COALTECH 2020

EVALUATION OF NEW AND EMERGING MINE WATER TREATMENT TECHNOLOGIES

PART D

Evaluation of the Savmin Sulphate Removal Process

COALTECH 2020 EVALUATION OF THE SAVMIN SULPHATE REMOVAL PROCESS

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1 TREATMENT PROCESS FUNDAMENTALS

1.1 Process Description

The main stream Savmin process consists of three (3) sequential treatment steps involving:

- Neutralisation, metals removal and gypsum crystallisation
- Selective sulphate removal by ettringite precipitation
- Softening and pH adjustment by re-carbonation.

Figure 1 shows a schematic process flow diagram. On a side-stream, the aluminium bound by the ettringite precipitate is recovered and recycled to the main stream, sulphate removal step. Gypsum is also crystallised in the side-stream treatment process.

The process produces a neutral, low metals and low sulphate product water. A number of waste sludge/slurry process stream are produced, including:

- A metal-rich gypsum sludge
- A relative pure gypsum sludge
- A calcium carbonate sludge

1.2 Component Process Reactions

1.2.1 Neutralisation, metals removal and gypsum crystallisation

The first process step, which can be integrated or disaggregated involves the classical high lime reactions:

- **Neutralisation**

$$Me^{2+} + Ca(OH)_2 \quad Me(OH)_2(s) + Ca^{2+}$$

$$2H^{+} + Ca(OH)_2 \quad 2H_2O + Ca^{2+}$$

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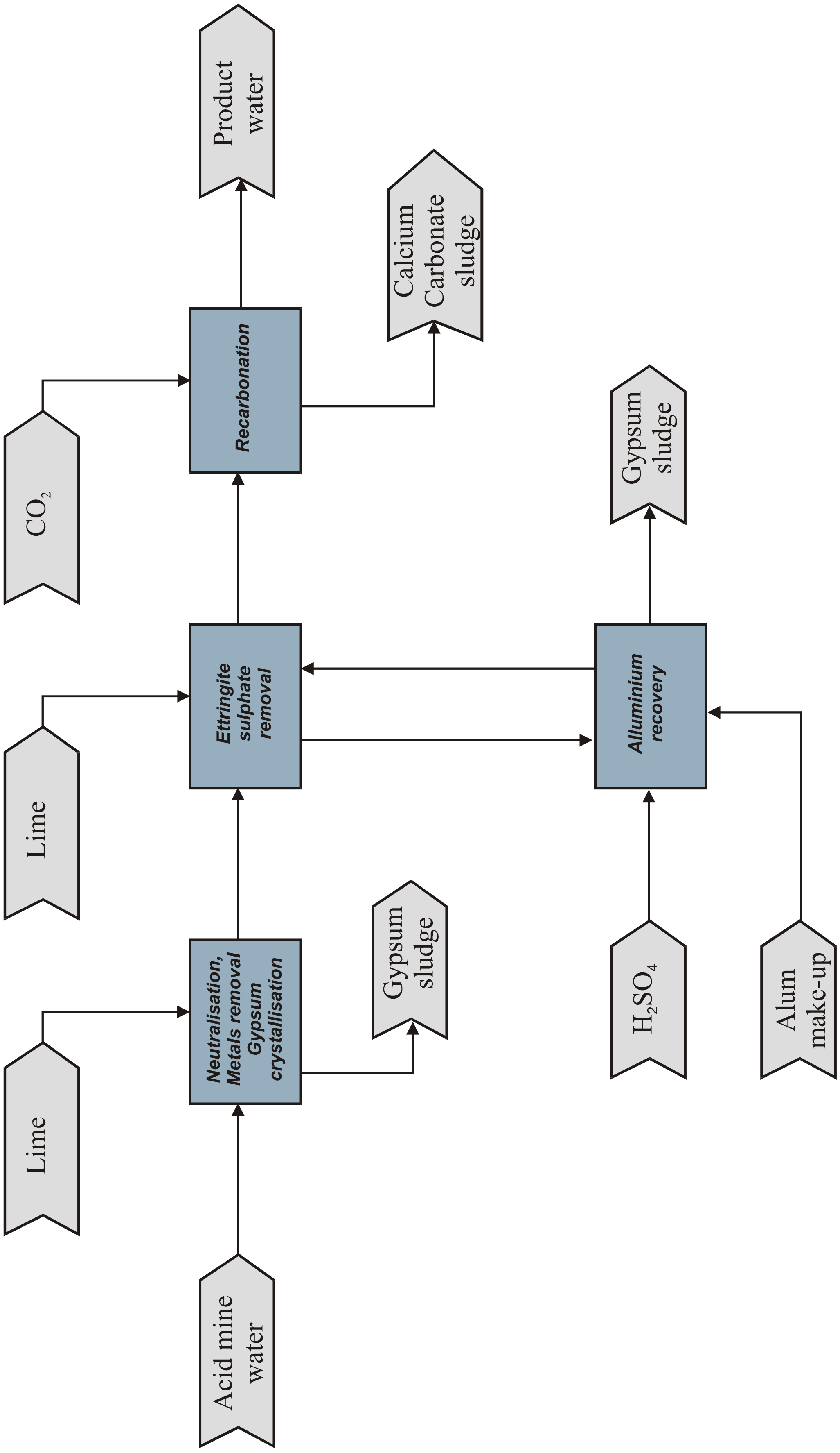

Figure 1 : Savmin Sulphate Removal Process

- **Magnesium Removal**

$$Mg^{2+} + Ca\,(OH)_2 \quad Mg\,(OH)_2(s) + Ca^{2+}$$

- **Gypsum Crystallisation**

$$Ca^{2+} + SO_4^{2-} + 2H_2O \quad CaSO_4 \,.\, 2H_2\,O(s)$$

This process step will remove most metals (except for some amphoteric metals such as aluminium, zinc etc.) and the sulphate associated with magnesium and calcium (partial removal).

1.2.2 Sulphate removal by ettringite precipitation

The precipitation of sulphate requires the addition of aluminium hydroxide to form the insoluble ettringite:

$$6\,Ca^{2+} + 3SO_4^{2-} + 2A\ell(OH)_3 + 31\,H_2O$$

$$3\,CaO.3\,CaSO_4 \,.\, A\ell_2O_3 \,.\, 31\,H_2O(s) + 6\,H^+$$

The ettringite precipitation reaction is optimised at relatively high pH, which has the following implications:

- Sufficient aluminium hydroxide is required
- Additional lime is required to supply the calcium requirements (over and above the feed calcium associated with the sulphate and to neutralise the acidity liberated by the precipitation reaction.

The solubility is ettringite sensitive to pH and requires control within a narrow pH range.

1.2.3 Softening and pH adjustment by re-carbonation

The product water is stabilised by re-carbonation, which involves the following reactions:

$Ca^{2+} + CO_3^{2-} \quad CaCO_3\,(s)$

$CO_2(g)+OH^- \quad HCO_3^{\,-}$

1.2.4 Recovery of aluminium

The ettringite precipitate can be decomposed by pH adjustment, typically using sulphuric acid:

$$3\,CaO \,.\, 3CaSO_4 \,.\, A\ell_2O_3 \,.\, 31H_2O\,(s) + 3\,H_2\,SO_4$$

$$6\,Ca^{2+} + \;6SO_4^{2-} + 2A\ell(OH)_3\,(s) + \;31\,H_2O$$

The solid aluminium hydroxide is separated from the solution.

The supersaturated gypsum solution is allowed to crystallise in a subsequent reaction step:

$$Ca^{2+} + \;SO_4^{2-} + 2H_2O \quad CaSO_4 \,.\, 2\,H_2O(s)$$

1.3 Process Conditions

The Savmin process is dependent on operation within relatively narrow pH-ranges for the different process steps.

The first step of neutralisation, metals removal and gypsum crystallisation requires a pH in the range of 12.0 to 12.4. The high pH is required to ensure precipitation of the magnesium hydroxide. It is important to realise that the residue sludge from this process may still leach magnesium if the pH drops again.

The second step of ettringite sulphate removal also requires a pH in the range of 11.4 to 12.4. The optimum pH is controlled at 11.8. The ettringite precipitate is not stable outside this pH range.

The third re-carbonation process step target pH is typically 7.8 to 8.6 depending on the specific requirements for use or discharge of the product water.

The aluminium recovery step requires an optimum pH of 6.5 to 6.8 for efficient ettringite decomposition.

The process sensitivity to temperature was not investigated and is not well established.

1.4 Process Constraints

1.4.1 Contact time

Chemical precipitation reactions are relatively rapid, provided that optimum process conditions are maintained. The typical retention times employed in the different process steps are 20 to 30 minutes. These contact times are relatively short compared to biological process requirements.

1.4.2 Gypsum crystallisation

Effective gypsum crystallisation is important at two of the treatment process steps:

- Neutralisation, metals removal and gypsum precipitation.
- Aluminium recovery from the ettringite.

The effective gypsum crystallisation is important for at least two reasons:

- Incomplete primary gypsum crystallisation will result in excess sulphate being carried forward to the ettringite precipitation step. This will make control of the ettringite precipitation process step difficult, since it is dependent on an accurate ratio between the sulphate feed mass and the aluminium recycle mass.
- Incomplete gypsum crystallisation will result in a high scaling potential in the entire process train. Scale formation will require additional maintenance resources.

1.4.3 Solids separation

The Savmin process is characterised by a relatively large number of solids/liquid separation steps. Depending on the exact process configuration, up to six (6) solids/liquid separators may be required:

- Separation of metal hydroxides and gypsum
- Separation of ettringite
- Separation of lime insolubles
- Separation of calcium carbonate
- Separation of aluminium hydroxide
- Separation of gypsum

It is noted that the ettringite sludge does not settle readily and may require settling agents, such as polymers.

The aluminium recovery step also requires very efficient separation of $A\ell(OH)_3$ to limit the aluminium loss from the process. A very effective solids/liquid separator, such as a filter will probably be required.

2 PROCESS EVALUATION

2.1 Plant Start-up

The plant can start-up in a short period of time, since no acclimatisation is required as in the case with biological treatment processes. The start-up may practically take a number of days (5-7) to reach steady state and stable operation. The start-up period will require charging the process with an appropriate amount of:

- Aluminium until an adequate $A\ell(OH)_3$ inventory has been developed
- Gypsum crystals until an adequate inventory has been developed. It is important to use the gypsum - dehydrate to speed up crystal formation.

2.2 Process Loading

The Savmin pilot plant was fed with an acidic mine water from Navigation Colliery. The feed water had the following macro-chemical composition:

SO_4 = 2320 – 2410 mg/ℓ
Ca = 727 – 817 mg/ℓ
Mg = 54 – 119 mg/ℓ
Na = 46 – 51 mg/ℓ
Cℓ = 1 - 4 mg/ℓ

The metal content of the acid mine feed water was low.

The pilot plant feed rate was 0.2 m^3/hour (4.8 m^3/day). It was noted that the pilot plant was originally designed for a maximum flow rate of 1 m^3/hour. The pilot plant testing was therefore done at a relatively low hydraulic loading rate.

The pilot plant was operated for a period of 21 days and the feed flow rate and composition were kept relatively constant during the entire testing period.

2.3 Process Conditions

2.3.1 Neutralisation, metals removal and gypsum crystallisation

The pilot plant treatment process was split into two (2) separate treatment steps:

- Neutralisation and metals removal
- Gypsum crystallisation

Figure 2.3.1 shows the process configuration employed in the pilot plant testing program.

The neutralisation and metals removal was achieved by high lime treatment. The milk of lime is contacted with the influent acid mine water. The average lime consumption was:

$Ca(OH)_2$ = 1.23 kg/m^3 mine water

Contact time = 30 mins.

The solids separation thickener downstream of the neutralisation step was operated with a relatively dilute underflow of approximately 1 %, resulting in a relatively large sludge flow (10 % of influent acid mine water feed)

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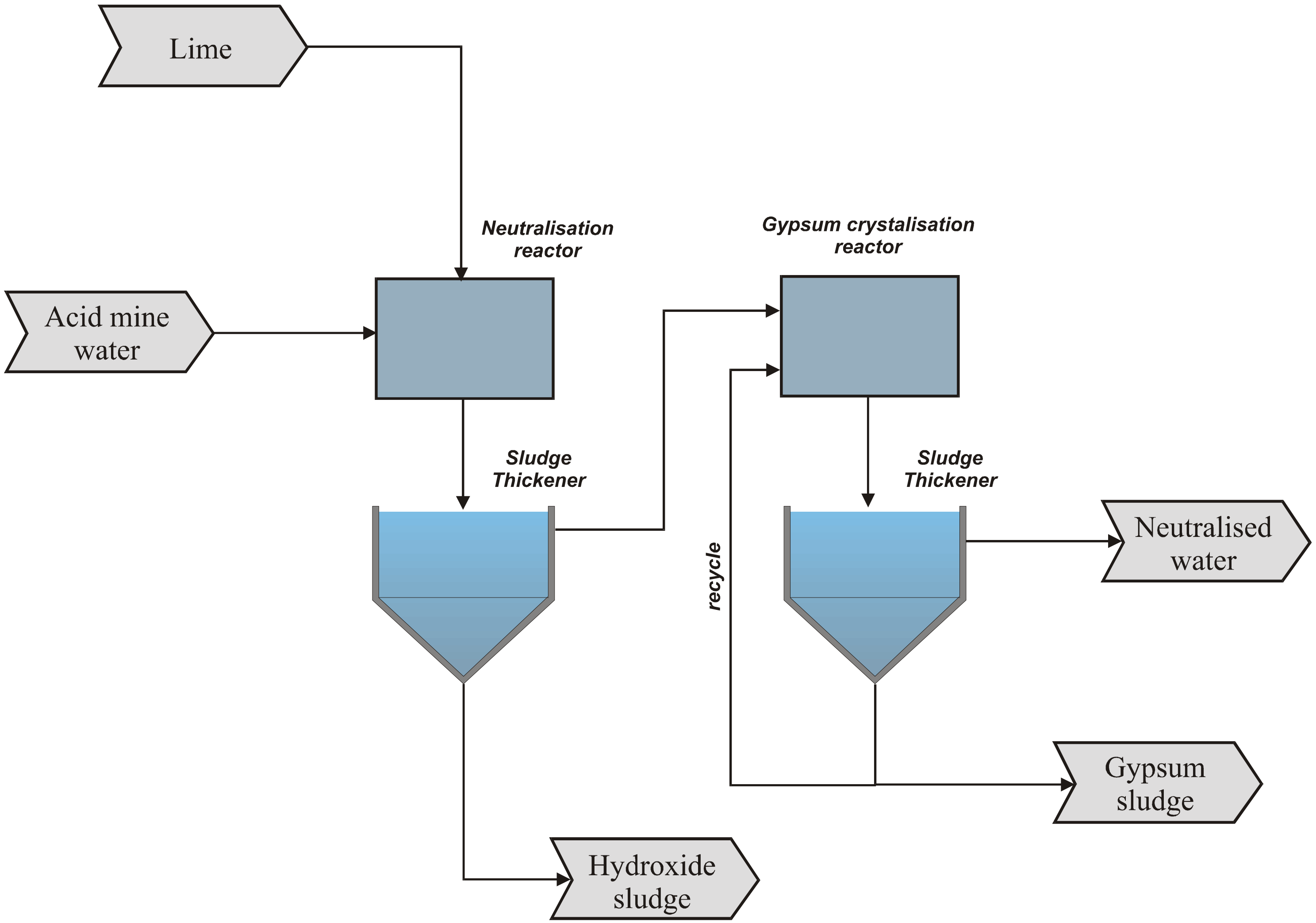


Figure 2.3.1 : Neutralisation, metals removal and gypsum crystallisation pilot plant

Gypsum crystallisation was achieved by a contact reactor followed by a solids separation thickener. The thickener underflow was recycled to the contact reactor to maintain an inventory of gypsum seed crystals. The contact reactor was operated at a solids content of 5 to 20 % with an apparent optimum of 10 %. The observed average amount of gypsum sludge production was:

$CaSO_4 . 2H_2O$ = 1.08kg/m^3 mine water

The pilot plant work also confirmed that the different processes of neutralisation, metals removal and gypsum crystallisation could be combined into a single reactor.

2.3.2 Sulphate removal by ettringite precipitation

Sulphate removal by ettringite formation depends on a controlled feed of $A\ell(OH)_3$ and controlled pH to optimise the ettringite precipitation. **Figure 2.3.2** shows the process configuration employed in the pilot testing program.

The pilot plant testing indicated the following chemical dose requirements:

$A\ell(OH)_3$ = 1.09 kg/m^3 of mine water

$Ca(OH)_2$ = 1.44 kg/m^3 of mine water

The average observed ettringite production = 6.6 kg/m^3 of mine water .

Practically, the aluminium dosage was implemented at a level equal to 120% of the stochiometric quantity needed. The stochiometric amount of $A\ell(OH)_3$ required is as follows:

2 moles $A\ell(OH)_3$ = 3 moles SO_4^{2-}

0.54 kg $A\ell(OH)_3$ = 1 kg SO_4^{2-}

Aluminium loss from the process can take place due to two (2) reasons;

- Solids carry-over from the solids separation thickener (a problem due to the poor settling properties of ettringite)
- Soluble aluminium at the relatively high pH (11.6 to 11.8) maintained in the reactor

The pilot plant work indicated that the aluminium loss from the ettringite treatment step is 2% to 3% under stable operating conditions.

The required contact time in the two-stage ettringite reactor is recommended to be 20 minutes in each reactor.

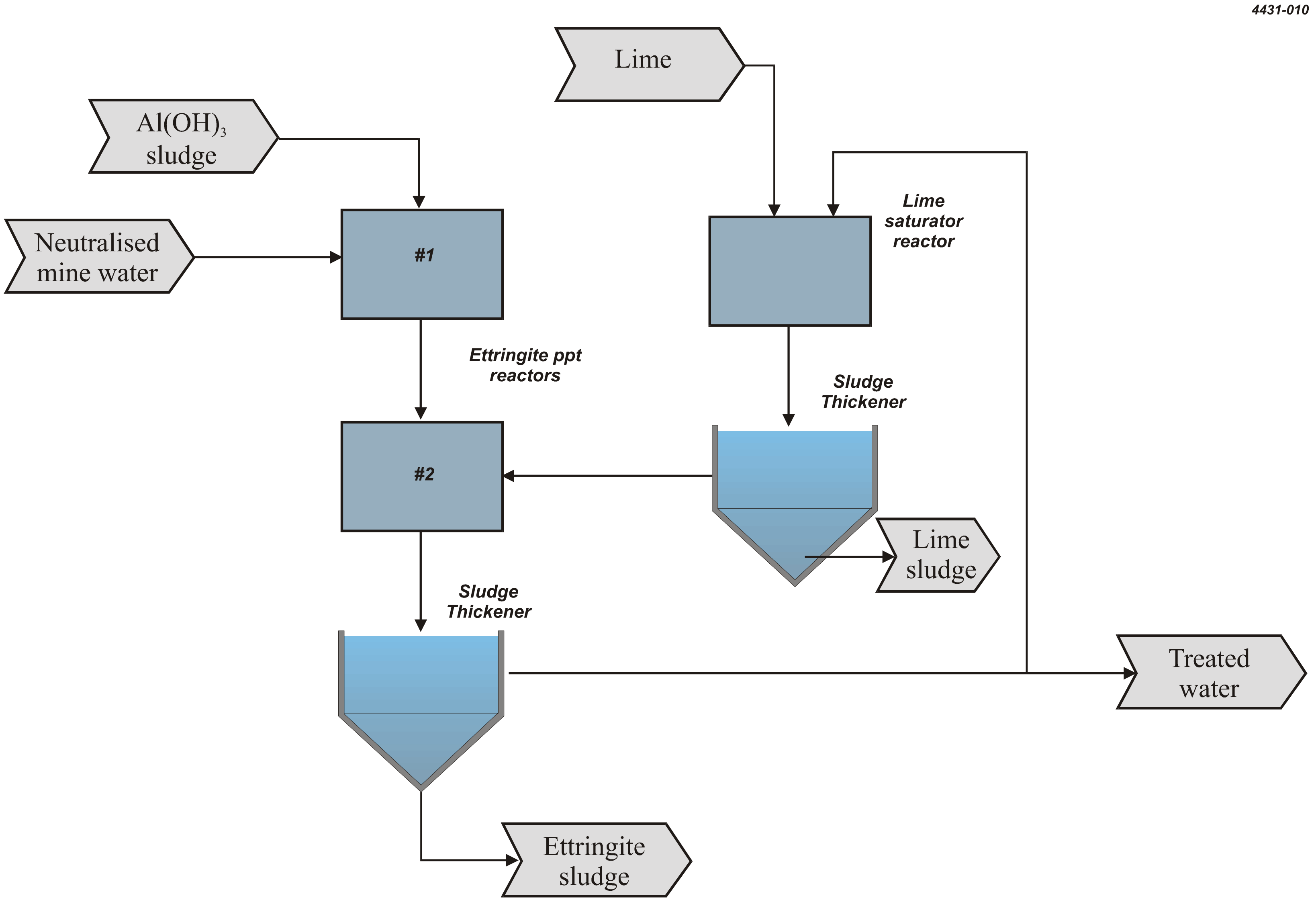


Figure 2.3.2 : Eltringite precipitation pilot plant reactor

The recycle stream of lime saturated water was operated at a rate of 60% to 80% of the main stream flow. This stream also required solids separation to remove the un-reacted lime solids. Such a high recycle stream would also place an additional hydraulic load onto the ettringite solids separation thickener.

2.3.3 Softening and pH adjustment

The pilot plant operation did not achieve effective re-carbonation due to the inefficient CO_2 dissolution device. The technology is, however, well proven and application to a full-scale installation should not present any problem.

The estimated CO_2 requirement for re-carbonation with a feed water pH of 11.8:

$CO_2 = 0.14$ kg CO_2/m^3 water

2.3.4 Aluminium recovery and gypsum crystallisation

The aluminium is recovered by decomposition of ettringite in a mildly acidic environment. **Figure 2.3.4** shows the process configuration employed in the pilot plant testing program.

The sulphuric acid addition was recorded to be;

$H_2SO_4 = 0.33$ kg/kg ettringite

The stoichiometric requirement of sulphuric acid for ettringite dissolution is:

3 moles H_2SO_4 = 1 mole ettringite

0.24 kg H_2SO_4 = 1 kg ettringite

Some additional H_2SO_4 is therefore required of pH adjustment.

The aluminium recovery and gypsum crystallisation reactors have the following residence times:

- Ettringite dissolution reactor = 60 min
- Gypsum crystallisation reactor = 30 min

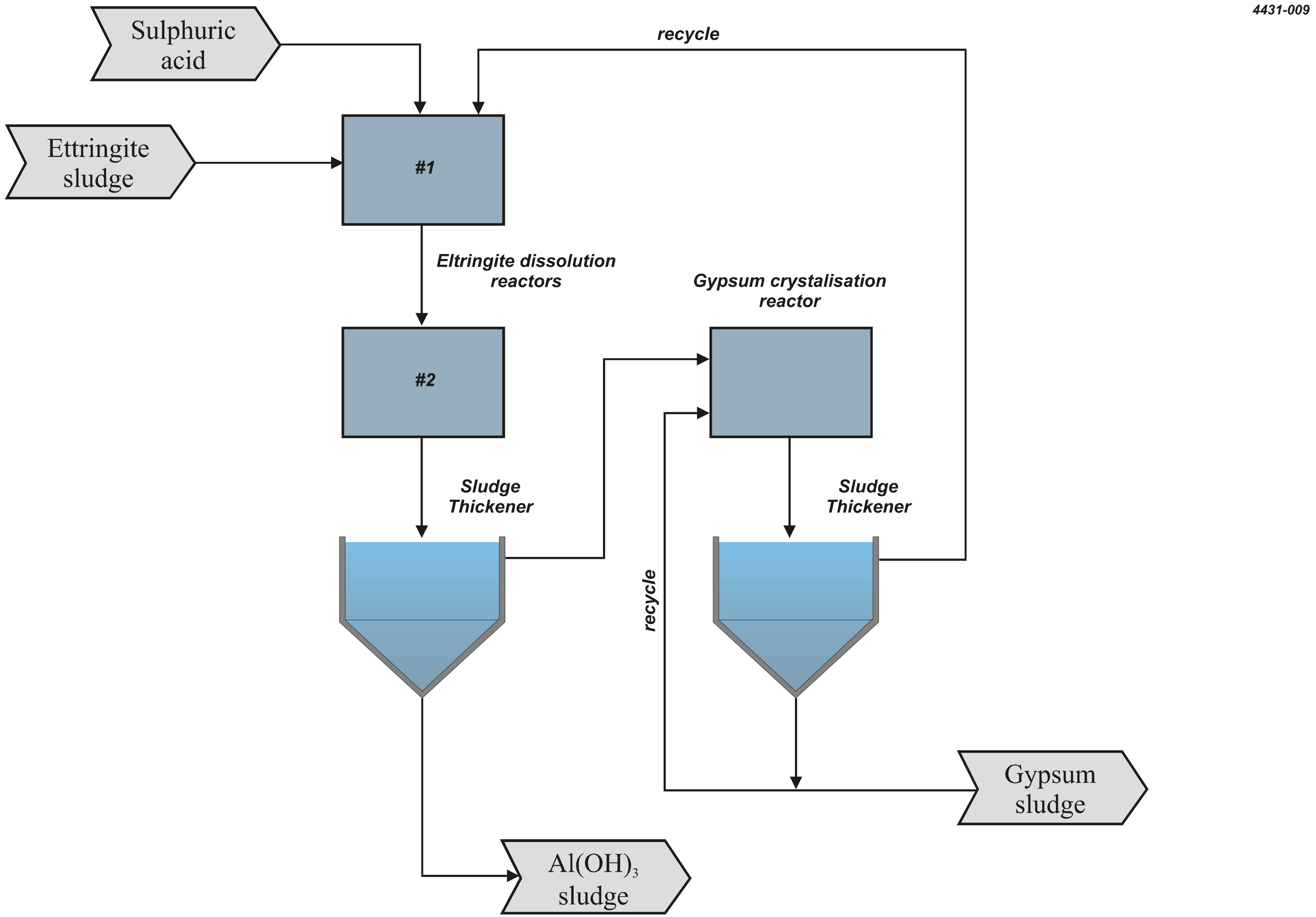


Figure 2.3.4 : Aluminium recovery and gypsum crystalisation

A high recycle rate is maintained from the gypsum crystallisation reactor back to the ettringite dissolution reactor. This is presumably done to elutriate the gypsum from the ettringite dissolution reactor forward into the gypsum crystallisation reactor. The recycle ratio expressed as:

Ettringite feed rate	:	recycle rate
1	:	20 – 25

This is a very high recycle rate and places a substantial hydraulic loading rate on the reactors and solids separation thickeners. The recycle flow rate may be optimised to potentially 1:10.

The solids separation following the ettringite decomposition must be very effective, since solids carry-over will constitute an effective loss of aluminium. Pilot plant testing also confirmed that $A\ell_2(SO_4)_3$ is an effective source of aluminium make-up to the process.

2.4 Process Control

The Savmin treatment process control is relatively simple and is based on manipulation of the following general process variables:

- Chemicals addition
- Recycle rates

The control of these generic process variables would depend on the specific reactor in the process.

2.4.1 Neutralisation, metals removal and gypsum crystallisation

The neutralisation process requires controlled addition of a lime slurry. The pH monitor in the neutralisation reactor determines the lime slurry addition rate. The target pH is typically 12.0 - 12.4.

The gypsum crystallisation process requires maintenance of a minimum solids inventory in the reactor. This is achieved by the thickener underflow recycle back to the reactor. A target solids content of 5 – 10% is typically applied. Excess gypsum sludge is wasted from the thickener underflow. The waste solids underflow rate can be controlled from a solids consistency (relative density) monitor in the gypsum crystallisation reactor.

2.4.2 Sulphate removal by ettringite precipitation

The ettringite precipitation process requires careful control of the $A\ell(OH)_3$ slurry addition to achieve optimum process conditions. Two-process control scenarios may exist:

- The feed from the upstream gypsum crystallisation reactor may contain a stable SO_4 concentration (typically the case if the acid mine water contains a high SO_4

concentration, more than 2000mg/ℓ), in which case the $A\ell(OH)_3$ addition can be proportional to the feed flow rate.

- The feed from the upstream gypsum crystallisation reactor may contain a variable SO_4 concentration (typically the case if the acid mine water contains a relatively low SO_4 concentration < 1200 mg/ℓ), in which case an on-line SO_4 monitor is required. The $A\ell(OH)_3$ slurry is then fed in proportion to the SO_4 mass feed rate, which requires monitoring of both the feed flow rate and the feed SO_4 concentration.

Control of the ettringite precipitation reactor pH is also important. This is achieved by maintaining a recycle of saturated lime water, controlled by a pH monitor in the ettringite precipitation reactor. Lime dosing is controlled to maintain a sufficient supply of lime saturated water. The lime-dosing pump can be controlled by recycle flow rate or by pH monitor in the lime saturator reactor.

The ettringite thickener underflow pump rate can be controlled by a solids consistency (RD) monitor, which allows pacing of the slurry underflow pump to maintain a target solids content. The ettringite thickener should also be equipped with a solids blanket level detector to prevent the loss of solids. The underflow slurry pump control is overridden by a signal indicating a high solids blanket level on the thickener. The underflow slurry pump will then speed up to draw the sludge blanket down.

2.4.3 Softening and pH adjustment

The dosing of CO_2 must be controlled to achieve a target pH in the product water. This is simply done by a feedback control from the product water pH water to the valve/compressor, which controls the supply of CO_2.

2.4.4 Aluminium recovery and gypsum crystallisation

The addition of sulphuric acid is controlled to achieve the target pH in the ettringite dissolution reactors. The pH monitor in the ettringite dissolution reactor controls the sulphuric acid feed pump.

The $A\ell(OH)_3$ slurry pump can be controlled by a solids consistency meter in the slurry line. The $A\ell(OH)_3$ slurry pump is then paced to maintain a certain target solids consistency (RD) in the thickener underflow. A sludge blanket level detector on the $A\ell(OH)_3$ thickener is also advisable to limit the risk of aluminium loss. This sludge blanket level detector will override the normal $A\ell(OH)_3$ slurry pump control and will speed up the pump, when the sludge blanket exceeds a certain threshold level.

The gypsum crystallisation process requires maintenance of a minimum solids inventory in the reactor. This is achieved by the thickener underflow recycle back to the reactor. A target solids content of 5 – 10% is typically applied. Excess gypsum sludge is wasted from the thickener underflow. The waste solids underflow rate can be controlled from a solids consistency (relative density) monitor in the gypsum crystallisation reactor.

The main recycle process stream from the gypsum crystallisation back to the ettringite dissolution reactor is presumably maintained at some recycle ratio determined during process start-up.

2.5 Process Performance

The Savmin pilot plant was fed at a relatively constant mine water flow with a relatively stable quality as reflected by the sulphate concentration. This steady feed and loading rate allowed the plant to be operated under ideal conditions in terms of a fluctuating feed flow and load.

2.5.1 Sulphate removal

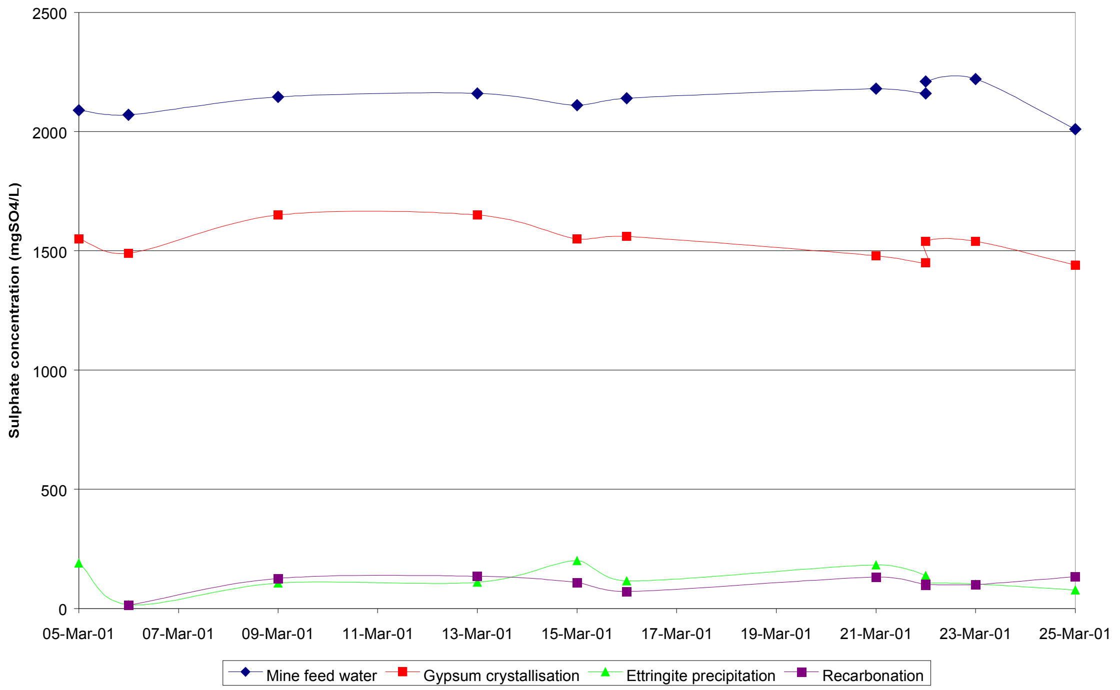
The mine water feed SO_4 concentration averaged 2136 mg/ℓ over the experimental period. The neutralisation/gypsum crystallisation process step decreased the SO_4 concentration to an average concentration of 1536 mg/ℓ.

The ettringite precipitation step was very effective in reducing the sulphate concentration to consistently below 200 mg/ℓ. The average SO_4 concentration over the experimental period of 21 days was 123 mg/ℓ.

A marginal further reduction in SO_4 concentration occurred in the re-carbonation process to an average SO_4 concentration in the product water of 102 mg/ℓ.

Figure 2.5.1 shows the sulphate concentration profile after different unit treatment processes in the Savmin process.

Figure 2.5.1 - Profile of Sulphate concentration in the Savmin Process

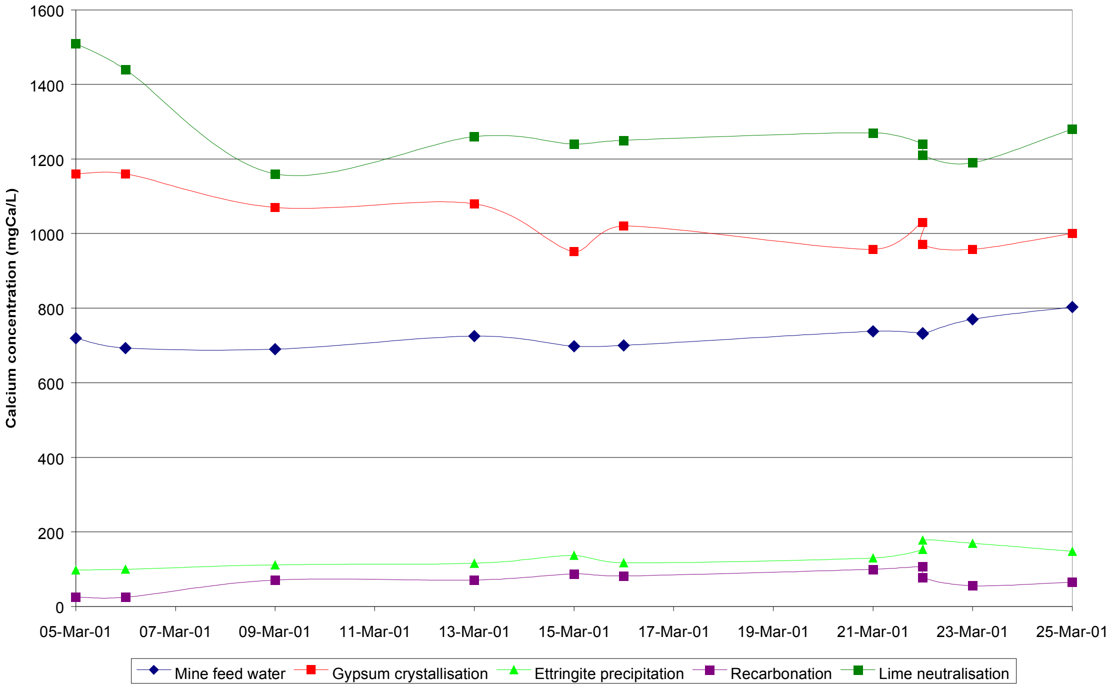


2.5.2 Calcium removal

The mine water calcium concentration (average 727 mg/ℓ as Ca) increased to 1277 mg/ℓ after high lime treatment and dropped again to 1033 mg/ℓ after gypsum crystallisation. The ettringite process was very effective in removing calcium levels down to below 150 -170 mg/ℓ (average 133 mg/ℓ). The calcium concentration was further reduced by re-carbonation to 70 mg/ℓ.

Figure 2.5.2 shows the calcium concentration profile after different unit treatment processes in the Savmin process.

Figure 2.5.2 - Profile of Calcium concentration in the Savmin Process



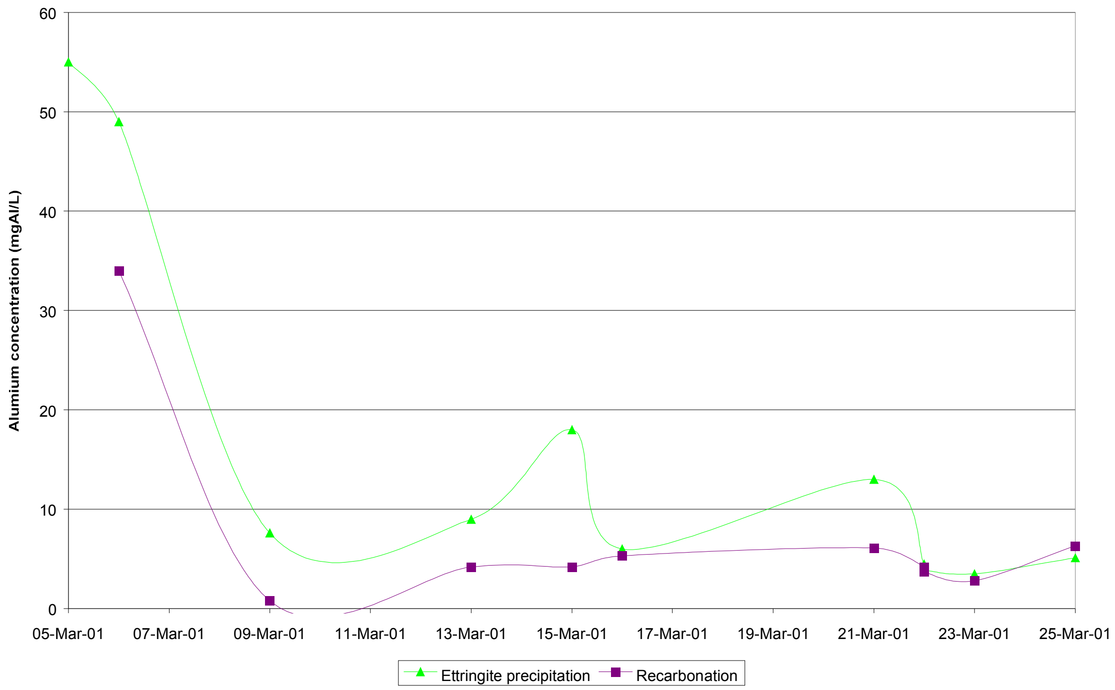
2.5.3 Aluminium Concentration

Aluminium make-up to the Savmin process is one of the main operation costs associated with treatment. Therefore, it is very important to contain the aluminium in the process. Aluminium is, however an amphoteric metal and will tend to remain in solution at the high process pH levels, typical of the Savmin process.

The aluminium concentrations after the ettringite process were initially very high, but these concentrations decreased after successful commissioning of the process. A further marginal decrease in aluminium concentrations was observed in the re-carbonation process.

Figure 2.5.3 shows the aluminium concentration profile after the ettringite precipitation and re-carbonation process steps.

Figure 2.5.3 - Profile of Aluminium concentration in the Savmin Process



2.6 Treatment Residue

The Savmin process generates a number of different treatment residue streams including:

- Metal hydroxide and gypsum sludge from the pre-neutralisation
- Gypsum sludge from the ettringite process
- Lime sludge from the make-up of milk of lime
- Calcite sludge from re-carbonation

The Savmin pilot plant results indicated the following sludge quantities:

Metal hydroxide = 0.59 kg TS/m^3 mine water
Gypsum sludge = 4.62 kg TS/m^3 mine water
Calcite sludge = 0.16 kg TS/m^3 mine water
Total sludge = 5.37 kg TS/m^3 mine water

The sludge generation can also be expressed per unit mass of sulphate removed:

= 2.67 kg TS/kg SO_4 removed

3 FULL-SCALE TREATMENT PLANT CONCEPTUAL DESIGN AND COSTING

The potential application of the treatment technology to a full-scale installation was investigated, based on the results of the Mintek Savmin Pilot Plant.

The potential application was taken to be one of the three regional mine water treatment facilities proposed by one of the previous Coaltech projects (Task 6.8.2) The specific regional facility is for one of Acid Mine Water in the Brugspruit Catchment, which is projected to have a modular size of 5 Mℓ/day at the following projected average mine water quality:

Conductivity = 560 mS/m
pH = 2.8
TDS = 4 210 mg/ℓ
Calcium = 580 mg/ℓ
Magnesium = 200 mg/ℓ
Sodium = 50 mg/ℓ
Sulphate = 2 530 mg/ℓ
Chloride = 55 mg/ℓ
Iron ≤ 100 mg/ℓ
Aluminium ≤ 20 mg/ℓ
Manganese = 27 mg/ℓ

The conceptual integrated sulphate removal process is shown in **Figure 3-D**.

The conceptual treatment process design was based on achieving the following product water quality targets:

- Sulphate, SO_4 ≤ 200 mg/ℓ
- pH range 6.5 – 8
- Iron ≤ 1 mg/ℓ
- Aluminium ≤ 1 mg/ℓ
- Manganese ≤ 1 mg/ℓ

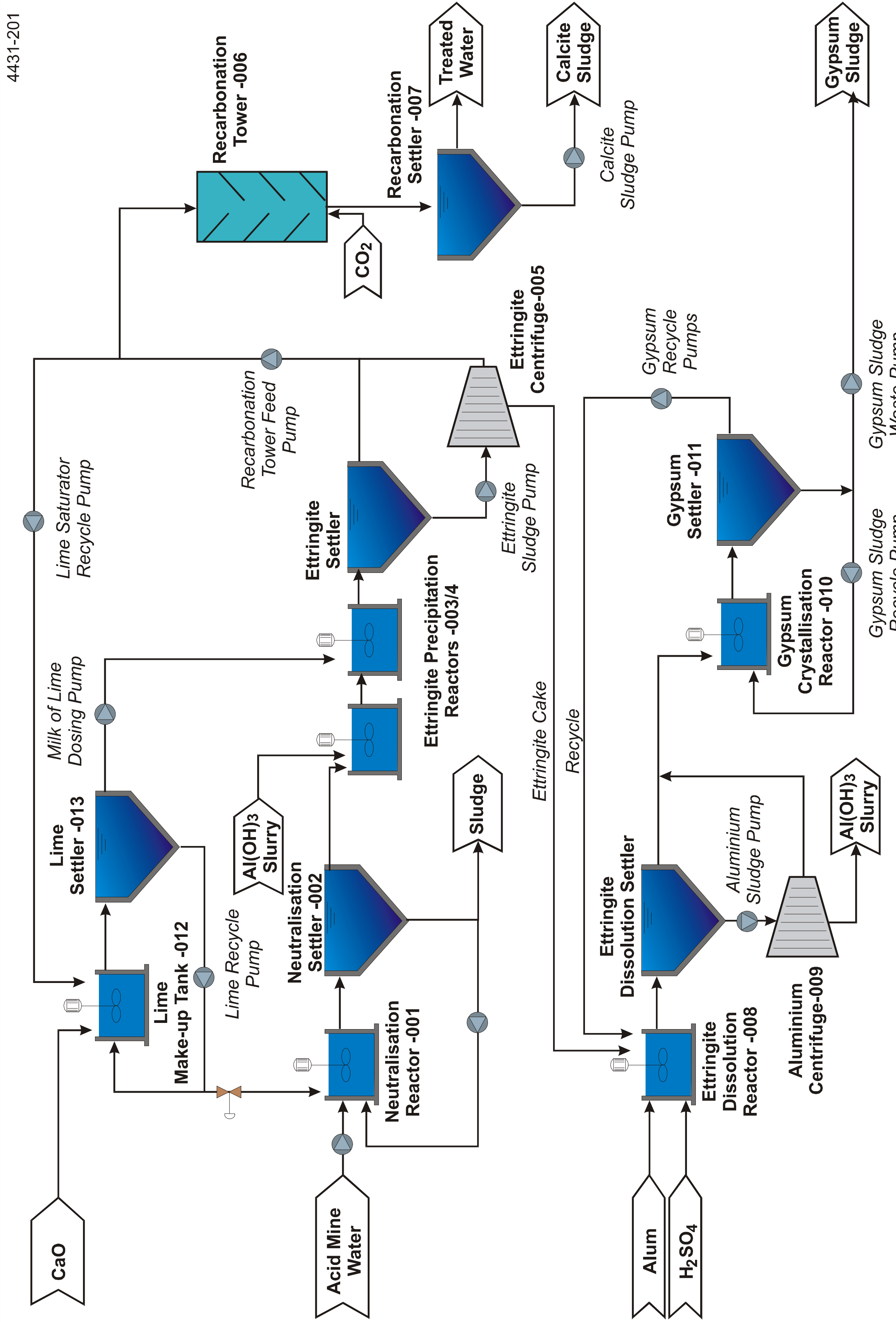


Figure 3 - D : General SAVMIN Process Flow Diagram

3.1 Process Design Criteria

3.1.1 Neutralisation Reactor and Settler

The neutralisation reactor was designed for the following duties:

Retention time = 30 mins
Mixing intensity = 70 W/m^3

The neutralisation settler was designed for the following hydraulic and solids loading:

Upflow rate = 0.7 m/hr
Solids loading rate = 80 kg SS/m^2/hr

3.1.2 Ettringite Reactors

The following design criteria were applied to the ettringite reactors:

Retention time:

- Reactor I = 20 mins
- Reactor II = 20 mins

Mixing intensity = 70 W/m^3

3.1.3 Re-carbonation column and settler

The following process design criteria were applied to the re-carbonation column and settler:

Column contact time = 10 mins
Settler – upflow rate = 1.5 m/hr
- Solids loading = 0.4 kg SS/m^2/hr

3.1.4 Ettringite Dissolution Reactor

The ettringite dissolution reactor was sized to meet the following criteria:

- Retention time = 60 mins
- Mixing intensity = 70 W/m^3

3.1.5 Gypsum Crystallisation and settler

The gypsum crystallisation and settler were sized to meet the following criteria:

- Retention time = 30 mins
- Settler upflow rate = 0.75 m/hr
- Solids loading = 80 kg SS/m^2/hr

3.2 Treatment Process Description

3.2.1 General Process Description

The practical application of the Savmin process incorporates a number of successive unit treatment processes in the main liquid treatment stream.

The acid mine water is first neutralised with associated metal removal and excess gypsum crystallisation. The lime is the preferred neutralised alkali and is dosed into the neutralisation reactor. The precipitated metal and excess gypsum are removed in the neutralisation settler.

The neutralised mine water then enters the two stage ettringite precipitation reactors. Aluminium hydroxide is added to the first reactor and milk of lime is added to the second reactor. The sulphate precipitates as ettingite solids, but gravity solids separation is very inefficient. The ettringite solids are removed by combination of ettringite settler/centrifuge. A part of the ettringite process product water is recycled back to the lime make-up facility.

The ettringite product water is finally stabilised by re-carbonation to adjust the pH and precipitate excess calcium hardness as calcite. The calcite solids are removed in a final re-carbonation settler.

The separated ettringite sludge is contacted with sulphuric acid to dissolve the sulphate salt and separate the aluminium hydroxide solids for recycle back to the ettringite reactor. The aluminium hydroxide sludge does not separate readily under gravity. A combination aluminium settler/centrifuge is utilised. The dissolved sulphate is precipitated as a gypsum sludge in a downstream crystallisation reactor and settler.

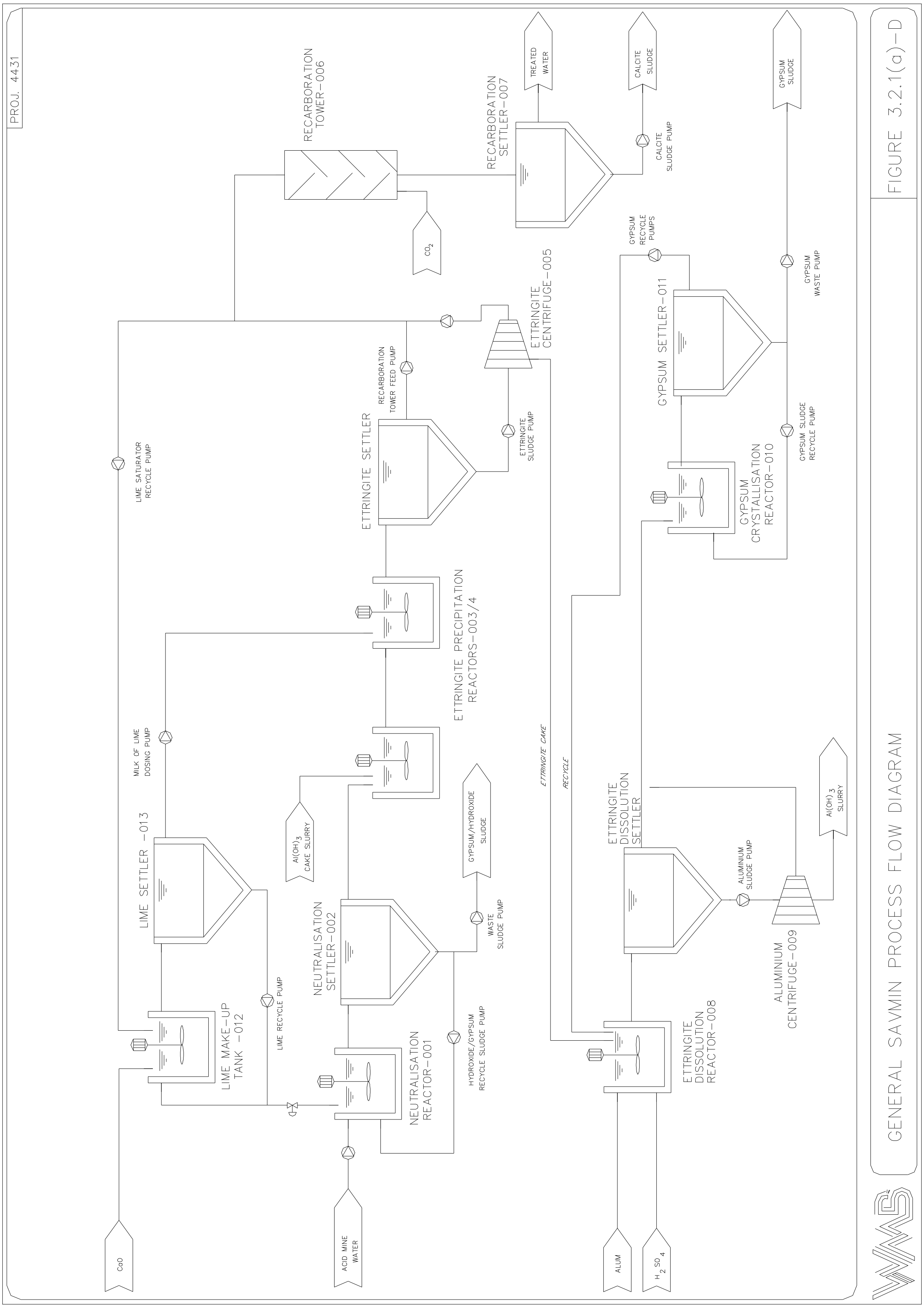
Lime is made up in a dedicated facility including a milk of lime settler and associated dosing equipment.

The overall process flow diagram is shown in **Figure 3.2.1(a)-D**. The individual unit treatment processes are briefly described below. The general plant layout is shown in **Figure 3.2.1 (b)-D**.

3.2.2 Neutralisation

The acid mine water is neutralised in a high lime treatment process. Sufficient lime is added to neutralise the free and mineral acidity and to precipitate the metals as hydroxides.

$$Me^{2+} + 2OH^{-} \quad Me(OH)_2 \text{ (s)}$$


PROJ. 4431
RECARBORATION TOWER-006
RECARBORATION SETTLER-007
TREATED WATER
CALCITE SLUDGE
CALCITE SLUDGE PUMP
GYPSUM SLUDGE
CO_2
ETTRINGITE CENTRIFUGE-005
GYPSUM RECYCLE PUMPS
GYPSUM WASTE PUMP
GYPSUM SETTLER-011
RECARBORATION TOWER FEED PUMP
ETTRINGITE SETTLER
ETTRINGITE SLUDGE PUMP
LIME SATURATOR RECYCLE PUMP
GYPSUM SLUDGE RECYCLE PUMP
GYPSUM CRYSTALLISATION REACTOR-010
ETTRINGITE PRECIPITATION REACTORS-003/4
MILK OF LIME DOSING PUMP
ETTRINGITE CAKE
RECYCLE
ETTRINGITE DISSOLUTION SETTLER
$Al(OH)_3$ SLURRY
$Al(OH)_3$ CAKE SLURRY
GYPSUM/HYDROXIDE SLUDGE
LIME SETTLER -013
ALUMINIUM SLUDGE PUMP
NEUTRALISATION SETTLER-002
WASTE SLUDGE PUMP
ALUMINIUM CENTRIFUGE-009
LIME RECYCLE PUMP
LIME MAKE-UP TANK -012
HYDROXIDE/GYPSUM RECYCLE SLUDGE PUMP
NEUTRALISATION REACTOR-001
ETTRINGITE DISSOLUTION REACTOR-008
CaO
ACID MINE WATER
ALUM
H_2SO_4
WMS
GENERAL SAVMIN PROCESS FLOW DIAGRAM
FIGURE 3.2.1(a)-D

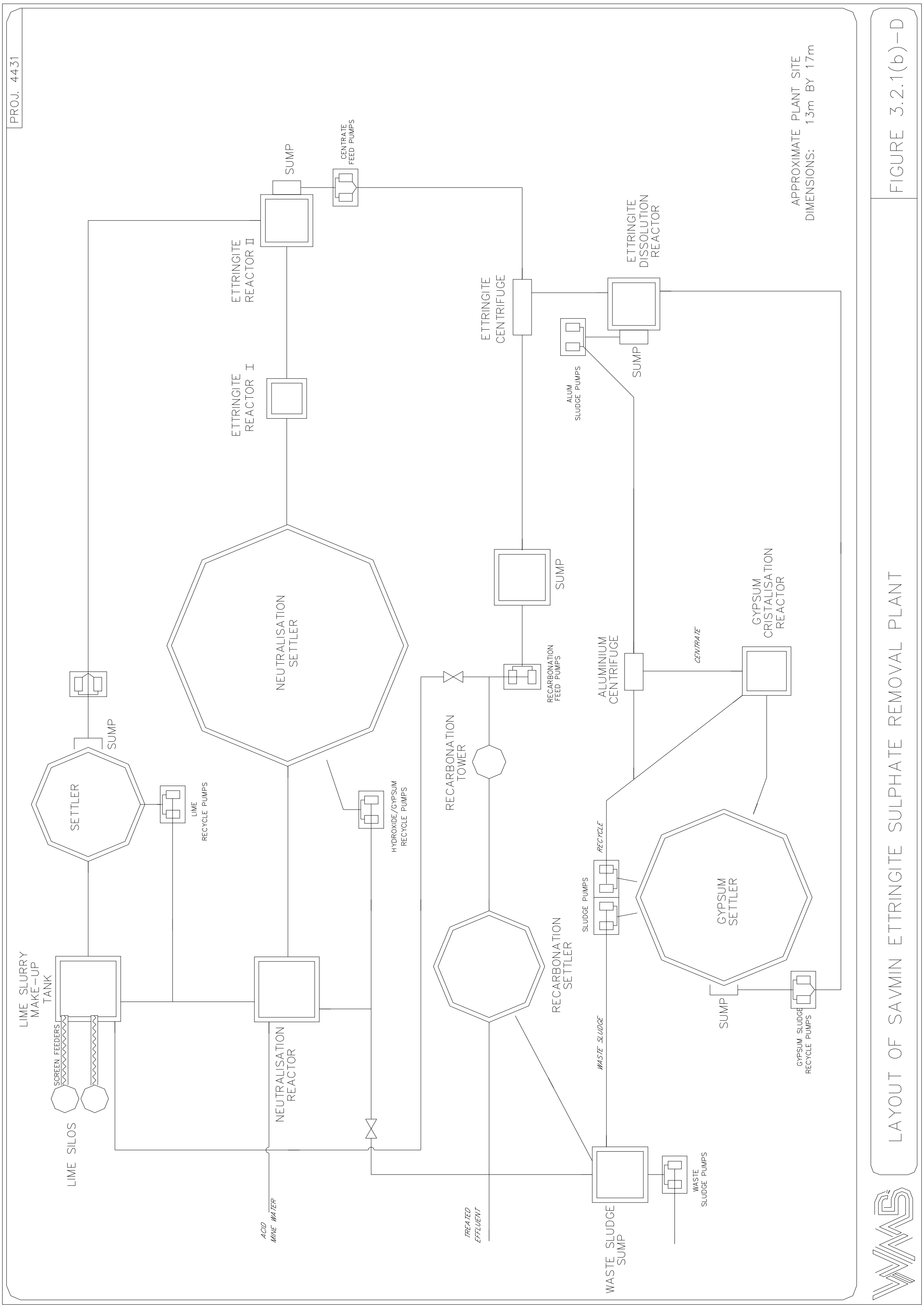


FIGURE 3.2.1(b)–D

LAYOUT OF SAVMIN ETTRINGITE SULPHATE REMOVAL PLANT

APPROXIMATE PLANT SITE DIMENSIONS: 13m BY 17m

Sufficient contact time is also allowed in the neutralisation reactor to stimulate precipitation of excess gypsum. The gypsum precipitation is further catalysed by the recycle of gypsum sludge from the downstream neutralisation settler.

The metal hydroxide and gypsum solids are settled in a neutralisation settler. This material settles and compacts well. A sludge solids concentration of 5 – 10 % in the neutralisation settler underflow is achievable. The settled solids are recycled to the neutralisation reactor. Excess solids are wasted to a disposal site.

The neutralised mine water flows to the ettringite reactor. The neutralised mine water quality can be controlled to a stable pH around 10 and a stable sulphate concentration of 1200 to 1400 mg/ℓ. The stable neutralised mine water quality is critical to the optimal performance of the downstream ettringite process.

Figure 3.2.2-D shows the process flow diagram for the neutralisation process.

3.2.3 Ettringite Precipitation

The ettringite process involves the precipitation of sulphate in the presence of aluminium hydroxide under controlled process conditions.

The primary ettringite reactor contacts the high sulphate mine water with aluminium hydroxide slurry. The sulphate is precipitated as ettringite sludge. The ettringite formation process is further advanced in a secondary ettringite reactor. Milk of lime is added to the secondary reactor to ensure an optimum pH for the effective removal of sulphate.

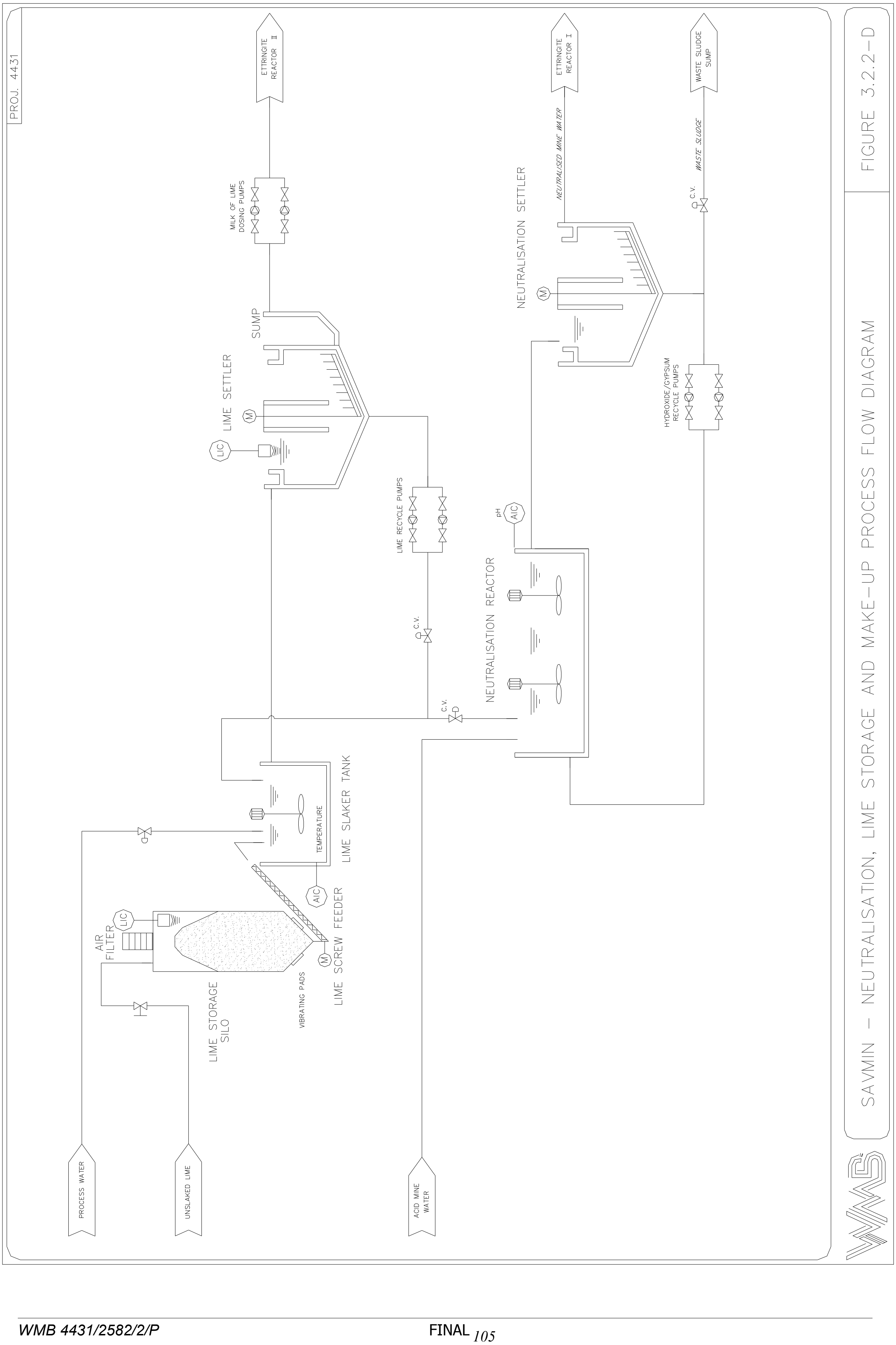
Ettringite sludge does not settle and compact well and gravity solids separation is not an appropriate technology. It is proposed to employ a dewatering centrifuge to separate the ettringite solids.

The ettringite precipitated process is shown in **Figure 3.2.3-D**.

3.2.4 Re-carbonation

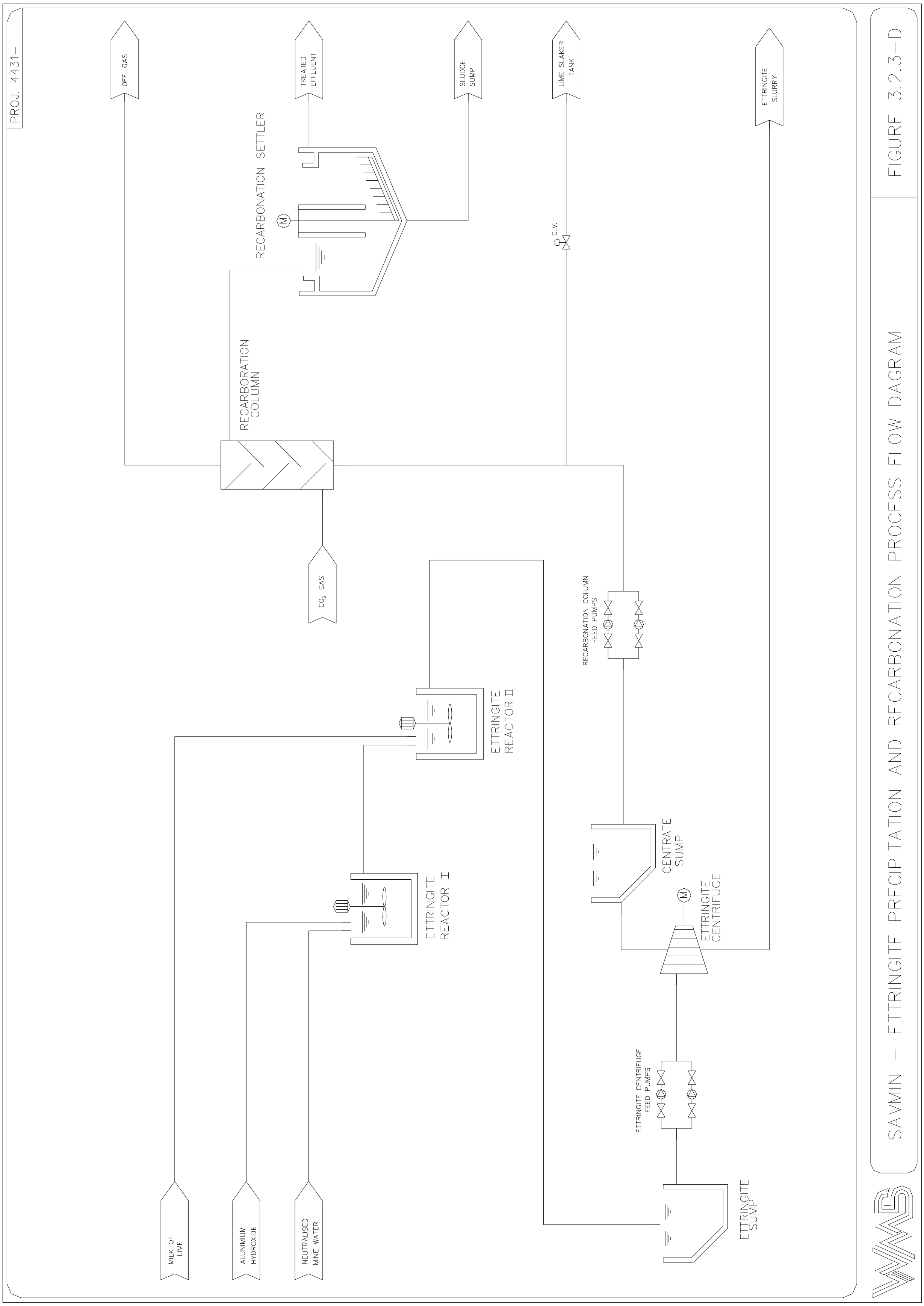
The ettringite process product water has a high residual pH and is also saturated with calcite. The re-carbonation process injected some CO_2 gas to correct the pH to the range of 8 – 8.5. In the process, some calcite solids may form and these are separated in a final re-carbonation settler. The calcite sludge is wasted and disposed.

The re-carbonation process flow diagram is shown in **Figure 3.2.3-D**.



SAVMIN – NEUTRALISATION, LIME STORAGE AND MAKE-UP PROCESS FLOW DIAGRAM

FIGURE 3.2.2-D



SAVMIN - ETTRINGITE PRECIPITATION AND RECARBONATION PROCESS FLOW DAGRAM

FIGURE 3.2.3-D

3.2.5 Aluminium Recovery

The ettringite solids are further processed to recover the aluminium for re-use in the process. The ettringite solids are contacted with sulphuric acid to drop the pH. The ettringite dissociates to form aluminium hydroxide, calcium and sulphate. The aluminium hydroxide solids are separated in a dewatering centrifuge. Mechanical dewatering is proposed due to the poor gravity settling and compaction properties of the aluminium hydroxide sludge. The separated aluminium hydroxide is recycled back to the ettringite reactor.

The centrate contains high calcium and sulphate concentrations and is treated in a downstream gypsum crystallisation reactor. The gypsum precipitation process is enhanced by recycling of gypsum sludge from the downstream gypsum settler. The recycled gypsum sludge acts as a seed material to accelerate the gypsum crystallisation process.

The gypsum solids are separated in a settler and the excess gypsum sludge is disposed.

The aluminium recovery process depends on a relatively high recycle flow from the gypsum settler back to the ettringite dissolution reactor. This recycle stream carries the calcium and sulphate forward to prevent co-precipitation with the aluminium hydroxide.

The aluminium recovery process diagram is shown in **Figure 3.2.5-D**.

3.2.6 Lime Make-Up and Dosing

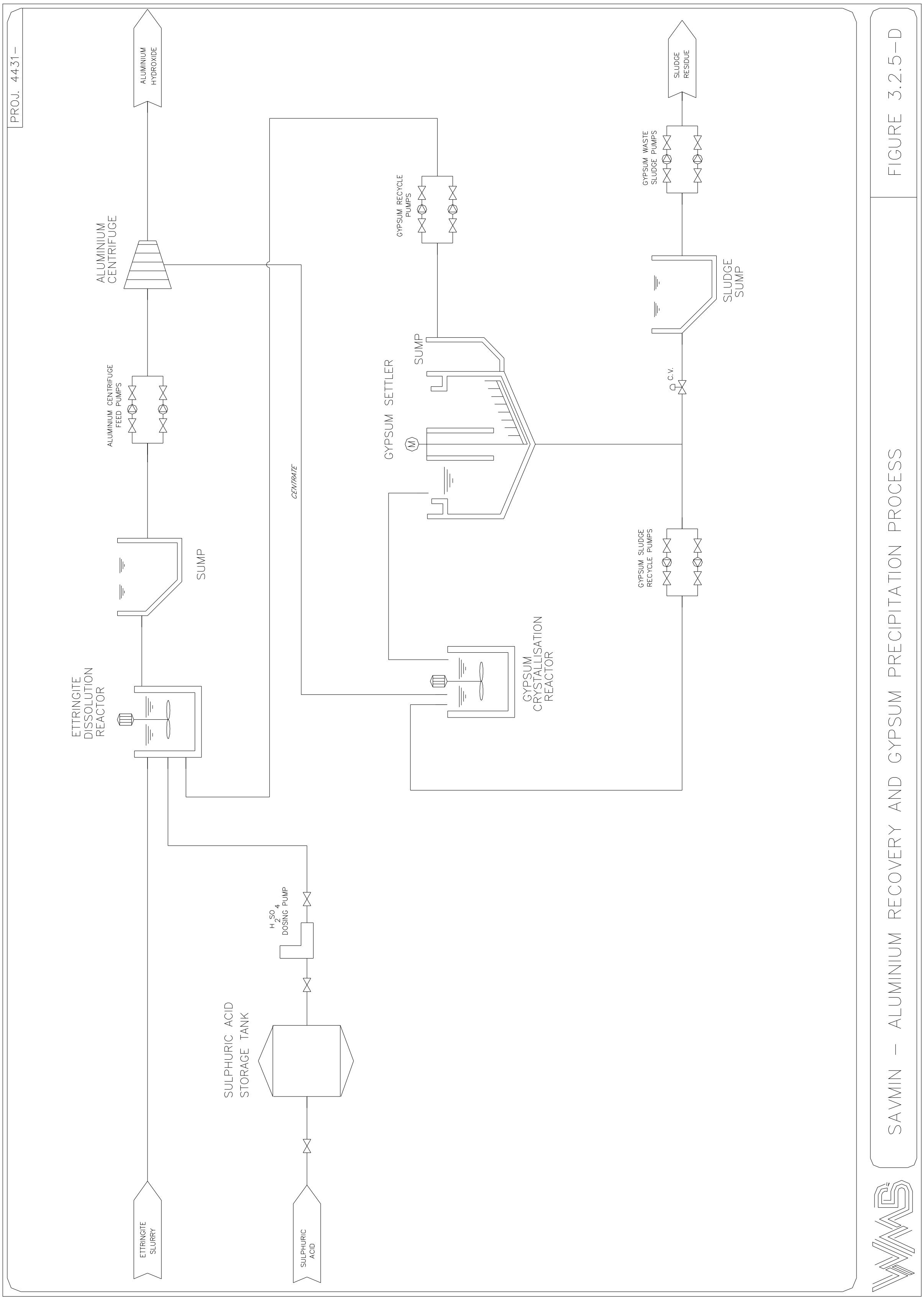
The Savmin process requires lime dosing for the purposes of:

- Neutralisation
- Ettringite

It is proposed to utilise unslaked lime in this application. The lime is stored in a bulk silo. A screw feeder controls the lime addition to a slake. The slaked lime slurry is treated in a lime settler. The thickened lime slurry is utilised for neutralisation of the influent mine water.

The dilute milk of lime (lime settler overflow) is used to control the secondary ettringite reactor pH. A recycle water stream from the ettingite process is also used for lime make-up purposes.

The lime storage , make-up and dosing process are shown in **Figure 3.2.2-D.**



SAVMIN – ALUMINIUM RECOVERY AND GYPSUM PRECIPITATION PROCESS

FIGURE 3.2.5-D

3.3 Treatment Residue Disposal

The collective waste sludge production of the Savmin process includes:

- Metal hydroxide/gypsum sludge
- Gypsum sludge
- Calcite sludge

A small amount of calcite sludge is produced and this can be recycled to the neutralisation reactor. The first contact zone of the neutralisation reactor can then be utilised for initial neutralisation, using calcite. The CO_2, which comes from this calcite neutralisation reaction, can also be recovered for re-carbonation.

The estimated excess waste sludge production is summarised below, based on the average mine water quality:

Type of Sludge	Production (ton TS/day)
Metal hydroxide/gypsum	13.7
Gypsum	24.8
Total	**38.5**

3.4 Capital Expenditure

The estimated capital expenditure (± 30 %) is summarised below:

Description	Mechanical	Civil	Electrical	Total
Lime storage & make-up	1 990 771.00	994 616.00		2 985 387.00
Neutralisation reactor/thickener	283 368.00	1 911 172.00		2 194 540.00
Ettringite process	186 000.00	460 392.00		646 392.00
Ettringite Dewatering	3 694 970.00	118 680.00		3 813 650.00
Re-carbonation	683 361.00	724 780.00		1 408 141.00
Ettringite dissolution reactor	110 772.00	281 250.00		392 022.00
Aluminium dewatering centrifuge	3 070 692.00	34 820.00		3 105 512.00
Gypsum crystallisation reactor/settler	538 778.00	1 304 043.00		1 842 821.00
Interconnecting pipework		900 000.00		900 000.00
Electrical equipment			1 750 000.00	1 750 000.00
Total	**10 558 712.00**	**6 729 753.00**	**1 750 000.00**	**19 038 465.00**

3.5 Operating and Maintenance Cost

The operating and maintenance costs were calculated to include the major components of:

- Chemicals
- Electrical power
- Operating personnel and labour
- Maintenance and repair

The operating and maintenance costs reflect the price indices of January 2002.

3.5.1 Chemical Usage

The chemical usage is estimated on the basis of the average mine water flow and load conditions.

The estimated chemical usage is summarised below:

Chemical type	Consumption (kg/day as pure)	Unit cost (R/kg as chemical)	Daily cost (R/day)
Unslaked lime	13 489	0.65	8 768
Ettringite – Polymer	80	35	2 800
Carbon dioxide (recovered)	818	-	-
Sulphuric acid	7 986	0.35	2 795
Aluminium sulphate	390	4.2	1 639
Aluminium hydroxide - polymer	11	35	385
Total			**16 387**

3.5.2 Electrical power

The installed power and the power drawn from each major individual mechanical equipment item were estimated. The electrical power cost was estimated using a unit rate of :

0.12 R/kWhr

The estimated installed power and the daily energy cost are summarised below:

Equipment item	Number installed	Installed power kW/unit	Operating hours/day	Daily power cost R/day
Mine water feed pumps	2	17	24	39.17
Neutralisation reactor mixers	2	11	24	50.69
Neutralisation settler bridge	1	1	24	3.46
Hydroxide/gypsum recycle pumps	2	17	24	39.17
Ettringite reactor mixers	2	7	24	32.26
Ettringite centrifuge feed pumps	2	55	24	126.72
Ettringite centrifuge	1	75	24	172.80
Ettringite dissolution reactor mixer	1	11	24	25.34
Re-carbonation Column feed pumps	2	30	24	69.12
Re-carbonation settler bridge	1	1	24	3.46
Calcite sludge pumps	2	2.7	2	0.52
CO_2 gas blower	2	0.64	24	1.46
Aluminium centrifuge feed pumps	2	22	24	50.69
Aluminium centrifuge	1	55	24	126.72
Aluminium hydroxide recycle pumps	2	1	24	2.53
Gypsum crystallisation mixer	1	11	24	25.34
Gypsum settler bridge	1	1	24	3.46
Gypsum recycle pumps	2	7	24	16.13
Gypsum sludge recycle pumps	2	11	24	25.34
Gypsum waste sludge pumps	2	11	24	25.34
Lime screw feeder	1	2	24	5.07
Lime slaker tank mixer	1	1	24	3.46
Lime settler bridge	1	1	24	3.46
Lime recycle pumps	2	3.7	24	8.52
Milk of lime dosing pumps	2	14	24	32.26
Sulphuric acid feed pumps	2	1	24	2.53
Total				**895**

3.5.3 Operating personnel and labour

The cost associated with operating personnel and labour was based on a reasonable assessment of the staffing requirements for a treatment plant.

The proposed categories of operating personnel and labour and associated monthly cost are summarised below:

Personnel Category	**Number**	**Unit Cost (R/Month)**	**Monthly Cost (R/Month)**
Plant superintendent	1	9 000	9 000
Process operators	4	6 500	26 000
Process assistants	2	4 500	9 000
Labourers	5	2 000	10 000
Total cost			**54 000**

3.5.4 Maintenance cost

Planned and preventative maintenance and associated repair work are costed as a fraction of the capital investment into different components of the plant. The estimated annual maintenance cost is summarised below:

Infrastructure component	**Capital expenditure R million**	**Annual allowance for maintenance %**	**Annual maintenance cost R/year**
Civil & building works	6.73	0.5	33 650
Mechanical equipment	10.6	2	211 180
Electrical & instrumentation	1.75	3	52 500
Total	**19.08**		**297 330**

3.5.5 Operating and Maintenance summary

The different operations and maintenance cost component are summarised as follows:

Cost component	**Daily cost (R/day)**	**Unit cost (R/m^3)**
1. Chemicals	16 387	3.28
2. Electrical power	895	0.18
4. Operating personnel	1 775	0.36
5. Maintenance	815	0.16
Total	**19 872**	**3.98**