Electronic Supplementary Information (ESI)

Phosphorus Recovery from Urine and Anaerobic Digester Filtrate: Comparison of Adsorption–Precipitation with Direct Precipitation

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1 reference

Table S1 – Phosphate adsorption to HAIX-Fe resin during continuous-flow column tests.

Bed volumes[a]	Fresh urine[b]	Hydrolyzed urine[b]	Anaerobic digester filtrate[c]
1st use			
Breakthrough	3.7–4.3	1.8–2.5	22.2
Saturation	10.5	17.3[a]	51.8[a]
2nd use			
Breakthrough	3.1–3.7	1.8–2.5	20.3–22.2
Saturation	11.7	17.3[a]	44.4[a]
3rd use			
Breakthrough	2.5	1.2–1.8	16.6
Saturation	11.1	17.3	44.4[b]

Breakthrough: $C/C_0 = 0.1$; saturation $C/C_0 = 1$.
[a] $C/C_0 = 0.94$. [b] $C/C_0 = 0.97$.

Table S2 – Phosphate concentration in regeneration solution.

Phosphate, mg P/L	Fresh urine[b]	Hydrolyzed urine[b]	Anaerobic digester filtrate[c]
Original waste water	672 ± 7	491 ± 15	77.4 ± 0.7
Regeneration, 1st use	419	241	263
Regeneration, 2nd use	669	492	502
Regeneration, 3rd use	783	652	693

Table S3 – Chemical equilibrium calculations in synthetic fresh urine at an Mg:K:P molar ratio of 1.5:2:1 and pH 9.3.[a]

Mineral/Solid phase	log IAP	SI
$Ca_3(PO_4)_2$ (am1)	–21.9	3.56
$Ca_3(PO_4)_2$ (am2)	–21.9	6.30
$Ca_3(PO_4)_2$ (beta)	–21.9	6.98
$Ca_4H(PO_4)_3 \cdot 3H_2O$	–40.5	7.47
$CaHPO_4$	–18.5	0.741
$CaHPO_4 \cdot 2H_2O$	–18.5	0.461
Hydroxyapatite ($Ca_5(PO_4)_3OH$)	–25.4	19.0
Potassium struvite ($KMgPO_4 \cdot 6H_2O$)	–9.60	1.02
$Mg_3(PO_4)_2$	–18.4	4.92
$MgHPO_4 \cdot 3H_2O$	–17.3	0.836

[a] Calculations made using Visual MINTEQ.[1] Ion activity product (IAP). Saturation index (SI).

Table S4 – Chemical equilibrium calculations in synthetic hydrolyzed urine at an Mg:N:P molar ratio of 1.5:37:1 and pH 9.3.[a]

Mineral/Solid phase	log IAP	SI
Hydromagnesite ($Mg_5(CO3)_4(OH)_2 \cdot 4H_2O$)	–3.72	5.04
Potassium struvite ($KMgPO_4 \cdot 6H_2O$)	–10.2	0.452
Magnesite ($MgCO_3$)	–4.85	2.61
$Mg_3(PO_4)_2$	–20.1	3.14
$MgHPO_4 \cdot 3H_2O$	–17.9	0.269
Struvite ($MgNH_4PO_4 \cdot 6H_2O$)	–9.29	3.97

[a] Calculations made using Visual MINTEQ.[1] Ion activity product (IAP). Saturation index (SI).

Table S5 – Chemical equilibrium calculations in spent regenerant corresponding to synthetic fresh urine at an Mg:K:P molar ratio of 1.5:1.5:1 and pH 9.3.[a]

Mineral/Solid phase	log IAP	SI
Potassium struvite ($KMgPO_4 \cdot 6H_2O$)	–9.82	0.8
$Mg_3(PO_4)_2$	–18.7	4.60
$MgHPO_4 \cdot 3H_2O$	–17.5	0.682

[a] Calculations made using Visual MINTEQ.[1] Ion activity product (IAP). Saturation index (SI).

Table S6 – Chemical equilibrium calculations in spent regenerant corresponding to synthetic hydrolyzed urine at an Mg:N:P molar ratio of 1.5:1.5:1 and pH 9.3.[a]

Mineral/Solid phase	log IAP	SI
$Mg_3(PO_4)_2$	–19.0	4.26
$MgHPO_4 \cdot 3H_2O$	–17.6	0.545
Struvite ($MgNH_4PO_4 \cdot 6H_2O$)	–10.2	3.08

[a] Calculations made using Visual MINTEQ.[1] Ion activity product (IAP). Saturation index (SI).

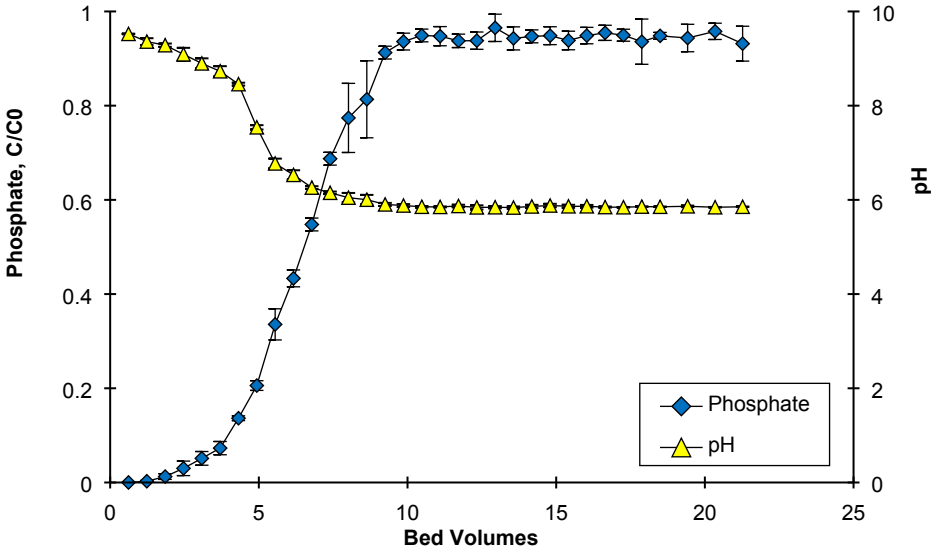

Figure S1 – Normalized effluent phosphate concentration and effluent pH for HAIX-Fe resin column operation treating fresh urine (C_0 = 713 ± 13 mg P/L, pH = 5.8). Results are mean of triplicate samples with error bars showing one standard deviation. Column operating conditions: 1 bed volume = 8 mL resin; empty bed contact time = 3.2 min; superficial linear velocity = 3.1 cm/min.

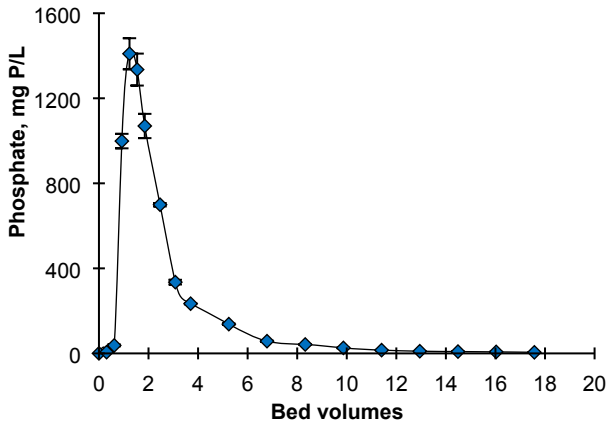

Figure S2 – Phosphate desorption from HAIX-Fe resin during column regeneration corresponding to adsorption tests using synthetic fresh urine. Results are mean of triplicate samples with error bars showing one standard deviation. Column regeneration conditions: 2.5% NaCl + 2% NaOH regeneration solution; 1 bed volume = 8 mL resin; empty bed contact time = 3.2 min; superficial linear velocity = 3.1 cm/min.

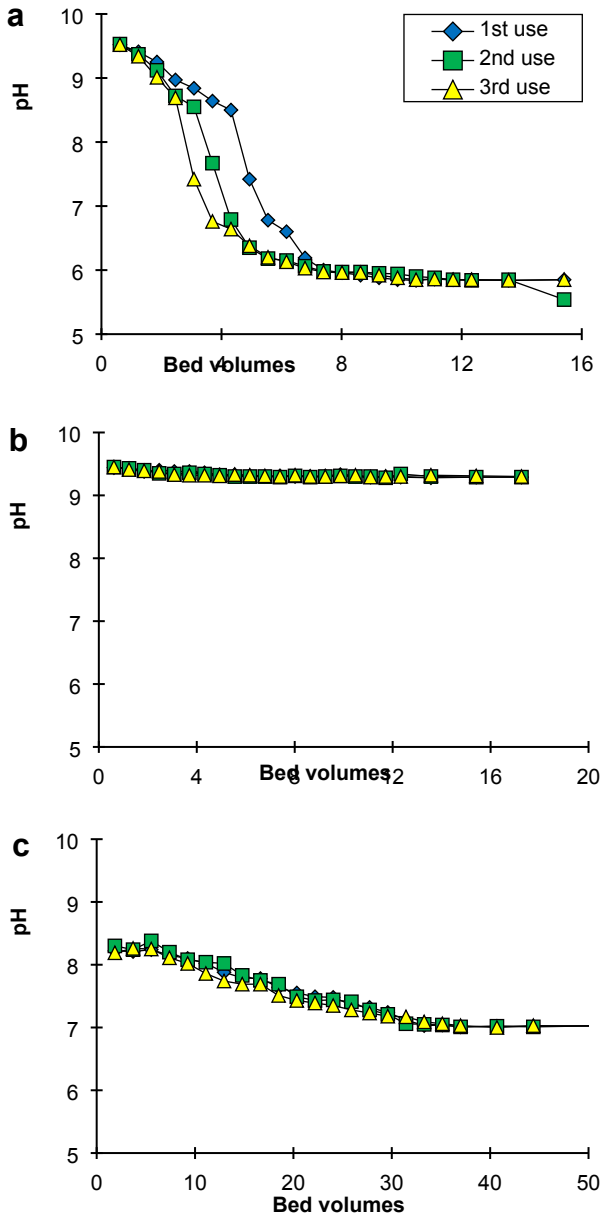

Figure S3 – Change in pH for phosphate adsorption to HAIX-Fe resin under continuous-flow column operation: (a) synthetic fresh urine (C_0 = 672 mg P/L, pH = 5.8), (b) synthetic hydrolyzed urine (C_0 = 491 mg P/L, pH = 9.3), and (c) real anaerobic digester filtrate (C_0 = 77 mg P/L, pH = 7.0). Column operating conditions: BV = 8 mL; EBCT = 3.2 min; SLV = 3.1 cm/min.

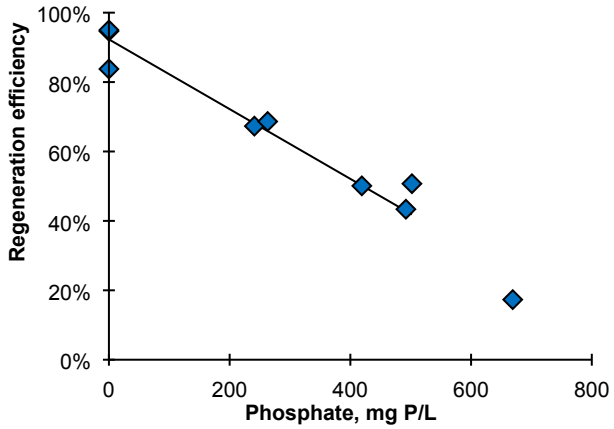

Figure S4 – Regeneration efficiency of HAIX-Fe resin saturated with PO_4-P as a function of increasing PO_4-P concentration in regeneration solution. Phosphate concentration equal to 0 is fresh regeneration solution. Phosphate concentration > 0 is recycled regeneration solution.

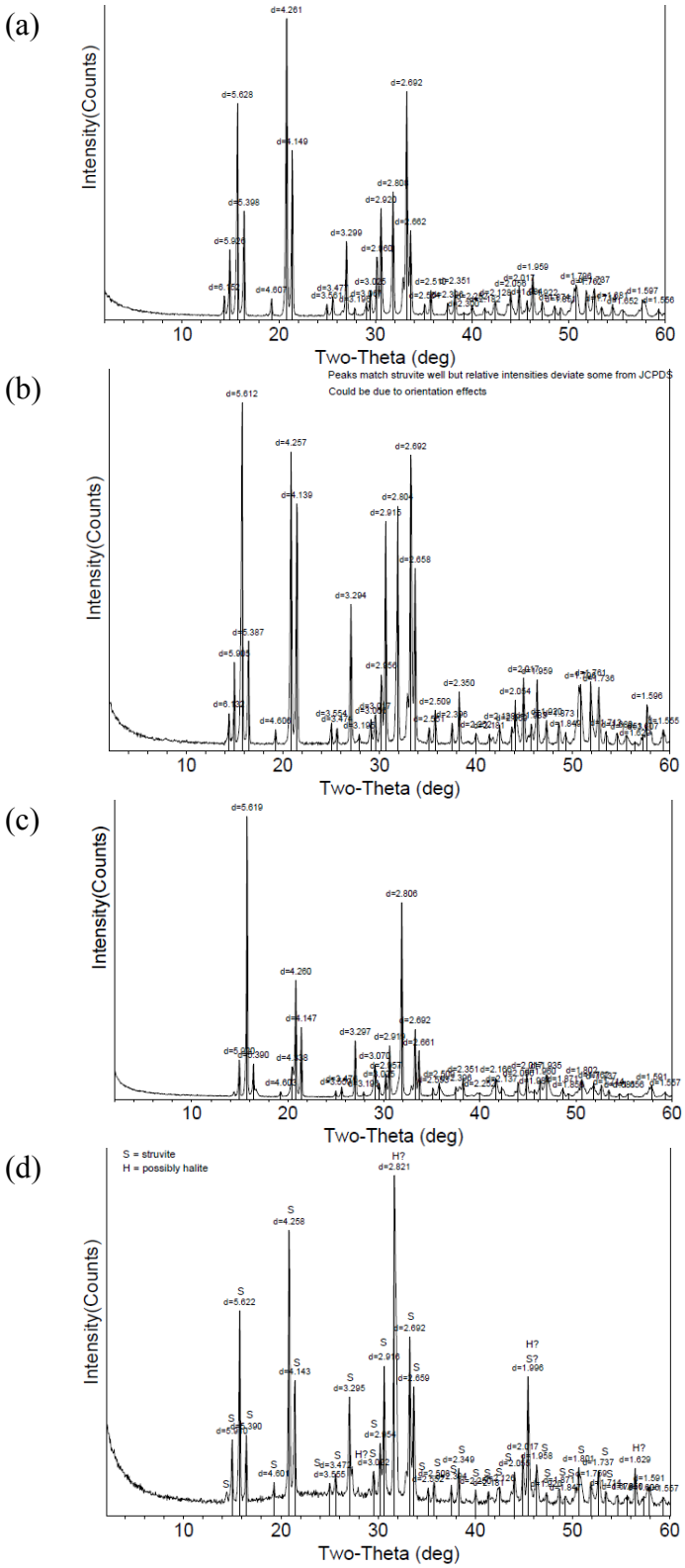

Figure S5 – XRD patterns for struvite precipitation in (a) synthetic hydrolyzed urine, (b) spent regenerant corresponding to hydrolyzed urine, (c) real anaerobic digester filtrate, and (d) spent regenerant corresponding to anaerobic digester filtrate. (S = struvite; H = halite.)

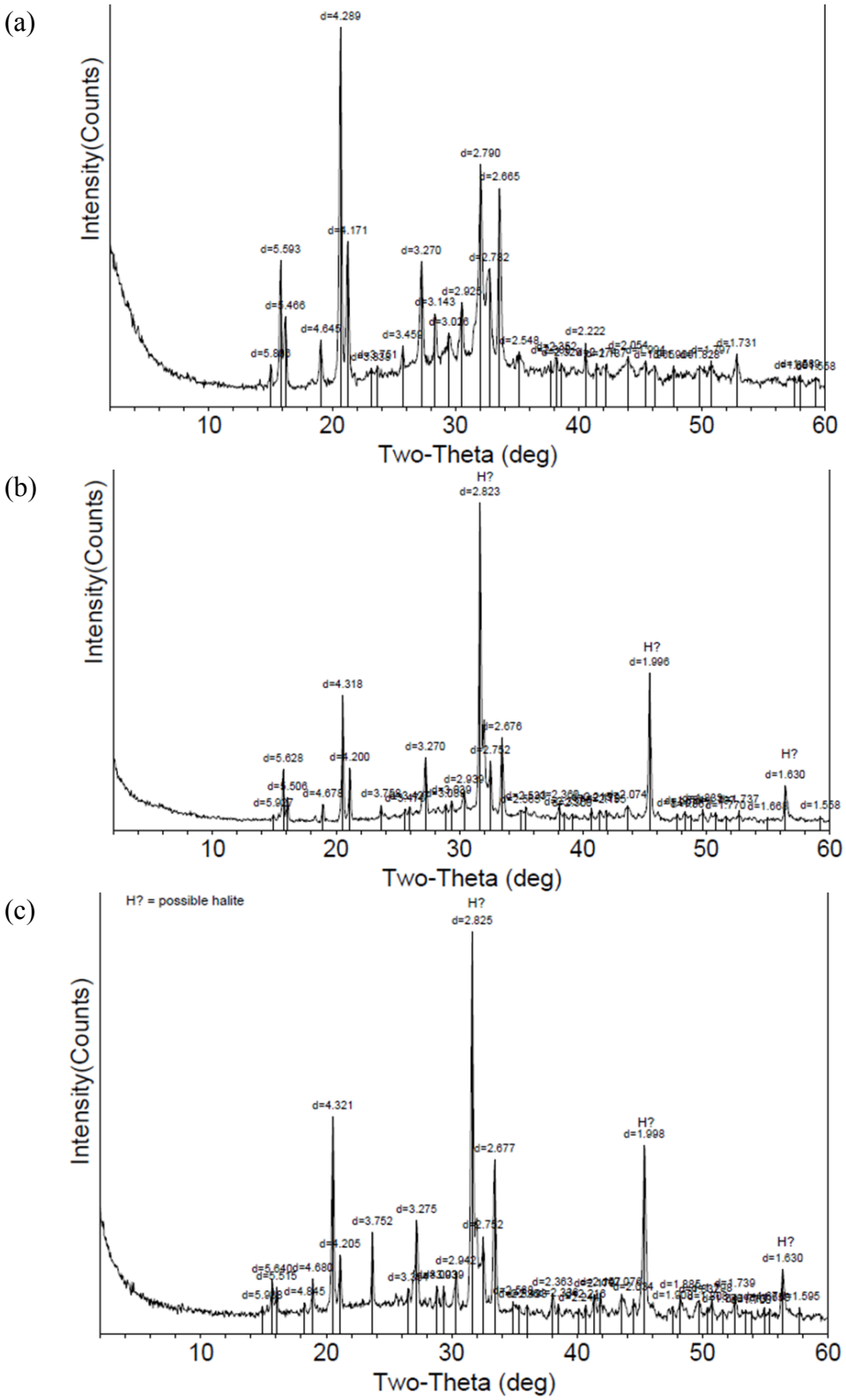

Figure S6 – XRD patterns for potassium struvite precipitation in (a) synthetic fresh urine, (b) spent regenerant corresponding to fresh urine, and (c) spent regenerant corresponding to hydrolyzed urine. (H = possible halite.)

References

1. Gustafsson, J. P. Visual MINTEQ, version 3.0. http://www2.lwr.kth.se/English/OurSoftware/vminteq/ (accessed 24 June 2013).