KUSILE POWER STATION
FLUE GAS DESULPHURIZATION
WASTEWATER TREATMENT PLANT

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Abstract

As result of the availability of coal in South Africa it continues to be the dominant source of energy for the country, but also a significant source of pollution. The major by-products of coal combustion are coal ashes, wastewater, and gaseous emissions to atmosphere. Sulphur emissions, in particular, pose an environmental concern since they contribute to acid rain formation and ozone depletion.

Control of gaseous emissions is one of the areas that are receiving considerable attention in support of sustainable development and has led to environmental regulations and legislatures becoming increasingly more stringent. As a result of these concerns, Eskom has made the decision to employ Flue Gas Desulphurization (FGD) technology for stations being constructed and where possible to retrofit on existing stations. .

Flue gas desulphurization is a technology used to reduce sulphur emissions in coal-fired power utilities by using pulverised limestone in a spray tower to react with sulphur dioxide in the flue gas and remove sulphur as a solid product (gypsum). The Kusile Power Station is a coal-fired power station located in the Delmas municipal area of the Mpumalanga province and, once fully operational, will generate approximately 4800 Megawatts(MW) of electricity. It will be the first power station in the country to incorporate the FGD technology which will remove approximately 90% of the sulphur dioxide (SO_2) and a significant portion of gaseous chlorides and fluorides that may be in the flue gases.

However, the FGD process results in the production of a FGD wastewater/brine stream which has significantly high concentrations of chlorides, magnesium, calcium, and heavy metals. This wastewater cannot be directly re-used elsewhere in the station. As Kusile Power Station is to be a zero-liquid effluent discharge site, this wastewater requires specialised treatment. As discussed in this paper, Kusile power station will employ a three step process of 1)Pre-treatment, 2)Evaporation/Concentration, and 3)Crystallisation to treat this wastewater. It will produce a clean water stream that can be reused which allows the power station to reduce its raw water intake by up to 3%. Wastes are processed into a solids cake that will be disposed off-site at an approved industrial waste storage site. The FGD Wastewater treatment plant will allow the Kusile Power Station to be a true zero-liquid effluent discharge site.

1. INTRODUCTION

1.1 Background

Eskom is the largest producer of electricity in Africa and provides South Africa with approximately 95% of its electricity. The utility has an approximate generation capacity of 38 744 Megawatts (MW) net and 93% of this electricity is produced using coal-fired technology.

The combustion of coal at a power station releases gases (via the flue gas stack) to the atmosphere. The gases released are primarily carbon dioxide, water vapour, and to a lesser volume, nitrogen oxides and sulphur oxides. As a result of the environmental concerns of these gases being linked to the formation of acid rain, Eskom has made the decision to employ Flue Gas Desulphurization (FGD) technology for stations being constructed and where possible to retrofit on existing stations.

Kusile Power Station is a coal-fired power station located in the Delmas municipal area of the Mpumalanga province. This station will consist of 6 boiler units of which each will be rated to generate 800MW with a total capacity of 4800MW. It is expected to begin commercial operation in 2014 and will be the first power station in Africa equipped with FGD scrubbers.

1.2 FGD Process Description

The FGD scrubbers to be used at Kusile will remove approximately 90% of the sulphur dioxide (SO_2) and a significant portion of gaseous chlorides and fluorides that may be present in the flue gases. In the FGD Scrubber (refer Figure 1 below), the flue gas enters the FGD absorber module and flows upwards. As it rises it makes contact with a limestone slurry that originates from a spray zone at the top of the absorber. The SO_2 is absorbed from the flue gas into the slurry, where it is neutralised with dissolved calcium carbonate and forms calcium sulphite hemihydrate ($CaSO_3$-1/2$H_2$0). The slurry is collected in a reaction tank at the bottom of the scrubber where the reactions have enough time to complete, and where oxidation air is added to convert the calcium sulphate hemihydrate to calcium sulphate dihydrate ($CaSO_4$-2H_2O) also known as gypsum. The slurry is continuously recycled. As SO_2 is removed from the flue gas, the gypsum solids concentration and that of other elements in the reaction tank increases. At a certain solids concentration set point (approximately 15%) a portion of the slurry is bled off and sent to a dewatering system to separate the water from the gypsum.

This FGD wastewater, produced from dewatering, has significantly high concentrations of chlorides, magnesium, calcium and heavy metals and cannot be re-used elsewhere in the station.

The pollutant content in this wastewater depends on the type of coal burned and the amount of impurities and heavy metals in the coal and limestone used. The coal is the primary source of the chlorides and sulphur in the wastewater. (4)

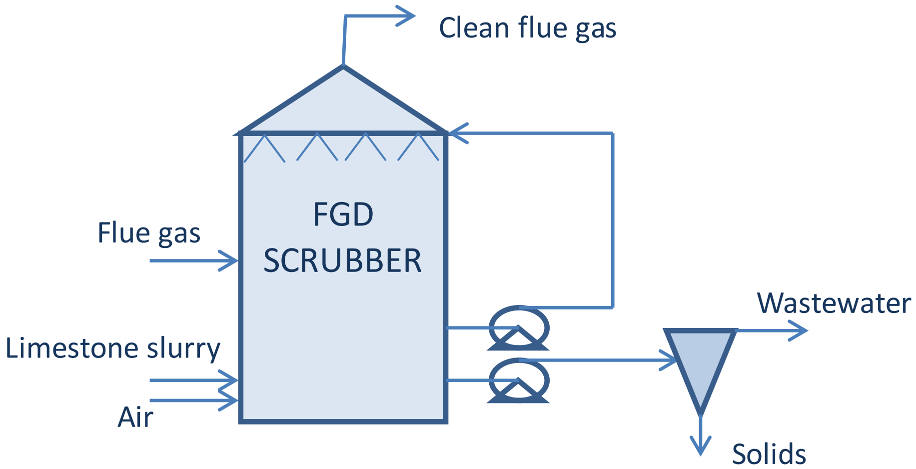

Figure 1: FGD Scrubber process schematic

1.3 Zero Liquid Effluent Discharge

To minimize plant raw water consumption and the environmental impacts, the Kusile Power Station will operate as a Zero Liquid Effluent Discharge (ZLED) station. This means that all wastewaters generated at the station will have to be stored, treated and re-used at the station. The adoption of this policy has been a motivating factor for the construction of the FGD wastewater treatment plant. As mentioned, due to the high pollutant content of the FGD brine, it cannot be re-used elsewhere in the power station. The three stage treatment plant to be constructed will treat this wastewater and a produce a clean water stream that can be used as feed to the demineralized/potable water treatment plant. The removed impurities from the wastewater will be bound in the form of a solids cake, hence allowing the station to be completely ZLED.

1.4 FGD Wastewater feed chemistry

The table below represents the anticipated composition of the wastewater feed, used to design the Wastewater treatment plant. As no conclusive information on wastewater quality was available at the time of the design, conservative values and ranges were estimated through research and consultant advice.

Table 1: FGD Wastewater chemistry composition (1)

Parameter	Concentration (mg/l as ion)	Parameter	Concentration (mg/l as ion)
Chloride	30 000	Chromium	0.3 - 5
Sulphate	1500 – 8000	Copper	0.1 – 0.85
Sulphite	<20	Mercury	0.05 – 0.8
Nitrate	100 – 1500	Nickel	0.2 – 6
Flouride	30 – 200	Lead	0.1 – 3
Calcium	4000 – 20 000	Selenium	0.2 – 1
Magnesium	200 – 5600	Vanadium	0 – 2.4
Sodium	75 – 1200	Zinc	5 – 10
Iron	30 – 400	Ammonium	<10 – 100
Aluminium	50 – 800	COD	100 – 150
Arsenic	0.05 – 3	pH	4 – 7
Boron	20 – 40	Total Suspended Solids	300 – 10 000
Cadmium	0.04 – 0.5	Cobalt	0.05 – 0.5

2. FGD WASTEWATER TREATMENT PROCESS

The FGD wastewater treatment process has been divided into 3 main sections:

- Pre-treatment
- Evaporation (Brine Concentration)
- Crystallisation

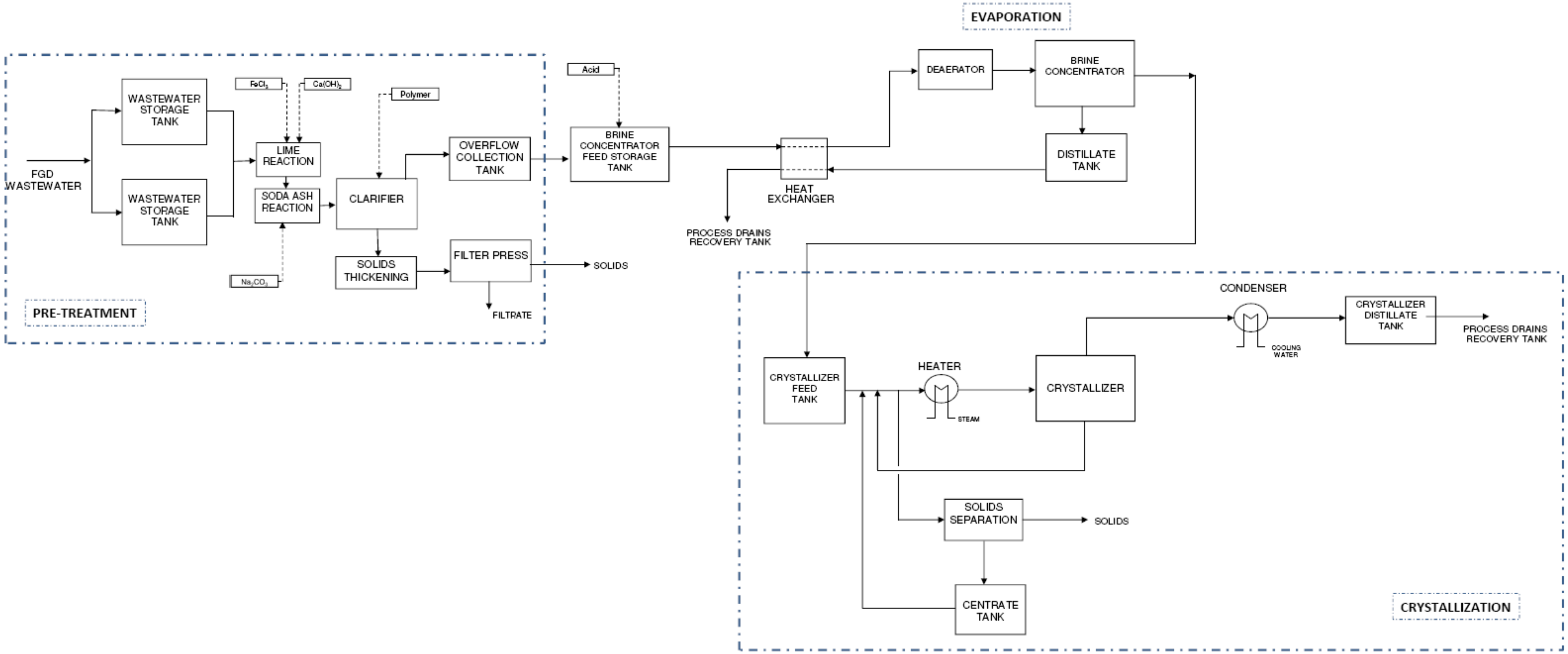

Figure 2: Process flow of FGD Wastewater treatment plant

2.1 Pre-treatment Process Description and Selection

The purpose of the pre-treatment system is to partially soften the wastewater before it is fed to the evaporation process system to prevent scale formation on heat exchange components. It is designed to provide the Evaporation system a feed with a hardness of approximately 1500mg/l calcium and 320mg/l magnesium as ion. The heavy metals are expected to also be reduced to very low concentrations in the pre-treatment process.

2.1.1 Softening

The influent feed stream can contain high concentrations of calcium, magnesium, sulphates and aluminium, which can all contribute to the scaling of downstream equipment and heat transfer surfaces. The softening process is a chemical precipitation process, where lime ($Ca(OH)_2$), and soda ash (Na_2CO_3), are added to form insoluble precipitates (primarily calcium carbonate and magnesium hydroxide) with the hardness-causing minerals.

The first step of the process is to add lime and raise the pH to 9-10. At this pH, metals like aluminium will precipitate as metal hydroxides. The dissolved calcium and magnesium concentration reduces as the calcium carbonate and magnesium hydroxide precipitates begin to form. Ferric chloride is also added into the lime reaction tank to neutralize the charges of the precipitated particles and enhance the rate of coagulation.

The second stage of the softening process is the addition of soda ash. Calcium in the wastewater reacts with the soda ash to form insoluble precipitates of calcium carbonate. Consequently, the reduction in the calcium concentration is directly proportional to the amount of soda ash added. The calcium concentration cannot be reduced too low as a certain amount of calcium is required for the seeded slurry operation of the Evaporator/Concentrator (to be discussed later). (2)

2.1.2 Clarification & Filtration

Settling of the precipitated solids takes place in the clarifier tank. As the wastewater slurry is fed into the clarifier it is dosed with polymer. The polymer promotes agglomeration of the smaller flocs into denser flocs that will settle easier.

The clarifier underflow is sent to a sludge holding tank. Sludge dewatering will be accomplished by the use of a plate filter press. The filtrate liquid from the filter press is sent back to the wastewater storage tanks and the solids dispatched for disposal.

As the pH of the wastewater has been raised by the lime addition, the clarifier overflow is directed to the clearwell where it is dosed with sulphuric acid to drop the pH to 7-8. At this pH, potential precipitation in downstream equipment and piping is reduced. It is then forwarded to the automatic backwash strainers en route to the Brine Concentrator (BC) feed tanks. The strainers protect the BC feed tanks from receiving particulate matter in the case of a clarifier upset. (2)

2.2 Evaporation/ Brine Concentration

From pre-treatment, the softened wastewater flows to the evaporation phase of the plant. This section of the plant consists of two independent trains to maintain the Eskom requirement for redundancy of critical operations; however both trains are capable of being run simultaneously.

2.2.1 Chemical treatment

Feed to the Brine concentrator (BC) is first stored in the BC feed tank. Sulphuric acid is added to the tank to lower the pH to 4-5 and convert the alkalinity to carbon dioxide (CO_2). The carbon dioxide will be removed later in the downstream deaerator. By decreasing the alkalinity, we decrease the possibility of carbonate scaling on the heat transfer surfaces of the BC feed heat exchanger and BC condenser tubes. Scale inhibitor, added as a precaution against heat exchanger fouling, and sodium sulphate will also be added to the feed tank. The sodium sulphate is needed to prepare the feed for the seeded slurry process which occurs in the BC. As the constituents in the FGD wastewater become concentrated in the BC, calcium sulphate eventually becomes saturated and precipitates out of the solution. As the feed has been pre-treated and the sulphates reduced, additional sodium sulphate is needed to ensure that the sulphate concentration in the BC is high enough to support the calcium sulphate precipitation. (2)

2.2.2 Heat Exchange & De-aeration

The wastewater then flows from the feed tank to a plate and frame heat exchanger, made up of titanium plates. In the BC Feed Heat exchanger, the cold feed enters at around 37^{o}C and is heated to approximately 96^{o}C by counter flowing hot distillate from the BC and hot condensate from the crystalliser.

The BC De-aerator is a packed stripper column that removes the carbon dioxide, dissolved oxygen, and other non-condensable gases from the feed, with the aid of a counter current flow of steam. The removal of the gases not only prevents possible fouling (as mentioned) but if not removed it may accumulate in the vapour space of the BC condenser and reduce the heat transfer efficiency. Removing dissolved oxygen also minimizes the potential for corrosion in downstream components. The steam also serves to heat the feed slightly and brings it closer to its boiling point. (2)

2.2.3 Brine Concentration

The next step in the process is brine concentration. Kusile Power station will be using a falling-film type evaporator (see Fig.3) that will operate in a seeded slurry mode. It consists of a vertical shell and tube heat exchanger that sits on an integral collection sump. Other components include a device to distribute the recirculating brine (located over the upper tube sheet), a vapour compressor, a recirculation pump and mist eliminators.

De-aerated wastewater is fed into the BC sump. The brine in the sump is continuously recirculated to the top of the vertical heat transfer tubes where the distributor device distributes the wastewater at its boiling temperature as a thin film around the inside surfaces of the tubes. As this film flows uniformly down the entire length of the tube a portion of the thin film vaporizes. The vapour is removed from the top of the BC sump, routed through mist eliminators to prevent solids carryover, compressed in an electric-driven vapour compressor, and introduced into the shell side of the vertical tubes. As heat is transferred across the tube from the vapour to the brine, the vapour condenses as distilled water and is collected in the distillate tank.

As the BC sump is a collection area for the recirculating brine. The recirculation pump is required to keep the concentrated brine recirculating at all times to prevent solids from settling. (2)

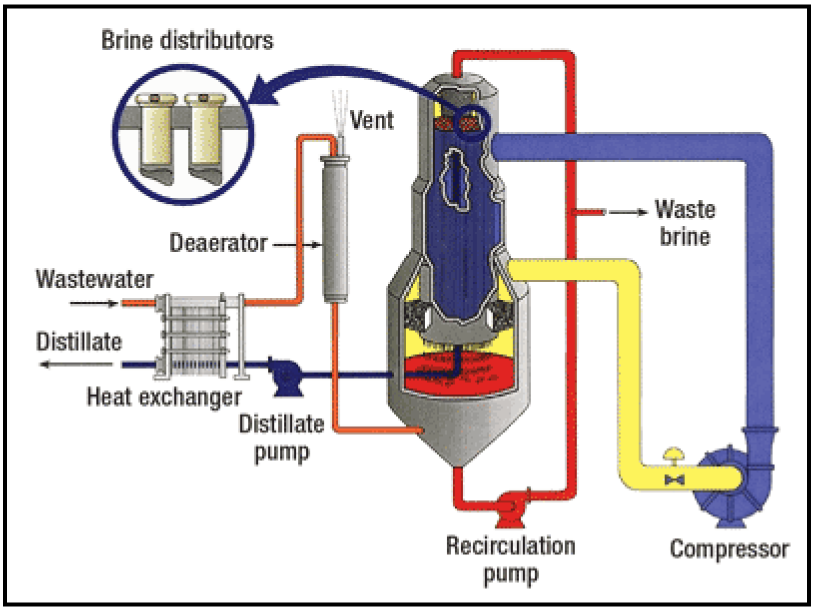

Figure 3: A schematic of a vertical-tube, falling-film Mechanical Vapor Compression (MVC) evaporator. (3)

2.2.3.1 Seeded Slurry operation in the Brine Concentrator

To minimize scaling, the concentration of the Total Dissolved Solids (TDS) and the Total Suspended Solids (TSS) needs to be controlled, and this is the purpose of the seeded slurry process. Seed (calcium sulphate crystals) is introduced into the BC. The seed has a surface area much greater than that of the heat transfer tubes. Thus, when further calcium sulphate starts to precipitate it will do so on the seed instead of the heat transfer surfaces.

Blowdown from the BC will be adjusted to maintain the required TSS level. A Seed Recycle system is will be in place to recover and recycle seed from the waste brine back to the recirculating brine. This system consists of a seed recycle pump and a hydrocyclone to separate the seed from the brine. The seed is then returned back in the BC sump at a rate necessary to maintain the required TSS level. (2)

2.3 Crystallisation

The Crystallizer System is designed to further concentrate the waste brine from the Brine Concentrator System. The Crystallizer Feed tank receives the concentrated waste (up to 267 000 mg/l TDS) from the BC. Its temperature is raised to approximately 93^{o}C by sparging low pressure steam into the feed tank, because by keeping the feed hot we minimize corrosion of downstream equipment.

The hot feed is pumped into the crystalliser recirculation duct and mixes with recirculating brine slurry from the crystalliser. It is then pumped through the crystalliser heater where its temperature rises a few more degrees, and then enters the crystalliser vapour body. The added heat causes water in the slurry to flash in the vapour body and precipitates salt crystals in the slurry. The vapour released passes through a mist eliminator en route to the crystalliser product condenser where it is condensed and sent to a crystalliser distillate tank.

In the BC, the feed is concentrated to approximately 80% of sodium chloride saturation. In the crystalliser, the brine is further concentrated past saturation point and, as a result, salts are continuously formed in the vapour body.

A side stream of the recirculating brine slurry is drawn from the recirculation duct to maintain a certain solids concentration in the vapour body. This stream is sent to a centrifuge as blowdown. The crystalliser centrifuge processes the blow-down producing a centrate and solids cake. The centrate is recycled back to the crystalliser. The solids salt cake is periodically removed from the centrifuge and collected for offsite transport. (2)

3. DESIGN CHALLENGES & PROPOSED SOLUTIONS

3.1. Late award of coal and limestone contracts

Due to concerns with the project schedule, at the time the FGD Wastewater treatment was being designed there was limited information available on the power station coal source and limestone supply source, as negotiations for these contracts were still being conducted. These inputs are the main source of contaminants in the wastewater and are critical to estimating the wastewater composition.

3.1.1. Solution

In the absence of this information, the FGD wastewater composition had been based primarily on assumptions based on limited borehole sampling from the expected coal source, literature, and from the experiences of international FGD plants.

3.2 Changes to FGD Scrubber design.

- As the Kusile project progressed, changes were made to the materials of construction of the FGD scrubbers. These changes saved costs and resulted in improved efficiency of the FGD scrubbers but consequently has resulted in the chloride content of the wastewater stream becoming significantly higher than original estimates.
- FGD gypsum has been used worldwide in the manufacturing industry for the production of wallboard and for other uses. Although presently a market has not been identified at Kusile, it was decided that the FGD scrubbers would be designed to be capable of producing a saleable gypsum byproduct in the future. This change required that the gypsum being produced be of a higher purity and lower moisture content. Consequently the following features were incorporated in the FGD design:
  - Very high degree of oxidation of the FGD solids.
  - A dewatering method that produces a very low moisture gypsum cake.
  - Solids waste handling facilities were designed to segregate gypsum disposal from fly ash and other solids waste.

- All these features led to a higher dissolved solids and chloride content being maintained in the scrubber. On evaluation of the overall changes to the chemistry and stream compositions, it had become apparent that the original WWTP designs/estimates were inadequate to meet FGD's new requirements.

3.2.1. Solution

The following include some of the major design changes that were implemented:

- Due to the increased dissolved solids loading, the clarifier, crystallizers, centrifuges were increased in size.
- Materials of construction of certain components had to be upgraded to minimize the potential for corrosion, as the higher dissolved solids wastewater is more aggressive.
- Change in the type of dewatering filter (belt filter to a plate press filter) and increase in the capacity of the filter presses
- Design of the vapour compressors was enhanced to accommodate an increased boiling point rise in the brine.
- An increase in dosing of chemicals and reagents.
- Larger systems for lime and soda ash including silos for storage and the dosing systems.

3.3 Solids waste handling.

The solids waste generated in the wastewater treatment plant will be namely dewatered clarifier solids (primarily calcium carbonate and magnesium hydroxide) and the final solids from the crystallizer centrifuge (primarily sodium chlorides and sulphates). Under the worst case scenario of both wastewater treatment trains in operation approximately 12.2 tons of waste will be generated per hour. Due to these large volumes there is currently no appropriate space on site to store this waste. It has been decided that these wastes be removed from the Eskom site and disposed of at an appropriate hazardous waste landfill. However, to date, we have not found a suitable waste removal contractor to remove this waste. As the wastewater treatment plant building is still being designed, it is the intention to optimise solids waste removal by designing the building to meet the removal method of the waste removal contractor if possible.

3.3.1. Solution

To prevent delays in the building construction, it appears likely that the building will have to be designed based on educated assumptions and from the feedback from similar treatment plants in the USA. However, if unloading modifications are required later, this could result in additional costs to the project.

3.4 Organic carry over.

The high organic content of the wastewater could lead to the possibility of low molecular weight and volatile organics being carried with the steam to the distillate tanks. The distillate is intended to be sent to a plant recovered water storage tank for reuse in the station. The recovered water may reduce the plants raw water consumption by up to 3%. However, some of the recovered water from other parts of the station might contain small traces of ammonia, which in combination with the warmer temperature, could lead to organic fouling/biogrowth and the wastage of that water. Organics could also potentially foul ion exchange resins in the demineraliser process and could eventually even affect the quality of the water sent to the boilers.

3.4.1. Solution

Under current investigation is the option of installing granular activated carbon filters before the distillate enters the recovered water tank. This would reduce the possible organic content of the distillate and reduce the likelihood of fouling/biogrowth. Piping is also being routed to allow the distillate to be directed to other processes if it causes problems in the makeup treatment system.

4. CONCLUSIONS

Due to current environmental concerns surrounding fossil-fuelled power stations in South Africa, and the rest of the world, flue gas desulphurization technology is becoming increasingly more common as a way to minimize the associated air pollution.

However, as mentioned, this technology results in the generation of a wastewater stream that requires specialized treatment. As discussed in this paper, Kusile power station will employ a three step process of pre-treatment, evaporation/concentration and crystallization to treat this wastewater. It will produce a clean water stream that can be reused and allow the station to reduce its raw water consumption by up to 3%, and a solids cake that will be disposed off-site. The FGD Wastewater treatment plant will allow the Kusile power station to be a true zero-liquid effluent discharge site.

Since the wastewater treatment plant was being designed concurrently with the FGD scrubbers, as the project progressed and more information on the FGD system became available, it was found that many of the initial chemistry assumptions estimates made had to be adjusted. This had led to changes in the sizing and the design of the waste water treatment process equipment, with significant associated cost increases. Eventually this may be offset, in part, by the ability to sell and beneficially use the FGD system gypsum in wallboard or other industries.

5. REFERENCES

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