The Coal Authority

Pilot Plant Testing to Determine the Process Implications of Treating Net Alkaline Mine Water using the High Density Sludge Process

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Contents

Coal Authority Coal Mine Water Treatment Schemes

Currently operate 76 schemes across UK coalfields

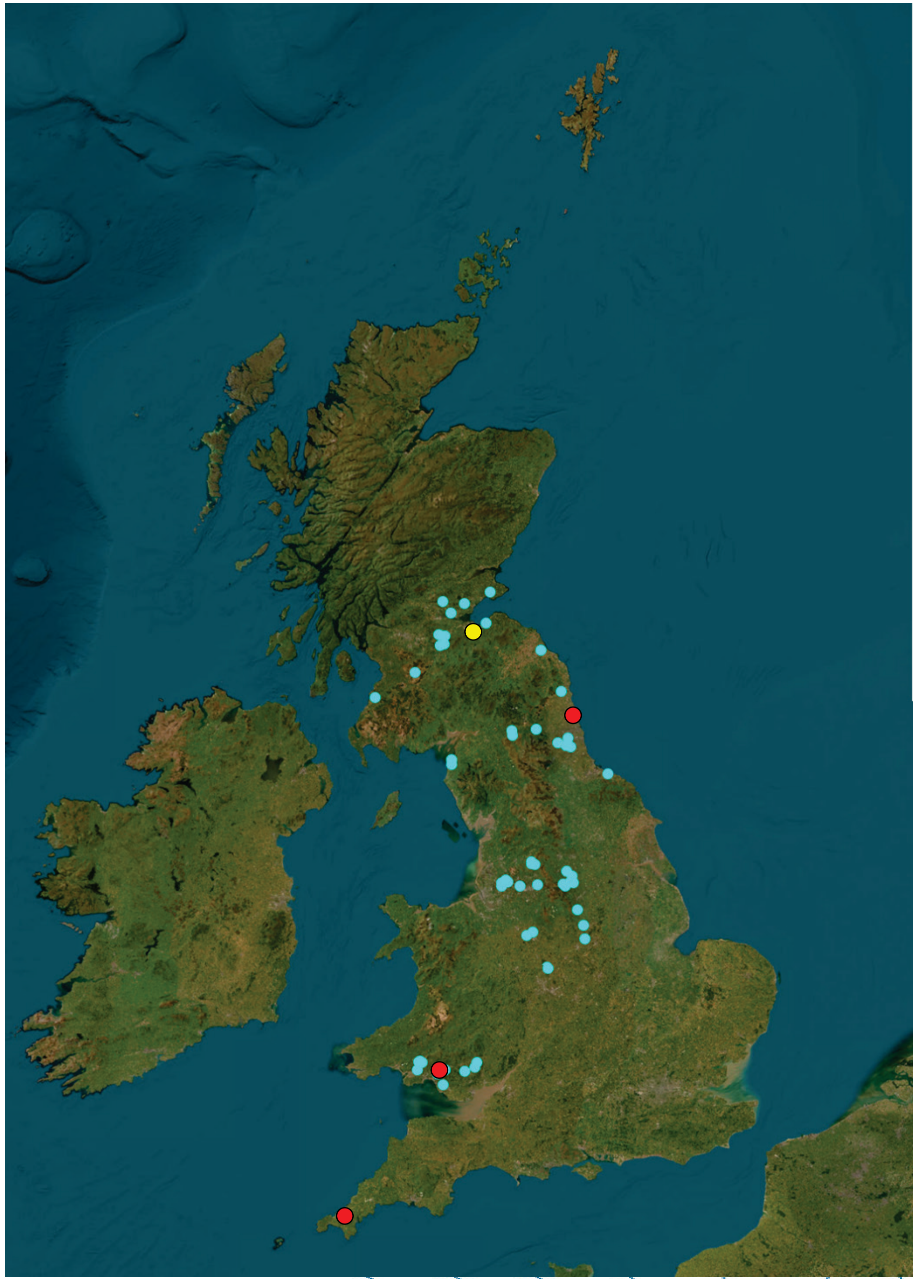
- 74 schemes use Passive / Semi Passive treatment
- 2 schemes use Active treatment
  - only Dawdon (County Durham) is HDS plant (2008)

Schemes focus on iron removal, protecting drinking water aquifers and surface waters

Total capacity of 200 billion litres per annum

Removing ≈2,700 tonnes of $Fe(OH)_3$ in 23/24

Typically net-alkaline in UK



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Old Fordell Adit Mine Water

Old Fordell Adit discharges into River South Esk

For period 2020-2023 discharge contained:

- Mean total iron 43.4 mg/L; mean total manganese 4.6 mg/L
- Predicted to increase to 80 mg/L total iron; 8 mg/L total manganese
- However during Q1 2024 mean total iron increased >50 mg/L
- Flow rate typically between 100 – 200 L/s

Requirement to remove both iron and manganese prior to discharge to prevent water pollution and river discoloration

Passive Scheme

- Two passive scheme options were modelled
- Option 1: Iron removal only scheme – land area 62,000 m^2
- Option 2: Iron and manganese removal scheme – land area 112,000 m^2
- BUT lack of suitable land in Dalkeith area

Treatment Scheme Options

Active Scheme

Smaller footprint required so active option considered

- Required land area approximately 8000 m^2

Advantages of High Density Sludge (HDS) Process

Ferric hydroxide precipitate produced

- High sludge settlement velocity
- Low settled sludge volume
- Mechanical dewatering yielded in excess 50% solids

HDS plant operational experience used in preliminary plant design

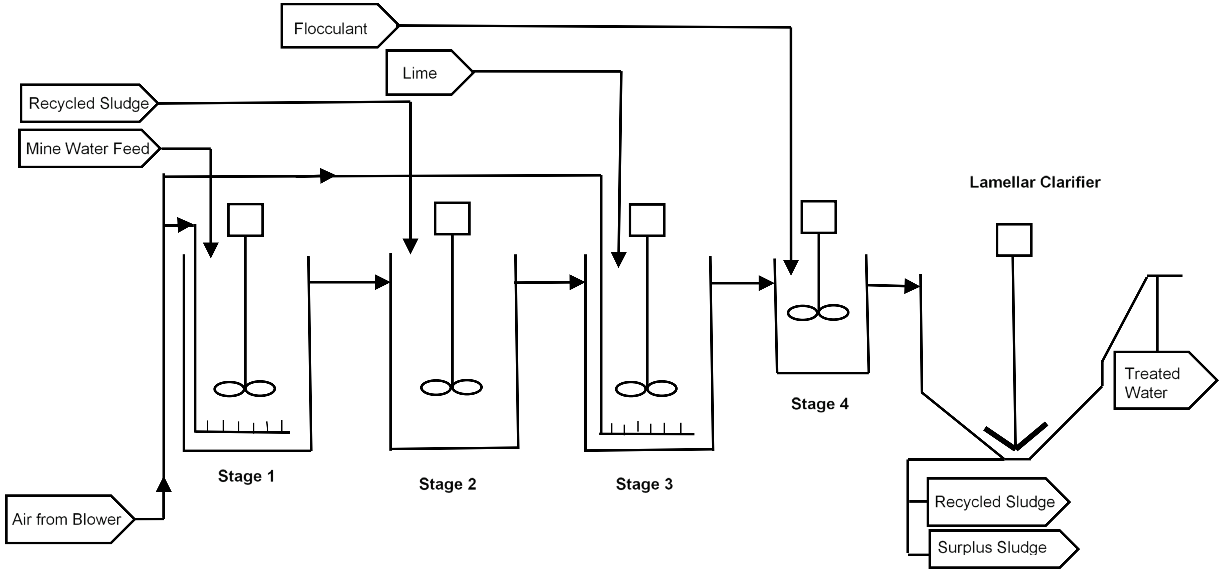
Aims of Pilot Plant Trial

3 week on-site pilot plant trial deployed to:

- Confirm the assumptions used in preliminary design work
  - Key stakeholder agreement that up to 200 L/s will be treated prior to discharge

- Understand how the plant's design and equipment selection influenced by:
  - Carbon dioxide stripping
  - Reagent consumption
  - Ferric hydroxide precipitation

Pilot Plant Layout



Component	Description	Volume (m^3)		Component	Description	Volume (m^3)
Stage 1	Degassing	0.67		Stage 4	Flocculant dosing	0.05
Stage 2	Sludge addition	0.67		Stage 5	Flash mixer	0.05
Stage 3	Lime dosing	0.67		Stage 6	Lamellar clarifier [1]	3.5 m^2
Lime Tank	5 %w/w lime storage	0.190		Flocculant tank	0.05 %w/w flocculant storage	0.09

Typical Mine Water Chemistry during Trial

	pH	Iron (total) (mg/L)	Iron (dissolved) (mg/L)	Manganese (total) (mg/L)	Manganese (dissolved) (mg/L)
Mean	6.4	46.2	43.5	4.41	4.49
Minimum	6.2	45.2	43.2	4.60	4.68
Maximum	6.6	53.1	49.0	4.84	5.01
	Calcium (mg/L)	**Magnesium (mg/L)**	**Sulfate (mg/L)**	**Total Alkalinity (mg/L)**	**Total Suspended Solids (mg/L)**
Mean	258	177	1123	185	51
Minimum	265	182	1110	184	32
Maximum	292	202	1280	214	74

Carbon dioxide (calculated): mean, 225 mg/L; 110 – 340 mg/L

Need for Carbon Dioxide Stripping - 1

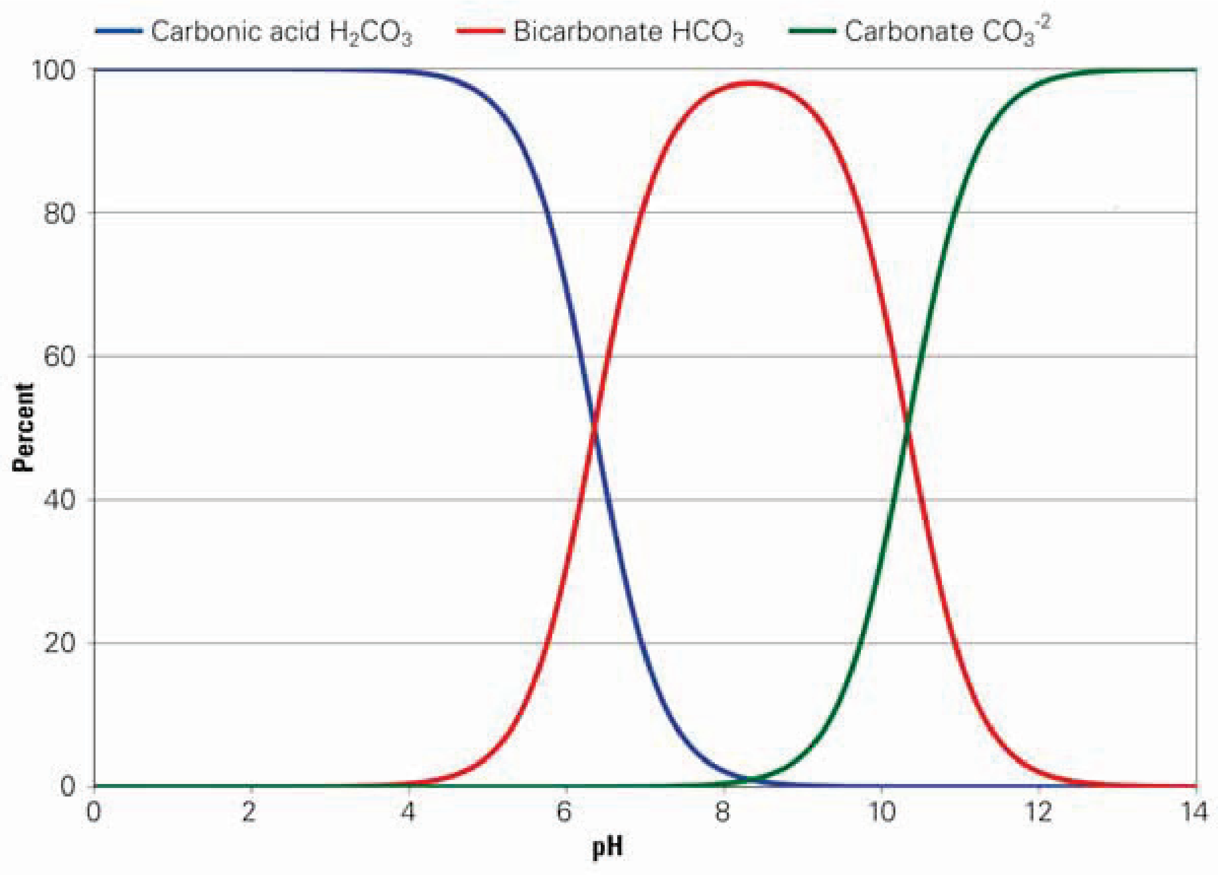
Dissolved inorganic carbon species vary with pH
pH 6-7 [circum-neutral] main species are:

- $H_2CO_3^*$, dissolved CO_2
- HCO_3^- , bicarbonate ion

Dissolved CO_2 rapidly interchanges with carbonic acid and the bicarbonate ion:

$$CO_2 + H_2O \rightleftharpoons H_2CO_3^*$$

$$HCO_3^- \rightleftharpoons CO_2 + OH^-$$



Need for Carbon Dioxide Stripping - 2

Equilibrium

$CO_{2(g)} + H_2O \rightleftharpoons [H_2CO_3]^* \rightleftharpoons H^+ + HCO_3^- \rightleftharpoons 2H^+ + CO_3^{2-}$

pH increase (alkali addition) converts more CO_2 to more HCO_3^- and more CO_3^{2-}

- Unwanted reactions increase alkali demand
- Excess CO_3^{2-} precipitates as $CaCO_3$
- CO_2 is an “alkali thief”

- Air stripping displaces CO_2
- HCO_3^- dissociates to CO_2 and OH^-
  - ➢ $HCO_3^- \rightleftharpoons CO_2 + OH^-$

Removing CO_2 decreases alkali demand - benefit

Carbon Dioxide Stripping

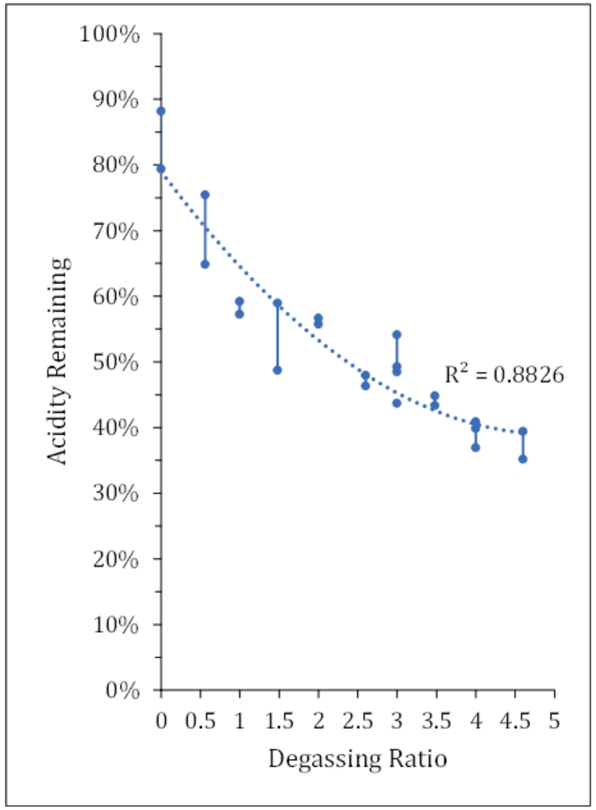
Operated in conventional precipitation mode and degassing air flow ratio varied between 0:1 to 4.5:1 (air:water volume)

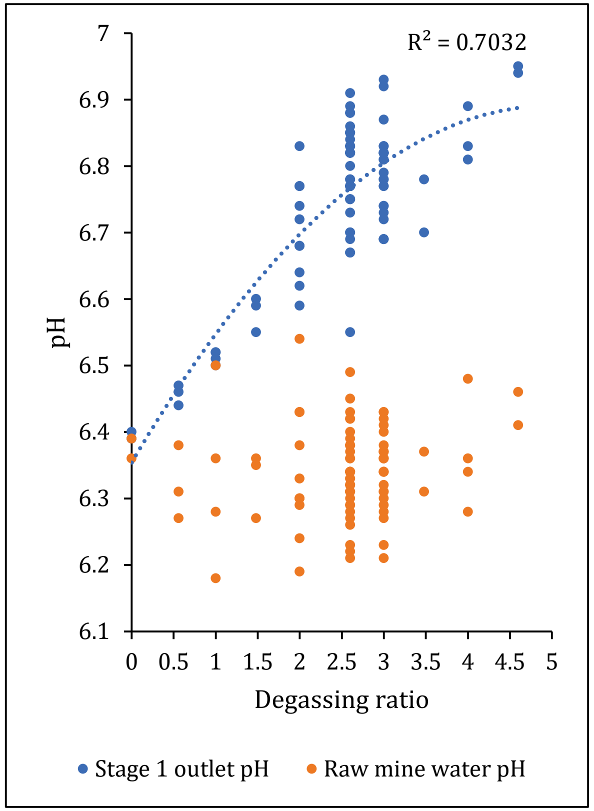
Increase in air:water ratio decreased mine water acidity

Resulted in 50% - 60% acid removal, for ratios >3:1 it trended to 40% acid remain

Mine water pH increased to about pH 6.9 from ≈ pH 6.4 and alkalinity maintained by

- $HCO_3^- \rightleftharpoons CO_2 + OH^-$





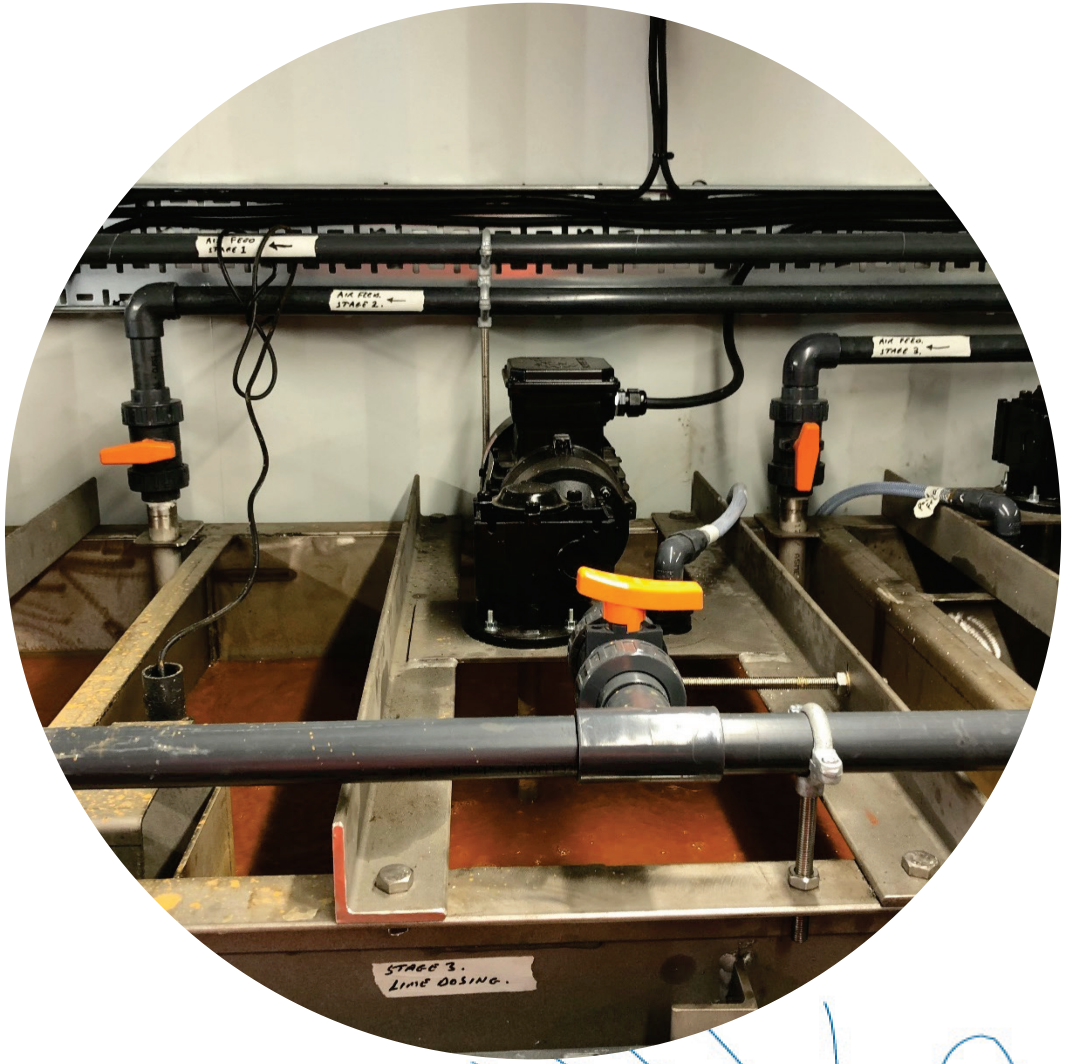
High Density Sludge Tests – Fe and Mn Precipitation

HDS precipitation pH varied pH 7.5 - 9.3
Degassing air flow 3:1 kept constant
(degassing air 75 L/min; mine water, 25 L/min)

	Raw Mine Water			Treated Water			
Precipitation pH	pH	Total Fe (mg/L)	Total Mn (mg/L)	pH	Total Fe (mg/L)	Dissolved Fe (mg/L)	Total Mn (mg/L)
7.5	6.4	53.1	4.86	7.8	2.76	0.03	3.79
8.0	6.3	52.3	4.71	8.1	4.30	0.06	4.13
8.5	6.3	61.5	4.77	8.3	0.16	0.01	0.64
8.75	6.4	54.5	4.79	8.3	0.12	0.01	0.71
9.3	6.4	52.6	4.44	8.9	0.45	0.41	0.49

Oxidation and precipitation of dissolved iron >99.1% across pH range tested

pH 7.5 optimum for removal iron only



High Density Sludge Tests – Fe and Mn Precipitation

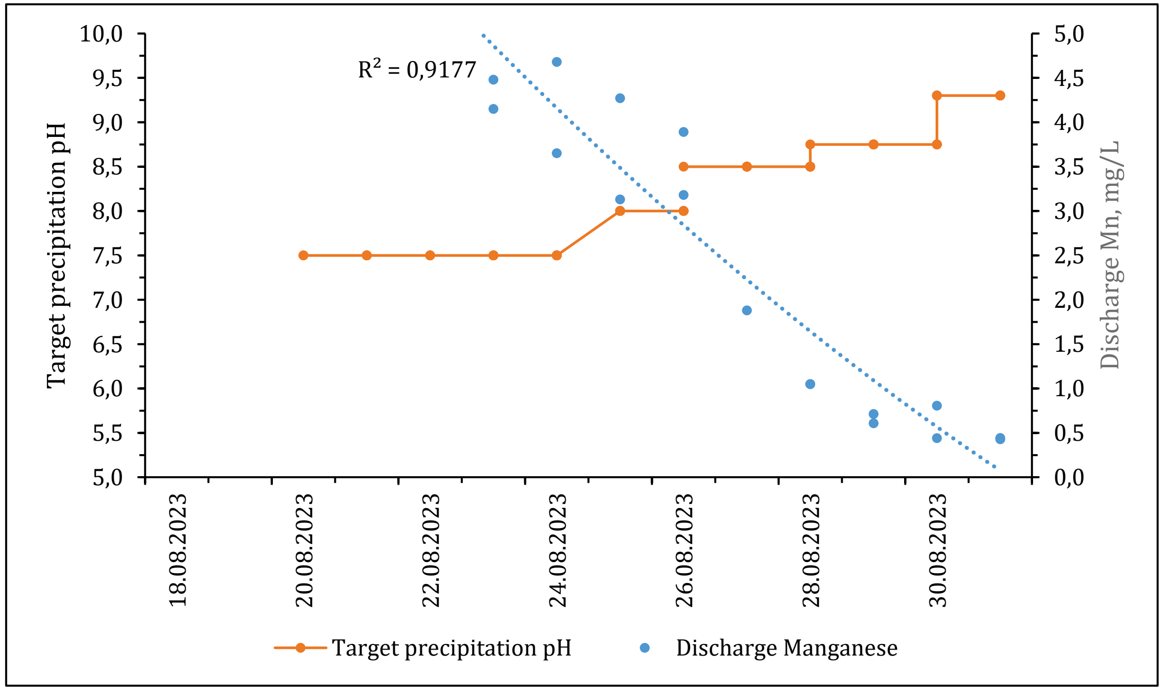
>85.1% manganese precipitated at >pH 8.5

at >pH 8.75, <1 mg/L manganese in discharge

- Process may need optimising

If <<1.2 mg/L manganese required in discharge,

treated water may require pH correction to meet anticipated environmental permit requirements



High Density Sludge Tests – Lime Use

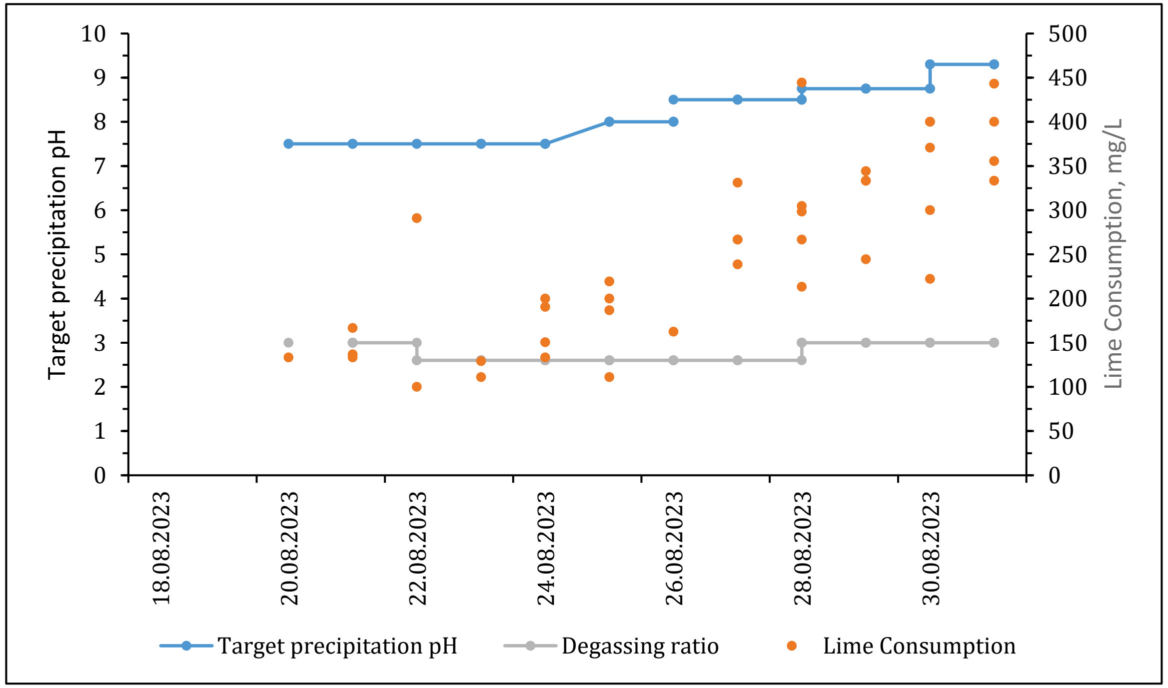
Lime consumption varied:

- To achieve precipitation pH
- In response to changes in mine water chemistry (exceptional wet weather!)
- Co-precipitation of $CaCO_3$

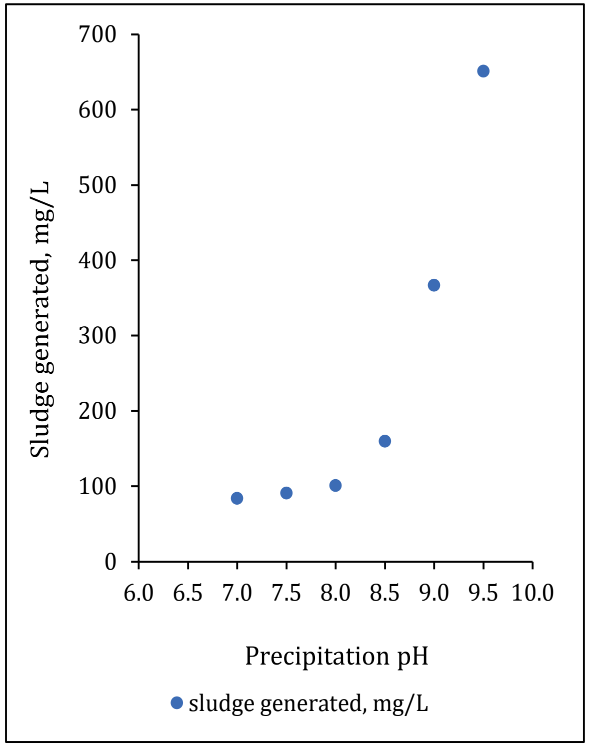
Lime used agreed with design prediction of 300 - 350 mg/L when operating at <pH 8.7

- Equivalent annually 892 - 2207 t hydrated lime

At >pH 8.7 lime use increased due to conversion bicarbonate ions to carbonate ions and precipitation of $CaCO_3$



High Density Sludge Tests – Sludge Generation



Measured indirectly by on site "jar tests"

As precipitation pH increased, mass of solids generated increased

For range pH 7-8 sludge generation was ≈ 90-100 mg/L

- equates to 574 - 637 t/a dry solids from 200 L/s flow

For >pH8 sludge generation increased significantly to 650 mg/L due to co-precipitation $CaCO_3$

- equates to 1009 t/a dry solids at pH 8.5 and 4010 t/a dry solids at pH 9.5

Sludge analysis confirmed $CaCO_3$ co-precipitation at >pH 8, with Ca content increasing from >15% up to 33%

pH	7.50	8.00	8.50	8.75	9.30	9.30
Fe	27.92%	23.07%	8.15%	8.59%	6.86%	6.45%
Mn	0.30%	0.46%	0.62%	0.57%	0.50%	0.49%
Ca	12.10%	14.59%	21.06%	24.26%	33.17%	33.12%
SO_4	1.03%	1.20%	2.01%	2.05%	2.10%	2.10%
OH	13.57%	12.34%	8.98%	7.38%	6.26%	7.80%
CO_3	9.67%	36.18%	36.18%	41.81%	44.27%	42.66%

Conclusions

Raw mine water contained more CO_2 than anticipated in preliminary design

Optimum degassing ratio ≈ 3:1air:water - achieved 50 - 60% decrease dissolved CO_2

Initially lab results suggested optimum ratio between 3:1 and 5:1, trial was at lower end

>99.1% iron removal achieved over range pH 7.5 - 9.3

At pH 7.5 only iron removed and minimised lime consumption to 100 - 150 mg/L

To achieve <1 mg/L manganese in treated water results suggest operating >pH8.75 and required 330 mg/L lime

Lime consumption increased at >pH 8 due to calcium carbonate precipitation

Set of operation conditions for HDS plant for commissioning

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Thank you for listening

Any questions?

The authors would like to thank the organisers and hosts of IMWA 2024 and all the operatives at Severn Trent Services who operate and manage our mine water treatment schemes.

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