Utilizing waste-derived aluminosilicate for water treatment: Pyrolysis and adsorption modelling

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Presentation Outline

- Introduction
- Experimental Work
- Results & Discussion
- Conclusion
- References

Introduction

E-Wastes: Printed Circuit Boards (PCBs)

- PCBs: platform upon which microelectronic components such as semiconductor chips and capacitors are mounted
- Is a mixture of woven glass reinforced resin and multiple kinds of metal
- Difficult to recycle because of their special physical and chemical characteristics
- Waste electrical and electronic equipment: 30 – 50 million tons/year
- Annual growth rate: 3-5%

Back Street Recycling

Manual sorting

↓

Acid wash/open incineration to recover the metals

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Environmental Issues

Disadvantages of traditional treatment methods

Landfilling

- Landfill gas (CO_2, CH_4)
- Leachate (Heavy metals)

Incineration

- Toxic emission
- (Furan, NO_x, SO_x, dioxin, heavy metals)
- Toxic Ash (Heavy metals)
- Particulates

Partial E-Waste Recycling

Pyrometallurgy Recycling Techniques

- Pyrolysis
- Vacuum pyrolysis

Hydrometallurgy Recycling Techniques

- Acid leaching
- Complex leaching

Biometallurgy Recycling Techniques

- Similar to hydrometallurgy recycling techniques

Green E-waste Handling

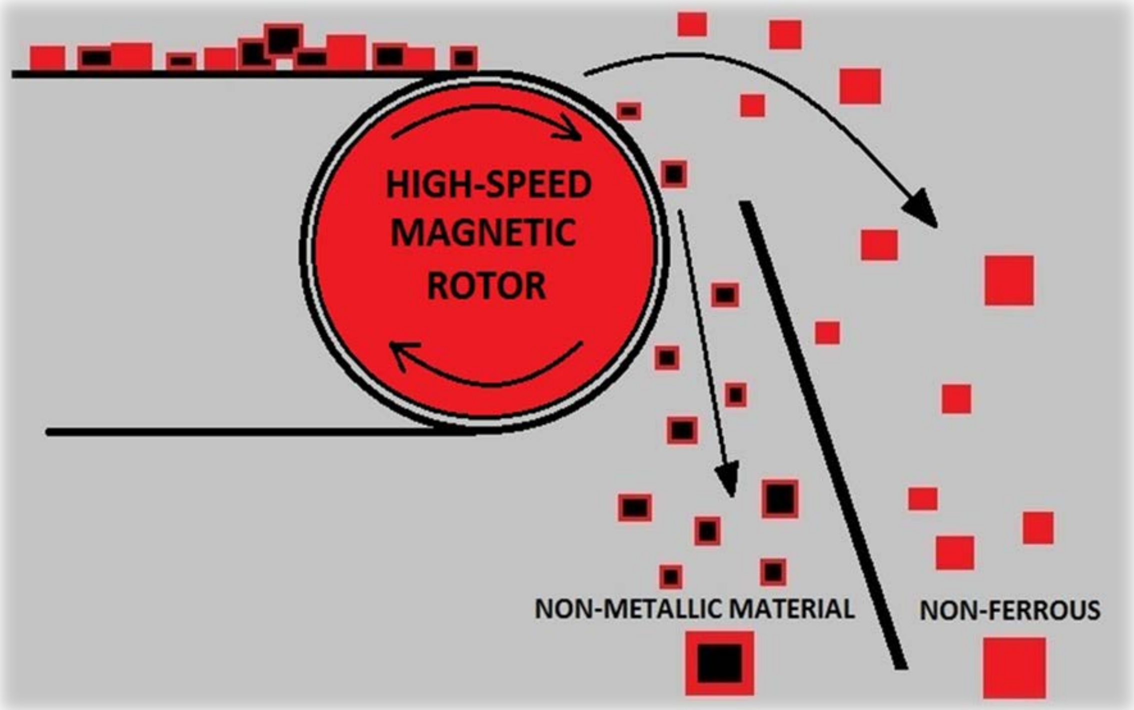
PCB E-waste → Hammermill → High-Speed Vortex Separation

Non-metal powder

Metal Concentrate

70%

30%



Corona Electrostatic Separation

Non-metallic part (NMP) of PCB

- Copper stream → smelting furnaces to recover pure high value copper

- Upto 70% of the non-metallic materials → landfills or zero value-added filler in cement

↓

Mainly consist of thermoset resins and glass fibers → cannot be re-melted or reformed because of their network structure

Total PCB Union Ltd., Hong Kong

Pyrolytic chemical activation of PCB at high temperatures in an inert atmosphere

Calcium aluminosilicate chain is broken down into smaller units → temperature & KOH

Isotherm modelling & optimization studies

RESEARCH OBJECTIVE

Aluminosilicate resin containing free Ca^{2+} & K^{+} available for ion exchange

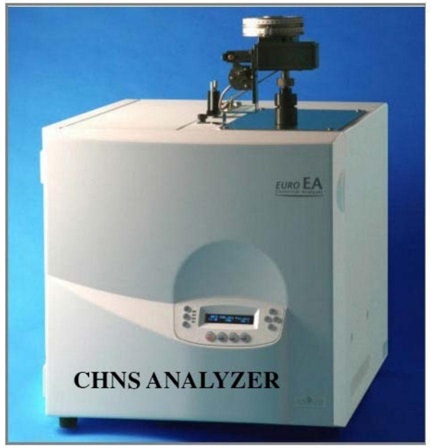
This research focuses on the removal of zinc using the resin

Increases economic value of the waste as the resin can be used for water treatment

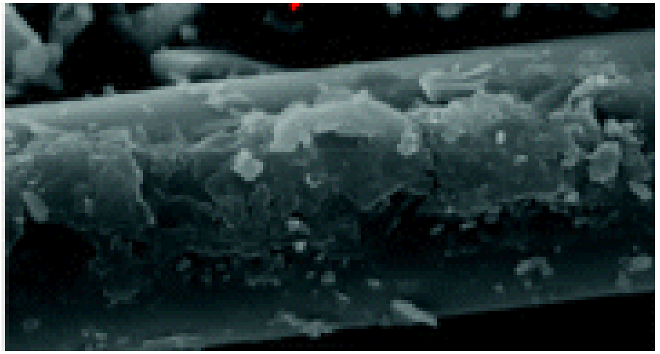
Analysis of non-metallic powder (NMP)

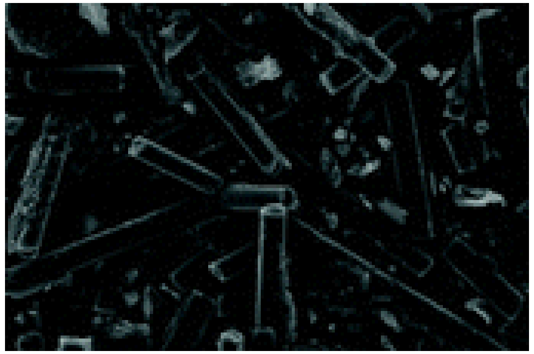
Elemental Analysis

Element	wt%
C	20
N	0.45
S	0.2
H	0.5



SEM Imaging





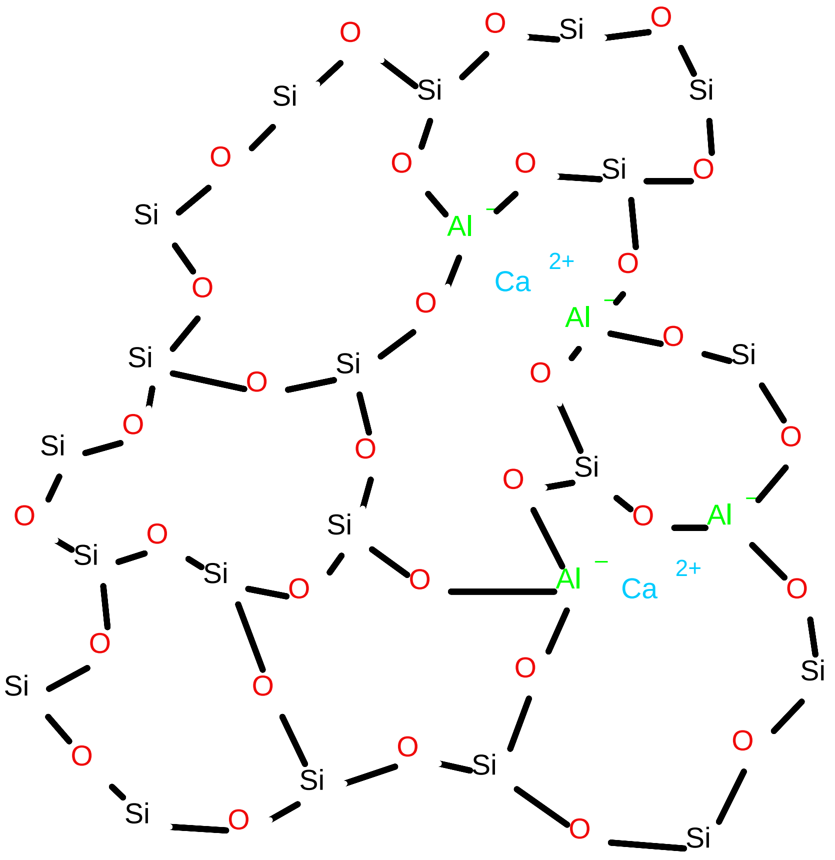
NMP

Experimental Work

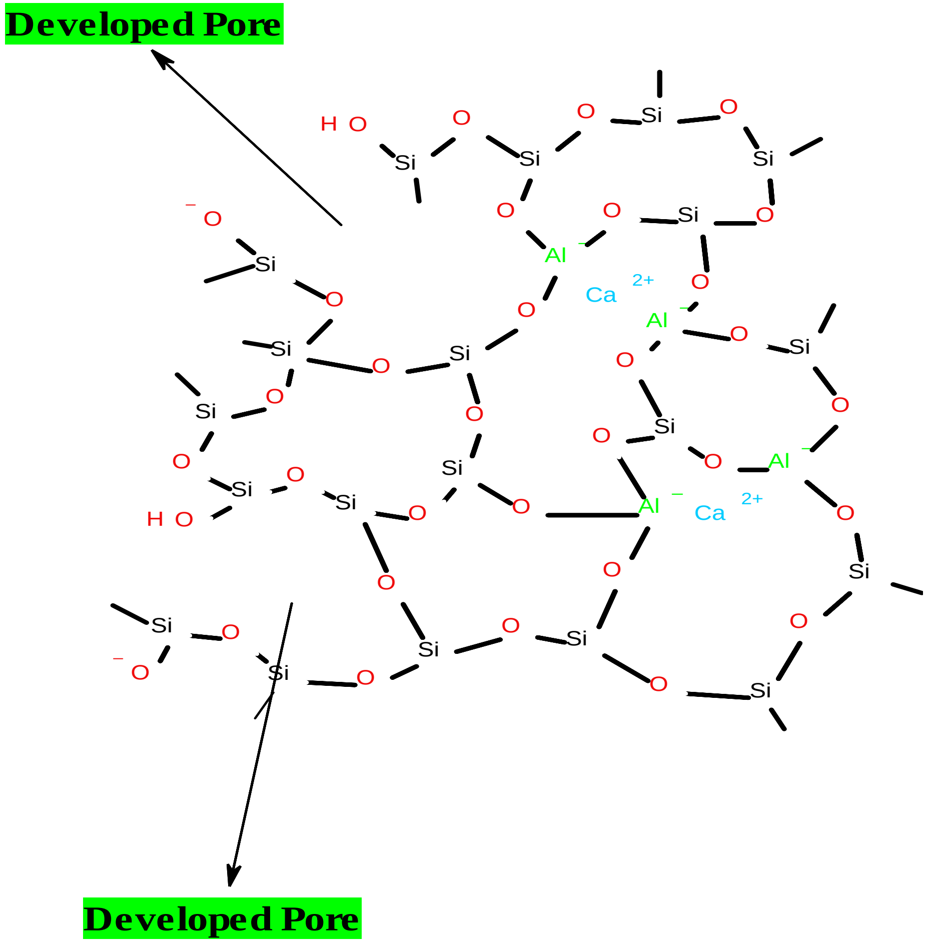
- Impregnation of NMP by KOH
- Carbon removal and activation at 250°C for 3 hrs in a furnace → A-NMP
- Washed and then dried at 110°C

Chemical Activation of NMP

BEFORE



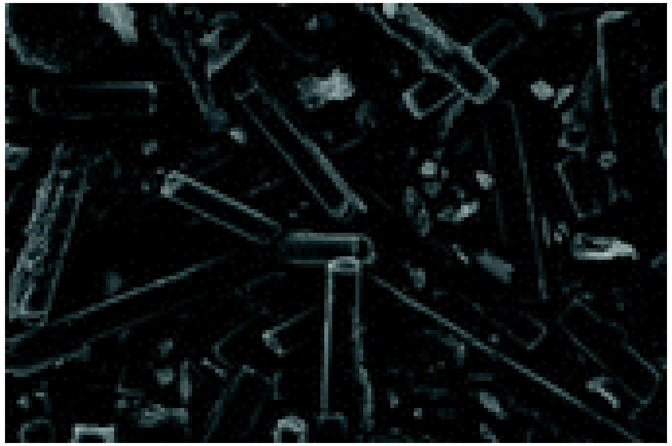
AFTER



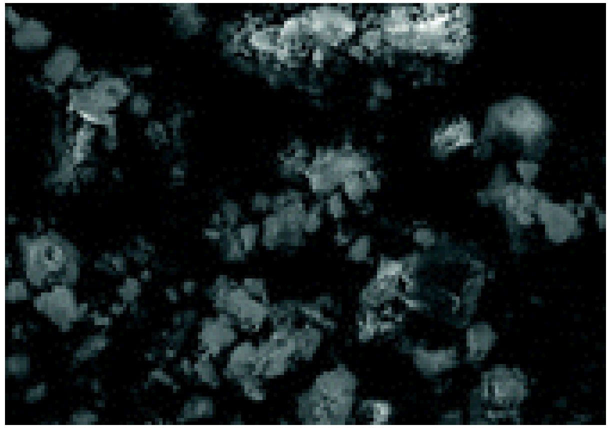
Surface Area Analysis

Sample ID	S_{BET} (m^2/g)	V_{micro} (cc/g)	V_{meso} (cc/g)	V_{total} (cc/g)	p/p_0
NMP	0.9	0.006	0	0.006	0.98
A-NMP	222	0.004	0.738	0.742	0.98

SEM Image



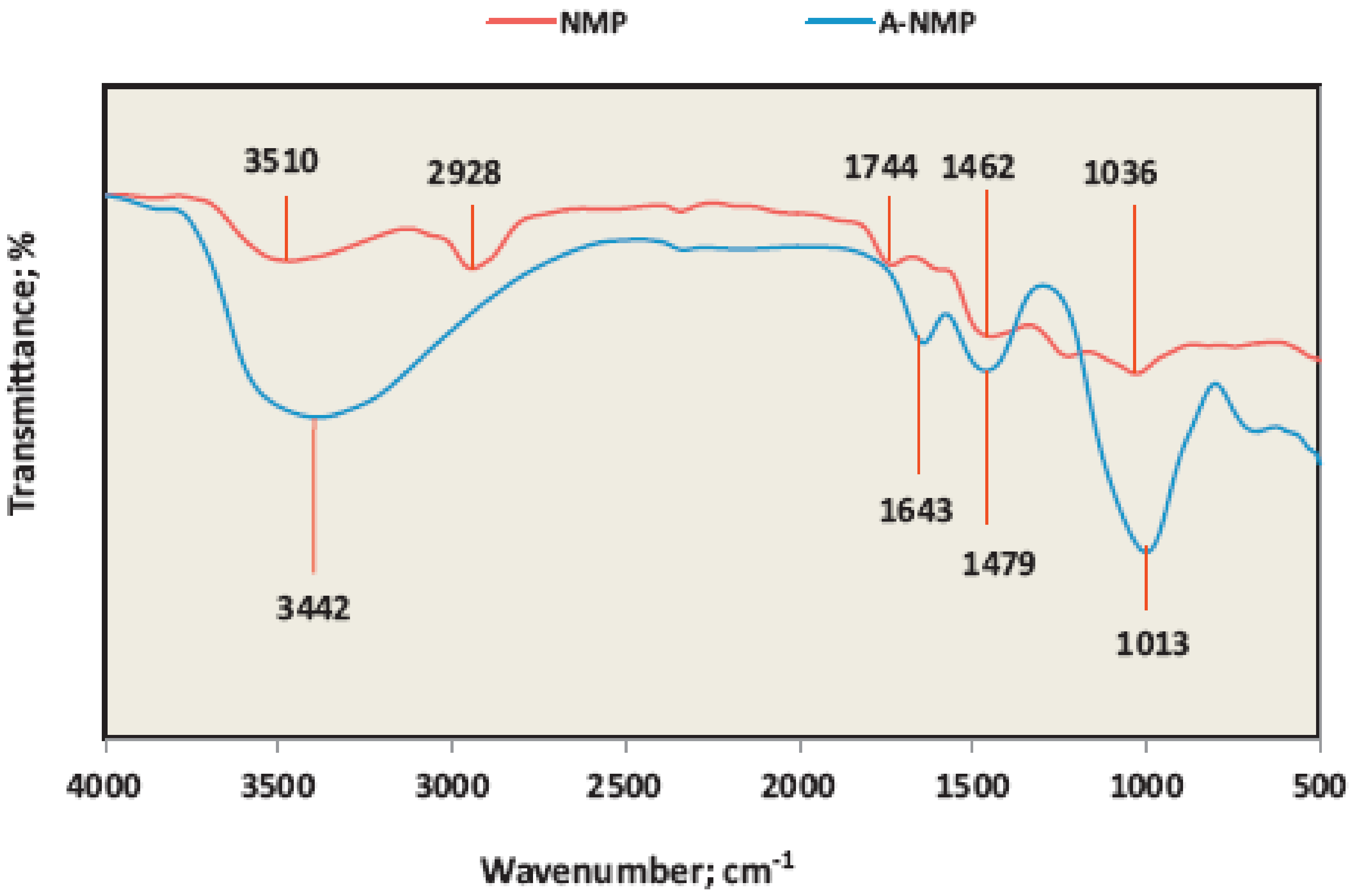
NMP



A-NMP

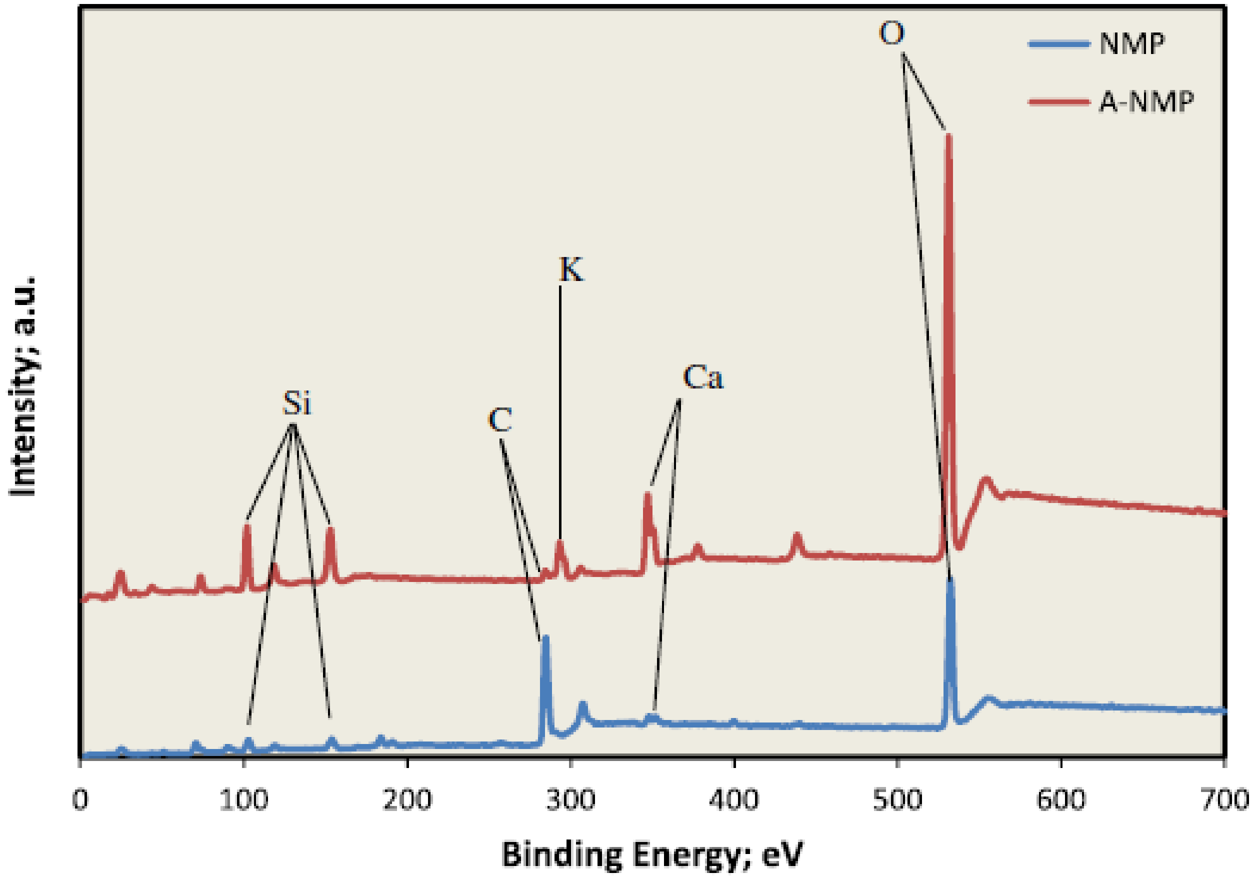
(amorphous, porous)

FTIR spectra before & after activation



2928 for A-NMP: Carbon burn off
1013-1036 for A-NMP: More siloxane groups on the surface and inside pores
3200-3600 for A-NMP: OH Stretching & formation of silanol group

Surface composition of NMP and A-NMP determined by XPS



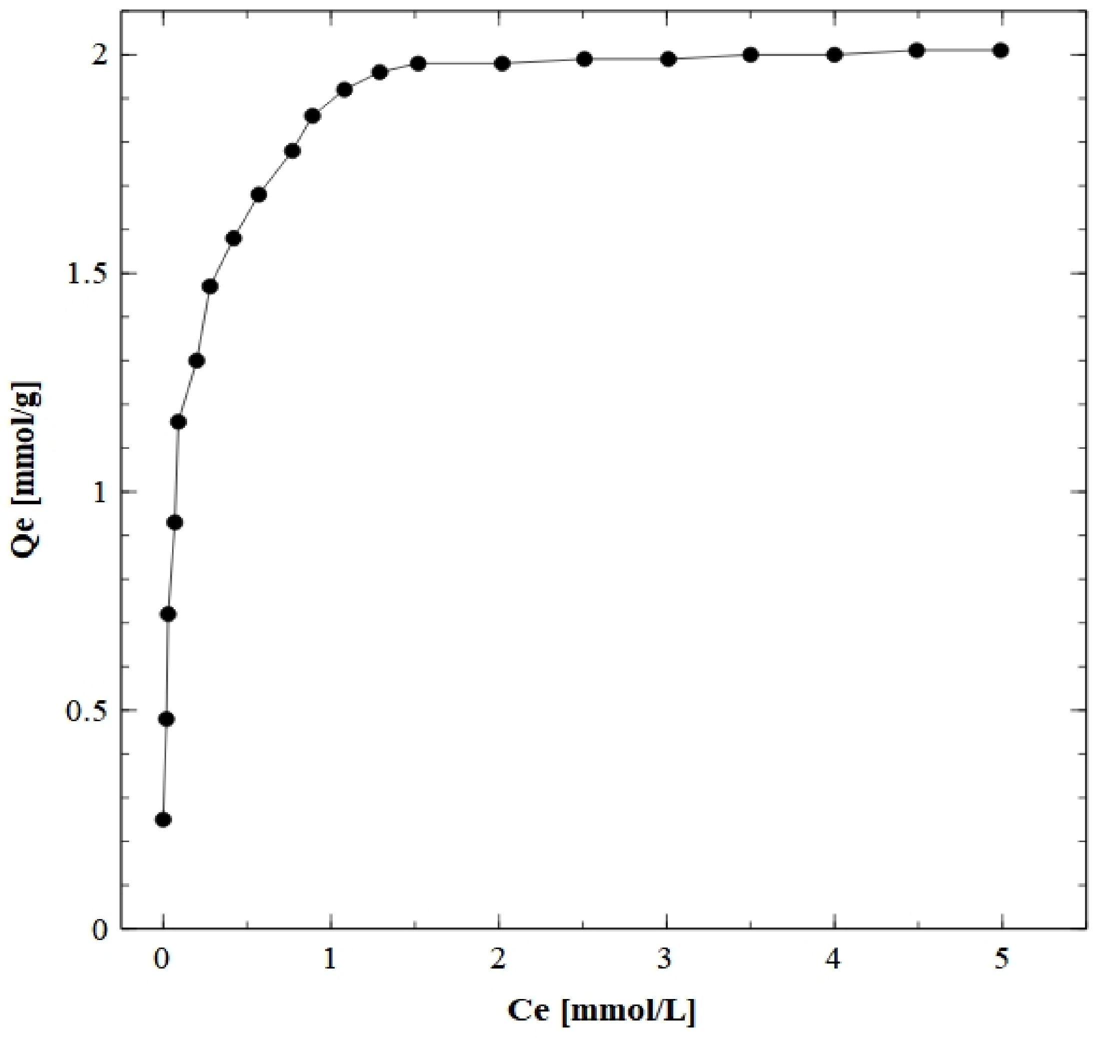
Element	Binding Energy (eV)	% mass	
		NMF	A-NMF
Si (2p)	102.5	11.12	23.65
C (1s)	285	48.06	1.79
K (2p)	293.8	0	12.02
Ca (2p)	347.4	1.14	8.03
O (1s)	531.7	30.12	48.26
Al (2s)	119.2	4.01	5.35

Principal elements in NMF and A-NMF determined by XRF

Element	Elemental Composition of NMF (mol%)	Elemental Composition of A-NMF (mol%)
Al	11.4	10.3
Si	50.6	43.4
Ca	29.7	26.6
Ti	0.10	0.10
Fe	0.10	0.15
Cu	0.60	0.30
Br	2.5	0.00
Ba	0.30	0.20
K	0.00	16.9

Equilibrium Isotherm for Zinc on A-NMF

- 50 mg A-NMF added to 0.5mM to 5mM zinc concentrations (50mL)
- Shaken at 120 rpm at 25°C until equilibrium was reached
- Filtered and pH-adjusted samples were analyzed by ICP-AES



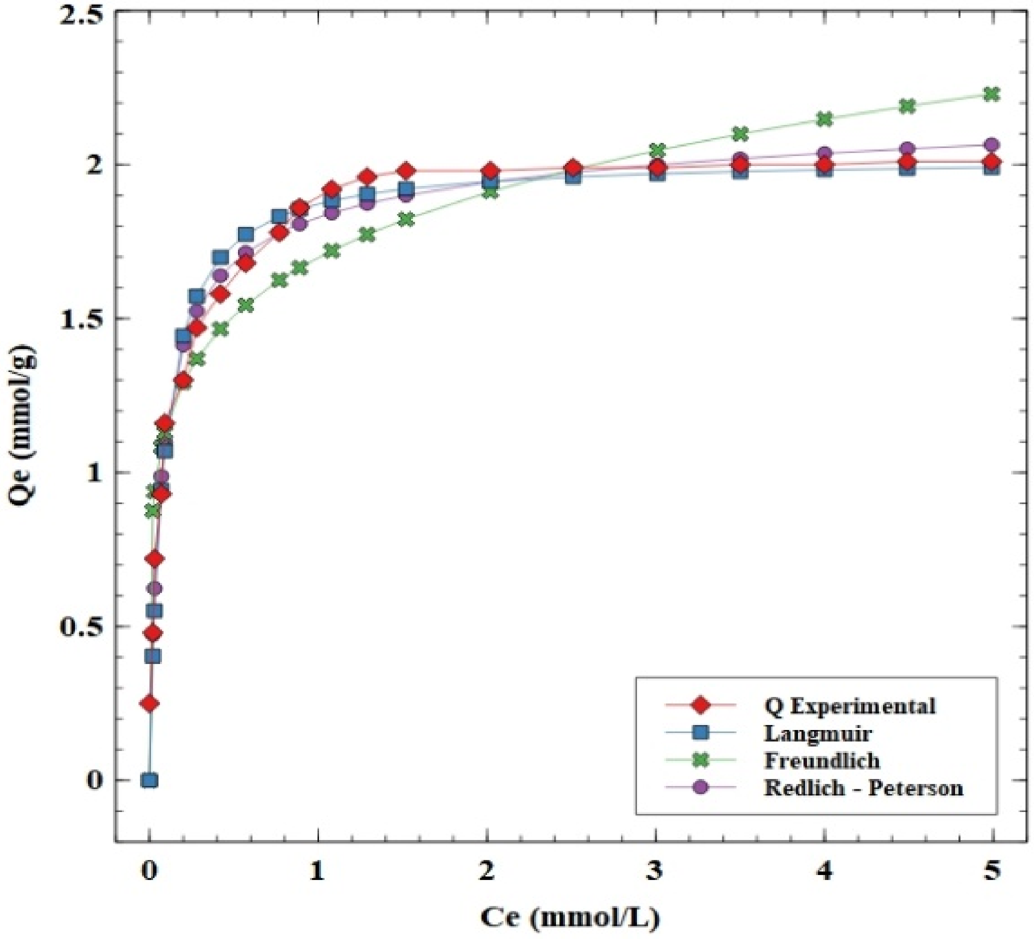
Zinc Adsorption Capacity Comparison Studies

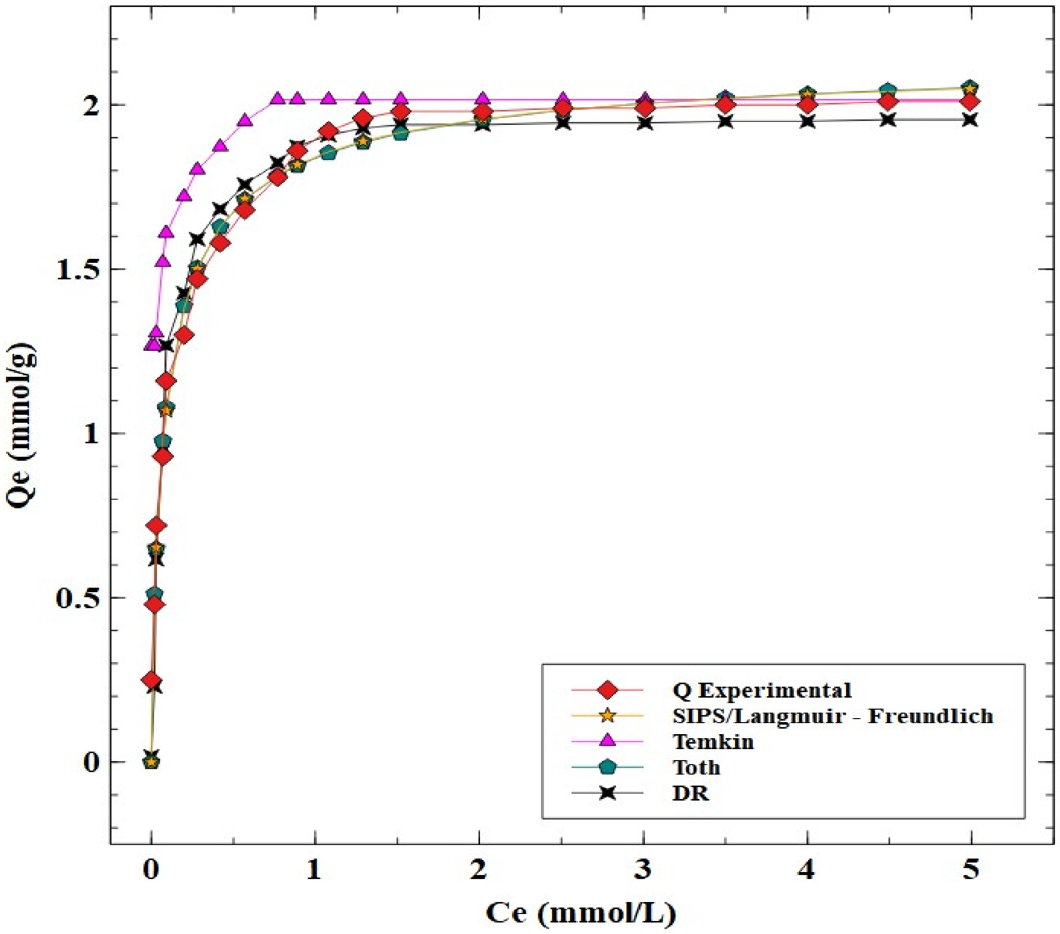
Source of adsorbent	Type of adsorbent	Zinc Adsorption capacity (mmol/g)
Plant	Wood-based granular activated carbon	0.058
Seaweed	Alginate extraction byproduct	0.78
Plant	Hardwood leaf	0.098
Plant	Date stones	0.14
Plant	Water Hyacinth root	0.48
Synthetic	Polyamidoamine dendrimers-decorated silica	0.42
Synthetic	Magnetic chlorapatite nanoparticles	1.18
PCB E-waste (This study)	Ion exchange resin	2.00

Model Isotherms Tested

Isotherm Model	Equation
Langmuir	$q_e = \frac{K_L C_e}{1 + a_L C_e}$
Freundlich	$q_e = a_F C_e^{b_F}$
Redlich–Peterson (RP)	$q_e = \frac{K_R C_e}{1 + a_R C_e^{b_R}}$
SIPS/ Langmuir-Freundlich (LF)	$q_e = \frac{K_{LF} C_e^{n_{LF}}}{1 + a_{LF} C_e^{n_{LF}}}$
Toth	$Q_e = \frac{Q_m C_e}{[K_T + (C_e^n)]^{\frac{1}{n}}}$
Temkin	$q_e = B ln A_T, + B ln C_e$
Dubinin-Radushkevich (DR)	$q_e = \left(\frac{Q_m \, exp = \left(RT ln \left(1 + {}^{1}/_{C_e}\right)\right)^2}{-2E^2} \right)$

Isotherm Modelling

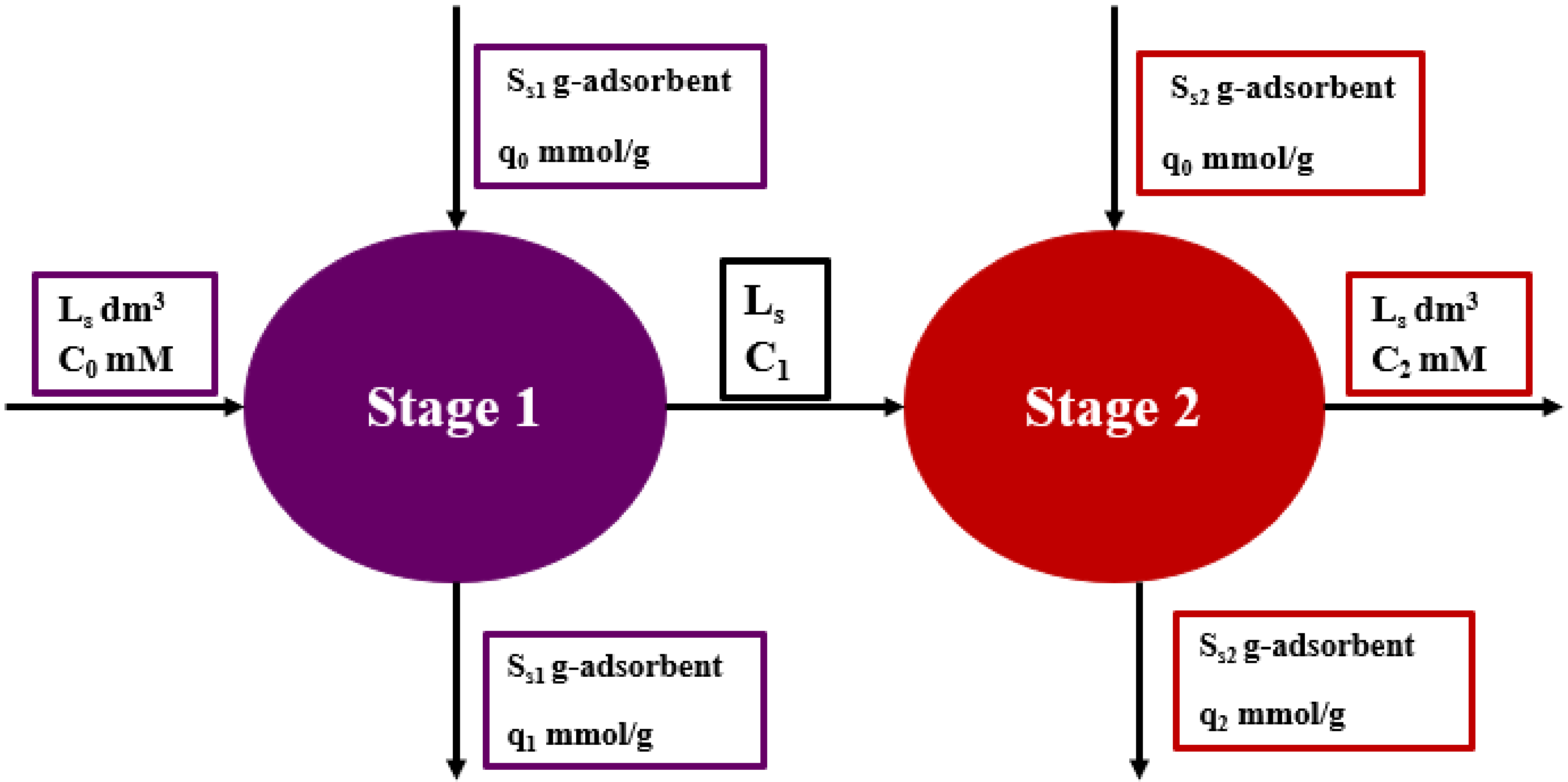




SOLVER

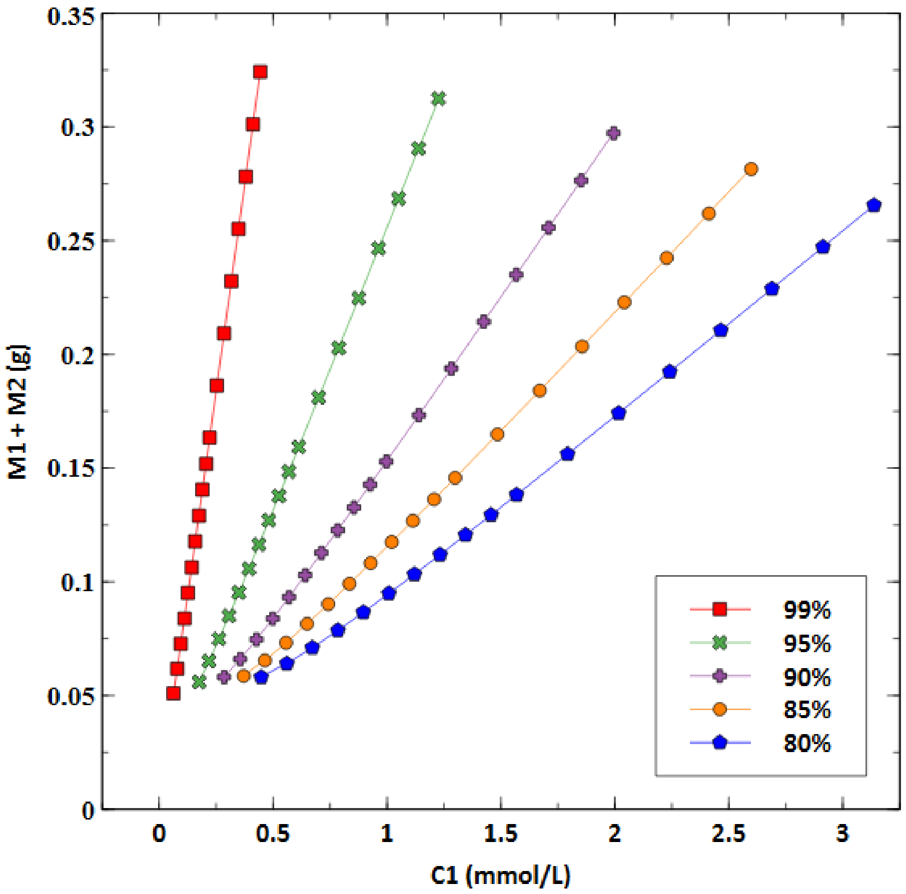
SIPS model
SSE: 0.10

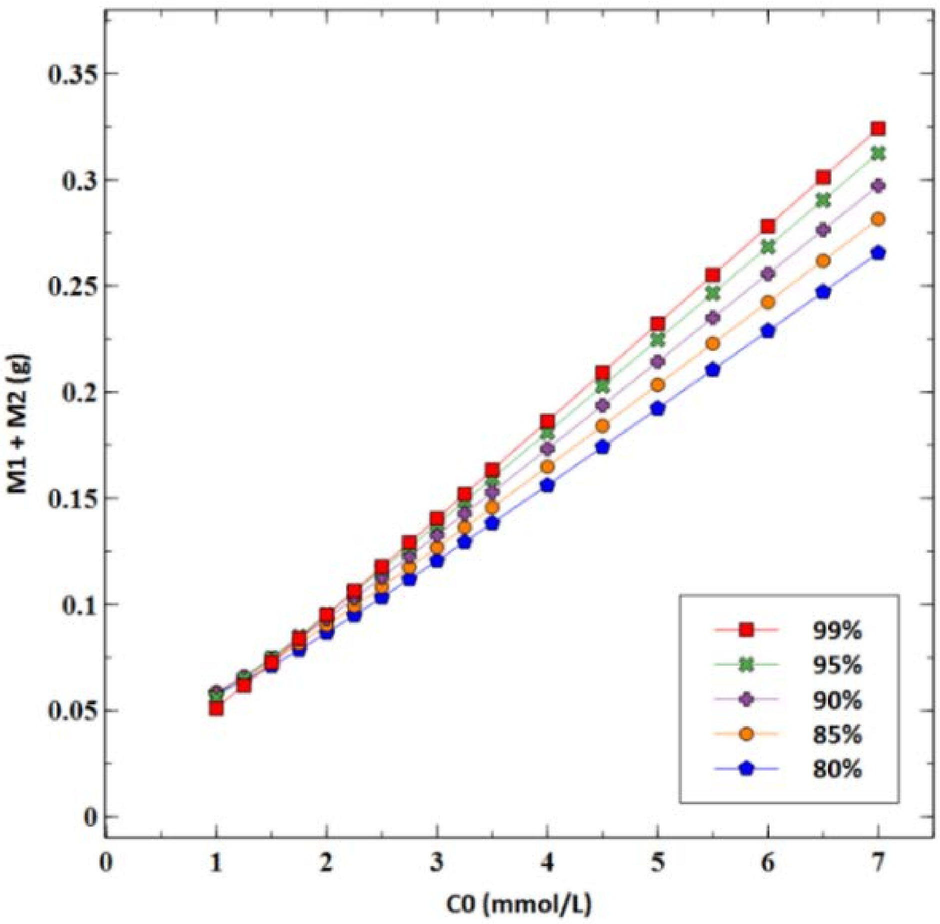
Designing a two-stage reactor based on SIPS model



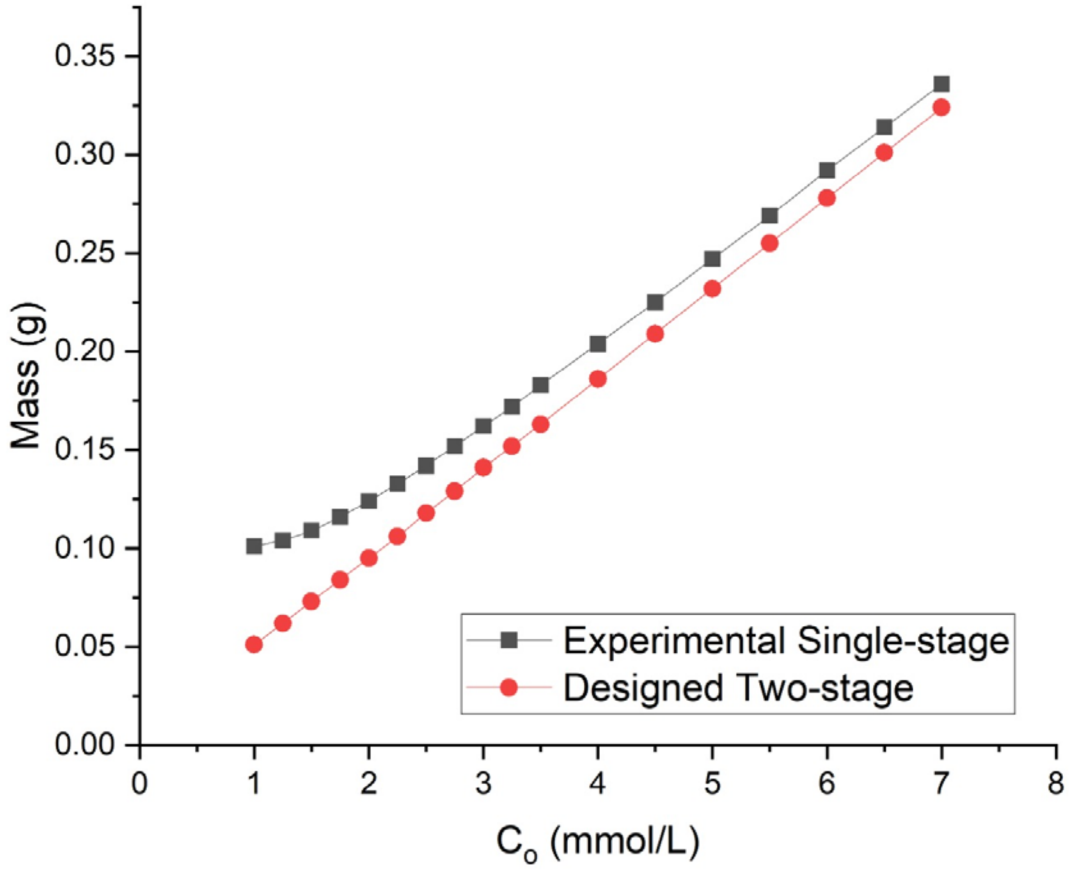
S: amount of adsorbent
q: metal ion concentration
C: concentration of solutions
L: amount of solution

Mass comparison between removal efficiencies





Adsorbent mass comparison for single and two-stage reactors



- For a two-stage reactor system for 99% zinc removal the mass required is much lower
- At lower concentrations- 1mmol/L zinc concentrations → 0.1 g for single stage Vs <0.05 g for designed two-stage adsorber system
- Two small reactors can save the amount of adsorbent needed, especially for low-capacity adsorbents

Conclusion

- Global E-waste pollution is on the rise and sustainable management is important
- Contains high amount of calcium aluminosilicate and is an excellent candidate for water treatment applications
- Pores are created by alkali cleavage by KOH of the silicate rings and burning off carbon (20 wt.%)

- Zinc removal efficiency is 2.01 mmol/g- better than several other reported adsorbents
- Designed two-stage adsorbent reactor is more economical, especially for lower concentrations of zinc
- Future upscaling and pilot-scale studies to be conducted

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Thank you for your attention

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