Use of natural coagulants to treat industrial wastewater

Prof Chedly Tizaoui & Dr Ed Lester-Card

Water and Resources Recovery Research (WR3) Lab
Department of Chemical Engineering
Faculty of Science and Engineering
Swansea University
E-mail: c.tizaoui@swansea.ac.uk

Content

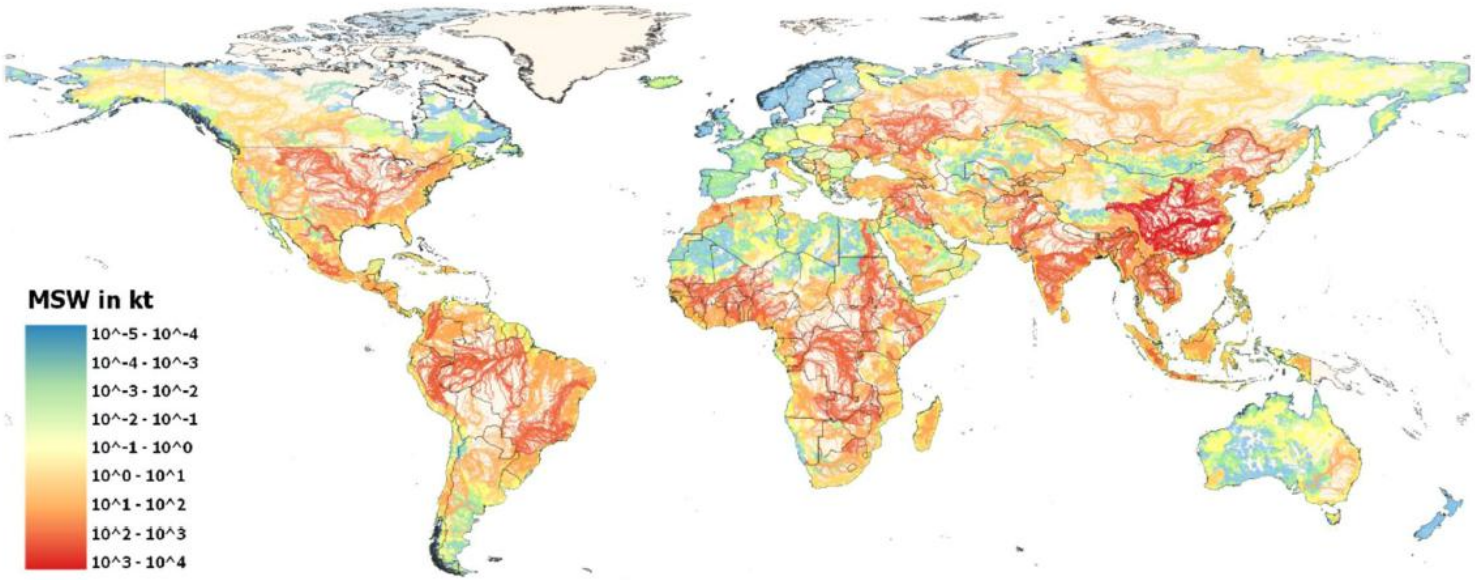
- Introduction: Water pollution – natural coagulants
- Research results – Moringa Oleifera for steel wastewater
- Research results – Aloe vera for sewage sludge
- Conclusions
- Questions

Global Water Challenges

UN SDG6

Global Water Challenges: Pollution

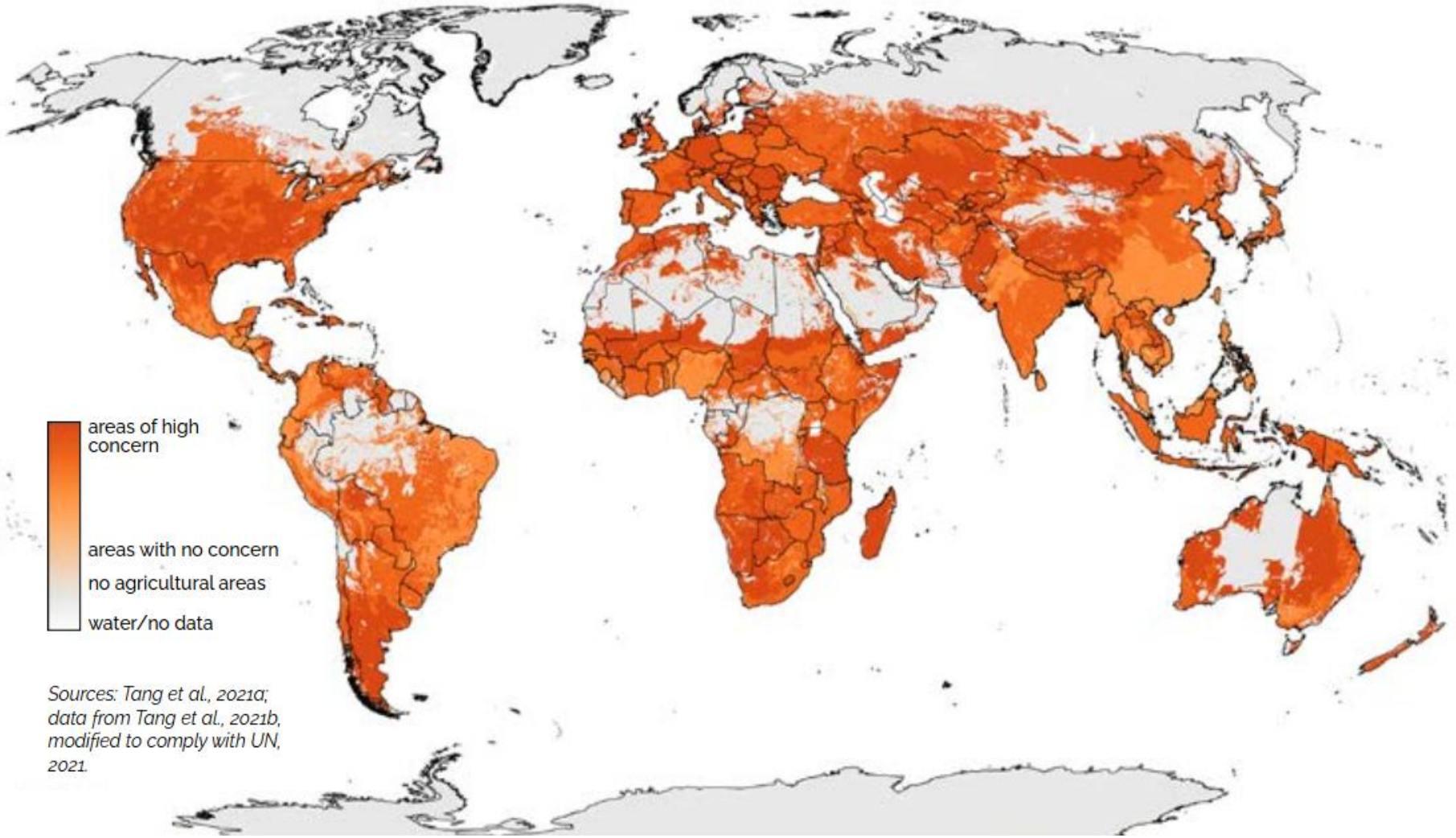
- Water stress is driven by factors beyond the physical abundance of water ➔ **water quality and pollution**
- Water uses (agriculture, industry, municipal) result in water pollution
- Currently, **80%** of the world's wastewater is discharged back into the environment without any treatment
  ➔ Causing widespread damage to ecosystems and contamination of critical human sources
- Polluters expose themselves to regulatory and reputational risks
- High operational risks and increased water treatment costs
- Investors are increasingly considering water as a **risk factor** when making investment decisions.
- Companies in the US reported $14 billion in water-related impacts in 2016 alone



Gómez-Sanabria & Lindl, The crucial role of circular waste management systems in cutting waste leakage into aquatic environments, nature comm, 5443 (2024)

Water pollution from agriculture

MAP S.11 **GLOBAL REGIONS OF CONCERN (GLOBAL AREAS SUSCEPTIBLE TO PESTICIDE POLLUTION)**

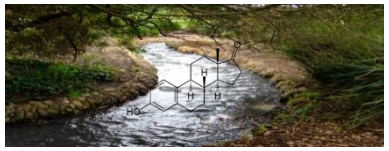


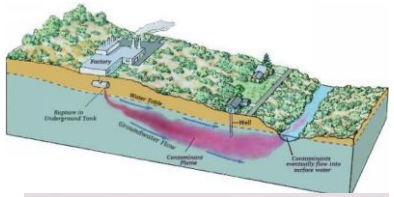
FAO, *The state of the world's land and water resources for food and agriculture: Systems at breaking point (SOLAW 2021). Available at: https://www.fao.org/land-water/solaw2021/en*

Water pollution

- Biodegrade (e.g. aspirin)
- Partial biodegradation (e.g. penicillins)
- Persist (e.g. clofibrate, triclosan, triclocarban)

Conventional WWTPs are not designed to eliminate micropollutants.



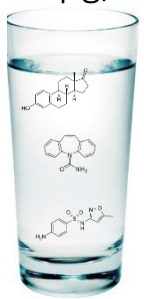


Threats to wildlife and aquatic system

Further treatment?

Human exposure to MPs via fruit and vegetable ~ 9.8 µg/P.week

>1µg/L



☞ Accumulation in food products threatening human health through the food chain
☞ Can also induce changes in plant hormone level, thus impacting plant health

Water pollution

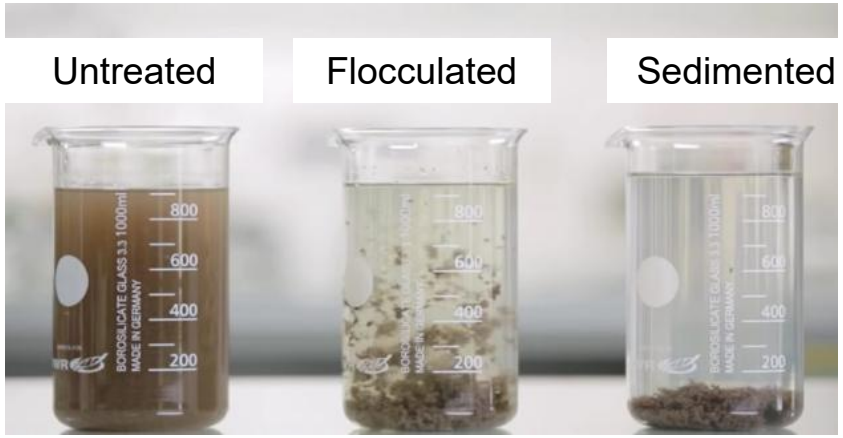
Serious water pollution incidents up 60% in England, Environment Agency says

https://www.bbc.co.uk/news/articles/cg5zl75dmm0o

But storm overflows let sewage spill for 3,614,428 hours in 2024, slightly up on 2023's 3,606,170 hours, and a record high.

Campaigners from Surfers Against Sewage are calling for transformational reform of the water industry (Matt Alexander Media Assignments/PA)

Flocculants in wastewater treatment



- **Conventional chemical coagulants/flocculants**
  - Ferric chloride
  - Polyaluminium chloride (PAC)
  - Synthetic organic polymers
  - Low cost
  - High dosages, accurate pH control, concerns around monomers, Al and sustainability

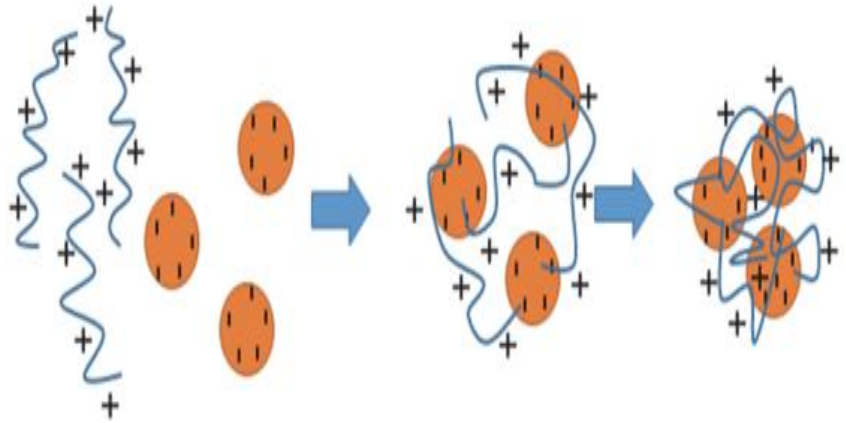
- **Natural bio-flocculants**
  - Chitosan, cellulose, tannin, Moringa oleifera, Aloe vera…
  - Sustainable, environmentally friendly, efficient, harmless, biodegradable, no secondary pollution
  - Sludge can be degraded by microorganisms

- **Grafted flocculants**
  - Synthetic polymers (polyacrylamide) + natural polymers (grafted starch).

- ➔ natural and grafted bioflocculants have huge potential to replace inorganic metal salts in WWT

Natural bio-flocculants – mechanisms

- Destabilise the colloidal particles by reducing zeta potential of particles
- Adsorb counterions to neutralise the particle charge
- Direct-flocculation (i.e. dual function – neutralises the negative charge and bridges the aggregated particles together to form densely packed flocs)➔ less volume of sludge



Natural bio-flocculants – Challenges

- Short shelf life ➔ suitable control is needed
- Flocs loose stability with time due to biodegradability
- Hydrolysis of certain groups along the main chain
- Variable composition

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Faculty of Science and Engineering

Dr Ed Lester-Card

Work

Senior Process Engineer - Arup

Education

Swansea University - EngD, MEng, AMIChemE

Career to Date

Water & Wastewater treatment background

- Swansea University/Tata Steel – EngD, Separation and Minimisation of Residual Oil
- USW – Microbial reactors
- Hydro Industries – Range of industrial treatment process design
- Severn Trent – In-house design focused on sewage plant upgrades

ARUP

Swansea University Prifysgol Abertawe

TATA STEEL

EPSRC Engineering and Physical Sciences Research Council

Cronfa Gymdeithasol Ewrop European Social Fund

Moringa Oleifera – A green Approach to Treating Oily Steelworks Wastewater

Oily Wastewater (OWW)

- Oil is commonly used as a coolant and lubricant for industrial machinery
- 52 tonnes of hydrocarbons discharged to water at Tata Steel UK 22/23 (Tata's Sustainability report)
- Oil concentrations vary in steel wastewater, literature values range from 20-550 mg/L

<u>Treatment Methods: Coagulation-Flocculation</u>

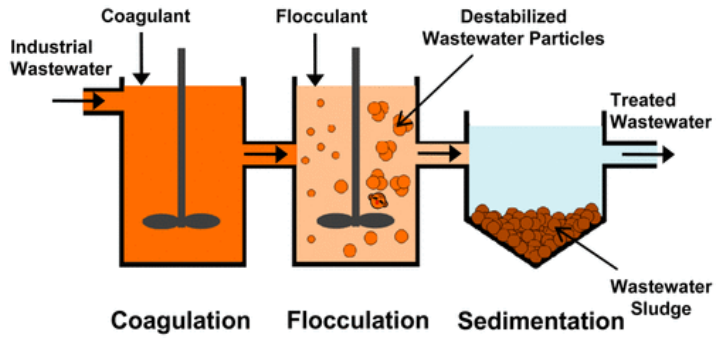
- Targets primarily emulsified/dispersed waste oil

- Oil droplets in water can be: free (150μm≥), dispersed (20-150 μm), emulsified (≤20 μm) or dissolved (≤5 μm)

- Common chemicals: metal salts (Fe/Al) and Synthetic Polymers

Drawbacks:

- Reliance on metal salt supply
- Harmful residue metals or acrylamide
- Hazardous by-product sludge
- H&S considerations



Coagulation-flocculation process

Moringa Oleifera – A green Approach to Treating Oily Steelworks Wastewater

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Moringa Oleifera (MO) Coagulant

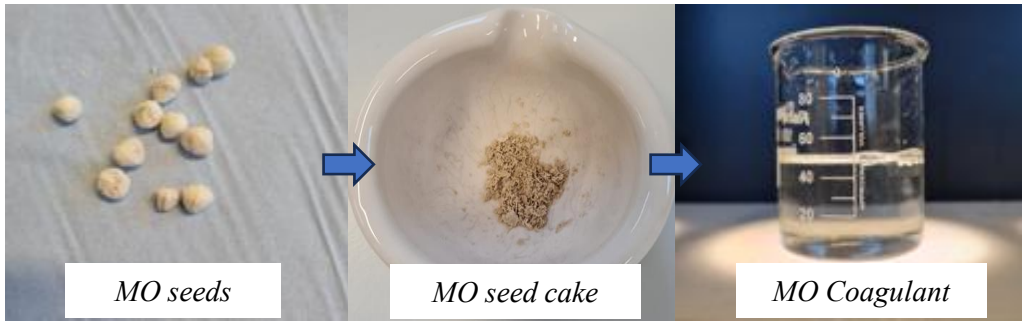
- Considered a multi-purpose tree, the seeds are rich in proteins and oil
- Moringa products are sold world-wide e.g. food supplement
- Early literature reported villagers in Sudan would use Moringa seeds to clarify river water
- The proteins in the seeds are cationic and can be used as a coagulant-flocculant

Shelled MO seeds

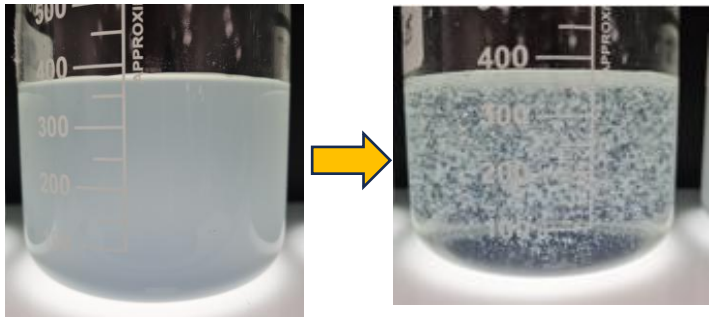
MO seed oil

Extraction of Coagulating Agent

- De-shelling, oil extraction, protein coagulant extraction
- Protein content of the seed cake 25g/100g (Bradford & Lowry assays)



Moringa Coagulant Extraction



Breaking an oil-water emulsion with Moringa

FTIR

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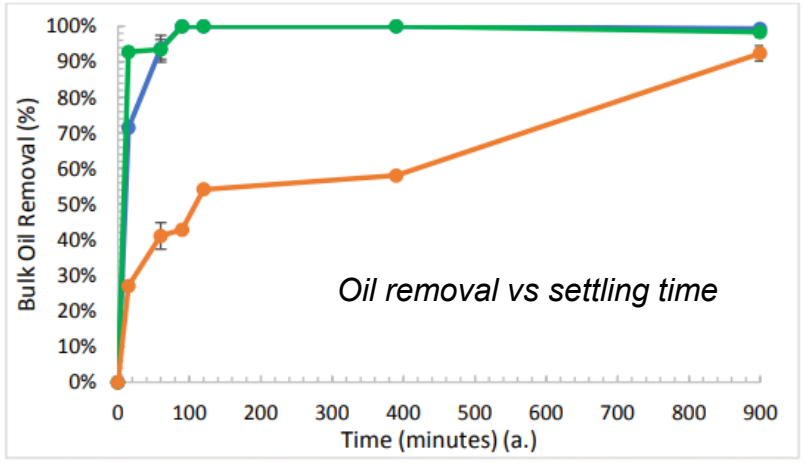
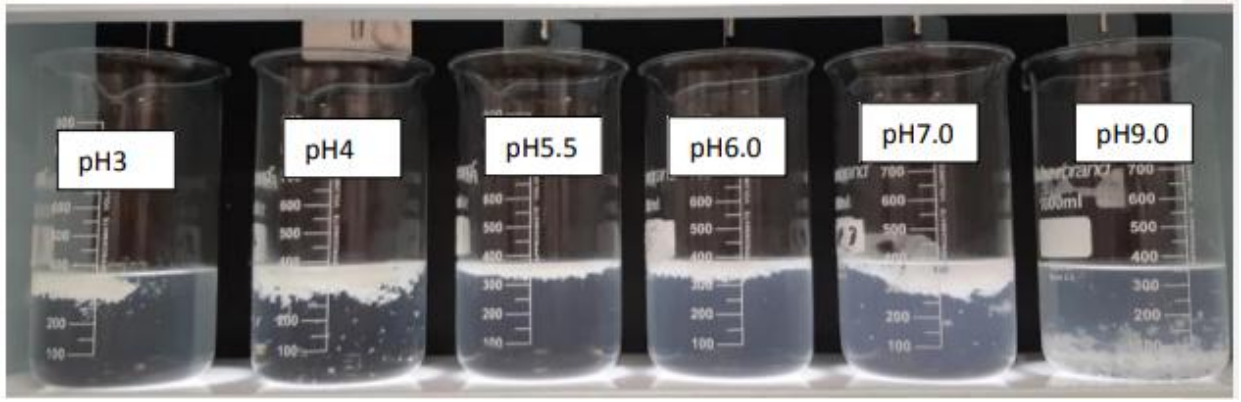
Comparing Moringa to conventional coagulants

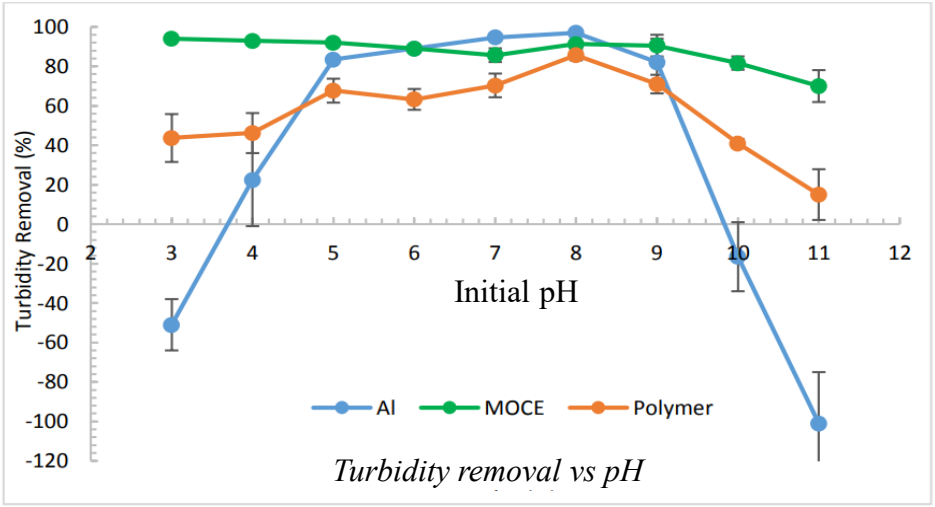
Jar test experiments

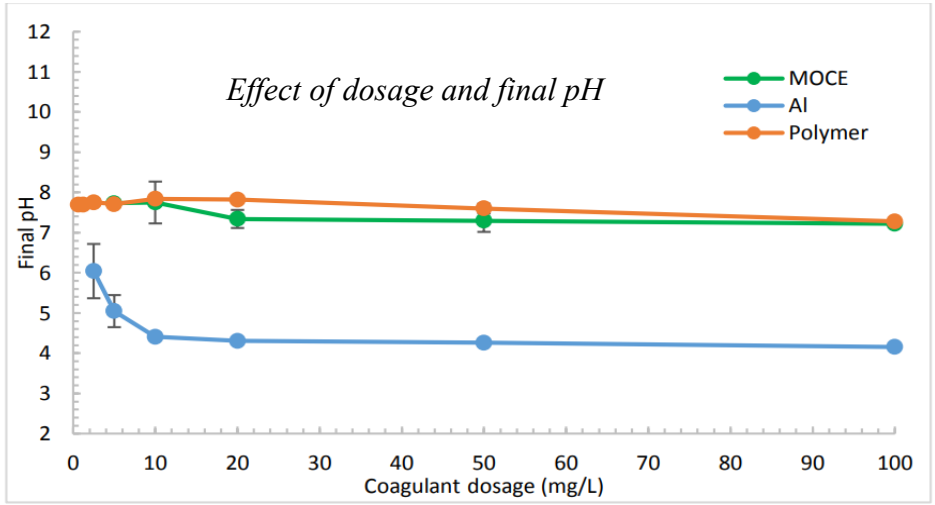
- Compared MO to Alum and Synthetic Polymer
- Moringa demonstrated rapid oil removal
- High removal rates across a wider pH range – Sweep Mechanism
- No post-treatment pH correction required – (noting: Alum consumes alkalinity)

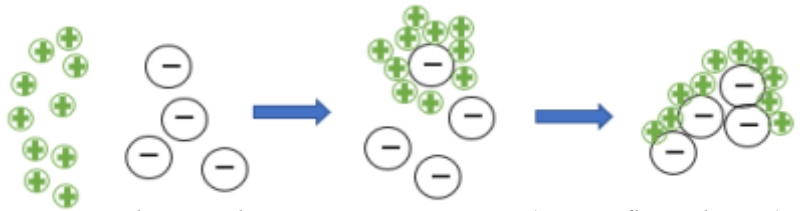




Moringa as a coagulant over a range of pH's







Oil Enmeshment in a precipitate (sweep flocculation)

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Steelworks Wastewater and Summary

- Tested hot mill and annealing plant wastewater
- Reduce polymer usage (67%) by blending with Moringa, providing a synergistic effect
- Polymer coagulants contain acrylamide, which is a known carcinogen and neurotoxin

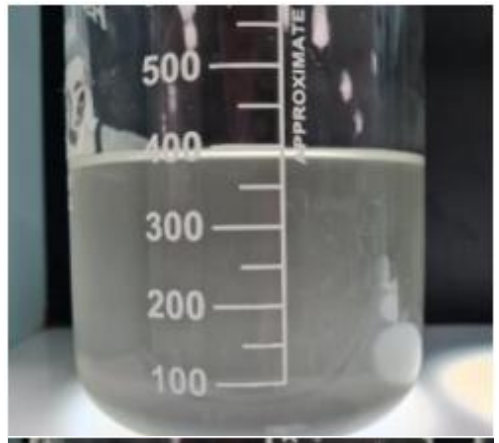
<u>Summary</u>

Moringa offers a range of benefits

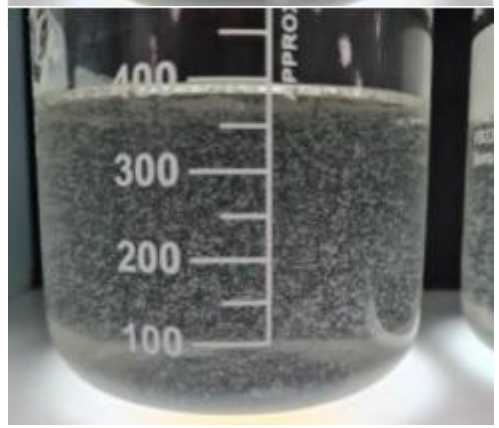
- Rapid oil removal
- No significant changes in initial pH
- Wider pH window of operation and effective at more extreme pH's
- Comparable removal efficiencies to conventional coagulants
- Can be combined with conventional flocculants at reduced dosages
- Safer to handle & non-toxic

Moringa at different dosages on hot mill wastewater

Annealing Plant OWW



Floc Formation



Fully settled

Aloe Vera (gel) for wastewater sludge treatment and odour removal

Aloe Vera (gel) for wastewater sludge treatment and odour removal

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Green rind: protective outer layer

Latex layer: bitter, yellowish

Gel: clear part (99.5% water)

- ➔ Polysaccharides, monosaccharides (glucose and mannose), vitamins, amino acids, protein, phenolic compounds
- ➔ Polymers give the gel its coag/floc properties
- ➔ Glyco-aloe-modinanthrone and tannins responsible for coagulation/flocculation
- ➔ High fibre content promotes adsorption
- ➔ Polysaccharide functional groups (carboxyl, hydroxyl, amine) and hydrogen bonds promote flocculation
- ➔ Hydroxyl and carboxyl groups promote metal binding
- ➔ Sludge dewatering due to the presence of Ca^{2+} and K^{+}, which have good water holding capacity, in the aloe mucilage

Aloe gel for wastewater sludge treatment and odour removal

Context:

- Find alternatives to expensive cationic polymers to dewater MWWT sludges
- Reduce/eliminate odour from treated sludge

Solution:

- Aloe gel was evaluated as a bioflocculent to enhance gravity settling of the sludge
- Evaluate the effect of aloe gel on settling and produced sludge
- Evaluate the effect of aloe gel on odour removal

Aloe gel for wastewater sludge treatment and odour removal

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Sludge samples

- Secondary settling tank of activated sludge process
- 400,000 people equivalent plant + industrial WW (textile, slaughterhouse and food wastewater)
- 20 L plastic jerry cans to fridge

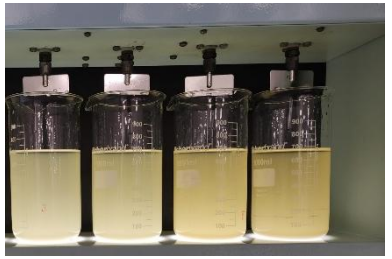
Measured parameters	Unit	Recorded values
pH	–	7.15 (at 25 °C)
Moisture content	%	84 ± 1
Total solids content (TS)	$g \cdot L^{-1}$	33 ± 1.2
Suspended solids (SS)	%	16 ± 0.5
VSS	$g \cdot Kg^{-1}$	2.6 ± 0.5
TOC	$mg \cdot Kg^{-1}$	473 ± 5
Ammoniacal-nitrogen	$mg \cdot L^{-1}$	400 ± 0.5
Total phosphorus	$mg \cdot Kg^{-1}$	6.53 ± 0.05
COD	mg O_2 L^{-1}	11,200 ± 10

Aloe gel for wastewater sludge treatment and odour removal

Preparation of Aloe gel

- 2-year-old plant
- Gel used fresh immediately after preparation

1, 3, 5, 7 % (V/V)



Aloe gel for wastewater sludge treatment and odour removal

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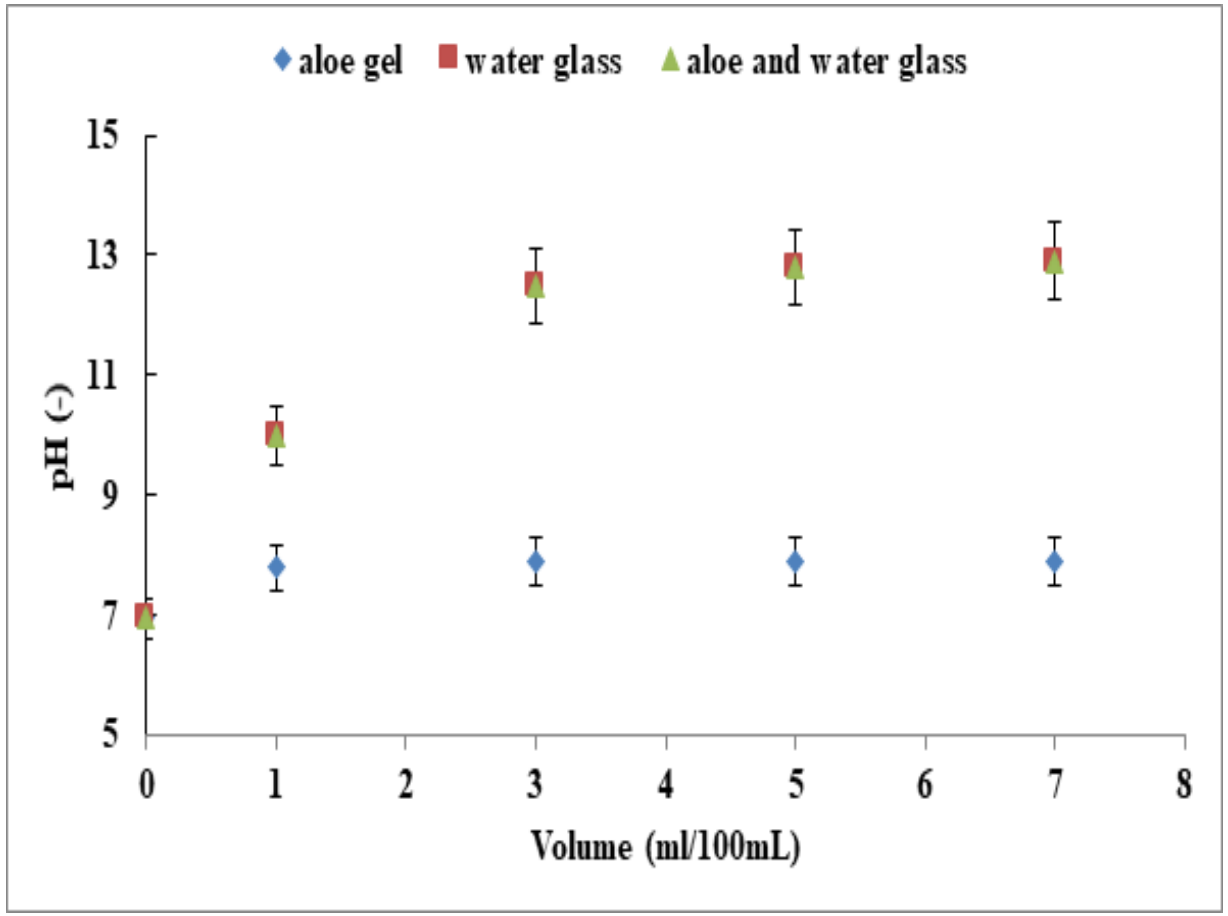
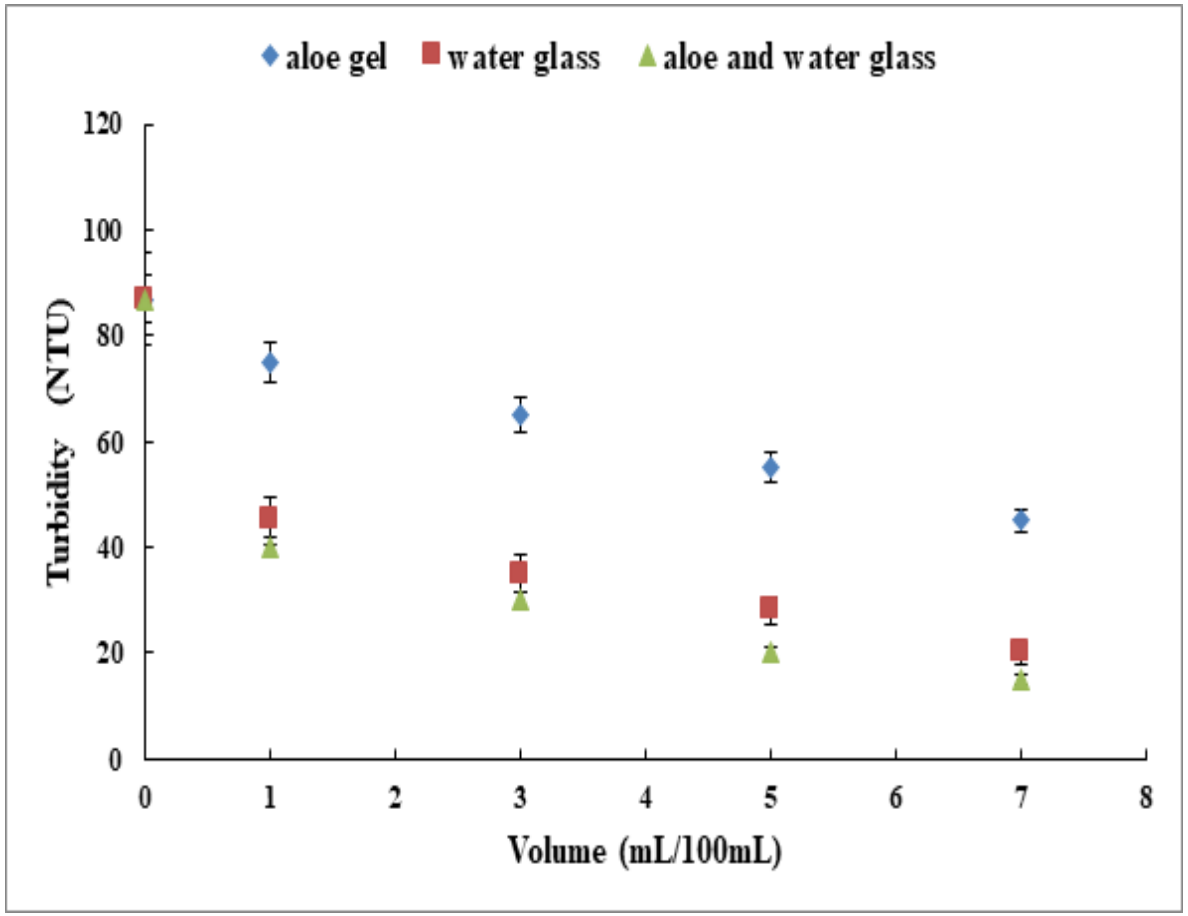
Effect on sludge's pH

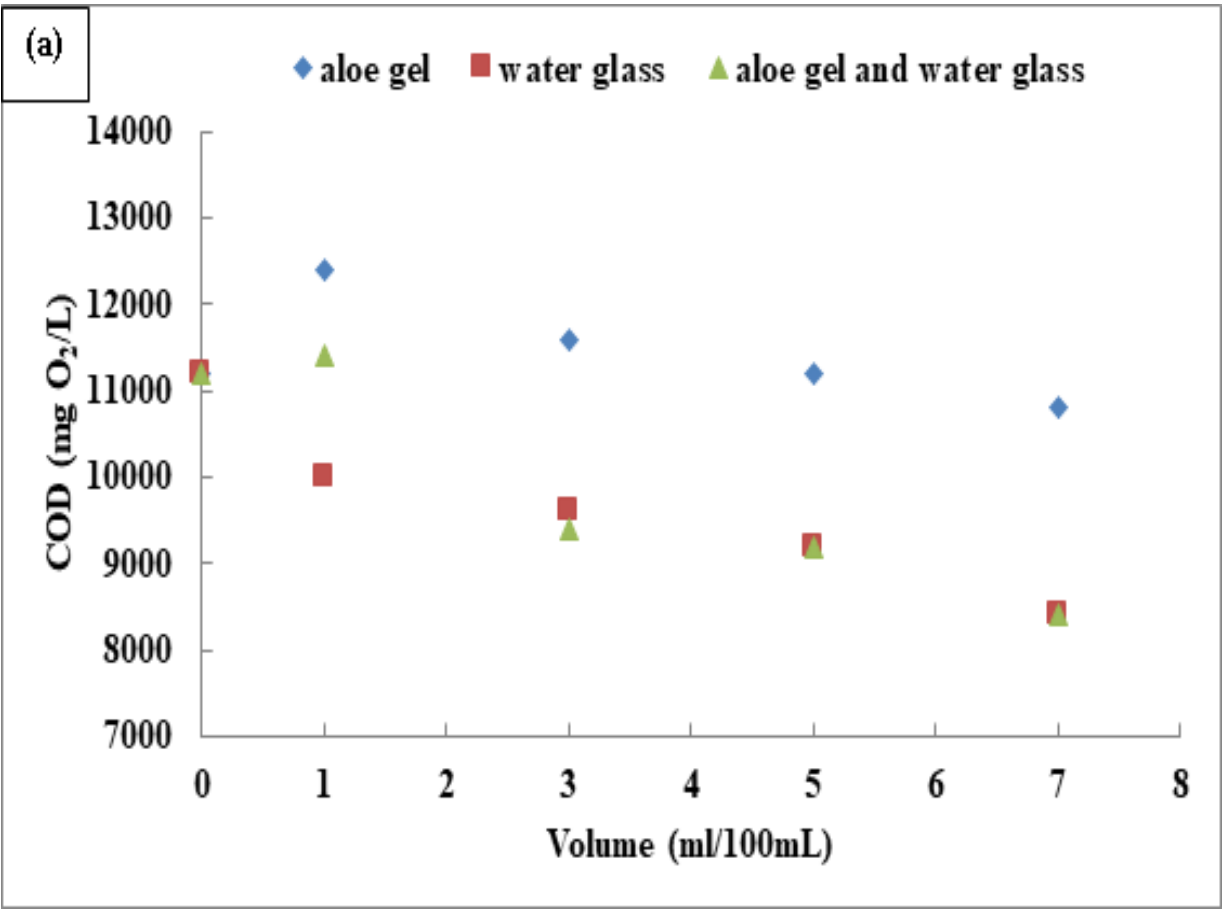


Turbidity removal

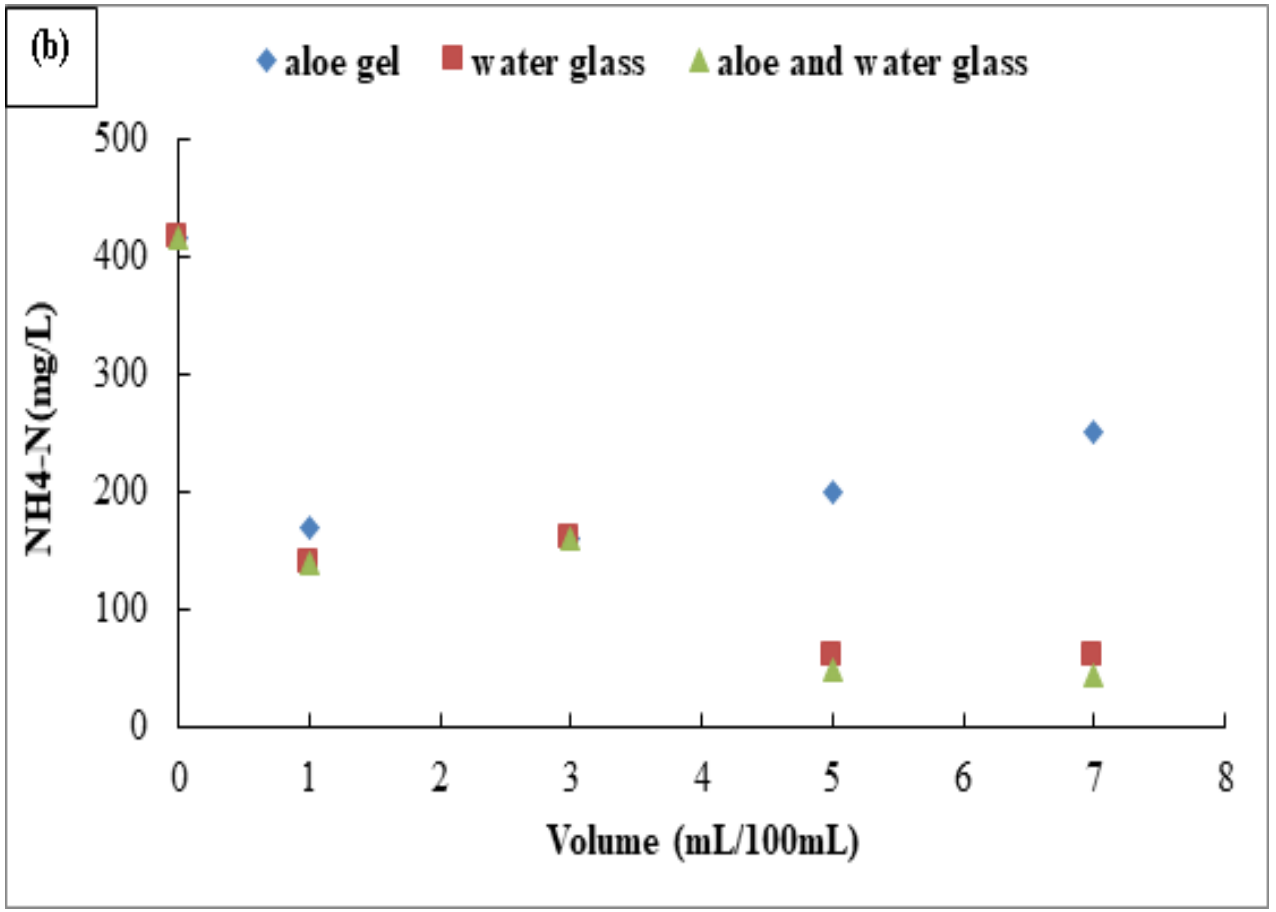


Aloe gel for wastewater sludge treatment and odour removal

COD removal



Ammonia-N removal



Aloe gel for wastewater sludge treatment and odour removal

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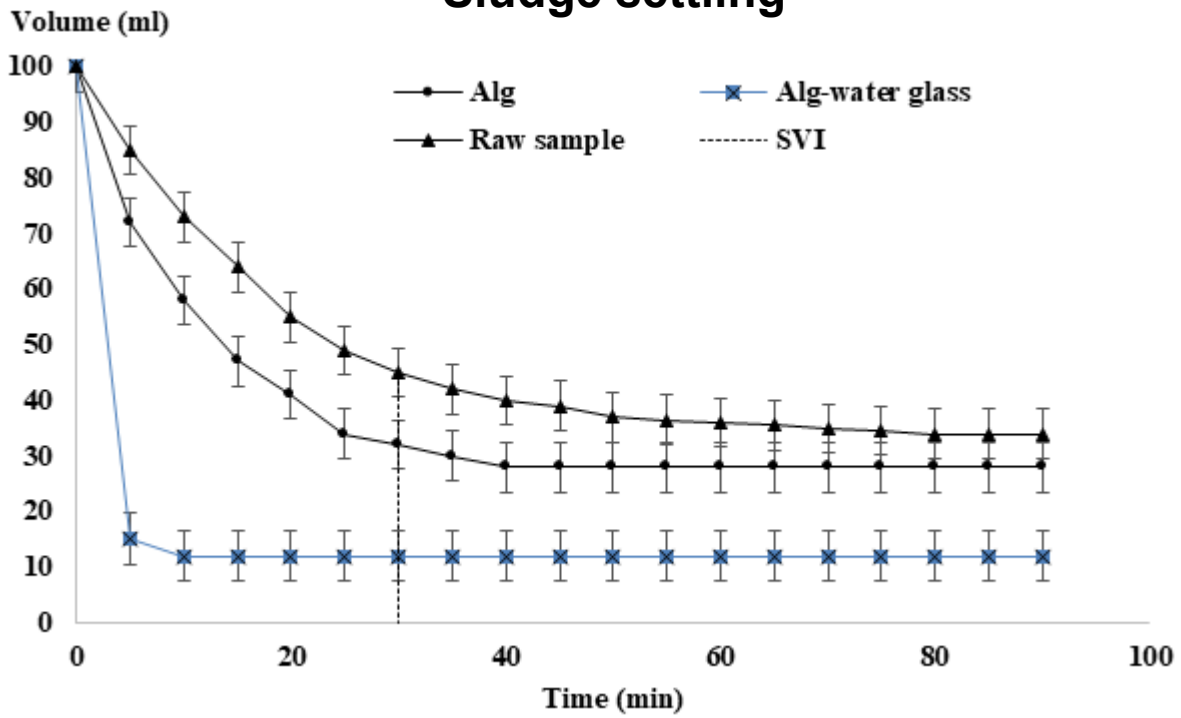
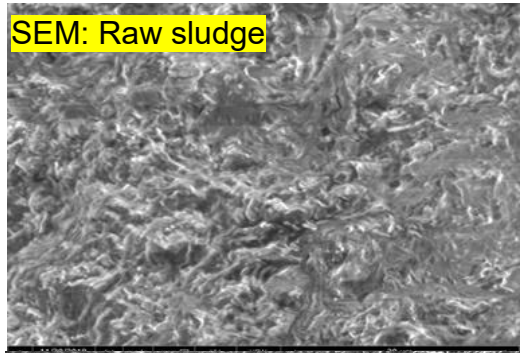
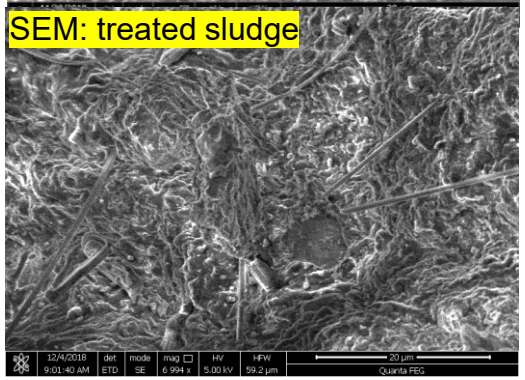
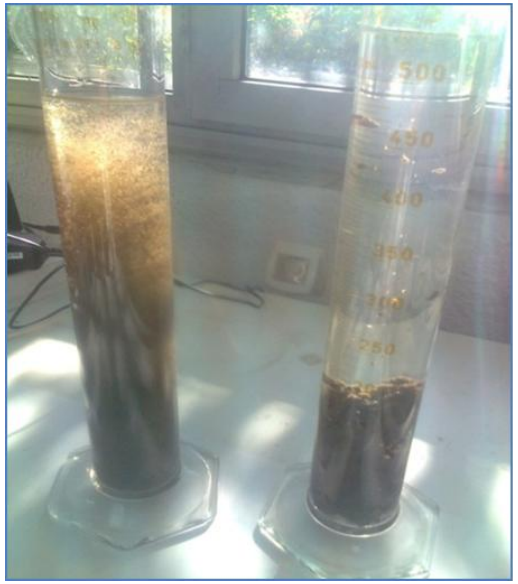
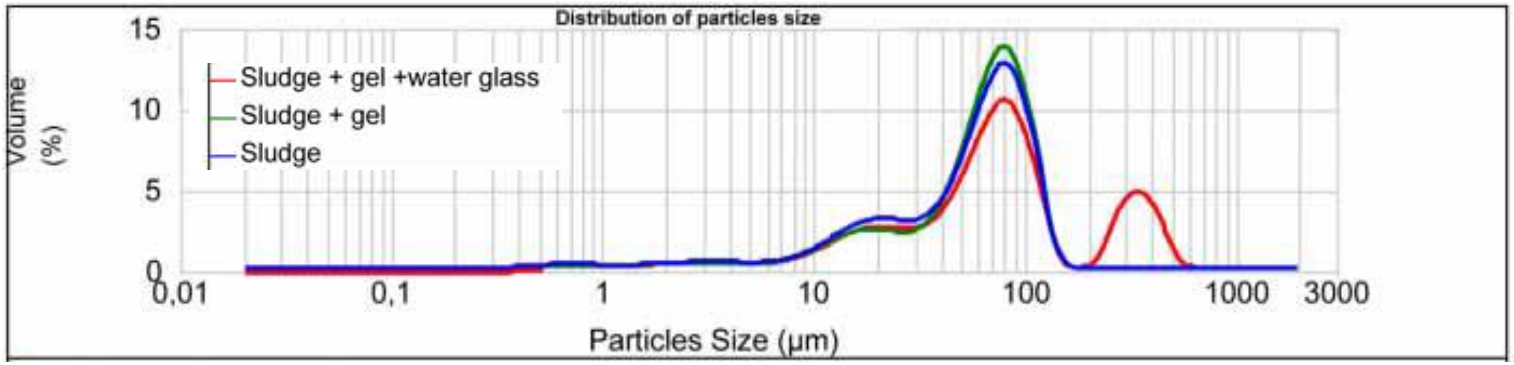
Sludge settling





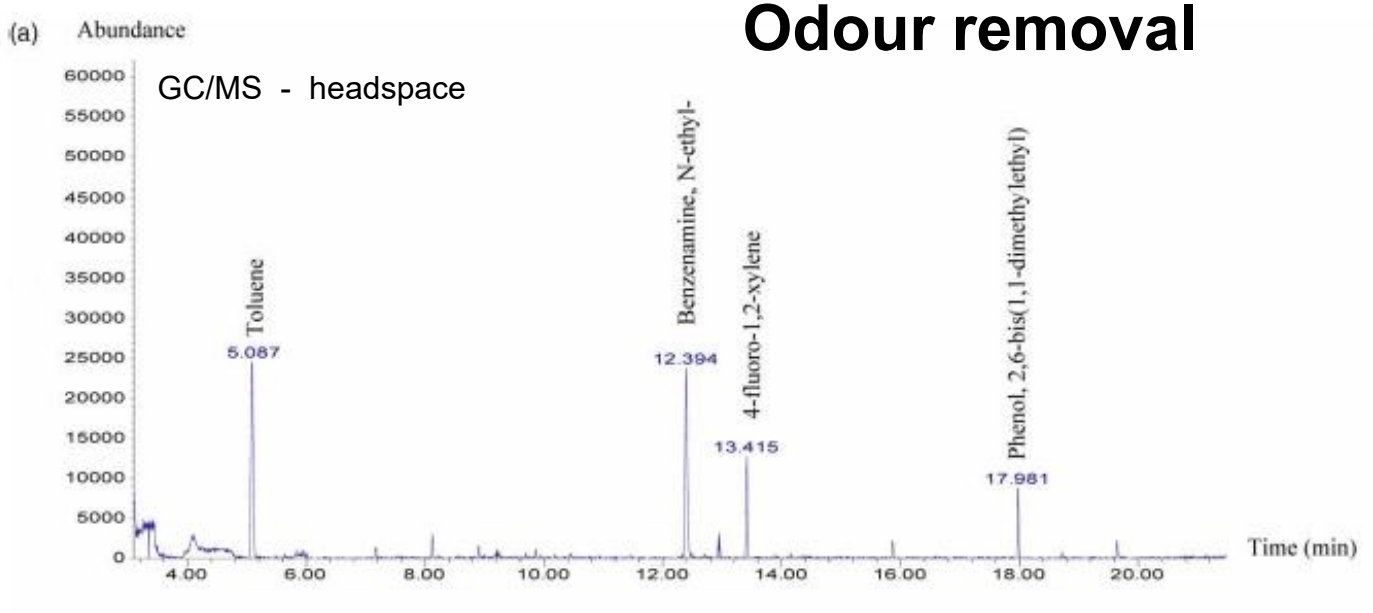




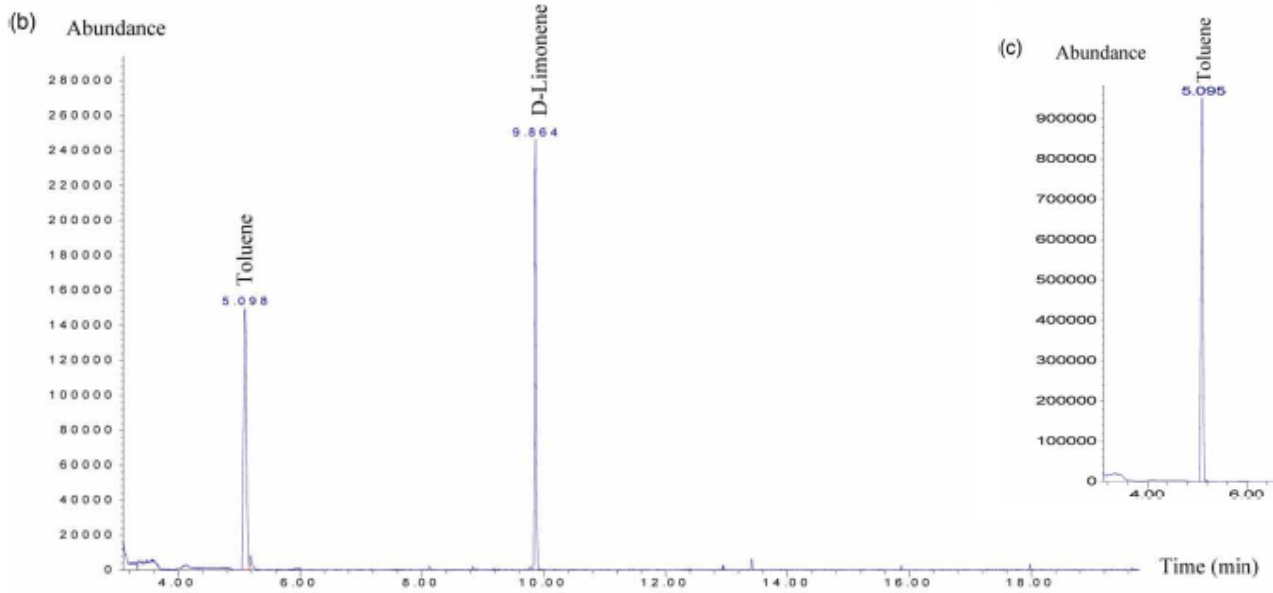


Aloe gel for wastewater sludge treatment and odour removal

Odour removal



Mass spectra of VOCs from:
(a) untreated sludge
(b) Aloe treated
(c) Water glass treated



➔ A human olfactory sensing showed that the twenty people did not detect unpleasant smell from the treated sludge

Conclusions

- Both Moringa and Aloe gel were found effective to exhibit coagulation/flocculation properties
- Effective: to reduce COD, turbidity, ammonia-N, odorous compounds, oil
- No pH changes
- Improved the settling velocity of sludge
- With further research, natural coagulants/bio-flocculants (such as aloe gel, MO) will form important alternative sustainable materials for coag/flocculation in wastewater

Acknowledgement

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TATA STEEL

EPSRC
Engineering and Physical Sciences Research Council

Cronfa Gymdeithasol Ewrop
European Social Fund

Dŵr Cymru
Welsh Water

Llywodraeth Cymru
Welsh Government

CANOLFAN RAGORIAETH SBRI
SBRI CENTRE OF EXCELLENCE

UKRI
Biotechnology and Biological Sciences Research Council

THE ROYAL SOCIETY

Questions

Prof Chedly Tizaoui & Dr Ed Lester-Card
Department of Chemical Engineering
Water and Resources Recovery Research Lab, Faculty of Science and Engineering, Swansea University, Swansea, UK
e-mail: c.tizaoui@swansea.ac.uk