EVALUATION AND OPTIMIZATION OF DUAL DIGESTION OF SEWAGE SLUDGE

PART 3 : EVALUATION OF THE TECHNOLOGY FOR PRACTICAL IMPLEMENTATION

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Part 1: Overall system performance	Report WRC 189/2/92
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TABLE OF CONTENTS

PAGE

PAGE

LIST OF TABLES

PAGE

LIST OF FIGURES

ABSTRACT

Dual Digestion is an alternative treatment process by means of which sewage sludges can be pasteurised and stabilised. The application of the technology is finding increasing favour in both the USA and in Europe as a method designed to improve on the performance of conventional anaerobic digestion, and also to produce a final product which is environmentally more acceptable. Research on the process to assess its suitability for application to the South African environment was initiated by the Water Research Commission and undertaken by a number of organisations. Johannesburg City Council carried out pilot-scale research on the aerobic phase of the two stage process. Milnerton Municipality used a full-scale system to evaluate both the aerobic and anaerobic phases of the process, utilising pure oxygen. Cape Town City Council also carried out full scale research on both phases of the process, but utilised air for their system.

The experience gained with the Dual Digestion Systems which have been in operation overseas, together with the data and practical experience obtained with the process through research in South Africa, are used to evaluate the technology for implementation locally. Aspects which are covered are the technology itself, the design and practical considerations for the establishment and operation of the system, the quality of the final product that can be expected, and finally the economic implications.

This report forms the final volume of a three-part document stemming from the full-scale research at Milnerton and is aimed at providing an overall view of the Dual Digestion System to decision-makers so as to assist them in assessing the suitability of the process for their specific applications.

ABBREVIATIONS

DDS	-	Dual Digestion System
Kl/d	-	Kilolitre per day
Kg/d	-	Kilogram per day
PSRP	-	Processes to Significantly Reduce Pathogens
PFRP	-	Processes to Further Reduce Pathogens
MJ/Kg O	-	Megajoule per kilogram oxygen consumed
OSR	-	Oxygen Supply Rate
OTR	-	Oxygen Transfer Rate
OTE	-	Oxygen Transfer Efficiency
OUR	-	Oxygen Utilisation Rate
OUR_{bio}	-	Maximum Oxygen Utilisation Rate of a sludge
Kg O/($m^3 \cdot h$)	-	Kilogram of oxygen utilised per cubic metre of sludge per hour
COD	-	Chemical Oxygen Demand
VS	-	Volatile Solids
mg/l	-	Milligrams per litre
MJ/h	-	Megajoules per hour
Y_H	-	Specific Heat Yield of a sludge

CHAPTER 1

INTRODUCTION

1.1 SLUDGE TREATMENT AS A PART OF WASTEWATER TREATMENT

The development of an urbanised South Africa will result in an increasing number of wastewater treatment works which will serve an ever-increasing percentage of the population. The volume of organic sludge produced by these installations will also increase accordingly, and treatment facilities will therefore have to be provided in order to accommodate the expected growth in demand.

Facilities for the treatment of organic sludges, which originate as by-products of the primary and secondary treatment processes incorporated in a wastewater treatment plant, can represent up to 50% of the capital and operating budget of such a plant. The effective and efficient employment of capital to establish sludge treatment facilities can therefore play a significant role in the economics of a treatment plant. A fair amount of effort has therefore been devoted, and will continue to be required, to the development and improvement of sewage sludge treatment technologies. Past research and development has ensured that a large number of alternative technologies are available to address sludge treatment problems, whilst present and future research will be aimed primarily at improving their effectiveness and efficiency.

1.2 EMERGENCE OF ENVIRONMENTAL AWARENESS

The goal of sludge treatment requires that the solid fraction of wastewater, after being separated from the liquid fraction, be treated and disposed of in an aesthetically and environmentally acceptable fashion. The pressures of urbanism and of resulting production of associated wastes such as sewage sludge have created a greater awareness of the potential detrimental effects on the environment. Policies on the disposal of treated sewage have therefore had to be reviewed so as to ensure that mankind and the environment within which he lives be adequately protected.

One result of this international awareness of the need for safer and more acceptable methods of disposal is that, in addition to the stabilisation of the organic content of the sewage sludge, hazardous substances have also to be eliminated or reduced to acceptable levels.
The site and method of final disposal for the sludge will determine the levels to which toxic chemicals, heavy metals and pathogenic organisms which may be contained in sewage sludges have to be eliminated or inactivated.

As a result of the trend towards environmental awareness, pressure has increased on managers and designers of wastewater treatment facilities to produce treated sewage sludges which are acceptable in terms of their specific final disposal option. Health authorities in many countries have laid down parameters through regulations and guidelines intended to exercise control over the disposal of sewage sludges and thereby reduce the health risk to the public.

The Department of National Health and Population Development, under whose jurisdiction the re-use of sludge as a disposal option will fall, has compiled Guidelines which define the classes of sludge after different types of treatment, together with the types of permissible re-use options that will be permitted in South Africa (Vivier, *et al*, 1988). A summery of the requirements for each of the four types of sludge is given in Annexure A.

1.3 PROBLEMS ASSOCIATED WITH THE NEW REQUIREMENTS

One result of the more stringent measures to control the disposal of sewage sludge on current sludge treatment practices in South Africa is that many authorities will be faced with a situation where the following issues have to be addressed:

* Traditional methods of sludge disposal such as land filling or application on land as a soil conditioner

will have to be reviewed in the light of the requirements of the guidelines laid down by the Department of National Health and Population Development. In future, the final disposal of sewage sludge will depend primarily on the quality of the end-product achieved after treatment.

* Limited areas of land available in and around wastewater treatment plants together with the danger of diffused pollution, especially within the urban environment, preclude traditional methods of disposal of sewage sludge such as landfilling on site.

  A higher quality of treated sludge will be required so as to be able to dispose of the end product in alternative ways.

* A higher quality end product will necessitate stricter control of industrial effluent as well as improvements to sludge treatment facilities. In many cases, improved sludge treatment will have to include a higher grade of stabilisation and some form of disinfection or sterilisation.

The dilemma which many Local Authorities responsible for the treatment of sewage sludge have to face is that they may have unit processes in their wastewater treatment works which are not sufficiently effective to achieve a desired standard. Despite the fact that technology and sludge treatment processes are available to produce a high quality final product, it could well be extremely expensive to change to other treatment processes in mid-stream, or to replace existing processes with new ones.

Upgrading of existing treatment facilities is an avenue which will normally provide the most cost-effective method to improve on the quality of treated sewage sludge. New and improved technologies which concentrate on this aspect are therefore of exceptional interest to managers and designers of sludge treatment facilities.

1.4 DUAL DIGESTION OF SEWAGE SLUDGE

A relatively new sludge treatment process which has been developed in the United States of America is Dual Digestion of sewage sludge which combines two individual sludge treatment processes, viz thermophilic aerobic digestion and anaerobic digestion, in a single two-step process.

From experience obtained in the United States of America and Europe it appears that a number of advantages and benefits are offered by this new process. (Water Research Commission, 1985)

* By employing aerobic digestion as the first step of the two step process, the following are possible:
  - disinfection (or pasteurisation) of the sludge can be achieved, provided that a sufficiently high thermophilic temperature and suitable retention time are maintained;
  - due to a retention time of as low as 1 day in the aerobic reactor, energy and oxygen requirements are lower than would be required for full aerobic treatment of the sludge, while a degree of stabilisation will still be achieved;
  - sludge is conditioned and solubilised during the aerobic treatment phase and this enhances the anaerobic digestion of the sludge as well as acting as an absorber for shock loadings which might be detrimental to the more sensitive anaerobic digestor;
  - the hot sludge from the aerobic reactor (thermophilic range) ensures that the anaerobic digestor can be operated at mesophilic temperatures without additional external heating;

* The anaerobic digestor, operating with conditioned and disinfected hot sludge from the aerobic reactor, possesses the following advantages over conventional externally-heated anaerobic system:
  - the methane produced by the anaerobic digestor is

available as an energy source for purposes other than that of heating the anaerobic digestor sludge;

- a retention time in the anaerobic digestor which is shorter than that required by conventional anaerobic digestion is possible with a similar or even improved volatile solids removal;

* The process as a whole offers other advantages:
  - much more rapid start-up than conventional anaerobic digestion;
  - stable, reliable process performance;
  - simple operation and control which can be automated;

The advantages claimed by the developers and users of the process in America and Europe offer definite opportunities for sludge treatment in South Africa:

* Existing anaerobic sludge digestion systems can be upgraded so as to produce a pasteurised sludge simply by adding the thermophilic aerobic stage as a first step. This would permit alternative methods of final disposal of treated sludge.

* By adding an aerobic step to existing anaerobic sludge treatment facilities, treatment capacity can be increased as a result of improved performance and a shorter retention time for anaerobic digestion.

* It may very well be feasible to add an anaerobic stage to existing aerobic sludge treatment facilities so as to increase treatment capacity and also to reduce operating costs due to less oxygen and power being required than for full aerobic treatment.

* A full Dual Digestion System can be considered as an alternative to other sludge treatment processes.

1.5 PURPOSE OF THIS REPORT

Although the process of Dual Digestion of sewage sludge has been implemented with great success in the United States of America and in Europe, it has, as yet, not been applied in South Africa.

The potential advantages offered by the process motivated the Water Research Commission to initiate research, first at pilot scale level and thereafter full-scale level so as to evaluate and optimise the process under South African conditions.

This report forms the final part of a three-part document dealing with the research carried out at full-scale level at the Potsdam Wastewater Treatment Works of Milnerton Municipality.

"Part 1 : Overall System Performance" deals with the actual research carried out, the operation of the full-scale Dual Digestor plant, and the results obtained.

"Part 2 : Aerobic Reactor Performance" deals in detail with the stoichiometry and kinetics of biological heat generation in the aerobic stage of Dual Digestion.

This volume, Part 3, will deal specifically with the evaluation of the technology and process of Dual Digestion for practical implementation in South Africa. The purpose of such an evaluation is to assist decision makers in assessing the risks and opportunities offered by the process.

CHAPTER 2

EXPERIENCE WITH DUAL DIGESTION OVERSEAS

2.1 RESEARCH AND DEVELOPMENT OF THE DUAL DIGESTION SYSTEM

The Dual Digestion System (DDS) is a proprietary sludge treatment process, developed during the 1970's by the Union Carbide Corporation in the United States of America (Drnevich, *et al*, 1978). The process was first investigated at laboratory and pilot scale level, and, after favourable results were obtained, introduced as a full-scale plant.

The DDS consists of a combination of two individual sludge treatment processes, namely thermophilic aerobic digestion and conventional mesophilic anaerobic digestion.

The first process, thermophilic aerobic digestion, is a process whereby disinfection and partial stabilisation of sludge is achieved at high temperatures of between 55° and 65°C. Sludge is introduced into a vessel (tank) and pure oxygen or air injected while thorough mixing is provided. Due to the energy transferred to the sludge by the mixer and the autothermal reaction caused by the biological degradation of the organic content of the sludge, sufficient heat is generated to achieve thermophilic temperatures. No additional external heating is required. Disinfection at these temperatures can be achieved within 2 hours, while stabilisation of the sludge can be achieved in as little as 4 days.

The advantages of this process are that it starts up rapidly, is very stable, recovers rapidly from shocks, consistently produces a stable disinfected sludge, and only requires vessels of moderate size.

The disadvantages of the process are the large amounts of energy and oxygen consumed during the operation and the fact that no methane is produced as by-product. This process is relatively new, and is not a popular method of sludge treatment in South Africa.

Anaerobic digestion on the other hand is one of the oldest methods of sewage sludge stabilisation and is widely used in South Africa. The process consists of a tank with external heating into which sludge is introduced and which is gradually digested through anaerobic degradation at mesophilic temperatures (37°C).

This is a low-rate process and even with mixing and external heating of the sludge to mesophilic temperatures of the order of 30° to 35°C so as to speed up the process, retention times in the 20 to 30 day range are still required. These long retention times require large tank capacity. The process itself starts up slowly and is very sensitive to upsets (shock loadings) which can bring the biological process to a halt. The recovery rate from shocks is also very slow. Advantages of the process, however, are that it produces a well stabilised sludge and its energy requirements are very low. Methane is produced as by-product which can be utilised as an energy source. The final product, however, is not pasteurised and this limits the disposal options.

By combining the two individual processes described above, the DDS becomes a two-step process with an aerobic first phase and anaerobic second phase.

The aerobic phase consists of a vessel with capacity sufficient for typically one day's retention time. Pure oxygen or air is introduced to the sludge while thorough mixing is provided and thermophilic temperatures are achieved via biological heating of the sludge through the aerobic degradation reactions (autothermal heating) and mechanical energy introduced by the mixing system. The prime function of this step is disinfection of the sludge, but a small amount of organic matter will also be oxidised in the process through the biological heat generated. The stabilisation of the sludge is then completed in a second stage anaerobic digestor which, due to the conditioning effect of the first step and the heat carried over by the sludge, may be operated at a very much reduced retention time than that required for conventional anaerobic digestion.

The dual digestion process as described above, was installed in 1980 as full-scale plant at Hagerstown, Maryland in the U.S.A. and was utilised by the United States Environmental Protection Agency as a demonstration project for the system. Results obtained at this plant illustrated the ability of the dual digestion system to achieve a significant reduction in the level of pathogenic organisms in sewage sludge, and also proved itself to be an effective sludge stabilisation process.

2.2 EXPERIENCE WITH DUAL DIGESTION IN UNITED STATES OF AMERICA

Subsequent to the development of the DDS and its successful demonstration at full-scale level at the Hagerstown Wastewater Treatment Plant in Maryland, at least five other full-scale DDS facilities for sludge treatment have been constructed in different parts of the U.S.A.
The motivation for installing these plants were cost and energy savings, process reliability and environmental benefits.

During 1986, a study project was undertaken on the three oldest Dual Digestion Plants in the U.S.A. to verify the full-scale performance claims of the technology (Appleton, *et al*, 1986a). These plants were the original Hagerstown Plant as upgraded in 1984, the plant at Lackawana, New York and the plant at Nutbush Creek, Henderson in North Carolina. The plants were of a very similar pattern in that they all use the same type of secondary treatment process for settled sewage namely pure oxygen activated sludge. A DDS was installed at all three plants by providing an aerobic reactor before existing two step anaerobic digestors. The existing primary digestors at these plants were used as the main anaerobic digestor for the DDS, while the existing secondary digestors were being used to provide additional digestion and solids/liquid separation. Pure oxygen for the aerobic reactors was provided from existing pressure swing absorption oxygen generation systems serving the activated sludge systems. Details of the three dual digestion plants and their performance, as gathered by Appleton and Venosa (1986a), have been reproduced in Table 1.

TABLE 1 : DETAIL OF THE THREE OLDEST DUAL DIGESTION PLANTS IN THE U.S.A.

	LACKAWANNA NEW YORK	HAGERSTOWN MARYLAND	NUTBUSH CREEK NORTH CAROLINA
TREATMENT PLANT DETAIL			
DDS startup date	February 1983	June 1980, upgrade May 1994	December 1982
Daily wastewater flow:			
design average (Kl/s)	0,20	0,35	0,18
peak flow (Kl/s)	0,30	0,53	0,37
Secondary treatment process	Oxygen activated sludge	Oxygen activated sludge	Oxygen activated sludge (for nitrification)
Oxygenation system capacity (Kg/d)	2210	12650	4410
Sludge type	Primary and secondary	Primary, secondary, cheese whey, septage	Primary, trickling filter and secondary
Sludge thickening type	Gravity	Dissolved air flotation	Dissolved air flotation
Sludge treatment prior to DDS	Two stage anaerobic digestion	Two stage anaerobic digestion	Two stage anaerobic digestion
DDS feed mode	Continuous	Intermittent	Intermittent
DDS design retention time: (days)			
aerobic reactor	1,17	0,90	1,25
anaerobic digestor	7,40	12,0	10,4
Sludge dewatering process	Centrifuge and/or drying beds	Plate-and-frame filter press	Drying beds
Final sludge disposal	Landfill	Farmland	Landfill
Use of methane from anaerobic digestor	Gas engine for oxygenation system and also compressor for building heating	Planned for use in vehicle fueling system	Gas engine for oxygenation system
OPERATIONAL DATA	(average over 30 week study period)	(average of upgraded system)	(no data available)
Total solids in sludge stream (%)	5,25	7,25	-
Total solids loading (Kg/d)	1940	3108	-
Volatile solids fraction (%)	62	80	-
Aerobic reactor data:			
Goal temperature (degree C)	55	52 to 55	
Achieved (degree C)	50	Could not not be measured	-
Actual retention time (days)	1,68	1,65	-
Oxygen feed (Kg/d)	620	not measured	-
Anaerobic reactor temperature (degree C)	Designed for thermophilic temperature of around 54°C, but obtained only 44°C	Designed for mesophilic temperature of around 35°C, obtained 36,8°C	-
Reduction of volatile solids (% of total volatile solids)			
Aerobic reactor	16,50	10,80	
Anaerobic digestor	19,33	41,20	-
Total removed	35,83	52,00	

The evaluation of the operational performance of the three plants by Appleton and Venosa produced the following important conclusions:

* The major pieces of equipment required by the DDS are an oxygen source and a mass transfer device to achieve efficient oxygen transfer. Although the ability to use air for autothermal aerobic digestion has been demonstrated, the use of high-purity oxygen provides advantages in that a faster oxygen dissolution rate is achieved and the low gas flow reduces the amount of heat lost through vent gas. The reliability and efficiency of the oxygen transfer system plays a major role in the successful operation of the aerobic reactor.

* Vent gas from the aerobic reactor had to be scrubbed following odour complaints.

* Design aspects regarding pipework controls and insulation must be considered with care so as to ensure ease of operation, prevent clogging of pipelines and minimise heat losses.

* As the anaerobic digestors did not require heating, the methane could be used as energy source for other purposes.

* The DDS is simple to operate with the main control variable being the oxygen feed rate. A consistent solids concentration of approximately 5% is important for good performance and ease of DDS operation.

* The pH and Alkalinity of the sludge in the aerobic reactor is increased during the conditioning process, and this assisted in the operation of the anaerobic digestor. No chemical addition was required in order to maintain the anaerobic digestor at optimal pH.

* The total volatile solids reduction achieved by the DDS

is high enough to comply with the minimum of 38% reduction as stipulated by the U.S. regulations for both "Processes to significantly reduce Pathogens" (PSRP) and "Processes to further reduce Pathogens" (PFRP).

* The reduction of indicator microbiological parameters of interest was greater through DDS treatment than those achieved by PSRP. It also equalled or exceeded those achieved by full thermophilic aerobic digestion which is a PFRP. (Appleton, *et al*, 1986b).

* Notwithstanding the results obtained during the evaluation, some doubt still remained whether the DDS could consistently produce a stabilised, pathogen-free sludge because of uncertainties associated with the operational aspects and reliability of the equipment. The oxygenation system of bubble diffusers and internal mixing of the aerobic reactor with a rotating shearing device would appear to be weak links in the system.

2.3 EXPERIENCE IN EUROPE

Anaerobic mesophilic digestion and land application for agricultural use are still the most widely adopted methods for sewage sludge treatment and disposal practised in Europe. New regulations which require higher hygienic standards, however, have put many mesophilic digestors under pressure. The consequence is that processes like DDS which can pasteurise sludge as part of the treatment process are being introduced and added to existing treatment facilities.

A study by Baier and Zwiefelhofer (1991) indicated that, at the end of 1990, more than 70 DDS plants were in operation or under construction in Europe. These plants were established by adding an aerobic thermophilic reactor as pretreatment to conventional mesophilic anaerobic digestion.

The European DDS differs somewhat from its American counterpart in the following aspects:

- aerobic reactors are mixed via an external pump and pure oxygen or air is introduced through a gas injector;
- the aerobic reactor is maintained at temperatures of 60° to 65°C with retention times of 1,5 to 2 days and batch feeding is practised to avoid recontamination;
- energy preservation is practised as far as possible - vent gas is recirculated to minimise heat loss; a heat exchanger is used to heat raw sludge and to cool aerobic reactor effluent before it is introduced into the anaerobic digestor; and methane from the anaerobic digestor is used as energy source to produce heat or electricity; and
- in addition to thickening of raw sludge before treatment, a storage tank with mixing and supernatant draw-off facilities is provided for consolidation of treated sludge before final disposal.

Baier and Zwiefelhofer could, after their study, conclude that the combination of aerobic thermophilic pretreatment and anaerobic mesophilic stabilisation of sewage sludge, known as the Dual Digestion System, has proved itself to be an effective and economical tool to eliminate pathogenic problems and to deal with non-optimal anaerobic digestor performance as well as insufficient thickening and dewatering of sludges. Their conclusions were based on the following findings at a number of DDS plants:

* The operation of the aerobic reactor ensures that each sludge particle would be exposed to a temperature of 65°C for a period longer than 60 minutes. No recontamination or short circuiting-could occur with a batch feeding system.

* The volume of biogas produced by the anaerobic digestor after aerobic pretreatment was not reduced due to the reduction of the volatile solids in the thermophilic aerobic reactor as compared with normal anaerobic digestion.

* As a result of the conditioning effect of the aerobic thermophilic step, sludge is more readily digested than untreated raw sludge and consequently total volatile solids reduction is enhanced in dual treatment.

* Mechanical dewatering of dual-treated sludge was found to be enhanced by 8% to 10% with a belt filter press as compared with conventional anaerobic digestion.

CHAPTER 3

RESEARCH AND EXPERIENCE IN SOUTH AFRICA

3.1 NEED FOR RESEARCH

The increasing problems with the disposal of sewage sludge in an environmentally acceptable manner and the requirements for increased hygienic controls in South Africa, prompted investigations into alternative sludge treatment processes which would incorporate some form of disinfection or pasteurisation to produce a sludge fit for disposal in the agricultural and horticultural industries.

During the development phases of the dual digestion system in the USA, the Water Research Commission identified its potential benefits to South Africa. As early as 1979, they embarked upon a research programme which was designed to investigate and evaluate the process for implementation under local conditions. The nature of South African sludges may very well require that modifications be made to the process so as to render a final product which could be disposed of in an acceptable manner.

3.2 PILOT SCALE RESEARCH AT JOHANNESBURG CITY COUNCIL

The first stage of the research programme in South Africa entailed investigations at pilot-scale level into autothermal thermophilic aerobic digestion using pure oxygen.

This work was undertaken as a joint venture between the Water Research Commission and the City Council of Johannesburg. The investigation was aimed at assessing the performance of autothermal thermophilic aerobic digestion, the effectiveness of the process in terms of the inactivation/destruction of selected pathogens as well as the effect of operating parameters on the efficiency of the process and operational problems associated with the running of the plant. The economic implications of operating at thermophilic temperatures utilising pure oxygen, and the viability of the dual digestion system in light of the results of the study were also assessed.

In the final report on the research project (Trim, 1984a; 1984b; Trim and McGlashan, 1985) it was concluded that the results achieved indicated that the process was very robust and rapidly attained a stable temperature of the order of 60°C. This temperature could be easily maintained and ensured disinfection of the sludge at retention periods of as low as one day.

The process was self-sustaining, very resistant to change, achieved high solids-loading rates and utilised oxygen efficiently. The major cost source for the process was the cost of oxygen.

It was also found that the aerobically treated sludge would not settle and was very difficult to dewater. Furthermore, the treated sludge was found to readily ferment anaerobically, thereby indicating the need for further treatment prior to final disposal. This further treatment could be provided by adding anaerobic digestion as a second step to complete the total system of Dual Digestion.

The work by the Johannesburg City Council was most encouraging, and has shown the potential for using the Dual Digestion process in South Africa to produce a final stable disinfected product which may be beneficially utilised in horticulture and agriculture.

3.3. FULL-SCALE RESEARCH AND DEVELOPMENT AT MILNERTON MUNICIPALITY

3.3.1 NEED FOR FURTHER RESEARCH

The pilot-scale studies by Johannesburg City Council highlighted a number of aspects which should receive careful study in order to ensure successful application of dual digestion in South Africa. A full-scale plant was required to investigate oxygen requirements, oxygen utilisation efficiencies with pure oxygen and air, the effect of foam formation on the autothermal aerobic process, temperature control of the aerobic reactor and minimum retention times in both the aerobic and anaerobic digestors, the efficiency of pathogen destruction, operational procedures required to prevent recontamination of the treated sludge and the performance of the anaerobic digestor.

As a continuation of their research programme, the Water Research Commission pursued the objective of establishing a full-scale dual digestion plant for evaluation and optimisation of the process. Such a plant was established at the Potsdam Wastewater Treatment Works of Milnerton Municipality.

The objectives of the research programme at Milnerton stipulated that the DDS be evaluated at full-scale level to establish procedures for the operation and control of the system and to investigate the optimisation and cost effectiveness of the process. Operational problems, dewaterability of the sludge and method of operation to prevent recontamination of disinfected sludge had also to be investigated.

An additional objective could be achieved at Milnerton's Potsdam Sewage Treatment Works, where the plant was to be established, in that the dual digestion system could be compared in parallel with the existing Zimpro Sludge Treatment plant with respect to costs and quality of final product.

3.3.2 DESCRIPTION OF THE FULL-SCALE PLANT

The dual digestion plant at the Potsdam Sewage Treatment Works was constructed by utilising two existing fibreglass tanks having a capacity of 50 cubic metres each, together with an existing 1000 cubic metre reinforced concrete anaerobic digestor. A diagrammatic layout of the plant is given in Figure 1.

The one fibreglass tank was used as gravity sludge thickener with supernatant draw-off, while the other acted as an aerobic reactor with effective capacity of 45 cubic metres. Lagging to the

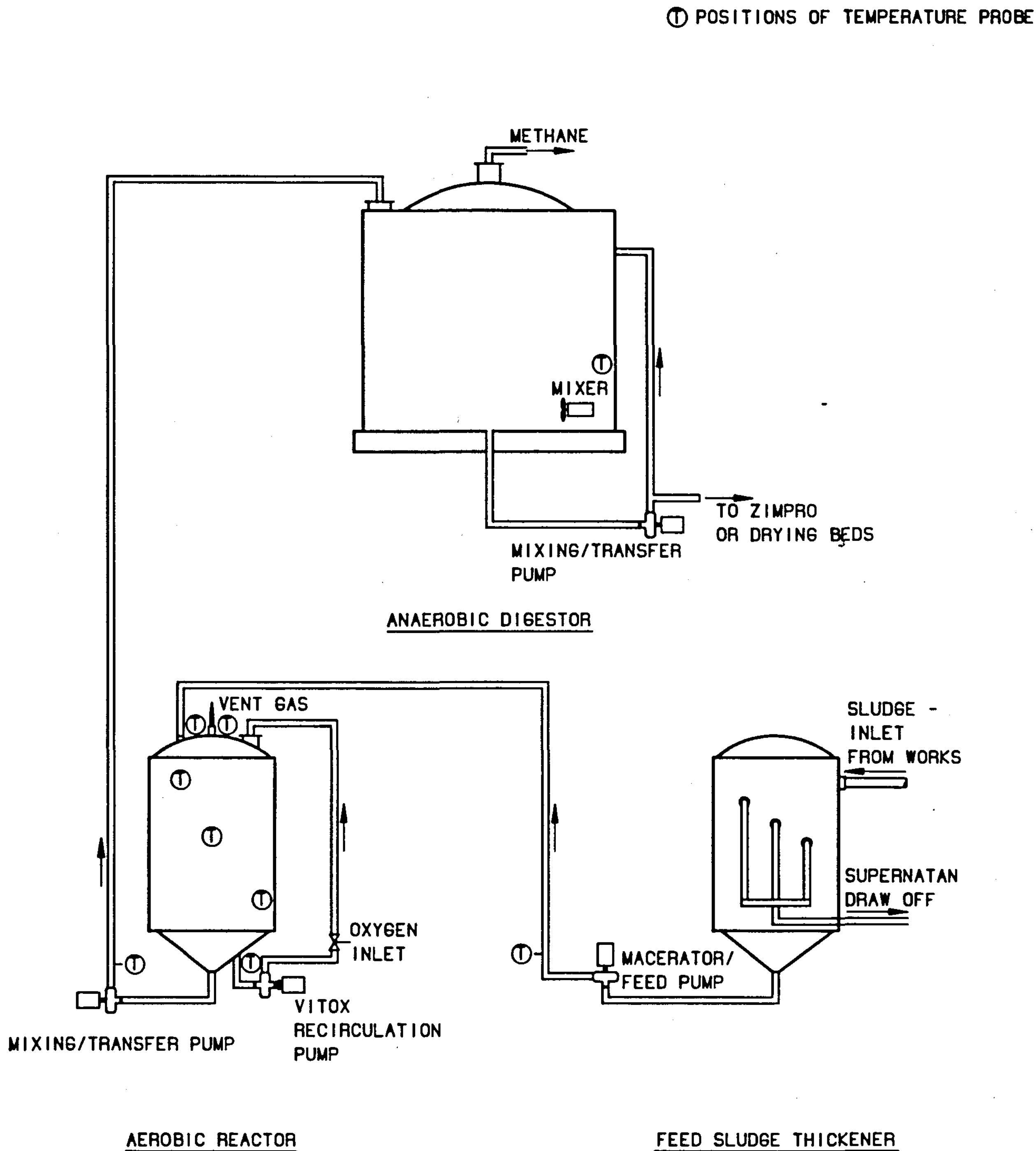

FIGURE 1 : SCHEMATIC LAYOUT OF FULL SCALE DUAL DIGESTION PLANT AT MILNERTON

aerobic reactor, ancillary pipework, pumps, control equipment, temperature-recording equipment and an oxygenation system were provided to complete the dual digestion system.

The full-scale dual digestion plant at Milnerton, the performance of the plant, research undertaken and results obtained are discussed in full detail in Part 1 of the Research Report (De Villiers *et al*, 1991). Only an abridged version of these items will therefore be presented in this report.

The aerobic reactor of the dual digestion plant was designed to accept primary and humus tank sludge and to operate in a batch mode on a draw and fill basis so as to avoid recontamination of pasteurised sludge. Following the draw-off of aerobically treated sludge which was pumped to the anaerobic digestor, partially thickened raw sludge (3,5% to 4% solids concentration) was introduced to the aerobic reactor. A macerator/pump was used to reduce any solid particles in the raw sludge to a size of less than about 9 mm before discharging it to the aerobic reactor.

The oxygenation equipment consisted of a Vitox system which introduced pure oxygen to the sludge by means of a venturi in the recirculating pipework. An external pump acted as mass transfer device to ensure adequate mixing of the aerobic reactor contents and dissolution of oxygen.

The anaerobic reactor was provided with an external pump and pipework for mixing and transfer of treated sludge to either the Zimpro Plant or the sludge drying beds, while a submersible mixer was provided to ensure good internal mixing of the anaerobic digestor.

The autothermal thermophilic aerobic step of the process was monitored and controlled by means of temperature probes connected to a recorder, and gas meters measuring the oxygen supply to the system. The temperature of the sludge in the anaerobic digestor was also monitored for controlling purposes.

3.3.3 PERFORMANCE OF THE PLANT AND RESULTS ACHIEVED
(For details see Parts 1 and 2 of this report)

3.3.3.1 Aerobic reactor

The aerobic reactor was operated between 55° and 65°C and it took about three days from cold start-up to reach the average operating temperature of 60°C. Foaming was present during the start-up operation, but stopped once a temperature rise in the aerobic reactor content was experienced. The operation of the aerobic reactor was found to be simple and easy, and relatively unskilled workers could be trained within a short period of time to operate the plant without any difficulty. The control equipment available played a major role in the ease of operation. Vent gas from the aerobic reactor had an unpleasant odour and was passed through a gas scrubber to avoid odour problems.

Items of mechanical equipment which were found to be of the greatest importance for the problem-free operation of the aerobic reactor are the macerator/pump for the raw sludge feed, and the circulation pump used for mixing and oxygenation of the sludge. Failure of these pieces of equipment will halt the operation of the plant immediately.

The aerobic step was operated at various retention times by altering the sludge feed rate and adjusting the oxygen supply rate accordingly in order to maintain operating temperatures. The power input by the recirculating pump remained virtually constant at about 20 kW.

A summary of different retention times and the oxygen consumption associated with each for the period January to December 1989 are reflected in Table 2.

The full-scale dual digestion plant at Milnerton, its performance and results obtained will be discussed only briefly in this report.

It was found that stable operation could be maintained at a minimum retention period of 1,25 days. The oxygen supply rate at this retention time varied from 10,35 kg/cubic metre of sludge treated in summer months to 14,2 kg/cubic metre in winter months.

TABLE 2 : THE MILNERTON PLANT - PERFORMANCE SUMMARY OF THE AEROBIC STEP FOR THE PERIOD 1988/89

	SUMMER MONTHS				WINTER MONTHS			
RETENTION TIME (days)	TOTAL RUN (days)	VOLUME OF LUDGE TREATE (cubic metres)	OXYGEN SUPPLY (Kg/cub.m.)	POWER SUPPLY (kWh/cub.m.)	TOTAL RUN (days)	VOLUME OF LUDGE TREATE (cubic metres)	OXYGEN SUPPLY (Kg/cub.m.)	POWER SUPPLY (kWh/cub.m.)
1.00	48	1985	10,90	12,1	0	0	0	0
1,20	22	807	11,12	13,6	60	2232	17,17	13,4
1,25	179	1225	10,35	14,3	35	6234	14,20	14,4
1,50	55	1639	12,20	16,77	93	2723	12,10	17,1
2,00	86	1901	8,02	22,6	28	641	9,50	21,8

The difference between winter and summer oxygen demand was due to a lower raw sludge temperature during winter which required more oxygen to maintain the reactor temperature. Retention times of oxygen to maintain the reactor temperature. Retention times of one day could not sustain stable conditions during winter and a temperature drop in the aerobic reactor was experienced, even after the oxygen supply had been increased.

Factors which have been found to play a major role in the efficiency of the process and of the amount of oxygen supplied, are the feed sludge concentration, the temperature of the feed sludge, the retention time and the operating temperature of the aerobic reactor. A thin watery sludge would require more oxygen per kilogram of dry solids treated because the high water content also has to be heated to operating temperature. Colder incoming sludge during winter requires more oxygen to reach operating temperature. The shorter retention periods result in a higher volume of cold sludge fed to the reactor per day and subsequently more oxygen is required to raise the temperature. Higher operating temperatures in the aerobic reactor, e.g. 65°C, require more oxygen for stable operation than operating temperatures of say 60°C.

3.3.3.2 **Anaerobic digestor**

The anaerobic digestor performed very well after a slow start-up. No seeding of the anaerobic digestor with sludge from another source could be carried out because of potential danger of reinfection of the pasteurised sludge. Start-up of the digestor was slow and it took three months before normal operation with a reasonable production of methane gas occurred. During the start-up period, feeding of the digestor had to be suspended due to a drop in pH and alkalinity. Chemicals (calcium hydroxide, sodium bicarbonate and sodium carbonate) had to be added in varying dosages so as to adjust the pH to above 6,8 before the digestor started operating properly and feeding could be resumed. When feeding is stopped because of the volatile fatty acids getting too high and the pH too low, the digestor contents begins to cool down as the only source of heating to the digestor is the hot aerobic feed sludge. Start-up is therefore a delicate balance between heating via feed sludge and pH control vie chemical addition. Once methane generation commences, the volatile fatty acids decrease rapidly to very low levels (approximately 50 mg/l) over a few days while pH increases and chemical dosing can be stopped. Feeding can then be resumed at the required rate.

It was found that no additional heating of the anaerobic contents was required during winter months. The incoming hot sludge from the aerobic reactor was sufficient to maintain mesophilic temperatures of between 35° and 38°C.

In summer, however, because of the higher ambient temperature, the feed rate to the anaerobic digestor had to be reduced so as to avoid overheating of the digestor contents. Feed to the anaerobic digestor had to be reduced which resulted in long retention times.

Shorter retention times, however, would be possible during summer months provided that the incoming hot sludge or anaerobic contents could be cooled sufficiently to maintain the sludge at the optimum mesophilic temperature range.

It was found that stable operation with a high gas production together with a high breakdown of volatile solids and C.O.D. could be achieved with a 20 day retention period in the anaerobic digestor. The very stable operation of the anaerobic digestor could be attributed to the conditioning of the sludge and the increase in pH and alkalinity in the aerobic reactor.

3.3.3.3 Pasteurisation

The ability of the aerobic stage to pasteurise the sludge was satisfactory. Analysis of sludge samples indicated that *Ascaris ova* are effectively killed and faecal coliforms are reduced by 9 orders of magnitude. Salmonella could not be detected in the raw feed sludge. This phenomena could possibly be ascribed to the low pH value of the sludge in the thickener. Salmonella apparently are very sensitive to acid conditions and their die off rate is rapid at low pH. The average microbiological analyses over a six month period are given in Table 3.

TABLE 3 : AVERAGE MICROBIOLOGICAL ANALYSIS ACROSS THE MILNERTON PLANT

ORGANISM		FEED SLUDGE	AEROBIC REACTOR	ANAEROBIC DIGESTOR
Faecal Coliforms	per g dry sludge	1.9×10^{12}	2.35×10^{4}	1.87×10^{4}
Ascaris Ova				
Viable	per 10g dry sludge	159	0	0
Non Viable	per 10g dry sludge	248	285	340

Mean of 16 tests

A number of tests have been disregarded due to the unreliability of data

Analysis of the anaerobic sludge has indicated that the mode of operation, that is batch feeding, has been very effective in preventing any recontamination of the sludge after pasteurisation in the aerobic reactor.

3.3.3.4 **Stabilisation**

The performance of the dual digestion system with respect to volatile solids and C.O.D. reduction was exceptionally good. A summary of average operating parameters for the aerobic reactor and anaerobic digestor as well as C.O.D. and solids reduction, are given in Table 4.

A overall volatile solids removal of 56,6% and C.O.D. removal of 53,6% were achieved with an average retention time of 1,53 days in the aerobic reactor and 22,3 days in the anaerobic digestor. It must be noted that the high average retention time in the anaerobic digestor was due to a low rate of sludge feed during warm summer months so as to avoid the required operating temperature of 35° to 38°C being exceeded.

The final product was found to be very stable and had a typical earthy odour of anaerobically treated sludge due to the very high reduction in volatile solids.

3.3.3.5 **Dewaterability**

The high volatile solids reduction achieved by the Dual Digestion System resulted in a low solids concentration in the treated sludge. From an initial average of 37,4 g/l in the feed sludge (for 1989), the total solids concentration decreased to an average of 18,4 g/l through the aerobic and anaerobic digestion processes. The higher water content of the sludge would therefore result in more effort being required for dewatering the treated sludge.

The treated sludge was found to be extremely fine and watery. Its odour was characteristic of a well-stabilised anaerobically digested sludge. During dewatering tests on sludge drying beds, it was found that sludge settled well, but blinded the bed

TABLE 4 : AVERAGE OPERATING PARAMETERS AND RESULTS OF CHEMICAL ANALYSIS THROUGH THE DUAL DIGESTION PLANT AT MILNERTON

PARAMETER	1988 VALUES	1989 VALUES
RETENTION TIME :		
Aerobic reactor (days)	1,38	1,53
Anaerobic reactor (days)	21,00	22,30
OPERATING TEMPERATURES :		
Aerobic reactor(°C)	60,36	59,36
Anaerobic reactor (°C)	35,26	37,67
SLUDGE TREATED :		
Volume treated per annum (m^3)	10536	10894
Average sludge concentration (g/l)	37,10	37,40
OXYGEN SUPPLIED :		
Per cubic metre of sludge treated (Kg)	13,24	11,9
Per kilogram of dry solids treated (Kg)	0,354	0,318
POWER CONSUMPTION:		
Per cubic metre of sludge treated (kWh)	15,28	16,80
Per kilogram dry solids treated (kWh)	0,41	0,45
Per kilogram volatile solids removed (kWh)	1,10	0,98
Per kilogram total solids removed (kWh)	0,71	0,88
COD :		
Feed (gram per litre)	50,30	49,10
Aerobic stage effluent (g/l)	43,20	40,20
Anaerobic stage effluent (g/l)	23,50	22,80
Total COD removal (%)	53,30	53,60
TOTAL SOLIDS :		
Feed (g/l)	39,89	37,40
Aerobic stage effluent (g/l)	37,10	32,30
Anaerobic stage effluent (g/l)	19,80	18,40
Total solids removal (%)	46,60	50,80
VOLATILE SOLIDS :		
Feed (g/l)	29,90	30,20
Aerobic stage effluent (g/l)	27,60	25,70
Anaerobic stage effluent (g/l)	13,80	13,10
Total volatile solids removal (%)	53,80	56,60
pH :		
Feed	5,60	5,60
Aerobic stage effluent	7,00	7,10
Anaerobic stage effluent	7,50	7,60
AMMONIA :		
Feed (mg/L)	187	175
Aerobic stage effluent (mg/L)	261	318
Anaerobic stage effluent (mg/L)	649	651
ALKALINITY (as Calcium carbonate to pH 5,75)		
Feed (mg/L)	9,2	15
Aerobic stage effluent (mg/L)	578	637
Anaerobic stage effluent (mg/L)	1895	1733

surface because of the presence of very fine sludge particles. Despite the high degree of stabilisation, gas production continued in the settled sludge on the bed and formed a crust on the surface of the supernatant liquid. The relatively clear supernatant liquid, trapped between the sludge and the crust, had to be decanted so as to allow for air drying of the sludge layer and of the crust on top of the drying bed. During hot, dry weather, sludge dried sufficiently to be removed manually after 6 to 8 days.

TABLE 5 : SUMMARY OF SLUDGE CHARACTERISATION AND DEWATERING TESTS CARRIED OUT ON DUAL DIGESTION TREATED SLUDGE FROM MILNERTON

DEWATERABILITY PARAMETER	WITHOUT ANY ADDITIVES	RESULTS OBTAINE WITH POLY-ELECTROLYTE	RESULTS OBTAINED WITH CHAR AND POLYELECTROLYTE
ADDITIVE DOSAGE :			
Polyelectrolite (Zetag 32) (Kg/ton dry solids)	-	5	1
Char (Kg/ton dry solids)	-	-	400
SOLIDS CONCENTRATION :			
Total solids,c (%)	2	2,8	2,8
Cake solids after filtration (%)	2,5	6,2	3,1
Cake solids after centrifugation (%)	13,4	12,7	19
Cake solids after 24 hrs gravity settling (%)	3,4	8,5	4,6
Cake solids after electro-osmotic dewatering (%)	4,8	5,6	11,8
IMPROVEMENT IN SOLIDS CONCENTRATION :			
Due to centrifugation (ratio of final/initial)	6,5	4,5	6,7
Due to gravity settling (ratio of final/initial)	1,6	3,4	1,6
DEWATERABILITY PARAMETERS :			
Capillary suction time, CST (s)	400	35	186
Filterability, c/CST	0,05	0,86	0,15
Specific resistance to filtration, SRF (x10power12 metre/Kg)	*	160	507
Dilute sludge volume index, DSVI (mL/gram)	*	22	23
MOISTURE CONTENT :			
Total (gram/gram dry solids)	7,1	7,1	5,1
Immobilised (gram/gram dry solids)	3,8	2,9	2,2
Bound (gram/gram dry solids)	2	6	2,2
Chemical (gram/gram dry solids)	1,6	1,2	0,8
DRYING TIME :			
Critical (hours)	1,9	1,5	1,6
Total (hours)	4,2	4,2	4,5

* unable to determine a value

Samples of treated sludge were analysed and tested by the Division of Water Technology of the CSIR to determine sludge characteristics with respect to dewaterability. A summary of the test results (Smollen, *et al* 1991) are given in Table 5 (see also Fig. 2).

The results obtained from the laboratory investigations indicated that sludge produced by the dual digestion system can be expected to be very difficult to dewater. Due to the high colloidal contents with an excess of fine particles, filtration methods of dewatering were ineffective due to blinding of the filter media and blocking of the passageways through the sludge cake.

The most effective method of dewatering appears to be centrifugation. The addition of polyelectrolyte improved solids concentration under gravity settling, while the addition of char and a small dosage of polyelectrolyte improved solids concentration after centrifugation.

3.4 INVESTIGATION INTO THE AEROBIC REACTOR KINETICS

Very early in the full-scale research programme a number of issues were identified which may influence the behaviour of the aerobic reactor. It was clear that the aerobic reactor in the dual digestion system could not be compared to and evaluated as a stand-alone thermophilic aerobic digestor as the objectives of the two processes differ. Volatile solids removal is not an objective in the aerobic step of the dual digestion plant, while the maintenance of a sufficiently high temperature at a short retention time is of utmost importance for disinfection purposes.

The strange behaviour of the aerobic reactor at retention times of one day when the reactor temperature started declining irrespective of the amount of oxygen supplied, raised a number of questions on the factors which govern the process economics and how to model the thermophilic aerobic reactor.

To enable the research team to clarify these issues, the need to carry out an in-depth study into the kinetics and stoichiometry of biological heat generation and oxygen utilisation in the aerobic reactor was identified and such a study was subsequently undertaken. The results and findings on this study have been comprehensively documented in a final report viz "Evaluation and Optimisation of dual digestion of sewage sludge, Part 2: Aerobic

Reactor Performance" by Messenger, *et al* (1991).

Through careful measurement of physical parameters and studying heat and oxygen balances across the aerobic stage, a number of important findings and conclusions about the kinetics of the process could be made:

* It was found that the relationship between the heat generated by the biomass and the oxygen utilisation remained constant with different oxygen supply rates and hydraulic retention times. This relationship enabled a heat yield of about 13 MJ/kgO for the sludge to be derived.

* The temperature of the sludge in the aerobic digestor could be accurately controlled by means of the oxygen supply rate (OSR), i.e. the rate of oxygen supplied to the oxygenation system, provided the oxygen transfer rate (OTR) of the oxygenation equipment was lower than the maximum oxygen utilisation rate (OUR) of the sludge. A decrease/increase in OSR under these conditions caused an immediate (within one hour) response in an average lower/higher reactor temperature.

* The maximum OUR for the Milnerton sludge, a mixture of primary and humus sludge, was measured at 0,38 kg O/(m^3.h).

* Operation at a very short retention time, that is one day retention, required a OSR equal to or greater than the OUR. The result is that the excess oxygen which could not be utilised by the sludge, caused heat losses through vent gas and subsequently a drop in reactor temperature. The fact that vent gas was saturated with water vapour at all vent gas flow rates, contributed to the heat loss.

* The oxygen transfer rate (OTR) and oxygen transfer efficiency (OTE=OTR/OSR) of the oxygenation equipment

were critical parameters in determining whether the design reactor temperature could be achieved. An increase in OSR would be associated by a decrease in OTE. At Milnerton, the OTE ranged between 0,80 and 1,00 for OSR's of 0,36 to 0,13 Kg O/(m^3.h).

* COD and/or volatile solids (VS) removal rates are not good parameters for quantifying the biological heat generation, nor for controlling the sludge temperature in the aerobic reactor.

* Simulation procedures for systems utilising oxygen, air or a combination of the two have been derived which will assist in the design of aerobic digestion in general. The design procedure is based on the solution of the steady-state heat balance of heat sources and heat losses across the reactor as described by the following simplified equation (Messenger, 1991a):

Heat sources = Heat losses

$$H_{bi} + H_{mi} = H_{sé} + H_{vé} + H_{we}$$

Where:

H_{bi} = biological heat generation rate

H_{mi} = mechanical heat input rate due to mixing/ oxygenation

$H_{sé}$ = nett heat loss in the effluent sludge

$H_{vé}$ = nett heat loss in reactor vent gas

H_{we} = nett heat loss through reactor wall and recirculation piping

* An algorithm was developed which could solve the unsteady heat balance and simulate temperature profiles of the aerobic reactor to within 0,5°C for variations in retention time, sludge feed temperature, OTR and OTE.

* Original research objectives, that is to determine biological oxygen requirements, oxygen transfer rate and oxygen transfer efficiency with pure oxygen, to achieve thermophilic temperatures by means of biological heat generation, minimum retention time, methods for temperature control and means of optimising the aerobic stage of dual digestion, were achieved by the investigation.

* The aerobic reactor at Milnerton could be operated at a one day retention time during hot summer months when the feed sludge (26°C) and ambient temperatures (30°C) were high. The OTR could then still be maintained below the OUR as less oxygen was required to raise the temperature of the aerobic reactor. During winter, however, when the feed sludge was cold (18°C) and ambient temperatures low (10°C), a retention time of 1,25 days was required to maintain the OTR below the OUR and the reactor temperature above 60°C.

3.5 FULL SCALE RESEARCH ON DUAL DIGESTION BY CAPE TOWN CITY COUNCIL USING AIR

The research programme at Milnerton also called for an investigation and evaluation of the dual digestion system using air.

The plant was designed and constructed to accommodate pure oxygen first due to the lower capital requirements. It was soon realised that both time and funds would be insufficient to accommodate a plant utilising air. A major reconstruction of pipework and mechanical equipment at the aerobic reactor would have been required to accommodate the much larger (5 times) gas flows. A research project to investigate the use of air in the dual digestion was subsequently undertaken by the City Engineer's Department of Cape Town at their Athlone Works. The plant consisted of an aerobic reactor with effective capacity of 184 cubic metres which was constructed as an inner core within an existing anaerobic digestor (Pitt, 1990). Space for a foam layer of up to 3 m deep, was allowed for in the aerobic reactor. Sludge feeding occurred in batches and air was supplied by a compressor. The oxygenation system consisted of coarse bubble diffusers at the bottom of the aerobic reactor and mixing was provided by two external pumps. The anaerobic digestor, which was formed by the outer core of the original digestor, had a minimum operating capacity of 1100 cubic metres and gas mixing of the contents was provided.

The average operating parameters and results of chemical analyses obtained at the Cape Town Plant for the period 1 November 1989 to 31 July 1990 were abstracted from Pitt (1990) and are presented in Table 6. Other findings as a result of the research, are the following:

* Foam was present on the surface of the reactor throughout the period of the research. The depth of the foam layer varied, and increased with the increase of air flow rate and sludge temperature. With reactor temperatures above 50°C, foam assisted in achieving higher OTE and therefore higher temperatures and lower retention times.

* Dissolved oxygen levels were generally low (0,1 mg/l) but increased with a decrease in sludge concentration indicating that the OUR is at least partly dependent on sludge concentration, increasing as concentration increases.

TABLE 6 : AVERAGE OPERATING PARAMETERS AND RESULTS OF CHEMICAL ANALYSIS THROUGH THE DUAL DIGESTION PLANT AT CAPE TOWN

PARAMETER		AVERAGE OVER PERIOD (1 NOV.1989 - 31 JUL.1990)
RETENTION TIME :		
Aerobic reactor	(days)	4,2
Anaerobic reactor	(days)	25 days minimum to ensure good mixing
OPERATING TEMPERATURES :		
Aerobic reactor	(°C)	49,3
Anaerobic reactor	(°C)	31,1
SLUDGE TREATED :		
Volume treated per annum	(m^3)	12066
Average sludge density	(gram/litre)	45,1
AIR FLOW :		
Average supply rate	(m^3/hour)	700
Per cubic metre of sludge treated	(m^3)	380
Per kilogram of dry solids treated	(m^3)	8,42
POWER CONSUMPTION:		
Per cubic metre of sludge treated	(kWh)	12
Per kilogram dry solids treated	(kWh)	0,27
Per kilogram volatile solids removed	(kWh)	0,57
Per kilogram total solids removed	(kWh)	0,57
COD :		
Feed	(gram/litre)	63,6
Aerobic step effluent	(gram/litre)	42,7
Anaerobic step effluent	(gram/litre)	26,1
Total COD removal	(%)	59
TOTAL SOLIDS :		
Feed	(gram/litre)	45,1
Aerobic step effluent	(gram/litre)	34,5
Anaerobic step effluent	(gram/litre)	24,0
Total solids removal	(%)	46,8
VOLATILE SOLIDS :		
Feed	(gram/litre)	36,8
Aerobic step effluent	(gram/litre)	27,6
Anaerobic step effluent	(gram/litre)	16,7
Total volatile solids removal	(%)	54,6
pH :		
Feed		5,4
Aerobic step effluent		7,4
Anaerobic step effluent		7,4
AMMONIA :		
Feed	(mg/L)	113
Aerobic step effluent	(mg/L)	365
Anaerobic step effluent	(mg/L)	771
ALKALINITY (as Calsium carbonate to pH 5,75)		
Feed	(mg/L)	40
Aerobic step effluent	(mg/L)	820
Anaerobic step effluent	(mg/l)	2920

* The dewaterability of the treated sludge after dual digestion was measured by the specific resistance to filtration (SRF) and compared with that of conventional anaerobic treatment.

	SRF median (10 tests)
Anaerobic	218×10^{12} m/kg
Dual Digestion with air	368×10^{12} m/kg

The higher value of SRF for dual digested sludge indicates a lower dewaterability than the conventional anaerobically treated sludge.

* The medians of microbiological counts across the plant are as follows:

	Feed	**Aerobic**		**Anaerobic**
Faecal Coliforms/ 100 ml	$9,3\times10^{8}$	$7,5\times10^{5}$		$4,3\times10^{4}$
Ascaris Ova/g		T<50°C	T>50°C	
dry solids	429	415	545	758
% viable	45	3	0	12

The high count for viable *Ascaris Ova* in the anaerobic sludge is probably due to the fact that the objectives of the research were not to specifically pasteurise the sludge. The research was undertaken to evaluate the dual digestion system with air oxygenation as a means for increasing the loading rate on anaerobic digestors by allowing shorter digestion retention times. The result was that no measures were taken to prevent contamination of anaerobic sludge (reactors were continuously fed and not batch fed while the anaerobic digestor was started with an unpasteurised sludge seed).

* The research has proved that air could be used in the dual digestion system. The plant is simple to operate and control. An important factor is the feed concentration thickness of raw sludge which, when too low, resulted in a temperature decrease in the aerobic reactor. A longer retention time is therefore required

to maintain temperatures in the aerobic reactor.

* The specific heat yield (Y_H) for sludge at the Athlone works was calculated to 13,6 MJ/kg O.

* Oxygen transfer efficiencies of between 9,9% and 34,8% were achieved with the oxygenation equipment. Low concentration feed sludges, however resulted in low OTE.

* Mesophilic temperatures could be maintained during the summer months, but during winter, heat requirements could not be sufficiently met to achieve the mesophilic temperatures

A comparison of the performance of air and oxygen aerobic reactors in dual digestion is given in Part 2 of this report and also by Messenger and Ekama (1991a)

CHAPTER 4

ASSESSMENT OF THE DUAL DIGESTION TECHNOLOGY IN THE LIGHT OF RESEARCH AND EXPERIENCE

4.1 TECHNOLOGY LIFE CYCLE OF THE DUAL DIGESTION SYSTEM

All technologies have to pass through life cycles. The typical life cycle of a technology entails a number of phases. From the inception point, the technology has to be developed and refined whereafter it is gradually applied in practice. As application grows, modifications and improvements are made to the original technology. As a result of a combination of several environmental trends giving rise to pressures necessitating new needs and requirements, a point is reached where technologies can not be meaningfully modified or improved so as to satisfy the new set of needs and requirements. At such a stage, unless drastic changes or further innovations can extend the growth phase, the technology can be considered to have reached maturity and the end of its life cycle, and it will gradually be phased out.

Anaerobic sludge digestion can be considered as the real workhorse of sludge treatment technology in South Africa, where the majority of wastewater treatment plants have applied the process in various forms. The technology can be considered as being in the last stages of its growth phase before going over to maturity. Because of an increase in environmental awareness and associated demands on sludge treatment, the inability of anaerobic digestion to produce a sludge which is environmentally acceptable in terms of pathogen destruction could very well cause the process to approach the end of its life cycle more rapidly. Many of the wastewater treatment plants which are presently applying anaerobic digestion will be under pressure to undertake major changes in sludge treatment to enable them to dispose of their sludges in an acceptable manner.

Aerobic digestion of sewage sludge on the other hand is a much newer type of sludge treatment process which is experiencing a very slow growth phase in South Africa. It is not favoured because of its very high running cost, and is therefore a technology which finds its application in special cases only.

Dual digestion can be seen as a process which makes use of the technologies contained in both aerobic and anaerobic digestion of sewage sludge. This unique combination has resulted in the development of a new hybrid technology which can be seen as a major innovation which may restore the vitality of anaerobic digestion and extend its life cycle into a new growth phase.

Since the dual digestion technology's inception in the USA during the early 1980's, it has entered a strong growth phase, particularly in Europe where a large number of wastewater treatment plants have applied the technology by adding an aerobic reactor before their existing anaerobic digestors. The inception of the dual digestion technology in South Africa, however , has only reached research and development level. Actual adoption and full-scale implementation must still take place for the technology to enter its local growth cycle.

If the experience in Europe is taken as an indication of the popularity of the technology, a strong growth phase with considerable stimulation from refinements and further developments can be expected in South Africa, once the initial resistance and skepticism have been overcome.

4.2 INFLUENCE OF GENERIC TECHNOLOGIES

The Dual Digestion System depends on a number of generic technologies which interact and influence each other. These generic technologies are combined and put together in such a fashion as to make up the dual digestion process as it is presently known. Some of the major generic technologies which have been applied in the Dual Digestion System are the following:

* materials handling
  - sludge pumping/maceration
  - dry solids removal
* separation
  - sludge thickening
  - sludge dewatering
  - screening
* gas transfer
  - oxygenation equipment

*	thermal conductivity	- insulation - heat exchange
*	biochemistry	- aerobic and anaerobic digestion of sewage sludge
*	control equipment	- electronic switchgear - heat sensors - digital recorders - computer hardware and software
*	gas combustion	- use of methane as an energy source

The improvement of dual digestion as a process will depend mainly upon the cross-fertilisation between these generic technologies and the subsequent research and development thereof. The challenges for improvement of these generic technologies may very well stimulate innovative minds, and lead to many new developments which may assist to optimise the dual digestion process further. Designers and contractors in Europe have already done much to optimise the sludge treatment process by incorporating high technology control equipment and also by reducing costs through reclaiming and re-using all energy sources in the form of vent gas, hot sludge and methane.

4.3 FUNCTIONAL PERFORMANCE OF THE PROCESS

The functional performance of a sludge treatment process can be evaluated by comparing the results obtained for certain key parameters against a set of objectives or against the results obtained by other types of sludge treatment.

4.3.1 PASTEURISATION

The first objective of the dual digestion system is to improve on the performance of normal anaerobic digestion by producing a sludge that is pasteurised and therefore free of pathogens. The results obtained from research carried out by both Milnerton (pure oxygen at Potsdam) and Cape Town (air at Athlone) are summarised in Table 7. These results have indicated that disin-

TABLE 7 : COMPARISON OF THE OPERATING PARAMETERS AND RESULTS ACHIEVED BY DIFFERENT DUAL DIGESTION PLANTS IN SOUTH AFRICA

PARAMETER	ATHLONE PLANT CAPE TOWN	POTSDAM PLANT MILNERTON
BASIC OPERATING PARAMETERS:		
Operating objective	To evaluate the DDS with air in terms of improved anaerobic digester performance	To evaluate and optimise the DDS with pure oxygen in terms of both pasteurisation and stabilisation
Sludge type	Primary and secondary from activated sludge	Primary and humus from biofilters
DDS oxygenation system	Compressed air by static diffusers, mixing with external pumps	Pure oxygen via vitox system, mixing with external pumps
Sludge feed:		
Feed mode	Batch feeding	Batch feeding
Volume treated per day (m^3)	44,2	29,4
Total solids loading per day (Kg)	1993	1135
Aerobic reactor data:		
Operating temperature (°C)	49,3	59,86
Retention time (days)	4,2	1,45
Oxygen feed (kg/d)	-	370
Air feed (cubic metre/day)	700	-
Anaerobic digestor data:		
Operating temperature (°C)	31,1	36,47
Retention time (days)	minimum 25	21,60
RESULTS ACHIEVED:		
VS removed (%)	54,6	55,2
TS removed (%)	46,8	48,7
Faecal Coliforms		
Feed sludge	$9,3x10^8$ per 100ml sludge	$1,9x10^{12}$ per g dry sludge
Aerobic reactor effluent	$7,5x10^5$ per 100ml sludge	$2,3x10^4$ per g dry sludge
Anaerobic reactor effluent	$4,3x10^5$ per 100ml sludge	$1,9x10^4$ per g dry sludge
Ascaris Ova (viable)		
Feed sludge	45	159
Aerobic reactor effluent	3 for temperature < 50°C 0 for temperature > 50°C	0
Anaerobic reactor effluent	12	0
Salmonella	not detected	not detected

fection of sewage sludge with respect to *Ascaris Ova* is adequate to produce at least a Type C but even a Type D sludge, depending on the metal content, in terms of the "Guidelines for the use of sewage sludge" (Vivier, *et al*, 1988).

A total absence of viable *Ascaris Ova* was recorded in the anaerobically treated sludge at the Milnerton Plant. Recontamination of the sludge after pasteurisation in the aerobic reactor was avoided by employing a batch feeding system and by starting the anaerobic digestor using pasteurised sludge.

The Cape Town plant produced similar results for the aerobic reactor effluent when the reactor temperatures were maintained above 50 °C with long retention times. With reactor temperatures below 50 °C, especially during winter months, this plant could not produce a total elimination of viable *Ascaris Ova*, but a significant reduction of pathogens was still recorded. The dual digestion anaerobic reactor at the Cape Town plant was started with anaerobically treated sludge which most probably accounts for the presence of viable *Ascaris Ova* in the finally treated sludge.

At both the South African plants a significant reduction in the presence of *faecal coliforms* has been recorded. The rate of regrowth of this organism, however, is so high that the requirement for a type C or D sludge, which stipulates a maximum count of 10 *faecal coliforms* per 100g dry sludge immediately after disinfection/sterilisation, seems impractical if regrowth would occur in the anaerobic digestor. No trace of *salmonella* could be detected in the feed sludge of either plant, probably due to the septicity of the raw sewage.

Studies in the USA (Appleton, *et al* , 1986b) on the effectiveness of the DDS in achieving pathogen destruction in comparison with processes classified as PSRP or PFRP, have indicated that the reduction in three indicator microbiological parameters; i.e. total *coliform*, *faecal coliform* and *faecal streptococci*; were greater for the DDS than for other processes listed as PSRP's, and equalled or bettered the performance of thermophilic digestion, a PFRP. Studies on the destruction of *salmonella spp.*

provided unreliable data for comparison due to very low concentrations relative to analytical detection levels.

Studies carried out on dual digestion plants in Europe have indicated that the system can reduce the presence of *enteorobacteriaceae* (EBC) from 10^7 per gram of raw sewage to a range of 1 to 50 per gram of treated sewage sludge, well within the limits of 100 EBC per gram of sludge stipulated by the Swiss legislation.

The research carried out by Milnerton and Cape Town therefore support the overseas findings in that the dual digestion system is able to produce a sludge which is free of viable *ascaris ova*, provided that the basic requirements for aerobic reactor temperature and retention times are adhered to, and that the mode of sludge feed and operation applied there, would eliminate recontamination.

4.3.2 STABILISATION

The second objective of the DDS is to produce a sludge which is well stabilised and does not produce unpleasant odours or attract flies.

The data as reflected in Table 7 indicate that the dual digestion plants at Cape Town and Milnerton were both capable of producing a well-stabilised sludge. Total solids reductions of between 46 to 49% and volatile solids removal of about 55%, were observed and these compare very favourably with conventional anaerobically digested sludge. Experience has also shown that the stabilised sludge does not create unpleasant odours and does not attract flies.

4.3.3 DEWATERABILITY OF THE FINAL PRODUCT

Experience at Milnerton has shown that the treated sludge produced by the dual digestion system is very fine and has a high water content due to the high reduction of solids through the digestion process. Despite its fineness, the sludge settles well which allows supernatent to be readily drawn off. As a result of residual development of gas in the waste sludge from the anaerobic digestor, some solids rise through the water body and form a layer on the liquid surface after the sludge has been discharged onto drying beds.

Despite its good settlement properties, the sludge exhibits poor dewatering characteristics. The fine particles tend to blind any type of filtering surface. When discharged onto sludge drying beds, the sand layer is blinded quite rapidly. With a layer of solids which forms a crust on the sludge liquid surface, drying time can be excessive due to supernatant trapped between the two layers of solids.

Dewaterability studies conducted on the final product from the Milnerton plant supported the findings on site (Smollen, *et al*, 1990). The sludge resisted any attempts towards dewatering by means of filtration by blinding the filter surface. Centrifugation of the sludge, however, produced reasonable results when a mixture of char and polyelectrolyte was added to the sludge. A solids concentration of 19% has been obtained in laboratory scale centrifugation tests.

Tests made on the sludges from Milnerton and Cape Town to determine filtration parameters provided a capillary suction time (CST) of approximately 400 (see Table 5), and a specific resistance to filtration (SRF) of 368×10^{12} metre per kilogram. The values of these two parameters have been superimposed on data obtained from similar studies on other types of treated sewage sludges in Figure 2 (Smollen, 1986).

From the data in Figure 2 it can be seen that the dewaterability of dual digested sludge falls within the same range as that of conventional anaerobically digested mixture of primary and secondary sludges.

Centrifugation has been found to be the most successful method of mechanical dewatering for anaerobically treated sludges and should therefore also produce satisfactory results with dual

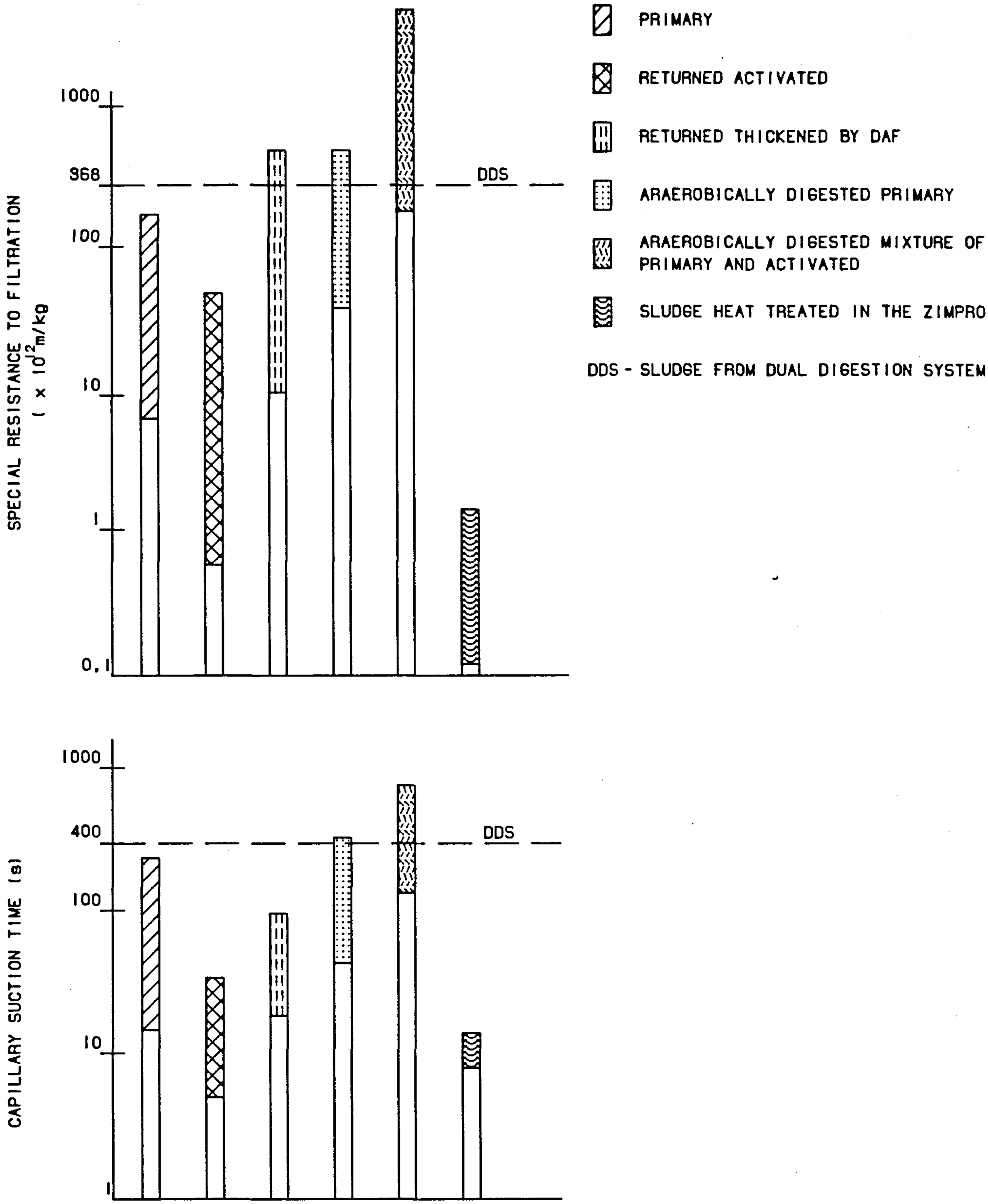

FIGURE 2 : COMPARISON OF THE DEWATERABILITY CHARACTERISTICS OF DUAL DIGESTED SLUDGE WITH THAT OF VARIOUS OTHER SLUDGES

SOURCE: M. SMOLLEN, 1986

digested sludges. Solids concentrations of above 20% have been achieved by dewatering dual digested sludge through centrifugation at the Lackawana Wastewater Treatment Works, New York (Appleton, et al, 1986a).

4.4 OPERATIONAL PERFORMANCE

Experience at both the Milnerton and Cape Town plants have indicated that the DDS is a process which is simple and easy to operate. The system is very robust and resistant to variations in sludge concentration. The aerobic phase proved to be a real shock absorber for the more sensitive anaerobic digestor.

The Milnerton plant experienced no difficulty in achieving thermophilic temperatures in the aerobic reactor. Operating temperatures around 60°C could be achieved quite readily and the oxygenation equipment provided an excellent means of temperature control. The temperature could readily be adjusted upwards or downwards simply by increasing or decreasing the oxygen supply rate. The amount of oxygen required to maintain a constant operating temperature depended upon the design operating temperature level itself. The stability of the aerobic phase ensured minimum supervision and the plant could be left to run on its own for extended periods. The level of trained staff required to operate the plant is relatively low, and even unskilled operators can handle easily the basic controls with the minimum amount of training.

Despite the claims that a retention time of one day is achievable in the aerobic reactor, the experience at Milnerton has shown that even with pure oxygen, a minimum retention period of 1,25 days was required to maintain stable operation. Factors such as the kinetics of the process, the limited ability of the sludge to utilise the available oxygen, operating temperature, oxygen transfer efficiency of the oxygenation equipment and the type of oxygen source (pure oxygen, air or a mixture of the two) all play a role in determining the lower limit for retention time.

Experience at the Cape Town Plant has indicated that retention time of 3 to 6 days should be adopted for a system utilising air as oxygen source and that operating temperatures above 50°C were difficult to achieve at a retention time shorter than 3 days. During winter months, operating temperatures of 50°C could not be maintained, even with retention times of up to 5 days.

As a result of the conditioning effect on the sludge in the aerobic reactor through solubilisation, as well as the increase in pH and alkalinity, the performance of the anaerobic digestor are enhanced considerably. The volatile solids removal in the aerobic phase is minimal (as little as 1,5%) at short retention times and has no detrimental effect on the methane production in the anaerobic digestor. About 0,5 cubic metre (STP) of methane per kilogram volatile solids removed or 0,36 cubic metre (STP) of methane per kilogram of COD removed, were achieved, comparable with the range normally observed in conventional anaerobic digestors.

The Milnerton aerobic reactor took between two and three days to reach operating temperatures of 60°C from a cold start-up. During start-up, foam was generated which resulted in sludge loss from the reactor via an overflow. Foaming, however, stopped completely once the reactor temperature started to increase. The absence of foam in the reactor during normal operation can be attributed to the low vent gas flows in the system and can be seen as a benefit of an oxygenation system using pure oxygen.

The Cape Town plant on the other hand, had to accommodate a foam layer on the liquid level within the aerobic reactor (Pitt, 1990). This foam layer was created by the high vent gas flows resulting from air being used as an oxygen source. The depth of the foam layer could be controlled around three metres provided that a long retention time was used. With short retention times, the volume of air has to be increased in order to provide the necessary oxygen to maintain operating temperatures. The large air flows would then result in the formation of excess foam and a loss of aerobic sludge through the overflows. Operating temperatures could not be maintained at short retention times due to the heat loss from foam overflow and vent gas.

From start-up the anaerobic digestor at Milnerton took about three months before producing methane, and despite the higher pH and alkalinity, careful chemical addition and sludge feeding was necessary to nurse the digestor to the desired state, that is a pH > 6,8 and increasing temperature towards 37°C. The long period of start-up can be attributed to the fact that no seeding of the digestor could be done to avoid contamination of pasteurised sludge. The only heating source for the digestor was the hot sludge from the aerobic reactor. While the hot sludge was necessary to maintain mesophilic temperatures, it also resulted in high concentrations of volatile fatty acids which tended to reduce the pH.

When operating normally, the digestor required no additional heating to maintain mesophilic temperatures. The retention of heat was so good that an average retention time of about 20 days was required to avoid overheating. During a trial run to evaluate the performance of the digestor, a retention period of 12 days was used. The digestor showed signs of overloading as the volatile acids in the sludge started to increase and the pH decreased. This exercise indicated that the claims of reducing the retention time in the anaerobic digestor to 10 days will most probably not be realised at full-scale plants in South Africa. The retention time of the digestor could, however, be reduced to about 15 days by the introduction of a system to control the temperature of the digestor content through cooling during summer months.

Experience at the Milnerton plant has shown that the successful operation of the DDS depends on the reliability of equipment. Problems with mechanical and control equipment, especially with the recirculation pump for the aerobic reactor oxygenation system and the temperature recorder system which was vital to the control of the processes and assisted in determining parameters such as OSR, OTR, and OTE, have highlighted the importance of these systems in the successful operation of the DDS. Although mechanical and electrical failures can upset the operation of the DDS, recovery is normally rapid provided that prolonged periods of shut-down are not experienced. When breakdowns or maintenance required that the operation of the aerobic reactor had to be suspended for periods of one hour or shorter, minimal foaming occurred when full operation was resumed and recovery was rapid. For-shut down periods longer than one hour, foaming similar to a start-up operation occurred and the oxygen supply had to be throttled to avoid loss of reactor contents through foam overflow. As foaming subsided, oxygen supply was increased to normal. The recovery rate of the aerobic reactor after prolonged periods of shut-down was found to be related to the length of the inactive period and the temperature of the reactor contents. The longer the shut-down period and the colder the reactor contents, the longer the recovery rate.

4.5 COMPATIBILITY

An important aspect which should be evaluated is the compatibility of the DDS with other processes in a wastewater treatment works.

The experience with dual digestion, both in South Africa and abroad, has shown that the DDS can be incorporated within an existing works with the minimum of disruption or alterations to the existing processes.

The most common method of establishment is to install a small aerobic reactor immediately before existing anaerobic digestors. The space required for the aerobic reactor and its equipment is minimal, and the alterations to pipework to incorporate the aerobic stage are also normally minimal. Apart from minor amendments to the sludge treatment facilities of a works, no other part of a wastewater treatment works are affected.

The equipment necessary for the DDS, together with spares and maintenance requirements, are all similar to what would normally be required at any wastewater treatment works. No new demands would therefore be placed on existing operations. The level of skill required to operate the DDS lies, in fact, at the lower operator's level.

4.6 OPERATING COSTS AND OPTIMISATION OF THE DDS

4.6.1 RECURRING RUNNING COSTS

The major cost item for the treatment of sewage sludge through the Dual Digestion System is associated with the energy requirements. Oxygen is needed for the autothermal reactions in the aerobic reactor, while electrical power is required to ensure transfer of oxygen to the sludge, as well as for mixing of both the aerobic and anaerobic digestors. Estimates of cost, based on pure oxygen and power supplied to the DDS at Milnerton under steady state conditions, are set out in Table 8.

TABLE 8 : RUNNING COST OF THE DUAL DIGESTION SYSTEM WITH PURE OXYGEN AT MILNERTON

AVERAGE VALUES	1988	1989
Operating temperature °C	60	60
Retention period days	1,25	1,5
Volume sludge treated (m^3/day)	36	30
Solids treated at 40 g/l (ton/day)	1,44	1,2
Oxygen supplied (Kg/m^3)	13,3	11,9
Power supplied (kWh/m^3)	14,3	17,2
Cost of oxygen per cub.m.treated	R 3,99	R 3,57
Cost or power per cub.m. treated	R 1,43	R 1,72
Total cost per wet cubic metre	R 5,42	R5.29
Cost per dry ton solids	R135,50	R132,25

(Power taken as 10c/kWh, Oxygen as 30c/Kg)

The major portion of the total running cost, approximately 90%, can be attributed to the operation of the aerobic reactor for the supply of oxygen and electrical power consumed for recirculation pumping and mixing purposes. The objective of the aerobic phase of the system is to pasteurise the sludge, and volatile solids removal is therefore minimal. Treatment costs should preferably be expressed per wet cubic metre of sludge treated rather than dry solids, bearing in mind that the bulk of the energy and oxygen is consumed in order to raise the temperature of water to thermophilic temperatures.

4.6.2 COMPARISON OF RUNNING COSTS

A comparison of the running costs of the Milnerton DDS plant (pure oxygen) with the DDS of Cape Town (air) as well as the Zimpro wet oxidation sludge treatment plant at Milnerton provided the information set out in Table 9.

TABLE 9 : COMPARISON OF RUNNING COSTS FOR ZIMPRO AND DUAL DIGESTION SLUDGE TREATMENT PLANTS

PARAMETER	ZIMPRO, MILNERTON	DDS, MILNERTON	DDS, CAPE TOWN
Operating temperature °C	180	60	50
Oxygen supply	air	pure oxygen	air
Process time (minutes)	15	-	-
Retention period:			
Aerobic (days)	-	1,5	4,6
Anaerobic (days)	-	20	25
Power used (kWh/m^3)	14,4	17,2	16,25
Diesel fuel used (l/m^3)	3,84	-	-
Oxygen used (Kg/m^3)	-	11,9	-
Running costs per m^3	R5,13	R5,29	R1,63
(Power taken as 10c/kWh, Fuel 96c/l, Oxygen 30c/Kg)			

When comparing the costs set out in Table 9, cognisance must be taken of the following:

* Unless the oxygen transfer efficiency of the oxygenation system can be improved to achieve thermophilic temperatures (50 to 60°C) during winter times, the DDS with air will probably classify as a treatment process which produces a Class B sludge in terms of the guidelines for the use of sewage sludge with its associated disposal options.

* The DDS with pure oxygen is able to achieve high temperatures, and findings indicate that it could probably be classified as a treatment process which can produce a type C or D sludge.

* The Zimpro plant is able to produce a type C or D sludge which dewaters extremely well.

* Only running costs associated with energy and oxygen consumption have been considered. A full cost comparison would have to include costs associated with capital requirements, personnel and maintenance and would be very specific to the application site. Such a detail costing exercise would be beyond the scope of this evaluation.

* The benefits associated with methane production have not been taken into account. The longer retention time of the DDS aerobic phase with air requires that a large proportion of the volatile solids have to be oxidised in order to generate heat, and the methane production in the anaerobic digestor is therefore lower that of than the DDS with pure oxygen.

4.6.3 DESIGN AND OPERATIONAL ASPECTS WHICH PLAY A ROLE IN RUNNING COSTS

4.6.3.1 The typical heat balance

The kinetics of the aerobic phase of dual digestion revolve around a heat balance which incorporates all the relevant factors which influence the operating parameters. Such a heat balance has been developed through the research at Milnerton (Messenger, *et al* ,1991b) and is given in Table 10.

As the oxygen and energy consumed by the aerobic reactor are the major cost items for treating sludge with the Dual Digestion system, it stands to reason that the efficient use and preservation of energy will be the prime objectives in order to keep costs to a minimum.

A number of aspects play a significant role in the efficiency of the aerobic process and consequently in the running costs.

4.6.3.2 Operating temperature of the aerobic reactor

An operating temperature in or the thermophilic range (50°C to 60°C) is required to ensure that pasteurisation takes place in the aerobic reactor. A temperature of 60°C would require a 2 hour residence time in order to produce a pasteurised sludge, while a temperature of 70°C would require a 30 minute residence time.

An operating temperature which is higher than necessary to achieve pasteurisation would require more oxygen, as more biochemical heat would be needed to heat the sludge from feed temperature to the reactor operating temperature and running costs would increase accordingly.

TABLE 10 : HEAT BALANCE FOR THE AEROBIC REACTOR OF THE DUAL DIGESTION SYSTEM

HEAT IN = HEAT OUT

$H_{\text{BIOCHEMICAL}} + H_{\text{MECHANICAL}} = H_{\text{LOSS IN SLUDGE OUT}}$
$+ H_{\text{LOSS IN SATURATED VENT GAS}}$
$+ H_{\text{LOSS IN TANK WALL AND PIPEWORK}}$

$H_{\text{BIOCHEMICAL}} = H_{bi} = Y_H.OTR.V_p$

$H_{\text{MECHANICAL}} = H_{mi}$ = 90% of mixing pump output

$H_{\text{LOSS IN SLUDGE OUT}} = V_p/R_H.D_sC_p(T_{se} - T_{si})$

$H_{\text{LOSS IN SAT. VENT GAS}} = a.(OTR.V_p)/(32.OTE).[C_{pg}(T_{ge} - T_{gi}) + h_{fg}.18(P_W/P_{dg})$

$H_{\text{LOSS IN TANK WALL AND PIPEWORK}} = H_{WE}$ = 20 MJ/h for Milnerton system

WHERE :

Y_H = Specific heat yield of the sludge (MJ/Kg O utilised)
OTE = Oxygen transfer efficiency = OTR/OSR
OTR = Oxygen transfer rate (kg O/h)
OSR = Oxygen supply rate (kg O/h)
R_H = Hydraulic retention time (days or hours)
V_p = Operating volume of reactor (m^3)
T_{se} ; T_{si} = Temperature of effluent and influent sludges (°C)
C_p = Specific heat of sludge = 4,184 MJ/(ton.°C)
D_s = Density of sludge = 1,0 (ton/m^3)
a = 4,79 for air ; 1,0 for pure oxygen
C_{pg} = Specific heat of dry vent gas
T_{ge} ; T_{gi} = Temperature of effluent and influent gas (°C)
h_{fg} = Latent heat of vent gas water vapour = 2,358 MJ/Kg
P_W = partial pressure of saturated water vapour at T_{ge} (mm Hg)
= $10^{[8,896 - 2238/(T_{ge}+273)]}$ mmHg
P_T = Total vent gas pressure (mm Hg) = 760 mm Hg at coast.
$P_{dg} = P_T - P_W$ = Partial pressure of dry vent gas (mm Hg)

4.6.3.3 Oxygenation system

The type of oxygenation system plays an important role in the efficiency of the aerobic reactor. The oxygenation system has an oxygen transfer efficiency (OTE) which depends on the oxygen supply rate (OSR), which is the rate at which oxygen is supplied to the system, and the oxygen transfer rate (OTR), which is the rate at which the system transfers oxygen to the sludge. The OTR depends on the type of equipment used to introduce and disperse the oxygen (either from pure oxygen or from air) and has an OTE associated with every OTR (OTE = OTR/OSR). The OTE of a system will decrease as the OSR increases.

An oxygenation system with a low OTE will require large volumes of pure oxygen or air in order to transfer a given mass of oxygen to achieve the desired biological heating. The oxygen or air not transferred escapes as vent gas which may account for considerable heat losses from the aerobic reactor as these gases are saturated with water vapour.

The high cost of oxygen requires that a DDS utilising pure oxygen makes use of an oxygenation system with a high OTE. The Vitox oxygenation system used at the Milnerton DDS plant was able to achieve OTE's ranging between 80% at high OSR (0,44 kg $O/m^3.h$ during short retention times of 1 day in aerobic reactor) to 100% at low OSR during long retention times of 3 days.

Where air is used to provide the oxygen for the autothermal reactions in the aerobic reactor a lower OTE is acceptable as the supply cost of the system is not such a critical factor. Low OTE of a system utilising air could, however, result in large volumes of gas (nitrogen and unused oxygen) passing through the sludge in the reactor unit. Apart from cooling the sludge body, these gases are vented and, because they are saturated with water vapour, this results in high heat losses in the system. Experience at the Cape Town DDS which utilised air with an oxygenation system of coarse-bubbles diffusers inside the aerobic reactor, has indicated that OTR's ranging from 0,12 to 0,19 $kgO/(m^3.h)$ and averaging around 0,14 $kgO/(m^3.h)$ with OTE's ranging from 0,09 to 0,23 can be expected of this system (Pitt, 1990).

During short retention times in the aerobic reactor, high air flows had to be maintained due to the low OTE of the oxygenation system. This resulted in high heat losses through vent gas and foam generation and a decrease in the operating temperature of the aerobic reactor. The result is that a longer retention period had to be adopted in order to obtain thermophilic temperatures.

4.6.3.4 Retention period in the aerobic reactor

A short retention time in the aerobic reactor requires a tank of small capacity and therefore capital requirements. The aim is therefore to obtain the shortest possible retention time in the aerobic reactor. The minimum retention time is directly related to the maximum biological oxygen utilisation rate, OUR_{bio}.

For the Milnerton sludge, which was a mixture of primary and humus tank sludge, the OUR_{bio} was measured around 0,38 kg $O/(m^3.h)$ at a VS concentration of 30 kg/m^3. For different sludges this value can be expected to vary, but by how much is uncertain at present. The maximum biological heat generation rate is limited by the sludge's OUR_{bio} through the specific heat yield Y_H of 13 MJ/kg O utilised, which in turn fixes the minimum retention time. These relationships are only valid for as long as the oxygenation system can transfer the required mass of oxygen to the liquid. This entails that OTR should be at least as high as OUR_{bio}. If $OTR < OUR_{bio}$, the OTR of the oxygenation system will set the minimum retention time in the aerobic reactor.

By reducing the retention period in the aerobic reactor, heat losses through sludge transferred to the anaerobic digestor increase accordingly. This heat loss has to be compensated for by heat generated through biological reactions. The maximum amount of heat that can be generated by the biomass is, however, determined by the OUR and the specific heat yield of the sludge. When the retention period is decreased beyond the point where the biomass can generate sufficient heat to balance heat losses, the reactor temperature will start to decrease.

If more oxygen is supplied in an attempt to increase the reactor temperature, the OTR would increase above the maximum OUR_{bio} of the sludge, and the vent gas and water vapour heat loss will increase due to the increase in unused oxygen. A decline in reactor operating temperature can be expected.

Experience at the Milnerton plant indicated that, at a maximum OUR of 0,38 kg $O/(m^3.h)$ and a heat yield of 13 MJ/(kg O utilised), a minimum retention period of 1,25 days for the aerobic reactor, could be sustained by the system.

4.6.3.5 Temperature of the raw feed sludge

The major part of energy input into the DDS goes into raising the temperature of incoming raw sludge. The temperature of the feed sludge will determine the total amount of oxygen required to generate biological heat.

Experience at the Milnerton DDS plant indicated that the warmer feed sludge during summer required approximately 25% less oxygen to achieve the same operating conditions as in winter, when feed sludge temperatures were lower. Results were obtained from accurate process modelling for oxygen and power consumption at steady state conditions using different feed sludge temperatures, and the effect of these variations on running cost are given in Table 11. The running cost during the summer months was on average about 17% lower than that for winter months as a result of the higher feed sludge temperature. The running cost also does not vary much with retention time. Retention time has therefore more influence on capital cost than running cost.

At the Cape Town DDS plant, problems were experienced in that thermophilic operating temperatures could not be maintained in the aerobic reactor during winter months. Because of the low OTE of the oxygenation system, sufficient heat could not be generated through autothermal reactions to make up for heat losses and also to raise the cold feed sludge to the desired temperature. The result was a decline in reactor temperature, even at extended retention periods of up to 5 days.

TABLE 11 : PURE OXYGEN DUAL DIGESTION SYSTEM AT MILNERTON - THE EFFECT ON OXYGEN AND POWER CONSUMPTION IN THE AEROBIC REACTOR BY DIFFERENT FEED SLUDGE TEMPERATURES

CONDITION 1:	Feed sludge temperature = 18°C , Reactor temperature = 60°C Volitile solids applied = 29,8 g/l				
RETENTION (DAYS)	OXYGEN SUPPLY RATE (Kg/h)	OXYGEN TRANSFER EFFICIENCY (%)	Kg OXYGEN PER CUB.M.	kWh PER CUB.M.	COST PER CUB.M. SLUDGE TREATED
1,0	27,5	81%	14,6	11,1	R5,49
1,25	20,0	87%	13,3	13,9	R5,38
1,5	15,0	94%	12,0	16,7	R5,27
3,0	5,0	100%	8,0	33,3	R5,73
CONDITION 2:	Feed sludge temperature = 26°C , Reactor temperature = 60°C Volitile solids applied = 29,8 g/l				
RETENTION (DAYS)	OXYGEN SUPPLY RATE (Kg/h)	OXYGEN TRANSFER EFFICIENCY (%)	Kg OXYGEN PER CUB.M.	kWh PER CUB.M.	COST PER CUB.M. SLUDGE TREATED
1,0	21,0	83%	11,2	11,1	R4,47
1,25	14,7	92%	9,8	13,9	R4,33
1,5	11,2	97%	9,0	16,7	R4,37
3,0	3,4	100%	5,4	33,3	R4,95
	Cost of oxygen = 30c/Kg ; Cost of power = 10c/kWh				

If the temperature of the raw feed sludge could be raised by external preheating and maintained at a high level, for example by burning the methane produced by the anaerobic digestor, running costs of the DDS with pure oxygen could be reduced considerably while the DDS with air would probably be able to maintain thermophilic temperatures in the aerobic reactor more readily.

4.6.3.6 Mechanical heat input

Much of the electrical power required to mix and oxygenate the aerobic reactor sludge can contribute directly to heating the sludge. The type of oxygenation system, however, would play a major role in the quantity of heat transferred.

With the Vitox oxygenation system used at the Milnerton DDS plant it was found that approximately 90% of the power output of the mixing and oxygenation pump contributed directly to heating the sludge. This formed a significant portion of heat sources, approximately 24% at 1,25 day and 42% at 3 day retention times respectively (Messenger, *et al*, 1991a).

The mechanical heat input by the oxygenation system at the Cape Town DDS plant contributed about 25% to the total heat sources (Pitt, 1990) as much of the electrical power was consumed by air compressors, and heat transfer to compressed air was very low.

4.6.3.7 Heat loss to surroundings

The heat loss to surroundings can be minimised by providing sufficient insulation and lagging to the aerobic reactor, mixing and recirculation pipework. The heat input required to compensate for the heat loss to the surroundings would then also be small. A heat loss to the surroundings of 20 MJ/h was measured at the Milnerton plant (Messenger, *et al*, 1991a).

4.6.3.8 Heat loss through vent gas and water vapour

At both the Milnerton plant (pure oxygen, Messenger, *et al.*, 1990, 1991b) and Athlone plant (air, Pitt, 1990) it was found that vent gas was saturated with water vopour as it left the aerobic reactor. Although the sensible heat loss through vent gases alone is relatively small, the heat loss due to the latent heat of vapourised water in the saturated vent gas can be significant.

With oxygenation systems which have low OTE's, and especially when air is used, the vent gas flow would tend to be high and heat losses through water vapour could be as high as 36% of total heat loss (Pitt, 1990). Oxygenation systems with a high OTE and utilising pure oxygen have heat losses through vent gas and water vapour only between about 1 and 2% (Messenger, *et al*, 1991a).

CHAPTER 5

ASPECTS TO CONSIDER FOR IMPLEMENTATION

5.1 ACCEPTANCE OF THE TECHNOLOGY

The DDS is a treatment process for sewage sludge pasteurisation and stabilisation not yet adopted for full-scale implementation in South Africa. However, the experience in the USA and the wide adoption of the process in Europe in an endeavour to improve on the quality of treated sewage sludge formerly derived from anaerobic digestion, are sure indications that the process has definite potential for acceptance and implementation locally.

Results obtained during research, both at pilot-scale level at the Johannesburg plant and full-scale level at the Milnerton plant (with pure oxygen) and the Cape Town plant (with air), have provided adequate evidence that the technology of dual digestion qualifies for acceptance as a feasible process for sewage sludge treatment in South Africa. Sufficient experience has been gained and detailed analyses have been carried out to design the process and predict with a high degree of confidence the behaviour of the system under a relatively wide range of operating conditions.

The process of dual digestion cannot be applied indiscriminately to all possible applications, nor can it be summarily disregarded as a feasible option for sludge treatment. As with any other sewage sludge treatment process, many aspects have to be considered and taken into account before dual digestion can be accepted and implemented in practice.

The experience with dual digestion thus far has been with a mixture of primary and secondary sludges from biofilters or waste activated sludge. It was found that these mixtures of sewage sludge could be handled by the DDS. Waste activated sludge from an extended aeration plant where primary sludge is absent, has not as yet been tested. The low volatile solids content of the sludge may well result in an OUR which will be too low to sustain autothermal reactions and to maintain thermophilic temperatures in the aerobic reactor. Until research has been conducted, the DDS should not be considered as treatment option for only waste activated sludge from extended aeration plants.

Although the majority of DDS plants have been constructed at facilities where anaerobic digestion of sewage sludge has been practised, it does not rule out the possibility that the system could be considered for implementation on a 'green field' site. The practical implications and economics of the process could be evaluated and weighed up against those of other treatment processes.

5.2 LEVEL OF TECHNOLOGY

Notwithstanding the complexity of the theory and technology behind the development of the DDS, operation of a dual digestion plant is relatively easy and simple. Only relatively low-level skills are required to operate a basic dual digestion plant. It would therefore be sound practice to ensure that the level of technology used in the equipment and controlling devices for a full-scale plant be appropriate and compatible with those which can readily be accommodated by the existing infrastructure for operation and maintenance. At the one end of the scale, a dual digestion plant can be designed to be extremely sophisticated by applying very modern and high technology equipment while at the other end it could be provided with the most basic controls.

A small wastewater treatment works where running costs are not that critical, could have a simple system with limited controls which are orientated towards manual operation. A large treatment works, on the other hand, which has an existing infrastructure which can handle high technology equipment, and where running costs would be critical due to the volume of sludge involved, could make use of computerised systems in order to automate the process to a large degree.

5.3 DESIGN ASPECTS

5.3.1 PROCESS DESIGN AND KINETICS

The objective of the system is to pasteurise and stabilise sewage sludge to levels which will allow it to be classified as a Type C or D sludge in terms of the guidelines for usage (Vivier, *et al*, 1988). To enable the system to achieve these objectives , a number of design aspects are important.

5.3.1.1 Aerobic reactor

* Sludge in the aerobic reactor must be exposed to a temperature of over 60°C for a minimum period of 2 hours or a temperature of 70°C for a minimum period of 30 minutes to ensure pasteurisation.

* For the design of the aerobic reactor, the heat-balance equation set out in Table 10 can be solved by assuming a steady state condition. A detailed description of the derivation of the equation and its terms, as well as a simulation model and computer programme which have been developed as part of the research programme, are described in PART 2 of the research report (Messenger, *et al*, 1991b).

* The maximum heat generated by the biological activity of the sludge depends on the specific heat yield of the sludge (Y_H) and the sludge's maximum oxygen utilisation rate (OUR_{bio}). The following values have been determined for a mixture of primary and humus tank sludges:

  Y_H = 12,8 MJ/kgO (for VS of 30 g/l, Milnerton)
  Y_H = 13,6 MJ/kgO (for VS of 36,8 g/l, Cape Town)
  OUR = 0,38 kgO/(cub.m per hour, for VS of 30 g/l at Milnerton).

A reliable method for estimating the OUR of a sludge has not yet been developed. Pilot-scale trials should for the time being be used to measure the OUR of different sludges. For most designs, however, a value for Y_H of 13,0 may be used.

* The sludge concentration play an important role in the heat generation by the biomass. It is possible that a low solids content will result in a low OUR which will reduce the metabolic rate and therefore the heat generation of the biomass per m^3 sludge volume. The heat generation rate could therefore be less for a thin sludge. To ensure reactor stability, a uniform sludge thickness is preferable with a solids content of 4 to 8 %.

* The unit treatment cost of the DDS lies in the volume of sludge to be treated, not the mass of dry solids to be treated. The more concentrated the sludge, the more sludge mass is treated per m^3 sludge volume and it would therefore be desirable to treat sludge with as high a concentration as possible.

* The oxygenation system for the aerobic reactor can utilise air, pure oxygen or a mixture of both. As the oxygenation system directly controls the amount of heat generated by the biomass in the aerobic reactor, it is important that this system should be able to transfer sufficient oxygen to achieve and maintain pasteurisation temperatures. For this reason it is preferred that the oxygenation system has a maximum oxygen transfer rate (OTR) which is larger than the maximum OUR (OUR_{bio}) of the sludge.

* For proper control of the temperature in the aerobic reactor, and in order to ensure that adequate conditioning of the sludge occurs within the aerobic phase, the system should operate at an OTR below the maximum OUR of the sludge, that is under oxygen limiting conditions.

* The OTR and oxygen transfer efficiency (OTE) of an oxygenation system, whether it be pure oxygen, air or a mixture of the two, is entirely dependent on the characteristics and type of oxygenation system, as well as on the geometry of the reactor.

The OUR_{bio} of the sludge and the OTR and OTE of the oxygenation system need to be known and well defined so as to ensure that the rate of biological heat generated can be predicted. It is important that, for both economical and practical reasons, an oxygenation system be adopted which has as high an OTE as possible. Two different types of oxygenation systems have been used in South Africa and their respective transfer efficiencies are the following:

- The Vitox system with pure oxygen as used by Milnerton at the Potsdam plant was able to achieve very high OTE's and OTR's. An OTE of 0,8 was achieved at retention periods of 1,25 days, while a value of 1 was obtained for retention periods of 3 days.(Messenger, *et al*, 1991a).
- A coarse-bubble aeration system with air as used by Cape Town at the Athlone Treatment Works produced an OTE of 0,09 at a 3 day retention and an OTE of 0,23 at a 6 day retention period, averaging at an OTE of 0,125. It was found that the OTR of this system was inadequate to maintain reactor temperatures during winter months due to the low OTE.

The heat loss in a system using pure oxygen is principally through the hot effluent sludge (80 to 90%) while the heat losses for a system using air is through the both hot sludge (average 59 %) and the saturated vent gas (36%). The high vent gas losses are due to the lower OTE of air oxygenation systems. It would be possible to improve on the OTE of a air oxygenation system by using equipment with a higher oxygen transfer rate for the same air supply rate, or by enriching the air with pure oxygen either by direct addition or through the application of adsorption technology.

* The OTE of the oxygenation system and the characteristics of the sludge to be treated will determine the size of the aerobic reactor. Experience has shown that for an oxygenation system using pure oxygen and treating sludges which have characteristics similar to those of Milnerton, a reactor which can accommodate a retention period between 1,25 and 2 days will be required. For an oxygenation system similar to the Cape Town system which utilises air, and for sludges of a similar nature, an aerobic reactor which can accommodate retention periods between 3 and 6 days will be required. The greater OTR and OTE, the shorter the required retention time.

* Energy conservation in the aerobic system of the DDS is critical to the economics of the process and provision for adequate insulation and lagging of the aerobic reactor and pipework should be made in the design phase. The mechanical heat available from the pumping plant should be utilized as a heat source to its fullest extent.

5.3.1.2 Anaerobic Digestor

* The design aspects associated with the anaerobic digestor for the DDS are similar to those of a conventional high-rate, heated anaerobic digestor operating at mesophilic temperatures of 35°C to 39°C. Adequate mixing has to be provided and methane draw off would be as normal.

* The digestor contents is maintained at mesophilic temperatures by means of the hot sludge which is transferred from the aerobic reactor. The Milnerton experience indicated that no additional heating of the digestor contents is necessary. In summer, however,

cooling of the sludge was required to avoid digestor overheating. Whether or not cooling in summer or additional heating in winter is required will depend entirely on the heat losses from the digestor.

* As the methane produced by the digester is not required to heat the sludge, provision must be made either to burn the methane off, or to use it in a combustion machine for the generation of power or heat.

5.3.1.3 Exploitation of heat sources for optimisation of the DDS

* The dependence of the DDS upon aerobic biological heat generation can be greatly reduced by heating the raw feed sludge. A preheated feed sludge would require less energy to maintain operating temperature in the aerobic reactor. Lower gas flows will then be required which in turn reduce the heat loss through vent gas, and also reduce the running cost of the system.

* One source of energy which could be used to heat feed sludge is heat exchange between the hot reactor effluent sludge and the cold reactor feed sludge. This source will most likely only be available during summer months when ambient temperatures are high and digestor wall heat losses are low. During winter the full heat of the pasteurised sludge may be required to maintain mesophilic temperatures in the anaerobic digestor unless the anaerobic digester is adequately insulated. Another drawback of this heat source is that it is intermittent due to the batch feeding system of raw sludge which is used to avoid short-circuiting and recontamination of pasteurised sludge.

* A further more consistent and continuous source of energy is the methane produced by the anaerobic digestor. The methane could be used to generate heat or power by means of which the temperature of the raw sludge could be raised.

5.3.2 Practical considerations

* The sludge normally obtained from primary and secondary sedimentation requires thickening before treatment. A sludge with a high concentration of solids is likely to have a higher OUR than a sludge with a low concentration and will therefore increase the rate of biological heat generated. The volume of sludge to be treated will also be reduced if it is thickened. Feed sludge thickening is therefore of primary importance to the economics of DDS.

* Although not essential, it would be advisable to screen raw sludge or macerate it so as to prevent blockages of pumps and pipework.

* In order to avoid recontamination of pasteurised sludge, the switchgear and controls must be designed in such a manner as to allow a batch feeding system with the draw off of the treated sludge from the aerobic reactor first being carried out first before the raw sludge is fed into the reactor.

* The efficient operation of the DDS depends primarily on the type of controls built into the system. A small DDS can be controlled manually provided that temperature gauges and air/oxygen flow meters are provided at critical points. Larger DDS plants can be provided with continuous recorders which will record all operational aspects (liquid levels, gas and liquid flows, power consumption and temperatures) right throughout the plant. Control could then be centralised or even automated.

* The successful operation of the plant depends largely upon the reliability of mechanical plant. Standby equipment or backup systems should be provided wherever possible. This is extremely important for the recirculation system which forms the heart of the aerobic process.

* No special allowance has to be made for foam in the aerobic reactor when pure oxygen is being used, and a minimum freeboard above the liquid level will be adequate. However, for a system where air is used, sufficient space must be allowed above the sludge liquid level to accommodate a permanent foam layer. The depth of this foam layer would depend on the OTR and OTE of the oxygenation system. No information is yet available to assist in determining the depth of the layer, but the DDS plant at Cape Town made allowance for a 3m deep foam layer in their aerobic reactor, and this appears to have been adequate under normal operating conditions.

* Provision may have to be made to scrub vent gas from the aerobic reactor so as to avoid unpleasant odours.

* Care must be taken in the specification and selection of materials, pipework and pumping plant for the handling of high temperature sludges having an abrasive nature.

* Adequate attention should be given to safety aspects with respect to potentially hazardous situations arising from methane and oxygen mixtures, and from the handling of hot sludges.

5.4 FINAL DISPOSAL OF END PRODUCT

The DDS does achieve its objective in that it produces a sludge which is well stabilised, does not cause odour nuisances or attract flies, and is pasteurised to the extent that all viable *Ascaris Ova* are eliminated. *Faecal coliforms* are reduced by up to 9 orders of magnitude by a DDS utilising pure oxygen (Messenger, *et al*, 1991a).

The sludge produced by the pure oxygen DDS complies with the requirements of the "Guidelines for the use of sewage sludge" issued by the Department of Health and Population Development to be classified as a Class C or D sludge, except for the characteristic with respect to *faecal coliform* count. The *faecal coliform* count of the treated sludge exceeds the prescribed maximum of 10 organisms per 100g dry sludge immediately after pasteurisation. When the opportunity for regrowth of *faecal coliforms* in the anaerobic digestor, and subsequent sludge dewatering before final disposal is considered, a case could be made out for a more practical approach to the classification of the sludge.

If some other parameter for the degree of pasteurisation could be negotiated, it would be possible to classify the sludge produced by a dual digestion system as a Type C or even Type D sludge. The options for final disposal of the sludge, especially in terms of re-use, would be broadened considerable from the much more restricted use for a Type B sludge, this being the classification of conventionally anaerobically treated sludge.

The characteristics of the dual digested sludge with respect to dewaterability rule out any form of filtration of the final product. Centrifugation would be the most effective form of mechanical dewatering, while conventional drying beds would offer an alternative. As a result of the excellent settling properties of the treated sludge, gravity thickening, as applied in Europe, could be a feasible option to reduce the volume of sludge before dewatering.

Other options for final disposal of the sludge in dewatered form could include application as fertiliser or additive to natural compost.

5.5 ECONOMIC EVALUATION

The DDS is a relatively simple sludge treatment process which requires only basic facilities in the form of two sludge holding tanks of different size and a set of mechanical equipment to drive the process. While the basic system will be adequate for a small sewage treatment works producing small quantities of sludge in a rural area, a large works within the urban environment will require more sophisticated equipment for control and optimisation of the process operation and running costs.

The costs associated with the DDS will depend on individual applications. The objectives and requirements, as well as the unit cost of treatment, could differ significantly between plants, this stemming from differences in existing treatment facilities and also the varied nature and characteristics of the sludge to be treated. An economic evaluation of the DDS will therefore be specific to a particular site.

Aspects which play a role in the capital requirements and operating costs, and which have to be considered during an economic evaluation of the DDS, are set out in Table 12. The requirements for two types of Dual Digestion Systems are listed to illustrate that the approach towards the design and operation of the system could differ between plants. Each of the two types of DDS plants represents a typical level of wastewater treatment associated within the South African environment and could be defined as follows:

High performance DDS :

This is a DDS which would be installed at a medium to large waste water treatment works which is normally located in larger urban areas. The volume of sludge to be treated requires cost effective systems with a high degree of efficiency. A source for pure oxygen, spares and back-up service for mechanical plant would be readily available. Trained and skilled personnel is available at the plant

Low performance DDS :

The low performance DDS would be installed at the smaller wastewater treatment works which is located at a small town. Operating costs are not critical due to low sludge volumes involved, but capital resources as well as trained and skilled staff are limited.

TABLE 12 : ASPECTS TO CONSIDER FOR ECONOMIC EVALUATION OF THE OF THE DUAL DIGESTION SYSTEM

ITEM	HIGH PERFORMANCE DDS	LOW PERFORMANCE DDS
CAPITAL REQUIREMENTS		
Civil construction:		
Additional raw sludge thickening	Required	-
Aerobic reactor	Required	Required
Anaerobic reactor	Required	Required
Treated sludge gravity thickening	Optional	Optional
Sludge drying beds	-	Optional
Mechanical plant and associated pipework:		
Screening/maceration of raw sludge	Required	Optional
Pumping plant to transfer sludge	Required	Required
Mixing system for aerobic/anaerobic	Required	Required
Heat exchanger to heat raw sludge	Required	-
Methane burner	-	Required
Combustion engine to utilise methane	Required	-
Centrifuge for dewatering of sludge	Required	-
Oxygenation equipment:		
Oxygen transfer efficiency requirements	High	Medium to low
Air compressors		
Pressure swing adsorption systems	The equipment can be used	
Gas separators for oxygen enrichment of air	individually or in combi-	
Pure oxygen storage systems	nation depending on the	
Oxygen injection systems	the site and the characte-	
Aerators, diffusers	ristics of the sludge	
Mass transfer devices for oxygen transfer		
Control equipment:		
Electrical switchgear for mechanical equipment	Required	Required
Liquid flow meters	Required	-
Gas flow meter for oxygen/air	Required	Required
Gas flow meter for aerobic reactor vent gas	Required	-
Gas flow meter for methane/biogas	Required	-
Temperature gauges	Required	Required
Temperature/flow recording (continuous)	Required	-
Automatic control via computerised systems systems	Required	-
Specialised laboratory equipment	Required	Optional
OPERATING ASPECTS		
Electricity cost	Plant dependent	
Pure oxygen cost	Plant dependent	
Personnel requirements for operation and maintenance	Highlevel training	Lowlevel training
FINAL DISPOSAL OF SLUDGE		
Landfill	Optional	Optional
Land application as solid or liquid fertiliser	Optional	Optional

CHAPTER 6

CONCLUSIONS

The research and experience with the DDS have eliminated a number of uncertainties with respect to the adoption and implementation of this technology in South Africa. It was established that the DDS is capable of achieving treatment objectives which will render a very high quality end product. An odourless, well stabilised sludge is produced after volatile solids and COD have been reduced by more than 50%. The sludge will be free of viable *Ascaris Ova* and *Faecal Coliforms* will have been reduced significantly if the required thermophilic conditions are met. No *Salmonella* could be detected in the sludges used during the research, and the destruction potential of DDS on this pathogen, is therefore still unknown. Despite the absence of data on *Salmonella* and the regrowth potential of *Faecal Coliform* in the anaerobic digestor and sludge dewatering facilities, there is a very strong case for regarding the final product from the DDS as Type C sludge in terms of the "Guidelines for the use of sewage sludges". If a raw sludge with a low heavy metal content is treated, a Type D sludge will be obtained.

The DDS is a very reliable process which is easy to operate and very responsive to control. The aerobic stage is predictable in terms of heat balance and oxygen utilisation, is very stable in operation and protects the anaerobic digestor against shock loads. It also assists the anaerobic digestor's performance through solubilisation of the organic compounds in the sludge and by raising the pH and alkalinity of the sludge. It also provides adequate heat for the anaerobic digestor to operate at its optimum temperature.

The treated sludge has a very fine consistency and, although it settles well under gravity conditions, it resists dewatering by any type of filtration method. It displays dewatering characteristics similar to that of conventional anaerobically digested sludge and could therefore be expected to behave similarly on drying beds. The best means of mechanical dewatering is by centrifugation after the addition of char and polyelectrolyte to produce an end product with a solids content of around 20%.

The DDS itself makes use of simple and low level technology. The process requires no high-level skills or expertise to operate provided the necessary control equipment is provided. The level of technology used in the mechanical plant and control equipment would depend entirely on the specific site and can be chosen to suit the local infrastructure. From simple low-level technology which could be maintained with a relatively low-level skilled work force available in the rural areas, the level of sophistication can be increased to fully automated systems which are more applicable to an environment where the skills and expertise to maintain the hardware and software are available.

Research has shown that the mechanical and electronic control equipment used in the DDS are vitally important to the successful operation of the process. The use of reliable plant which is compatible with the maintenance support and services available, adequate standby facilities and a properly managed preventative maintenance programme is an important aspect to reduce risks of failure to the system.

The DDS can be designed with the aid of parameters and guidelines obtained from the research done in South Africa and outlined in this 3 part report . The system can be installed in the sludge treatment facilities of an existing sewage treatment works with the minimum of disruption and alterations.

The overseas' claims of a 1 day retention in the aerobic reactor and a 10 day retention in the anaerobic digestor could not be substantiated through the South African research. It was found that the minimum retention period in the aerobic reactor is determined mainly by two factors. The one is the characteristics of the sludge in terms of its OUR and the other the OTE of the oxygenation system. With pure oxygen and an oxygenation system which has an OTE of 80%, and a sludge with an OUR of 0,38 KgO/(m^3.h), a minimum retention period of 1,25 days can be achieved. A similar sludge but with an oxygenation system using air and with an OTE of 0,12 will require a minimum retention period of 3 days to maintain mesophilic temperatures. Although not verified conclusively, research has shown that a minimum retention period of 15 days is required in the anaerobic digestor to maintain steady state conditions.

Due to its flexibility, the capital expenditure necessary to install a DDS may differ significantly between sites. Factors which will influence capital cost and also running cost will be the type of oxygenation system used, the source of oxygen (pure oxygen, air or a mixture) and the level of technology applied in the control equipment. The DDS is a consumer of energy, but at the same time also a producer of energy in the form of methane. This energy source can be very efficiently used to reduce running cost of the plant or for some other purpose. By applying energy conservation methods, it would be possible to have a plant which produces a nett surplus of energy with the added benefit of sludge pasteurisation

A number of constraints have to be taken into account during planning and feasibility studies of DDS's:

* Not all sewage sludges can be treated with the DDS - little information on the use of DDS to treat waste activated sludge from extended aeration plants for instance is available and it would be very risky to attempt this option without research.

* Oxygenation systems using pure oxygen would produce more effective treatment, but pure oxygen is very expensive. An alternative of oxygen enriched air may prove to be more feasible than either oxygen or air only.

* Foam can be expected from oxygenation systems utilising air as oxygen source. Sufficient free board needs to be allowed in the aerobic reactor to accommodate foam.

* Air oxygenation systems with low OTE may experience difficulties in obtaining thermophilic temperatures during the winter months unless the retention time is

sufficiently long. If thermophilic temperatures are not achieved in the aerobic reactor, then, depending on the heat losses from the anaerobic digestor, mesophilic temperatures may not be achieved in the anaerobic digestor without additional heating.

* Recontamination of treated sludge could undo all the efforts of pasteurisation and consequently operational procedures such as batch feeding play an important part in design.

* The poor dewaterability characteristics of the treated sludge has to be considered when determining final disposal options. The quality of sludge that is Type C or D which is higher than that from conventional anaerobic digestion, which is a Type B, offer opportunities for alternative methods of disposal.

* Limited research has been carried out on different sludges to determine their maximum OUR (OUR_{bio}) and the effect of sludge type and solids concentration on the OUR_{bio} of a sludge. This matter will probably receive attention as the demand for DDS grows. The same would apply to the OTR and OTE of different oxygenation systems with various mixtures of air and pure oxygen.

Despite the constraints set out above, sufficient information has been gathered through the research to conclude that the Dual Digestion System could find a position within the sludge treatment field in South Africa. It is a process which has definite merit for consideration in the following cases:

* DDS could be used to upgrade and improve the working of an overloaded anaerobic digester and to improve on the quality of the final sludge product.

* DDS can be installed as a temporary solution and to provide breathing space until alternative sludge treatment facilities are available.

* DDS can be implemented by adding an aerobic reactor to existing anaerobic digestors, or by adding an anaerobic digestor to an existing aerobic sludge treatment plant.

* DDS can be provided as full system and as alternative sludge treatment process.

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ANNEXURE A

CLASSIFICATION OF SEWAGE SLUDGE TO BE USED OR DISPOSED OF ON LAND

TYPE OF SEWAGE ts SLUDGE	ORIGIN/TREATMENT (EXAMPLES)	CHARACTERISTICS/QUALITY STANDARD
TYPE A SLUDGE	RAW SLUDGE COLD DIGESTED SLUDGE SEPTIC TANK SLUDGE OXIDATION POND SLUDGE NIGHT SOIL	* USUALLY UNSTABILISED AND CAN CAUSE ODOUR NUISANCE AND FLY-BREEDING * CONTAIN PATHOGENIC ORGANISMS * VARIABLE METAL CONTENT
TYPE B SLUDGE	ANAEROBIC DIGESTED SLUDGE WITH HEATING SURPLUS ACTIVATED SLUDGE HUMUS TANK SLUDGE	* FULLY OR PARTIALLY STABILISED SLUDGE - NOT CAUSE SIGNIFICANT ODOUR NUISANCES OR FLY-BREEDING * CONTAIN PATHOGENIC ORGANISMS * VARIABLE METAL CONTENT
TYPE C SLUDGE	PASTEURISED SLUDGE HEAT TREATED SLUDGE LIME STABILISED SLUDGE COMPOSTED SLUDGE IRRADIATED SLUDGE FUMIGATED SLUDGE	* CERTIFIED TO COMPLY WITH THE FOLLOWING QUALITY REQUIREMENTS: - STABILISED - SHOULD NOT CAUSE ODOUR NUISANCES OR FLY-BREEDING - CONTAIN NO VIABLE ASCARIS OVA PER 10g DRY SLUDGE - MAXIMUM 1 SALMONELLA ORGANISM PER 100g DRY SLUDGE - MAXIMUM 10 FAECAL COLIFORMS PER 100g DRY SLUDGE IMMEDIATELY AFTER TREATMENT (DISINFECTION/ STERILISATION) * VARIABLE METAL CONTENT NB - IF NOT CERTIFIED, THIS SLUDGE IS CONSIDERED AS A TYPE B SLUDGE
TYPE D SLUDGE	PASTEURISED SLUDGE HEAT TREATED SLUDGE LIME STABILISED SLUDGE COMPOSTED SLUDGE IRRADIATED SLUDGE FUMIGATED SLUDGE	* CERTIFIED TO COMPLY WITH THE FOLLOWING QUALITY REQUIREMENTS: - STABILISED - SHOULD NOT CAUSE ODOUR NUISANCES OR FLY-BREEDING - CONTAIN NO VIABLE ASCARIS OVA PER 10g DRY SLUDGE - MAXIMUM 1 SALMONELLA ORGANISM PER 100g DRY SLUDGE - MAXIMUM 10 FAECAL COLIFORMS PER 100g DRY SLUDGE IMMEDIATELY AFTER TREATMENT (DISINFECTION/ STERILISATION) * MAXIMUM METAL CONTENT IN mg/kg DRY SLUDGE - Cadmium 20 - Cobalt 100 - Chromium 2750 - Copper 750 - Mercury 10 - Molibdenium 25 - Nickel 200 - Lead 250 - Zinc 2750 * USER MUST BE INFORMED ABOUT THE MOISTURE AND N P K CONTENT * USER MUST BE WARNED AGAINST APPLICATION OF MORE THAN 8 t/ha/yr OR 1 kg/10 m^2 (DRY SLUDGE) TO SOIL AND THAT pH OF THE SOIL SHOULD PREFERABLY > 6