozonation and membrane separation for color removal and disinfection by-product control. *J Am. Water Works Assoc.* 83,5:74-79.

Toerien. A (1988) *'n Ondersoek no osonering as voorbehandeling vir drinkwater.* Potchefstroom: University of Pothefstroom for Christian Higher Education.

Van Breemen. A N , Nieuwstad. Th J and Van der Meent-Olieman. G C (1979) The fate of fulvic acids during water treatment. *Water Res.* 13:771-779.

Van Heerden. I P *(1995) Recordings of water usage in City Deep Abattoir,* (UnPub).

Venosa. A D and Meckes, M C (1983) Control of ozone disinfection by exhaust gas monitoring. *J of the Water Pollut. Control Fed* 55,9:1163-1167.

Vik. E A. Carlson, D A. Eikum. A S and Gjessing. E T (1985) Removing aquatic humus from Norwegian lakes. *J Am. Water Works Assoc.* 77.3:58-66.

Weber, W J (1984) Activated carbon systems for treatment of waters and wastewaters. In: *JOA/NIWR International Conference on Ozone or Alternative Oxidants and Activated Carbon on Water and Wastewater Treatment.* Pretoria: CSIR: 1-26.

Weber. W J and Jodellah, A M (1985) Removing humic substances by chemical treatment and adsorption. *J Am. Water Works Assoc.* 77,4:132-137.

White. G C (1992) *Handbook of chlorination and alternative disinfectants,* New York:Van Nostrand Rheinhold.

Wine. R L (1964) *Statistics for scientists*

APPENDIX

		04-06-1997	
ANALYSES	Raw	Plant	Reservoir
pH		7	7.2
Turbidity (NTU)		3	12
Conductivity (mS/m)		170	148
Colour (HAZEN)		15	50
Total Hardness (CaCO3)		120	130
Calcium Hardness (CaCO3)		76	76
Alkalinity (CaCO3)		216	2140
Calcium (Ca)		30	30
Magnesium (Mg)		11	13
Chloride (Cl)		280	975
Sulphate (SO4)		24	23
Total Dissolved		1105	962
Corrosion Indexes:			
Stability pH (pHs)		7.6	8
Langelier Index		-0.4	-1.7
Ryznar Stability Index		8	9.7
Corrosivity Index		2.1	5.9

		26-06-1997	
ANALYSES	Raw	Plant	Reservoir
pH	7.6	7.2	6.3
Turbidity (NTU)	9	1.6	2.3
Conductivity (mS/m)	158	170	152
Colour (HAZEN)	70	40	50
Total Hardness (CaCO3)	180	160	200
Calcium Hardness (CaCO3)	80	90	130
Alkalinity (CaCO3)	390	210	70
Calcium (Ca)	32	36	52
Magnesium (Mg)	24	17	17
Chloride (Cl)	145	295	275
Sulphate (SO4)	27	24	26
Total Dissolved	1027	1105	988
Corrosion Indexes:			
Stability pH (pHs)	7.4	7.6	8
Langelier Index	0.2	-0.4	-1.7
Ryznar Stability Index	7.2	8	9.7
Corrosivity Index	0.6	2.1	5.9

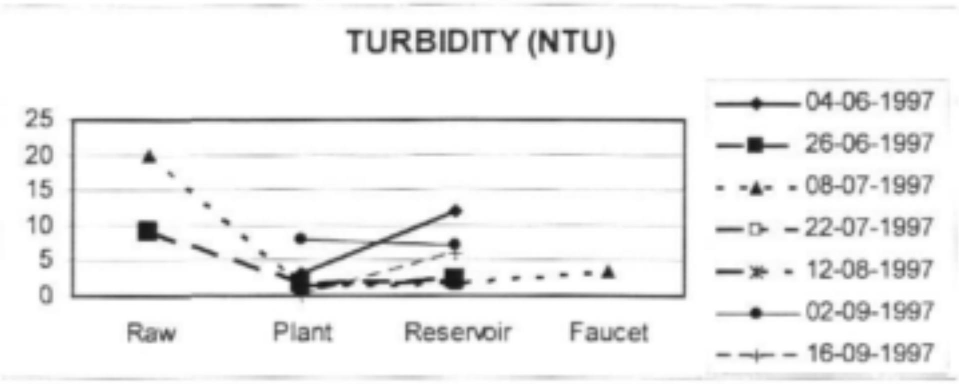
		08-07-1997		
ANALYSES	Raw	Plant	Reservoir	Faucet
pH	7.6	6.8	6.5	8.1
Turbidity (NTU)	20	1.1	1.8	3.5
Conductivity (mS/m)	138	157	152	32
Colour (HAZEN)	70	5	5	5
Total Hardness (CaCO3)	162	154	160	110
Calcium Hardness (CaCO3)	84	94	90	66
Alkalinity (CaCO3)	346	174	46	90
Calcium (Ca)	34	38	36	26
Magnesium (Mg)	19	15	17	11
Chloride (Cl)	120	263	260	15
Sulphate (SO4)	33	26	31	8
Total Dissolved	890	1013	981	206
Corrosion Indexes:				
Stability pH (pHs)	7.4	7.7	8.3	8.1
Langelier Index	0.2	-0.9	-1.8	0
Ryznar Stability Index	7.3	8.6	10.1	8.2
Corrosivity Index	0.6	2.3	8.7	0.3

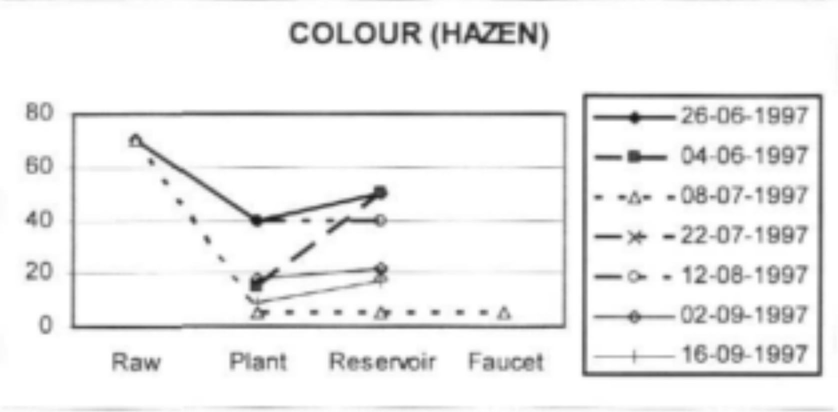
ANALYSES:		22-07-1997	
ANALYSES	Raw	Plant	Reservoir
pH			6.3
Turbidity (NTU)			1.8
Conductivity (mS/m)			136
Colour (HAZEN)			20
Total Hardness (CaCO3)			162
Calcium Hardness (CaCO3)			102
Alkalinity (CaCO3)			50
Calcium (Ca)			41
Magnesium (Mg)			15
Chloride (Cl)			260
Sulphate (SO4)			33
Total Dissolved			884
Corrosion Indexes:			
Stability pH (pHs)			8.2
Langelier Index			-1.9
Ryznar Stability Index			10.1
Corrosivity Index			8

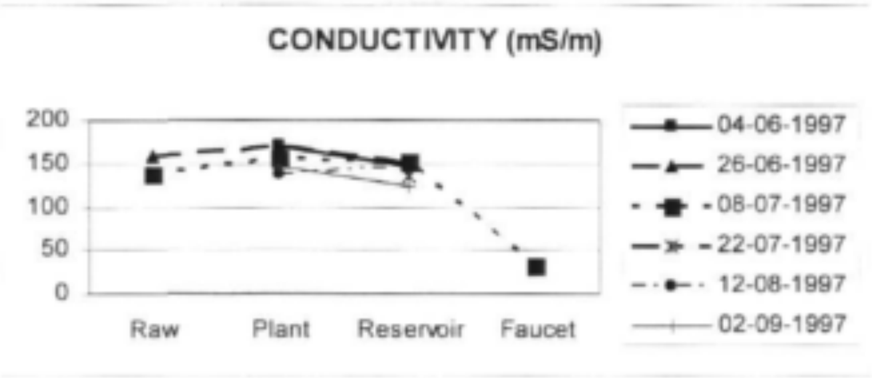
		12-08-1997	
ANALYSES	Raw	Plant	Reservoir
pH		7	6.4
Turbidity (NTU)		1.4	2
Conductivity (mS/m)		139	148
Colour (HAZEN)		40	40
Total Hardness (CaCO3)		142	154
Calcium Hardness (CaCO3)		92	98
Alkalinity (CaCO3)		124	46
Calcium (Ca)		37	39
Magnesium (Mg)		12	14
Chloride (Cl)		243	272
Sulphate (SO4)		27	34
Total Dissolved		897	955
Corrosion Indexes:			
Stability pH (pHs)		7.8	8.2
Langelier Index		-0.8	-1.8
Ryznar Stability Index		8.7	10.1
Corrosivity Index		3	9.1

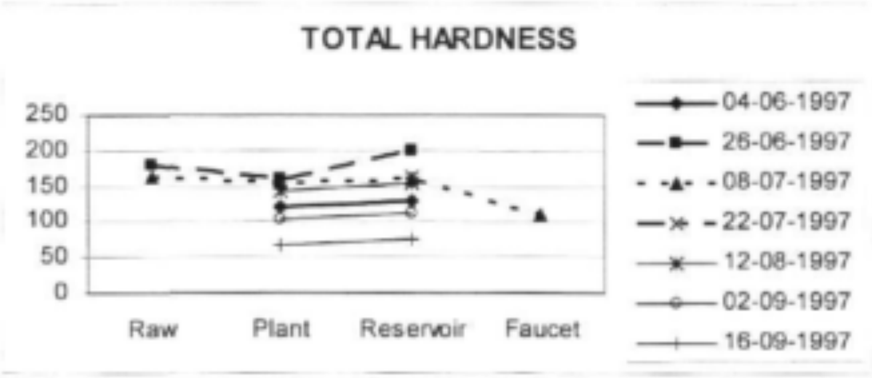
		02-09-1997	
ANALYSES	Raw	Plant	Reservoir
pH		6.9	6.3
Turbidity (NTU)		8	7
Conductivity (mS/m)		148	125
Colour (HAZEN)		18	22
Total Hardness (CaCO3)		103	112
Calcium Hardness (CaCO3)		63	74
Alkalinity (CaCO3)		228	72
Calcium (Ca)		25	30
Magnesium (Mg)		10	9
Chloride (Cl)		267	247
Sulphate (SO4)		53	58
Total Dissolved		638	650
Corrosion Indexes:			
Stability pH (pHs)		7.8	8.2
Langelier Index		-0.8	-1.8
Ryznar Stability Index		8.7	10.1
Corrosivity Index		3	9.1

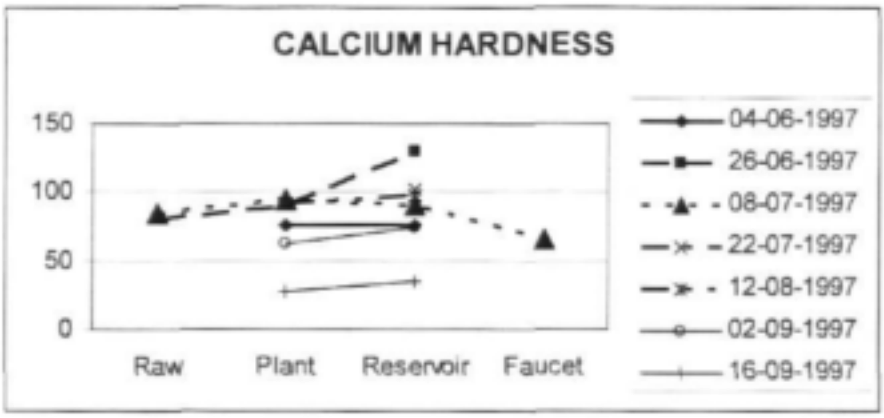
ANALYSES:		**16-09-1997**	
ANALYSES	**Raw**	**Plant**	**Reservoir**
pH		6.4	5.9
Turbidity (NTU)		0	6
Conductivity (mS/m)		114	113
Colour (HAZEN)		9	17
Total Hardness (CaCO3)		68	77
Calcium Hardness (CaCO3)		28	35
Alkalinity (CaCO3)		84	49
Calcium (Ca)		11.1	15.1
Magnesium (Mg)		9.7	10.3
Chloride (Cl)		251	248
Sulphate (SO4)		72	73
Total Dissolved		410	388
Corrosion Indexes:			
Stability pH (pHs)		7.8	8.2
Langelier Index		-0.8	-1.8
Ryznar Stability Index		8.7	10.1
Corrosivity Index		3	9.1

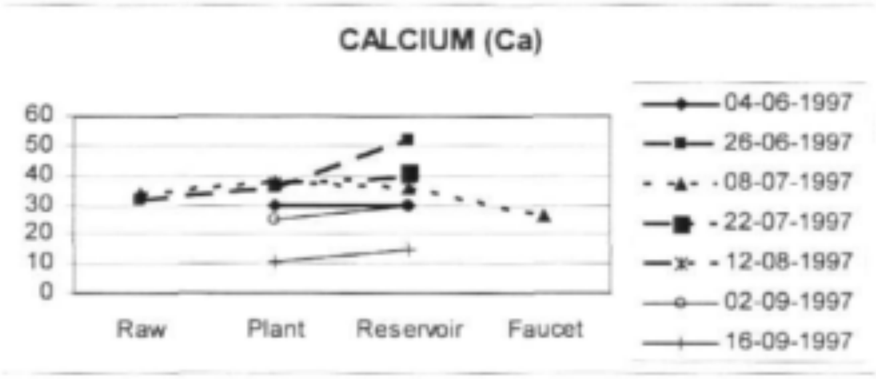

TURBIDITY (NTU)
25
20
15
10
5
0
Raw
Plant
Reservoir
Faucet
04-06-1997
26-06-1997
08-07-1997
22-07-1997
12-08-1997
02-09-1997
16-09-1997

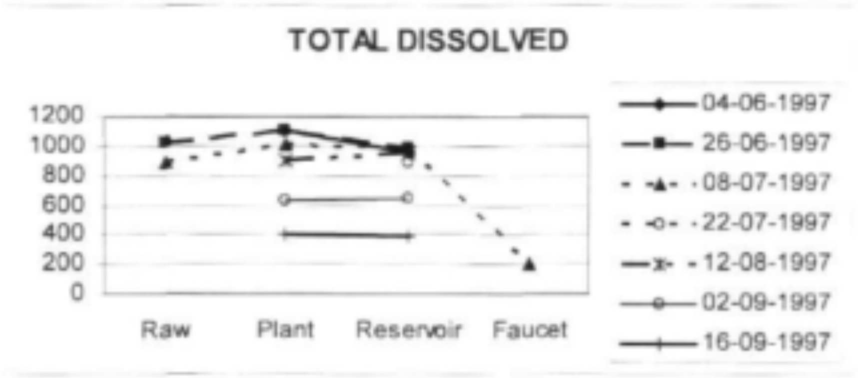

COLOUR (HAZEN)
80
60
40
20
0
Raw
Plant
Reservoir
Faucet
26-06-1997
04-06-1997
08-07-1997
22-07-1997
12-08-1997
02-09-1997
16-09-1997

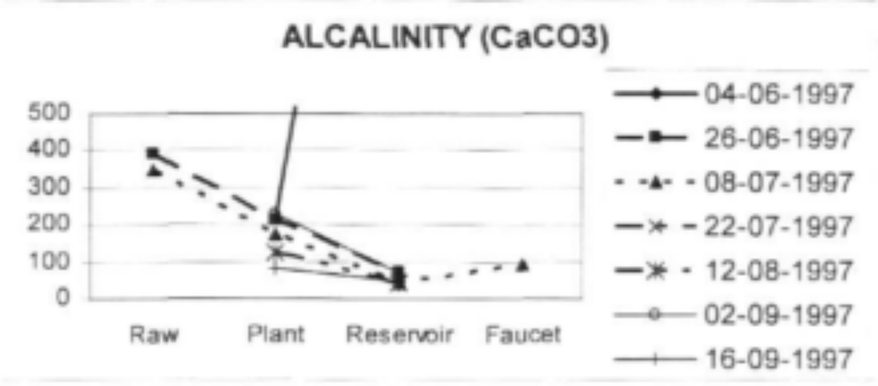

CONDUCTIVITY (mS/m)
200
150
100
50
0
Raw
Plant
Reservoir
Faucet
04-06-1997
26-06-1997
08-07-1997
22-07-1997
12-08-1997
02-09-1997

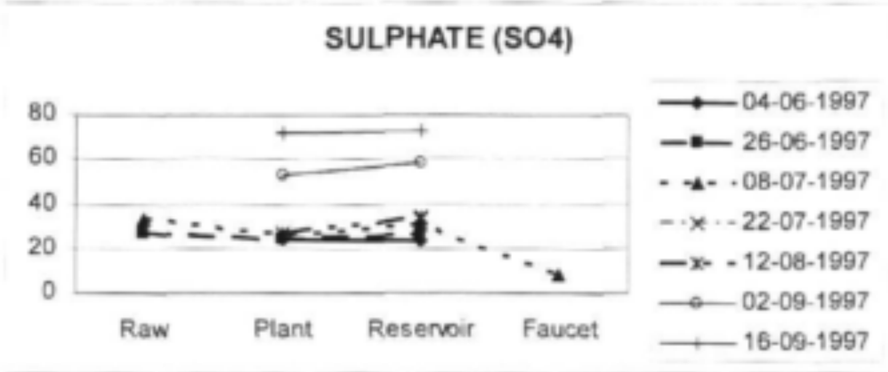

TOTAL HARDNESS
250
200
150
100
50
0
Raw
Plant
Reservoir
Faucet
04-06-1997
26-06-1997
08-07-1997
22-07-1997
12-08-1997
02-09-1997
16-09-1997

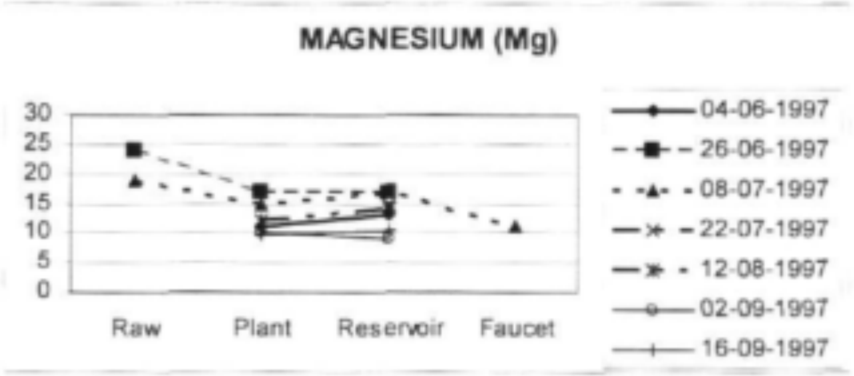

CALCIUM HARDNESS

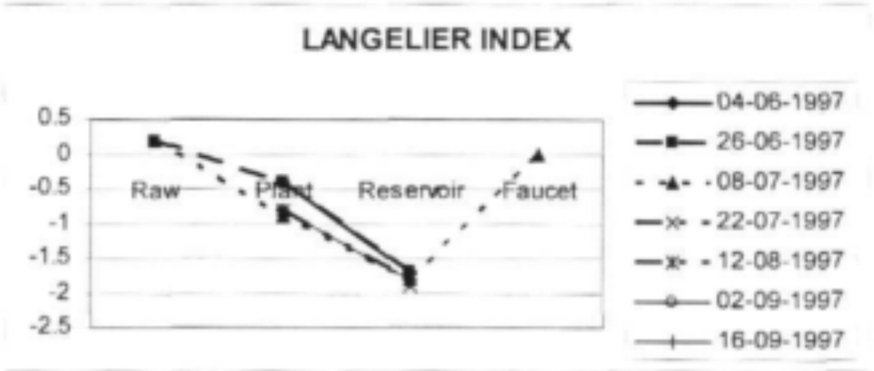

CALCIUM (Ca)

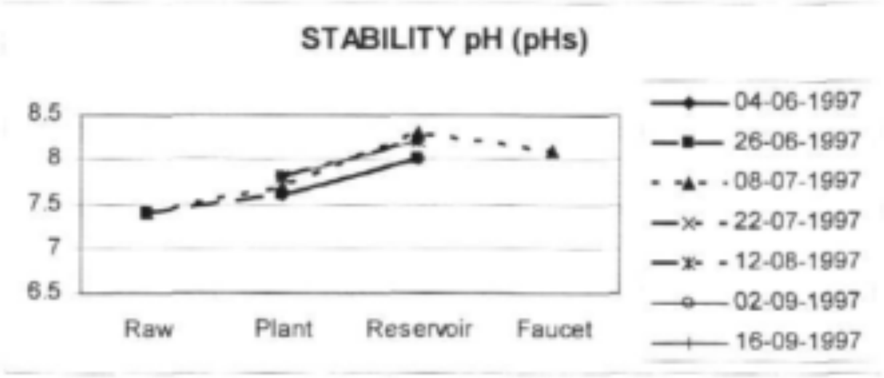

TOTAL DISSOLVED

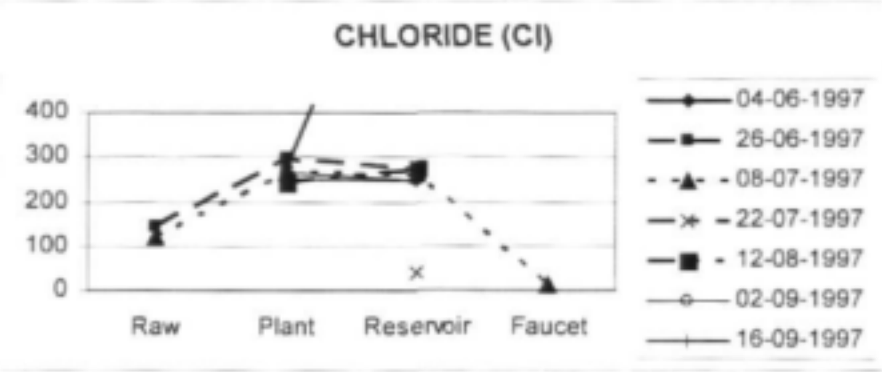

ALCALINITY (CaCO3)

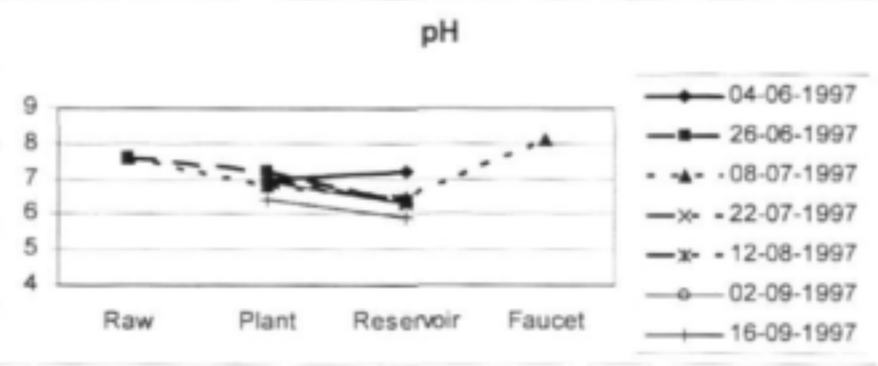

SULPHATE (SO4)
80
60
40
20
0
Raw
Plant
Reservoir
Faucet
04-06-1997
26-06-1997
08-07-1997
22-07-1997
12-08-1997
02-09-1997
16-09-1997

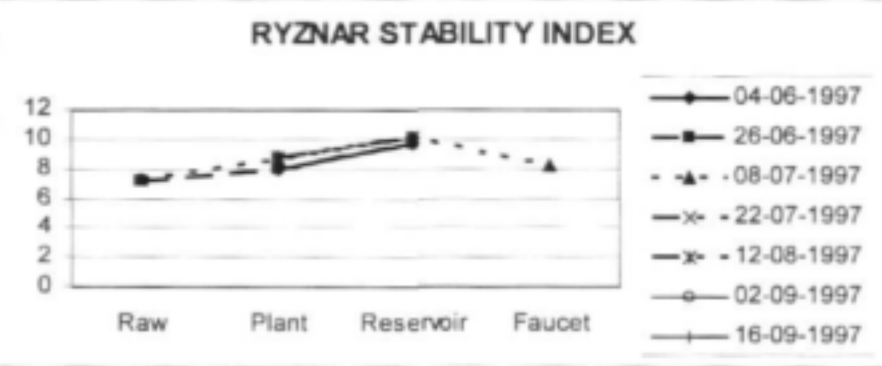

MAGNESIUM (Mg)
30
25
20
15
10
5
0
Raw
Plant
Reservoir
Faucet
04-06-1997
26-06-1997
08-07-1997
22-07-1997
12-08-1997
02-09-1997
16-09-1997

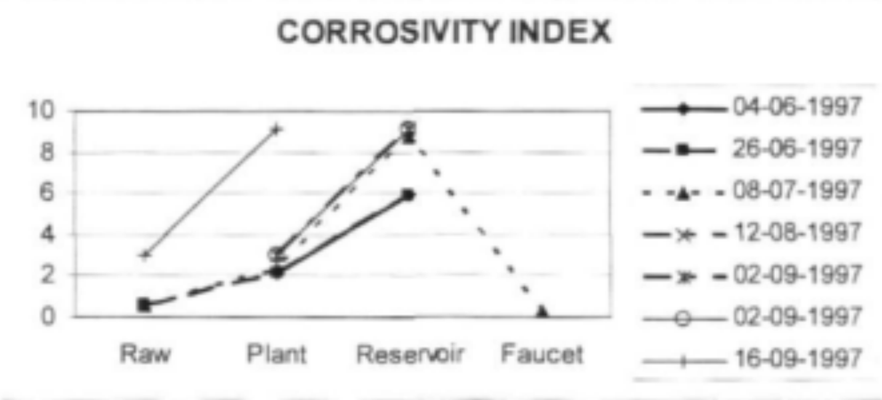

LANGELIER INDEX
0.5
0
-0.5
-1
-1.5
-2
-2.5
Raw
Plant
Reservoir
Faucet
04-06-1997
26-06-1997
08-07-1997
22-07-1997
12-08-1997
02-09-1997
16-09-1997

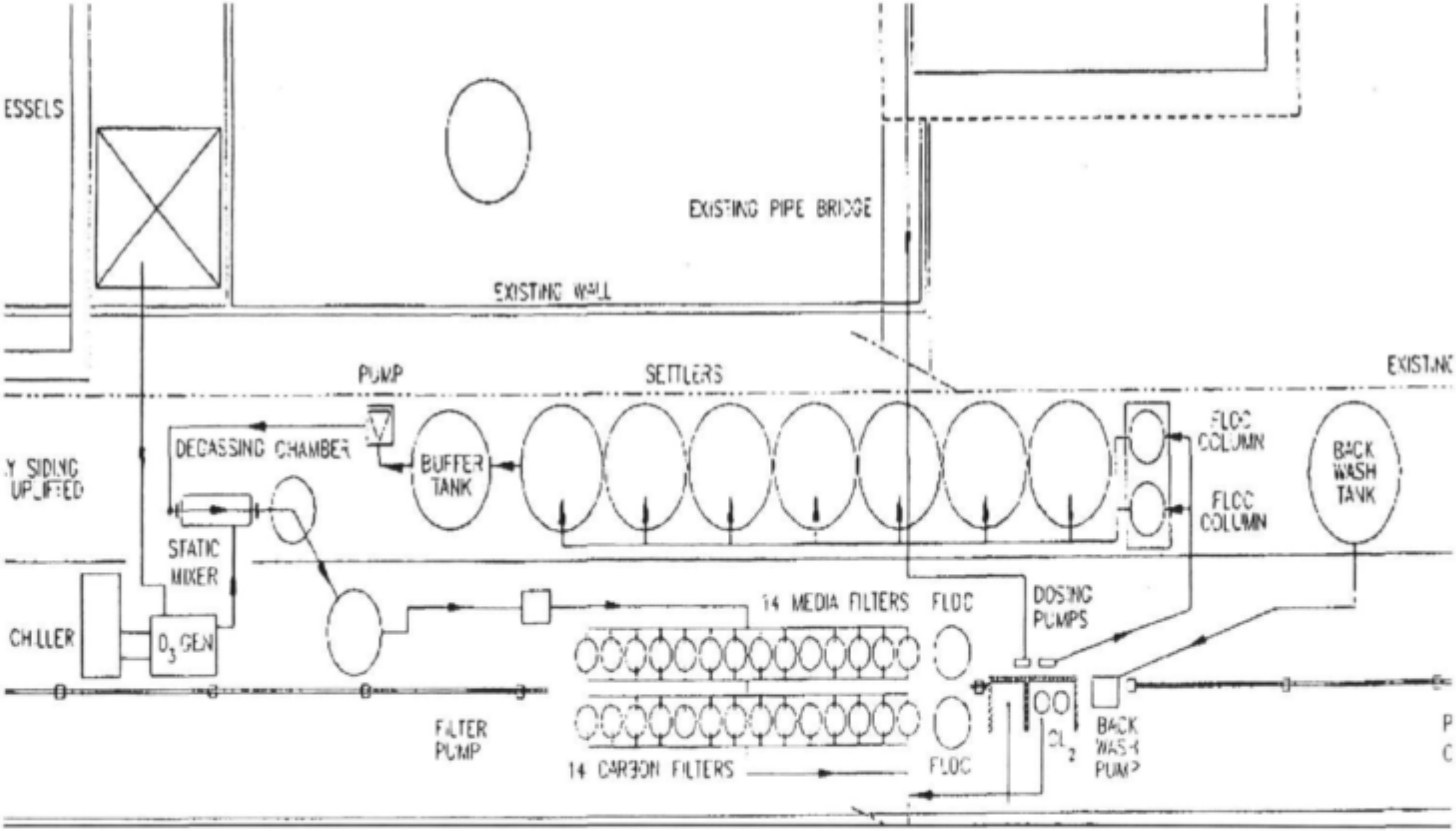

STABILITY pH (pHs)
8.5
8
7.5
7
6.5
Raw
Plant
Reservoir
Faucet
04-06-1997
26-06-1997
08-07-1997
22-07-1997
12-08-1997
02-09-1997
16-09-1997


CHLORIDE (Cl)


pH


RYZNAR STABILITY INDEX


CORROSIVITY INDEX


ESSELS
EXISTING PIPE BRIDGE
EXISTING WALL
PUMP
SETTLERS
EXISTING
Y SIDING
UPLIFTED
DEGASSING CHAMBER
BUFFER TANK
FLOC COLUMN
FLOC COLUMN
BACK WASH TANK
STATIC MIXER
CHILLER
O_3 GEN
14 MEDIA FILTERS
FLOC
DOSING PUMPS
FILTER PUMP
14 CARBON FILTERS
FLOC
CL_2
BACK WASH PUMP
P
C

TO ORDER: Contact **Publications** - Telephone No: 012 330 0340
Fax Number: 012 331 2565
E-mail: publications@wrc.org.za

1770053514

Water Research Commission
Private Bag X03, Gezina, 0031, South Africa
Tel: +27 12 330 0340, Fax: +27 12 331 2565
Web: http://www.wrc.org.za

Designed by The Kashan Group K-2102 (www.kashangroup.com)