Hydrothermal treatment of digested sludge for nutrient recovery

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Technology development → Growth of population → Social problems

Waste management

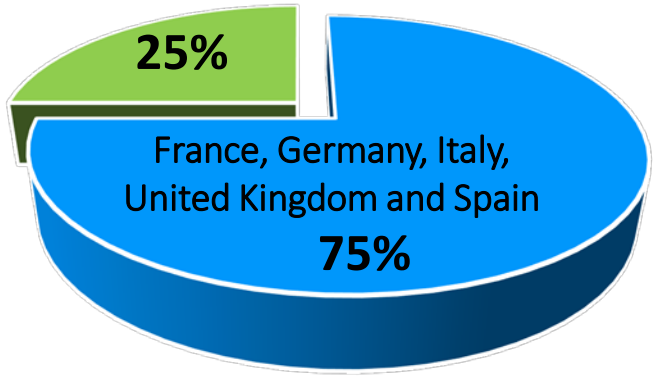
Landfilling

Storage

Fertilizers

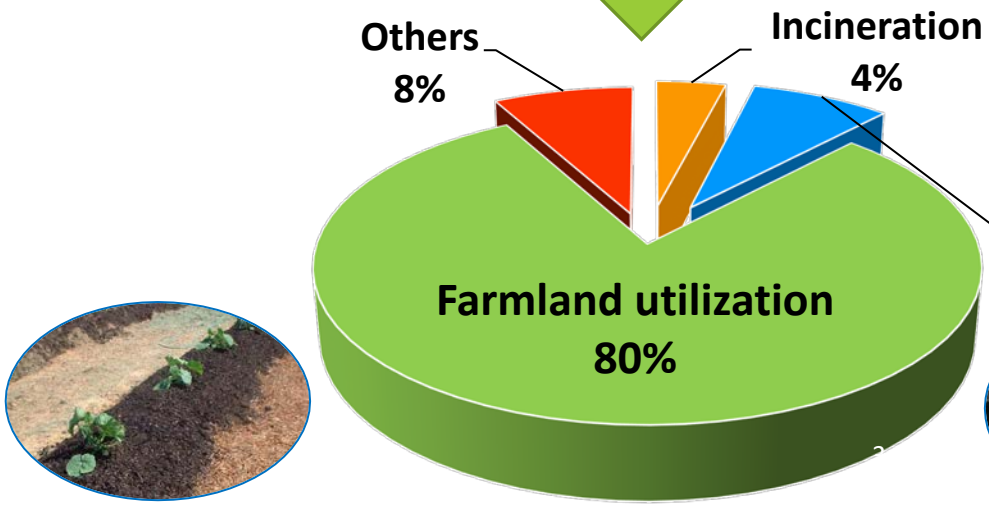
Sewage sludge management

Europe ~ 10 millions t/year (d.b)

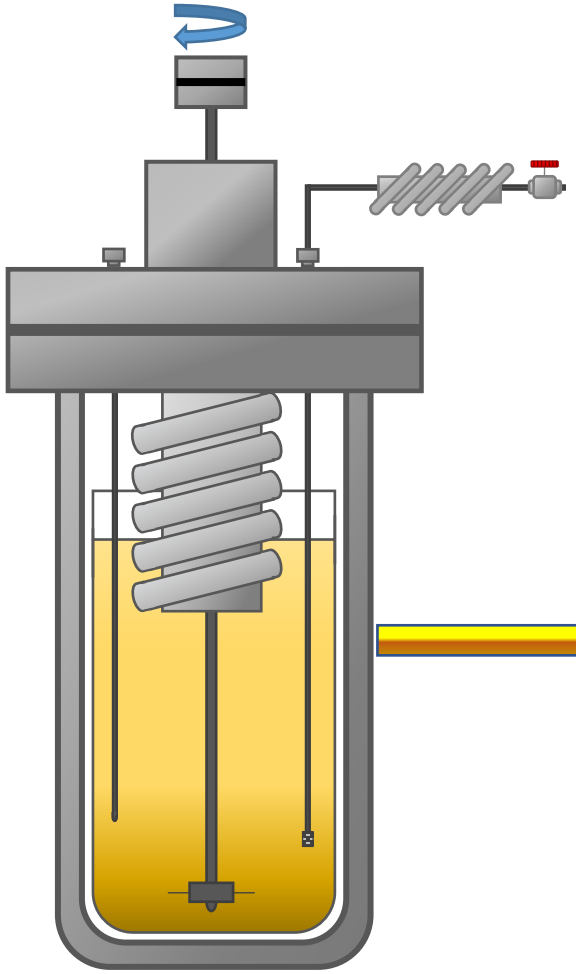


Anaerobic Digestion

Digestate



Digested sludge	
Total phosphorus (g/kg)	28
Total nitrogen (g/kg)	56
Total potassium (g/kg)	31
Solid content (%)	10

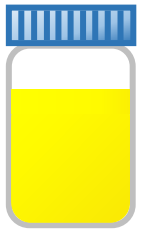


T = 170, 200, 230 °C

t = 1 h

- Exothermic reaction
- Aqueous solution
- 170-250 °C
- Self-generated pressure

Process water (PW)

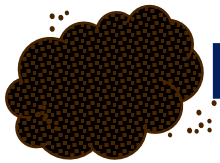


PW170

PW200

PW230

Hydrochar (HC)

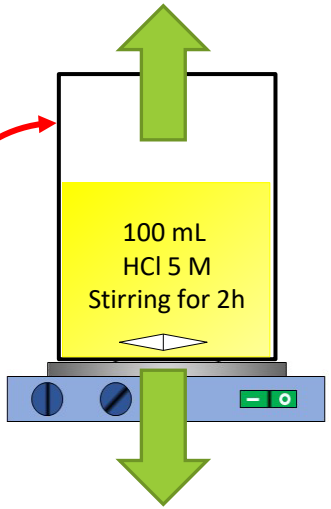


HC170

HC200

HC230

10 g



Leachate (L)

L170

L200

L230

Washed HC (WHC)

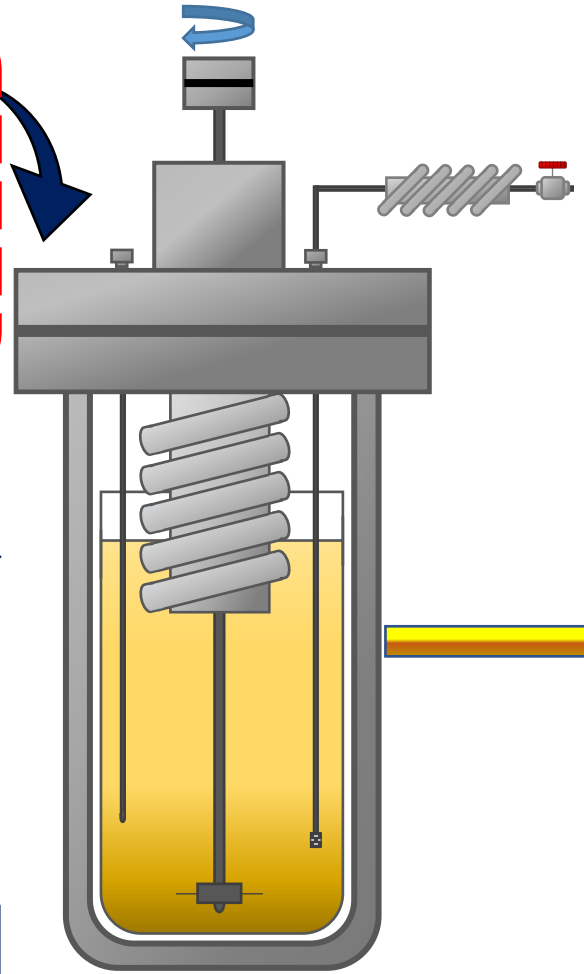
WHC170

WHC200

WHC230

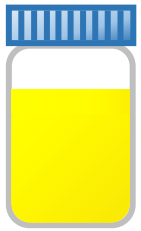
Digested sludge	
Total phosphorus (g/kg)	28
Total nitrogen (g/kg)	56
Total potassium (g/kg)	31
Solid content (%)	10

+ HCl
(0.1 – 0.5 M)



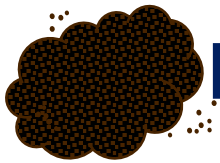
T = 170, 200, 230 °C
t = 1 h

Process water (PW)



PW170
PW200
PW230

Hydrochar (HC)



HC170
HC200
HC230

10 g

+ HCl

Leachate (L)

~~PW-A-170~~ L170
~~PW-A-200~~ L200
PW-A-230 L230

100 mL

~~HC-A-170~~
~~HC-A-200~~
HC-A-230

Washed HC (WHC)

WHC170
WHC200
WHC230

+ HCl
(0.1 – 0.5 M)

T = 170, 200, 230 °C
t = 1 h

Process water (PW)

Hydrochar (HC)

+ HCl

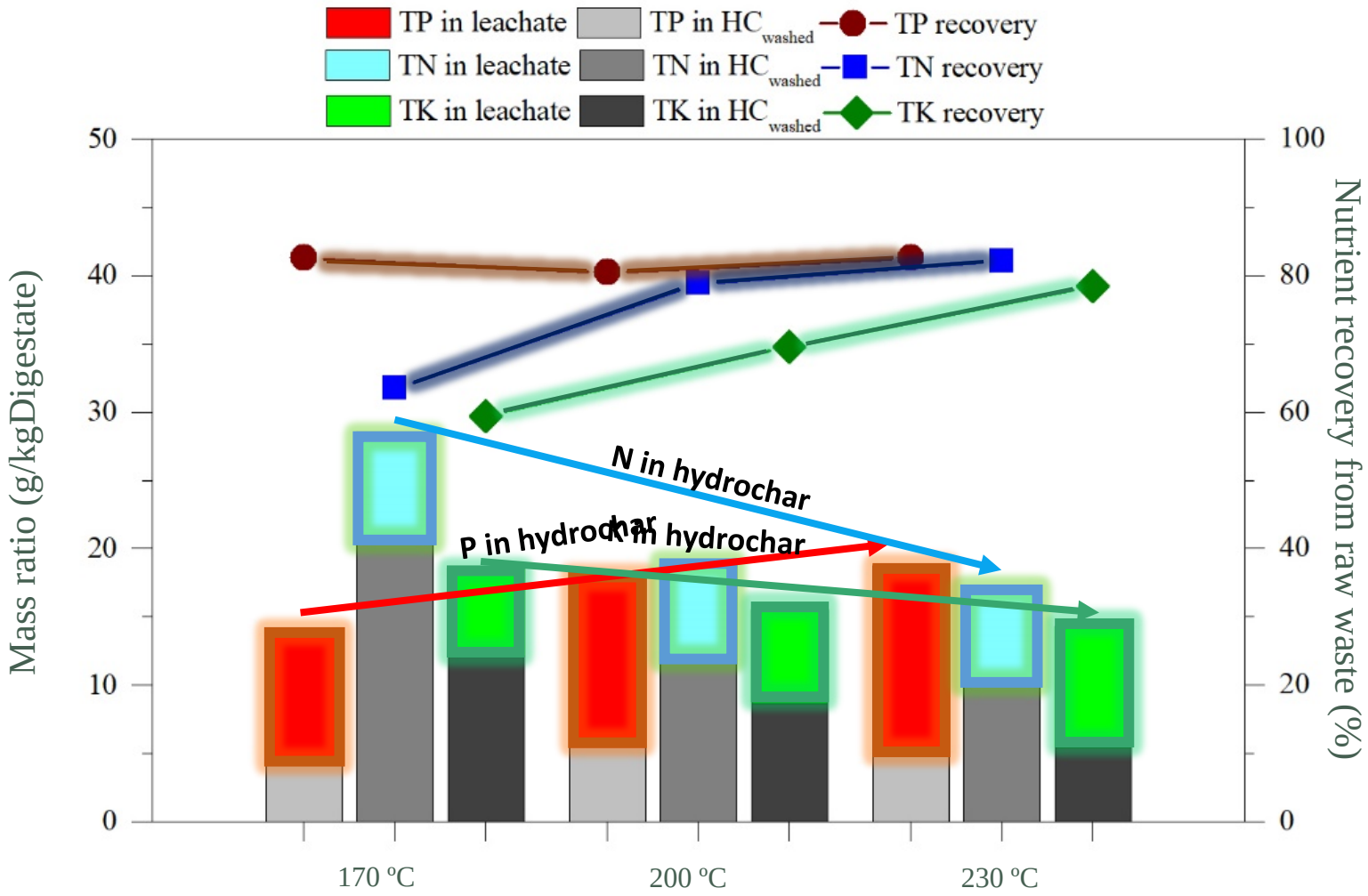
PW170	PW-170-[HCl]
PW200	PW-200-[HCl]
PW230	PW-230-[HCl]
HC170	HC-170-[HCl]
HC200	HC-200-[HCl]
HC230	HC-230-[HCl]

P, N, K

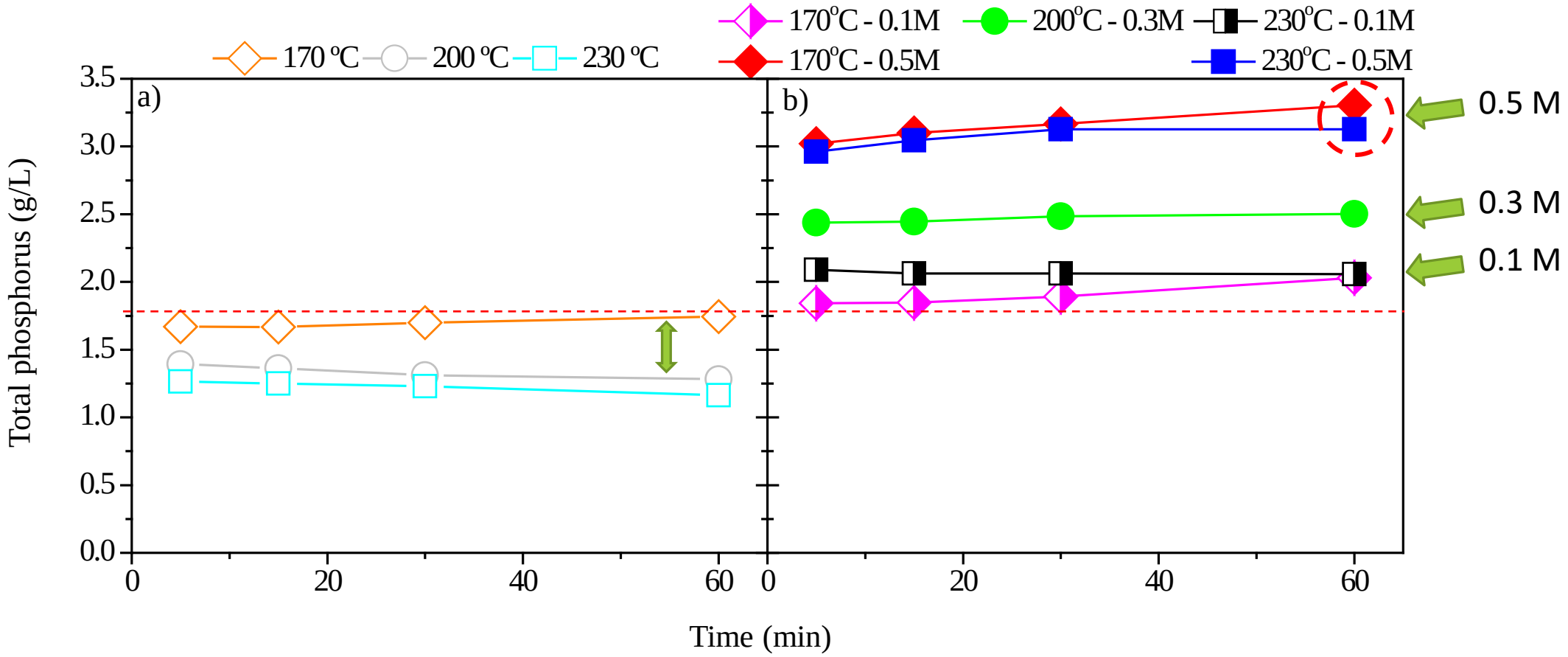
OBJECTIVE

To study the effect of **temperature** and the addition of **acids** during the **hydrothermal carbonization** of digested sludge to **recover phosphorus, nitrogen and potassium** into the **process water**

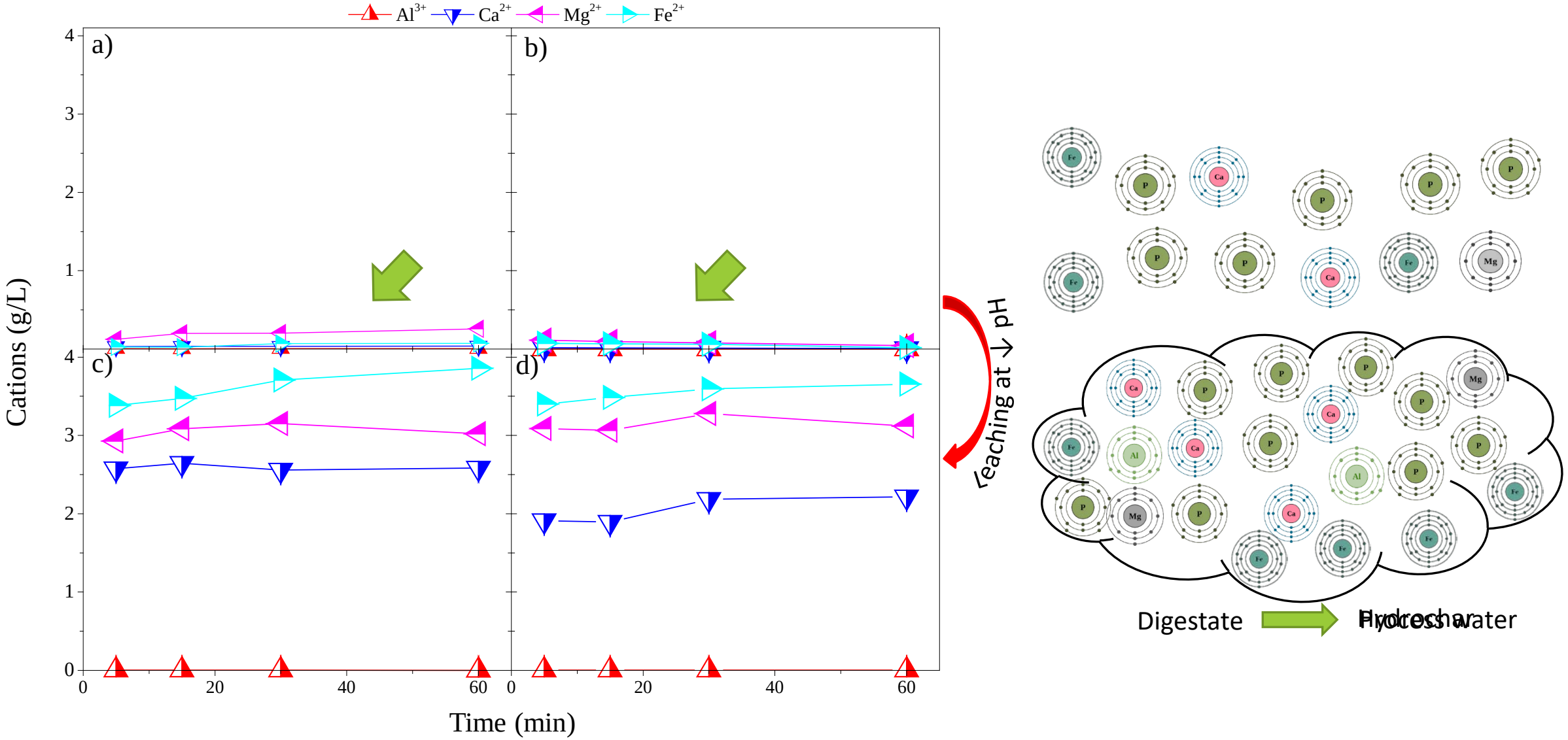
Nutrient recovery from HC



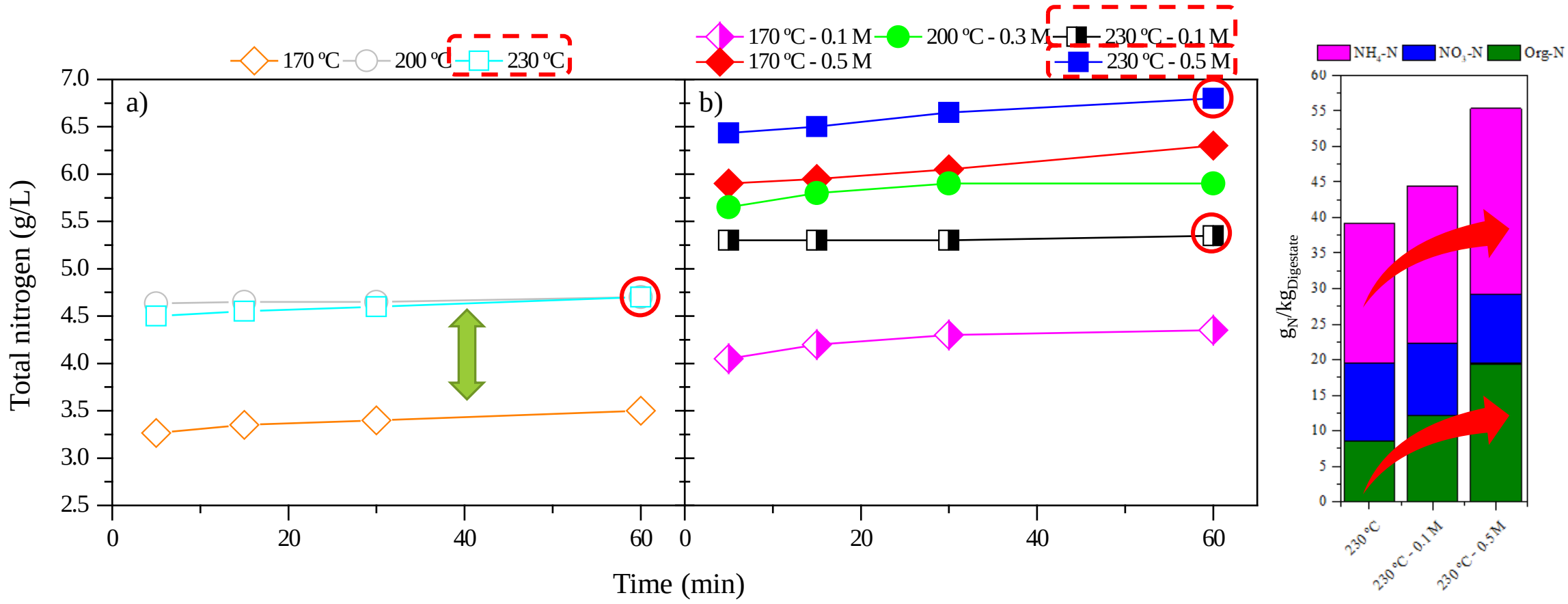
Distribution of nutrients after acid leaching of hydrochar and nutrient recovery in process water plus leachate



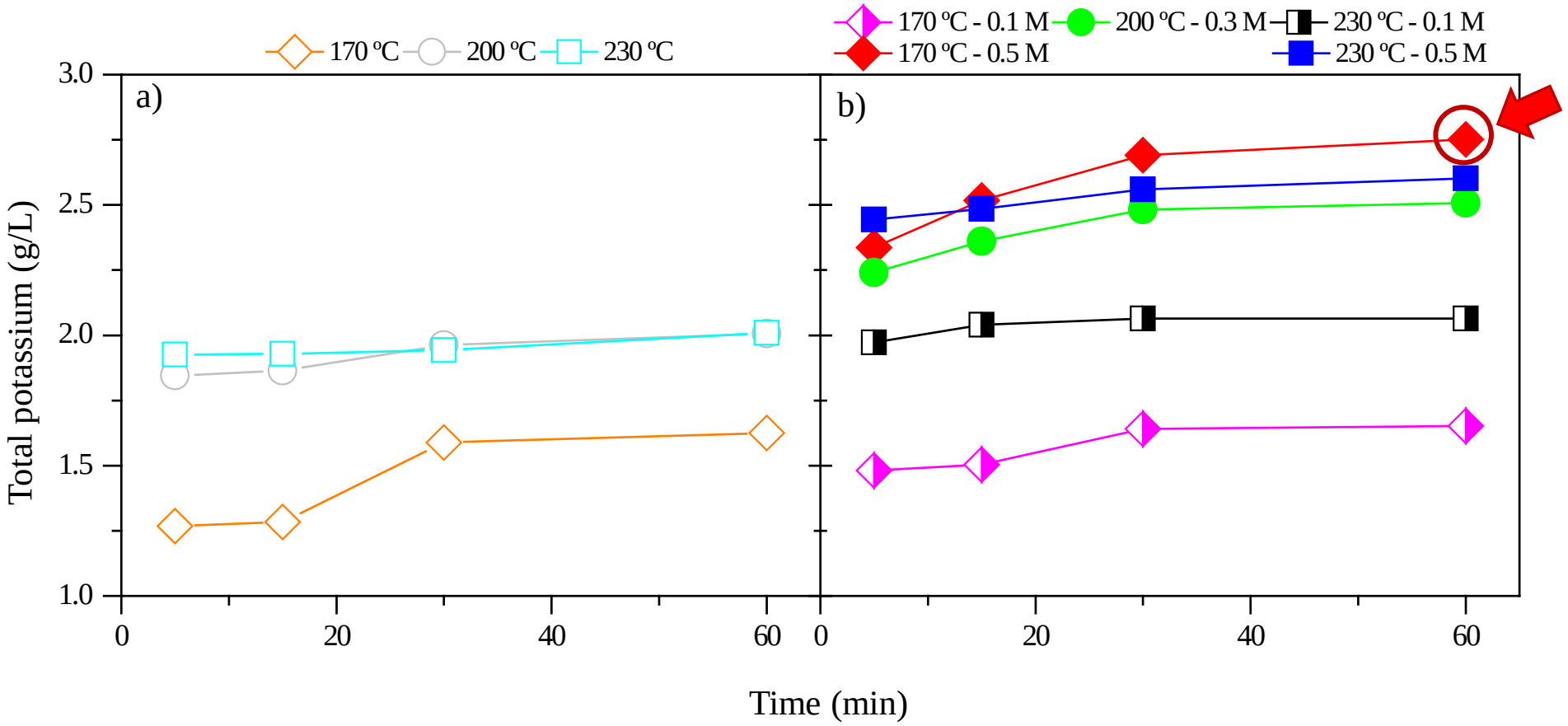
Evolution of total phosphorous in the process water during HTC reaction (a) without acid, (b) mediated by HCl



Evolution of metallic cations dissolved in the process water during HTC at (a) 170 ºC and (b) 230 ºC and HTC mediated by 0.5 M HCl at (c) 170 ºC and (d) 230 ºC



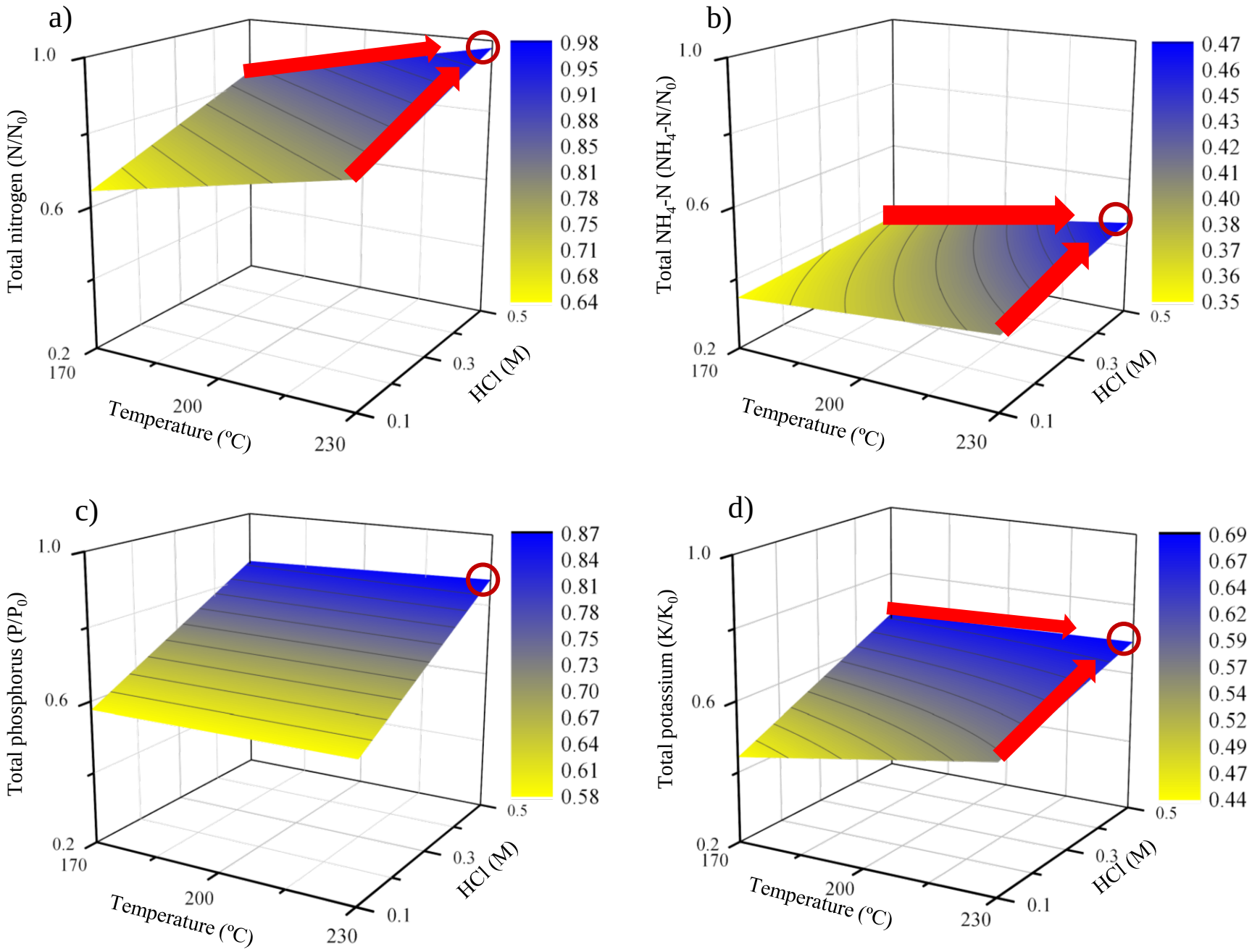
Evolution of total nitrogen in the process water during HTC reaction (a) without acid, (b) mediated by HCl



Evolution of total potassium in the process water during HTC reaction (a) without acid, (b) mediated by HCl

Distribution of nutrients in hydrochar and process water from HTC of digested sludge (d.b)

Sample	N	P	K	Sample	N	P	K
HC-170	28.4	14.1	18.4	PW-170	27.9	13.9	13.0
HC-200	18.8	18.2	15.2	PW-200	37.3	10.2	15.9
HC-230	16.9	18.6	14.5	PW-230	39.2	9.7	16.8
WHC-170	20.6	4.3	12.0	L-170	7.8	9.8	6.4
WHC-200	11.8	5.5	8.4	L-200	7.0	12.7	6.8
WHC-230	10.0	4.8	5.7	L-230	6.9	13.8	8.8
HC-170-0.1	19.8	11.0	18.3	PW-170-0.1	36.5	17.0	13.4
HC-170-0.5	8.7	3.6	10.9	PW-170-0.5	47.4	24.9	20.7
HC-200-0.3	11.0	9.5	12.1	PW-200-0.3	45.1	19.0	19.2
HC-230-0.1	11.7	10.9	13.9	PW-230-0.1	44.5	17.1	17.3
HC-230-0.5	0.9	3.3	11.2	PW-230-0.5	55.4	25.5	21.2


a)
Total nitrogen (N/N0)
1.0
0.6
0.2
0.98
0.95
0.91
0.88
0.85
0.81
0.78
0.75
0.71
0.68
0.64
170
200
230
Temperature (°C)
0.1
0.3
0.5
HCl (M)
b)
Total NH4-N (NH4-N/N0)
1.0
0.6
0.2
0.47
0.46
0.45
0.43
0.42
0.41
0.40
0.38
0.37
0.36
0.35
170
200
230
Temperature (°C)
0.1
0.3
0.5
HCl (M)
c)
Total phosphorus (P/P0)
1.0
0.6
0.2
0.87
0.84
0.81
0.78
0.75
0.73
0.70
0.67
0.64
0.61
0.58
170
200
230
Temperature (°C)
0.1
0.3
0.5
HCl (M)
d)
Total potassium (K/K0)
1.0
0.6
0.2
0.69
0.67
0.64
0.62
0.59
0.57
0.54
0.52
0.49
0.47
0.44
170
200
230
Temperature (°C)
0.1
0.3
0.5
HCl (M)

Hydrochar Management

Solid Biofuel ??

ISO 17225-8

"Graded thermally and densified biomass fuels"

HHV (MJ kg^{-1})	Ash (%)	VM (%)	N (%)	S (%)
> 18	< 10	< 75	< 3	< 0.5

T – [HCl]		Proximate analysis (wt. %)				Ultimate analysis (wt. %)					HHV (MJ kg^{-1})
		Yield	FC	VM	Ash	C	N	S	H	O	
Digested sludge	X	-	10.8±0.3	59.4±0.4	29.8±0.2	30.5±0.3	5.6±0.1	1.4±0.1	4.6±0.1	28.1±0.1	12.6
HC170	X	76.4	11.1±0.2	49.9±0.3	39.0±0.1	28.3±0.1	3.7±0.1	1.1±0.1	4.2±0.1	24.0±0.1	11.5
HC200	X	57.6	11.3±0.1	45.3±0.8	43.4±0.1	27.7±0.1	3.3±0.1	1.2±0.1	3.9±0.1	20.5±0.1	11.4
HC230	X	57.1	11.4±0.1	43.9±0.1	44.7±0.1	27.3±0.2	3.0±0.1	0.7±0.1	3.9±0.1	17.4±0.1	12.5
WHC170	X	50.8	19.2±0.1	70.3±0.1	10.5±0.1	42.7±0.6	2.6±0.1	0.4±0.1	5.1±0.1	38.7±0.1	17.0
WHC200	✓	39.7	18.7±0.1	71.2±0.1	10.1±0.1	52.3±0.2	2.1±0.1	0.2±0.1	5.9±0.1	29.4±0.1	21.9
WHC230	✓	40.1	19.0±0.1	71.3±0.1	9.7±0.1	52.4±0.1	2.0±0.1	0.2±0.1	5.7±0.1	30.0±0.1	21.9
HC-170-0.1	X	53.7	12.1±0.5	50.2±0.1	37.7±2.3	28.4±0.1	3.7±0.1	1.0±0.1	4.1±0.1	25.1±0.1	11.3
HC-170-0.5	X	25.9	16.7±0.3	48.3±0.1	35.0±0.7	30.9±0.4	3.3±0.1	0.9±0.1	4.2±0.1	25.7±0.1	12.4
HC-200-0.3	X	31.9	12.6±0.1	47.4±0.1	40.0±0.1	31.2±0.6	3.5±0.1	0.8±0.1	4.2±0.1	20.3±0.1	13.2
HC-230-0.1	X	31.5	12.5±0.2	47.4±0.1	40.1±0.3	31.5±0.6	3.5±0.1	1.0±0.1	4.2±0.1	19.7±0.1	13.1
HC-230-0.5	X	51.4	17.4±0.1	43.9±0.1	38.7±0.1	29.1±0.2	2.3±0.1	1.2±0.1	3.8±0.1	24.9±0.1	12.7

Hydrochar Management

Use in soils ??

T – [HCl]	metals (mg kg^{-1})							
	As	Cd	Cr	Cu	Hg	Ni	Pb	Zn
Regulation (EU) 2019/1009	**40**	**2**	**2**	**300**	**1**	**50**	**120**	**800**
Digested sludge	< 0.1	< 0.1	0.6	0.6	< 0.1	0.4	< 0.1	3.7
HC170	< 0.1	< 0.1	0.7	0.5	< 0.1	0.4	< 0.1	2.4
HC200	< 0.1	< 0.1	0.6	0.7	< 0.1	0.4	< 0.1	3.2
HC230	< 0.1	< 0.1	0.4	0.7	< 0.1	0.4	< 0.1	4.7
WHC170	< 0.1	< 0.1	0.2	0.3	< 0.1	0.1	< 0.1	2.3
WHC200	< 0.1	< 0.1	0.3	0.5	< 0.1	0.2	< 0.1	2.5
WHC230	< 0.1	< 0.1	0.3	0.5	< 0.1	0.2	< 0.1	2.6
HC-170-0.1	< 0.1	< 0.1	0.4	0.6	< 0.1	0.3	< 0.1	2.8
HC-170-0.5	< 0.1	< 0.1	0.3	0.7	< 0.1	0.2	< 0.1	2.5
HC-200-0.3	< 0.1	< 0.1	0.3	0.4	< 0.1	0.2	< 0.1	2.2
HC-230-0.1	< 0.1	< 0.1	0.3	0.5	< 0.1	0.2	< 0.1	3.1
HC-230-0.5	< 0.1	< 0.1	0.2	0.5	< 0.1	0.2	< 0.1	2.1

Organic fertilizer & Soil amendment

Conclusions

P recovery in process water

87 % P

[HCl] = 0.5 M

T = 170-230 °C

t = 60 min

N recovery in process water

98 % N

47 % NH_4-N

[HCl] = 0.5 M

T = 230 °C

t = 60 min

K recovery in process water

69 % K

[HCl] = 0.5 M

T = 170-230 °C

t = 60 min

Hydrothermal treatment of digested sludge for nutrient recovery

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CTM2016-76564-R (Spanish MINECO),
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