TECHNOLOGY / OPPORTUNITY FEASIBILITY REPORT

FINAL

ADDITIONAL SCOPE OF WORK FOR THE ACTIVITY: CONDUCT A FEASIBILITY STUDY FOR A REGIONAL WASTEWATER WORKS FOR THE ILEMBE DISTRICT MUNICIPALITY

Contract No.: VILP/I/017

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Acronyms and Abbreviations

BNR	Biological Nutrient Removal
CAPEX	Capital Expenditure
CHP	Combined Heat and Power
CPG	Contract Participation Goal
CoGTA	Department of Cooperative Governance and Traditional Affairs
COD	Chemical Oxygen Demand
DBSA	Development Bank of Southern Africa
DEA	Department of Environmental Affairs
DME	Department of Minerals and Energy
DoT	Department of Transport
DWS	Department of Water and Sanitation
IDM	iLembe District Municipality
IDP	Integrated Development Plan
IPP	Independent Power Producer
KDM	KwaDukuza Local Municipality
MLM	Mandeni Local Municipality
MLSS	Mixed Liquor Suspended Solids

MPLM	Maphumulo Local Municipality
MTSF	Medium Term Strategic Framework
NLM	Ndwedwe Local Municipality
NT	National Treasury
OPEX	Operational Expenditure
PCU	Vuthela Programme Project Coordinating Unit
PSC	Project Steering Committee
SDF	Spatial Development Framework
SP	Service Provider
SRT	Solids Retention Time
TKN	Total Kjeldahl Nitrogen
ToR	Terms of Reference
WAS	Waste Activated Sludge
WWTW	Wastewater Treatment Works

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1 INTRODUCTION

This report is the Technology / Opportunity Feasibility Report for Contract VILP/I/017 Additional Scope of Work for the Activity: Conduct a Feasibility Study for a Regional Wastewater Works for the iLembe District Municipality. The project forms part of the Vuthela LED Programme (the Programme), which is a collaboration of the iLembe District Municipality, the Switzerland State Secretariat for Economic Affairs (SECO) and the KwaZulu-Natal Department of Economic Development, Tourism and Environmental Affairs (KZN EDTEA). This Technology / Opportunity Feasibility Report addresses the relevant sections of the scope of work as set out in the revised Inception Report Rev 5.

The Vuthela LED Programme footprint comprises the iLembe District Municipality and its local municipalities of KwaDukuza, Mandeni, Ndwedwe and Maphumulo. The primary purpose of the programme is the improvement of the economic future of the iLembe District residents through the sustainable economic growth of the local economy and the creation of higher, better and more inclusive employment and income generating opportunities.

The project falls under the Municipal Infrastructure Component (MIC) of the Programme, which focuses on the improvement and development of municipal infrastructure.

The project scope is the investigation of:

- Options to optimise water and energy efficiencies to inform the design of the KwaDukuza Regional Wastewater Treatment Works (WWTW) as well as future wastewater infrastructure upgrades within the iLembe District Municipality;
- The potential for energy generation from WWTW associated activities, using the KwaDukuza Regional Wastewater Treatment Works as basis for recommendations;
- The potential for water re-use and reclamation, with particular consideration for the sale of treated effluent from WWTW in the iLembe District Municipality, using the KwaDukuza Regional WWTW as a sample;
- The impact of any beneficiation activities on treatment process design and the potential financial impact of implementation thereof.

2 BACKGROUND

The development of a regional wastewater treatment works (WWTW) located in KwaDukuza is included in the Regional Water and Sanitation Master Plan compiled by Messrs Bosch Stemele (Pty) Ltd in June 2016. The project was further adopted for implementation by the iLembe District Municipality in its 2017-2022 Integrated Development Plan, which allocated funding for the initiative over the budget period of 2018-2020 from the Municipal Infrastructure Grant (MIG). The Business Plan for the design and construction of the KwaDukuza WWTW was approved by the Department of Water and Sanitation (DWS) in January 2018 and is currently in the process of fund allocation by the Department of Cooperative Governance and Traditional Affairs (CoGTA).

Shortly following the launch of the Vuthela LED Programme in November 2017, the KwaDukuza Regional WWTW was identified as a possible project for economic beneficiation investigation. Royal HaskoningDHV, as contracted Engineering Services Providers for the design (process, civil, mechanical and electrical design) of the KwaDukuza Regional WWTW, were invited to submit a proposal for the investigation of options to optimise energy and water efficiencies, to investigate the potential for energy generation as well as the potential for water re-use and reclamation. The proposal was accepted, and the Inception Meeting was held on 17 January 2019.

Progress on the project activities has been negatively affected as data pertinent to the system selection (technology) aspect of the study was not available. This data pertains to influent characteristics, particularly existing industrial effluent composition and impact, as well as the baseline discharge standard (, i.e. the target standard for discharge to river, excluding the on-sale standard). In October 2019, it was agreed that the scope of the project would be amended to a small degree to become a scoping study to investigate feasible economic beneficiation opportunities in the larger context of wastewater treatment in the iLembe region. The outcome to the study would then be applied to the design of the Regional KwaDukuza WWTW as part of the design process for that Works.

3 OBJECTIVES OF THE TECHNOLOGY/OPPORTUNITY FEASIBILITY STUDY

The objectives of the project are as described in the Terms of Reference issued on 24 July 2018, subsequent responding proposal dated 30 July 2018, and further outcome realignment following discussions with Vuthela on 8 October 2019. The re-aligned objectives are summarised as:

To expand on the scope of the contract for the Provision of Engineering Services for the New Regional KwaDukuza Wastewater Treatment Works to include:

- The investigation of options to optimise water and energy efficiencies in the treatment process configuration through the application of inventive green energy options;
- The investigation of energy generation potential (process sludge to energy via biogas), as well as likelihood of off-take consumption options;
- The investigation of potential options for water re-use and reclamation, with emphasis on the sale of treated effluent (non-potable supply) to industrial or other potential consumers;
- The impact of any beneficiation activities on treatment process design and the potential financial impact of implementation thereof.

The above scope is to inform the New Regional KwaDukuza Wastewater Treatment Works design, but in general to also inform future wastewater infrastructure upgrades within the municipality.

4 ASSUMPTIONS

4.1 Assumptions

The following assumptions are relevant to this study:

- It is assumed that potential off takers for treated effluent water or energy are interested if a feasible business case is presented;
- It is assumed that IDM will launch awareness and information campaigns on water re-use (addressing social, cultural and technical concerns) and that these will not be a factor in the determination of the business case. Social studies in this aspect are excluded from the scope of this project;
- Negotiation / detailed discussions with potential off-takers of energy and treated effluent water such as Sappi, Gledhow Sugar Company, Eskom and others are not part of this appointment. The necessity of negotiation / detailed discussion will be highlighted and included in the activities in the blueprint to implementation. However, a sample of stakeholders around the proposed new KwaDukuza Regional WWTW will be consulted to determine the appetite for beneficiation from the WWTW products;
- There will likely be gaps in the data provided; however, at this stage of the project, assumptions will be made where insufficient information is available. These assumptions will be reported and if the lack of data becomes a substantial risk for the future, activities will be included in the blueprint to implementation in order to obtain this information or mitigate these risks. This is a scoping study and the outcome will inform the scope for a detailed feasibility study for the additional scope of work components of future WWTW studies;
- IDM will still have the option of a conventional WWTW;
- The full feasibility for the establishment of a regional WWTW will continue parallel to this study and includes various other items. This report will inform the expanded system selection of the proposed regional WWTW.

5 HOW BEST TO USE THIS STUDY

This study's aim is to inform as too the available and applicable technologies for the conditions and treatment aims for iLembe District Municipality. Therefore, the findings of this report should be utilised as a first-order test to establish the probable feasibility of a technology in relation to its proposed treatment objective. As such, the methodology utilised in this report is outlined below.

5.1 Applicable Methodology Employed

The study is broken down into sections applicable to singular wastewater treatment / beneficiation objectives relevant to iLembe District Municipality's specific objectives. These sections will be:

- Main Treatment Process (heart of the treatment plant for organic content and biological nutrient removal);
- Biogas Generation and Optimization;
- Biogas Utilization (Heat and Electrical Generation);
- Water Reclamation Technologies / Options;
- Energy Efficient Design;
- Water Efficient Design;

These main sections may contain subsections in order to address specific areas of relevance within the section. All technologies will be compared on the same basis as is outlined in the basis of design; further comparison with a note as to their scalability will be included where appropriate.

Each of the technologies that is applicable to the treatment / beneficiation objectives as set out under each section will be investigated to determine the following:

- Indicative sizing of major structures;
- Block flow diagram to illustrate technology and process unit interaction;
- Indicative OPEX and CAPEX (order of magnitude) of most viable configurations;
- Indicative cost of water or gas/heat/electricity per unit produced where relevant;
- Risk identification;
- Impact on main treatment process;
- High level permitting considerations per option.

5.2 Scaling Methods

In order to comment on the scalability of a technology the following will be considered when this topic is discussed:

- Civil or mechanical construction;

- Reasonable modular size where applicable;
- Operational cost implication of the technology in terms of power consumption/ manpower when scaled;

It is expected that most technologies will not follow a linear relation between implemented size and the above points. Care will thus be taken to allow for a suggested reasonable range of implementation and parameters to consider.

When considering a technology's feasibility for implementation, the viability of the technology to perform its required treatment / beneficiation objectives need to be weighed in terms of possible future changes in both the population/areas served as well as plausible legislative changes. The technologies that would be deemed applicable for this study would have to either be able to accommodate certain changes, and/or where such risks may be foreseen these will be noted.

5.3 Size / Volume Related Sensitivity

Expanding on section 5.2, care must always be taken to consider whether a technology is a viable option in terms of the size of its implementation. In this case the technology footprint and related CAPEX and OPEX will be used as the determination of a technology's feasibility.

5.4 Assessment Criteria

Each technology considered for this study will be assessed against the following criteria:

- Effectiveness of technology in terms of the investigated treatment / beneficiation objective;
- Efficiency of technology in terms of the investigated treatment / beneficiation objective;
- Capital cost estimate of technology implementation in relation to the prescribed size/volume of plant as set out in the basis of design;
- Operational cost indicator and relevant factors influencing the operability of specific technologies;
- Risk identification related to the technologies implementation (technology safety, environmental impacts, permitting risks, as well as social acceptance);

5.5 Who Should Use the Study

The study is meant for individuals with a fair background in wastewater treatment, in order to assist them with a first-order selection of relevant technologies for treatment objectives they will encounter within IDM. As such, the focus of this report is to explain the relevant performance of the technologies with relation to their feasibility to IDM, and not their underlining process methodology (unless otherwise relevant to the above assessment criteria).

It should be noted that using this study should only be the departure point in the technology selection process and each process selected should be developed in order to ascertain the correct metrics for the specific treatment objective of the individual case.

6 BASIS OF DESIGN

The Basis of Design for this study is set out below to provide the baseline where possible for the assessment/comparison of technologies in terms of their feasibility of implementation.

6.1 WASTEWATER SPECIFICATION

This section sets out the baseline influent wastewater / sewer influent quality to be treated by the main process, which will further inform the input parameters to specific technologies. Sections 6.1.3 and 6.1.2 address the effluent quality of both the main process treatment technology as well as those applicable to feasible beneficiation technologies.

6.1.1 INFLUENT QUALITY

A generic influent waste water quality for a typical South African mixed-income group, as defined by the Water Research Commission (WRC – April 2009), forms the baseline for the study Table ***1***. It should be noted that when technologies are considered for implementation, it is of vital importance that a proper and comprehensive characterisation of the wastewater to be treated be conducted. Such a characterisation should be compared to the characterisation set out in this report in order to achieve the best technology selection.

Table 1: Typical domestic sewage quality for South African of mixed income feed source (WRC – April 2009)

Parameter	Units	Value
BOD as O_2	mg/ℓ	250 - 350
COD as O_2	mg/ℓ	500 - 700
Settleable Solids	mg/ℓ	8 - 10
Suspended solids	mg/ℓ	200 - 350
TKN	mg/ℓ	60 - 85
Ammonia as N	mg/ℓ	40 - 50
Phosphate as P	mg/ℓ	10 -13

For this study Table ***2*** below sets out the selected influent design.

Table 2: Influent design quality for the generic WWTW as well as the main process option comparison

Parameter	Units	Max	Average	Design Value
BOD as O_2	mg/ℓ	400	300	350
COD as O_2	mg/ℓ	900	650	750
Settleable Solids	mg/ℓ	10	8	10
Suspended solids	mg/ℓ	400	250	350
TKN	mg/ℓ	85	55	60
Ammonia as N	mg/ℓ	60	45	50

Parameter	Units	Max	Average	Design Value
Phosphate as P	mg/ℓ	14	8	12

6.1.2 RIVER DISCHARGE QUALITY

Two quality standards for discharge to the river will be considered for this study. The discharge standard will be the General Limit Standard as well as the Special Limit Standard (these are outlined below in Table ***3***).

Table 3: Effluent discharge quality for discharge to local river

Parameter	Units	General Limit Value	Special Limit Value
COD*	mg/ℓ	75*	30*
pH		5.5 < pH < 9.5	5.5 < pH < 7.5
Total suspended solids	mg/ℓ	< 25	<10
Nitrate as N	mg/ℓ	< 15	1.5
Ammonia as N	mg/ℓ	< 6	< 2
Ortho Phosphate as P	mg/ℓ	10	1 (median) and 2.5 (maximum)
Conductivity	mS/m	70 above intake to a maximum of 150	50 above intake to a maximum of 100
Free Chlorine	mg/ℓ	< 0.25	0

*****After removal of algae

For the basis of the generic WWTW as well as the Main Treatment Process only the General Limits will be considered. The special limits will be addressed in a subsection of section 7.1 in order to address the future implication of such discharge limits on the technology selection process.

6.1.3 TREATED EFFLUENT REQUIREMENTS

As part of the treatment / beneficiation technology viability, section 7 **Error! Reference source not found.**will consider a variety of treatment / beneficiation technologies with varying treatment capabilities. The three broad water qualities that could be produced by these technologies at a WWTW for offtake would be:

- Agricultural use (irrigation);
- Potable quality;
- Intermediate industrial quality.

The possibility to supply local industry or agriculture with a source of water in the form of treated effluent, or of a quality better suited to their specific needs, will be considered. As the effluent quality will be dependent on the specific final application, the final effluent quality will be expressed per option reviewed.

The option for irrigation will typically be required to produce water that adheres to the South African Water Quality Guidelines for Irrigation (DWAF 1996). These typical limits are listed in Table 4 below with a more comprehensive table in Appendix A1

Table 4: Selected South African Water Quality Guideline limits for Irrigation

Parameters	Units	Irrigation standards	Notes
pH		≥ 6.5 to ≤ 8.4	
Electrical Conductivity	mS/m	< 90	Consideration to be given when applied to salt sensitive vegetation Recommended limit < 40
Suspended Solids	mg/ℓ	< 50	For irrigation equipment protection
Colour	PtCo Units	N/A	
Turbidity	N.T.U.	N/A	
Total Alkalinity as $CaCO_3$	mg/ℓ	N/A	
Chloride as Cl	mg/ℓ	< 100	
Fluoride as F	mg/ℓ	< 2	
Total Faecal Coliforms	per 100 mℓ	<1000	<10 for crops to be eaten Raw
Sodium as Na	mg/ℓ	≤ 70	Refer to SAR below
Sodium as SAR = [sodium]/([calcium] + [magnesium])0.5	[ ] in mmol/ℓ	< 2	Sodium Absorption Rate

The possibility to treat the effluent to potable water standards will also be investigated, as the best possible quality of water emanating from the WWTW. It should be noted that the process for treatment to potable water quality will need to be well considered against the offset potential (against abstraction from existing sources) and known perceivable attitudes towards such systems. The applicable water quality standard is SANS 241:2015, with selected limits in Table 5 below and an expanded table in Appendix 0

Table 5: Shortened list of SANS 241:2015 Limits

Parameter	Unit	SANS 241:2015 Limits
pH	-	5 ≤ pH ≤ 9.7
Electrical Conductivity	mS/m	≤ 170
Total Dissolved Solids	mg/ℓ	≤ 1200
Colour	PtCo Units	≤ 15
Turbidity	N.T.U.	≤ 1 (operational) / ≤ 5 (aesthetic)

Parameter	Unit	SANS 241:2015 Limits
Free Residual Chlorine as Cl_2	mg/ℓ	≤ 5
Monochloramine	mg/ℓ	≤ 3
Total Alkalinity as $CaCO_3$	mg/ℓ	---
Chloride as Cl	mg/ℓ	≤ 300
Sulphate as SO_4	mg/ℓ	≤ 500 (acute) / ≤ 250 (aesthetic)
Fluoride as F	mg/ℓ	≤ 1.5
Nitrate as N	mg/ℓ	≤ 11
Nitrite as N	mg/ℓ	≤ 0.9
Combined Nitrate & Nitrite	mg/ℓ	≤ 1
Free and Saline Ammonia as N	mg/ℓ	≤ 1.5
Free Cyanide as CN	µg/ℓ	≤ 200
Total Organic Carbon as C	mg/ℓ	≤ 10
Phenols	µg/ℓ	≤ 10
Total Coliform Bacteria	per 100 mℓ	≤ 10
E. coli	per 100 mℓ	Not detected
Heterotrophic Plate Count	cfu / 1 mℓ	≤ 1000
Somatic Coliphages	per 10 mℓ	Not detected

The third option in terms of water quality would be to treat to process water quality for industrial use however, this is dependent on the specific requirements of the industry. As part of this study, the local industries that could potentially benefit from such an arrangement have been contacted in order to discuss the specific water quality specification they would require. To date, the industries have not supplied detailed specifications but efforts to obtain such information are ongoing. In order to address this, additional technologies to significantly decrease TDS may be considered as well.

6.2 GENERIC WWTW LAYOUT FOR STUDY BASELINE

The design for the generic WWTW is based on a conventional activated sludge process. The plant in question will have a 10 MLD capacity and conform to the influent and effluent characteristics as set out in sections 6.1.1 and 6.1.2 above. A WWTW will typically comprise the following processes:

- Preliminary Treatment Process;
    - Screening;
    - Grit and detritus removal;
    - Primary sedimentation;

- Conventional Activated Sludge Process – Main Treatment Process;
- Secondary clarification;
- Disinfection;
- Polishing treatment and discharge.

The mainstream sludge handling processes incorporate the following:

- Primary sludge screening and thickening;
- WAS sludge thickening;
- Sludge digestion;
- Sludge conditioning / drying.

Figure 1 below shows the typical process flow diagram for a system as described above.

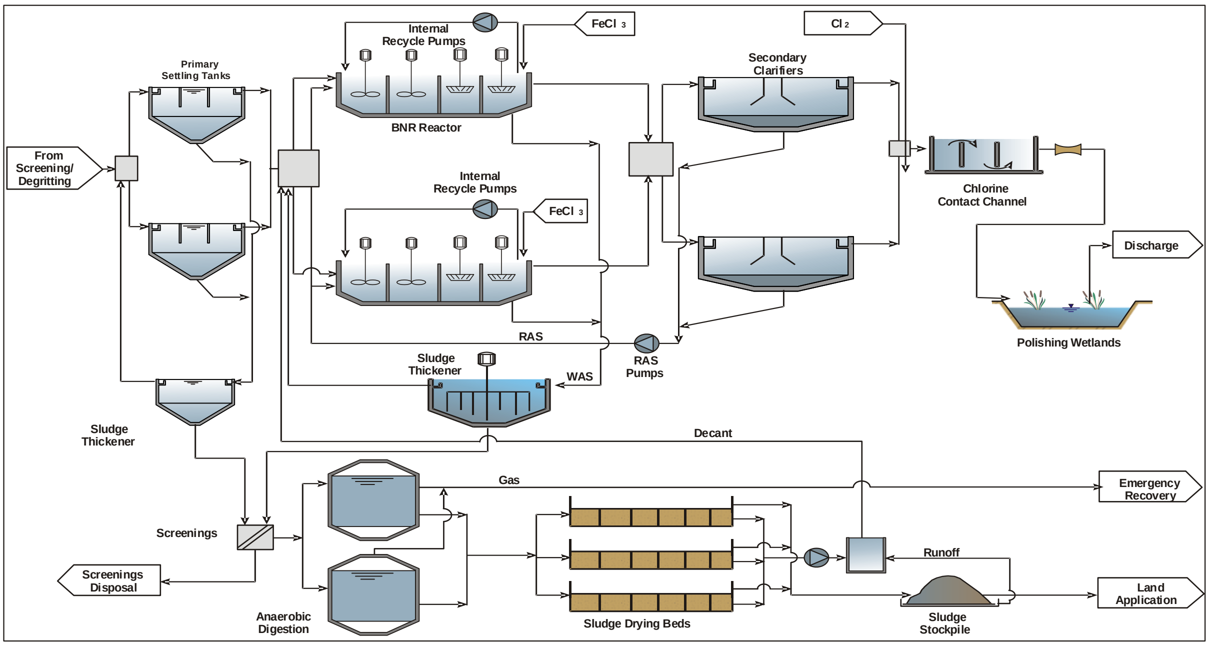


Figure 1: General flow diagram of the generic WWTW as described above

The design is set up to allow for the generic design considered allows for COD removal, waste (sludge) stabilization as well nitrification, de-nitrification and biological phosphate removal to a level in compliance with the general discharge stands (see Table ***3*** above). The design allows for the integration of the beneficiation technologies as will be discussed in the sections below.

Additional to the consideration outlined above the following design parameters for the conventional activated sludge process were assumed:

- Solids retention time (SRT) of 12 days;
- Mixed liquor suspended solids (MLSS) of 3 500 mg/ℓ;
- Design to allow for nitrification, de-nitrification as well as phosphate removal.

The generic design would typically yield the following design outcomes (Table ***6*** below):

Table 6: Generic WWTW typical design values.

Parameters	Units	Value	Notes
Reactor – Activated Sludge Reactor	m^3	+/- 9 000	Approximation based on 12d SRT and MLSS of 3500 mg/l
Grit Mass	ton TS/day	1.8 – 4.5	This will inform solid waste disposal cost
Sludge mass	ton TS/day	2.5 – 3.3	Dependent on daily load changes
WAS Sludge volume	m^3/day	90 – 135	Dependent on solids load and Clarifier performance

The values in table 6 will inform the technology comparison.

7 TECHNOLOGY / OPPORTUNITY FEASIBILITY

7.1 Main Treatment Process

This section will consider technologies for the reduction of COD, TKN and phosphate through biological processes, to be described in section 7.1.1 to 7.1.6, in order to achieve the general discharge limits set out in Table ***3*** above. The subsequent sections 7.2.1 and 7.2.2 will discuss options to achieve special discharge limits as set out in Table ***3*** above.

7.1.1 Anaerobic Ponds with Trickling Filters

Technology option one consists of anaerobic ponds followed by trickling filters. Essentially these are two technologies chosen to work in combination in order to achieve desired process treatment objectives. Both these technologies are well proven and in place all over the world. The anaerobic ponds will provide COD removal, waste (sludge) stabilization as well as nitrification; the trickling filters will assist with further COD removal, nitrification and very limited denitrification. A general process flow diagram for such a system is shown in Figure 2.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below (***Table 7*** and):

Table 7: Typical design values for a 10 MLD plant with anaerobic lagoon and trickling filters.

Parameters	Units	Value	Notes
Reactor – Anaerobic Lagoon	m^3	> 20 000	SRT of typically 50 – 100 days with hydraulic retention time of 20 – 50 days (20d selected)
Trickling filter area	m^2	5 000	Hydraulic loading rate of 1 – 4 $m^3/m^2.d$ (2 selected)
Trickling filter volume	m^3	2 500	Typical depth of rock filled filter 1 – 2.5 m (2 selected)
Typical footprint of main civil units	m^2	13 450	Inclusive of clarifier area required
Power Consumption / OPEX	kWh/d	1 068	Limited to main process units including recycles
Capital cost	R mil	>100	Limited to cost of civil structures and Mechanical equipment

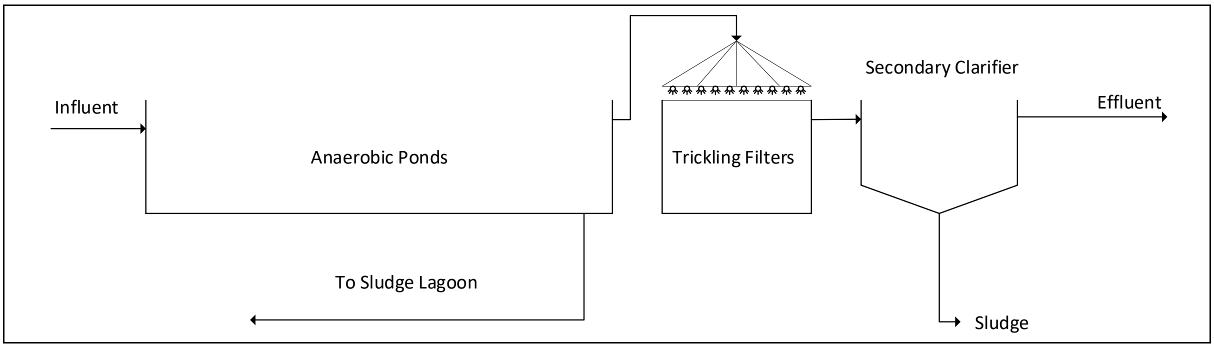


Figure 2: Anaerobic ponds with Trickling Filters process flow diagram

The footprint of such a plant is large and would typically be implemented where space is available in abundance or where the flow to be treated is relatively low.

The advantages and disadvantages of this option are listed below:

Advantages:

- The process has a low energy requirement in comparison with the other alternatives;
- The process units require minimal operator intervention and limited maintenance;
- Alternative 1 is not as capital intensive in comparison with the other alternatives and has a lower operating cost due to the lower energy requirement;
- No additional aeration for the trickling filter;
- Robust system that requires very little intervention in its day-to-day operations;
- The process allows for the removal of COD, as well as nitrification and limited de-nitrification.

Disadvantages:

- A sludge lagoon is required in order to stabilize the sludge prior to drying on the sludge drying beds or application to land;
- Odour problems may arise with this technology configuration;
- The anaerobic ponds will likely need to be lined to prevent groundwater contamination, increasing capital expenditure;
- Phosphate is not biologically removed in the process and requires additional chemical dosing (such as $FeCl_3$);
- Limited denitrification takes place in the process and as such this should be considered when designing to the correct Nitrate standard;
- There is no potential for energy recovery with this technology configuration.

Associated risks with the technology option:

- Unable to meet the required phosphate discharge standard without additional chemical dosing;
- Odour concerns would require the plant to be located away from populated communities;
- Sludge stabilization pond should be included in the design if sludge was to be sent for land application.

High level permitting considerations:

- Care should be taken to ensure the system complies with the required phosphate discharge standards applicable to the discharge system;
- Care should be taken to ensure the system complies with the required nitrate (NO_3-N) discharge standards applicable to the discharge system;

7.1.2 Extended Aeration

Extended aeration is the second process technology for the removal of COD and facilitation of nitrification. This technology consists of a large aerated reactor in combination with secondary clarifiers to facilitate sludge recycling (Return Activated Sludge (RAS) is recycled to the aeration basin inlet from the bottom of the secondary clarifiers). Aeration may be achieved through numerous technologies (surface and fine bubble most common), the merits of each which will be discussed in subsequent sections. Waste Activated Sludge (WAS) may be wasted directly from the aeration basin or from the RAS line.

A general process flow diagram for such a system is shown in Figure 3.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below (Table ***8***):

Table 8: Typical design values for a 10 MLD plant based on the extended aeration process.

Parameters	Units	Value	Notes
Extended Aeration reactor volume	m^3	15 160	SRT of typically 20 – 30 days with MLSS of 2000 – 4000 mg/l (20d SRT and MLSS of 3500 mg/l selected)
Typical footprint of main civil units	m^2	5 040	Inclusive of Clarifier area required
Power Consumption / OPEX	kWh/d	3 480	Limited to main process units including recycles
Capital cost	R mil	70 - 80	Limited to cost of Civil structures and Mechanical equipment

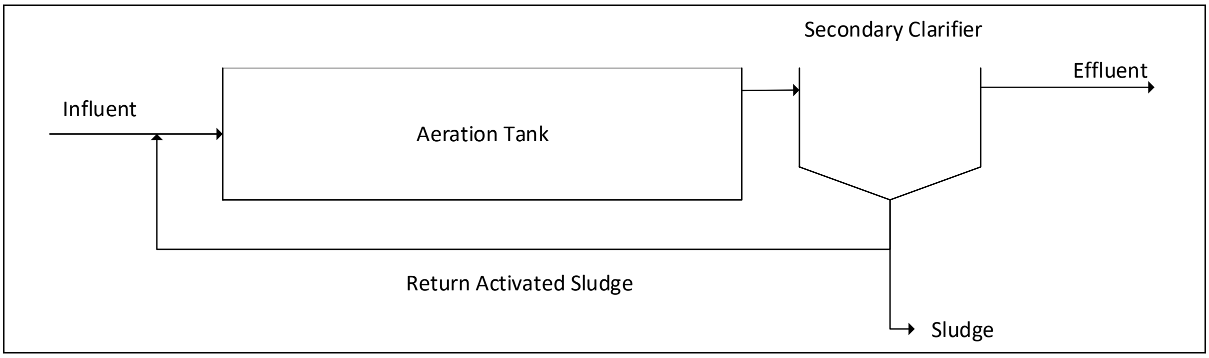


Figure 3: Generic Extended Aeration process flow diagram

The advantages and disadvantages of the treatment technology are listed below:

Advantages:

- This process produces a stable sludge that may be disposed to a landfill site, or may be used as fertilizer and applied to agricultural land under certain conditions;
- The process allows for the removal of COD, as well as nitrification to oxidise ammonia;
- In comparison to the other technology alternatives this is a fairly simple system to operate.

Disadvantages:

- This process is capital intensive, as large aeration basins are required, as well as high in operating cost, as the mechanical aeration process has a high energy demand;
- The technology does not allow for de-nitrification and will therefore not meet the nitrate (NO_3-N) discharge standard;
- Return activated sludge pumping increases energy consumption;
- Phosphate is not removed in the process, and requires additional chemical dosing (such as $FeCl_3$);
- There is only limited potential for energy recovery.

Associated risks with the technology option:

- Unable to meet the required phosphate discharge standard without additional chemical dosing;
- Unable to meet the required nitrate (NO_3-N) discharge standard without additional process steps;
- Energy consumption with the large aeration reactor needs to be considered in terms of future OPEX.

High level permitting considerations:

- Care should be taken to ensure the system complies with the required phosphate discharge standards applicable to the discharge system;
- Care should be taken to ensure the system complies with the required nitrate (NO_3-N) discharge standards applicable to the discharge system;

7.1.3 Conventional BNR– Activated Sludge Process

The conventional BNR – Activated Sludge process is an improvement on the extended aeration process described in section 7.1.2. In addition to primary settling to remove particulate COD, the process consists of a reactor that allows for anoxic, anaerobic and aerobic zones in order to facilitate COD removal, waste (sludge) stabilization as well nitrification, de-nitrification and biological phosphate removal. This process will include additional internal recycle streams (in addition to the RAS stream) within the process to facilitate the treatment objectives. Waste Activated Sludge (WAS) may be wasted directly from the aeration basin or from the RAS line. There are a number of different process configurations that may be employed in this setup – the UCT process is utilised in this case (it has been implemented with great success throughout South Africa).

A general process flow diagram for such a system is shown in Figure 4.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below (***Table 9***):

Table 9: Typical design values for a 10 MLD plant based on the generic Conventional Activated Sludge process.

Parameters	Units	Value	Notes
Reactor – Activated Sludge Reactor	m^3	9 000	Approximation based on 12d SRT and MLSS of 3500 mg/l
Typical footprint of main civil units	m^2	3 500	Inclusive of Clarifier area required
Power Consumption / OPEX	kWh/d	4 368	Limited to main process units including recycles
Capital cost	R mil	50 - 60	Limited to cost of Civil structures and Mechanical equipment

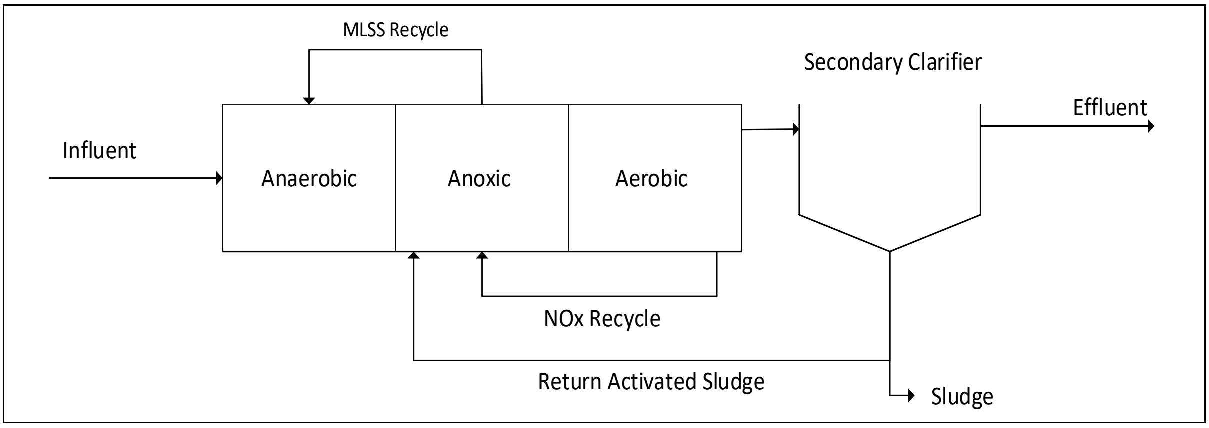


Figure 4: Conventional BNR – Activated Sludge treatment process flow diagram

The advantages and disadvantages of this technology are listed below:

Advantages:

- The technology produces a very stable sludge that may be disposed of to a landfill site or utilized as fertilizer and applied to agricultural land depending on the legislation concerning the utilisation of sewage sludge;
- This technology alternative allows for COD removal, phosphate removal, as well as nitrification and de-nitrification. The technology configuration should meet all discharge standards without the need for additional chemical dosing;
- The BNR reactor configuration allows for some flexibility in operation which could improve its response to influent flow/load variability;
- This process produces sludge with good methane-rich gas production potential that allows for energy recovery.

Disadvantages:

- The proposed process has a higher energy consumption compared to technologies from sections 7.1.1 and 7.1.2, due to the additional process units and the associated pumping and aeration requirements. This could be potentially offset by energy generation using biogas;
- In comparison to the simpler technologies from sections 7.1.1 and 7.1.2, this process requires regular intervention to maintain the optimum treatment conditions;
- Due to its increased amount of mechanical equipment it may be one of the more CAPEX intensive technologies.

Associated risks with the technology option:

- Treatment plant operators will need to be skilled to maintain optimum process conditions and regular intervention will be required.

High level permitting considerations:

- Considering the possibility of energy recovery through sludge digestion and biogas-to-energy, permitting surrounding such structures will have to be considered (Gas handling and Storage in particular).

7.1.4 Moving Bed Biofilm Reactor (MBBR)

The Moving Bed Biofilm Reactor (MBBR) process makes use of specialised plastic media to facilitate the attached growth of biomass in the reactor. This substantially increases the area of activity within the reactor and as such leads to a smaller reactor footprint. The process consists of a reactor that is typically 60% filled with the media and allows for COD removal, waste (sludge) stabilization as well nitrification and de-nitrification. The process has the benefit of not requiring the recirculation of activated sludge (RAS) due to the use of media that fix the biomass within the reactor. In order to facilitate nitrogen removal, it may be required to include an internal nitrate recycle stream. The available media designs have a vast range of specific surface areas and as such, care must be taken when choosing an appropriate media. These values typically range from 350 m^2/m^3 to greater than 1200 m^2/m^3 with a typical media for wastewater treatment having a specific surface area of +/- 600 m^2/m^3.

A general process flow diagram for such a system is shown in Figure 5.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below (***Table 10***).

Table 10: Typical design values for a 10 MLD plant based on the generic MBBR process.

Parameters	Units	Value	Notes
Reactor – MBBR	m^3	< 7500	Media surface area +/- 600 m^2/m^3 and allowing for Nitrogen removal.
Typical footprint of main civil units	m^2	3 125	Inclusive of Clarifier area required
Power Consumption / OPEX	kWh/d	5 028	Limited to main process units including recycles

Parameters	Units	Value	Notes
Capital cost	R mil	50 - 60	Limited to cost of Civil structures and Mechanical equipment

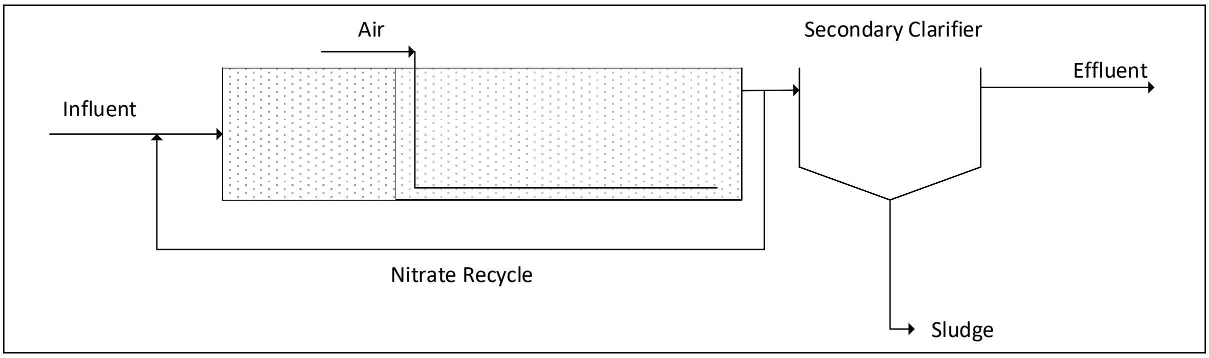


Figure 5: Typical MBBR treatment process flow diagram

The advantages and disadvantages of this technology are listed below:

Advantages:

- The technology produces a very stable sludge that may be disposed of to a landfill site or utilized as fertilizer and applied to agricultural land depending on the legislation concerning the utilisation of sewage sludge;
- This technology alternative allows for COD and phosphate removal, as well as nitrification and de-nitrification;
- The MBBR reactor configuration is robust and is capable of handling process fluctuations more readily than some of the other technologies discussed;
- This process produces sludge with good methane-rich gas production potential that allows for energy recovery;
- The use of an attached growth process with a large surface area greatly reduces the reactor footprint;
- Due to the reactor effluent containing relatively low concentrations of solids, the typical concerns of sludge bulking in the secondary clarifier is avoided thereby increasing ease of clarifier operations.

Disadvantages:

- The system requires a higher dissolved oxygen operational setpoint (typically 3 – 4 mg/l) which may result in higher OPEX compared to the prior mentioned technologies that operate at 2 mg/l and below. Some of this could be potentially offset by energy generation using biogas;
- In comparison to the simpler technologies from sections 7.1.1 and 7.1.2, this process requires regular intervention to maintain the optimum treatment conditions;
- Due to its increased amount of mechanical equipment (compared to technologies discussed in from sections 7.1.1 and 7.1.2), it may be one of the more CAPEX intensive technologies.
- Phosphate is not removed in the process, and requires additional chemical dosing (such as $FeCl_3$);

- Replacement of the suspended media at intervals will increase OPEX cost.

Associated risks with the technology option:

- Unable to meet the required phosphate discharge standard without additional chemical dosing;
- Treatment plant operators will need to be skilled to maintain optimum process conditions and regular intervention will be required.

High level permitting considerations:

- Considering the possibility of energy recovery through sludge digestion and biogas-to-energy, permitting surrounding such structures will have to be considered (Gas handling and Storage in particular).
- Care should be taken to ensure the system complies with the required phosphate discharge standards applicable to the discharge system;

7.1.5 Membrane Bio Reactor (MBR)

The Membrane Bio Reactor process is an activated sludge process technology as described in section 7.1.3, where the difference is that the secondary clarifier is replaced by a membrane filtration process (typically submerged in the aerobic zone of the reactor). The process as such will allow for anoxic, anaerobic and aerobic zones in order to facilitate COD removal, waste (sludge) stabilization as well nitrification, denitrification and biological phosphate removal. This process will include additional internal recycle streams (in addition to the RAS stream) within the process to facilitate the treatment objectives. Waste Activated Sludge (WAS) is wasted directly from the reactor. There are a number of different process configurations that may be employed in this setup – the UCT process and modified Bardenpho process configurations among them. The fact that the sludge produced in this reactor does not need to have good settling qualities, both the SRT and MLSS can be increased. The MBR process may typically operates at a MLSS of 12 000 mg/l and as such greatly reduce the footprint of the main treatment process.

The membranes used for these applications fall under either the Micro (MF) or Ultra (UF) filtration ranges and would be arraigned either a hollow tube (UF) or plate structure (MF) for the application. It should be noted that these membranes are air scoured regularly and may require the occasional chemical clean. Although Ultra filtration membranes do remove viruses and bacteria from the waste water it is best practice to still disinfect the treated effluent.

A general process flow diagram for such a system is shown in Figure 6.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below (Table ***11***).

Table 11: Typical design values for a 10 MLD plant based on the generic MBR process.

Parameters	Units	Value	Notes
Reactor – MBR	m^3	2 500	MLSS of 12 000 mg/l
Typical footprint of main civil units	m^2	+/- 700	No clarifier required for MBR process
Power Consumption / OPEX	kWh/d	6 018	Limited to main process units including recycles
Capital cost	R mil	50 - 60	Limited to cost of Civil structures and Mechanical equipment

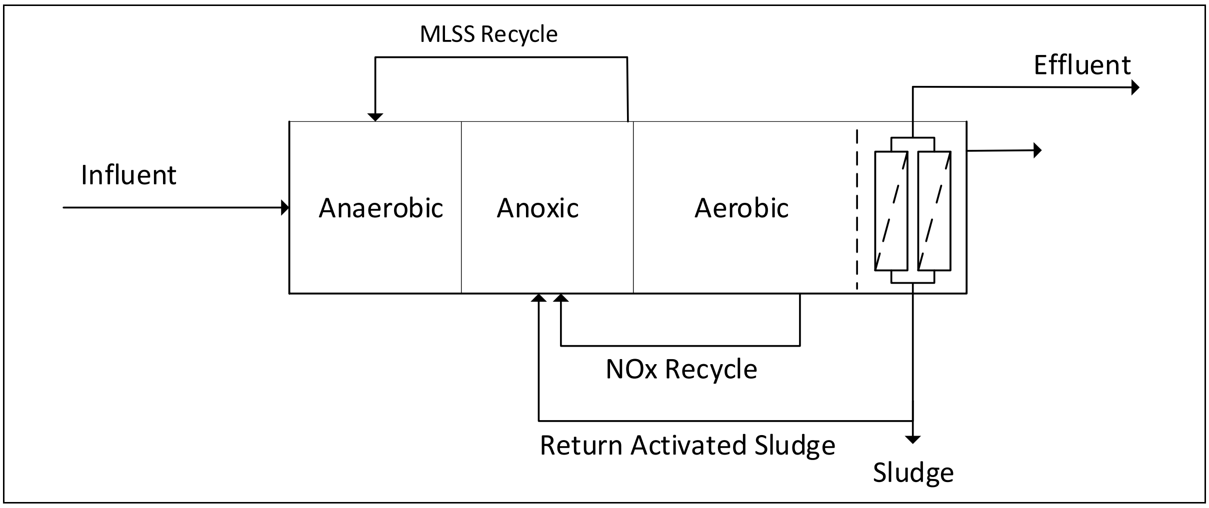


Figure 6: Typical MBR treatment process flow diagram

The advantages and disadvantages of this technology are listed below:

Advantages:

- Better effluent quality due to the complete capture of solids – this may also facilitate the beneficiation options of the treated effluent greatly;
- A greatly reduced footprint due to the higher MLSS concentrations, as well as no need for a secondary clarifier;
- The process is not susceptible to filamentous activated sludge;
- The technology produces a very stable sludge that may be disposed of to a landfill site or utilized as fertilizer and applied to agricultural land depending on the legislation concerning the utilisation of sewage sludge;
- This technology alternative allows for COD removal, phosphate removal as well as nitrification and de-nitrification. The technology configuration meets all discharge standards without the need for additional chemical dosing;
- The reactor configuration allows for some flexibility in operation which could improve its response to influent flow/load variability;
- This process produces sludge with good methane rich gas production potential that allows for energy recovery.

Disadvantages:

- Cleaning and maintenance of membranes can be onerous;
- Membranes will require replacement at regular intervals and as such will lead to higher OPEX cost;
- High quality of operational staff will be required in order to operate the process to achieve optimum treatment objective and safeguard the membranes from possible damage.
- Due to its increased amount of mechanical equipment, and the membranes, it may be one of the more CAPEX intensive technologies.

Associated risks with the technology option:

- The possibility of regularly replacing the membranes needs to be considered as it would greatly inflate the OPEX cost;
- Treatment plant operators will need to be skilled to maintain optimum process conditions and regular intervention will be required.

High level permitting considerations:

- Considering the possibility of energy recovery through sludge digestion, permitting surrounding such structures will have to be considered (Gas handling and Storage in particular).

7.1.6 Aerobic Granular Sludge Process

The Aerobic Granular Sludge (AGS) process is a technology based on the unique features of aerobic granular biomass. The formation of the granular biomass under carefully selected process conditions allows for the simultaneous existence of nitrifiers, denitrifiers, and PAO communities to co-exist on the same granule. This implies that the reactor will facilitate COD removal, waste (sludge) stabilization as well nitrification, de-nitrification and biological phosphate removal, all in a single aerobic zone. An additional characteristic is the that the sludge produced has far superior settling characteristics over previously discussed technologies (settling rates in excess of 10 times higher). As all the process steps required to achieve the desired treatment objectives occur in the same reactor, there is no requirement for any recycle streams. The reactor will typically operate in batch stages namely:

- Simultaneous fill and draw (decant);
- Reaction stage;
- Rapid settling (waste sludge is drawn from the reactor at this stage).

This operation also eliminates the secondary clarifier as a process unit. The AGS process will typically operate at a MLSS of 8 000 mg/l. This combined with the reduction in additional reactor zones will greatly reduce the footprint of the main treatment process.

A general process flow diagram for such a system is shown in Figure 7.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below (Table ***12***).

Table 12: Typical design values for a 10 MLD plant based on the generic Granular Activated Sludge process.

Parameters	Units	Value	Notes
Reactor – Aerobic Granular Sludge	m^3	5 400	MLSS of 8 000 mg/l
Typical footprint of main civil units	m^2	+/- 1500	No clarifier required for MBR process
Power Consumption / OPEX	kWh/d	3 215	Limited to main process units including recycles
Capital cost	R mil	75 - 90	Limited to cost of Civil structures and Mechanical equipment

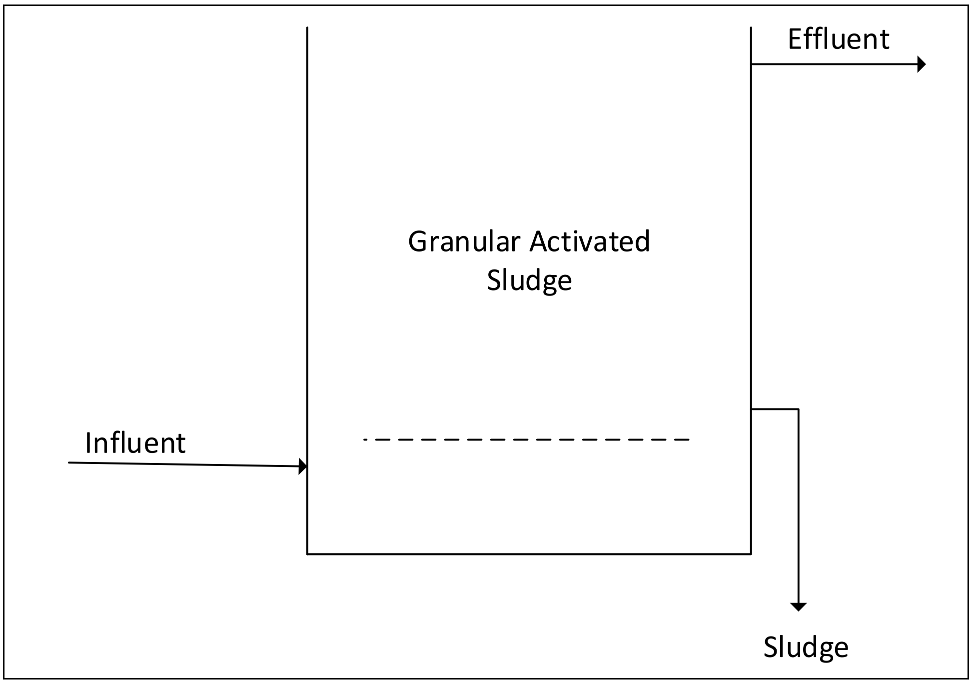


Figure 7: Typical Aerobic Granular Sludge treatment process flow

The advantages and disadvantages of this technology are listed below:

Advantages:

- A greatly reduced footprint due to the higher MLSS concentrations and elimination of superfluous reactor zones;
- The technology produces a very stable sludge that may be disposed of to a landfill site or utilized as fertilizer and applied to agricultural land depending on the legislation concerning the utilisation of sewage sludge;
- This technology alternative allows for COD removal, phosphate removal as well as nitrification and de-nitrification. The technology configuration meets all discharge standards without the need for additional chemical dosing;

- Reduction in ancillary mechanical equipment in comparison to above mentioned technologies should lead to an attractive CAPEX cost;
- The reduced reactor size and no need for recycle streams will lead to substantial reduction in energy requirement;
- This process produces sludge with good methane-rich gas production potential that allows for energy recovery.

Disadvantages:

- Initial development of the sludge granules in the reactor requires a high level of process expertise;
- High quality of operational staff will be required in order to operate the process to achieve optimum treatment conditions.

Associated risks with the technology option:

- Treatment plant operators will need to be skilled to maintain optimum process conditions and regular intervention will be required.

High level permitting considerations:

- Considering the possibility of energy recovery through sludge digestion and biogas-to-energy, permitting surrounding such structures will have to be considered (Gas handling and Storage in particular).

7.2 Water Reclamation Technologies / Options

This section will deal with technologies that may be considered to treat wastewater from a WWTW as was laid out in the basis of design from general discharge limits to achieve one or more of the following treatment objectives:

- Special discharge limits water quality;
- Water that meets irrigation water use standards;
- Reclaimed water for industrial reuse;
- Reclaimed water to potable standards.

This section discusses numerous technologies that will most likely be used in conjunction with one another in order to attain these goals. It should be noted where not intrinsically stated that the end product of a treatment process would meet one of the aforementioned treatment goals it should not be assumed, and attention should only be given to its treatment capabilities.

7.2.1 Advanced Oxidation Processes

Advanced Oxidation Processes (AOPs) for wastewater treatment is employed in the cases where there are constituents left in the wastewater that have not been oxidised by the preceding biological treatment steps. These AOP would be employed either to destroy specific elements left over or to reduce COD to a specific standard below the South African General discharge limits. AOP processes would generally only be installed after the secondary clarification step prior to final disinfection.

The processes all rely on the in-situ production of hydroxyl radicals (^{-}OH). This species is a very strong oxidiser able to oxidise most chemical substances present in wastewater and allows for fast reaction times.

AOP technologies rely on starter oxidising agents such as ozone, oxygen and hydrogen peroxide, often in conjunction with an energy source such as ultraviolet light, or a catalyst (such as TiO_2) to produce the hydroxyl radicals. These processes are capable of greatly reducing COD in wastewater, but the processes are susceptible to some of the following factors:

- Bicarbonate and carbonate species which act as scavengers and thus react with the hydroxyl radicals and decrease thy process efficiency;
- The pH level of the wastewater, as this determines the distribution of bicarbonate and carbonate species;
- Presence of metal ions such as iron(II) and manganese(II) which also act as scavengers;
- Turbidity of the wastewater, as this may hinder UV light transmission;

It should be kept in mind that AOP are typically only implemented together with a form of sand/media filtration, and often membrane filtration as well. This is done to mitigate the factors above that may impede the efficiency of the AOP.

The section below outlines three of the most relevant AOPs for wastewater treatment (for this study, processes that use expensive catalyst such as TiO_2 have been excluded). It is also worthwhile to note that there are a few proprietary systems that are available in the market; these however can only be evaluated on a case by case basis.

For the purposes of the comparison, the demand in COD reduction from General Discharge Limit of 75 mg/l COD to Special Discharge Limit of 30 mg/l for the defined 10MLD plant is assumed.

7.2.1.1 Ozone and Hydrogen Peroxide AOP Process

Ozone and hydrogen peroxide based AOP is up to 70% efficient in COD reduction, with the following equation describing the generation of hydroxyl radicals (^{-}OH):

$$2O_3 + H_2O_2 \rightarrow 2OH^- + 3O_2$$

The ozone is produced utilising LOX (liquified oxygen) as the feedstock to ozone generating units. The LOX is typically stored in large gas cylinders (up to 15 tons). These need to be stored in a secure access-controlled environment. The hydrogen peroxide is most commonly available as a 50% active liquid solution and will require bunded and access-controlled bulk storage onsite. The typical dosing rates for ozone and hydrogen peroxide is 2-4 g of ozone per g COD destroyed, with the stoichiometric equivalent for the hydrogen peroxide. These values are guidelines and will be adjusted to the site-specific conditions. Retention times for the reaction could vary from 5 to 30 minutes.

A general process flow diagram for such a system is shown in Figure 8: Typical Advance Oxidation process based on ozone and hydrogen peroxide as reagentsFigure 8.

The indicative size of the technology for comparative purposes, utilising the basis of design, is described below in Table ***13*** .

Table 13: Typical design values for a 10 MLD plant based on the Ozone and Hydrogen Peroxide advanced oxidation process.

Parameters	Units	Value	Notes
Oxidation reactor size	m^3	210	Retention time of 30 min
Typical footprint of main civil units	m^2	+/- 185	Inclusive of supporting infrastructure such as required chemical storage and reagent makeup
Power Consumption	kWh/d	1800	Limited to main process units including power used for reaction or reagent generation
Chemical Consumption	R/d	4 000	Reagent consumption
Capital cost	R mil	15 - 20	Limited to cost of Civil structures and Mechanical equipment

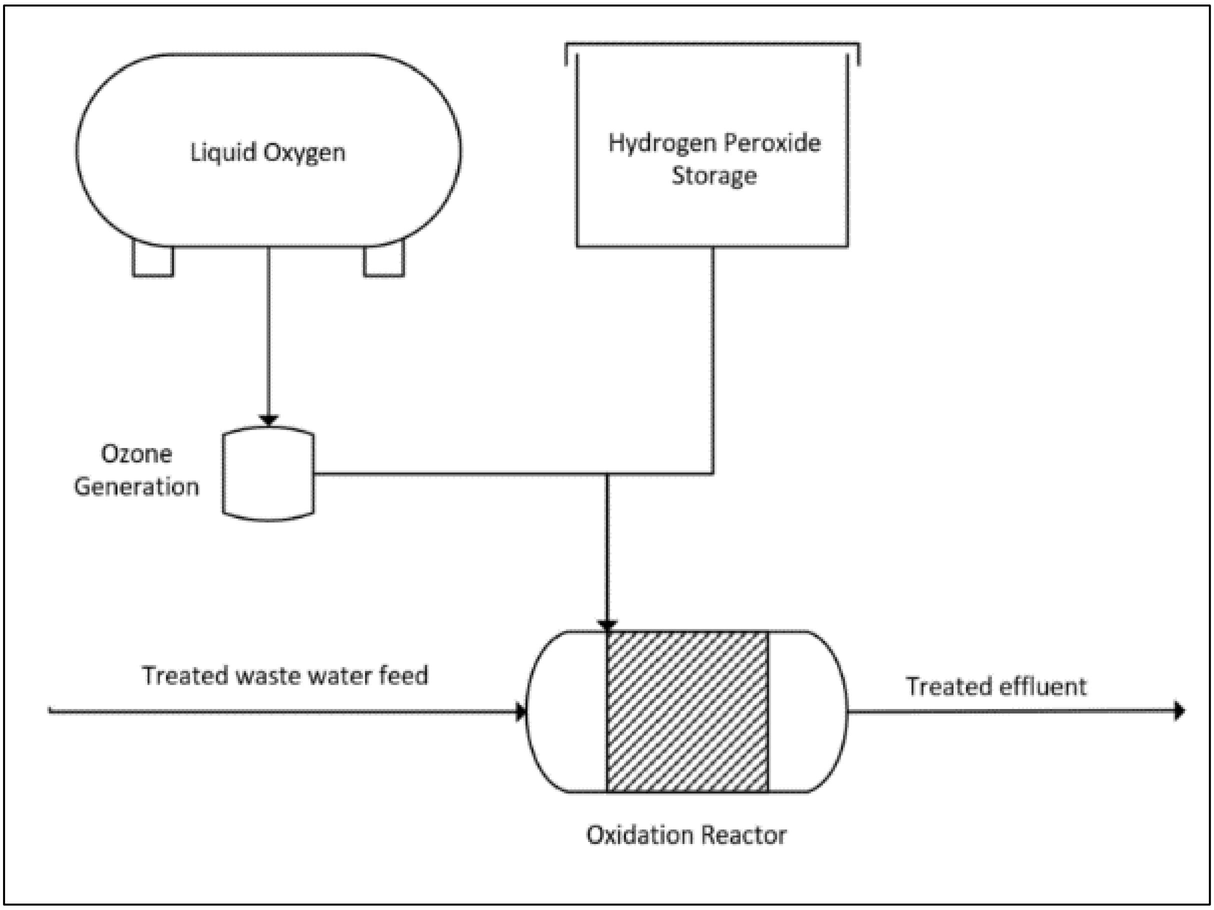


Figure 8: Typical Advance Oxidation process based on ozone and hydrogen peroxide as reagents

The advantages and disadvantages of this technology are listed below.

Advantages:

- The reactions occur quickly, and efficiently reduce the COD in the effluent with minimum retention times required;
- The process has a relatively small footprint;
- Should the process be operated efficiently, no new intermediary contaminants will be present in the product water;
- The process also functions as a disinfection step and should ozone be considered as a final disinfection step then there may be the added benefit of not having to duplicate certain process units;
- No waste stream is generated in this process;
- The combination of ozone and hydrogen peroxide reduces the chemical cost associated with the use of pure ozone (the more expensive reagent).

Disadvantages:

- Process is susceptible to the presence of chemical scavengers that may lead to higher reagent consumption and therefore higher operating cost;
- The process is reagent and power intensive, raising the overall operating cost;

- Specialised equipment for the generation of ozone is capital intensive;
- High competency is required of operational staff in order to operate the process to achieve optimum treatment conditions.

Associated risks with the technology option:

- Treatment plant operators will need to be skilled to maintain optimum process conditions and regular intervention will be required;
- Additional reagents onsite pose an additional health risk and operations will have to be trained accordingly;
- Care must be taken not to have residual hydrogen peroxide in the reactor product.

High level permitting considerations:

- The addition of reagents and ozone generating equipment should be considered in terms of the correct handling, storage and use according to the regulations applicable.

7.2.1.2 Ozone and Ultraviolet Light AOP Process

Ozone and ultraviolet light based AOP is up to 70% efficient in COD reduction, with the following equation describing the generation of hydroxyl radicals (^{-}OH):

$O_3 + UV \rightarrow OH^-$

The ozone reacts/activated with the UV light to produce hydrogen peroxide which in turn reacts with the excess ozone to form the hydroxyl radicals. It should be noted that double the amount of ozone will be required to produce the same amount of hydroxyl radicals in comparison to the ozone and hydrogen peroxide process. The ozone is produced utilising LOX (liquified oxygen) as the feedstock to ozone generating units. The LOX is typically stored in large gas cylinders (up to 15 tons). These need to be stored in a secure access-controlled environment. The typical dosing rates for ozone are 4 - 10 g of ozone per g COD destroyed. These values are guidelines and should be adjusted to the site-specific conditions. Retention times for the reaction could vary from 5 to 30 minutes.

This process may require an additional unit prior to dosing of the reagent into the reactor. This unit would house the ultraviolet unit and allow for the reaction required to generate the hydroxyl radicals to take place. The UV lamps can however be installed directly in the reactor. Such a process would require the wastewater to be low in turbidity and other fouling agents, to ensure the ultraviolet lamps continue to perform effectively over time.

A general process flow diagram for such a system is shown in Figure 8: Typical Advance Oxidation process based on ozone and hydrogen peroxide as reagents Figure 9.

The indicative size of technology for comparative purposes, utilising the basis of design, is described below in ***Table 14***.

Table 14: Typical design values for a 10 MLD plant based on the ozone and ultraviolet light process.

Parameters	Units	Value	Notes
Oxidation reactor size	m^3	210	Retention time of 30 min
Typical footprint of main civil units	m^2	+/- 200	Inclusive of supporting infrastructure such as required chemical storage and reagent makeup
Power Consumption	kWh/d	>1800	Limited to main process units including power used for reaction or reagent generation
Chemical Consumption	R/d	2 000	Reagent consumption
Capital cost	R mil	15 - 22	Limited to cost of Civil structures and Mechanical equipment

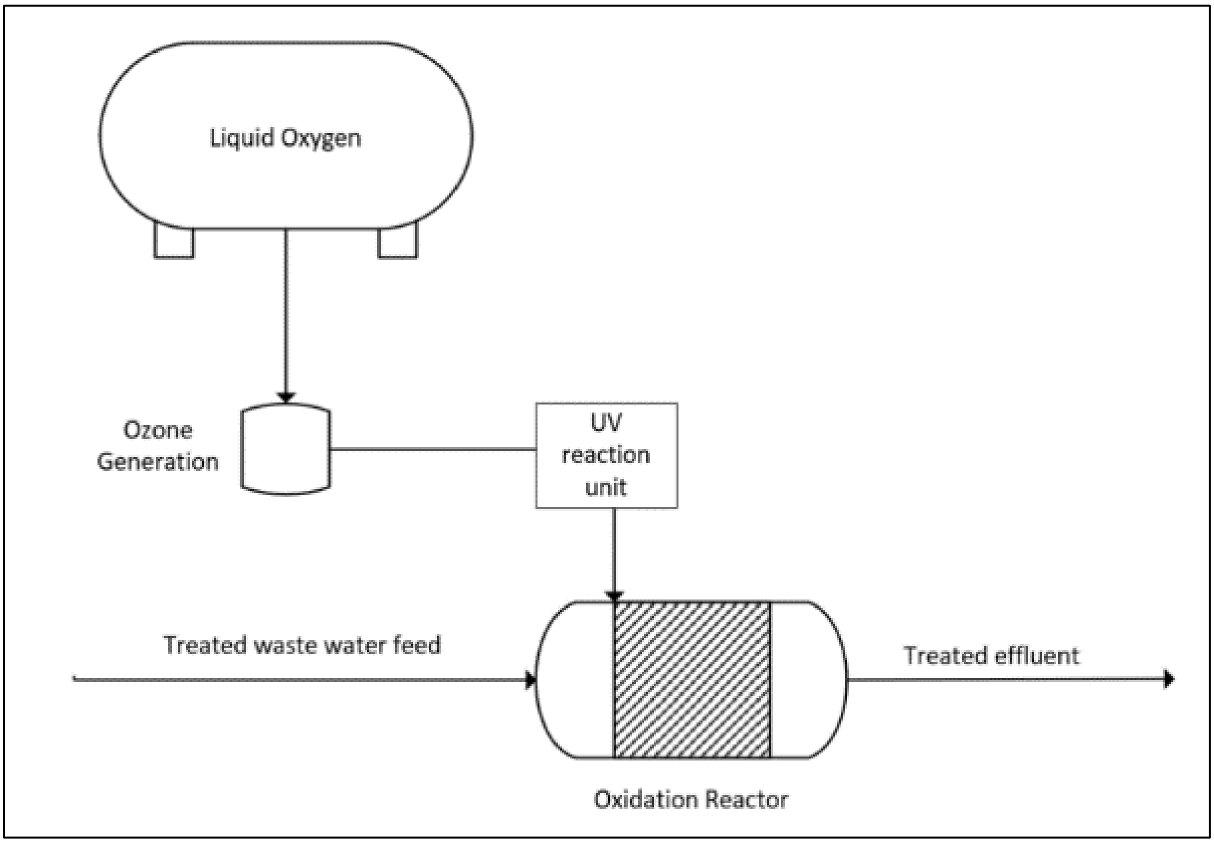


Figure 9: Typical Advance Oxidation process based on Ozone and Ultra Violet Light as reagents

The advantages and disadvantages of this technology are listed below.

Advantages:

- The reactions occur quickly, and efficiently reduce the COD in the effluent with minimum retention times required;
- The process has a relatively small footprint;
- Should the process be operated efficiently, no new contaminants (oxidation products) will be present in the product water;

- The process also functions as a disinfection step and should ozone be considered as a final disinfection step then there may be the added benefit of not having to duplicate certain process units;
- No waste stream is generated in this process.

Disadvantages:

- The process is susceptible to the presence of chemical scavengers that may lead to higher reagent consumption and therefore operating cost;
- The process is reagent and power intensive raising the overall operating cost;
- Specialised equipment for the generation of ozone is capital intensive;
- Ultraviolet light generation introduces an additional source of intensive power use;
- UV lights are prone to fouling and require regular maintenance;
- High competency is required of operational staff in order to operate the process to achieve optimum treatment conditions.

Associated risks with the technology option:

- Treatment plant operators will need to be skilled to maintain optimum process conditions and regular intervention will be required;
- Additional reagents onsite pose an additional health risk and operations will have to be trained in accordingly;

High level permitting considerations:

- The addition of additional ozone generating equipment should be considered in terms of the correct handling, storage and use according to the regulations applicable.

7.2.1.3 Hydrogen Peroxide and Ultraviolet Light AOP Process

Hydrogen Peroxide and ultra violet light based AOP is up to 70% efficient in COD reduction with the following equation being responsible for the generation of hydroxyl radicals (^{-}OH):

$H_2O_2 + UV \rightarrow 2OH^-$

Hydrogen peroxide reacts with the UV light (homolytic bond cleavage) to form the hydroxyl radicals. It should be noted that hydrogen peroxide has poor UV absorption characteristics – as such, a more intensive UV source needs to be applied than with the ozone and UV AOP process, and excess peroxide dosing is necessary to achieve the desired hydroxyl formation. The UV lamps would be installed directly in the reactor which also impacts the ease of maintenance. Such a process would require the waste water to be treated to be low in turbidity and other fouling agents to ensure that the ultraviolet lamps do not get fouled over time and as such diminish their performance. The typical dosing rates for ozone and hydrogen peroxide is extremely dependant on the waste water treated and may exceed 15 g of hydrogen peroxide per g COD destroyed. These values are guidelines and should be adjusted to the site-specific conditions. Retention times for the reaction could vary from 5 to 30 minutes.

This process is not often employed for drinking water treatment as it results in high concentrations of hydrogen peroxide remaining in the treated water. This may not be a concern if the water is used in a non-potable reclamation scheme depending on the process units to follow this step.

A general process flow diagram for such a system is shown in Figure 8: Typical Advance Oxidation process based on ozone and hydrogen peroxide as reagentsFigure 10.

The indicative size of technology for comparative purposes, utilising the basis of design, is described below in ***Table 15***.

Table 15: Typical design values for a 10 MLD plant based on the hydrogen peroxide and ultraviolet light process.

Parameters	Units	Value	Notes
Oxidation reactor size	m^3	210	Retention time of 30 min
Typical footprint of main civil units	m^2	+/- 120	Inclusive of supporting infrastructure such as required chemical storage and reagent makeup
Power Consumption	kWh/d		Limited to main process units including power used for reaction or reagent generation
Chemical Consumption	R/d	6 - 8 000	Reagent consumption
Capital cost	R mil	12 - 17	Limited to cost of Civil structures and Mechanical equipment

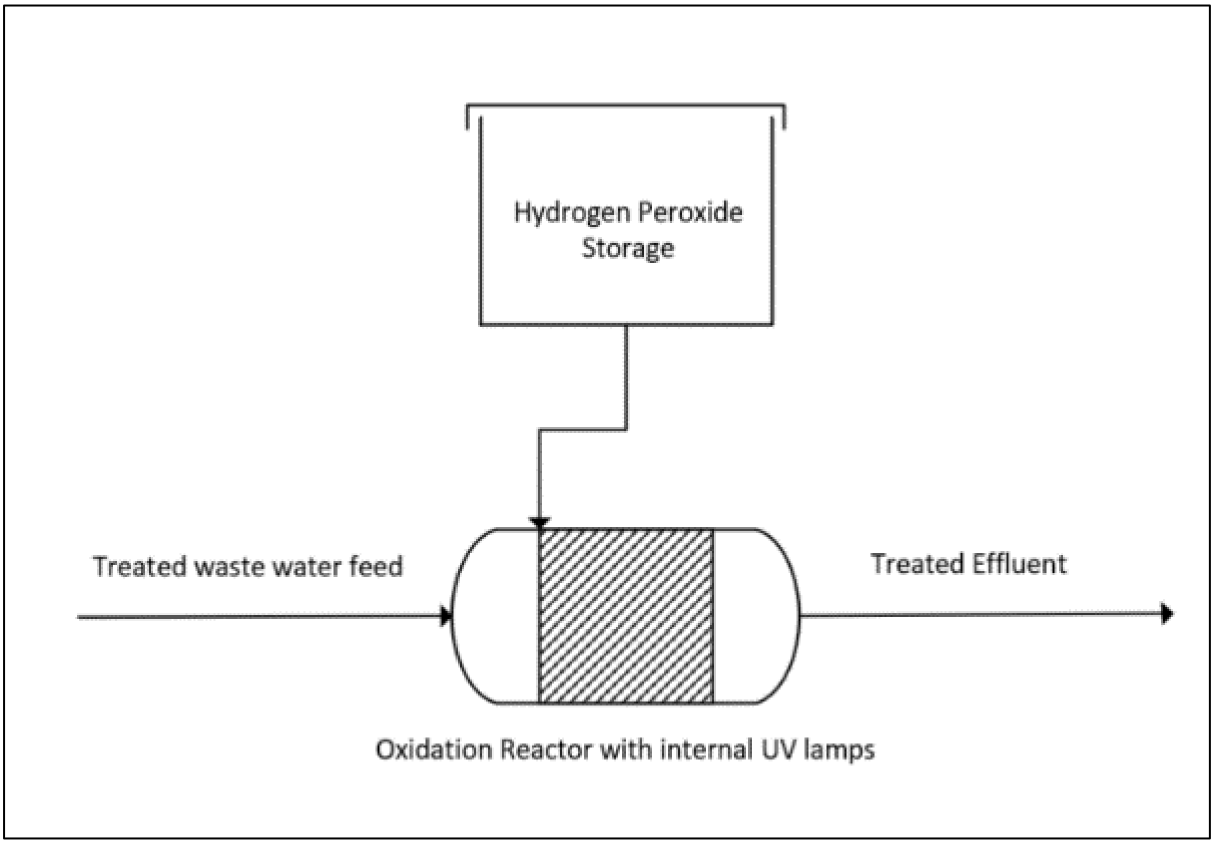


Figure 10: Typical Advanced Oxidation process based on hydrogen peroxide and ultraviolet light as reagents.

The advantages and disadvantages of this technology are listed below.

Advantages:

- The reactions occur quickly, and efficiently reduce the COD in the effluent with minimum retention times required;
- The process has a small footprint;
- Hydrogen Peroxide is a relate inexpensive reagent and depending on the usage requirement for the specific process it may have significant impact on OPEX;
- No waste stream is generated in this process.

Disadvantages:

- Process is susceptible to the presence of chemical scavengers that may lead to higher reagent consumption and as such operating cost;
- The process is will require additional UV input to compensate for hydrogen peroxides low absorption rate;
- Residual hydrogen peroxide in the treated water may not be desirable depending on the ultimate use;
- Ultraviolet light generation introduces an additional source intensive power use;
- UV lights are prone to fouling and will require regular maintenance;

- High quality of operational staff will be required in order to operate the process to achieve optimum treatment conditions.

Associated risks with the technology option:

- Treatment plant operators will need to be skilled to maintain optimum process conditions and regular intervention will be required;
- Additional reagents onsite pose an additional health risk and operations will have to be trained in accordingly;

High level permitting considerations:

- The addition of additional ozone generating equipment should be considered in terms of the correct handling, storage and use according to the regulations applicable.

7.2.2 Membrane / Media Filtration Technology

Filtration forms a vital part of water treatment to potable or other reclaimed water qualities. There are numerous filtration technologies available, with each one addressing a specific need within a treatment train. Filtration is employed to address some of the following needs within a process train:

- Removal of excess suspended solids / colloidal particles;
- Lowering of turbidity;
- Absorption of constituents and organic material left over from other processes;
- Removal of viruses;
- Removal of bacteria;
- Lowering of TDS;
- Near-complete desalination;
- Protection for downstream process units.

Filtration processes are generally split into two categories: media filtration and membrane filtration. The first is employed mainly for suspended solids removal or absorption of constituents through the use of different types of media such as sand or activated carbon. The latter is employed for the removal of viruses, bacteria and lowering of TDS where required. For this study, the following filtration processes were considered:

- Rapid Gravity Sand Filtration;
- Pressurised Sand Filtration;
- Granular Activated Carbon Filtration;
- Ultrafiltration;

- Nanofiltration;
- Reverse Osmosis.

These technologies have been evaluated as they would typically be employed to achieve reuse water quality as part of a reclamation scheme following the plant design laid out in section 6.2.

7.2.2.1 Rapid Gravity Sand Filtration

The technology is a tried and tested process for the removal of suspended solids and would typically be installed after a final clarification process of a WWTW, at the start of the reclamation process. This would ensure that, should there be carry-over from the final clarification step, most of these suspended solids would be removed and not impede the downstream processes.

The filters typically consist of a concrete structure housing a drainage collection system and filled with coarse sand. The wastewater (treated effluent) is fed to the top of the structure where it then gravitates through the media to the collection system. These filters require backwashing typically once or twice a day, but otherwise very little interference is required in general operations. The wash water from the backwash operation is typically returned to the head of works of the WWTW.

These filters may be used in conjunction with a flocculant (Alum) dosed prior to the filter feed to enhance the capture of smaller particles but this is generally assessed on a case by case basis. Provision should be made to supply adequate wash water for the backwash cycles (product water from the filter is used for this purpose).

Figure 11 shows the typical illustration of the main elements of a rapid gravity sand filter.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below in Table ***15Table 16***.

Table 16: Typical design values for a 10 MLD Rapid Gravity Sand Filter process.

Parameters	Units	Value	Notes
Filter structure footprint	m^2	210	Typically, 3 to 4 units for a 10 MLD flow
Loading rate	m/h	5.5	Hydraulic rate typical for final effluent
Backwash Duration		2 x daily	Based on 2 - 10 min per wash
Backwash Flowrate	m/h	30	
Power Consumption	kWh/d	N/A	Negligible due to limited backwash requirements.
Capital cost	R mil	15	Limited to cost of civil structures and mechanical equipment

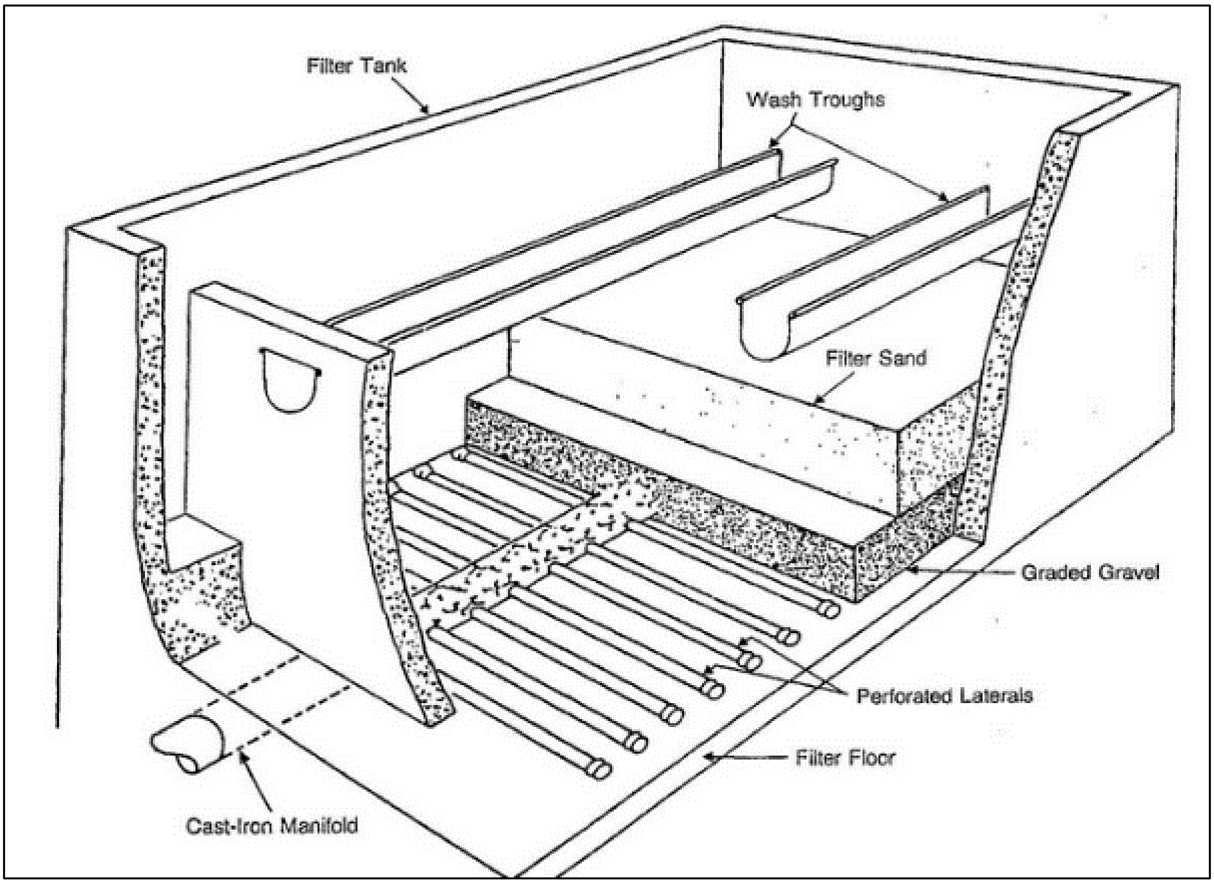


Figure 11: Typical example of a Rapid Gravity Sand Filter

The advantages and disadvantages of this technology are listed below.

Advantages:

- Gravity fed with little to no additional power requirements should a hydraulic gradient be available onsite, this would typically be accommodated for in a greenfield site. (only backwash pump);
- Established process technology with robust performance;
- The filtrate backwash is the only waste stream generated and is most commonly returned to the returned to the Head of Works of the WWTW. It typically does not require additional treatment and would only slight add to the hydraulic and solids load to the works.
- No need for highly trained operational staff.

Disadvantages:

- Large footprint in comparison to pressure filtration.;
- If not maintained correctly, short circuiting in the sand may occur and as such lead to solids breakthrough;
- Civil structure may be capital intensive.

Associated risks with the technology option:

- Treatment plant operators will need to ensure backwashing occurs as required to avoid short circuiting. These durations and frequencies may have to be adjusted from time to time depending on the feed water quality;
- Additional reagents onsite pose an additional health risk and operations will have to be trained in accordance (should a flocculant be required);

High level permitting considerations:

- Standard civil construction regulations applicable.

7.2.2.2 Pressure Sand Filtration

Pressure sand filtration is employed to remove suspended solids and lower turbidity and are often used as a protection step for filters sensitive to larger particles. The technology is widely available from a number of suppliers and functions according to the following principles: a pressurised feed, increased bed depth and higher hydraulic loading rate when compared to rapid gravity sand filtration. The process would typically be installed after a final clarification process of a WWTW at the start of the reclamation process. This would ensure that should there be carry over from the final clarification step that most of these suspended solids be removed and not impede the downstream processes.

The filters consist of a steel structure housing a drainage collection system and filled with coarse sand. The wastewater (treated effluent) is pressure-fed (pumped) into the top of the tank where it flows through the media to the collection system. These filters require backwashing typically once or twice a day, but otherwise very little interference is required in general operations (operations is generally automated). The wash water from the backwash operation is typically returned to the head of works of the WWTW. The filters will typically be arraigned in a battery consisting of several smaller filters to ease operations. Ancillary equipment such as feed and backwash pumps are typically shared between such units in a bank.

These filters may be used in conjunction with a flocculant (Alum) dosed prior to the filter feed to enhance the capture of smaller particles but this is generally asses on a case by case basis. Provision should be made to supply adequate wash water for the backwash cycles (product water from the filter is used for this purpose).

Figure 12 shows the typical illustration of the main elements of a pressure sand filter.

The indicative size of technology for comparative purposes, utilising the basis of design, is described below in Table ***15Table 17***.

Table 17: Typical design values for a 10 MLD Pressure Sand Filter process.

Parameters	Units	Value	Notes
Total filter area	m^2	42	Typically, 8 to 12 units for a 10 MLD flow
Loading rate	m/h	10	Hydraulic rate typical for final effluent
Backwash Duration		2 x daily	Based on 2- 5 min per wash
Backwash Flowrate	l/s	30	

Parameters	Units	Value	Notes
Power Consumption	kWh/d	500 - 600	
Capital cost	R mil	10 - 13	Limited to cost of civil structures and mechanical equipment

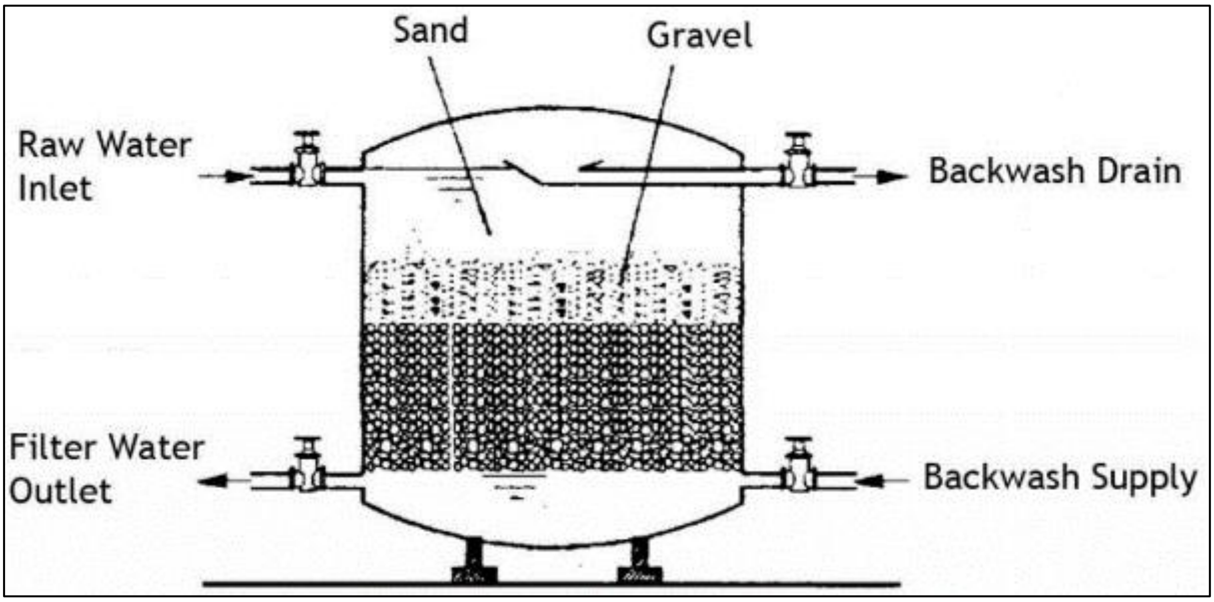


Figure 12: Typical example of a Pressure Sand Filter

The advantages and disadvantages of this technology are listed below.

Advantages:

- High hydraulic loading capacity and small footprint;
- Established process technology with robust performance;
- The filtrate backwash is the only waste stream generated and is most commonly returned to the returned to the Head of Works of the WWTW. It typically does not require additional treatment and would only slight add to the hydraulic and solids load to the works;
- No need for highly trained operational staff (filter plant operation is typically automated).

Disadvantages:

- If not maintained correctly short circuiting in the sand may occur and as such lead to solids carry over;
- Continuous pump feed raises OPEX.

Associated risks with the technology option:

- Treatment plant operators will need to ensure backwashing occurs as required to avoid short circuiting, these duration and frequencies may have to be adjusted from time to time depending on the feed water quality;
- Additional reagents onsite pose an additional health risk and operations will have to be trained in accordance (should a flocculant be required);

High level permitting considerations:

- Standard civil construction regulations applicable.

7.2.2.3 Granular Activated Carbon Filtration

Granular activated carbon filters are used for the removal of organic constituents and residual disinfectants. The process unit is often found either at the end of a process train or in front of a membrane filtration process unit. Activated carbon has a typical surface area of 1 000 m^2/g and is made from numerous raw materials (wood, coal, petroleum, nut shells etc.)

Activated carbon removes organic components through absorption and catalytic reduction of disinfectants. The absorption of organics leads to the requirement of replacing the spent media from time to time (wholly dependent on the operational circumstances of the bed in question).

Activated carbon filters are designed in a similar manner to pressure filtration vessels, with bed height ranging from 1 to 10 meters in depth and from 0.3 to 4.0 meters in diameter. Contact times range typically from 6 to 30 minutes, though there is significant variation between situations. Typical linear velocity rates though the bed range between 5 and 20 m/h.

The filters will typically be arraigned in a battery consisting of several smaller filters to ease operations (maintenance and media replacement/regeneration in particular). Ancillary equipment such as feed and backwash pumps are typically shared between such units in a bank. Provision should be made to supply adequate wash water for the backwash cycles (product water from the filter is used for this purpose).

Figure 13 shows the typical illustration of the main elements of a GAC filter.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below in ***Table 18***.

Table 18: Typical design values for a 10 MLD GAC process.

Parameters	Units	Value	Notes
Total filter area	m^2	35	Typically, 3 to 4 units for a 10 MLD flow
Loading rate	m/h	12	Hydraulic rate typical for final effluent
Backwash Duration		2 x daily	Based on 2- 5 min per wash
Backwash Flowrate	l/s	100	
Power Consumption	kWh/d	N/A	If gravity fed only backwash pumps
Cost of GAC media	R/m^3	4000- 7500	Depending on supplier and grade
Capital cost	R mil	14 - 18	Limited to cost of Civil structures and Mechanical equipment

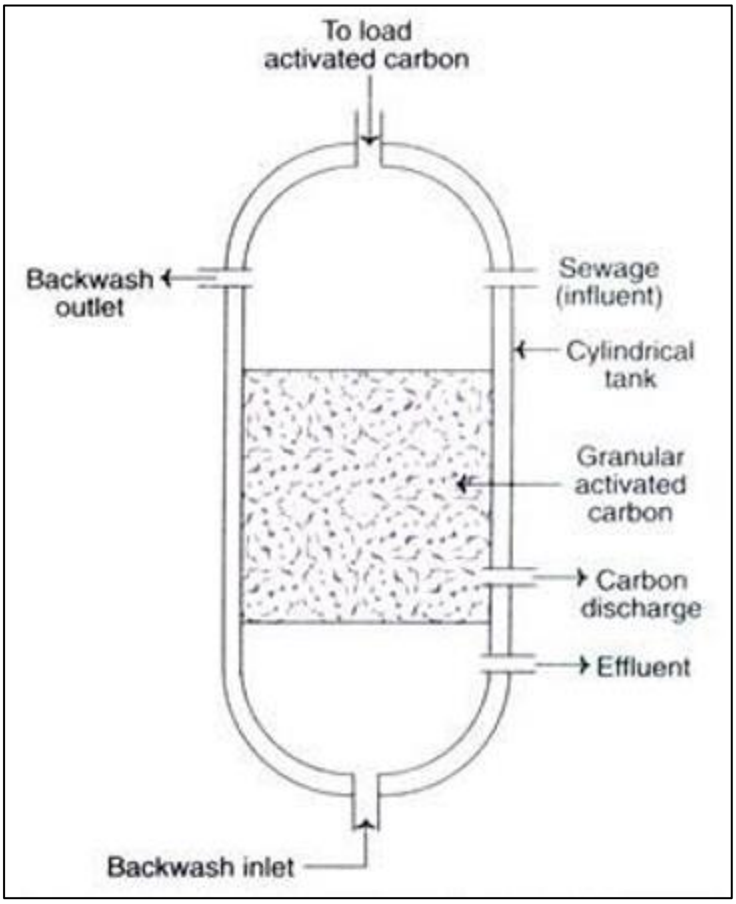


Figure 13: Typical example of a GAC Filter

The advantages and disadvantages of this technology are listed below:

Advantages:

- GAC absorbs organic material not removed through biological processes as well as capture small suspended solids that may remain still be present in the treated stream;
- It absorbs post disinfection contaminants such as chloramines;
- High surface area of GAC allows for greater surface area for reactions and absorption to take place in comparison with sand or similar filtration media. Resulting in a smaller footprint per available area;
- Filtrate backwash typically does not require additional treatment and is often returned to head of works. (contaminants are bounded to or within the GAC material);
- The process does not require intensive intervention as its operation is typically automated.

Disadvantages:

- If not maintained correctly short circuiting in the sand may occur and as such lead to solids carry over;
- GAC bed will have to be replaced from time to time as the GAC is absorption quality is spent. This replacement period is determined by the type of material to be absorbed and as such has a fast range from 6 months to a couple of years.

Associated risks with the technology option:

- Spent GAS should be disposed of in within the correct regulatory processes set out for such a media. This will largely depend on where in the process train these filters are installed;

High level permitting considerations:

- Standard civil construction regulations applicable.

7.2.2.4 Membrane Filtration

Membrane filtration are processes where waste water is "forced" via pressure through a semipermeable membrane to remove constituents from the waste water. Membrane filtration technologies are typically classified by the participle size it rejects. This is demonstrated in Figure 14 below. As is seen the appropriate membrane technology or combination thereof would be selected in terms of the treatment goal against the required constituent removal criteria.

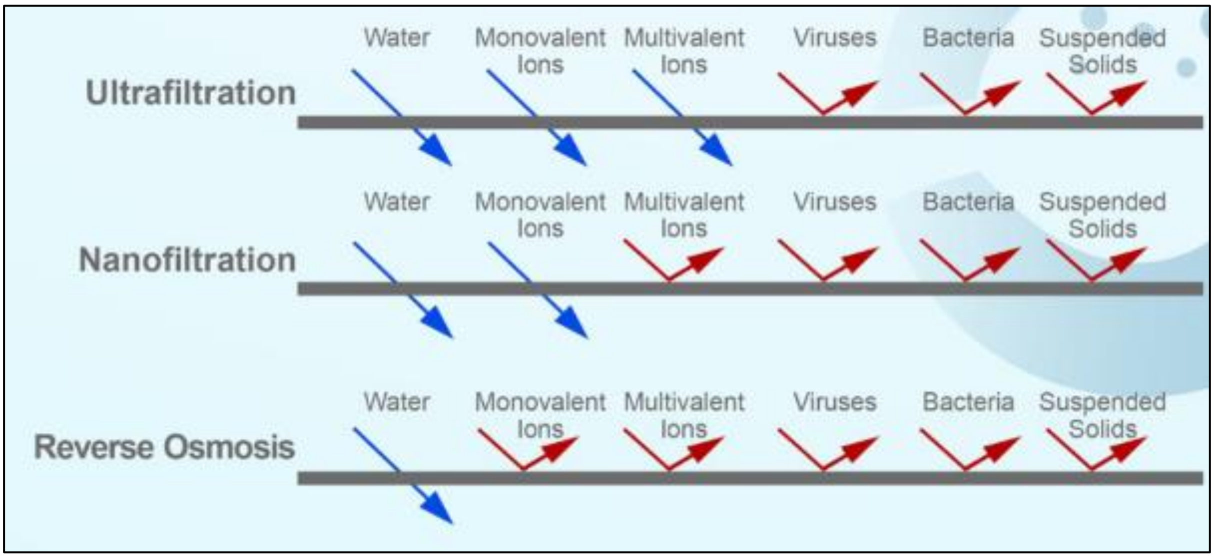


Figure 14: Membrane filtration rejection comparison

As an example, should the membrane process be employed only to remove residual suspended solids, viruses and bacteria an Ultrafiltration (UF) membrane process step would be sufficient. If partial or near total desalination is required (removal/lowering of TDS) then Nano (NF) and Reverse Osmosis (RO) filtration will be required. It should be noted that NF and RO processes is typically preceded by a UF treatment step to protect the more sensitive NF and RO processes.

Membrane filtration units for the advanced treatment and water recovery application will be in a pressurised vessel arrangement as is seen in Figure 15 below. All three of these systems will have a similar system layout with the main difference being the type of membrane in the pressure vessels, feed pumps. As the pose size of the membrane decrease by type so the feed pressure to the specific membrane rises.

Figure 15: Skid mounted membrane pressure vessel installation

A typical layout of these system is displayed in Figure 16 below.

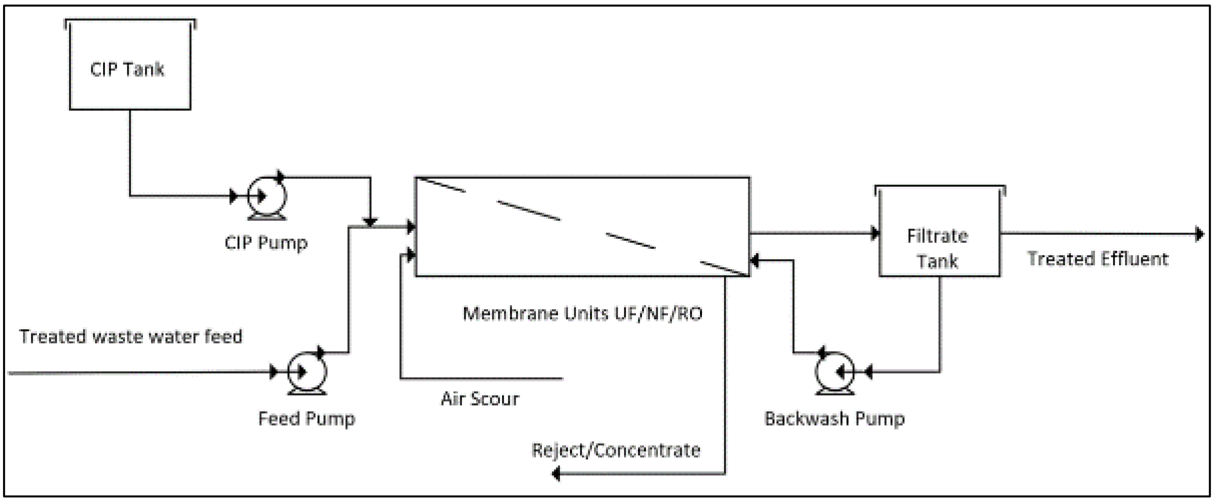


Figure 16: Generic membrane system layout (UF, NF and RO)

7.2.2.4.1 Ultra Filtration

Ultrafiltration removes particles of up to 0.01micron in size this included viruses and bacteria as well as residual fine suspended solids. The technology is typically employed as a polishing and safety step prior to final discharge of water, or as a precursor to either NF or RO processes as a safe guard. The UF reject typically does not require additional treatment and may be returned to the plant inlet.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below in ***Table 19***

Table 19: Typical design values for a 10 MLD UF process.

Parameters	Units	Value	Notes
Membrane skid layout		4/1	4 duty and 1 standby unit
Product recovery	%	92	Typically, 85 to 95
Typical operating Flux	$L/m^2.h$	34	Typical 30 - 60
Constituent rejection rate	%	>90	> 96 For TSS with Viruses and Bacteria have a Log 3- 6 rejection value. i.e. near 100% rejection
Operating pressure	kPa	300	Typical 65 - 350
Power consumption	kWh/ m^3	0.15	0.2 – 0.3
Chemical cost	R/m^3	0.15	Variable
Capital cost	R mil	13.5	Limited to cost of Membrane Skids and related Civil structures (plinths) and Mechanical equipment

The advantages and disadvantages of this technology are listed below:

Advantages:

- Removal viruses and bacteria to non-detectable levels.
- UF reject typically does not require further treatment;
- Complete removal TSS and NTU reduced to <0.1;
- Comparatively low operating pressure leads to reduces power consumption;
- Treated water may meet irrigation standards depending on the TDS requirements.

Disadvantages:

- No removal of TDS;
- Membranes will require replacement at regular intervals and as such will lead to higher OPEX cost;
- High quality of operational staff will be required in order to operate the process to achieve optimum treatment objective and safeguard the membranes from possible damage;
- Chemical consumption may vary due to changes in incoming water quality and as such may vary.

Associated risks with the technology option:

- The technology is sensitive to changes in the incoming water quality and may run the risk of fouling (additional cleaning or replacement of membranes) and or not achieving the desired final water quality;
- Additional reagents onsite pose an additional health risk and operations will have to be trained in accordance;

High level permitting considerations:

- Additional reagent onsite will have to be considered in terms of the correct handling, storage and use of the regents in terms of the regulations applicable.

7.2.2.4.2 Nano Filtration

Nano filtration removes particles of up to 0.001micron in size (molecular range in size typically di-valent molecules). It is typically employed for the reduction of TDS following a UF process step. The technology typically removes between 40 and 60 % of TDS in the stream depending on the overall makeup of the TDS. This will typically enable the product water to meet irrigation standards and even potable water standards. It should be noted that the TDS makeup and concentration would be the determining factor for reaching these standards and will have to be asses on a case to case basis.

The reject from the NF process will have elevated TDS and as such might not be suitable for release to the environment without additional treatment. Reject from the NF process would typically be routed to an evaporation dam. Additional treat is costly and will have to be selected in accordance with the final disposal objectives.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below in Table ***20***.

Table 20: Typical design values for a 10 MLD NF process.

Parameters	Units	Value	Notes
Membrane skid layout		4/1	4 duty and 1 standby unit
Product recovery	%	85	Typically, 85 to 90
Typical operating Flux	$L/m^2.h$	34	Typical 14 - 20
Constituent rejection rate	%	>90	40 – 60% of TDS total
Operating pressure	kPa	520	Typical 500 - 1400
Power consumption	kWh/m^3	0.375	0.4 – 0.5
Chemical cost	R/m^3	0.15	Variable
Capital cost	R mil	14.8	Limited to cost of Membrane Skids and related Civil structures (plinths) and Mechanical equipment

The advantages and disadvantages of this technology are listed below:

Advantages:

- Removal of 40 – 60 % of TDS (multi-valent).
- Favourable power consumption over RO due to lower operating;
- Treated water may meet irrigation and or potable water standards depending on the TDS requirements.

Disadvantages:

- Requires an UF process step as protection;
- Reject stream will require additional treatment prior to disposal/discharge;
- Membranes will require replacement at regular intervals and as such will lead to higher OPEX cost;
- High quality of operational staff will be required in order to operate the process to achieve optimum treatment objective and safeguard the membranes from possible damage;
- Chemical consumption may vary due to changes in incoming water quality and as such may vary.

Associated risks with the technology option:

- The technology is sensitive to changes in the incoming water quality and may run the risk of fouling (additional cleaning or replacement of membranes) and or not achieving the desired final water quality;
- Additional reagents onsite pose an additional health risk and operations will have to be trained in accordance;

High level permitting considerations:

- Additional reagent onsite will have to be considered in terms of the correct handling, storage and use of the regents in terms of the regulations applicable.

7.2.2.4.3 Reverse Osmoses Filtration

Reverse osmoses filtration removes particles of less than 0.001micron in size (molecular range in size typically down to mono-valent). RO filtration is employed for the complete desalination processes with TDS removal rates of as high as 98%. The product water will meet irrigation and drinking water standards and may even require remineralization to depending on the final use. The system functions though the high applied pressure through the selective membrane to overcome osmotic pressure. The system is sensitive to feed water quality changes and should not be employed without a prior UF process step.

The reject/brine from the RO process will have significantly high TDS levels and as such is not suitable for release to the environment without additional treatment. RO reject is typically stored in an evaporation dam, alternative treatment to lower the TDS in the brine stream are available but would typically be cost prohibitive (such as flash distillation).

Often in RO systems are designed with multiple stages to reduce the amount of brine. This is done by feeding the subsequent stage with the reject from the prior stage. With such a system an overall recovery of up to 99% is possible, this is a 10 – 15 fold decrease in the amount of brine. Significantly reducing the disposal and treatment cost. The cost of the additional stages most often far outweighs the increase in OPEX and CAPEX of the RO system.

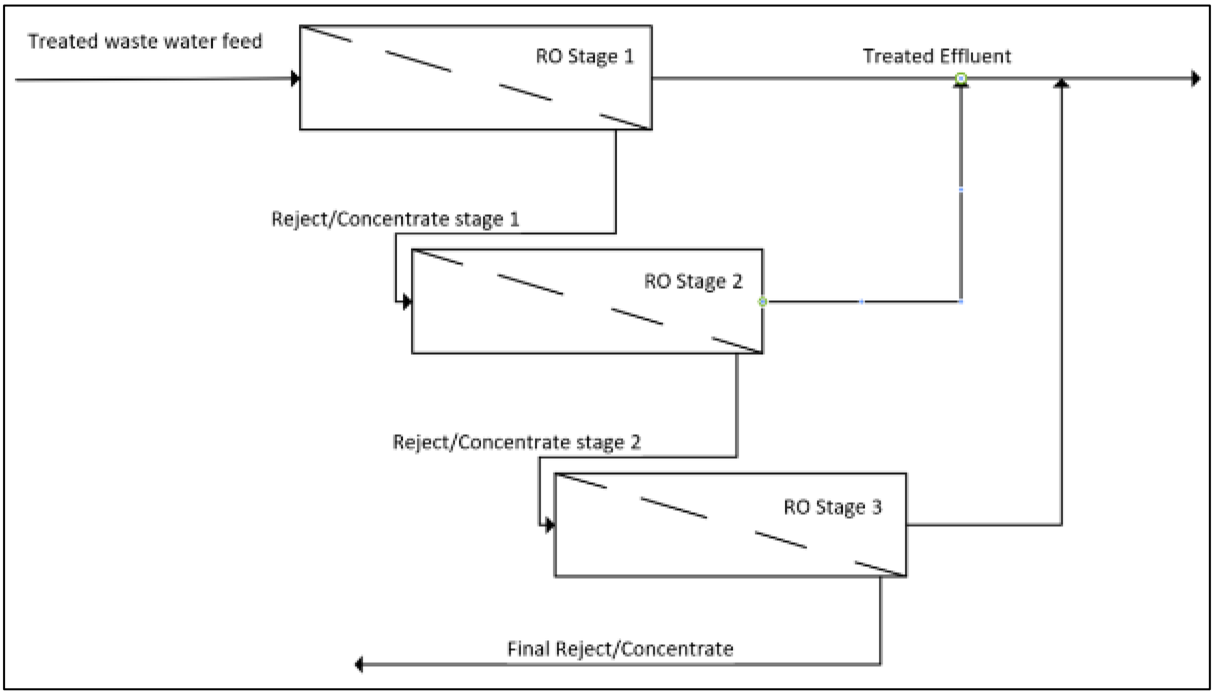


Figure 17: Example of a 3 stage RO filtration system flow.

Reject from the NF process would typically be routed to an evaporation dam. Additional treat is costly and will have to be selected in accordance with the final disposal objectives.

Indicative size of technology for comparative purposes utilising the basis of design as is set out above is described below in ***Table 15***Table ***21***.

Table 21: Typical design values for a 10 MLD RO process.

Parameters	Units	Value	Notes
Membrane skid layout		4/1	4 duty and 1 standby unit
Product recovery	%	85	Typically, 80 to 85
Typical operating Flux	L/m^2.h	34	Typical 14 - 20
Constituent rejection rate	%	>95	90 – 98% of TDS
Operating pressure	kPa	640	Typical 600 - 1900
Power consumption	kWh/ m^3	0.64	0.5 – 0.65
Chemical cost	R/m^3	0.15	Variable

Parameters	Units	Value	Notes
Capital cost	R mil	14.8	Limited to cost of Membrane Skids and related Civil structures (plinths) and Mechanical equipment

The advantages and disadvantages of this technology are listed below:

Advantages:

- Removal of up to 98% of TDS (desalination).
- Treated water will meet irrigation and potable water standards.

Disadvantages:

- Requires an UF process step as protection;
- Reject stream will require additional treatment prior to disposal/discharge (expensive brine dam or an extended multi stage system);
- Membranes will require replacement at regular intervals and as such will lead to higher OPEX cost;
- High pressure operation leads to increase in OPEX;
- High quality of operational staff will be required in order to operate the process to achieve optimum treatment objective and safeguard the membranes from possible damage;
- Chemical consumption may vary due to changes in incoming water quality and as such may vary.

Associated risks with the technology option:

- The technology is sensitive to changes in the incoming water quality and may run the risk of fouling (additional cleaning or replacement of membranes) and or not achieving the desired final water quality;
- Additional reagents onsite pose an additional health risk and operations will have to be trained in accordance;

High level permitting considerations:

- Additional reagent onsite will have to be considered in terms of the correct handling, storage and use of the regents in terms of the regulations applicable.

7.3 Sludge Digestion, Biogas Generation and Optimization

The anaerobic digestion of sludge stemming from the main treatment reactor as well as the primary sedimentation tanks both stabilizes the sludge and produces methane gas. This section will focus on beneficiation of this sludge through the production of biogas for use as a source of energy. The section will inform on different anaerobic digestion technologies, options to increase methane production as well as option to biogas treatment and finally biogas utilization most applicable to municipal sludge treatment.

7.3.1 Overview of the Biogas Generation, Treatment and Utilization System

Figure 17 below shows a schematic of a typical biogas generation, treatment and utilization system. The biogas generation on the schematic consists of biogas reactors, biogas storage, digestate tank and digestate storage. The biogas treatment section consists of gas drying, pressurization, flaring, heating, desulfurization and air dosing. The utilization section consists of a biogas boiler and a combined heat and power. Biogas upgrading to biomethane is not considered in this section as the scope is limited to heat and electricity generation.

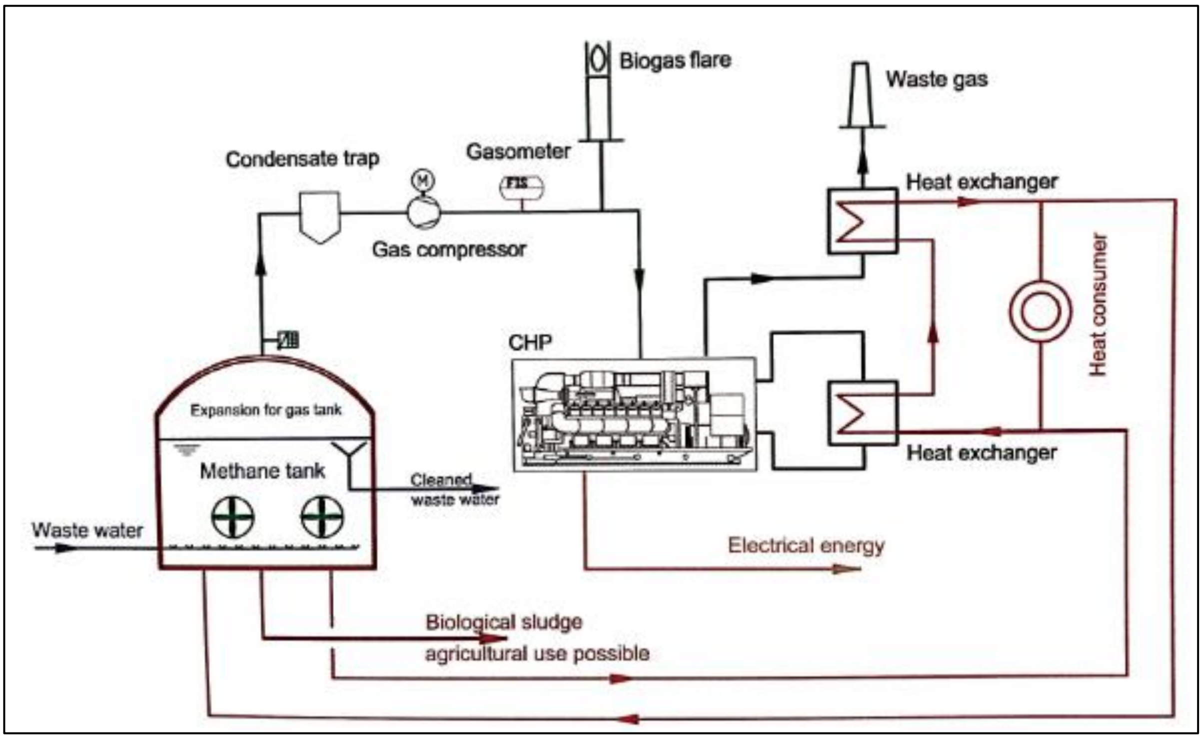


Figure 18: Biogas Generation, Treatment and Utilization from WWTW sludge.

Typical Biogas Generation Process is as follows: Primary and secondary sludge will be fed into a premix pit/well for chemical dosing. The waste sludge will be fed into the digester tank for biogas generation and chemical desulphurization. Biogas will be transferred into a gas storage tank while the digestate left will be transferred into a digestate tank. Biogas will then be transferred to the gas treatment section of the plant. For the purpose of this study it is assumed that the anaerobic digestion will take place within the Mesophilic operating range.

Table 22 Biogas Parameters of the Sewage sludge

Substrate	DM [%]	VS [%DM]	Methane yield [$m^3 CH_{4,N}/t_{VS}$]	Methane yield of fresh substrate [$m^3 CH_{4,N} / t_{FM}$]
Sewage sludge	4	70	315	9
http://www.archea-biogas.de				

For a 10 MLD plant the amount the amount of gas to be generated can be determined as follows:

1. Total BOD = 350 x 10^{-3} kg/l x 10 000 000 l/d = *3 5000 000 kg/day*
2. Total Biomass (FM) generated by the aerobic process (**0.5 kg /BOD**) = 3 500 000 kg/day x 0.5 = *1 750 000 kg/day*
3. Methane Yield (9 m^3/ t_{FM}) = 1 750 t/d x 9 m3 = 15 750 m3/d (CH_4) = 656.3 m^3/h
4. Electrical Demand = 656.3 m3/h x 6 kWh/m3 = *3 938kW*
5. Annual Electrical Energy Production = 3 938 kW x 8760 h = *34 496 880kWh*
6. Power requirements of the Aerobic Process (**0.75 kWh/kg COD**) = 0.75 kWh/kg COD x 0.750 kg/L x 10 000 000L = *5 625 000 kWh*
7. Amount of digestate produced (**20%** of aerobic process) = 20% x 1 750 000 kg/day = *350 000kg/day*

7.3.2 Pre- treatment of Sewage Sludge

Sewage sludge can be treated outside the reactor to enhance the digestion process. Studies using microwaves as a pre-treatment method has shown the following results:

That the quantity of biogas produced with and without pre-treatment using continuous microwave pre-treatment for 5 minutes and 15 minutes enhances the anaerobic digestibility rate and biogas production by 38.5% and 11.9% respectively compared to intermittently pre-treated sewage sludge sample which only increases by 15.4% and 4.8%. The additional quantity of biogas has shown to be able to increase potential green energy to 45% from current 7% which can offset the energy usage generated by fossil fuels and reduces the CO_2 emission to generate energy from fossil fuels. The replacement of green energy has potential to reduce annual CO_2 emission by 4,329.6 ton for a modern mechanized STP for 250,000 population equivalents in urban setting.

The table below shows the efficacy of short continuous treatment over long intermittent treatment. The short continuous treatment with microwaves shows high efficiency with regards to the amount of gas produced and the amount of fossil fuels can be offset due to the use of sewage sludge pre-treatment.

Table 23 Comparison between continuous and intermittent sludge pre-treatment

Type of heating	Time (minutes)	Power (W)	Energy Supplied (kJ)	Biogas Produced (L)	Green Energy Potential from Biogas (kJ)	Efficiency %
Continuous	5	80	64.8	5.4	31.59	48.8
Intermittent	5	80	64.8	4.5	26.33	40.6
Continuous	15	80	201.6	4.7	27.5	13.6
Intermittent	15	80	198.0	4.4	25.74	13%

7.3.3 Thermophilic Digestion

Although mesophilic digestion is the focus of the technology review it is beneficial to briefly look at what thermophilic digestion could offer. Thermophilic process is reached by heating the reactor sufficiently past the 35 – 38 deg required for mesophilic digestion. This will increase the increase biogas yield and reduce the hydraulic retention time (see Table ***24***) as the application of heat to the reactor speeds up the reaction. Figure 19 below shows an example of such a heating arrangement within a digester.

Figure 19 Digester with water heating pipes from Thermophilic process

Thermophilic process operates at a temperature range of between 55 – 58 Degrees Celsius and it has the lowest hydraulic retention time. It is the most efficient anaerobic digestion process, but it requires more sophisticated process control as it is more sensitive to slight temperature changes and the presence of ammonia.

Table 24 Comparison of HRT and operating temperature of Biogas processes

Temperature range	Related HRT
psychrophilic (~10-25°C)	~40-60 days
mesophilic (~35-38°C)	~25-35 days
thermophilic (~55-58°C)	~15-25 days

Higher temperatures require more energy, but the biogas yield is also higher. The thermophilic process is comparatively less stable than the mesophilic process. Thermophilic bacteria are more sensitive to temperature fluctuations of ±1°C, while mesophilic bacteria tolerate variations of ±3°C. Furthermore, thermophilic bacteria react more sensitively to higher ammonia concentrations. In general, thermophilic biogas plants require greater controlling and monitoring efforts.

The table below shows advantages and disadvantages of the thermophilic process.

Table 25 Advantages and Disadvantages of Thermophilic process

Thermophilic Process - Disadvantages	Thermophilic Process - Advantages
Higher heater energy demand	Increased gas output due to the faster reaction; higher methane gas content and reduces hydrogen sulphide content in the biogas
Sludge water's quality getting worse	Staying-duration shorter
Sensitivity to the sudden temperature fluctuation, more precise temperature regulation demand	Smaller reactor volume demand
sensitivity to the toxic heavy metals	More pathogen destruction
	Sludge's dehydration improves
	Reduced foam formation in the reactor

7.3.4 Anaerobic Digestion Reactor Technologies

This section will focus on a number of anaerobic digestion processes with focus on main digestion reactor.

7.3.4.1 Anaerobic Contact Process (ACP)

This process is essentially an anaerobic activated sludge process. It consists of a completely mixed reactor followed by a settling tank. The settled biomass is recycled back to the reactor which leads to SRT being longer than HRT. ACP is able to maintain high concentration of biomass in the reactor and thus high slid retention time. The gasifier installed downstream of the digester allows the removal of biogas bubbles (CO_2, CH_4) attached to sludge which may otherwise float to the surface. It suitable for the treatment of wastewater containing suspended solids which render the microorganisms to attach and form settleable flocs.

Table 26 Anaerobic Contact Process performance parameters

Parameters	Units	Value	Notes
Loading Rate	Kg COD/m^3.d	2 - 5	

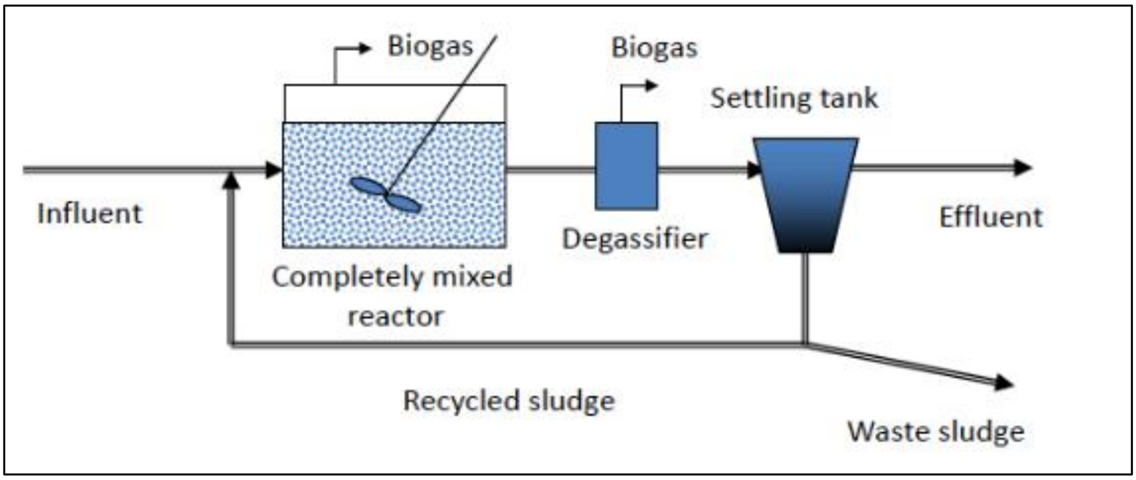


Figure 20 Anaerobic Contact Process

Advantages:

- Link between high biomass concentration, greater efficiency and smaller reactor size is the idea of ACP;
- Settling of anaerobic sludge in a settling tank and its return back to the reactor allows further contact between biomass and raw waste;
- In ACP, due to sludge recycling, the SRT is no longer coupled to the HRT as a result, considerable improvements in treatment efficiency can be achieved.

Disadvantages:

- Poor sludge settling from as anaerobic bacteria continue to produce gas in the settling tank;

- Multiple process units may increase operability complexities.

7.3.4.2 Upflow Anaerobic Filter

The reactor treats dilute soluble organic waste and the waste water is distributed across the bottom and the flow was in the upward direction through the bed of rocks. The whole filter is submerged completely, and anaerobic microorganisms accumulate within voids of media (rocks or other plastic media. The media retain or hold the active biomass within the filter. The non – attached biomass within the interstices forms a bigger floc of granular shape due to rising gas bubbles and it contributes significantly to waste treatment.

Table 27 Upflow Anaerobic Filter performance parameters

Parameters	Units	Value	Notes
Loading Rate	Kg COD/m^3.d	5 - 10	It is available in up flow (ANFU) and downflow(ANFD) configurations.
Hydraulic Retention Time	hours	0.5 - 4	
Potential Plant Capacity	m^3/hCH$_4$	164	
Investment Cost	R/m^3/h	39000	
Cost of operations & maintenance	% of Investment Cost		
Efficiency	90%		

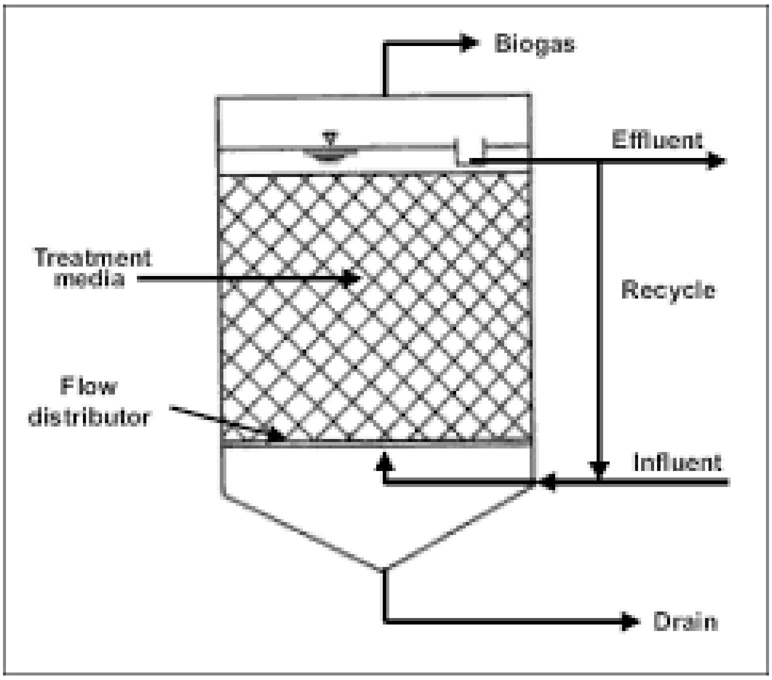


Figure 21 Upflow Anaerobic Filter Process

Advantages:

- The process's resistance to shock loads and inhibitions make anaerobic filter suitable for the treatment of both dilute and high strength wastewaters.

Disadvantages:

- Deterioration of the filter bed due to the gradual build-up of non-biodegradable biosolids;
- The bed deterioration may lead to channelling through the bed (it is therefore not suitable for treatment of waste waters with high solid contents);
- The introduction of a packing material that requires occasional replacement raises the OPEX cost.

7.3.4.3 Downflow Anaerobic Filter

Downflow anaerobic filter has a settling tank and a series of filter tanks that allows both sedimentation and floatation to take place. The digestion of dissolved solids take place in the series of filter tanks. The gas generated in the filter tanks is harvested from the outlet in the sedimentation tank. The use of series filter tanks allows high reduction of COD. The move from using rocks to synthetic filter media has resulted in void volume increasing from 40-50% to 85-95%. This new media also has a high specific area typically 100m^2/m^3.

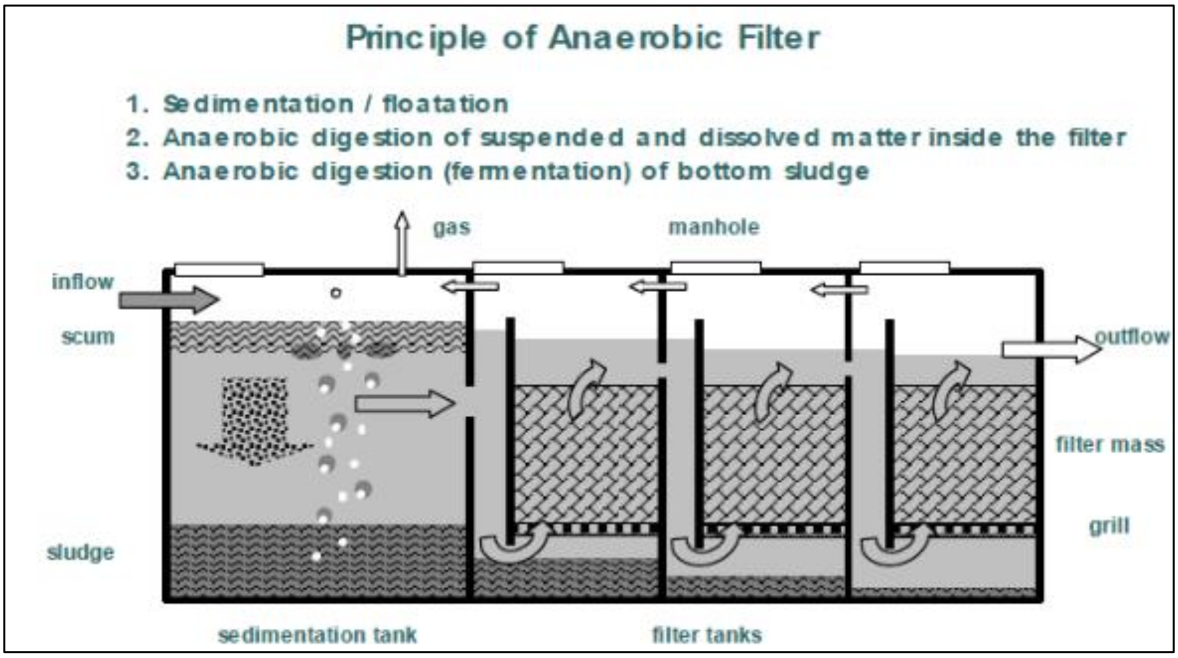


Figure 22 Downflow Anaerobic Filter process

The downflow reactor operates in a similar fashion to the up-flow. filter process and shares its advantages and disadvantages.

7.3.4.4 Upflow Anaerobic Sludge Blanket (UASB)

UASB is a very compact and highly efficient option for the treatment of wastewaters with high concentrations of organic compounds (COD loads between 3000 – 30 000 mg/l). Active bacteria form a suspension, which is retained inside the reactor. The substrate flows through this layer of active bacteria and is degraded into biogas. Compared to other wastewater applications, the treatment in a UASB reactor is more demanding. A well-functioning UASB can have elimination rates of 70 – 95% of the organic material (COD and BOD)

The following are key considerations of the UASB reactor:

- It requires a constant hydraulic load is required
- It is important to retain a constant temperature (34 – 39 Deg. Celsius) and constant pH (approx. 6)
- Wastewaters with high organic loads may necessitate the need to control the nutrient ratio e.g. by adding nitrogen

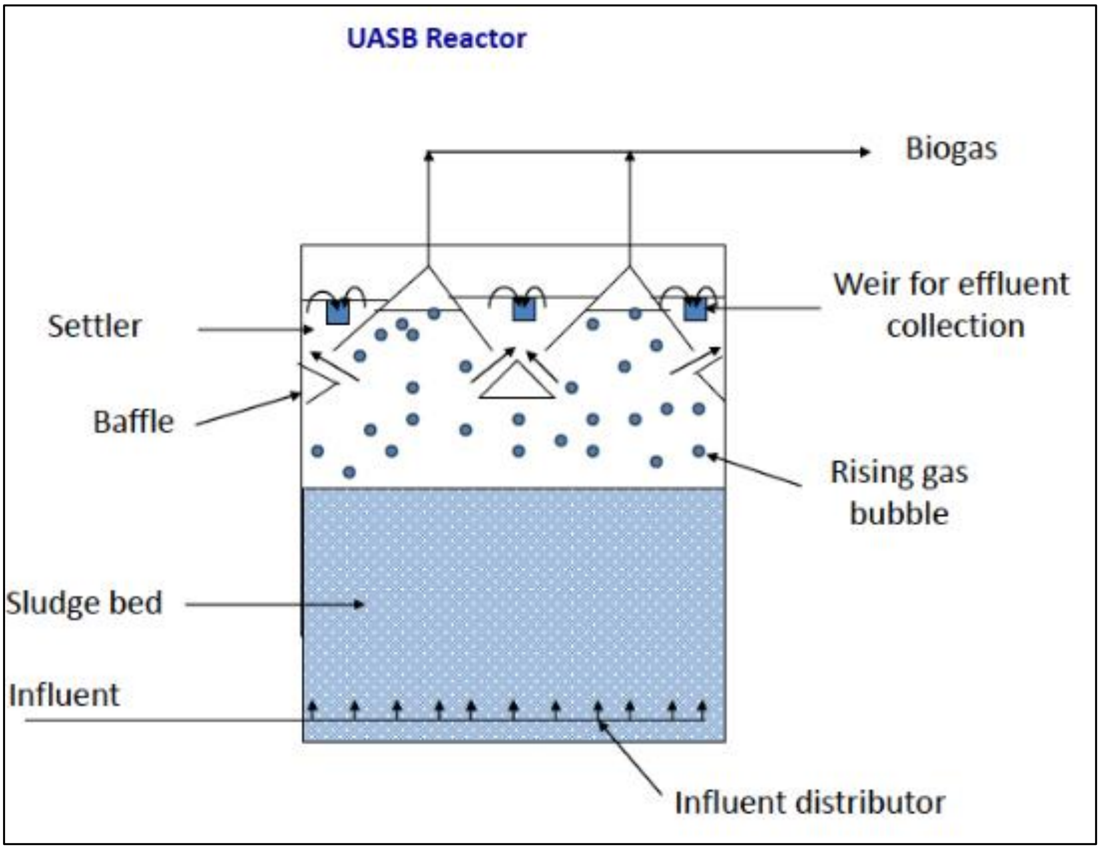


Figure 23 Upflow Anaerobic Sludge Blanket Process

Table 28 Upflow Anaerobic Sludge Blanket performance parameters

Parameters	Units	Value	Notes
Loading Rate	Kg COD/m^3.d	15 - 30	
Hydraulic Retention Time	hours	0.6	

Parameters	Units	Value	Notes
Potential Plant Capacity	m^3/hCH_4	173	
Investment Cost	$R/m^3/h$	47 000	
Cost of operations & maintenance	% of Investment Cost	2%	
Efficiency	In mesophilic conditions the organic load varies according to the characteristics of the substrate between 5 – 25 kg biogas COD/m^3.d.Hydraulic retention time is between 4 and 12 hours. Biogas production is related to the removal of organic matter and can reach values of 75 – 95 %. The methane concentration in biogas produced from UASB is always greater than 60%, and a specific methane production of $0.35Nm^3/kg$ COD removed can be considered.		

Advantages

- Reduction of organic loads with simultaneous energy use.
- Can treat combination of domestic and industrial sewage;
- The granular sludge that forms has superior settling characteristics over that of other anaerobically digested sludges.

Disadvantages

- Complex system that requires continuous monitoring and skilled operational staff in o order to maintain its process conditions;
- Due to the complexity and sensitivity of the reactor it is not suitable for a system with irregular and substantial fluctuations.

7.3.4.5 Agitated Lagoon Covered Lagoon

Agitated covered lagoon is an adaptation of complete mixed tank reactors. The biogas efficiency over non agitated covered lagoon is improved. Insulation of the lagoons against heat losses is not feasible, hence it only makes to implement these types of reactors in locations with warm climate. An external heat exchanger is required to maintain the required process temperature. Multiple substrates, e.g. manure and other pumpable or pre-treated material (DM 10 – 15%) can be treated.

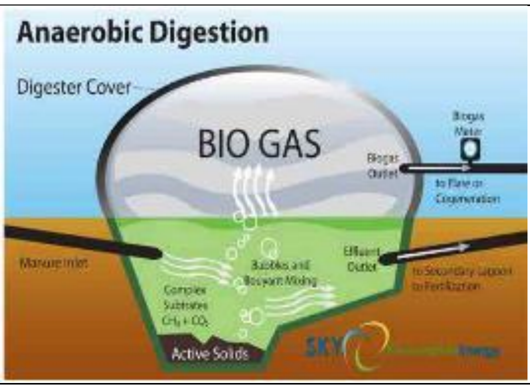


Figure 24 Agitated Covered Lagoon Process

Table 29 Agitated Covered Lagoon performance parameters

Parameters	Units	Value	Notes
Loading Rate	Kg COD/m^3.d	3	
Hydraulic Retention Time	hours	6	
Potential Plant Capacity	m^3/hCH_4	50 - 1000	
Investment Cost	R/m^3/h	8000- 13 000	
Cost of operations & maintenance	% of Investment Cost	1- 3	
Efficiency	Depends on ambient temperatures and the availability of thermal energy/heating equipment to heat up the digester to an optimal temperature. When completely agitated and optimal temperature range and efficiency comparable to CSTR with gas production rates depending on input substrate of approx.. 0.7 to >3m^3 Biogas/m^3 lagoon		

Advantages

- Economic agricultural alternative;
- Utilisation of otherwise beneficiated waste sources;
- Independence of feed commodities;
- Digestion increases the quality of the sludge for use as fertilisers.

Disadvantages

- Competition for agricultural land and other use;
- Operating costs and technical complexity for agriculture.

7.3.4.6 Single Tank Mixed Anaerobic Digestor

This digester utilizes primary and secondary sludge of the waste water treatment works. Since this kind of sludge have a very low solids contents, it is advisable to dehydrate the sludge to reduce the required digester volume. Interest in the application of co-substrates has increased significantly, due to the high yield and use of fat in grease traps in the process of co-digestion.

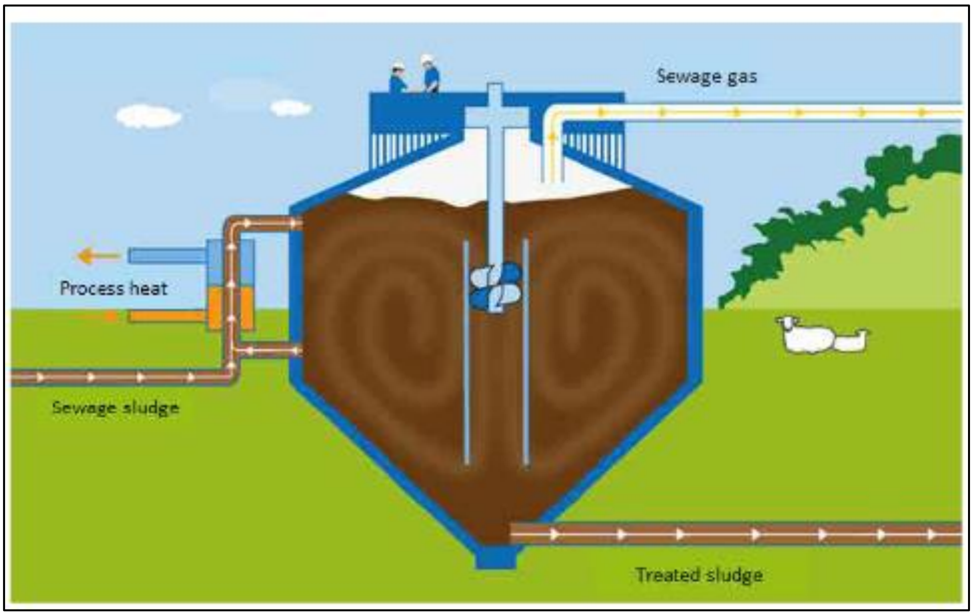


Figure 25 Anaerobic Digester for Sludge Treatment process

Table 30 Anaerobic Digester for Sludge Treatment performance parameters

Parameters	Units	Value	Notes
Loading Rate	Kg COD/m^3.d	4.5	
Hydraulic Retention Time	hours	4 - 8	
Potential Plant Capacity	m^3/hCH_4	50 - 2500	
Cost of operations & maintenance	% of Investment Cost	2- 4	
Efficiency	For biogas production of sewage sludge, an efficiency of 85% of organic dry matter degradation is estimated with specific biogas yields as indicated below: • Primary sludge: approx. 0.57 Nm^3/ kg$_{VS}$ • Excess sludge: approx. 0.33 Nm^3/ kg$_{VS}$ • Mixed sludge : approx. 0.43 Nm^3/ kg$_{VS}$		

Advantages:

- Greater energy efficiency in sewage treatment;
- Reduction of organic loads with energy use;
- Possibility of energy self-consumption;
- Reduced effluent load.

Disadvantages:

- More complex operation of Waste Water Treatment Works;
- If sludge is used for incineration, its calorific value is reduced.

7.4 Biogas Treatment & Upgrading

Biogas tends to contain moisture and trace impurities like hydrogen sulphide, ammonia and sometimes siloxanes. These impurities are detrimental for end use equipment of biogas – hydrogen sulphide and ammonia are very corrosive, and siloxanes result in hard abrasive deposits which wear internal combustion engines. In addition, the presence of carbon dioxide in appreciable concentrations makes the gas unsuitable to use as a fuel for automobiles or for injection into natural gas grid lines.

Therefore, before the biogas can be utilised, it needs to be dried, impurities need to be removed and the gas upgraded to the quality required.

7.4.1.1 Biogas Moisture Removal

The biogas leaving the digester is normally fully saturated with moisture. When the ambient temperature is lower than the dew point temperature of the biogas, the capacity of the biogas to hold moisture decreases and the excess moisture condenses. Condensed moisture in the biogas piping will result in:

- Pitting and corrosion of the blower impeller due to handling of impure water
- Corrosion of the biogas pipes.
- Corrosion of heat exchanger tubes.
- Contamination of activated carbon or siloxane filter where installed
- Corrosion of internal combustion engine.
- Reduction in the calorific value of the biogas

In order to remove the condensate that may form, the piping system should slope to ensure that the condensed water can accumulate at the lowest point. At this point, a condensate trap and condensate removal system must be provided.

Top of the digester condensate removal system	Inside of the condensate removal system

Figure 26: Digester Condensate removal system

7.4.1.2 Condensing Dryer

This type of dryer uses a refrigeration chiller to produce cold water which is used in a tube bundle heat exchanger to cool the biogas to a temperature below its dewpoint temperature. This forces the condensation of some moisture – the cooled biogas passes through a demister to knock out the droplets of condensation, which then accumulates and is taken out through the condensate trap. A final biogas temperature of between 20°C to 4°C is typically achieved.

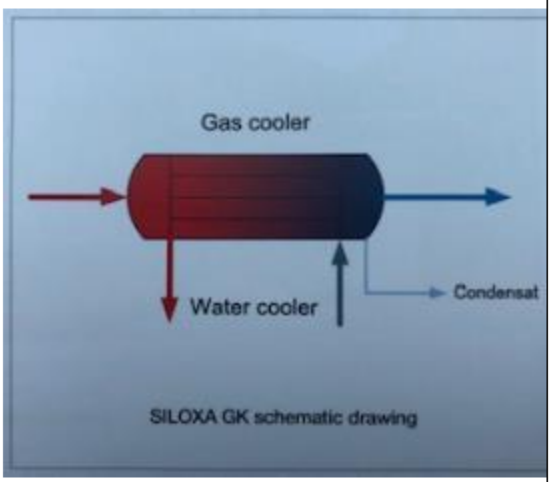
Refrigerated Power Dryer	Schematic of the condensing heat exchanger
	

Figure 27: Condensing dryer process

7.4.1.3 Adsorption Dryer

This system consists of two separate adsorbers that are used alternatively. Each vessel contains a packed bed of desiccant which allows dew points of as low as -80°C. The moist gas is passed though the desiccant bed which retains the moisture. The water molecules are deposited on the specific surfaces of the desiccant. When the desiccant is saturated with water, the system switches over to the second filter. Meanwhile the over-saturated filter is regenerated, using the process known as heat regeneration. Dried gas is heated and passed through the filter bed – increasing the temperature enables moisture to be removed from the desiccant. The gas then passes through a tube bundle heat exchanger where the water condenses out. After this, the regeneration gas is reheated and goes through the cycle again. Before beginning the regeneration cycle again, the heated filter is cooled to return to its initial operating status.

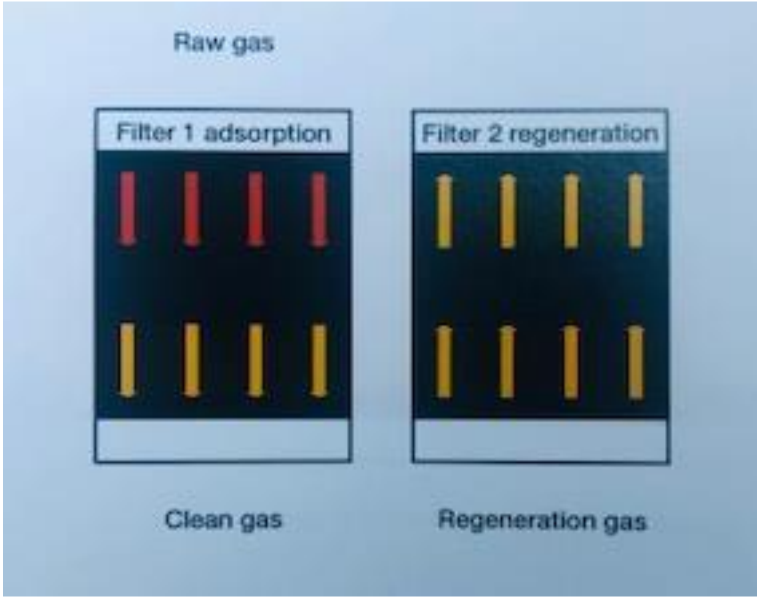


Figure 28: Adsorption dryer process

7.4.1.4 Removal of H_2S

Before biogas can be utilized, it is necessary to remove all harmful impurities that will negatively impact the functionality or efficiency of the utilizing equipment. The combination of sulphur and moisture in biogas results in the formation of sulfuric acid which is very corrosive to mild steel products. There are several methods of desulphurisation which can be categorised into biological, chemical and physical.

Biological Desulphurisation

Air is injected in the gas phase of the reactor and the same bacteria in the reactor result in the desulphurisation of the gas. This is a very cost-effective method, as no separate reactor is required for these processes to take place. The oxygen required for desulphurisation is generated by Pressure Swing Adsorption (PSA) .

Sulphate layer on the roof of the reactor	PSA System for Oxygen generation

Figure 29: Biological desulphurisation process

7.4.1.5 Trickle Bed Reactor

A trickle bed reactor is a continuously working application that uses specific microorganisms which oxidise sulphur into sulphate in an external reactor by using air which is injected into the reactor.

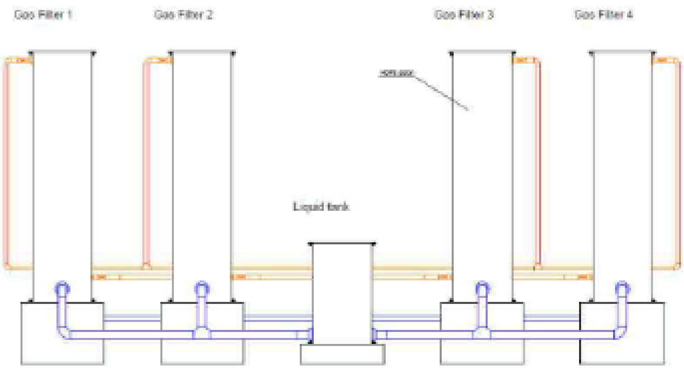
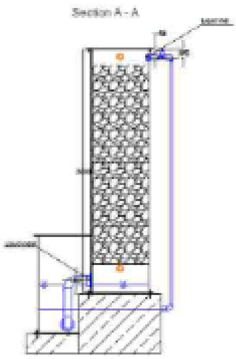
Four Trickle Bed Reactor configuration	The inside of Trickle Bed Reactor
	

Figure 30: Trickle Bed Reactor process

7.4.1.6 Water Scrubbing

In water scrubbing, water is used as an adsorbent for H_2S and CO_2 from the biogas. The biogas is compressed to 10bar before scrubbing. Usual methane contents of cleaned gas range around 97%. The electrical energy demand for this type of treatment ranges around 0.25 kWh/m3 treated raw gas.

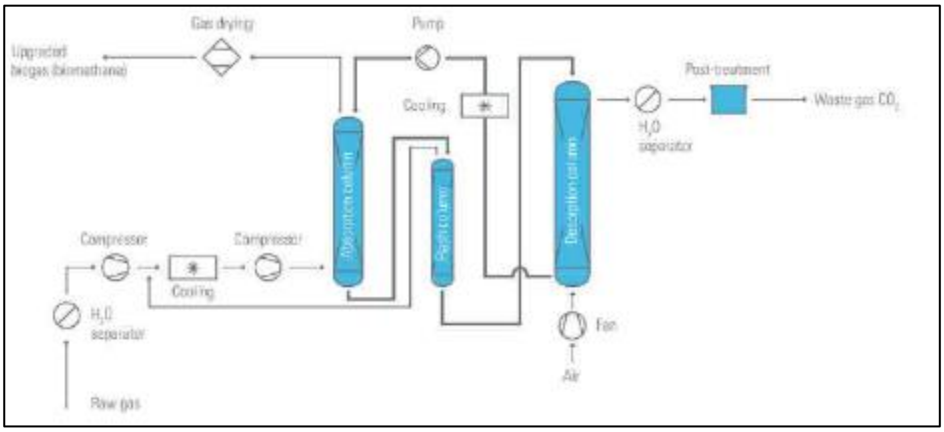


Figure 31: Water scrubbing process

7.4.1.7 Elimination of siloxanes by activated carbon adsorption

Biogas from organic wastes, or municipal or industrial wastewaters can contain increased concentrations of siloxanes. When combusted in gas engines, these form abrasive sediments inside the engine and lead to increased wear of mechanical components. Siloxanes therefore need to be removed from biogas before utilization.

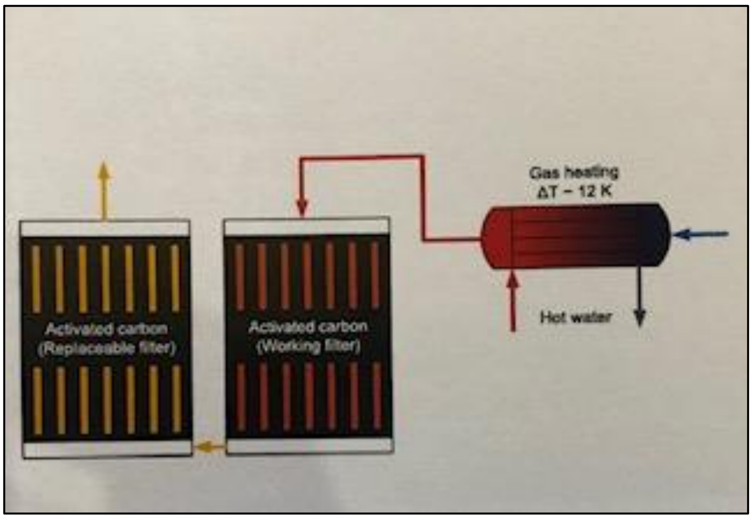


Figure 32 Removal of siloxanes using activated carbon

Biogas is sent to an external reactor filled with activated carbon to remove siloxanes. The holding time of the activated carbon filter needs to be designed according to the biogas siloxane load. Continuous analyses of the cleaned gas should be performed to guarantee timely replacement of saturated activated carbon.

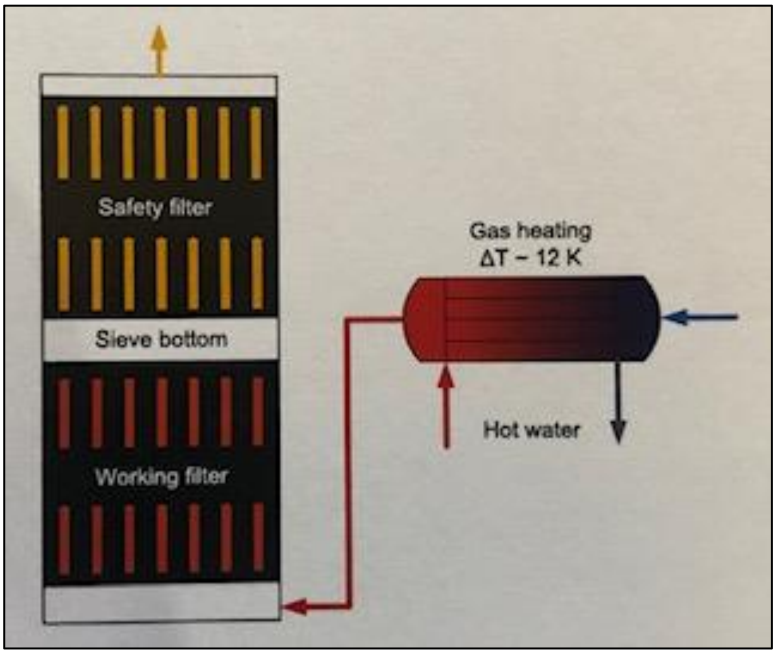


Figure 33 Siloxanes removal using a double filter system

7.4.1.8 Summary Comparison of gas cleaning technologies. Elimination of siloxanes by activated carbon adsorption

Below is the comparison of all gas cleaning processes discussed. The table provides a selection process and comparison in terms of process requirements. Electrical power and chemical reagent requirements of each process are shown.

Table 31 Comparison of Desulphurisation processes

Method	Energy demand electrical	Consumables		Air Injection	Purity ppm	Problem
		Consumption	Disposal			
Biological desulphurisation inside digester	yes	yes	no	yes	50 -2000	Imprecise process control
External biological desulphurisation	yes	yes	yes	Yes	50 - 100	Imprecise process control
Bioscrubber	yes	no	no	No	50 - 100	High process cost and complexity

Sulphide precipitation	0	yes	no	No	50-500	Sluggish process
Internal chemical desulphurisation	0	yes	yes	yes	1 - 100	Greatly diminishing purification effect
Activated carbon	0	yes	yes	Yes	<5	Large disposal

7.4.2 Biogas Upgrading

Injection of biogas into the gas grid or its use for mobility requires methane enrichment and the removal of contaminants. There are different processes to achieve this goal. Both chemical and physical processes can be used to remove carbon dioxide from biogas thereby increasing the methane concentration and the calorific value.

7.4.2.1 Amine Scrubbing

This is a chemisorption method, also called “rinsing with amine”. It uses a mixture of water and ethanolamine as a means of absorbing the undesired elements to be removed from the biogas, mainly CO_2 and H_2S. There is no need for pressurisation since regeneration takes place by heating. Post treatment is unnecessary because the process produces high purity gas with little loss of methane.

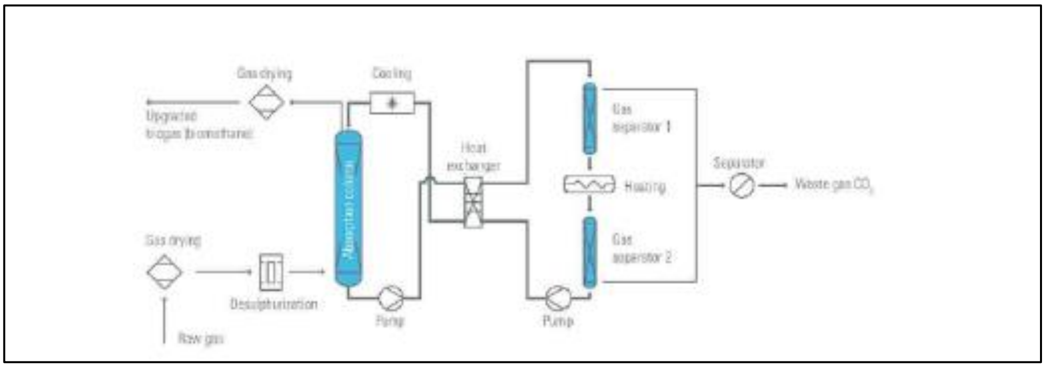


Figure 34: Amine Scrubbing process

7.4.2.2 Pressure Swing Adsorption

Pressure swing adsorption uses adsorbents (activated carbon, zeolite and carbon molecular sieves) to remove CO_2 from biogas. Other gas components (H_2O, H_2S, N_2 and O_2) can also be removed. Cleaned biogas has a methane content of greater than 96%. The electrical energy recoverable from this gas is around 0.25 kWh/m3 of treated gas.

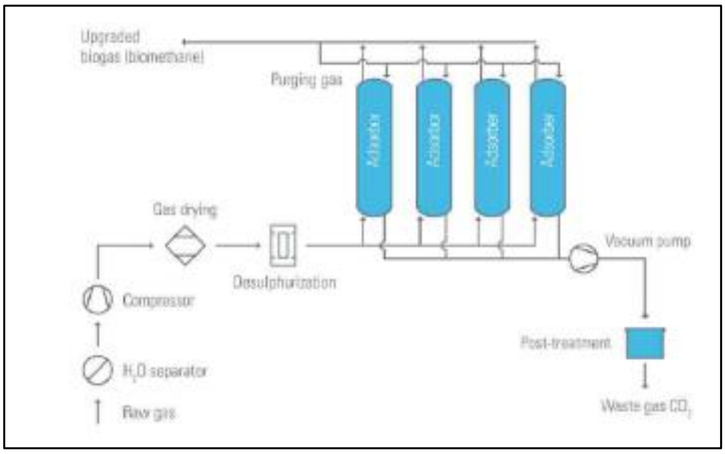


Figure 35: Pressure Swing Adsorption process

7.4.2.3 Gensorb Scrubbing

This is a physical process that uses a pressurised organic reagent (a mixture of polyglycols) as the adsorbent. Impurities (CO_2, H_2S and H_2O) are adsorbed during an increase of pressure in the adsorption column. The complete desorption occurs with a partial depressurisation by heating (50 – 80°C) and aeration of the washing solutions. There is a need for post treatment (oxidation/burning).

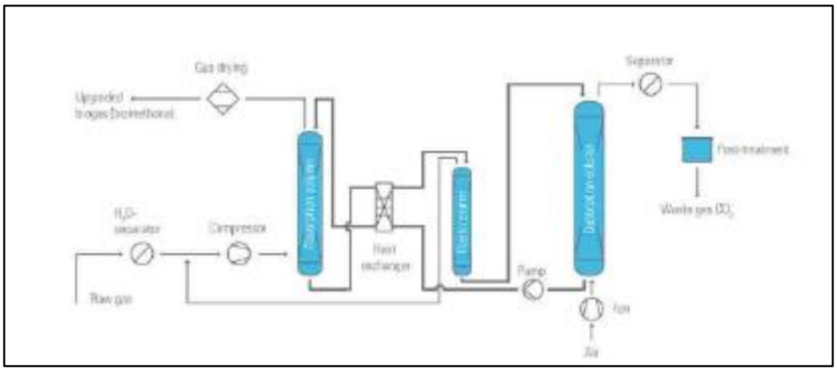


Figure 36: Gensorb scrubbing process

7.4.2.4 Membrane Separation

Membrane separation uses the difference between the permeability of polymer membranes to separate the gas of interest (CH_4), from dust and aerosols, thereby drying and de-sulphurising. As with physical desulphurisation, the disposal of the wash is preceded by post treatment.

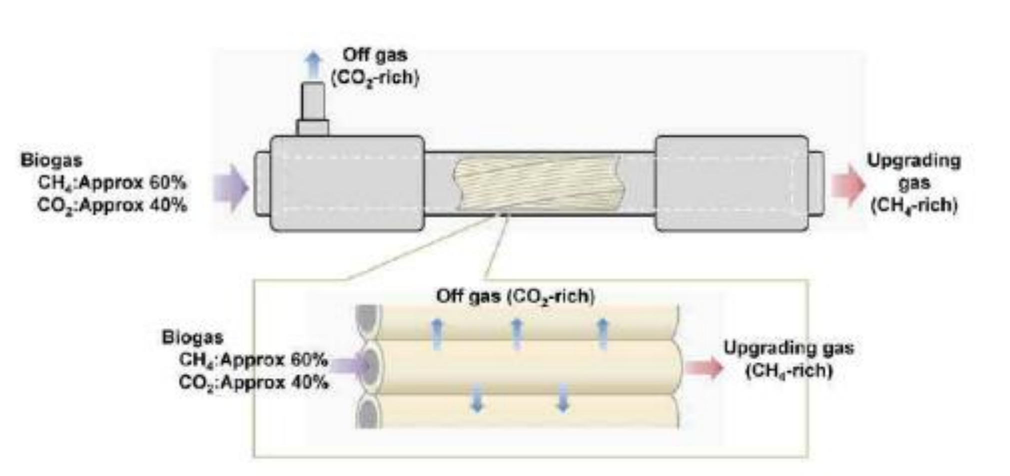


Figure 37: Membrane separation process

Table 32: Comparison of CO_2 Removal Process

Parameters	**PSA**	**Water Scrubbing**	**Chemical Absorption**	**Physical Adsorption**	**Membrane**
Typical plant capacity(Nm3/h biomethane)	300 - 800	200 - 1200	400 - 2000	300 - 1500	50 – 500
Demand electrical energy (kWh/Nm3 biomethane)	0.46	0.46	0.27	0.49 -0.67	0.25 – 0.43
Demand thermal energy (kWh/Nm3)	-	-	0.65	0.30	-
Temperature(Deg. Celsius)	-	-	110-160	55 - 80	-
Pressure (bar)	4 - 7	5-10	0.1 - 4	4 -7	5 -10
Methane loss(%)	1 - 5	1 - 5	0.1	1- 4	1- 8
Gas treatment	Yes	Yes	Yes	Yes	Yes
Desulphurisation	Yes	Depending on process	Yes	Yes	Yes
Demand of process water	No	Yes	Yes	No	No
Demand of Chemical Additives	No	No	yes	yes	no

The following table shows reference material from European installations comparing the investment and operational costs of different upgrading systems. The comparison is shown in terms of the volume of biomethane produced.

Table 33: Cost comparison of different upgrading systems

Costs	PSA	Water Scrubbing	Chemical Absorption	Physical Adsorption	Membrane
Investment (Euro/Nm^3/h biomethane)					
100 Nm^3/h bio-methane	10 400	10 100	9 500	9500	7 300- 7 600
250 Nm^3/h bio-methane	5 400	5 500	5 000	5 000	4 700 – 4 900
500 Nm^3/h bio-methane	3 700	3 500	3 500	3 500	3 500 – 3 700
Operation (ct/Nm^3 biomethane)					
100 Nm^3/h bio-methane	12.8	14.0	14,4	13.8	10.8 – 15.8
250 Nm^3/h bio-methane	10.1	10.3	12.0	10.2	7.7 – 11.6
500 Nm^3/h bio-methane	9.2	9.1	11.2	9.0	6.5 – 10.1

7.5 Biogas Utilization

Options for utilization of biogas (offsetting gas (after treatment), CHP, hot water);

After treatment, conditioning and upgrading (to biomethane) the gas is ready to be used for heating, combined power and heat and gird injection (for use as automobile fuel) .

7.5.1 Biogas Boiler

Where steam or hot water is the only requirement, a fired tube boiler can be fired with biogas. Or it can be used as an alternative when the CHP is not available or grid injection is not possible. These boilers can work with either atmospheric burners or blower driven burner. The atmospheric burners will work with a capacity of up to 35kW, the air is brought to the combustion chamber by the suction force generated by the gas flow. The force draft burners with a built in blower can have can capacities up to 10M, for capacities up to 30 MW,a separate blower is installed.

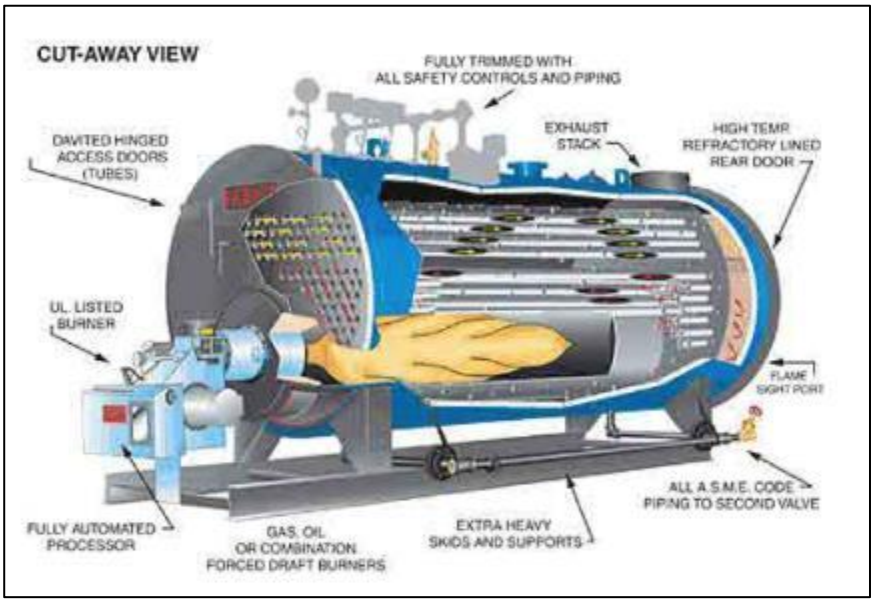


Figure 38 Biogas Boiler Process

Table 34 Biogas Boiler performance parameters

Parameters	Units	Value	Notes
Input and Technical Requirements	- Gas needs to be dry (RH <60%) and free of particles - The methane content must be above 50% with constant quality (changes of max. 50% Wobbe Index) - Gas pressure should be constant - Valves and accessories needs to be corrosion resistant and free of ferrous metals (additional costs) - The total concentration of sulphuric compounds inside the gas should not exceed 1000 ppm - A flame holder should always be installed		
Power Rating	1kW to 150MW		

Parameters	Units	Value	Notes
Investment Cost	Euro/kW	30- 80	
Cost of operations & maintenance	% of Investment Cost	2- 3	
Efficiency	Efficiency is up to 95%		

7.5.2 Combined Heat Cooling

Combined heat and power units simultaneously generate heat and electricity. A combustion engine connected to an electricity generator is used. To maximise the efficiency of the unit heat is extracted at the following four places:

- Cooling water from the engine block
- In the cooled exhaust manifold with water
- In the gas heat exchanger
- In the intercooler (intermediate cooling)

Produced heat can be used at a temperature of around 80 Deg.Celsius, with a temperature of 20K between input and output.

Spark Ignition Engines has been developed exclusively for burning a gaseous fuel and based on the principle of Otto engines, utilise the excess air to reduce CO2 and SO2 emissions. To incinerate biogas a minimum methane concentration of 45% is required. The life expectance of gas spark ignition engines range from 40 000 to 60 000 hours operation time. The typical performance is between $50kW_{el}$ and $2MW_{e}l$.

Synchronous or asynchronous (induction) generators are used in CHP units. Because of high reactive current consumption, it makes sense to use asynchronous generators only in units with a rating lower the 100kWel. Synchronous generators are normally used in biogas plants.

Advantages:

- Designed specifically for gas
- Lower emissions
- Lower maintenance and operational costs

Disadvantages:

- Higher invest costs
- Lower efficiency in lower power ranges

Figure 39 Combined Heat and Power Engine

Table 35 Combined Heat and Power engine performance parameters

Parameters	1Units	Value	Notes
Input and Technical Requirements	- Engines requires a minimum content of 45% in biogas - It requires the H_2Scontent to be below 400ppm - It must be free from Siloxanes - It must be free from water vapor		
Power Rating	50kW_{el} to 2MW_{el}		
Potential Plant Capacity	kW	100	600
Investment Cost	Euro/kW	1200O	600
Cost of operations & maintenance	Euros /k$Wh_{el\ produced}$	0.015	
Efficiency	- Electrical efficiency range from 30% to 45%. - Thermal efficiency range from 50% to 60% - Combined efficiency of up to 95%		

7.6 Energy Efficiency Design

Options for energy saving (fine bubble aeration, variable speed drives, advanced oxygen control etc.);

When surveying the energy consumption of the wastewater treatment plant it found that around 70% energy consumption goes into the motors used in the aeration of aerobic ponds. Oxygen is required for the microbial degradation of organic material before it goes to the next stages of the treatment. The aeration can be achieved by the following methods in an order of efficiency: (1) mechanical stirrers driven by fixed speed motors, (2) Mechanical stirrers driven by variable speed drive motors controlled by dissolved oxygen demand and (3) the most efficient option being the fine bubble aeration, which is an injection of oxygen in the aerobic ponds using submerged nozzles supplied with air by a variable speed drive blowers. The figures below show the options discussed.

Paddle Stirrer	Energy Efficient Induction Motor
	

Figure 40 Aeration paddle stirrer and a drive motor

The following are the average cost of the equipment:

- The cost of the energy efficiency motors is roughly R1000/kW
- The cost of the variable speed drive is roughly R1500/kW
- The cost of Dissolved Oxygen Meter is R170 000

Dissolved Oxygen Meter	Variable Speed Drive
	

Figure 41 Dissolved Oxygen Meter and Variable speed drive

Fine Bubble Aeration System

A fine bubble aeration system is the energy efficient option for the use of mechanical aerators on the

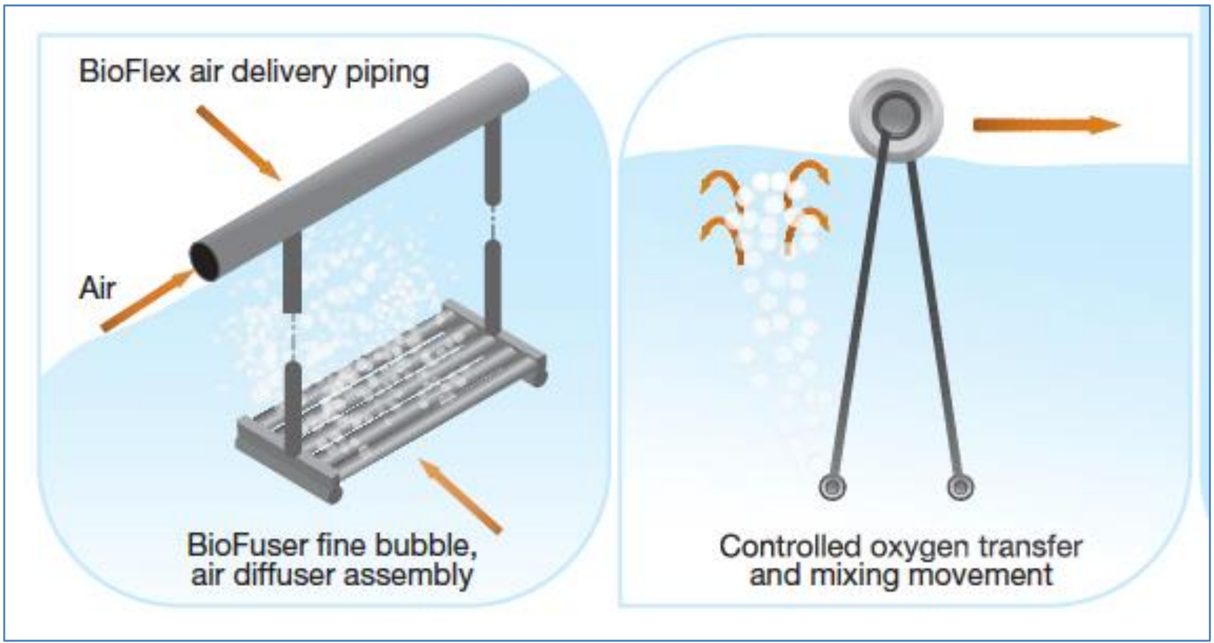


Figure 42 Fine bubble aeration system

7.7 Sludge Beneficiation

Sludge handling and disposal can be one of the largest operating costs to a wastewater treatment plant, not only in the fees for disposal of the sludge, but also the cost of the transport to take it to the disposal point. However, there are a number of further downstream processing options for gaining additional value from the sludge after digestion. For the purposes of this section, it is assumed that the sludge has been digested in order to generate biogas.

Each of the technologies listed here should generate some value for the sludge, which as a minimum should offset the operating costs and improve the overall finances of the wastewater treatment plant. An added benefit is that further processing of the sludge and beneficial use typically results in very little or no waste which will alleviate the WWTW obligations in terms of sludge disposal as set out by the South African regulations on the handling, classification and disposal of hazardous waste.

In particular, wastewater sludge contains carbon, nitrogen and phosphorus as elements which can be recovered and valorised: The carbon has value as fuel (for instance, converted to methane in digestion, or otherwise burned directly to carbon dioxide) as well as for supplying organic matter to soils. The most valuable aspect of wastewater sludge is the nutrients that are present in the sludge. These nutrients originate from the food eaten by the population served by the wastewater treatment plant. Fertilisers rich in nitrogen and phosphorus are applied in order to grow the crops that are eaten. Therefore, considering a circular economy, the nutrients that accumulate in wastewater sludge should be utilised once more in agriculture, and offsetting the amount of 'virgin' fertiliser needed.

As a lower value outlet, sludge can also be used as an additive in materials, such as in making cement or in brick manufacture.

In addition, wastewater sludge contains other minor constituents that could be extracted depending on unique situations, such as humic acids. However, many of the technologies in this space are in the developmental phase and do not have full-scale operating plants or a clear financial business case in current markets. As such, they are not considered directly relevant to the iLembe context, but should be watched as they are commercialised over the following decade.

As such, there are multiple approaches to beneficiating sludge, ranging from manual and rudimentary, to sophisticated modern technologies that produce higher value products. The following approaches are felt to be the most compelling in the iLembe context.

- Composting
- Phosphate recovery (struvite extraction)
- Pelletising (for use as fuel or fertiliser)
- Cement manufacture
- Brick manufacture

7.7.1 Composting

Composting is a means of improving the sludge quality for agricultural use. It involves storing the sludge under aerobic conditions at elevated temperatures (50 – 55°C) for an extended period of time (> 15 days). This accelerates various natural processes, such as the decomposition of organic material in order to stabilise it, and the destruction of pathogens. If sludge is to be applied to land, it is necessary that the sludge be stabilised. What is meant by a stable sludge is one in which there is limited decomposition of organic matter under atmospheric conditions and therefore it does not attract or support vectors (flies, etc).

The sludge is often laid out in long windrows under cover, which require regular turning in order to keep the sludge aerated. This turning can either be done by hand, or by automated compost turning machines that traverse the long windrows. Composting is often carried out in combination with other organic residues (such as corncobs, nut shells or bark from timber operations), partly as stiff additive residues provide structure to the combined sludge to allow better circulation of oxygen.

Advantages:

- Simple, low technology approach which can use local manual labour;
- More financially attractive than landfill (depending on disposal cost);
- Compost could be utilised locally;
- There could be synergies with nearby agricultural residues.

Disadvantages:

- Large footprint required;
- Area needs to be covered to keep compost dry from rain and maintain heat.

7.7.2 Phosphate (struvite) recovery

A more recent approach for creating saleable products from sewage sludge is recovering nutrients as struvite. Struvite is magnesium ammonium phosphate (NH_4MgPO_4) and is primarily a means to extract the phosphate from the sludge stream. There are a number of proprietary technologies to recover phosphate as struvite, but generally they are applied to the return liquors from the sludge dewatering step. This stream has an elevated phosphate concentration but with the phosphates dissolved and easily accessible. Typically, struvite is forced to precipitate by dosing an additive chemical to the sludge return liquors.

Advantages:

- Highest value product produced;
- Nutrient recovery in a form that can most easily be an input to commercial fertilisers.

Disadvantages:

- High capital investment with limited business case currently;
- Sophisticated processes that require careful operation and skilled operators.

7.7.3 Pelletising

Pellets have a higher density of the solid material (therefore lowering the transport cost per ton) and are easier to handle, being free flowing. The intense pressure to produce pellets also assists to reduce moisture in the material, thus improving the net calorific value for combustion. However, although biosolids pellets burn well, they do have a high ash content (approximately 40%, which includes the nutrients). As such, wastewater sludge can be co-pelletised with other organic wastes in order to improve the fuel quality, particularly to lower the ash content.

Pelletising sludge may also make it more suitable for direct application as a fertiliser. For this application, binders such as clay or starch are used. The pellets can also be fortified with other materials in order to provide a more consistent nutrient content, which makes the product more marketable.

Advantages:

- Simple, mechanical process;
- Simplifies transport and handling;
- Some flexibility to include other materials to improve the properties of the pellets.

Disadvantages:

- Pelletising machines are high wear items and therefore high maintenance items;
- Binders and other additives likely required;
- High ash content in sludge limits its direct application as a fuel;
- Naturally variable nutrient content limits its direct application as a fertiliser.

7.7.4 Cement Manufacture

Wastewater sludge can also be utilised in cement manufacture. The sludge is fired in the cement kiln to provide calorific value, and the remaining ash is then incorporated within the cement. The benefit to the cement manufacturing facility is that the sludge provides a cheap energy source for the kiln and offsets fossil fuel usage.

Advantages:

- Able to accommodate significant volumes of sludge;
- Less sensitive to natural variations in sludge quality.

Disadvantages:

- Requires a significant scale;

- Requires a cement kiln within a reasonable distance.

7.7.5 Brick Manufacture

An area of interest is the utilisation of sludge (biosolids) in brick making. The biosolids are used to reduce the amount of clay required. It has been found that up to 15% of the brick mass could be contributed by biosolids, with the bricks still achieving satisfactory qualities.

Locally, the concept of manufacturing bricks with sludge as a significant ingredient has the added appeal of job creation for semi-skilled labourers, as well as entrepreneurial enterprises within the local community.

Advantages:

- Simple process, utilising semi-skilled labour;
- Potential to be a community employment project.

Disadvantages:

- Low value outlet for the sludge.

8 Waste Water Treatment Works and Community Partnerships

An important component to consider during the development of a treatment works work scheme is to consider where there are possible opportunities for partnering with the local community and where there may be a benefit to the local community. This may often result in upliftment of the community by impacting their quality of life. All these projects may be considered green initiatives as they allow for the beneficiation of waste products thus limiting the typical impact on their disposal pathways.

These interactions between the community may be in various formats with the community either being physically involved in the interaction or in some cases in simply benefit from the WWTW in a manner.

For any of these interactions the following should be considered in on a case by case scenario:

- Community buy-in: the community should be consulted and supportive of any such initiative to ensure the project success;
- Community impact: Consider if the community as a whole is benefiting from the interactions or will it only be a partnership with certain members from the community;
- Health and safety of the community – Any undertaking in partnership with the community should adhere to the strictest standards for Health and Safety and no interaction should have the potential negatively impact the health and safety of the community;
- Is the municipality in a position to support such a project in the long term?

The section highlights some possible community partnerships that may be applicable in the IDM context.

8.1 Aqua Culture project

The use of WWTW infrastructure for aquaculture is the concept of such a partnership. In such a case the final polishing dams at a WWTW is utilised to farm fish (catfish or other appropriate local species). An example of this type of project would be the project Kumasi Metropolitan Assembly (KMA) and the private company Waste Enterprisers Ltd. In Ghana. Here the final maturation pond of a WWTW is used as the cultivating dam for catfish. The catfish is then sold, and the proceeds benefits both the local works and the private public company.

Advantages:

- Employment and generation of income for the local community though a specific established local entity;
- Possible income generation for the WWTW / IDM;
- Simple process, utilising semi-skilled labour;
- Additional production of local food source;
- Such a project may assist in diminishing the treatment loads to a WWTW.

Disadvantages:

- The quality of the wastewater feed in the specific ponds will have to monitored in order to adhere to required regulations as well as to not negatively impact the fish themselves;
- If the WWTW does not have existing ponds that may be used for such a purpose they would have to build. This may not be possible on the available allocated site and as such hinder the establishment of such a project;

8.2 Non edible agricultural possibilities

Should suitable land be available next to or on the site of the WWTW the opportunity exists for the agrobusiness of non-edible crops. As an example, the cultivating of Hyparrhenia Hirta (grass) (or other eligible thatching material) to be used at thatching material is an option. For such a partnership the WWTW would be able to supply threated or partially treated water for irrigation as well as composted sludge to enhance crop yield. Such agribusiness may further provide for local entrepreneurial enterprises within the local community by establishing raw material sources for them.

Advantages:

- Employment and generation of income for the local community though specific established local entities;
- Possible income generation for the WWTW / IDM;
- Simple process, utilising semi-skilled labour;

Disadvantages:

- The quality of the wastewater feed will have to adhere to the South African guidelines for irrigation;
- Care should be taken to ensure that neither the wastewater supplied for irrigation nor the composted sludge should be used for the cultivation other than the non-edible crop specified for the project;
- Access to reasonable areas of land suitable for such cultivation should be available within easy access of the WWTW.

8.3 Community public space beatification

Although a well-established concept for partnering with the local community has been the supply of composted sludge and in cases the supply of treated wastewater for the establishment of parks or sports fields within communities it should remain a consideration. The addition of public spaces is almost always a benefit to any community and will benefit the standard of living for people in such communities.

Advantages:

- Local community access to recreational facilities such as parks and sports fields;

- Often a direct benefit for the WWTW employees as they hail from these local communities;
- Good will towards the municipality;

Disadvantages:

- Often difficult to secure community involvement with the establishment and upkeep of such project and therefore the cost of such a project would typically reside with the municipality;
- Once such a project is started it should be continuously supported by the municipalities side in order not to generate resentment to local municipalities.

8.4 Brick Making

This could benefit the community in a number of manners and encourage entrepreneurial enterprises. The topic is discussed in section 7.7.5 above.

9 TECHNOLOGY/OPPORTUNITY FEASIBILITY ASSESMENT

As the outcome of the study is to provide the reader with different sets of technologies to compare against each other (in terms of their performance to attain a chosen treatment objective), a reference resource in the form of pdf sheets was developed for specific technology groupings, where direct comparison and impact may be established though comparison. This reference resource is set out per the following technology groupings:

- Main treatment process technologies;
- Water reclamation technologies;
- Sludge digestion technologies;
- Biogas generation technologies;
- Biogas treatment and optimization technologies;

These sheets should be used as a quick reference to determine the initial capability of the technology in question or possible solution to a specific treatment goal. It is then advised to return to the report to further ascertain the viability of such a technology against the proposed treatment goals.

An example of such a sheet is shown below in Figure 43 below and they can be found in appendix A3 to A7. This reference sheet will indicate clear technology advantages over others in its group in green, in order to speedily asses these technologies against each other or their specific applicability to a treatment objective.

The CAPEX and comparative OPEX indicators in these reference sheets will quickly indicate if there exists an opportunity to employ the specific technology under foreseen budgetary constraints (please note that the CAPEX and OPEX is based on design values as set out in the basis of design for this document).

	Technology	Anaerobic Lagoon and Trickling Filter	Extended Aeration	Activated Sludge Reactor (anoxic and anaerobic zones)	Moving Bed Biofilm Reactor	Membrane Bio Reactor	Aerobic Granular Sludge Process
	COD Reduction	Yes	Yes	Yes	Yes	Yes	Yes
	Nitrification	Yes	Yes	Yes	Yes	Yes	Yes
	Denitrification	No / Limited	No	Yes	Yes	Yes	Yes
	Phosphate removal	No	No	Yes	Yes	Yes	Yes
	Requires Secondary Clarifier	Yes	Yes	Yes	Yes	No	No
	Able to meet General Discharge Limits	No	No	Yes	Yes	Yes	Yes
Comparative Values for a 10 MLD Plant	Reactor Volume m^3	>22500	15 200	9 000	< 7500	2 500	5 400
	Typical footprint of main civil units m^2	13 400	5 100	3 500	3 100	+/- 700	+/-1500
	Power Consumption / OPEX kWh/d estimation	1 100	3 500	4 400	5 000	6 000	3 200
	Capital cost R in Mil.	> 100 Mil	70 - 85 Mil	50 - 60 Mil	50 - 65 Mil	55 - 75 Mil	65 - 75 Mil

Figure 43 Main process technology comparison reference sheet example

10 RECOMMENDATIONS AND CONCLUSIONS OF STUDY

There are numerous technology options available to achieve various treatment objectives that may arise within the iLembe District Municipality. The reference resource developed will provide the user with initial insight as to a specific technology's viability within the pertinent treatment objectives.

It is recommended that this resource be used only as part of an initial feasibility scope to determine a possible new treatment solution or determine the plausibility of upgrading existing infrastructure to achieve new treatment goals. It should be noted that the specific design figures noted in the report are only for comparative goals to compare the different technologies to each other. It is not recommended to directly scale them without scrutinising and re-evaluating the basis of design set out in the report in order to confirm its relevance to specific scenarios.

It is further recommended that technical staff and relevant technology suppliers be contacted after the initial comparison when the reference resource is used in future. This would be to determine the technologies' relevancy or possible improvements made to such technologies since the date of this report.

ANNEXURES

A1 South African Water Quality Guidelines limits for Irrigation

Table 36: South African Water Quality Guideline limits for Irrigation

Parameters	Units	Irrigation standards	Notes
pH		≥ 6.5 to ≤ 8.4	
Electrical Conductivity	mS/m	< 90	Consideration to be given when applied to salt sensitive vegetation Recommended limit < 40
Total Dissolved Solids	mg/ℓ		
Suspended Solids	mg/ℓ	< 50	For irrigation equipment protection
Colour	PtCo Units	N/A	
Turbidity	N.T.U.	N/A	
Free Residual Chlorine as Cl_2	mg/ℓ	N/A	
Monochloramine	mg/ℓ	N/A	
Total Alkalinity as $CaCO_3$	mg/ℓ	N/A	
Chloride as Cl	mg/ℓ	< 100	
Fluoride as F	mg/ℓ	< 2	
Nitrogen total	mg/ℓ	--	
Total Organic Carbon as C	mg/ℓ	N/A	
Total Feacal Coliform	per 100 mℓ	<1000	<10 for crops to be eaten Raw
Sodium as Na	mg/ℓ	≤ 70	Refer to SAR below
Sodium as SAR = [sodium]/([calcium] + [magnesium])0.5	[ ] in mmol/ℓ	< 2	Sodium Absorption Rate
Aluminium	mg/ℓ	< 5	Ideal up to 20 mg/ℓ acceptable for most crops
Arsenic	mg/ℓ	< 0.1	
Berillium	mg/ℓ	0.1 - 0.5	
Boron	mg/ℓ	< 0.5	Higher level may be allowed but specific to type of crop and duration of irrigation
Cadmium	mg/ℓ	< 0.01	
Chromium (VI)	mg/ℓ	< 0.1	
Cobalt	mg/ℓ	< 0.05	
Copper	mg/ℓ	< 0.2	up to 5 mg/ℓ may be allowed but specific to type of crop and duration of irrigation

Parameters	Units	Irrigation standards	Notes
Iron	mg/ℓ	< 5	up to 2 mg/ℓ may be allowed but specific to type of crop and duration of irrigation
Lead	mg/ℓ	< 0.2	up to 20 mg/ℓ may be allowed but specific to type of crop and duration of irrigation
Lithium	mg/ℓ	< 2.5	
Manganese	mg/ℓ	--	<0.1 For irrigation equipment protection
Molybdenum	mg/ℓ	< 0.1	
Nickel	mg/ℓ	< 0.2	up to 20 mg/ℓ may be allowed but specific to type of crop and duration of irrigation
Selenium	mg/ℓ	< 0.02	up to 0.05 mg/ℓ may be allowed but specific to type of crop and duration of irrigation
Uranium	mg/ℓ	< 0.01	up to 0.1 mg/ℓ may be allowed but specific to type of crop and duration of irrigation
Vanadium	mg/ℓ	< 0.1	up to 1.0 mg/ℓ may be allowed but specific to type of crop and duration of irrigation
Zinc	mg/ℓ	< 1	up to 5.0 mg/ℓ may be allowed but specific to type of crop and duration of irrigation

A2 Appendix 2: South African Drinking Water Standards SANS 241:2015

Table 37: Full SANS 241:2015 Limits

Parameter	Unit	SANS 241:2015 Limits
pH		≥5 to ≤ 9.7
Electrical Conductivity	mS/m	≤170
Total Dissolved Solids	mg/ℓ	≤1200
Suspended Solids	mg/ℓ	---
Colour	PtCo Units	≤15
Turbidity	N.T.U.	≤1 / ≤5
Free Residual Chlorine as Cl_2	mg/ℓ	≤5
Monochloramine	mg/ℓ	≤3
Total Alkalinity as $CaCO_3$	mg/ℓ	---
Chloride as Cl	mg/ℓ	≤300
Sulphate as SO_4	mg/ℓ	≤500 / ≤250
Fluoride as F	mg/ℓ	≤1.5
Nitrate as N	mg/ℓ	≤11
Nitrite as N	mg/ℓ	≤0.9
Combined Nitrate & Nitrite	mg/ℓ	≤1
Free Cyanide as CN	µg/ℓ	≤200
Total Organic Carbon as C	mg/ℓ	≤10
Phenols	µg/ℓ	≤10
Total Coliform Bacteria	per 100 mℓ	≤10
E. coli	per 100 mℓ	Not detected
Heterotrophic Plate Count	cfu / 1 mℓ	≤1000
Somatic Coliphages	per 10 mℓ	Not detected
Free and Saline Ammonia as N	mg/ℓ	≤1.5
Sodium as Na	mg/ℓ	≤200
Calcium as Ca	mg/ℓ	---
Magnesium as Mg	mg/ℓ	---
Aluminium as Al	µg/ℓ	≤300
Antimony as Sb	µg/ℓ	≤20
Arsenic as As	µg/ℓ	≤10

Parameter	Unit	SANS 241:2015 Limits
Barium as Ba	µg/ℓ	≤700
Boron as B	µg/ℓ	≤2400
Cadmium as Cd	µg/ℓ	≤3
Total Chromium as Cr	µg/ℓ	≤50
Copper as Cu	µg/ℓ	≤2000
Iron as Fe	µg/ℓ	≤ 2000 / ≤300
Lead as Pb	µg/ℓ	≤10
Manganese as Mn	µg/ℓ	≤ 400 / ≤100
Mercury as Hg	µg/ℓ	≤6
Nickel as Ni	µg/ℓ	≤70
Selenium as Se	µg/ℓ	≤40
Uranium as U	µg/ℓ	≤ 30
Zinc as Zn	µg/ℓ	≤5

A3 Main treatment process comparison table

	Technology	Anaerobic Lagoon and Trickling Filter	Extended Aeration	Activated Sludge Reactor (anoxic and anaerobic zones)	Moving Bed Biofilm Reactor	Membrane Bio Reactor	Aerobic Granular Sludge Process
	COD Reduction	Yes	Yes	Yes	Yes	Yes	Yes
	Nitrification	Yes	Yes	Yes	Yes	Yes	Yes
	Denitrification	No / Limited	No	Yes	Yes	Yes	Yes
	Phosphate removal	No	No	Yes	Yes	Yes	Yes
	Requires Secondary Clarifier	Yes	Yes	Yes	Yes	No	No
	Able to meet General Discharge Limits	No	No	Yes	Yes	Yes	Yes
Comparitive Values for a 10 MLD Plant	Reactor Volume m^3	>22500	15 200	9 000	< 7500	2 500	5 400
	Typical footprint of main civil units m^2	13 400	5 100	3 500	3 100	+/- 700	+/-1500
	Power Consumption / OPEX kWh/d estimation	1 100	3 500	4 400	5 000	6 000	3 200
	Capital cost R in Mil.	> 100 Mil	70 - 85 Mil	50 - 60 Mil	50 - 65 Mil	55 - 75 Mil	65 - 75 Mil

A4 Water reclamation technologies / option comparison table

Technology	Rapid Gravity Sand Filters	Pressure Sand Filters	Granular Activated Carbon Filters	Ozone and Hydrogen Peroxide Process	Ozone and Ultra Violet Light Process	Hydrogen Peroxide and Ultraviolet Light Process	Ultra Membrane Filtration	Nano Membrane Filtration	Reverse Osmoses Membrane Filtration
				Advanced Oxidation Processes					
Suspended Solids Removal	Yes	Yes	Yes	No	No	No	Yes	N/A	N/A
Removal of Organic Material	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Removal of Bacteria	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Removal of Viruses	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes
Lowering of TDS	No	No	No	Slight	Slight	Slight	No	Yes	Yes
Near Complete Removal of TDS	No	No	No	No	No	No	No	No	Yes
Acts as Protection for Downstream Processes	Yes	Yes	Yes	No	No	No	Yes	No	No
Requires upstream protection	No	No	No	No	No	No	Yes	Yes	Yes
Comparitive Values for a 10 MLD Plant									
Typical Unit Layout Duty /Standby	4 / 0	11 / 1	4 / 0	2 / 0	2 / 0	2 / 0	4 / 1	5 / 1	6 / 1
Chemical cost r/m^3	N/A	N/A	N/A	0.4	0.2	0.6 - 0.8	0.15	0.15	0.15
Power Consumption / OPEX kWh/d estimation	N/A	500 - 600	N/A or +/- 600	1 800	> 1 800	< 1 800	+/- 1 500	+/- 3 750	+/- 6 400
Capital cost R in Mil.	15 Mil	10 - 13 Mil	14 - 18 Mil	15 - 20 Mil	15 - 22 Mil	12 - 17 Mil	13.5 Mil	14.8 Mil	14.8 Mil

A5 Sludge digestion comparison table

	Technology	Anaerobic Contact Process (ACP)	Upflow / Downflow Anaerobic Filter	Upflow Anaerobic Sludge Blanket (UASB)	Agitated Lagoon Covered Lagoon	Single Tank Mixed Anaerobic Digestor
	Digestion of sewage sludge	Yes	Yes	Yes	Yes	Yes
	Digestion of industrial COD	No	No	Yes	Selctive	Selctive
	Digestion of agricultural waste	No	No	Selctive	Yes	Selctive
	Digestion of mixed source feed	No	No	Yes	Yes	Yes
	Relative opperational complexity	High	Low	High	Low	High
	Loading Rate Kg COD/m^3.d	2 - 5	5 - 10	15 - 30	3	4.5
Comparitive Values for a 10 MLD Plant	Hydraulic retention time (hours)	N/A	0.5 - 4	4 - 12	6	4 - 8
	Potential plant capacity m^3/h CH_4	N/A	164	173	> 50	50 - 2500
	OPEX (% of investment cost)	N/A	< 2	2	1 - 3	2 - 4
	Capital cost R/m3/h (thousands '000)	N/A	624	752	128 - 208	560 - 720

A6 Biogas treatment – Desulphurization comparison table

Technology	Biological desulphurisation inside digester	External biological desulphurisation	Bioscrubber	Sulphide precipitation	Internal chemical desulphurisation	Activated carbon
Requires electrical power input	Yes	Yes	Yes	No	No	No
Consumables - consumption/replacement media	Yes	Yes	No	Yes	Yes	Yes
Consumables - disposal required	No	Yes	No	No	Yes	Yes
Air Injection	Yes	Yes	No	No	Yes	Yes
Purity ppm	50 - 2000	50 - 100	50 - 100	50 - 500	1 - 100	<5
Comparative system disadvantage	Imprecise process control	Imprecise process control	High process cost and complexity	Sluggish process	Greatly diminishing purification effect	High disposal cost of media

A7 Biogas treatment – Carbon Dioxide comparison table

	Technology	Pressure Swing Adsorption (PSA)	Water Scrubbing	Chemical Absorption	Physical Adsorption	Membrane
	Gas treatment (CO_2 removal)	Yes	Yes	Yes	Yes	Yes
	Desulphurisation	Yes	Process dependant	Yes	Yes	Yes
	Demand of process water	No	Yes	Yes	No	No
	Demand of Chemical Additives	No	No	Yes	Yes	No
	Typical plant capacity(Nm^3/h biomethane)	300 - 800	200 - 1200	400 - 2000	300 - 1500	50 – 500
	Demand electrical energy (kWh/Nm^3 biomethane)	0.46	0.46	0.27	0.49 - 0.67	0.25 – 0.43
	Demand thermal energy (kWh/Nm^3)	-	-	0.65	0.3	-
	Temperature(Deg. Celsius)	-	-	110 - 160	55 - 80	-
	Pressure (bar)	4 - 7	5 - 10	0.1 - 4	4 - 7	5 - 10
	Methane loss (%)	1 - 5	1 - 5	0.1	1 - 4	1 - 8
Investment (Euro/Nm^3/h biomethane)	100 Nm^3/h bio-methane	166 000	161 000	152 000	152 000	116 000 - 121 000
	250 Nm^3/h bio-methane	86 000	88 000	80 000	80 000	75 000 - 78 000
	500 Nm^3/h bio-methane	59 000	56 000	56 000	56 000	56 000 - 59 000
Investment (R/Nm^3/h biomethane)	100 Nm^3/h bio-methane	2.0	2.2	2.3	2.2	1.7 - 2.5
	250 Nm^3/h bio-methane	1.6	1.6	1.9	1.6	1.2 - 1.8
	500 Nm^3/h bio-methane	1.4	1.4	1.8	1.4	1.0 - 1.6