WATER RESEARCH COMMISSION PROJECT NO. 201

THE TREATMENT OF INORGANIC BRINES AND CONCENTRATES

APPENDIX 10

Visit to Lethabo Power Station

10 March 1988

Pollution Research Group
Department of Chemical Engineering
University of Natal
Durban

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STEERING COMMITTEE 1988

APPENDIX 6

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1 INTRODUCTION

Lethabo Power Station is a wet-cooled power station which, when fully commissioned, will consist of six units, each with a capacity of 618 MW. Construction commenced in 1981 and at present four units are fully constructed and commissioned. The life of the station is projected to be 40 years.

Lethabo is a zero effluent discharge plant and hence innovative effluent stream structuring has been implemented to match the effluent production to the potential disposal possibilities. This report examines the total water and effluent system at Lethabo Power Station

2 POWER PRODUCTION

The power production process at Lethabo follows the conventional route: coal is conveyed from the nearby mine, is pulverised and then sprayed into the burner of the boiler where it ignites. The heat is used to vaporise very pure water in the boiler and the steam produced is used to drive the turbines with the generation of electrical energy. The condensed steam is then polished and recycled to the boiler for revaporisation. Each m^3 of steam generates approximately 19 kW.

The coal is mined by the open cast method. The coal reef being utilised at Lethabo is of extremely low quality, containing 40% ash with a colorific value equivalent to a Provita biscuit. Approximately 10 000 tons/day of coal is consumed at Lethabo.

The ash is conditioned and quenched before being discharged to a temporary ash dump within the station site. The dump is surrounded by a drain which collects any run-off and prevents pollution of the natural water system.

It is envisaged that most of the ash produced at Lethabo will be returned to the empty mine, by laying it on top of the overburden and replacing any topsoil and vegetation which was removed during the mining operation.

3 WATER REQUIREMENTS

The complexity of the water system at Lethabo is due to the fact that an extremely high quality water must be produced before power production is possible. The basic water requirements include:

(i) cooling water. A thermodynamic requirement of the electrical power production process is that exhausted steam must be cooled and condensed. The cooling water is recooled in large cooling towers. Approximately 25 to 30 Ml/day of water vapour is discharged from the top of each cooling tower. The thermodynamic efficiency at Lethabo is relatively high in comparison to the older power stations, with an evaporation rate of 1,7 l/kWh.

The quality of the cooling water feed is not critical since a treatment plant consisting of lime soda softening and acid dosing is always available to control the scaling index of this stream. The most important parameter of this stream is the TDS level since an increase in TDS causes a proportional increase in the TDS of the effluent requiring disposal. The sulphate level of the water in the cooling tower loop is also important since this level is the limiting factor on the number of cooling cycles achievable between blowdowns. Sulphate levels above 1 300 ppm are avoided in order to prevent degradation of the concrete structure of the cooling tower.

(ii) demineralised water. The quality control of this stream is highly sophisticated and the specifications are 0,06 to 0,07 µS/cm KHI. The daily production of demineralised water at Lethabo is 5,8 Ml.

Obviously minimal feed water TDS is desirable since this reduces the ionic loading on the ion exchange resins, requiring less frequent regeneration cycles and decreasing the volume and chemical loading of the regeneration effluent.

(iii) Potable water. This is used for domestic purposes and is stockpiled for fire fighting purposes. At the peak of the construction of the power station potable water consumption was 10 Ml/day. After commissioning of all six units the general consumption is anticipated to drop to 4,5 to 5 Ml/day. This stream must meet potable water standards, particularly with respect to turbidity and colour.

(iv) fly ash conditioning. The ash fines are conditioned with water at a rate of approximately 2,75 Ml/day. The original system design accommodated a 20% moisture content of the ash. To date the average moisture content achievable is 8%, but future developments should elevate it to 12%. Quality requirements of this stream are that it be neutral.

(v) bottom ash quenching. Approximately 1,8 Ml/day of water is required for this purpose. Again, low quality water suffices so long as it is neutral.

The total water requirements of the Lethabo Power Station, when fully commissioned, will be approximately 170 Ml/day.

4 WATER CIRCUITS

The water circuits may be divided into three sections;

(i) the raw water circuit in which raw water is clarified to produce potable water and water for supply to the demineralisation plant.

(ii) the boiler circuit in which demineralised water is boiled, recondensed, polished and recycled.

(iii) the cooling tower circuit.

Figure 1 illustrates the overall water balance at Lethabo Power Station during 12% moisture in the ash.

4.1 The Raw Water Circuit

Figure 2 illustrates this circuit.

Raw water is extracted from the Vaal River and pumped to reservoirs from where it is gravity fed to the pump station. At Lethabo, the quality of raw water is relatively good in terms of sulphate contamination (20 mg/l $SO_4^{=}$) but contains suspended solids, mainly in the form of aluminium silicates.

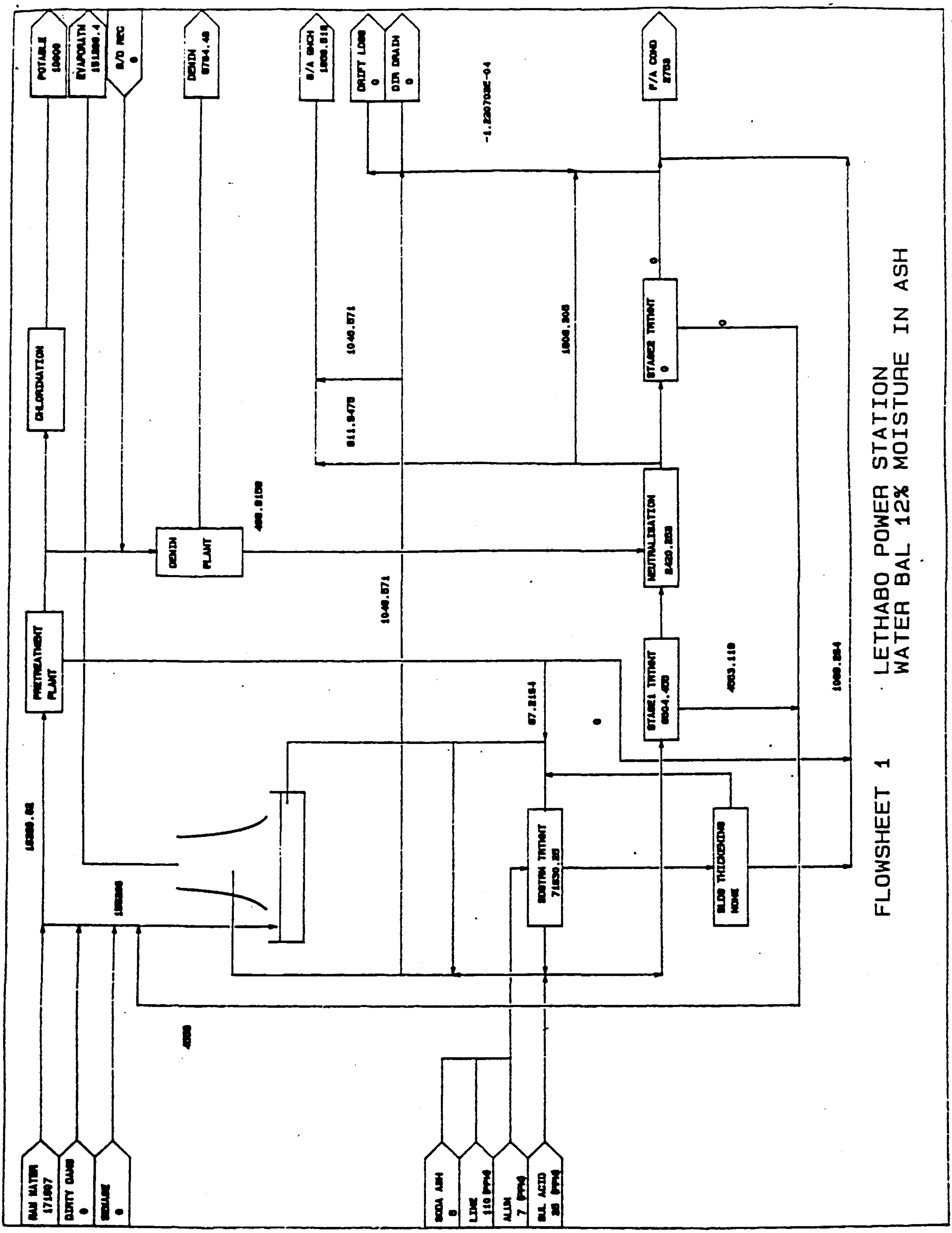
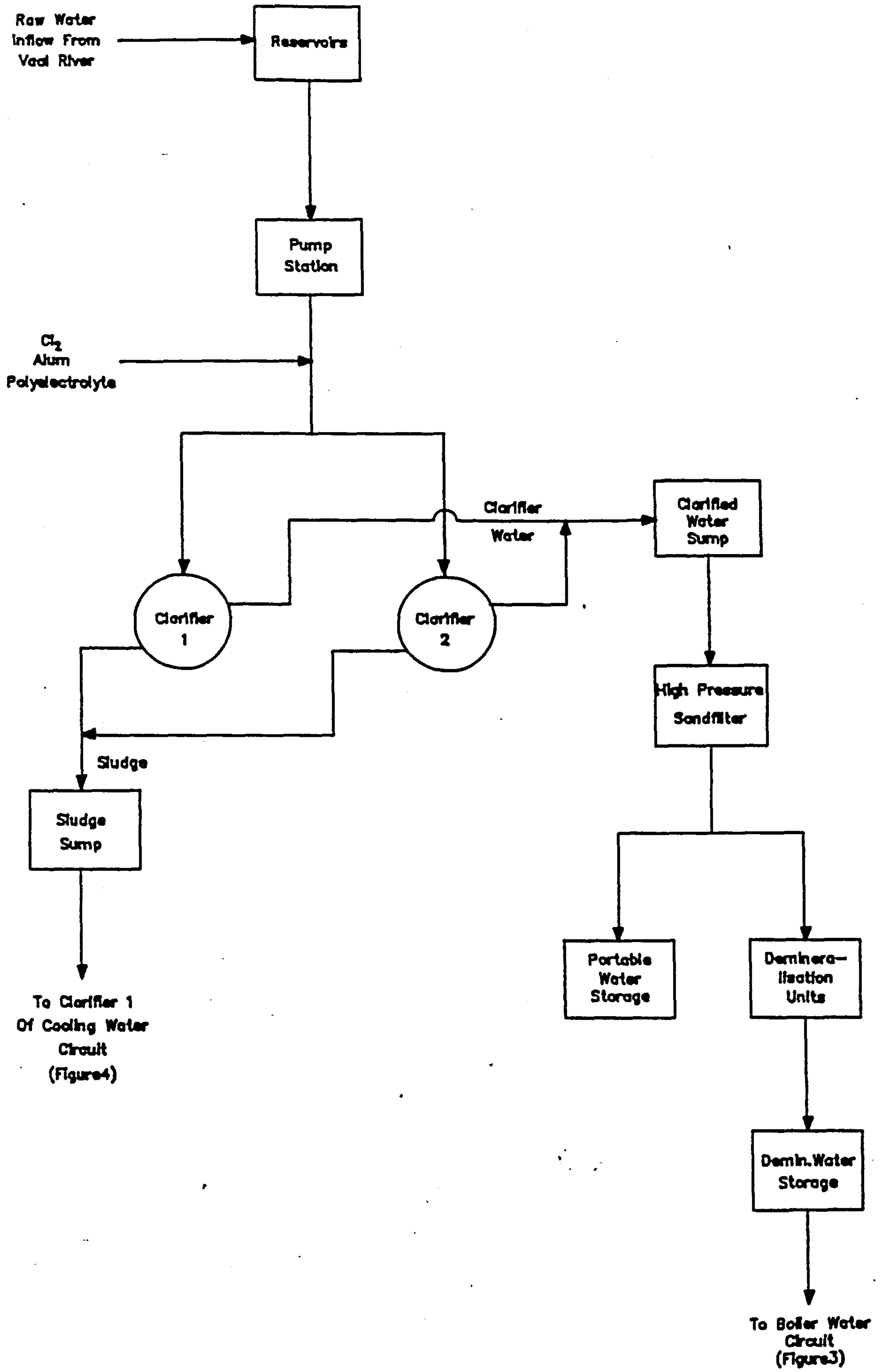


FIGURE 1 : Overhead Presented at Department of Water Affairs: ESKOM Meeting, 11 March 1988 entitled 'Flowsheet 1 : Lethabo Power Station, Water Balance 12% Moisture in Ash'

FIGURE 2 : Raw water circuit



The water is pumped from the pump station to one of two clarifiers. Chlorine and alum (50 to 75 mg/l) are dosed in line and polyelectrolyte is dosed immediately before the clarifier. This enables maximum reaction time of the alum before polyelectrolyte addition which minimises polyelectrolyte dosing requirements. Each clarifier is 18 m in diameter with an upward flow of 3,5 m/h and a throughput of approximately 730 m^3/h.

The sludge underflow from these clarifiers is discharged to a sump, from where it is pumped to Clarifier 1 of the cooling water circuit for further treatment.

The clarified water is discharged into a sump from where it is pumped through one of four high pressure sand filters to remove any suspended matter carried over from the clarifiers. Each sandfilter is designed to treat 250 m^3/h of clarifier overflow.

The filtered water is stored either as:

(i) potable water, after pH adjustment. Approximately two-thirds of this water is made available for fire-fighting purposes after pH correction with sodium carbonate. The facility exists for by-passing the sandfilters and using clarified water for fire-fighting.

(ii) demineralisation unit feed. Three demineralisation trains exist, each consisting of a cation exchanger, a degasser, a weak anion exchanger and a strong anion exchanger. There is facility available to reuse the sodium hydroxide in the regeneration of the strong anion resin for the regeneration of the weak anion resin.

4.2 The Boiler Water Circuit

Figure 3 illustrates this circuit.

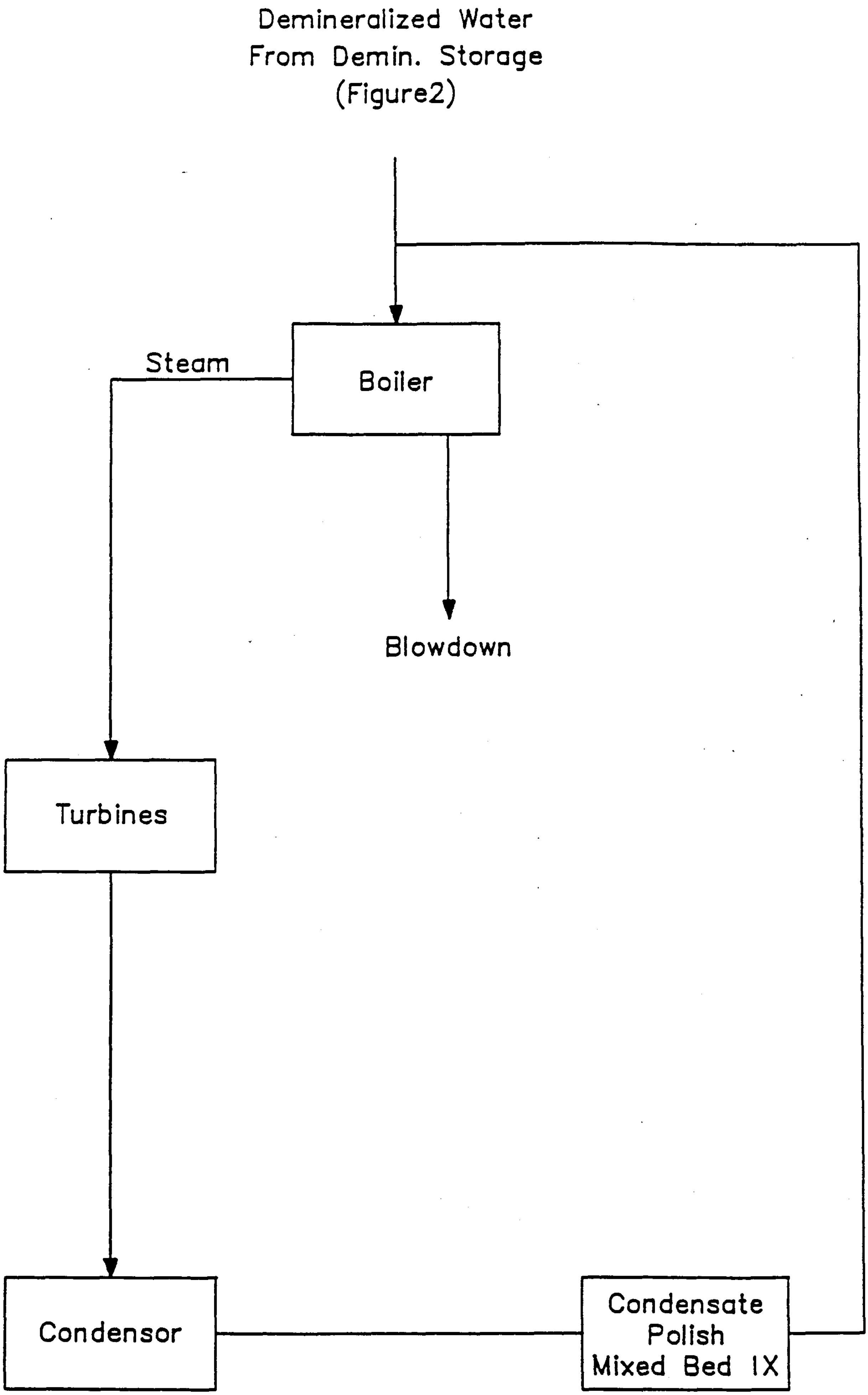
Demineralised water is used as make-up to the boiler water circuit. The exhausted steam from the turbines is condensed and then polished in one of three mixed bed reactors before being recycled to the boiler. The demineralised water storage system is sized to give 1 hour of total steaming capacity storage.

The mixed beds are regenerated in separate vessels. The anion and cation resins are separated on density by backflushing. The cation resin is less dense than the anion resin and separates as the top layer. The resins are then physically separated into two vessels for regeneration. The complete exclusion of all anion resin from the cation resin is important since the cation resin is regenerated using sulphuric acid and the sulphate ions bond irreversibly to the sites on the anion resin. In practice, some anion dust is present in the cation resin due to attrition of the resin beads.

The cation resin is regenerated by pumping a weak acid solution in at the top and a strong acid solution in at the bottom. This is done to prevent calcium and magnesium adhesion of the resin at the top of the bed.

The anion resin is regenerated with sodium hydroxide followed by ammonium hydroxide. The latter regeneration chemical stream is then recycled to the cation resin to remove residual sodium.

FIGURE 3: Boiler water circuit



4.3 Cooling Tower Water Circuit

Cooling water is required to condense the exhaust steam from the turbines. Figure 4 shows the cooling tower water circuit. The cooled water is used in the condensers to cool the exhaust steam from the turbines and it is either:

(i) recirculated to the cooling tower for recooling.

(ii) treated in one of three clarification ponds before being recycled to the cooling tower. Approximately 10% of the cooled water is recycled through the clarifiers.

The three clarifiers are used for specific duties:

(i) The No. 1 clarifier is used for effluent recovery. All effluents from the station, the submerged scrapper conveyor effluent and the returns from the station and sewage drains are treated here. Dosing agents include alum (5 mg/l) and polyelectrolyte (2 mg/l).

(ii) The No. 2 clarifier is used principally for the treatment of cooling water. Polyelectrolyte is the principle dosage chemical.

(iii) The No. 3 clarifier is used for lime softening of the cooling water to remove calcium bicarbonate. The calcium bicarbonate is considered unstable in the cooling towers where liberation of CO_2 results in calcium scaling. The optimum pH of softening is 10,2. At this pH minimal carry-over of calcium hydroxide back into the water circuit occurs. However, since chemical treatment is required only to enable the water to stay within the specification limits in the cooling towers over-treatment is not considered necessary and thus softening is carried out at pH 9,8, which is considered sufficient to destroy the M-alkalinity in the water. The clarified water returns to the cooling tower via the clarified water launders. Acid addition (sulphuric acid) is used to reduce the pH of the softened water to between 8,7 to 9, thus trimming any alkalinity not removed during lime softening.

The sludge drained from the bottom of the clarifiers is either:

(i) screened to remove solids and used for fly ash conditioning.

(ii) pumped onto the ash fields.

Sludge volumes are approximately 12 to 20 Ml per unit per month at 3,5% solids and 150 NTU.

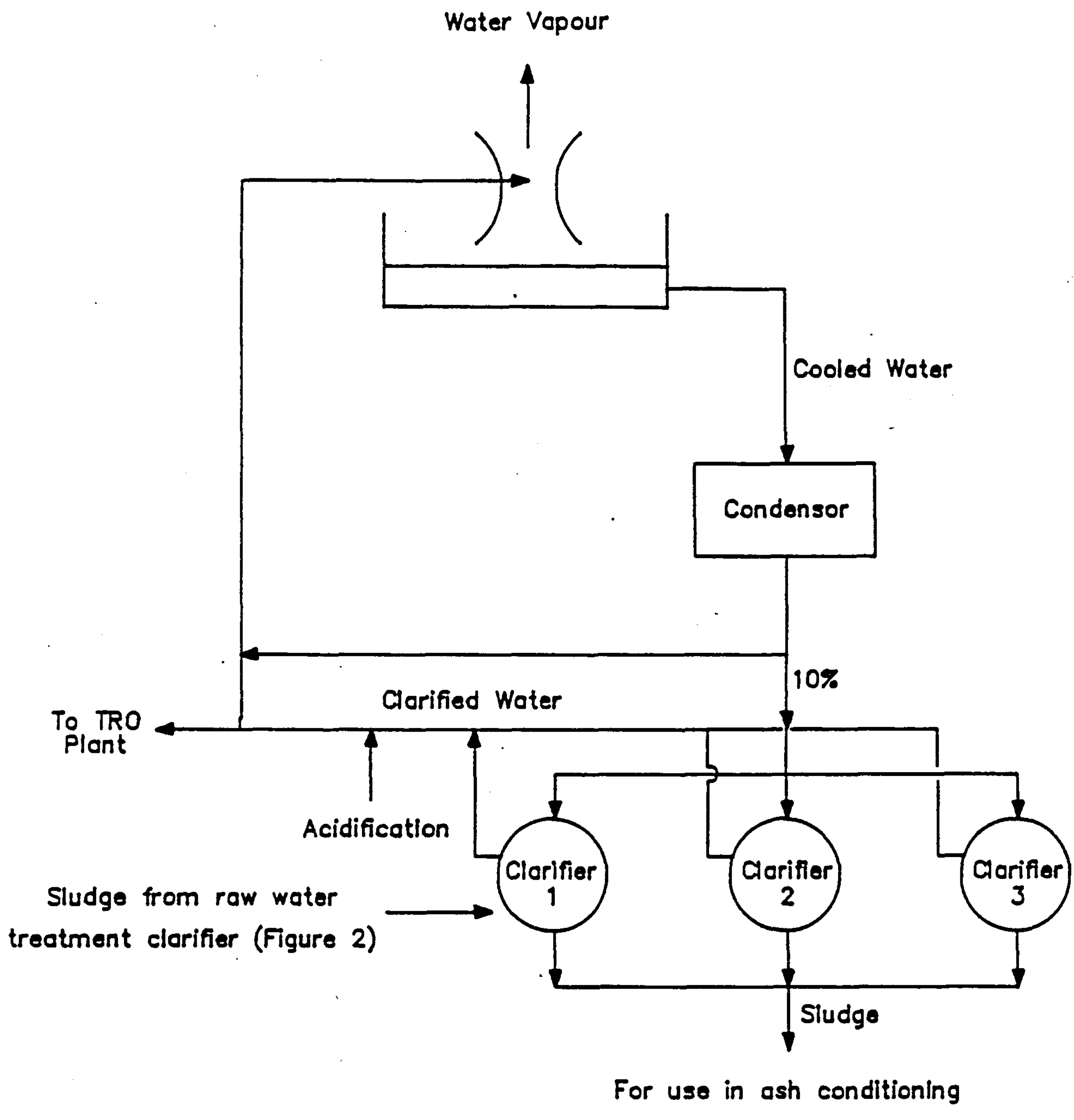
In order to maintain a salt mass balance and to avoid excessive build-up of TDS in the circuit, an amount of salts equal to all the salts entering the site in the raw water feed must be removed from the water reticulation system. In order to achieve this, a bleed stream is extracted from the clarified cooling water after acidification before re-entering the cooling tower, and treated by reverse osmosis (section 5.1)

5 THE EFFLUENT HANDLING SYSTEM

The main effluents produced at the station are:

(i) cooling tower blowdown (high in sulphates).

FIGURE 4 : Cooling tower circuit



(ii) cooling water sludge from the clarifiers (turbid and high in calcium carbonate).

(iii) potable water sludge from the clarifiers.

(iv) demineralisation regenerant effluent.

The station has a zero effluent discharge and hence the effluent production must be balanced with the effluent disposal facilities. The major disposal sinks include fly ash conditioning and bottom ash quenching. Figure 5 shows the total effluent handling system at Lethabo.

5.1 Reverse Osmosis

A portion of the circulating cooling tower water is treated in a Bintek tubular reverse osmosis (TRO) unit.

The TRO unit consists of three sections, at least one of which has been operating for the past 18 months at any one time. The plant consists of 5 800 modules of cellulose acetate membranes. The design feed concentration is 1 250 mg/l TDS and the design capacity is to treat a maximum of 9 Ml/day with the production of 6,5 Ml/day of permeate. Design fluxes are 500 to 600 l/m^{2}day. Additional operating data is as follows:

pretreatment	chlorination, pH and temperature adjustment
operational temperature	30°C
operational pH	3 to 6
point rejection	90%
design water recovery	70%
operational water recovery	75%
operating pressure	40 bar
maximum allowed pressure	60 bar
flow	0,5 m/s
cleaning type	sponge ball

The membranes are guaranteed against mechanical defaults for a period of 5 years. To date 17% of the membrane area has been replaced at the expense of the supplier due to mechanical failure. The cost per module is R300.

The capital cost of the TRO plant was R8 million. Amortised over 15 years this translates to a cost of R0,90 to R1,00 per m^3. Operating costs are 50 to 60 c/m^3, of which one third is due to membrane replacement, one third is due to electrical costs and the remainder is due to maintenance, labour and cleaning requirements.

Scaling problems have been experienced and operating conditions are being adjusted to minimise scaling. In addition, suitable methods for pretreatment are to be investigated.

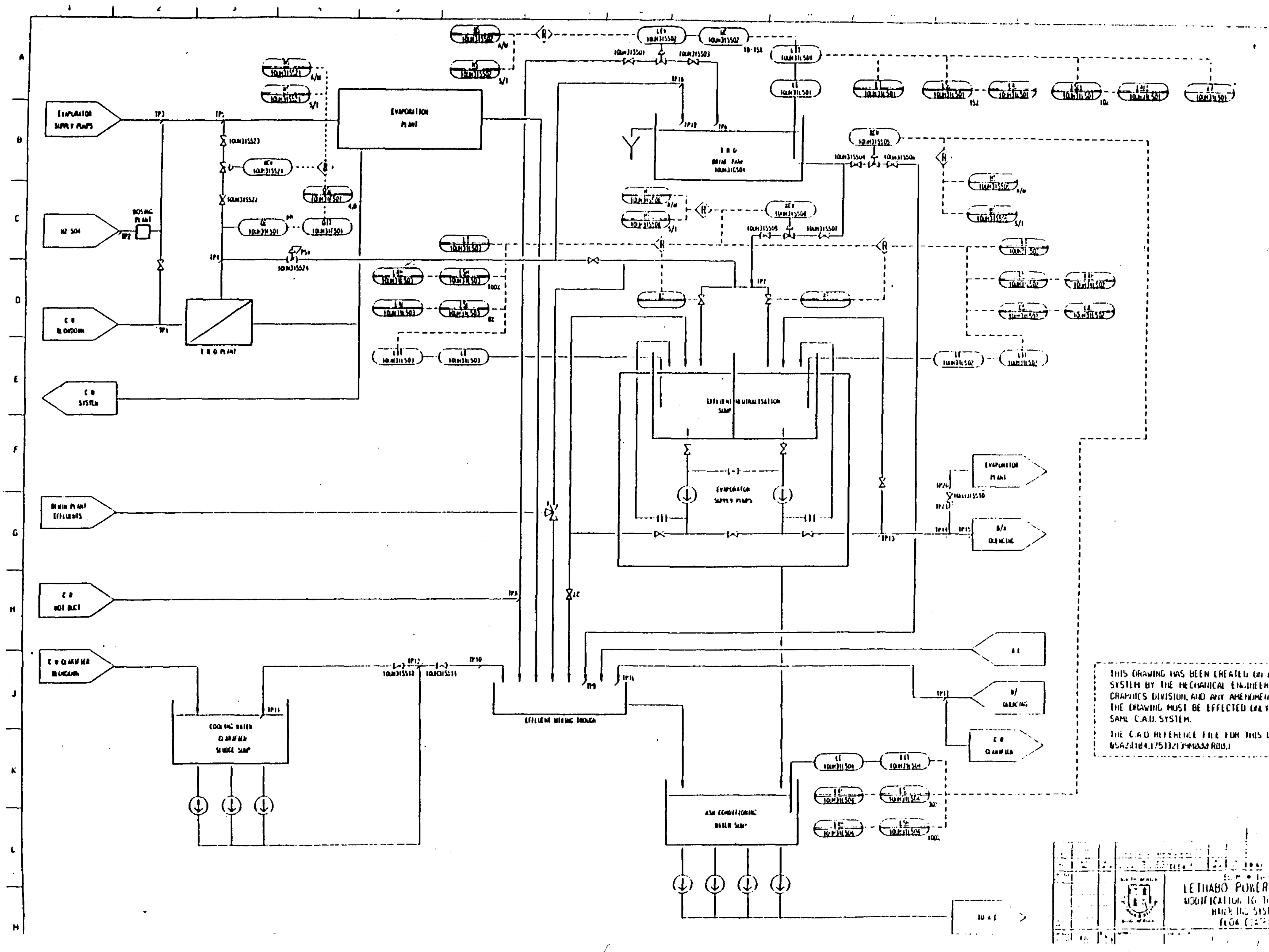


Figure 5 : Eskom Drawing, CAD Reference File Q5A: (104, 175)32139M000.R00;1

At present cooling tower make-up is approximately 80 to 100 Ml/day at a TDS of 80 mg/l (i.e. 8 tons TDS/day). The reverse osmosis plant is designed to treat 10 tons TDS/day. At present, due to the low percentage availability of the TRO unit only 2 to 3 tons TDS/day is being treated. Finally, the plant is adaptable for changes in the TDS of the raw water feed.

The permeate from the TRO unit is returned to the cooling water circuit launders. The conductivity of this stream varies from 250 to 400 µS/cm. The TRO concentrate is discharged to the effluent neutralisation sump together with the demineralisation regeneration chemicals and other station effluents. In the sump it is neutralised with lime before being pumped to the vapor compression evaporation unit (section 5.2) for further concentration.

5.2 <u>Evaporation</u>

Two vapour compression evaporators, supplied by the Israeli Desalination Engineering Co., are installed at Lethabo, each with an evaporative capacity of 22 m^3/h, designed to operate on a 95% water recovery. These evaporation units are required to close the effluent circuit allowing maximum water recovery and minimum discharge. The concentrated brine is theoretically the only real effluent blowdown at the station and is discharged to the effluent mixing trough before being used for fly ash conditioning.

Severe scaling problems have been encountered with the evaporators. In addition various engineering modifications have been carried out to the units to improve the performance against the feed stream. In order to control or eliminate scaling various approaches have included:

(i) the use of a scale inhibitor supplied by Anikem.

(ii) the removal of the calcium sulphate scale from the heat exchange surfaces by conversion of it to calcium bicarbonate using sodium carbonate and the removal of calcium bicarbonate by solubilizing it in the presence of sulphamic acid.

(iii) careful control of the feed streams to the evaporator such that the scaling index is minimised. Such proposals include direct rerouting of the ion exchange waste regeneration effluents to ash conditioning, by-passing the evaporator.

5.3 <u>Drainage System</u>

The drainage system consists of two parts:

(i) the storm water and sewage dam which is relatively clean and which is the only dam at the station which is allowed to overflow into the river. Water from this dam is recycled to the cooling water circuit.

(ii) the dirty water dam into which all the station effluents and ash dump run-off is discharged. This system consists of several ponds through which water is channelled enabling silt removal, oil skimming and settling. The overflow is used for irrigation and dust suppression of the ash dumps, or for reuse in the cooling tower circuit. It may also be subjected to further treatment in the clarifiers where the elevated pH assists in the aggregation of oil into the sludge.

The quality of the ground water in the drainage area and the quality of the dam contents are monitored routinely.

6 WATER AND EFFLUENT MANAGEMENT

Water and effluent management objectives include:

6.1 Minimisation of Water Consumption and Effluent Production

The largest consumer of water at the station is the cooling system which is operated at approximately twenty cycles of concentration. The frequency of blowdown is determined by the sulphate level in the recycled stream, and this is maintained below 1 300 mg/l. Thus a significant impact on water usage and effluent pollution loading would be to decrease blowdown by operating at higher cycles of concentration. The quality of the cooling water in the circuit is maintained by:

(i) sidestream precipitation which treats 90 Ml/day of cooling water in one of three clarifiers.

(ii) pH control using sulphuric acid to maintain the scaling index at a low level.

(iii) biocide dosing for algal growth control.

(iv) operating the concentration cycle as close to the maximum as possible; this is achieved by good control.

Increased cycles of concentration would be possible if:

(i) non-concrete or improved concrete materials of construction were used for the packing in the cooling towers, such that higher levels of sulphate could be attained.

(ii) a method for sulphate removal and control were available (see section 8.2).

Eskom have considered and/or implemented various technologies at their different power stations which will enable water recovery from their effluent, thus minimising the volume of effluent produced. These include:

(i) RO (section 5.1) for concentration of cooling water.

(ii) ED (at, for example, Tutuka in place of RO).

(iii) evaporation (section 5.2) for additional brine concentration.

(iv) sludge thickening to enable water recovery from the clarifier sludges (3,5% solids).

(v) sludge dewatering to produce a solid suitable for land fill.

Virtually the only salt sink available at present is the ash system and methods to enable increased disposal site salt capture include:

(i) optimum utilisation of the brine streams available for bottom ash quenching. This involves, for example, the rechannelling of demineralisation resin regenerant wastes directly to the ash system, thus by-passing the evaporator.

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(i) optimum utilisation of the brine streams available for bottom ash quenching. This involves, for example, the rechannelling of demineralisation resin regenerant wastes directly to the ash system, thus by-passing the evaporator.

(ii) increasing the moisture uptake by the ash, which is presently running at only half of the original estimated disposal capacity.

In terms of the overall system flexibility then, the major considerations as far as the water balance is concerned are the dissolved solids content of the raw water and the ash moisture uptake.

6.2 Water Reuse by Cascading

Various cascading systems have been implemented in which product water from one process is cascaded for use as low quality water in another process:

(i) the sewage and contents of the clean drainage system and dam are reused in the cooling water circuit, for ash field irrigation and dust suppression and is also allowed to be discharged into the water course.

(ii) extensive facilities exist for the recovery of the contents of the dirty drain and dam system for reuse in the cooling system.

(iii) the sludge produced during the clarification of raw water for potable and demineralisation use is recovered as cooling water by means of the cooling water clarification system.

(iv) the cooling water blowdown, the evaporator blowdown and various other brines of low quality are used for bottom ash quenching, for fly has conditioning and for floor and equipment washing.

(v) the facility exists at Tutuka, but not at Lethabo, for the recovery of boiler blowdown to, not only the cooling system, but to the demineralisation plant in the case where it is of sufficiently good quality for reuse in steam generation.

(vi) in the regeneration of the ion exchange units of the demineralisation plant, the effluent produced during the rinse sequence is monitored for conductivity and at an acceptably low conductivity the waste rinse water is recovered and stored for reuse.

(vii) the ammonium hydroxide regenerant stream, used for regenerating the anion part of the mixed bed ion exchange unit for condensate polishing, is reused as a final regenerant of the cation part of the same unit (section 4.2).

7 CAPITAL COSTS OF THE WATER HANDLING SYSTEM

The estimated capital cost of each unit in the water and effluent handling system is listed below:

	R-million
cooling water treatment and recovery	63,5
potable and demin water production	42,5
condensate polishing	54,5

condensate dosing	3,0
reverse osmosis	11,0
evaporation	5,3
Total	179,3

8 SUMMARY - FUTURE DEVELOPMENTS

8.1 Increased Waste Water Recovery

In various other newer power stations boiler blowdown is being recovered and recycled to the demineralisation unit.

In addition, the operation of the TRO plant and evaporation units are under investigation in order to increase the water recoveries of these processes to design recoveries.

8.2 Increased Cooling Cycles

Investigations are constantly in progress into techniques for increasing the cooling cycles to maximise reuse before cooling tower blowdown.

Eskom is presently investigating the feasibility of implementing a sulphate removal process which has been developed at the University of Natal under a contract from the Water Research Commission. The process involves precipitation of the sulphates as barium sulphate, using barium carbonate. The barium sulphate is reduced to barium sulphide with coke in a rotary kiln. The barium sulphide is then leached and converted to insoluble barium carbonate by contacting the solution with carbon dioxide. The barium carbonate is recycled at 95% recovery and the sulphide is liberated as hydrogen sulphide gas. The conversion of this gas to sulphur and/or subsequently to sulphur tri- or dioxide gas is conventional technology.

It is envisaged that the sulphate rich wastes at Lethabo could be desulphonated and recycled. In addition, the acid mine waters from the surrounding mines could be treated at Lethabo. It is estimated that the total sulphate loading of the mine waters would be approximately 50 to 70 tons/day as $SO_4^=$. The sulphate loading of Lethabo wastes is a function of the raw water concentration and, assuming a sulphate level of 20 mg/l and a water consumption of 150 Ml/day, is 3 ton/day as $SO_4^=$.

It is envisaged that the sulphur produced from the given streams by this process, approximately 24 tons/day as S, could be converted to sulphur trioxide for use in the Lethabo stacks to increase the conductivity of the waste flue gas in the electrostatic precipitators. At present 3,7 tons of sulphur per unit per day (or 22 tons of sulphur in total) is converted to sulphur trioxide at Lethabo for this purpose.

8.3 Dry-cooled Stations

To reduce the use of water for power generation, Eskom is in the process of moving towards dry-cooling processes in future power-stations where this is economically feasible. Dry-cooling reduces the water use per unit of electricity generated to about 22% of that of the latest wet-cooled power-stations.

8.4 Sludge Thickening

The application of cross-flow microfiltration to sludge thickening and dewatering is presently being investigated on a semi-technical scale at Lethabo.

8.5 Effluent Disposal

Improved methods of effluent disposal such as improved moisture uptake by the ash and increased salt capture during bottom ash quenching are being investigated. The operation of the RO and evaporation units, to prevent occurrences such as scaling, which inhibits waste treatment and disposal, is being studied.

8.6 Environmental Issues

In an effort to prevent salination of the surrounding surface and underground water resources, methods of increasing the salt retention of the ash dumps and hence minimising leaching, are being investigated. In addition, concrete drains have been constructed around the ash dumps such that any drainage and leachates from the dumps are captured and do not run-off into the surrounding environment.