

Figure 1. Example of nanoparticle functionalized to binding molecule receptor selective for analyte, ion, or molecule.

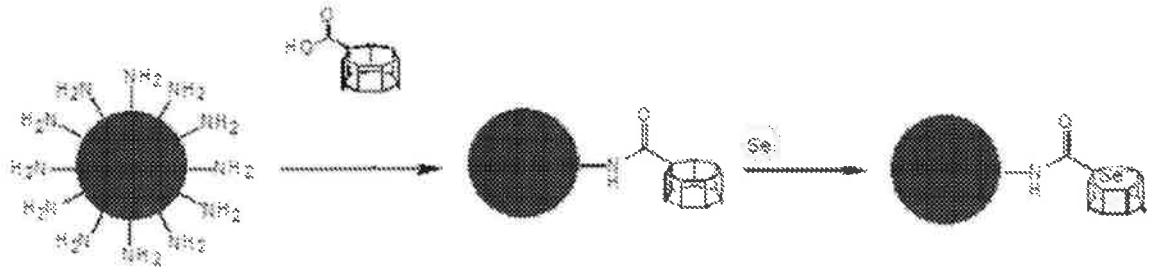


Figure 2. Example of nanoparticle functionalized to binding molecule receptor selective for analyte, ion, or molecule

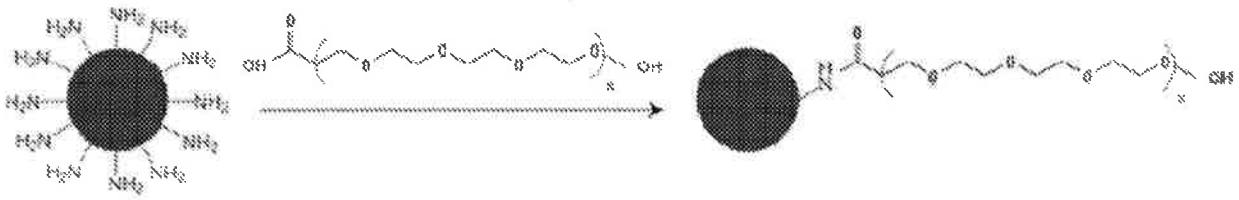


Figure 3. Schematic of magnetic nanoparticle with amine functionalization cross-linked to COOH-PEG-OH of various length spacer (x).

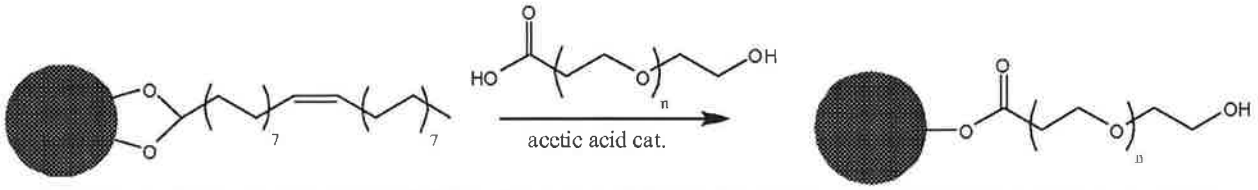
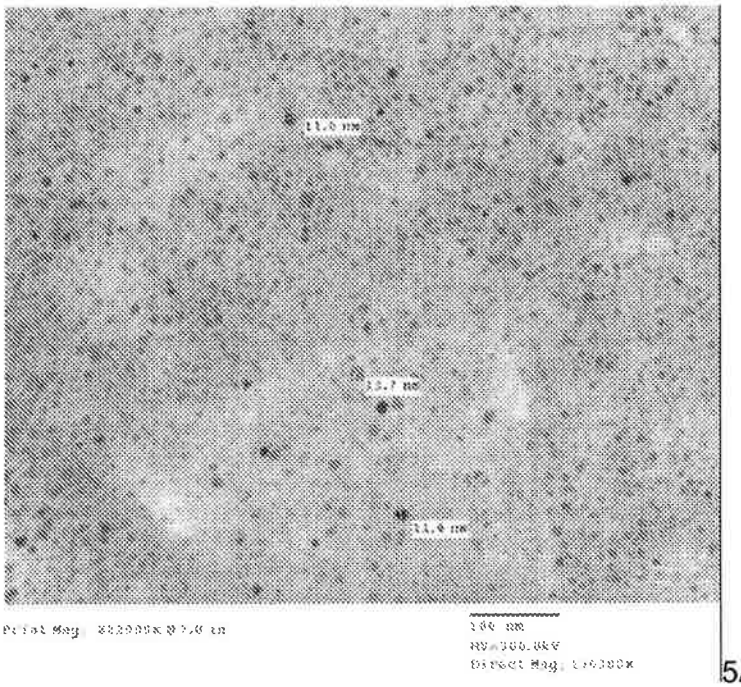
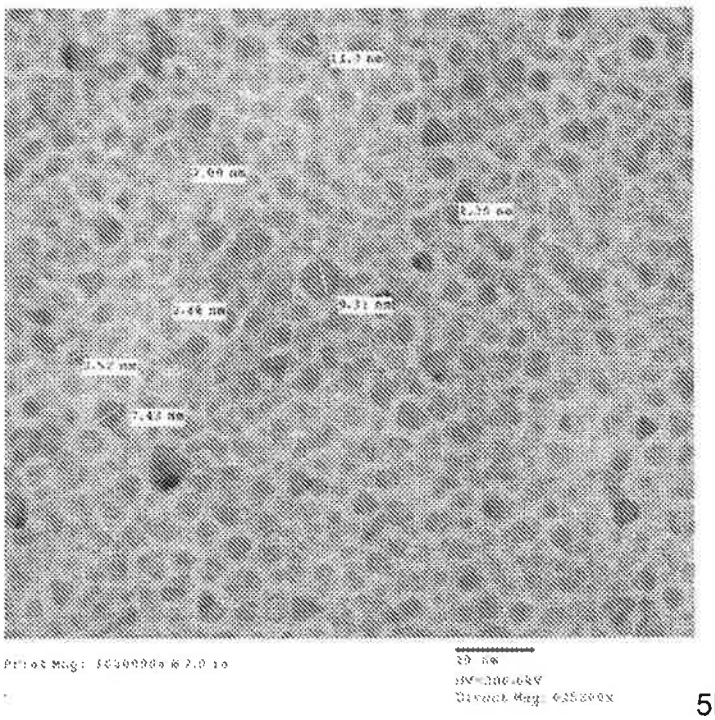


Figure 4. Schematic of magnetic nanoaparticles with oleic acid surfactant exchanged for PEG-OH surfactant for selenate adsorption.



5A.



5B.

Figures 5A and 5B: Transmission Electron Microscopy bright field images of monodispersed approx. 7 to 13 nm magnetite nanoparticles.

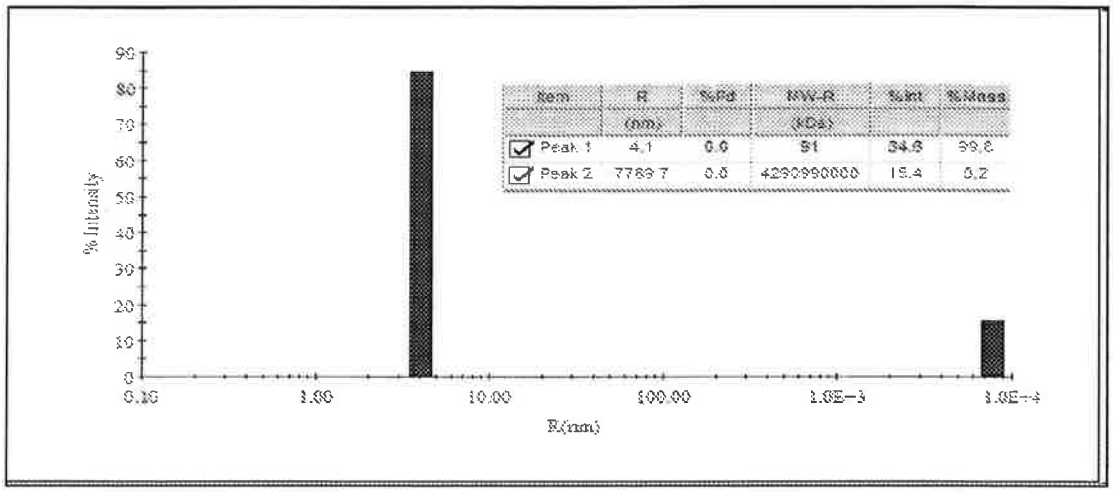


Figure 6. DLS of thermal decomposition monodispersed 4nm Radius (8nm diameter) iron oxide nanoparticles

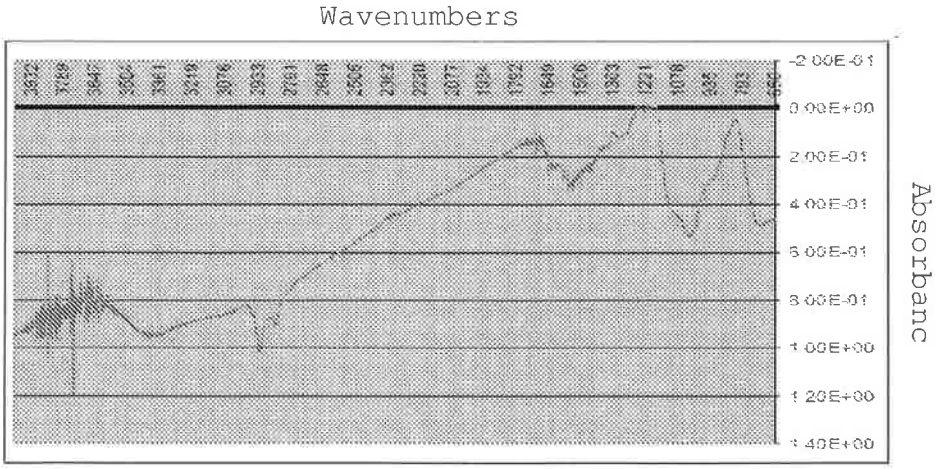


Figure 7: Fourier transform infrared spectroscopy (FTIR) of amine conjugated superparamagnetic iron oxide nanoparticles

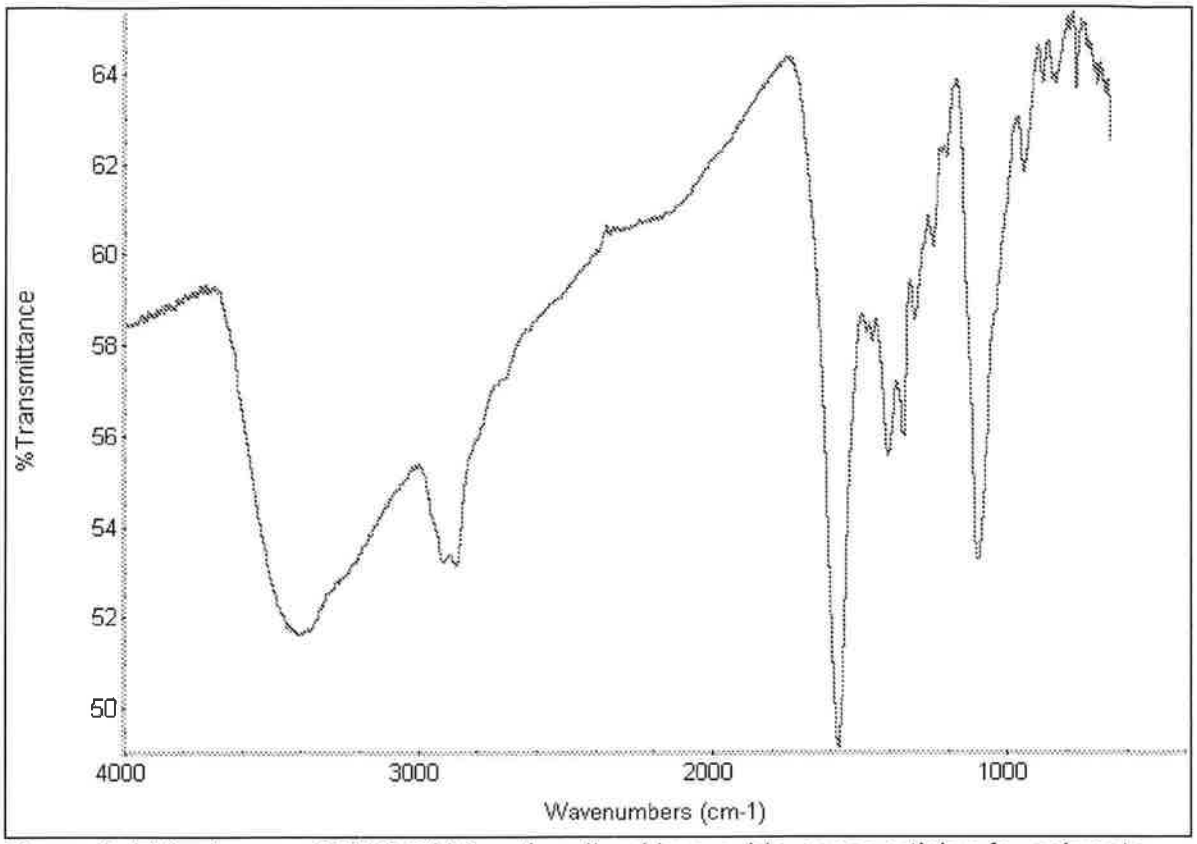


Figure 8. FTIR image of PEG-OH functionalized iron oxide nanoparticles for selenate removal.

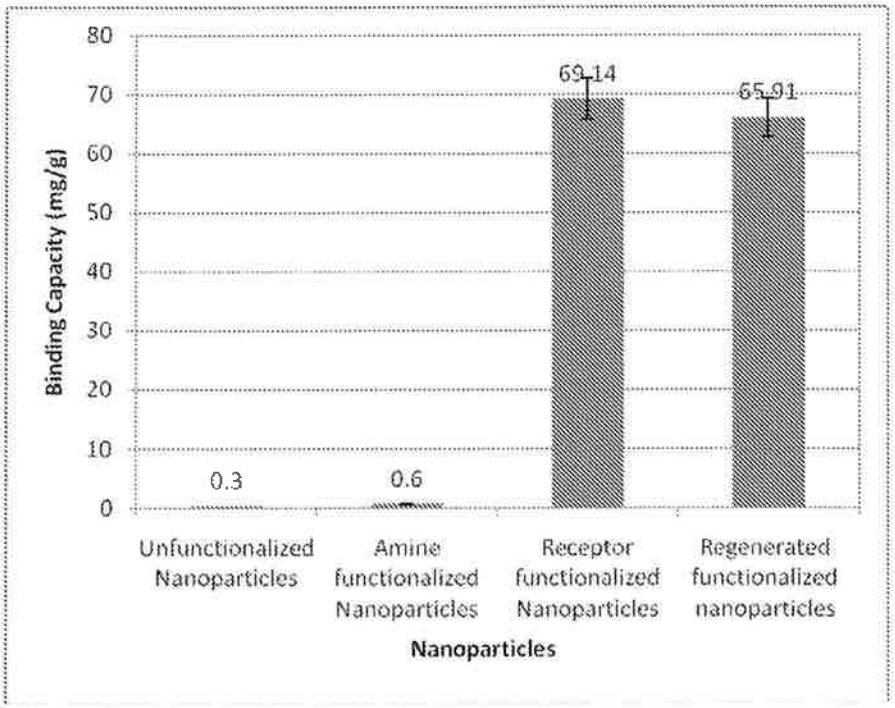


Figure 9: Binding capacity of functionalized nanoparticles compared to unfunctionalized and amine functionalized nanoparticles.

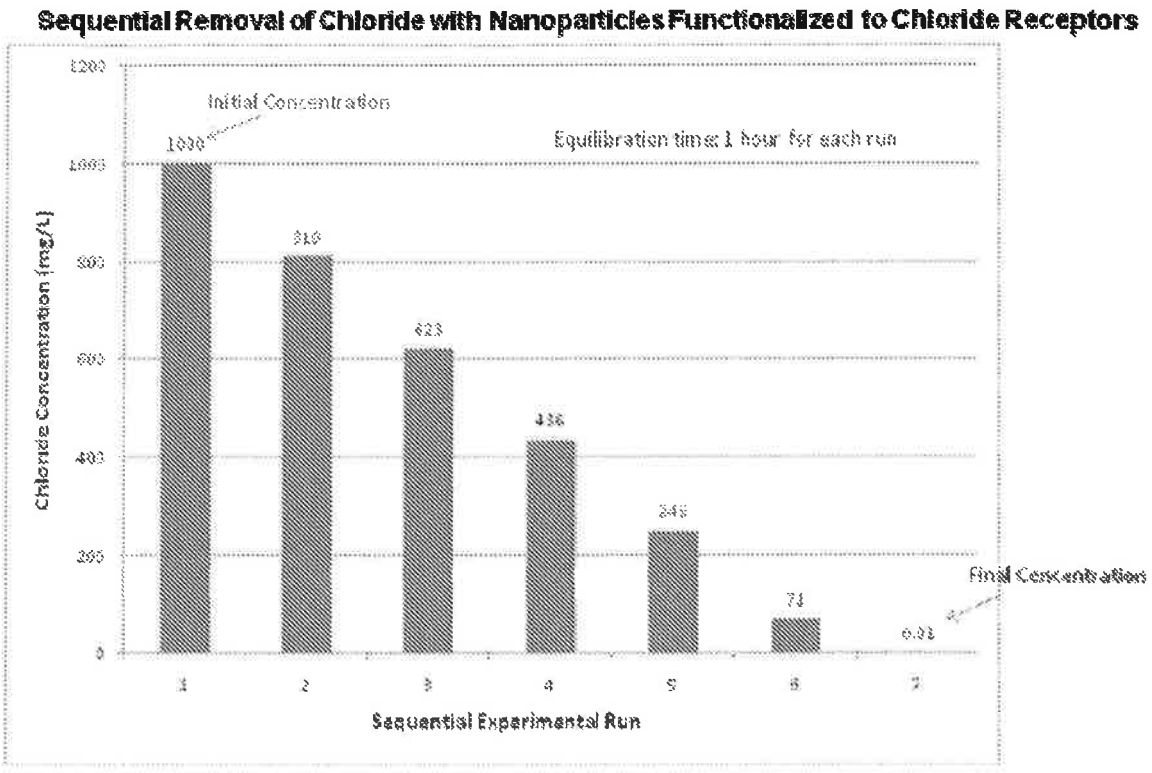


Figure 10: Sequential removal of chloride with nanoparticles functionalized to chloride receptors. With six runs of the ADS water treatment process the 10mL solution of 1000mg/L concentration of chloride had a final concentration of 0.01mg/L chloride.

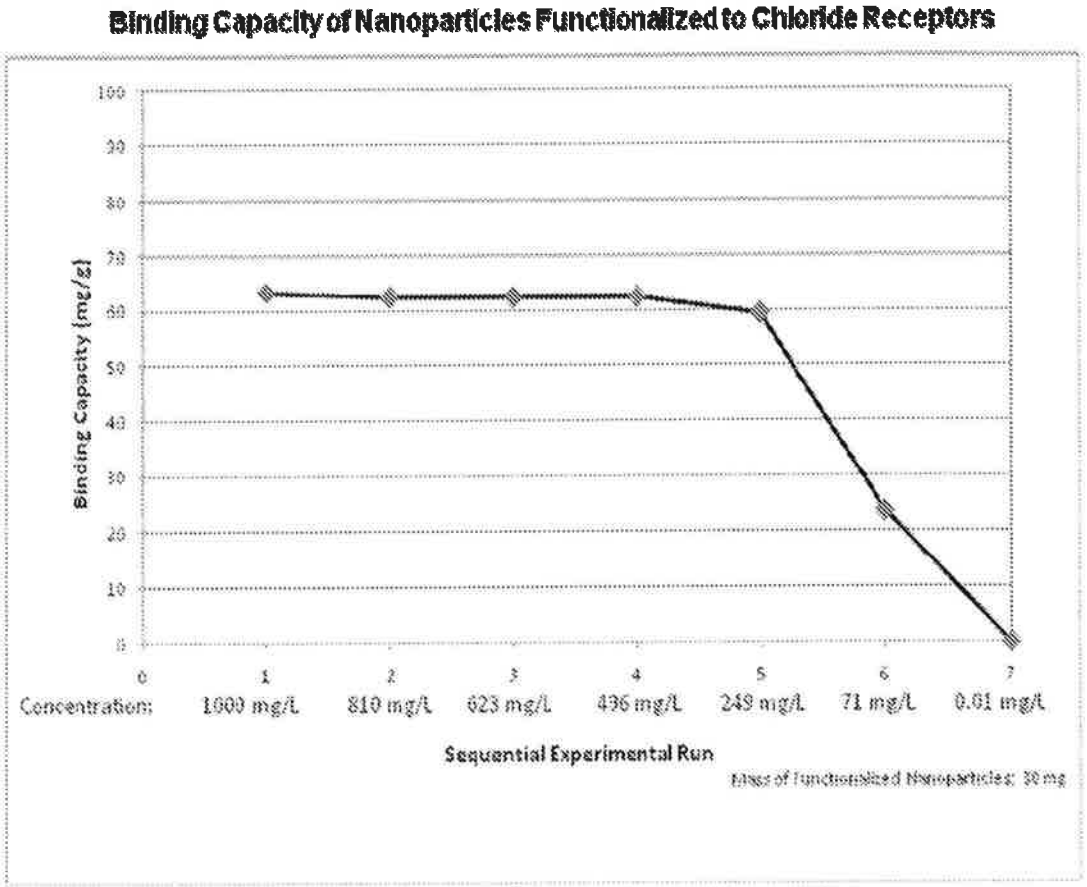


Figure 11: Binding capacity of sequential chloride removal with initial concentration of 1000mg/L to a final concentration of 0.01mg/L. Binding capacity is stable at about 62mg/gram of nanoparticles, showing stable reusability.

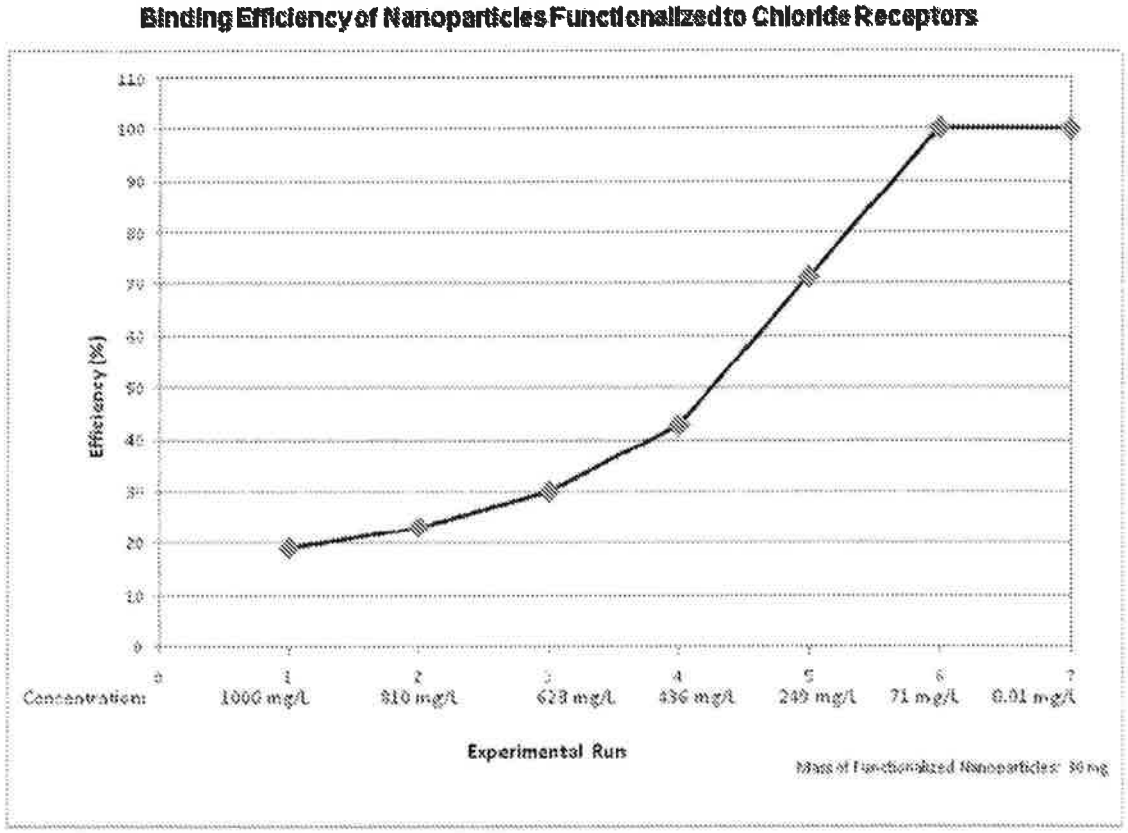


Figure 12: Binding efficiency of nanoparticles functionalized to chloride receptor for sequential chloride removal. The efficiency is greater when ratio of nanoparticle to concentration of chloride is favorable.

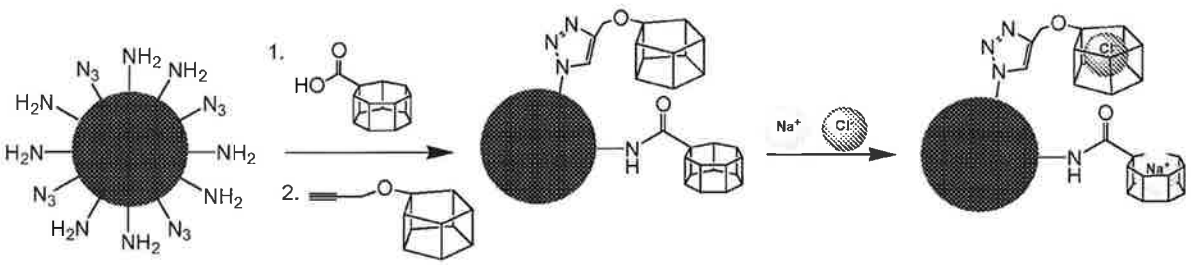


Figure 13: Conjugation of magnetic nanoparticles to individual amide-linked cation receptors capable of binding to sodium ions and triazine-tethered anion receptors capable of binding to Chloride ions.

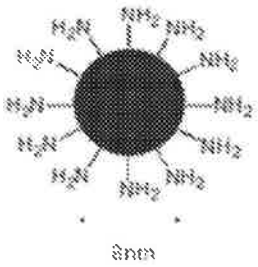
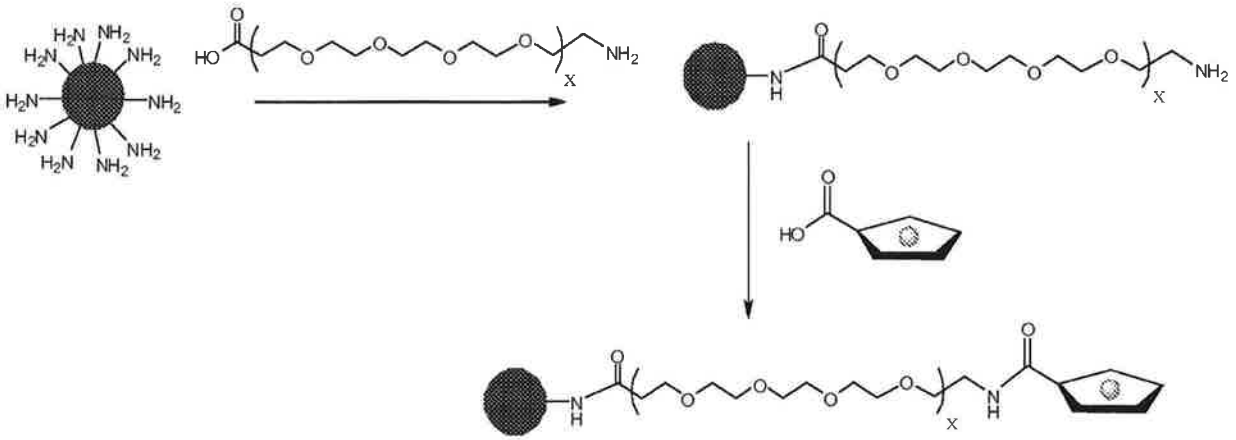
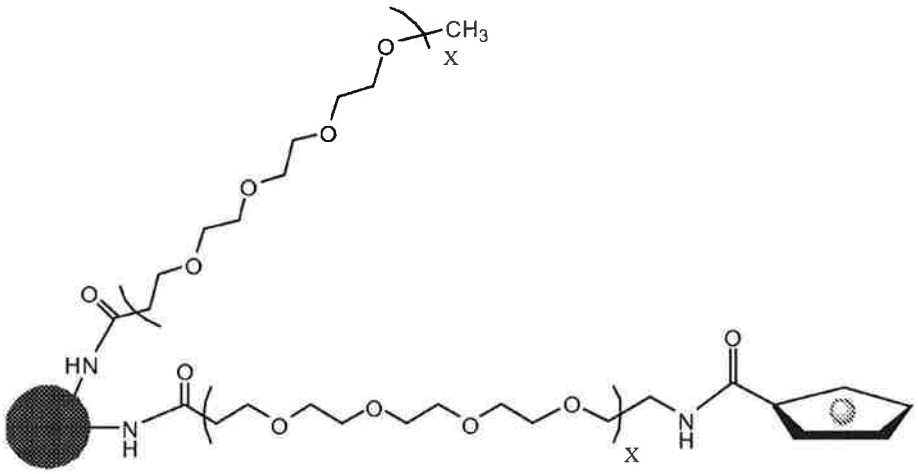


Figure 14: Amine functionalized magnetic nanoparticles.



15A.



15B.

Figures 15A and 15B: PEG spacers of 4-24 units, 18.1Å-108.6Å, or longer (represented by x) used as linkers between magnetic nanoparticles and ion receptors. Individual cation and anion receptors as well as polymer receptors (not shown) may also be conjugated using PEG spacers (A). Dual PEGylated magnetic nanoparticles with varying lengths of both ion receptor terminated and methyl terminated PEG chains (B).

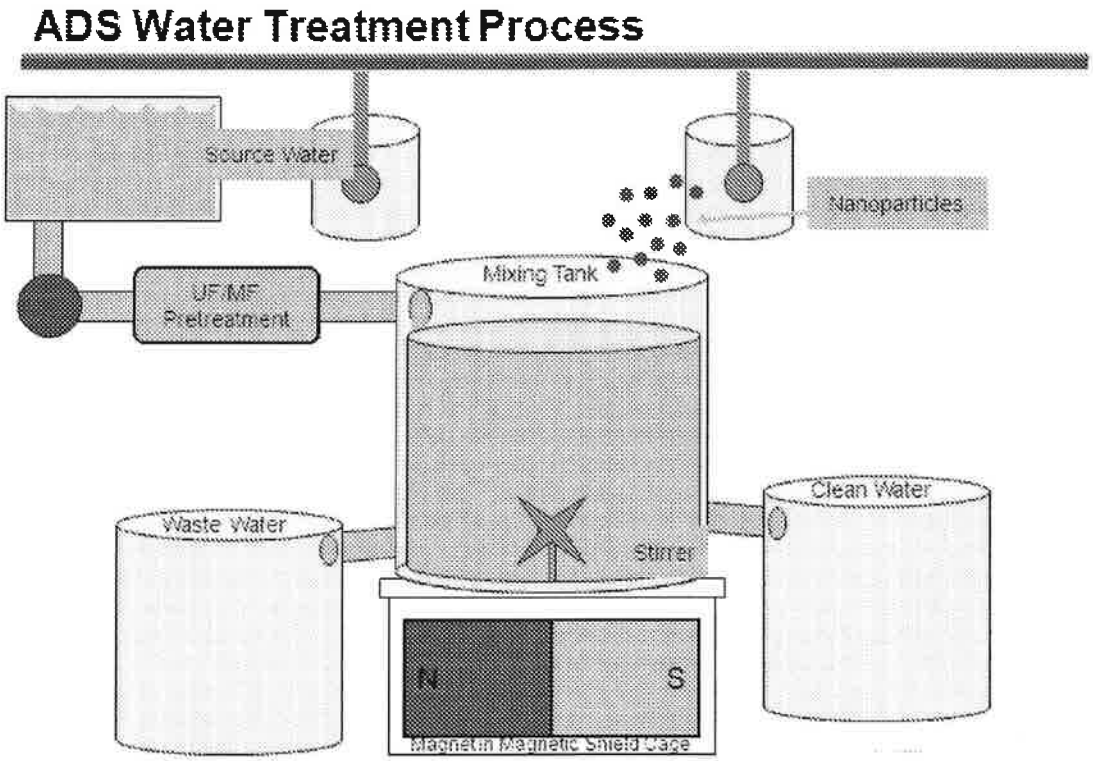
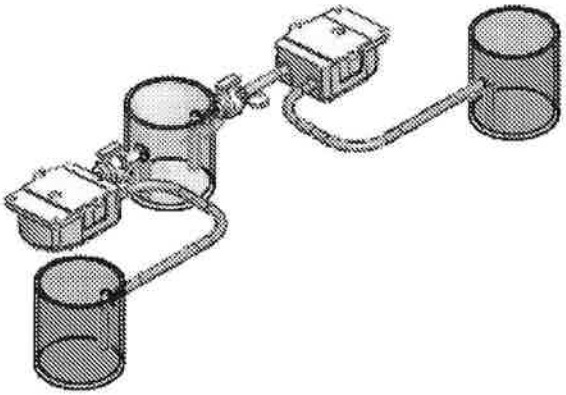
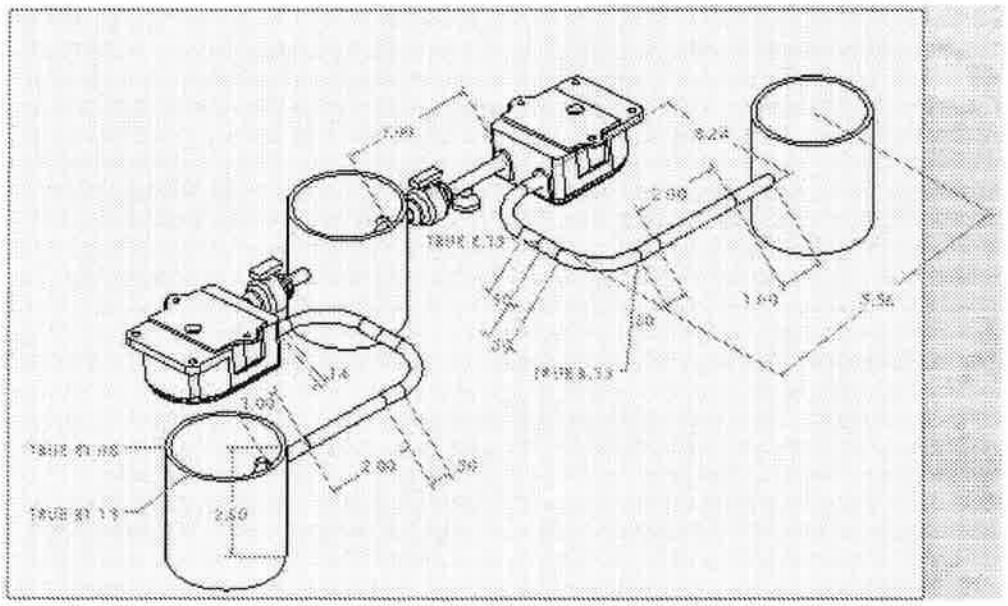


Figure 16. Diagram of water treatment remediation process using magnetic nanoparticles.



17A



17B

Figure 17A and 17B. Diagrams of water remediation apparatus using magnetic nanoparticles. Mixing tank (gray), clean water tank (blue), and waste water tank (red). Permanent magnet, not shown, would be below mixing tank. Stirrer, not shown, would be in mixing tank. 2 way water pumps allow for water to flow from tank to tank for multiple cycles. All numbers are laboratory scale and can be scaled up or down as desired.

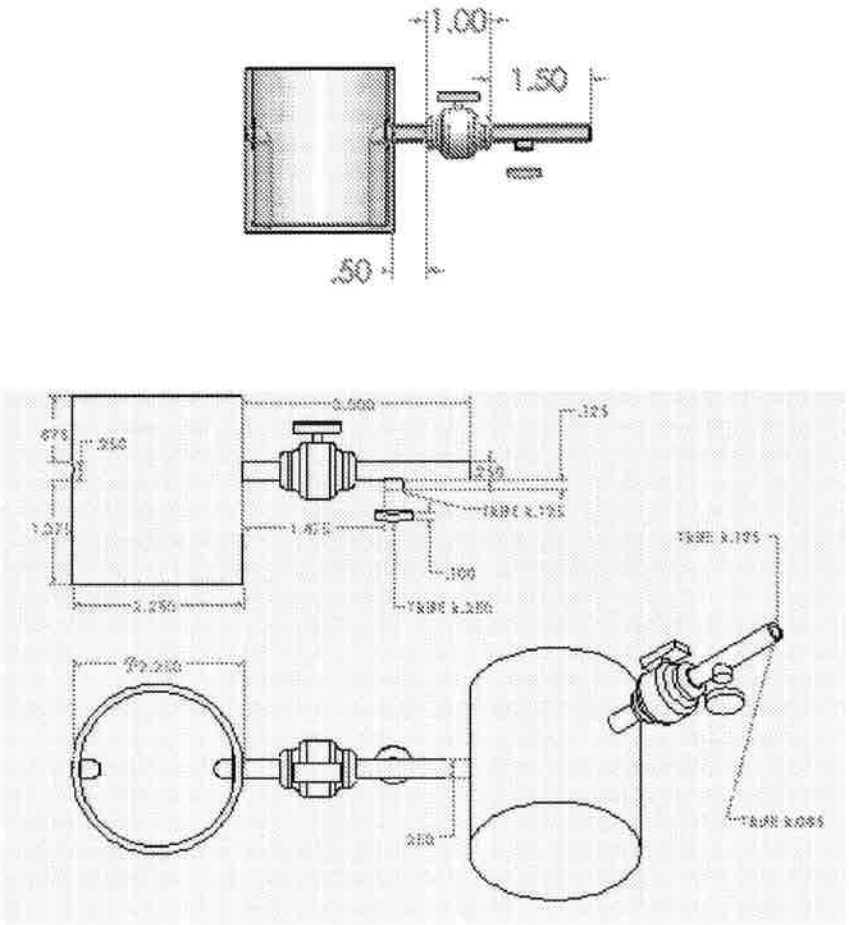


Figure 18. Images of mixing tank with piping, pump and electromagnet for catching runoff nanoparticles and pulling them from solution before contaminating other tanks. All numbers are laboratory scale and can be scaled up or down as desired.

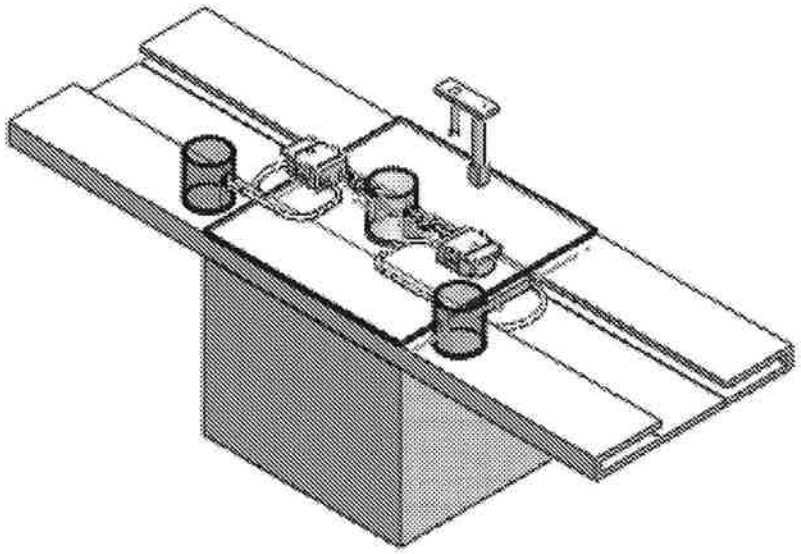


Figure 19. Diagram of laboratory scale apparatus on magnetic cage with sliding magnetic cage cover. Stirrer illustrated above mixing tank (gray tank).

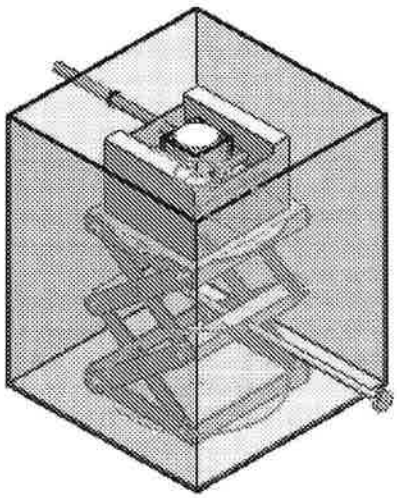


Figure 20. Magnetic cage with jack for lifting and lowering permanent or electromagnet. Magnet (gray) in block container (yellow) with lever for moving permanent magnet right and left (green).

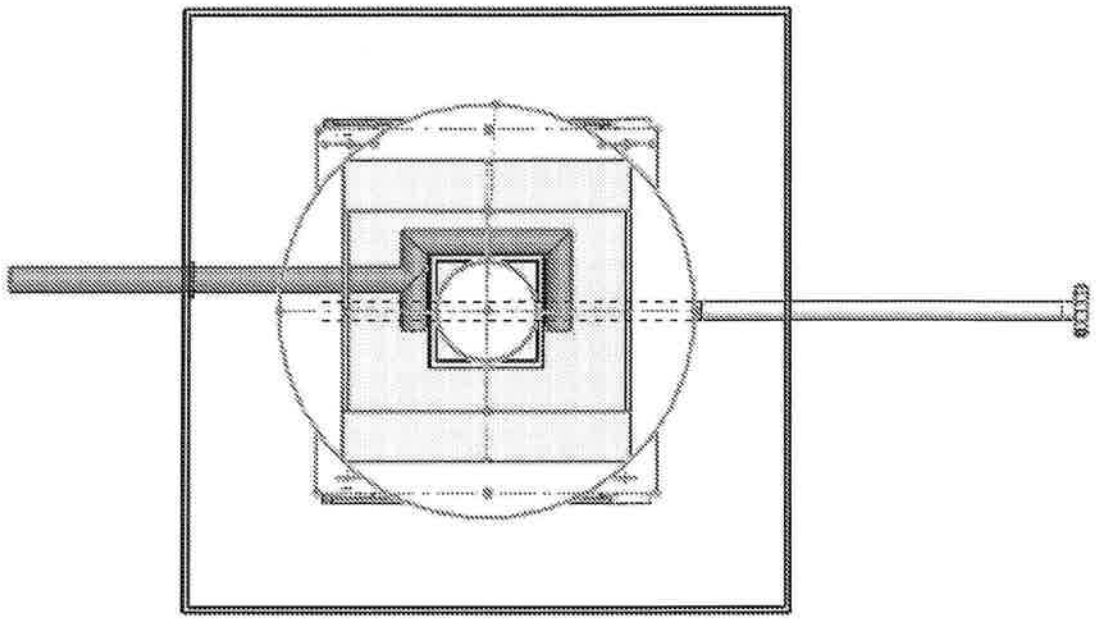


Figure 21. Aerial view of magnet (gray) in magnet block container (yellow) and lever for moving magnet right and left for proper decanting of magnetic nanoparticles (green).

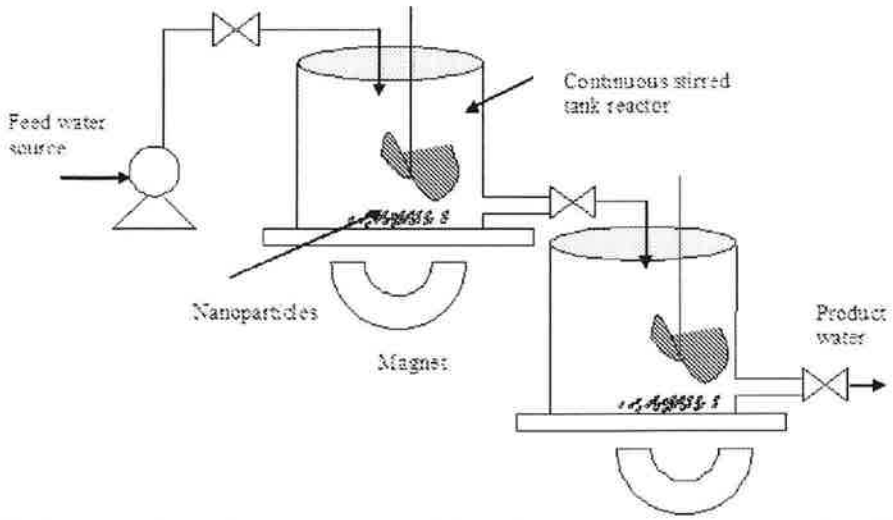


Figure 22: Process flow diagram of novel desalination process using functionalized magnetic nanoparticles and continuous batch process.

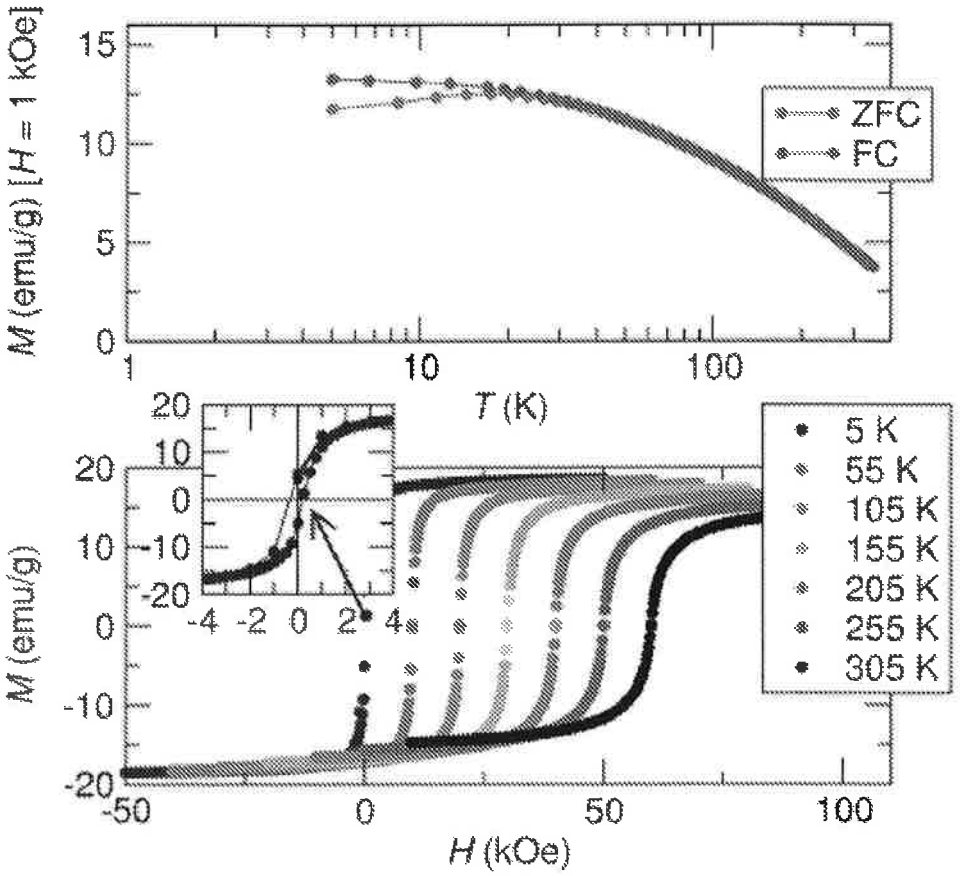


Figure 23. Magnetic characterization of oleic acid coated iron oxide nanoparticles. Characterization work done using a Super Quantum Interference Device (SQUID) magnetometry.

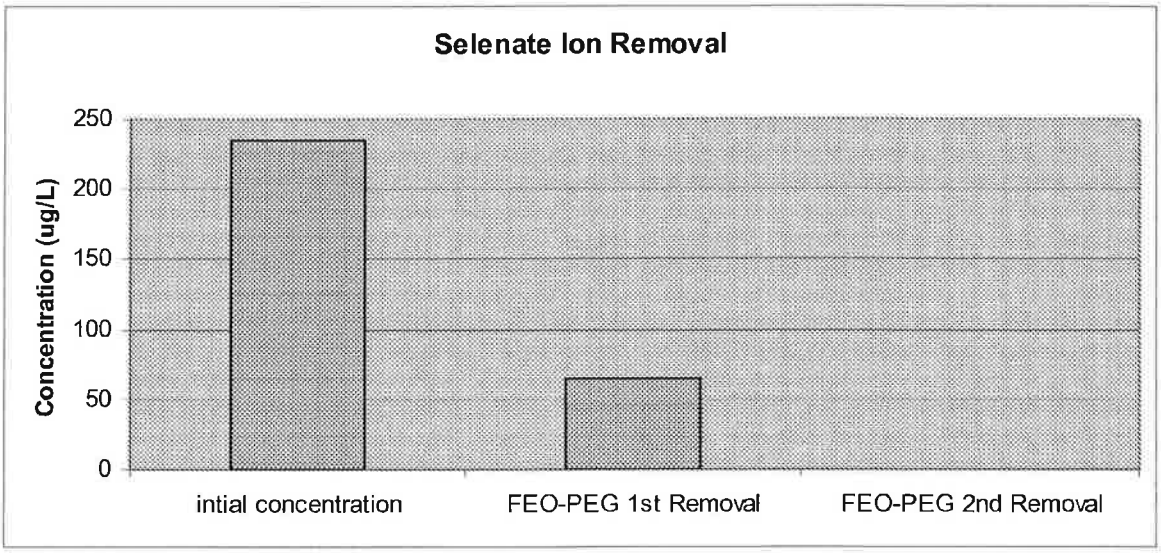


Figure 24. Complete Selenate ion removal from aqueous solution using 2 sequential treatments with PEG-OH surface functionalized iron oxide nanoparticles. Initial concentration of 234.6µg/L selenate was used. 15mg (+/- 3mg) of material was used in 5mL of selenate solution. After 1st removal regeneration of nanoparticles were done with NaOH cleaning solution.

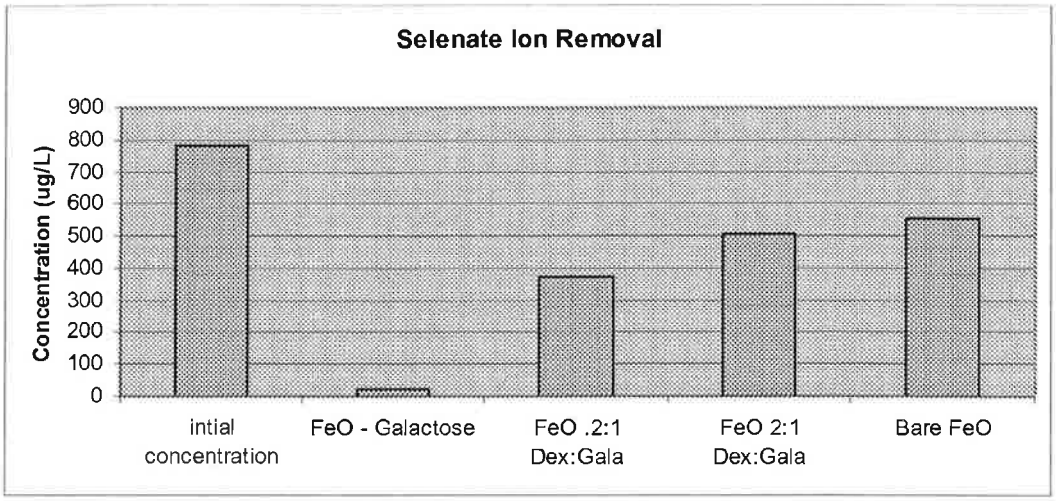


Figure 25. Selenate ion removal from aqueous solution with initial selenate concentration of 782 µg/L. 15mg (+/- 3mg) PEG-OH functionalized, Galactose functionalized, Dextran/Galactose 0.2:1 ratio functionalized, Dextran/Galactose 2:1 ratio functionalized, and bare iron oxide nanoparticles were used to treat water. All samples were 15mg (+/- 3mg) of material in 5mL of selenate solution.

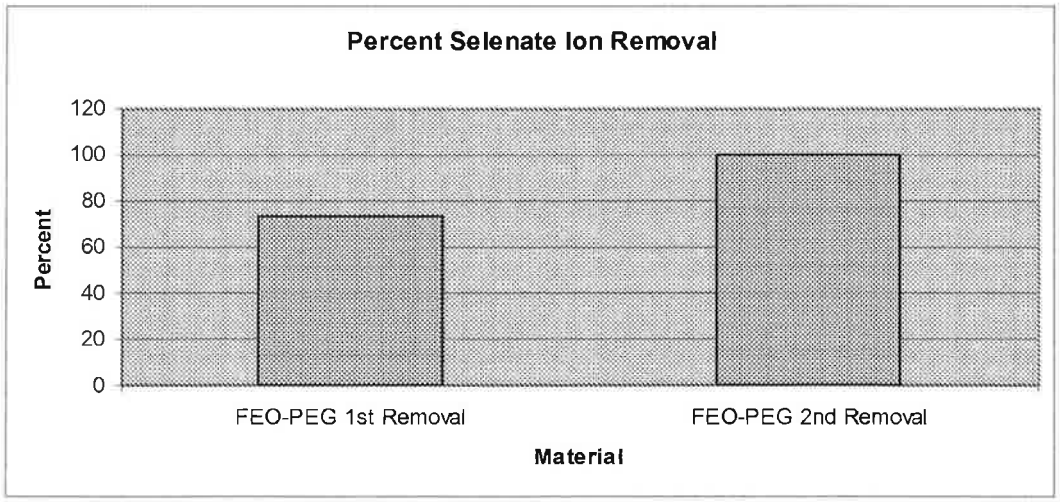


Figure 26. Percent Selenate ion removal of sequential treatment of aqueous solution with 15mg PEG-OH surface functionalized nanoparticles in 5ml of solution. After 1st removal regeneration of nanoparticles were done with NaOH cleaning solution.

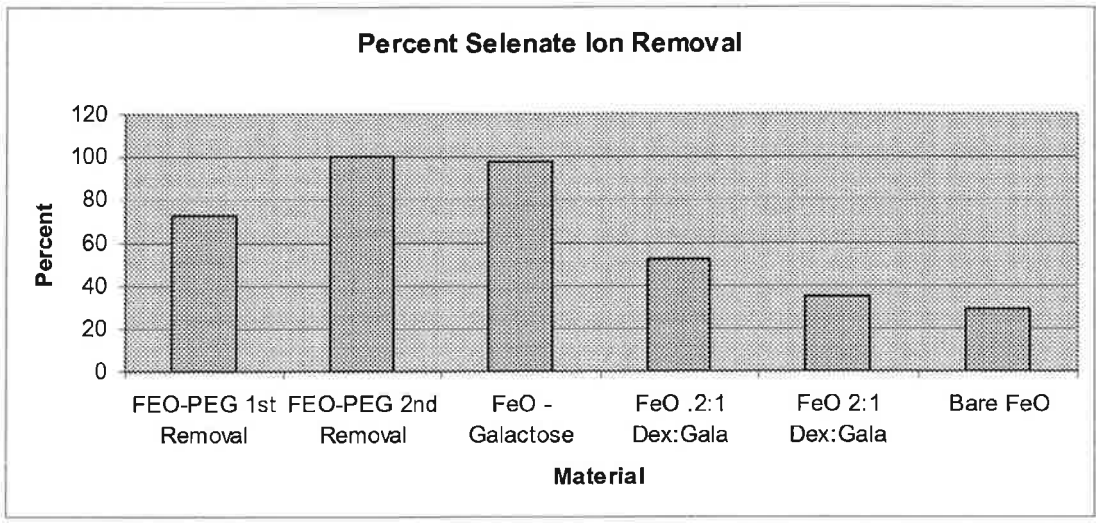


Figure 27. Percent Selenate ion removal of PEG-OH functionalized, Galactose functionalized, Dextran/Galactose 0.2:1 ratio functionalized, Dextran/Galactose 2:1 ratio functionalized, and bare iron oxide nanoparticles used to treat water. All samples used 15mg (+/- 3mg) nanoparticulate material in 5mL of selenate solution.

Material	%Loss	Concentration (ug/L)
Initial concentration		234.6
FeO-PEG 1st Removal	73	64.4
FeO-PEG 2nd Removal	100	0

Material	%Loss	Concentration (ug/L)
Initial concentration		782
FeO-Galactose	98	19.32
FeO 0.2:1 Dex:Gala	52	372.6
FeO 2:1 Dex:Gala	35	506
Bare FeO	29	552

Figure 28. Concentration differences and percentage of selenate removal. Samples were pure DI water with sodium selenate salt solution of initial concentration of 234.6µg/L and 782µg/L respectively. All samples used 15mg (+/- 3mg) of nanoparticulate material in 5mL of selenate solution.