BIO-REMEDIATION OF MINE WATER

Harma Greben

Division of Natural Resources and the Environment

CSIR

South Africa

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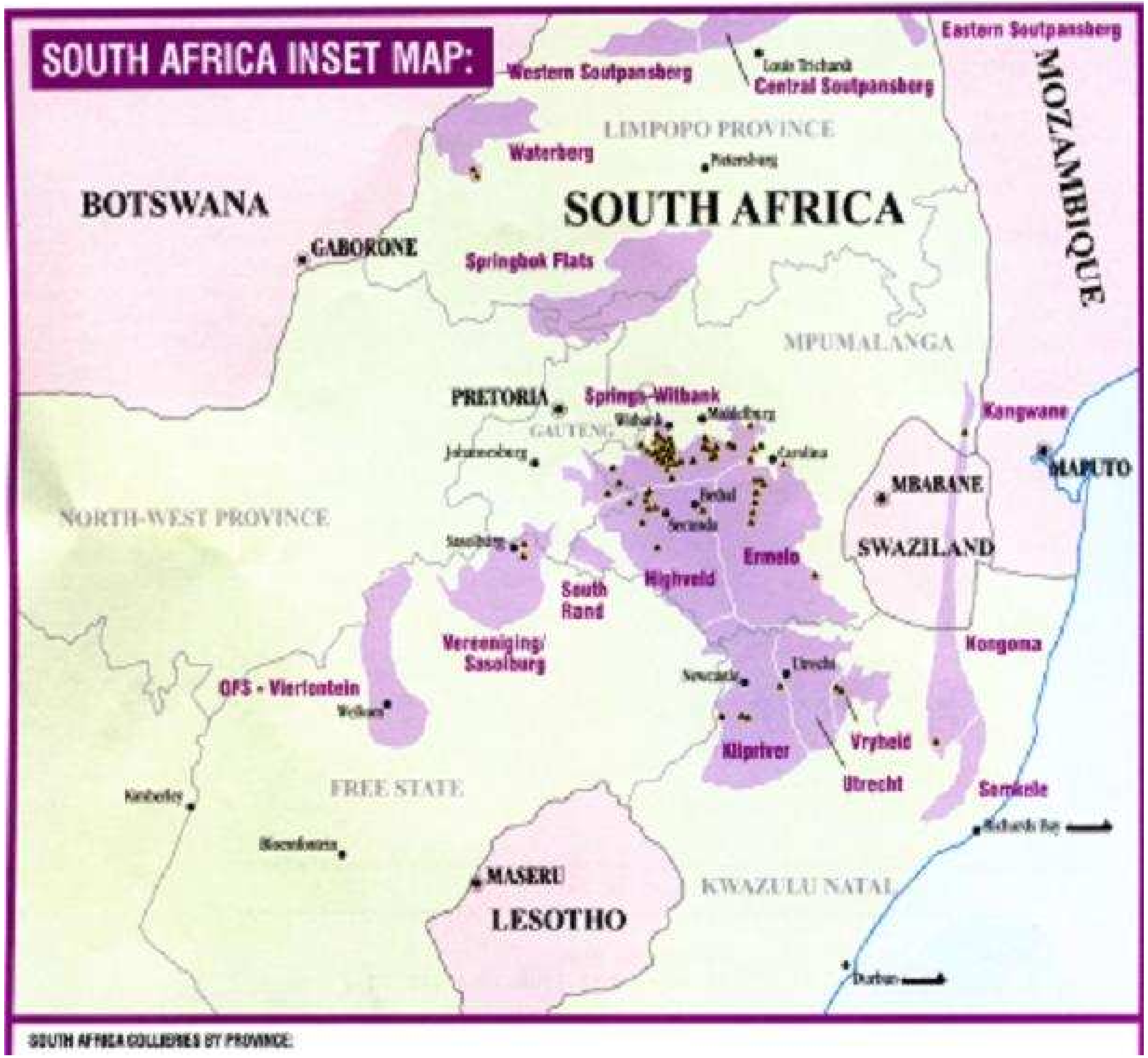
Introduction

Mining History in South Africa

- Gold Mining started in the late 1880's on the farm Langlaagte, west of Johannesburg
- Soon thereafter coal mining started in the Witbank Area as well as in Northern Natal
- Diamond mining in Kimberley

Chinese coal miners in an illustration of the *Tiangong Kaiwu* Ming Dynasty encyclopedia, published in 1637 by Song Yingxing.

Coal fields in South Africa



Wealth versus environment

- SA is 5th largest coal producer in the world
- SA is third largest coal exporter
- South Africa gains economic prosperity from the act of mining

- The mining industry contributes negatively to the pollution of the water environment by producing Acid Mine Drainage.

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Impact of mining

By act of mining: AMD is formed

Arises from oxidation of pyrite, due to exposure to air and water.

$2FeS_2 + 7O_2 + 2H_2O \rightarrow 2FeSO_4 + 2H_2SO_4$

Characteristics of AMD:

High SO4: Salinity

High acidity: low pH

High metal content

Environmental impact:
Water pollution

AMD

Water Pollution trough mining in South Africa

Statistics

- Mpumalanga coal field produces 40-50ML/d,

  may increase to 120ML AMD/d

- Gauteng mining area produces 300-400 ML AMD/d

Anno 2006

Mine water remediation

- Biological treatment
- Chemical treatment
- Physical treatment

Possible ground water contamination

Chemical treatment

CSIR Limestone/Lime Neutralisation

The integrated limestone/lime process is used for treating acid, iron and sulphate-rich water with powder calcium carbonate.

- Acidic mine effluents are neutralised
- Sulphate is removed from 20 g/ℓ to less than 2 g/ℓ
- Metal removal (Ca, Mg), using lime

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Full scale implementation of CSIR neutralisation technology

South Africa:

- Ticor, Limestone/lime
- Navigation and Kromdraai mines, Anglo coal (both Limestone)
- Namaqua Sands Limestone/lime
- Zincor (limestone)
- Optimum (limestone)

Botswana

- BCL (limestone)

Australia

- Iluka resources (limestone/lime)

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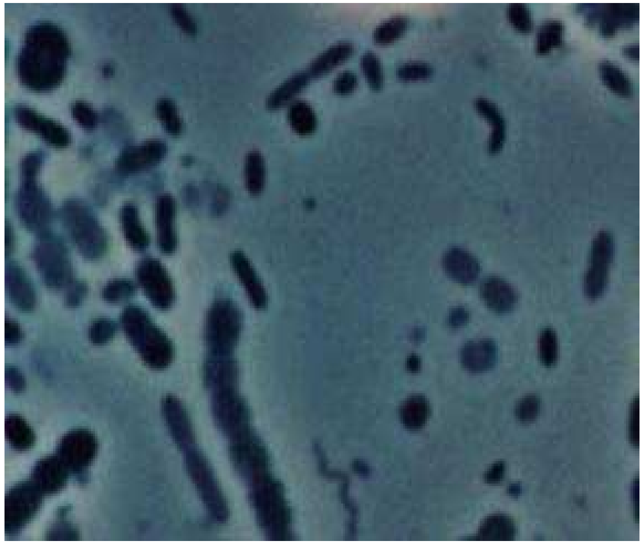
Biological Sulphate (SO_4) removal

- Requires Sulphate Reducing Bacteria (SRB)
- Requires a carbon and energy source
- Requires SO_4
- Requires anaerobic conditions



Microorganisms

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CSIR developed biological treatment

Biological AMD treatment using alternative carbon and energy sources

- Degradation products of cellulose occurring in grass
- Volatile Fatty Acids (VFA) and hydrogen (H_2) production
- VFA and H_2 can function as C+E source for SRB

Grass: potential source of sustainable energy

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Biological degradation of cellulose

Polymers
Cellulose; Protein; Carbohydrates; Lipids; etc

→ Hydrolysis

Monomeres
Sugar; Amino acids; etc

→ Fermentation

Volatile Fatty Acids (VFA)
Acetic, Propionic, Butyric, Valeric

Microorganisms produce VFA and H_2

Use of natural occurring microorganisms

- Rumen fluid from ruminant →

- SRB participate in the degradation of the polymers and monomers to produce VFA

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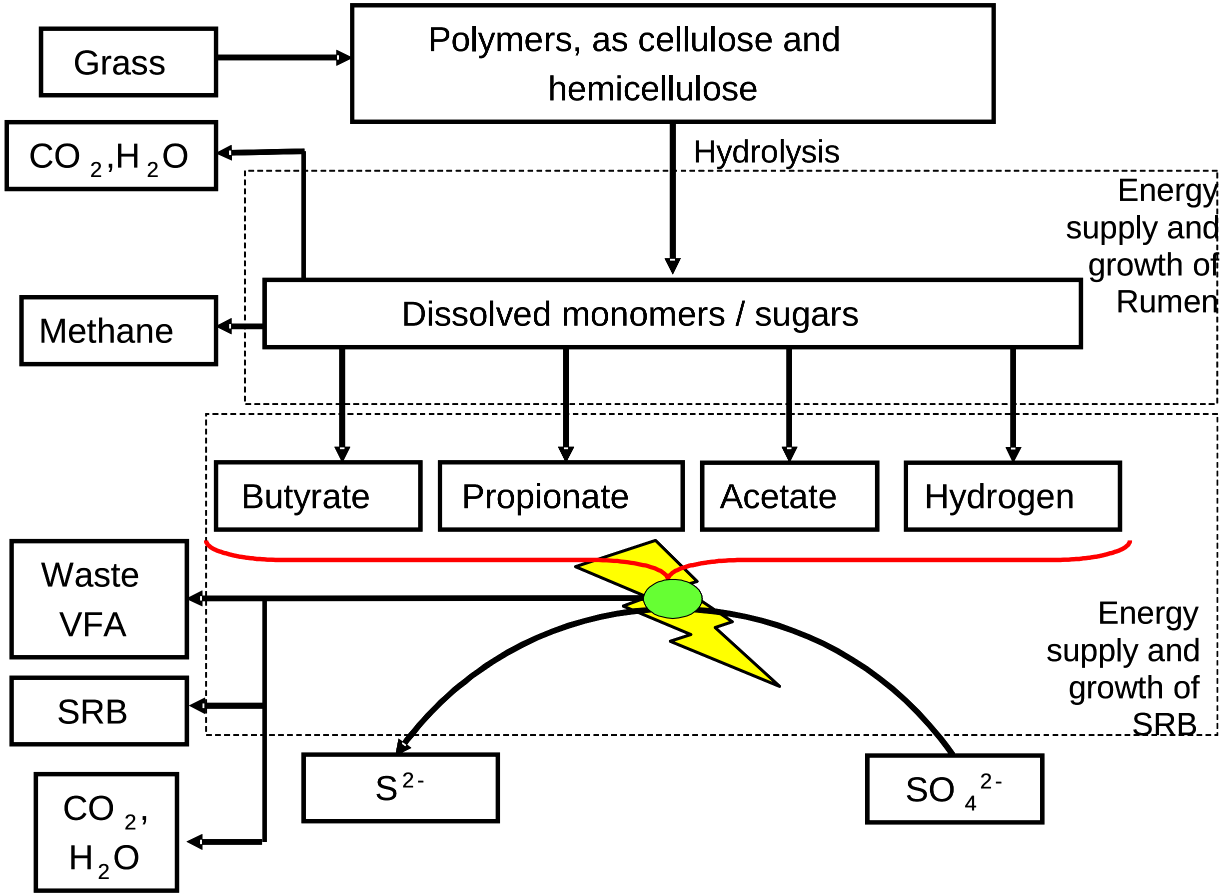
Grass
Polymers, as cellulose and hemicellulose
CO 2,H 2O
Hydrolysis
Energy supply and growth of Rumen
Methane
Dissolved monomers / sugars
Butyrate
Propionate
Acetate
Hydrogen
Waste VFA
SRB
CO 2, H 2O
Energy supply and growth of SRB
S 2-
SO 4 2-

Benefits of biological SO_4 removal

- Sulphate removal to <200 mg/L
- Alkalinity production to increase pH
- Sulphide is the reduction product of sulphate
- Metal removal due to Metal-sulphide precipitation

Biological SO_4 reduction using grass-cellulose as the carbon and energy source

Aim of study

To remove biologically:

- Sulphate from AMD
- Sulphide after sulphate reduction

CSIR developed biological treatment plant

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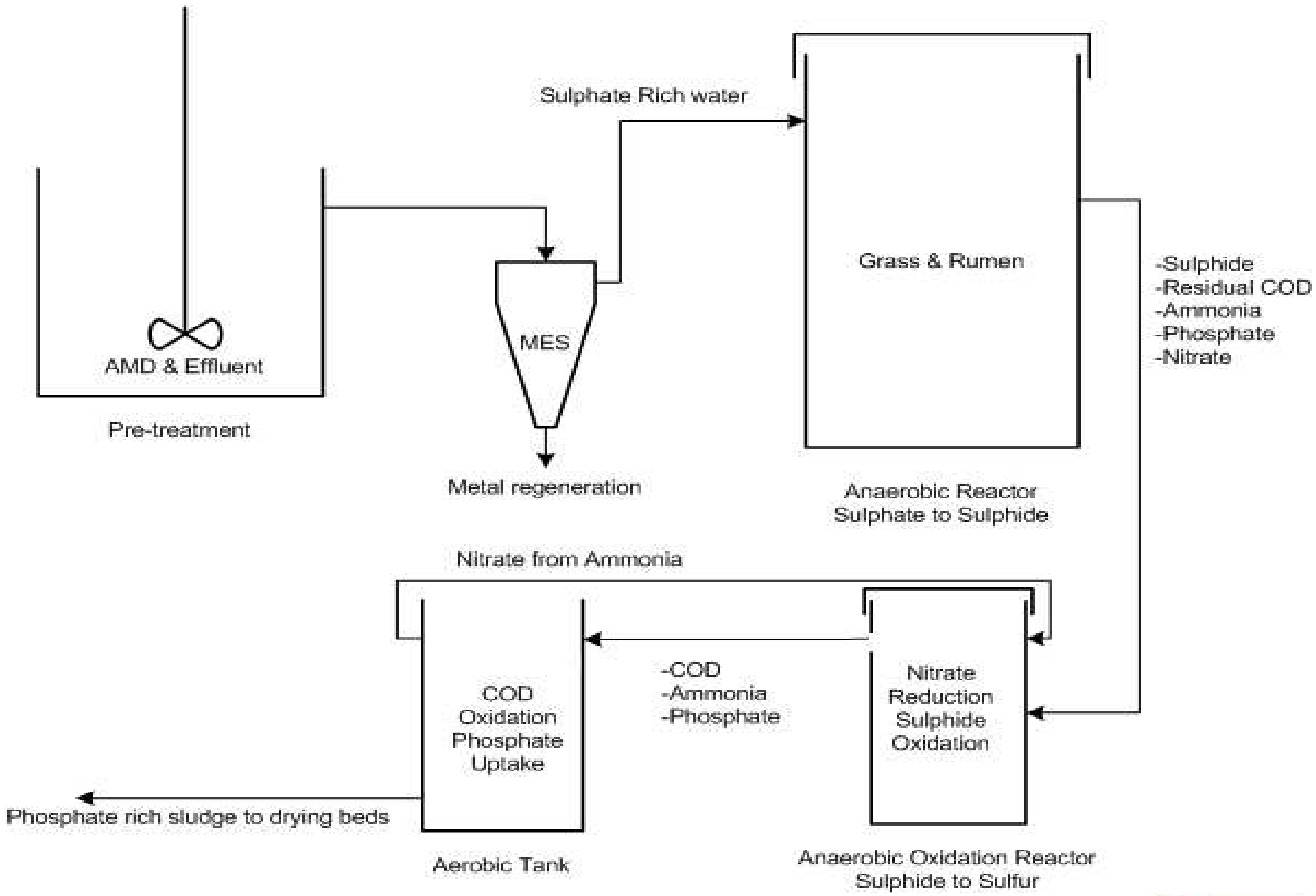
Materials and Methods

Feed water

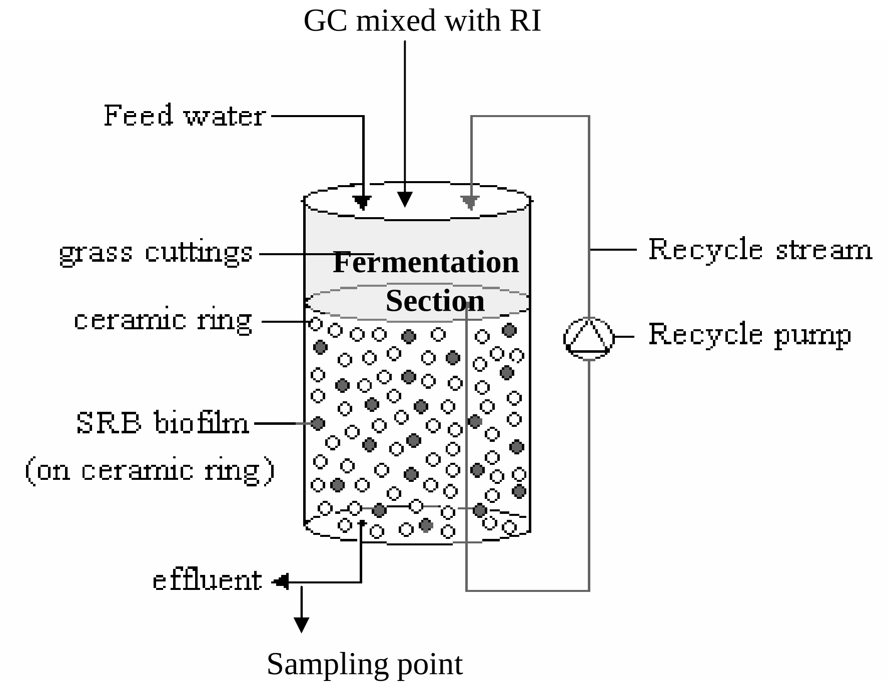
- Pre-treated AMD
- Mix 1 part AMD with 1 part of reactor effluent

Purpose

- Metal removal
- pH increase of AMD


Sulphate Rich water
AMD & Effluent
Pre-treatment
MES
Metal regeneration
Grass & Rumen
Anaerobic Reactor
Sulphate to Sulphide
-Sulphide
-Residual COD
-Ammonia
-Phosphate
-Nitrate
Nitrate from Ammonia
COD
Oxidation
Phosphate
Uptake
-COD
-Ammonia
-Phosphate
Nitrate
Reduction
Sulphide
Oxidation
Phosphate rich sludge to drying beds
Aerobic Tank
Anaerobic Oxidation Reactor
Sulphide to Sulfur

Reactor: Hybrid Reactor System



Schematic overview of HFS reactor system.

Laboratory study:
continuous operation of hybrid reactor

Reactor contains

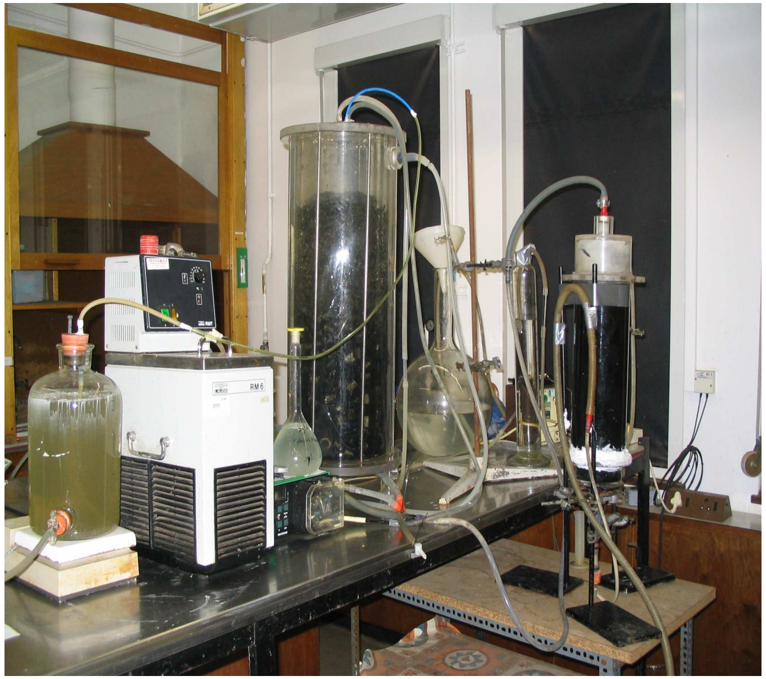
1. Grass cuttings as cellulose source
2. Cellulose degrading microorganisms
3. SRB

Feed water:

Pre-treated AMD for pH increase and metal precipitation

Principle

VFA and H_2 production and utilisation in reactor for biological sulphate removal



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Reactions using VFA and H_2 for SO_4 removal

$$\text{Propionate}^- + \tfrac{3}{4}\, SO_4^{2-} \rightarrow \text{Acetate}^- + HCO_3^- + \tfrac{3}{4}\, HS^- + \tfrac{1}{4}\, H^+$$

$$\text{Butyrate}^- + \tfrac{1}{2}\, SO_4^{2-} \rightarrow 2\ \text{Acetate}^- + \tfrac{1}{2}\, HS^- + \tfrac{1}{2}\, H^+$$

$$8H_2 + 2SO_4^{2-} + 2H^+ \rightarrow 2\, HS^- + 8H_2O$$

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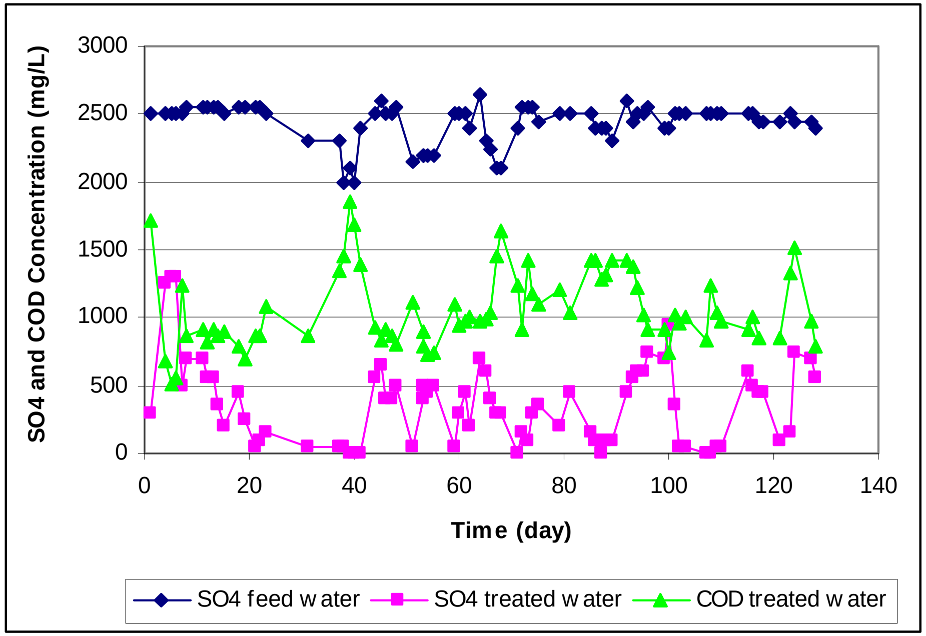
Results

Sulphate removal (mg/L)



Sulphate removal as function of COD

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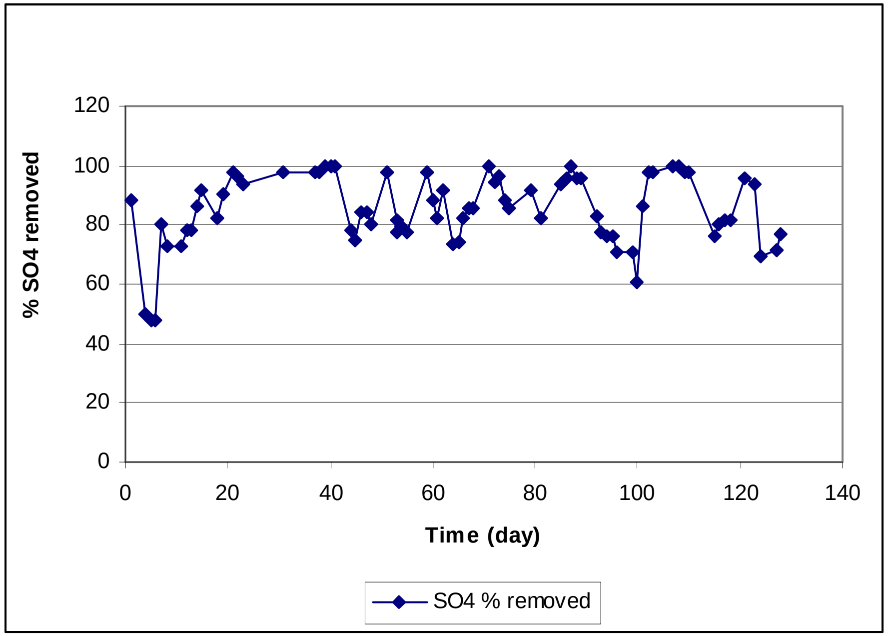
Percentage Sulphate removal efficiency



Average sulphate removal was 85%

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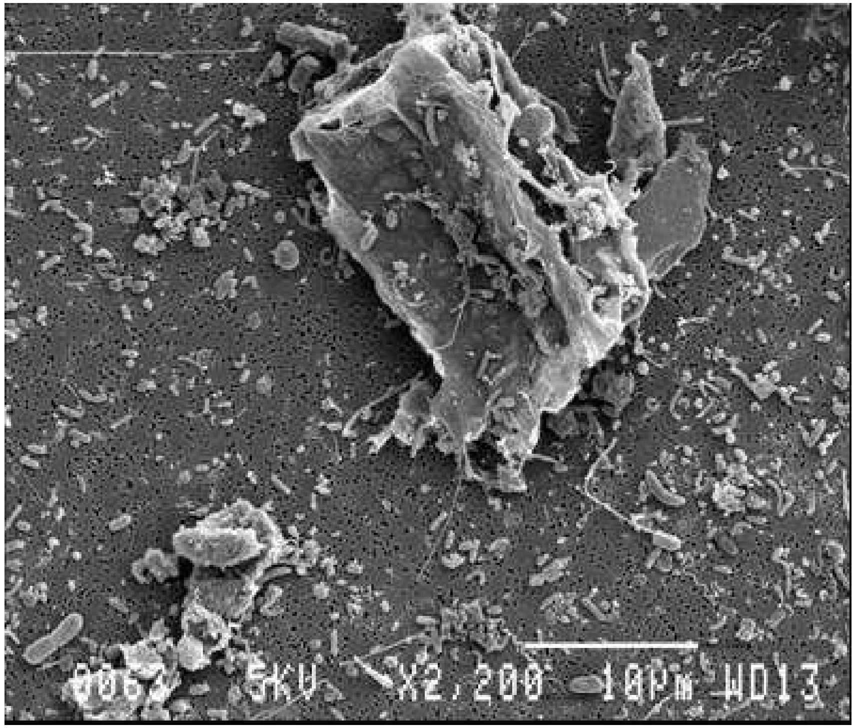
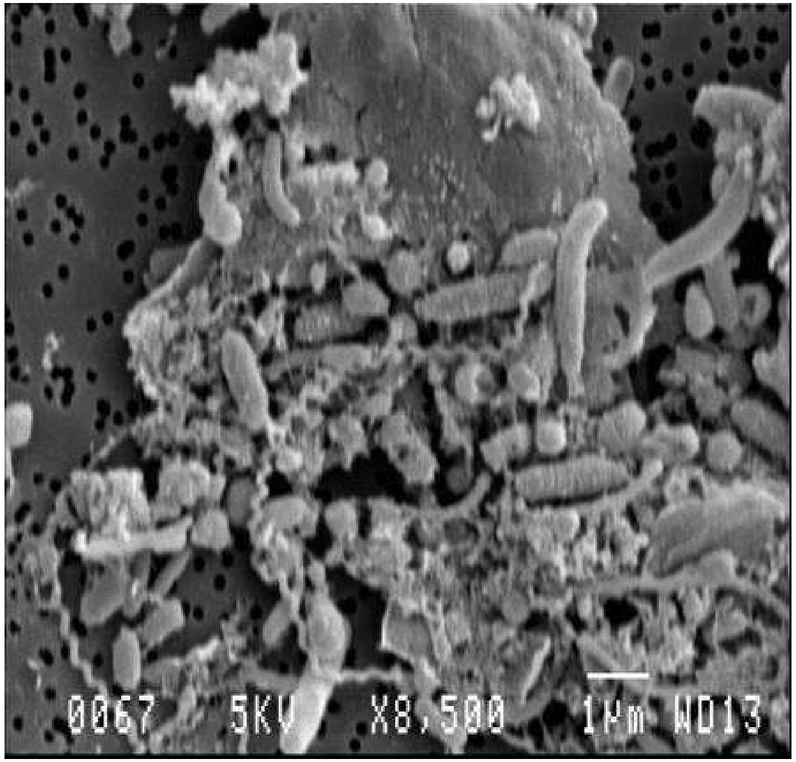
Results scanning electron microscope





Metal removal

Metal	AMD	Pre-treated AMD	Effluent HFS
Aluminium	24	14	<0.09
Chromium	<0.05	<0.05	<0.05
Iron	851	102	0.21
Lead	0.15	<0.03	<0.03
Manganese	48	27	5.9
Nickel	11	4.3	0.04
Zinc	1.4	0.94	<0.06

All units in mg/L

Sulphide oxidation after sulphate reduction

Biological sulphide oxidation using air

- By *Thiobaccilus* Species
  - *Thiobacillus thioparus*,
  - *Thiobacillus denitrificans* and
  - *Thiobacillus ferroxidans* (Chung et al., 1996).

- Producing sulphur or sulphate
  - $HS^- + \frac{1}{2} O_2 \rightarrow S + OH^-$
  - $HS^- + 2\ O_2 \rightarrow SO_4^{2-} + H^+$

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Experimental conditions of a continuous laboratory study

Period (days)	Air supply to reactor (L/min)
29-43	0.2
44-59	0.4
62-81	0.6
83-97	0.8

Results of biological sulphide oxidation after continuous laboratory studies

Air supply (L/min)	S^{2-} removed (g/d)	Sulphur produced (g/d)	$\%SO_4$ increase in reactor
0.2	5.13	1.98	8
0.4	4.45	1.96	28
0.6	4.62	2.06	**47**
0.8	5.77	1.28	**57**

Conclusions continuous operation SO_4/grass/rumen reactor and biological sulphide oxidation

- Efficient sulphate removal (Average 85%)
- Metal removal, especially iron
- Biological sulphide oxidation achieved, at low air concentration, otherwise SO_4 is end product rather than Sulphur
- Based on obtained results, pilot scale reactor will be constructed

For more information

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Thank You

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