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REPORT

ESKOM-MEDUPI

FGD Effluent Waste Water Treatment Plant Concept Feasibility Report

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Submitted to :

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EXECUTIVE SUMMARY

Medupi Power Station, located in Limpopo, is in the process of designing and installing Flue Gas Desulphurisation (FGD) Technology to control sulphur dioxide emissions which is required to meet the South African Minimum Emission Standards. This report describes the process undertaken to evaluate and identify suitable the process technologies to treat effluent from the (FGD) process at a new Wastewater Treatment Plant (WwTP).

Evaluation of the process technologies were conducted for two different water qualities (Case 1 and 2) during a trade off workshop. At the workshop robust discussions and interrogation of the evaluation criteria were undertaken to ensure that the scoring provided an accurate reflection of the technology being evaluated. Following the trade off of the two options, thermal evaporation was ranked as the preferred option for Case 1 and 2. The thermal evaporation technology will be developed further during the conceptual design.

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FGD	Flue Gas Desulphurisation
WwTP	Wastewater Treatment Plant
ZLED	Zero Liquid Effluent Discharge

1 INTRODUCTION

Medupi Power Station, located in Limpopo, is in the process of designing and installing Flue Gas Desulphurisation (FGD) Technology to control sulphur dioxide emissions. This is required to meet the South African Minimum Emission Standards. The current design is based on the wet limestone FGD process. This process utilises wet limestone (consisting primarily of $CaCO_3$) to react with gaseous SO_2 to form gypsum ($CaSO_4 \cdot 2\ H_2O$) in a forced oxidation process. A stream concentrated with gypsum crystals is bled from the absorber to a gypsum dewatering system. The bleed steam from the dewatering system (called FGD blowdown) needs to be treated in order to recover the water.

Eskom therefore appointed Zitholele Consulting to design a water treatment plant to treat the FGD blowdown stream so that the water can be re-used. A requirement of the project is to have zero liquid waste discharge on the Medupi site. The design process will consist of the following two phases:

1. Concept design phase to evaluate different options and select the preferred solution.
2. Engineering design phase on the selected solution in order to inform an Engineering Procurement and Construction (EPC) Contract.

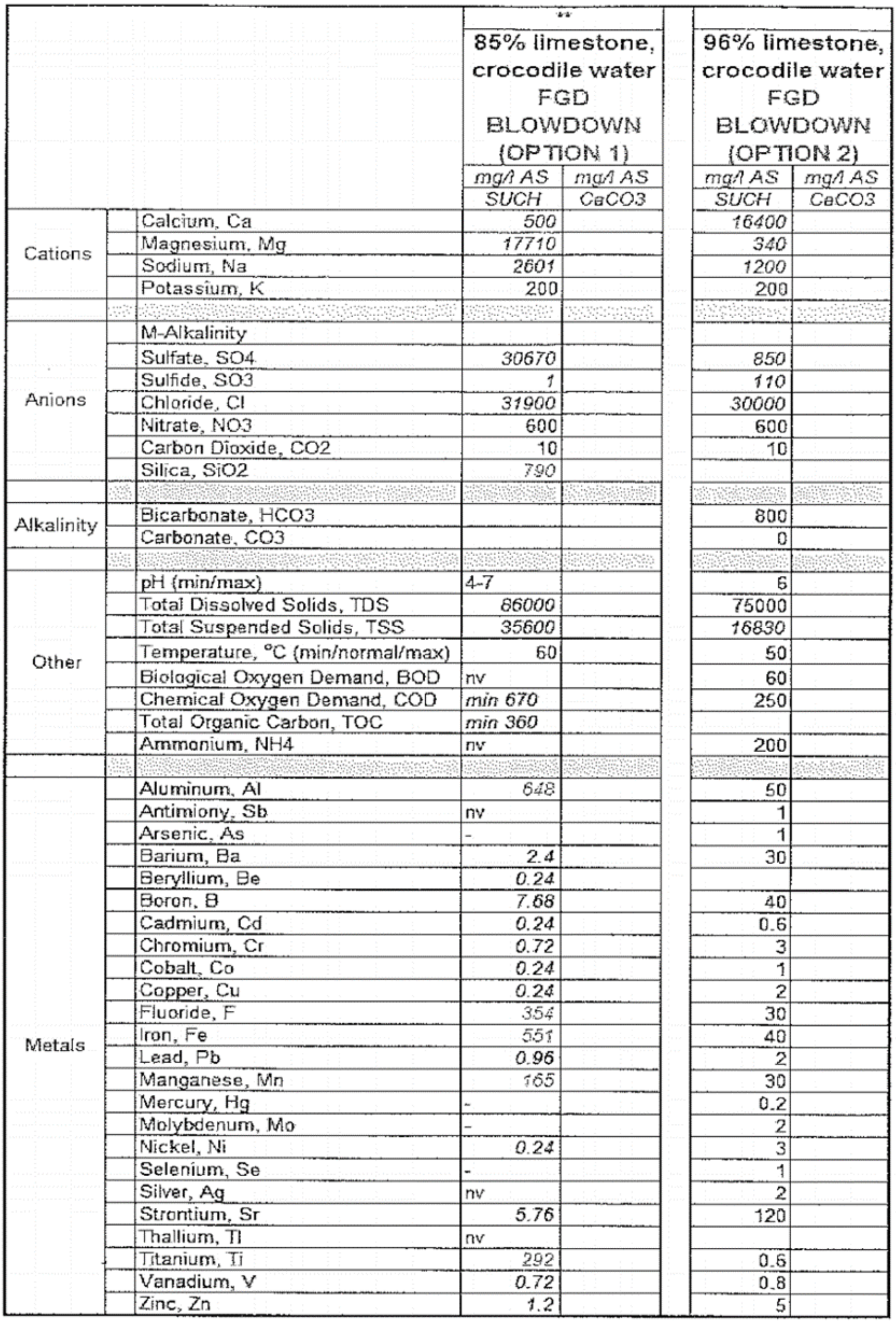
The aim of this document is to describe the process design that was performed for the concept design.

2 BASIS OF DESIGN

Currently, two design cases for the FGD plant are being considered. The effluent water from the FGD will differ depending on which case is selected. The design feed water quality for each option that needs to be treated by the FGD effluent water treatment plant (FGD EWTP) is shown in Figure 1. The maximum design flows for each option is as follows:

- Case 1 = 44 m^3/h
- Case 2 = 45 m^3/h

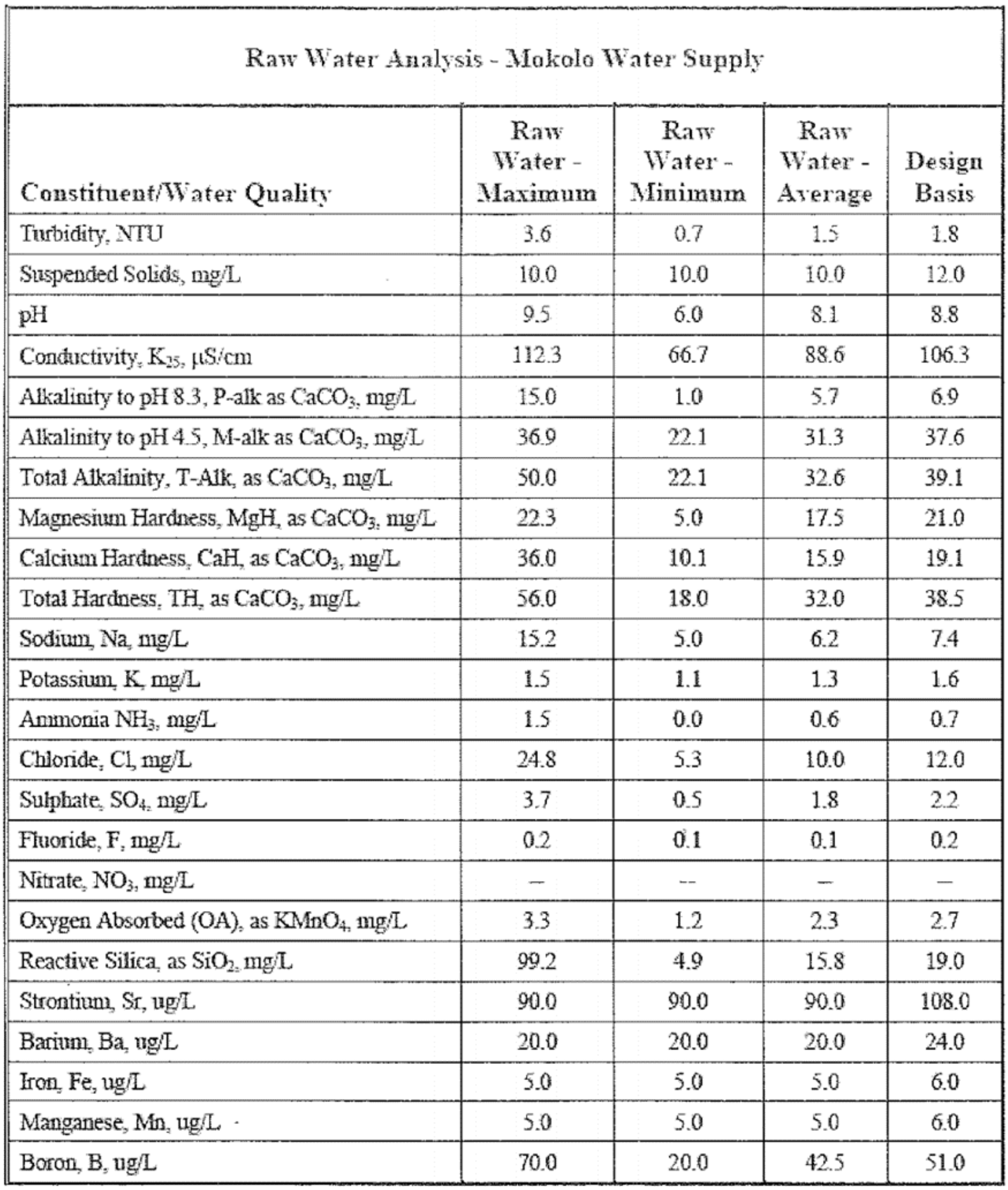
The design should furthermore be able to cater for a minimum flow of 12 m^3/h.



		85% limestone, crocodile water FGD BLOWDOWN (OPTION 1)		96% limestone, crocodile water FGD BLOWDOWN (OPTION 2)	
		mg/l AS SUCH	mg/l AS CaCO3	mg/l AS SUCH	mg/l AS CaCO3
Cations	Calcium, Ca	500		16400	
	Magnesium, Mg	17710		340	
	Sodium, Na	2601		1200	
	Potassium, K	200		200	
Anions	M-Alkalinity				
	Sulfate, SO4	30670		850	
	Sulfide, SO3	1		110	
	Chloride, Cl	31900		30000	
	Nitrate, NO3	600		600	
	Carbon Dioxide, CO2	10		10	
	Silica, SiO2	790			
Alkalinity	Bicarbonate, HCO3			800	
	Carbonate, CO3			0	
Other	pH (min/max)	4-7		6	
	Total Dissolved Solids, TDS	86000		75000	
	Total Suspended Solids, TSS	35600		16830	
	Temperature, °C (min/normal/max)	60		50	
	Biological Oxygen Demand, BOD	nv		60	
	Chemical Oxygen Demand, COD	min 670		250	
	Total Organic Carbon, TOC	min 360			
	Ammonium, NH4	nv		200	
Metals	Aluminum, Al	648		50	
	Antimiony, Sb	nv		1	
	Arsenic, As	-		1	
	Barium, Ba	2.4		30	
	Beryllium, Be	0.24			
	Boron, B	7.68		40	
	Cadmium, Cd	0.24		0.6	
	Chromium, Cr	0.72		3	
	Cobalt, Co	0.24		1	
	Copper, Cu	0.24		2	
	Fluoride, F	354		30	
	Iron, Fe	551		40	
	Lead, Pb	0.96		2	
	Manganese, Mn	165		30	
	Mercury, Hg	-		0.2	
	Molybdenum, Mo	-		2	
	Nickel, Ni	0.24		3	
	Selenium, Se	-		1	
	Silver, Ag	nv		2	
	Strontium, Sr	5.76		120	
	Thallium, Tl	nv			
	Titanium, Ti	292		0.6	
	Vanadium, V	0.72		0.8	
	Zinc, Zn	1.2		5	

Figure 1: Design feed water quality

The target water quality is based on the raw water quality of the Mokolo Water supply. The minimum, maximum and average values of the Mokolo water supply is shown in Figure 2, as well as the selected design basis values in the last column. The FGD EWTP must be designed such that the treated water quality meets the values listed in the Design Basis column.



Raw Water Analysis - Mokolo Water Supply

Constituent/Water Quality	Raw Water - Maximum	Raw Water - Minimum	Raw Water - Average	Design Basis
Turbidity, NTU	3.6	0.7	1.5	1.8
Suspended Solids, mg/L	10.0	10.0	10.0	12.0
pH	9.5	6.0	8.1	8.8
Conductivity, K_{25}, µS/cm	112.3	66.7	88.6	106.3
Alkalinity to pH 8.3, P-alk as $CaCO_3$, mg/L	15.0	1.0	5.7	6.9
Alkalinity to pH 4.5, M-alk as $CaCO_3$, mg/L	36.9	22.1	31.3	37.6
Total Alkalinity, T-Alk, as $CaCO_3$, mg/L	50.0	22.1	32.6	39.1
Magnesium Hardness, MgH, as $CaCO_3$, mg/L	22.3	5.0	17.5	21.0
Calcium Hardness, CaH, as $CaCO_3$, mg/L	36.0	10.1	15.9	19.1
Total Hardness, TH, as $CaCO_3$, mg/L	56.0	18.0	32.0	38.5
Sodium, Na, mg/L	15.2	5.0	6.2	7.4
Potassium, K, mg/L	1.5	1.1	1.3	1.6
Ammonia NH_3, mg/L	1.5	0.0	0.6	0.7
Chloride, Cl, mg/L	24.8	5.3	10.0	12.0
Sulphate, SO_4, mg/L	3.7	0.5	1.8	2.2
Fluoride, F, mg/L	0.2	0.1	0.1	0.2
Nitrate, NO_3, mg/L	–	--	–	–
Oxygen Absorbed (OA), as $KMnO_4$, mg/L	3.3	1.2	2.3	2.7
Reactive Silica, as SiO_2, mg/L	99.2	4.9	15.8	19.0
Strontium, Sr, ug/L	90.0	90.0	90.0	108.0
Barium, Ba, ug/L	20.0	20.0	20.0	24.0
Iron, Fe, ug/L	5.0	5.0	5.0	6.0
Manganese, Mn, ug/L	5.0	5.0	5.0	6.0
Boron, B, ug/L	70.0	20.0	42.5	51.0

Figure 2 : Design feed water quality

3 SCREENING OF OPTIONS

Based on a literature survey and previous FGD effluent treatment projects, various high-level options were developed for the effluent treatment plant. After consultation with various vendors and experts in the field, some of these options could be eliminated as part of a screening stage, before developing them further. The options that were considered, as well as the reasons for eliminating or retaining them, are documented in this section. Concept designs were developed for only the options that passed the screening stage.

It must be noted that this study was limited to the evaluation of treatment options to enable the re-use of the FGD effluent water. Waste produced will be transported to a waste disposal facility. Other options, such as the encapsulation of the purge water by mixing it with fly ash to form an inert paste, were not investigated. Encapsulation could potentially provide a cost-effective solution compared to treatment and off-site disposal of the waste.

After analysing the feed water quality, it is clear that the solution will have to consist of some form of pre-treatment to remove suspended solids, metals and supersaturated constituents. To meet the required treated water quality with zero liquid discharge, further treatment using some form of desalination and waste management will be required. The pre-treatment and desalination options are described in more detail below.

4 PRE-TREATMENT OVERVIEW

While a number of pre-treatment options may be considered, a typical physical-chemical treatment process commonly used for FGD wastewater treatment was selected in this project for preliminary process development and cost estimation.

The aim of pre-treatment plant is flow equalization, calcium sulphate desaturation, suspended solids and trace metals removal, and pH adjustment. The main pre-treatment processes are described briefly below (for a detailed description, refer to section 4.1).

Flow Equalization: The purpose of flow equalization tank is to minimize variation in flows and loads and optimize the downstream treatment plant size. Based on site conditions, it is assumed that the heat loss in the equalization tank will not be significant, and will not impact the calcium sulphate solubility, which increases as the temperature decreases.

Desaturation: This step is to reduce the concentration of sulphate in the wastewater stream by adding lime to raise the pH to approximately 8.5 to 9 to precipitate calcium sulphate. Raising the pH higher will result in calcium carbonate precipitation but would lead to higher lime costs and higher sludge processing and handling costs.

Primary Clarification: Removes the bulk of suspended solids and calcium sulphate produced in the desaturation reactor. A fraction of the sludge from the clarifier is recirculated to the desaturation reactor to provide additional site for calcium sulphate precipitation and hence improve process efficiency.

Heavy Metals Removal: To meet low effluent limits for heavy metals including mercury, and as metal sulphide have lower solubility than metal hydroxides, organo-sulphides (for example TMT-15) is added to precipitate heavy metals.

Coagulation: Iron salt such as ferric chloride (FeCl3) is typically added to neutralize particle charge and assist with the formation of dense flocs.

Flocculation: Polymer is typically added for floc agglomeration and to form dense flocs that can be removed in the downstream clarifier.

Secondary Clarification: To remove suspended solids, and metal precipitates. A fraction of the sludge is recycled to assist form dense stable flocs and improve process efficiency.

pH adjustment: pH is adjusted back to neutral by dosing acid (as required by the downstream processes).

Filtration: To reduce suspended solids load on the downstream treatment processes, the water is typically filtered using granular media filter having high solid holding capacity.

5 PRE-TREATMENT OPTIONS EVALUATED

Either Lime ($Ca(OH)_2$) and Soda Ash (NaOH) can be used for desaturation. Lime is typically used as it is substantially cheaper than Soda Ash.

Lime is normally dosed as a milk-of-lime solution, which can be prepared from either of the following two chemicals:

- Option 1: Quicklime (CaO)
- Option 2: Hydrated lime ($Ca(OH)_{2)}$

For Option 1, a slaker system is required to convert quicklime (CaO) to slaked or hydrated lime (Ca(OH)2). This is done by mixing water with the quicklime and allowing the following exothermic reaction to take place:

CaO + H2O --> $Ca(OH)_2$

The slaked lime can then be made up to a milk-of-lime solution by adding additional make-up water.

For Option 2, the lime is already hydrated, thus only water needs to be added to the lime to make up the milk-of-lime solution. The advantage of option 2 is that less infrastructure is required compared to option 1. The disadvantage of option 2 is that the density of hydrated lime is only 560 kg/m3, compared to about 1000 kg/m3 for quicklime. This means that the volume of dry feed material that needs to be transported to site for option 1 will be 40% less than option 2. Based on this, it was decided that, due to the savings in transport costs, Option 1 will be the preferred option.

Three permutations in terms of the dosing position and removal of the precipitated solids was considered:

- Option 1:
    - Lime is dosed to Reactor 1.
    - Precipitated solids are removed in Primary Clarifier.
    - Organo-sulphide is dosed to Reactor 2.
    - Ferric is dosed to Reactor 3.
    - Remaining suspended solids and precipitated metal sulphides are removed in Secondary Clarifier.
    - This option is typically used when the suspended solids in the feed stream is high (above 1 to 2% solids).
- Option 2:
    - Similar to Option 1, except that the clarifier between Reactor 1 and 2 is removed.
    - Effluent from Reactor 1 flows directly into Reactor 2.
    - All solids are removed using one clarifier after Reactor 3.
    - This option can be used when the solids loading is not too high, e.g. if solids in the feed stream is below 1%.
- Option 3:
    - Similar to Option 2, except that the lime and organo-sulphides are dosed to the same reactor. Reactor 2 is therefore eliminated.
    - This option is also used when the solids loading is relatively low, although dosing lime and organo-sulphides in separate reactors seems to be the preferred option in most applications.

Due to the high solids loading in the FGD purge stream (about 3.6% for Case 1 and 1.7% for case 2), as well as due to the fact that only a small saving will be achieved by eliminating Reactor 2, it was decided to use Option 1 described above for the pre-treatment. For a detailed description of this process, refer to section 4.1.

6 DESALINATION OPTIONS EVALUATION

The water from the pre-treatment section will still have a high TDS concentration that needs to be removed using desalination technology. For desalination, the following options were considered:

Option 1a: Reverse osmosis, followed by thermal evaporation and crystallisation of the brine to achieve a zero-liquid discharge.

Option 1b: Reverse osmosis, followed by freeze crystallisation of the brine to achieve a zero-liquid discharge.

Option 1c: Reverse osmosis, full brine stream is transported to a waste disposal facility.

Option 2a: Thermal evaporation and crystallisation of the full stream from the pre-treatment section.

Option 2b: Freeze crystallisation of the full stream from the pre-treatment section.

Option 3a: Forward osmosis, followed by thermal evaporation and crystallisation of the brine to achieve a zero-liquid discharge.

Option 3b: Forward osmosis, followed by freeze crystallisation of the brine to achieve a zero-liquid discharge.

After approaching some reverse osmosis (RO) suppliers with the given water qualities, the feedback received was that the TDS in the water to too high for RO to be a feasible option. This feedback eliminated options 1a, 1b and 1c.

Based on past experience and exposure to Forward Osmosis, it was concluded that forward osmosis (Option 3a and 3b) can also be ruled out for this project due to the following:

- Previous comparative studies have shown forward osmosis to be very expensive.

To our knowledge, there is no full-scale installation of Forward Osmosis for FGD wastewater treatment. It will therefore probably require piloting, which is not an option for this project due to the tight time constraints.

Difficulties might be experienced in obtaining local support for the technology, which will further increase the risk of using this technology.

Option 2a and 2b were selected for further evaluation as part of the concept design phase. These two options are described in more detail in the following sections. The pre-treatment process described earlier in the report was assumed for both these options.

After developing concept designs for the two options, they were evaluated in a trade-off study workshop to select the preferred option. The outcome of the trade-off study is also document in this report.

It must be noted that there are some proprietary or patented technologies associated with specific vendors, such as the CoLD process from Veolia that could potentially be used. In order not to limit the solution to one specific vendor, these proprietary technologies were not included as options in the concept study. However, when the water treatment plant is put out on tender, it is recommended that tenderers be allowed to propose alternatives, which will open the door for these proprietary technologies to also be considered.

7 PROCESS DESCRIPTION OF CONCEPT DESIGNS

The water treatment plant process can be divided into two major sections:

- Pre-treatment Desalination (two options were evaluated)
    - Option 1: Thermal evaporation and crystallisation of the full stream from the pre-treatment section.
    - Option 2: Freeze crystallisation of the full stream from the pre-treatment section. This option will require polishing treatment of the product water using UF and RO, as well as thermal evaporation and crystallisation of the brine stream to achieve a zero-liquid discharge solution.

Simplified block flow diagrams for the two options for the FGD waste water treatment plant are shown in Figure 3 and Figure 4 below. The detailed process flow diagrams of the common pre-treatment section, as well as the two desalination options, are given in Appendix B.

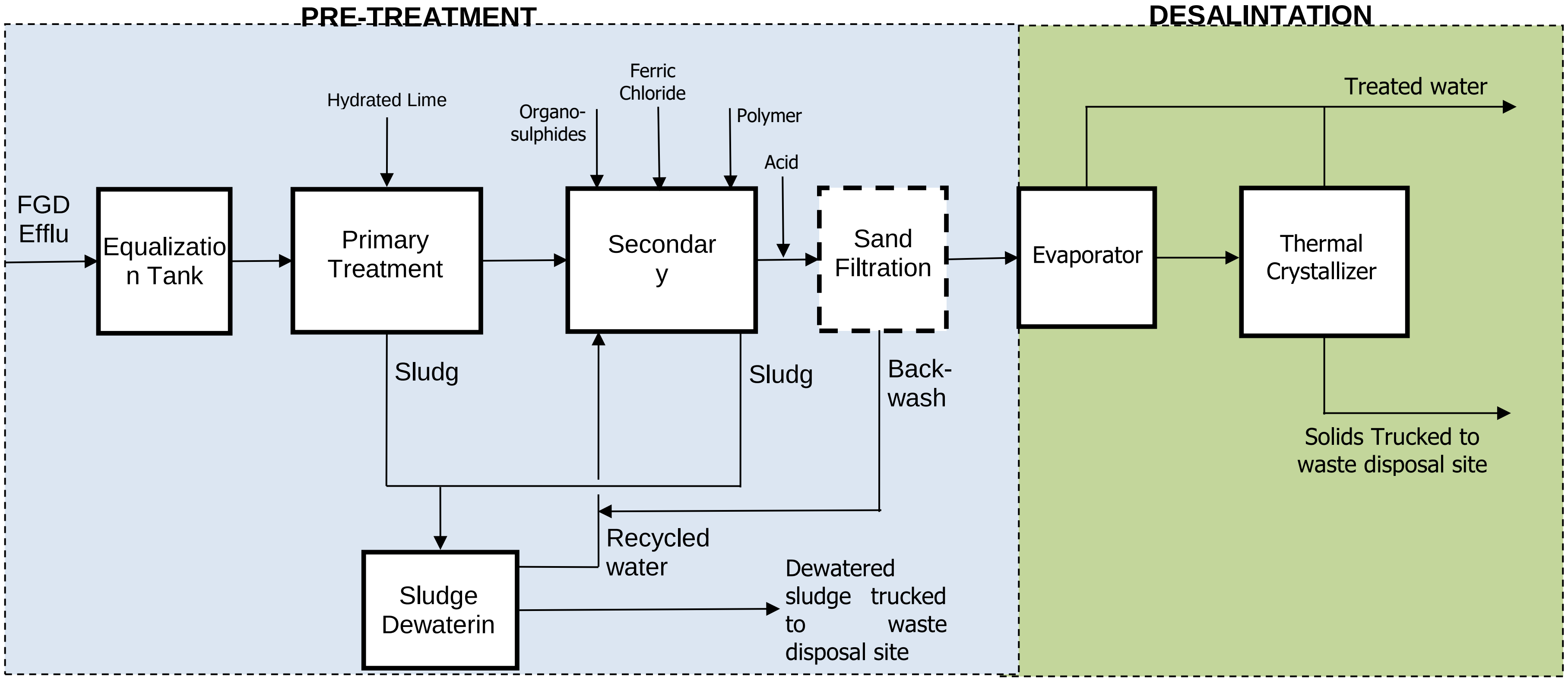


Figure 3 : Block flow diagram of Option 1

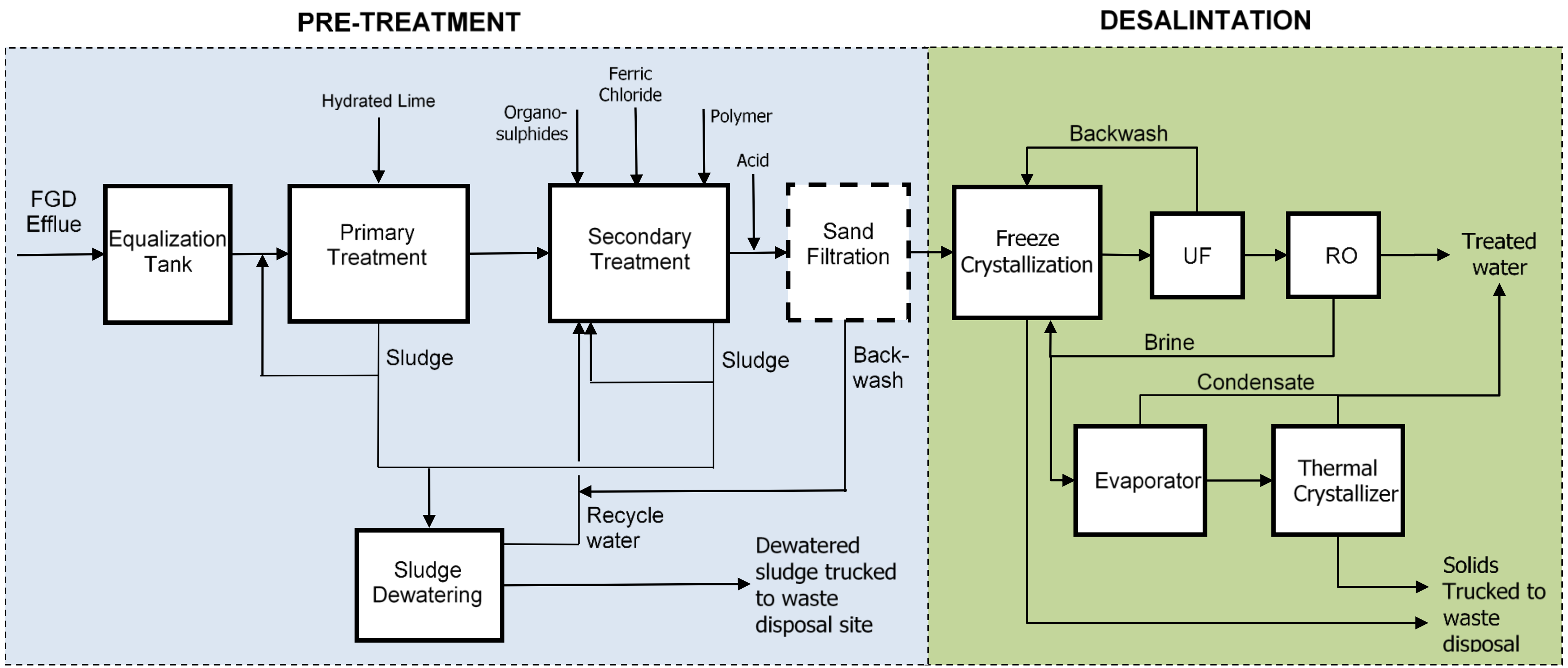


Figure 4 : Block flow diagram of Option 2

7.1 Pre-Treatment

7.1.1 Primary Treatment

The FGD effluent is fed to an equalisation tank which buffers flow and water quality variations. The equalisation tank is mixed using a motorised mechanical mixer to prevent the suspended solids from settling.

From the equalisation tank, the feed water flows under gravity to the first reaction tank (Reactor 1). A milk of lime solution is dosed to Reactor 1 using a lime dosing system (refer to section 4.1.2 for details of the lime dosing system). The addition of an alkali (hydrated lime) is used to increase the pH of the equalization tank effluent to 9. The pH in Reactor 1 will be measured and the lime addition will be varied to control the pH. The Reactor is mixed using a motorised mechanical mixer.

Increasing the pH aids in the precipitation of metals and some heavy metals as metal hydroxides (metal solubility typically decreases with an increase in pH). Some water softening is also achieved through the precipitation of Ca and Mg as CaCO3, CaSO4 and Mg(OH)2.

The effluent from Reactor 1 is directed to the Primary Clarifier, which removes the suspended solids from the stream. The overflow from the clarifier gravitates to the second reaction tank (assumed to contain less than 100 mg/L suspended solids). The sludge underflow is pumped back to Reactor 1 at a flow rate of equal to 100% of the feed flow to the plant. Recycling the underflow build up the solids concentration to about 10%. A purge stream is drawn off from the clarifier underflow and sent to the Thickener for further thickening.

The primary treatment is used to de-supersaturate and soften the water. This reduces scale formation in the downstream equipment, which increases the reliability and efficiency of the process.

7.1.2 Lime Dosing System

A brief process description for the quicklime dosing option is as follows:

Quicklime is delivered by bulk tankers and transferred into a quicklime silo, from where it is slaked with water in a detention-type slaker. The slaked lime is transferred using a slaker transfer pump to the lime slurry makeup tanks. Water is added to the slaked lime to dilute it to a 10% milk-of-lime solution. The solution is allowed to mature for 2.5 hours. Once matured, the milk-of-lime slurry is transferred to the dosing tank.

From the dosing tanks the lime slurry solution is dosed to Reactor 1 using a dosing pump. The dosage rate will be controlled based on the measured pH in Reactor 1. A pH of about 9 will be targeted.

7.1.3 Secondary Treatment

The overflow from the primary clarifier is directed to Reactor 2, where an organo-sulphide solution is dosed to further precipitate any heavy metals as metal sulphides. Reactor 2 is mixed using a motorised mechanical mixer. Reactor 2 overflows to Reactor 3.

To aid in flocculation of the precipitated metals, Ferric Chloride solution is dosed to Reactor 3. The iron salt helps to form denser flocs, which enhance the secondary clarifier performance. In addition, the iron salts also assist in co-precipitating remaining metals and some organic matter present in the feed.

Polymer is dosed to the effluent from Reactor 3 to aid with coagulation in the Secondary Clarifier. Since the suspended solids concentration in the feed to the Secondary Clarifier will be fairly low, a solid contact clarifier is used. The overflow from the Secondary Clarifier (assumed to contain less than 20 mg/L suspended solids) flows into the Sand Filter Feed Tank, from where it is pumped through a pressurised sand filter (refer to Section 4.1.5). The clarifier bottoms sludge (assumed to contain 1% solids) is recycled back to Reactor 2. A purge stream is send to the Thickener.

7.1.4 Sludge Thickening and Dewatering

The sludge purge streams from both the primary and secondary clarifiers are directed to the Sludge Thickener. The overflow from the thickener (assumed to contain less than 40 mg/L suspended solids) flows into the Recycle Water Tank. The thickened sludge from the bottom of the thickener is pumped to the Sludge Buffer Tank. The buffer tank is sized for 24 hours of storage to allow for maintenance time on the filter press. The sludge tank is equipped with a motorised mechanical mixer to keep the solids in suspension.

The effluent from the sludge buffer tank is directed to a dewatering unit. The dewatering unit consists of a plate-and-frame filter press. The dewatered sludge (assumed to contain 60% moisture) is sent to a sludge storage facility sized for storing 7 days of sludge. The dewatered sludge is trucked away for off-site disposed. The pressate water from the dewatering unit is directed to the Recycle Water Tank, from where it is pumped to Reactor 2.

7.1.5 Sand Filtration

The overflow from the secondary clarifier is cleaned further using pressurised sand filtration. There is a possibility that sand filtration will not be required depending on the requirements of the technology used for desalination.

The clarifier overflow is collected in the Sand Filter Feed Tank, from where it is pumped through multiple pressure filters. Acid is dosed upstream of the sand filters to neutralise the water. Backwashing of the filters is done one at a time using the filtrate from the other filters. The backwash water is sent to the Recycle Water tank for recycling back to Reactor 2. The filtrate is sent to the desalination process.

7.2 Desalination

7.2.1 Option 1: Thermal Evaporation and Crystallization

While there are various types and configuration of thermal evaporators, mechanical vapour compression (MVR) evaporators are typically used for FGD wastewater treatment with multiple existing full-scale installations. Hence MVR was selected for further evaluation in this project.

In thermal evaporation, heat is added to the high TDS concentrate to boil it. Steam is collected and condensed to form a purified distillate, whilst the concentrate that remains is further treated using crystallisation. Heat is added by mechanical compression of vapor. A combination of an evaporator, crystallizer and a filter press is typically used to achieve zero liquid discharge. Evaporators for the FGD wastewater application are often falling film type with or without a seeded slurry system. Crystallizers are typically forced circulation types.

In a falling film evaporator, the feed is pumped through a heat exchanger that raises the temperate of the feed water and cools the outflowing distillate/condensate. The heated feed is pumped to the evaporator sump, from where fluid is constantly pumped to the distribution box on top of tube bundle for heat transfer. As the concentrate flows down the tubes, it forms a thin film and a fraction of the flow evaporates. Calcium sulphate crystals forms as feed is concentrated. The seeded slurry provides precipitation nuclei and prevents scaling of the heat transfer tubes. The concreted fluids falls back into the sump and is recirculated. The vapour is passed through mist eliminators and directed to the vapour compressor, which compresses and heats the vapour. The heated vapour is transfer back to the evaporator where it exchanges heat with the recirculating hot concentrate and condenses on the outside heat exchanger tube. As the condensate flow down the exchanger tube, it transfers heat to the concentrate on the inside of the tube. This results in evaporation of the concentrate, and the evaporation cycle is sustained. The heat from the distillate is used to heat the incoming raw feed water as described earlier.

The following treatment components are typically included in a conventional thermal evaporation system:

Feed Tank: Adjust pH and neutralize bicarbonate alkalinity to enable preheating of the wastewater in plate heat exchangers.

Plate Heat Exchangers: To preheat the inlet wastewater with heat recovered from recovered distillate.

Deaerator: To remove dissolved carbon dioxide, dissolved oxygen, and non-condensable gases.

Brine Concentrator: Falling film evaporator for water evaporation.

Recirculation Pump: To recirculate brine and concentrate it to the desired concentration prior to discharge for further processing.

Mechanical Vapor Compressor: To compress the vapour formed and recycle the latent heat of vaporization.

Seed Crystal Addition and Recovery System: For addition of calcium-sulphate seed crystals. The dissolved calcium sulphate in FGD wastewater preferentially precipitate on the seed crystals rather than the brine concentrator tubes, thus reducing scaling.

In a forced-circulation crystallizer, concentrated brine from evaporator is pumped to an agitated crystallizer feed tank. From the tank, the brine is pumped through a shell and tube heat exchanger to a forced circulation crystallizer operating under vacuum. Brine is heated in the heat exchanger with heat recovered from vapor. The heated brine flashes as it enters the crystallizer body and releases sensible heat of vapor. Salt crystals form and crystallize in the concentrated brine (slurry) that collects in a sump at the bottom of the crystallizer body. The slurry is circulated and a portion is sent to solids handling system consisting of centrifuge or pressure filter, or is sent directly for solidification. The vapor collected from the crystallizer body is recompressed and introduced to the heat exchanger’s shell side to provide thermal energy for continued evaporation.

Feed Tank

Shell and tube heat Exchangers: To preheat the inlet wastewater with heat recovered from recovered distillate.

Brine Concentrator: Forced circulation evaporator for water evaporation.

Recirculation Pump: To recirculate brine and concentrate it to the desired concentration prior to discharge for further processing.

Mechanical Vapor Compressor: To compress the vapor formed and recycle the latent heat of vaporization

7.2.2 Option 2: Freeze Crystallization

When water freezes, it generally forms ice crystals that are pure, leaving behind a more concentrated salt solution. The ice can be separated and allowed to melt to produce a product with low TDS. By removing the water in the form of ice, the remaining solution becomes supersaturated with the salt and crystals start to form. Since ice is less dense than water and brine, it floats to the surface, while the denser salt crystals settle to the bottom. The pure water (ice) and salt crystals can be separated according to density in a solids/solids separator.

Freeze crystallisation requires less energy compared to evaporative crystallisation, since the heat of fusion for ice is substantially less than the heat of evaporation. In addition, the temperature change required to freeze water is generally less compared to boiling it. However, various methods can be employed to improve the efficiency of both freeze crystallisation as well as thermal crystallisation, such energy recovery through pre-heating the feed, etc.

A simplified flow schematic for the freeze crystallisation process is shown in the figure below.

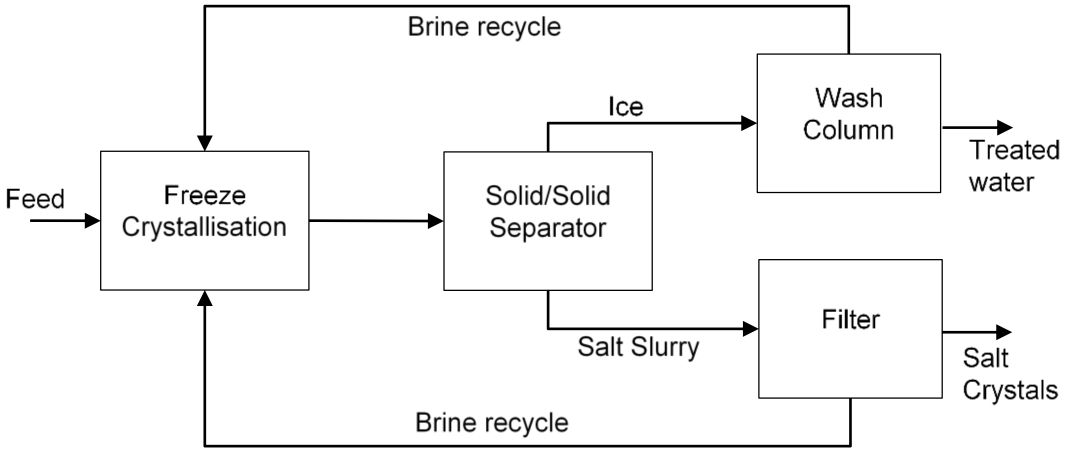


Figure 5 : Simplified block flow diagram of Freeze Crystallisation

8 PROCESS DESIGN

The process design for the two options is documented in this section.

8.1 Process Design Approach

A process design, as well as a detailed mass and component balance, was performed for both options evaluated, as well as for both feed water quality cases. A total of four design were therefore developed as follows:

Option 1: Pre-treatment and thermal evaporation / crystallisation

- Case 1 feed water quality
- Case 2 feed water quality

Option 2: Pre-treatment and freeze crystallisation

- Case 1 feed water quality
- Case 2 feed water quality

The pre-treatment section is identical for Option 1 and 2. The sizing of the components does however differ for the Case 1 and Case 2 design feed water qualities.

The pre-treatment section is identical for Option 1 and 2. The sizing of the components does however differ for the Case 1 and Case 2 design feed water qualities.

Dosing rates of chemicals, as well as sludge produced, were calculated for each of the four options as part of the mass balance.

Once the mass balance was fixed, the flows were used to size the equipment based on selected design criteria. The major infrastructure and equipment, as well as the design criteria used to size the various units, are given in the following sections.

8.2 Major Infrastructure and Electrical Equipment List

A summary of the major infrastructure is given in Table 1, including the design criteria used to size the infrastructure.

Note: Unless otherwise indicated, the volumes reported are the minimum required process volume and does not include dead zones or freeboard requirements.

The major electrical equipment is given in Table 2 below, including the design criteria used to size the equipment. The pumps are only preliminary sized based on an assumed required head, the exact sizes can only be determined once the required delivery head (including static head and losses in pipes) has been determined.

Different sizes for Case 1 and Case 2 feed water quality are given in the two tables. No details of the crystallisation processes are given; since these processes was treated as a block box (costing and footprint sizes were obtained directly from vendor). Additional equipment required for polishing treatment of the freeze crystallisation option is listed at the end of each table.

Table 1: Infrastructure of Case 1 and 2

Description	Type	Number (oper.)	Number (standby)	Number (total)	Case 1 Design size/unit	Case 2 Design size/unit	Units	Design criteria	Additional information - Case 1	Additional information - Case 2
Equalization Tank	Tank	1		1	360	360	m3	8 hours storage		
Reactor 1	Reactor	2		2	24	24	m3	30 minutes retention time		
Primary Clarifier	Central Drive with Rake Lift	1		1	8	9.5	m	0.5 m/h upflow rate	Side wall depth: 3 m Cone slope: 1/12 Sludge hopper volume: 1.2 m3	Side wall depth: 3 m Cone slope: 1/12 Sludge hopper volume: 1.0 m3
Reactor 2	Reactor	1		1	22	24	m3	15 minutes retention time		
Reactor 3	Reactor	1		1	22	24	m3	15 minutes retention time		
Secondary Clarifier	Solids Contact Clarifier	1		1	9	9.3	m	0.7 m/h upflow rate	Side wall depth: 3 m Cone slope: 1/12 Sludge hopper volume: 0.6 m3	Side wall depth: 3 m Cone slope: 1/12 Sludge hopper volume: 0.7 m3
Thickener	Central Drive Thickener	1		1	14	9.6	m	500 kg/(m2.d) solids loading rate	Side wall depth: 3 m Cone slope: 1/6 Sludge hopper volume: 0.6 m3	Side wall depth: 3 m Cone slope: 1/6 Sludge hopper volume: 0.4 m3
Sludge Buffer Tank	Tank	1		1	460	260	m3	24 hour storage		
Dewatering Press	Sludge Storage Facility	1		1	850	460	m3	7 days storage		
Sand filter feed tank	Tank	1		1	15	16	m3	20 minutes retention time		
Sand filter	Pressure Sand Filter	3	1	4	2.8	3	m3	10 m/hr filtration rate		
Recycle Water Tank	Tank	1		1	13	7	m3	20 minutes retention time		
Quick Lime Silo	Lime Silo	1		1	70	70	m3	7 days storage		
Lime Slaker Tank	Tank	2		2	28	28	m3	12 hour storage		
Lime Make-Up Tank	Tank	2		2	28	28	m3	12 hour storage		
Lime Dosing Tank	Tank	1		1	60	55	m3	12 hour storage		
Ferric Storage Tank	Drum	2		2	0.2	0.2	m3	7 days storage		
Polymer Make-Up and Curing Tank	Tank	1		1	0.4	0.5	m3	12 hour storage		
Polymer Dosing Tank	Tank	1		1	0.4	0.5	m3	12 hour storage		
Evaporator / Crystalliser	As per vendor information									
Polishing Treatment (only for Freeze Desalination)										
UF Feed Tank	Tank	1		1	17	18	m3		25 minutes retention time	
UF Filters		76		76						
UF Pressure Vessels		76		76						
UF Racks		2		2			m3			
UF CIP tank	Tank	1		1	0.4	0.4				
RO Filters		100		100						
RO Pressure Vessels		7		7						
RO Racks		1		1			m3			
RO Feed Tank	Tank	1		1	17	18	m3		25 minutes retention time	
Permeate flush tank	Tank	1		1	7.5	8	m3			
RO CIP tank	Tank	1		1	0.4	0.5	m3			
Brine Evaporator / Crystalliser	As per vendor information									

Table 2 : Electrical Equipment for Case Design 1 and 2

Description	Type	Number (operational)	Number (standby)	Number (total)	Case 1 Design size/unit	Case 2 Design size/unit	Units	Design criteria
Equalization Tank - Mixer	Rapid mixer	1		1	18.5	18.5	kW	45 W/m3
Equalization Tank - Pump	Centrifugal pump	1	1	2	2.2	2.2	kW	Assumed 10 m pump head and 70% efficiency. If gravity flow is possible, pump not required
Reactor 1 - Reactor Mixers	Rapid mixer	2		2	3	3	kW	120 W/m3
Primary Clarifier - Bridge motor	Bridge motor	1		1	4	4	kW	Assumed motor size
Primary Clarifier - Sludge recycle pump	Progressive cavity pump	1	1	2	2.2	2.2	kW	Assumed 10 m pump head and 70% efficiency.
Reactor 2 - Reactor Mixers	Rapid mixer	1		1	3	3	kW	120 W/m3
Reactor 3 - Reactor Mixers	Rapid mixer	1		1	3	3	kW	120 W/m3
Secondary Clarifier - Bridge motor	Bridge motor	1		1	4	4	kW	Assumed motor size
Secondary Clarifier - Sludge recycle pump	Progressive cavity pump	1	1	2	1.1	1.5	kW	Assumed 10 m pump head and 70% efficiency.
Stage 1 - Thickener - Bridge motor sizing	Bridge motor	1	1	2	7.5	5.5	kW	Assumed motor size
Stage 1 - Thickener - Waste sludge pump	Progressive cavity pump	1	1	2	5.5	3	kW	Assumed 10 m pump head and 70% efficiency.
Dewatering Press - Sludge Buffer Tank Mixer	Rapid mixer	1		1	45	30	kW	90 W/m3
Dewatering Press	Plate and Frame Filter	1	1	2	1.1	1.1	kW	Estimate
Dewatering Press - Sludge removal conveyor	Conveyor	1		1	0.75	0.37	kW	Estimate
Sand filter - Feed pumps	Centrifugal pump	1	1	2	TBD	TBD	kW	Still to be determined
Recycle Water Return Pump	Centrifugal pump	1		1	1.5	1.1	kW	Assumed 10 m pump head and 70% efficiency.
Dosing - H2SO4 - Dosing Pump	Peristaltic pump	1	1	2	0.18	0.18	kW	Assumed 5 m pump head and 70% efficiency.
Dosing - Lime Slaker Mixer	Rapid mixer	2		2	3	3	kW	Based on mixing intensity of 250 s^{-1}
Dosing - Slaked Lime Transfer Pump	Peristaltic pump	1	1	2	0.37	0.37	kW	Assumed 5 m pump head and 70% efficiency.
Dosing - Lime Slurry Mixer	Rapid mixer	2		2	3	3	kW	Based on mixing intensity of 250 s^{-1}
Dosing - Lime Slurry Transfer Pump	Peristaltic pump	1	1	2	0.37	0.37	kW	Assumed 5 m pump head and 70% efficiency.
Dosing - Lime Dosing Mixer	Rapid mixer	1		1	4	4	kW	Based on mixing intensity of 200 s^{-1}
Dosing - Lime Dosing Pump	Peristaltic pump	1	1	2	2.2	2.2	kW	Assumed 10 m pump head and 70% efficiency.
Dosing - Ferric - Mixer	Slow mixer	2		2	0.18	0.18	kW	Based on mixing intensity of 400 s^{-1}, minimum motor size
Dosing - Ferric - Dosing Pump	Peristaltic pump	1	1	2	0.18	0.18	kW	Assumed 10 m pump head and 70% efficiency, minimum motor size
Dosing - Polymer Make-Up Mixer	Mixer	1		1	0.18	0.18	kW	Based on mixing intensity of 25 s^{-1}, minimum motor size
Dosing - Polymer Transfer Pump	Peristaltic pump	1	1	2	0.18	0.18	kW	Assumed 5 m pump head and 70% efficiency.
Dosing - Polymer Dosing Mixer	Mixer	1		1	0.18	0.18	kW	Based on mixing intensity of 25 s^{-1}, minimum motor size
Dosing - Polymer Dosing Pump	Peristaltic pump	1	1	2	0.18	0.18	kW	Assumed 10 m pump head and 70% efficiency.
Dosing - Carrier Water Booster Pump	Centrifugal pump	1	1	2	0.18	0.18	kW	Assumed 10 m pump head and 70% efficiency.
Polishing Treatment (only for Freeze Desalination)								
UF Feed Pump	Centrifugal pump	1	1	2	5.5	5.5	kW	Assumed 30 m pump head and 70% efficiency.
UF Feed Backwash Pump	Centrifugal pump	1	1	2	55	55	kW	Assumed 32 m pump head and 70% efficiency.
UF Air Scour Blower	Blower	1		1	11	11	kW	
UF CIP pump	Peristaltic pump	1	1	2	0.75	0.75	kW	
UF CIP Tank Mixer	Rapid mixer	1		1	0.18	0.18	kW	50 W/m3
RO feed pump	Centrifugal pump	1	1	2	75	75	kW	Assumed 375 m pump head and 70% efficiency.
RO CIP pump	Centrifugal pump	1	1	2	2.2	2.2	kW	
RO CIP Tank Mixer	Rapid mixer	1		1	0.18	0.18	kW	50 W/m3

8.3 Chemical Consumption

The major chemicals that will be dosed, as well as the average chemical usage and the basis of calculation, are listed in Table 3 below. All the chemicals listed below are for the pre-treatment section, hence there is no distinction between Option 1 and Option 2.

Table 3: Dosing Chemicals

Chemical	Dosing calculation	Case 1	Case 2
Quick Lime (90% purity) dosed to Reactor 1	Target pH in the reactors = 9	9166 kg/d	8755 kg/d
Organo-sulphide	Based on vendor dosage rate	TBD (1)	TBD (1)
Ferric chloride	Assumed 10 mg/L dosing rate	19.3 kg/d	21.6 kg/d
Polymer	Assumed 2 mg/L dosing rate	3.9 kg/d	4.3 kg/d
Sulphuric Acid (98% w/w) dosed to pH correction tank	Target pH = 6.5	32.6 L/d	7.5 L/d

Note 1: The amount of organo-sulphide to be dosed needs to be informed by the vendor of the chosen organo-sulphide

8.4 Waste Produced

An estimate of the waste quantities that will be produced for the two options and the two feed water cases are given in Table 4.

Waste Stream	Units	Option 1		Option 2	
		Case 1	Case 2	Case 1	Case 2
Dewatered Sludge Cake	kg/h	6708	3587	6708	3587
	m^3/h	5.0	2.7	5.0	2.7
Salt crystals	kg/h	3298	3168	8573	6046

9 CONVEYANCE OF WASTE

9.1 Pre-treatment facility to the waste handling and storage facility

Following pre-treatment, the effluent will enter a dewatering building containing plate and frame presses for both the Sludge and Salt streams. The presses will be used to dewater both waste streams thereafter, the Sludge and Salts in both Option 1 and 2 will be transported from the dewatering building at the pre-treatment facility to the waste handling and storage facility via a conveyor. Figure 6 shows the position of the Sludge and Salt conveyors.

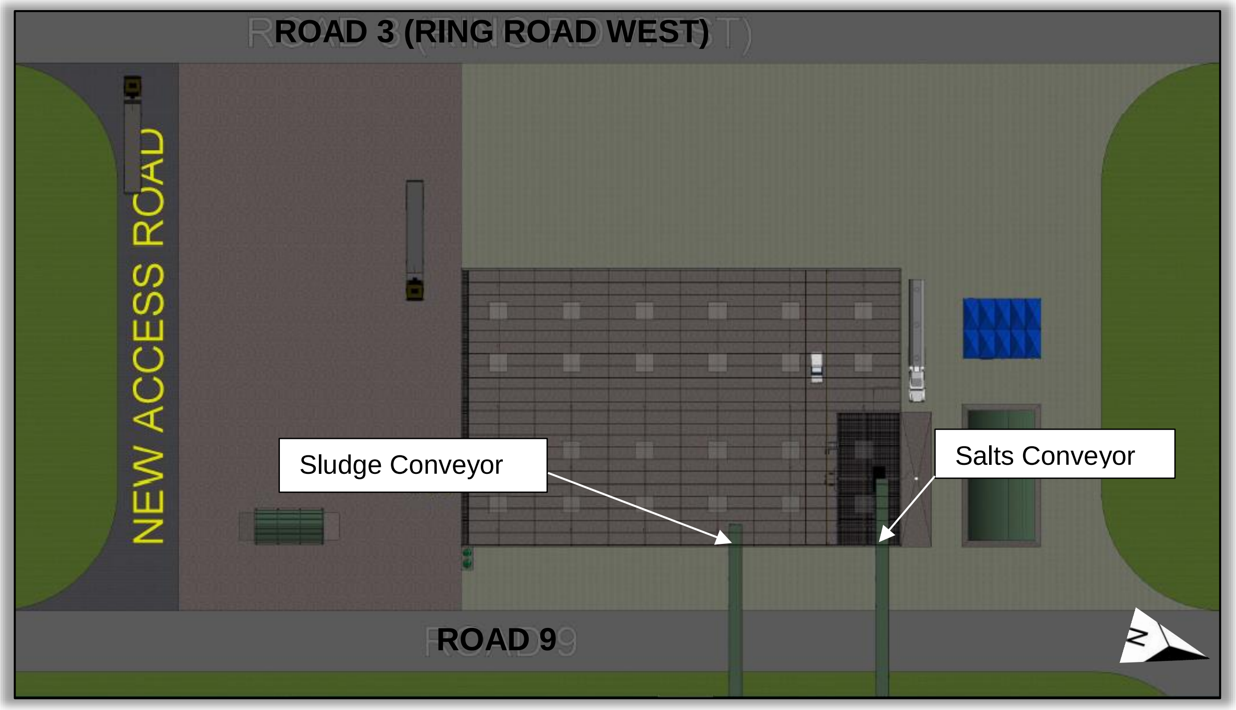


Figure 6: Position of Sludge and Salts conveyor at waste handling and storage facility

9.2 Waste handling and storage facility to Holfontein

- Truck operation

The average number of trucks required to transport waste is based on the working hours at Holfontein which are between 6h00 and 22h00. A total of 10 hours travelling time to and from Medupi Power Station was assumed which results in the loading of waste onto the trucks between 11h00 and 17h00. Figure 7 shows the route that trucks will use when entering the waste handling and storage facility.

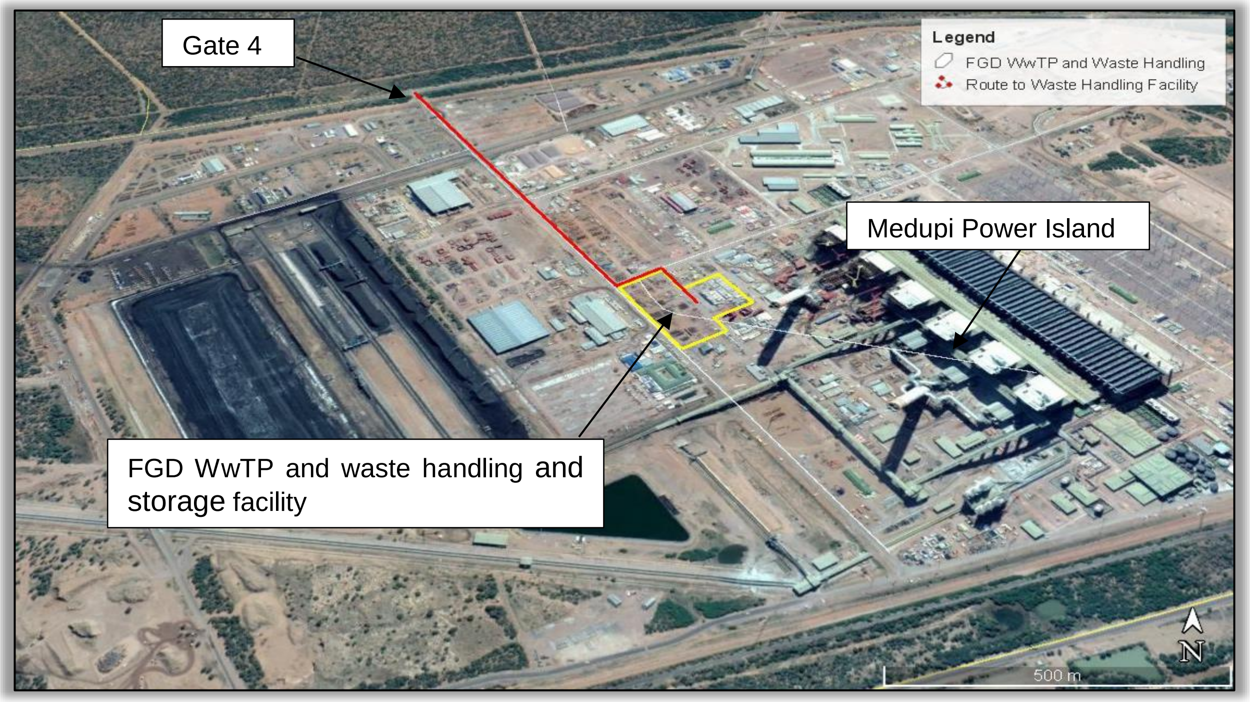


Figure 7: Route for trucks to access the FGD WwTP and the waste handling and storage facility

- Sludge

Sludge will be discharged via the conveyor onto the concrete surface bed at the waste handling and storage facility. A front-end loader will be used to remove the waste and arrange it in rows at the entrance of the waste handling and storage facility. As trucks arrive to collect the Sludge from the waste handling and storage facility, the front-end loader will be utilised to pick up and dispose the waste in the back of the truck. The truck will then follow the route shown on Figure 7 to exit the Power Station and drive back to Holfontein. The daily amount of trucks required to transport Sludge from the waste handling and storage facility to Holfontein is provided in Table 4.

Table 4: Daily amount of trucks required to transport Sludge from the waste handling and storage facility to Holfontein

Scenario	Number of trucks required
Sludge - Option 1 Case 1	6
Sludge - Option 1 Case 2	3
Sludge - Option 2 Case 1	6
Sludge - Option 2 Case 2	3

- Salt

Option 1

The Salts will be held in two reinforced concrete tanks. Details of the tanks are provided in Section 10.2. A duty and standby pump will be installed adjacent to the tanks. The pump will draw out the

Salt and discharge it into a tanker via an outlet pipe. The daily amount of trucks required to transport Salts from the waste handling and storage facility to Holfontein is provided in Table 5.

Table 5: Daily amount of trucks required to transport Salts from the waste handling and storage facility to Holfontein – Option1

Scenario	Number of trucks required
Salts - Option 1 Case 1	3
Salts - Option 1 Case 2	3

Option 2

The Salts will be discharged via the conveyor onto the concrete surface bed. A front-end loader will be used to remove the waste and arrange it in rows at the entrance of the waste handling and storage facility. Approximately 3 trucks per day will be utilised to transport Salts from the waste handling and storage facility. The daily amount of trucks required to transport Salts from the waste handling and storage facility to Holfontein is provided in Table 6.

Table 6: Daily amount of trucks required to transport Salts from the waste handling and storage facility to Holfontein – Option 2

Scenario	Number of trucks required
Salts - Option 2 Case 1	7
Salts - Option 2 Case 2	5

10 WASTE HANDLING AND STORAGE FACILITY

10.1 General

The waste handling and storage facility will consist of a concrete surface bed with rear guard installed at the joints to render the surface watertight. The perimeter of the facility will have 2m high reinforced concrete walls. A structural steel roof cladded with IBR sheeting will be used to prevent rainfall from falling directly onto the surface bed.

The waste handling and storage facility has been designed in terms of the Department of Environmental Affairs Norms and Standards for the storage of waste. The following aspects have been incorporated into the design:

- All tanks used to store liquid waste will be contained in bunded areas have impermeable floors and a capacity of at least 110% of the total contents of the liquid stored;
- Areas where spills may occur contain a sump that drains into the dirty water system;
- A stormwater interception channel has also been provided at the entrance of the waste handling and storage facility that will divert contaminated run off into the dirty stormwater system;

- The waste handling and storage facility contains access gates to prevent unauthorised entry; and
- A perimeter fence will be provided around the facility with adequate signage. The signs will indicate the risks involved with entering the site, hours of operation, the name, address, telephone number and person responsible for the operation of the facility.

10.2 Salts

Option 1

Salts will be transported via the conveyor into two reinforced concrete tanks with dimensions 10m x 10.5m x 2m that can contain a volume of 210m^3. A total storage capacity of 7 days will be provided with each tank having a 3.5 day storage capacity. The tanks have been separated to allow for maintenance. A concrete slab with a sump and a dirty drain will be provided to contain spillages that occur whilst the Salts are being pumped into the tankers. Figure 8 shows the Salts handling area and the additional infrastructure for Option 1.

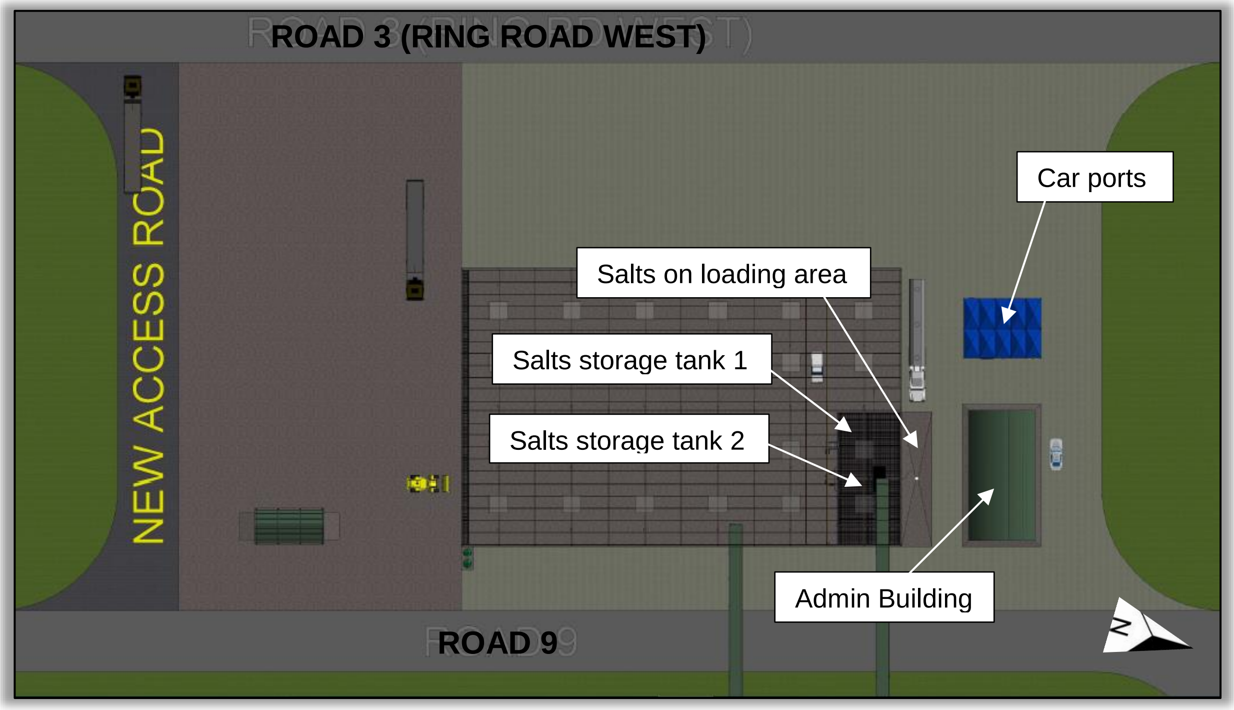


Figure 8: Layout of waste handling and storage facility – Salts Option 1

Option 2

Salts will be discharged via the conveyor onto the concrete surface bed. The area for the Salts handling area is 40m x 10m. When exiting the waste handling and storage facility all trucks will go through the wheel wash bay where any excess waste will be washed from the trucks tyres into a dirty drain.

Figure 9 shows the Salts handling area and the additional infrastructure for Option 2.

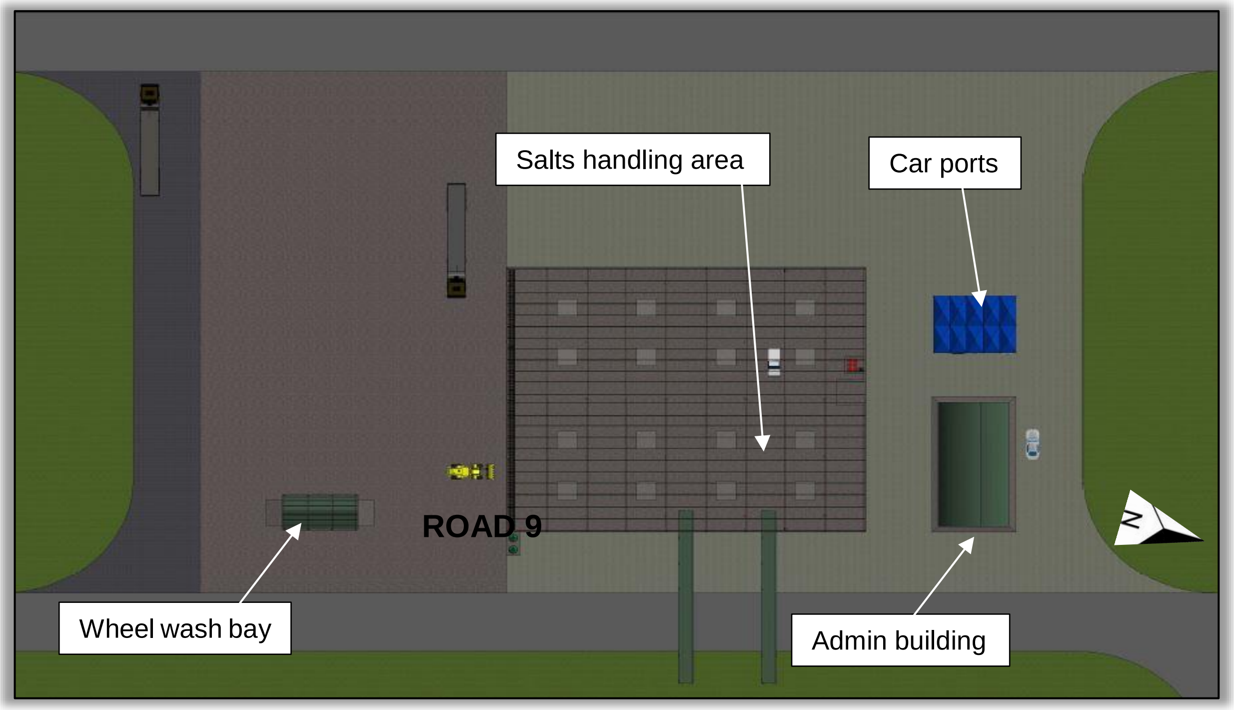


Figure 9: Layout of waste handling and storage facility – Salts Option 2

10.3 Sludge

Sludge will be discharged via the conveyor directly onto the concrete surface bed for Option 1 and 2. The Sludge handling area is 40m x 40m for Option 1 and 40m x 20m for Option 2. When exiting the waste handling and storage facility all trucks will go through the wheel wash bay where any excess waste will be washed from the trucks tyres into a dirty drain. Figure 10 shows the Sludge handling area and the additional infrastructure.

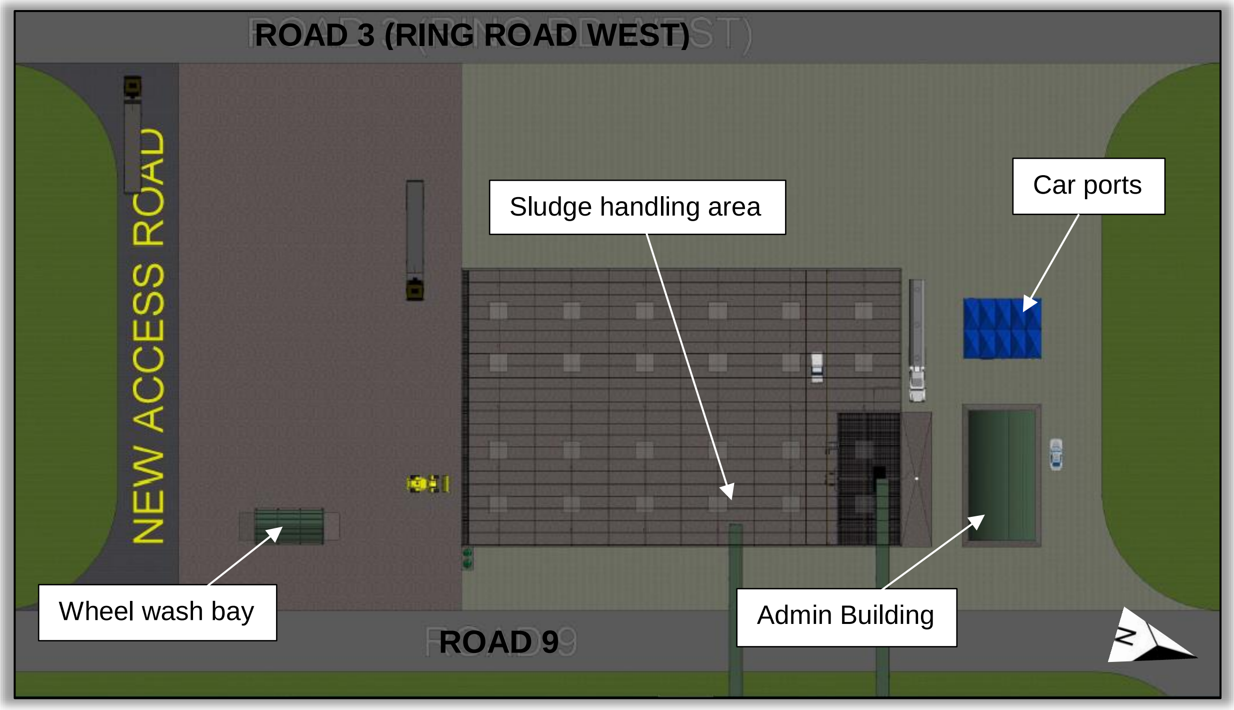


Figure 10: Layout of waste handling and storage facility – Sludge

11 STORMWATER MANAGEMENT

The stormwater management design for the waste handling and storage facility includes a clean and dirty water system. The two systems have been separated to prevent contamination of clean stormwater runoff.

The design of the waste handling and storage facility minimises the amount of dirty stormwater runoff. The structural steel roof covering the facility ensures that most of the runoff that would have been contaminated is now regarded as clean. The dirty areas are limited to the area in front of the of the waste handling and storage facility, the conveyor corridor from the dewatering building to the waste handling and storage facility and the plinths where the pumps sit. All the dirty stormwater will flow via the dirty stormwater system into a dirty water sump. All other areas on site has been classified as clean areas therefore, the runoff generated from those areas will flow into the clean storm water system.

12 SITE SERVICES

The admin building at the waste handling and storage facility will contain a potable water and sewer reticulation that will be connected to the existing water supply and sewer system. Electricity for the building will be supplied by the existing electrical supply on site.

13 TRADE OFF WORKSHOP

A trade-off workshop was held on the 8th February 2018 and attended by Zitholele, Eskom Engineering and Eskom Environmental stakeholders. The workshop was utilised to evaluate the shortlisted process technologies for Case 1 and 2 water qualities. The criteria for the trade-off workshop were developed by Zitholele and Eskom's Process Engineers. Prior to the trade off workshop Zitholele populated the trade-off matrix as a basis for discussions. During the workshop, robust discussions were held and scoring of the various criteria was rigorously interrogated until the project team were satisfied that the scoring was representative of the technology being evaluated. The criteria that were evaluated during the workshop has been defined in Table 7.

Table 7: Description of trade off criteria

Theme	Criteria	Description
Environmental and Social	Site footprint	The area of the footprint for the WwTP and the waste handling facility – based on calculations
	Volume of waste	The total volume of waste produced by the process technology – based on calculations
	Type of waste	The Type of waste as per the waste assessment
Health and safety of people	Exposure of operating and maintenance staff	The potential harmful exposure of the technology on the operating and maintenance staff
	Inherent Safe Design	Safety risks associated with a particular technology
Financial	Life cycle cost analysis	Life cycle cost analysis of the technology and the waste handling and storage facility – based on calculations
	Capital cost	Capital cost analysis of the technology and the waste handling and storage facility – based on calculations
Constructability	Project execution schedule and time	The duration of construction for the process technology
	Ease of construction	The ease of construction particularly experience of other plants constructed globally
Operability	Flexibility of operation	The impact of variations in feedwater volumes and qualities
	Reliable achievement of the product flow and quality	The ability to reliably achieve the product flow and water quality on a continual basis
	Ease of operation	The ease of operating the process technology

Theme	Criteria	Description
Maintainability	Ease of cleaning/ maintenance and access	Easy access during cleaning and maintenance of the plant
	Plant availability	The availability of the plant locally
	Local availability of spares to support the plant	The availability of spares locally (i.e. Proximity to Lephalale)
	Maintainability	Maintainability during operations including local support for special maintenance activities
Utility Consumption	Energy	The amount of electricity and steam required to operate the process technology – calculated
	Chemicals	The amount of chemicals required to operate the process technology – calculated
	Cooling water	The amount of cooling water required to operate the process technology – calculated

Following evaluation of the two options, the thermal evaporation technology was ranked higher than the freeze crystallization technology for both Case 1 and 2.

14 CONCLUSION

Following the evaluation of the various options during the trade off workshop it was decided that the go forward option for both Case 1 and 2 would be Thermal Evaporation.

Appendix A : Process Flow Diagrams

APPENDIX B : PROJECT PROGRAMME