

Lignin cationization for the removal of phosphates and nitrates from effluents of wastewater treatment plants

Supplementary material (S):

S1: Phosphate kinetics data

Time (mins)	Absorbance @880 nm									Final Conc. (mg/mL)			Ave Conc	Qt (mg/g)	t/qt	ln(qe-qt)	Removal %
	I	II			III			I	II	III							
0.00	0.54	0.51	0.52	0.54	0.51	0.52	0.54	0.51	0.52	0.61	0.61	0.61	0.61	0.00	0.00	-1.41	0.00
1.00	0.16	0.21	0.19	0.21	0.22	0.21	0.22	0.21	0.18	0.20	0.23	0.21	0.21	0.20	5.09	-3.02	64.85
2.50	0.20	0.21	0.21	0.21	0.21	0.22	0.21	0.21	0.19	0.22	0.23	0.21	0.22	0.19	12.90	-2.97	63.90
5.00	0.18	0.21	0.20	0.22	0.23	0.20	0.21	0.20	0.22	0.20	0.23	0.22	0.22	0.19	25.90	-2.95	63.68
10.00	0.21	0.25	0.26	0.27	0.28	0.25	0.19	0.20	0.17	0.26	0.29	0.19	0.25	0.18	55.71	-2.72	59.20
20.00	0.19	0.19	0.16	0.17	0.17	0.18	0.17	0.20	0.18	0.19	0.18	0.19	0.18	0.21	94.81	-3.37	69.58
30.00	0.18	0.19	0.18	0.20	0.18	0.18	0.18	0.18	0.16	0.19	0.19	0.18	0.19	0.21	143.00	-3.34	69.19
40.00	0.18	0.13	0.17	0.18	0.18	0.14	0.21	0.20	0.22	0.16	0.17	0.22	0.18	0.21	188.57	-3.41	69.96
50.00	0.17	0.18	0.17	0.18	0.18	0.16	0.17	0.17	0.17	0.18	0.18	0.18	0.18	0.21	232.85	-3.49	70.82
60.00	0.19	0.18	0.17	0.19	0.20	0.18	0.22	0.19	0.18	0.19	0.20	0.21	0.20	0.21	292.30	-3.22	67.70
70.00	0.18	0.18	0.16	0.19	0.19	0.19	0.19	0.19	0.16	0.18	0.20	0.18	0.19	0.21	333.66	-3.34	69.19
80.00	0.22	0.18	0.17	0.19	0.18	0.18	0.16	0.18	0.16	0.20	0.19	0.17	0.19	0.21	381.33	-3.34	69.19
90.00	0.16	0.16	0.15	0.15	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.16	0.22	402.94	-3.82	73.67

S2: Phosphate isotherms data

Ci (ppm)	Absorbance @ 880 nm								Conc (ppm)			qt (mg/g)			
	I	II	III	I	II	III	I	II	III	I	II	III			
1	0.3	0.28	0.27	0.34	0.34	0.25	0.39	0.39	0.29	0.31	0.35	0.4	0.34	0.32	0.3
0.9	0.34	0.34	0.29	0.29	0.31	0.27	0.35	0.36	0.26	0.36	0.32	0.37	0.27	0.29	0.27
0.8	0.23	0.23	0.23	0.3	0.31	0.28	0.23	0.23	0.19	0.25	0.33	0.23	0.27	0.24	0.28
0.7	0.19	0.21	0.22	0.23	0.24	0.23	0.2	0.22	0.21	0.22	0.25	0.22	0.24	0.23	0.24
0.6	0.18	0.18	0.18	0.18	0.18	0.19	0.18	0.19	0.17	0.19	0.19	0.19	0.21	0.21	0.21
0.5	0.15	0.15	0.13	0.15	0.14	0.16	0.16	0.16	0.15	0.14	0.15	0.15	0.18	0.17	0.17

Ci (ppm)	Ce (ppm)	1/Ce	Log Ce	Ln Ce	qe (mg/g)	1/qe	Log qe	Ce/qe
1	0.36	2.81	-0.45	-1.03	0.32	3.1	-0.49	1.1
0.9	0.35	2.86	-0.46	-1.05	0.27	3.64	-0.56	1.27
0.8	0.27	3.7	-0.57	-1.31	0.26	3.78	-0.58	1.02
0.7	0.23	4.34	-0.64	-1.47	0.23	4.26	-0.63	0.98
0.6	0.19	5.36	-0.73	-1.68	0.21	4.84	-0.68	0.9
0.5	0.15	6.79	-0.83	-1.92	0.18	5.67	-0.75	0.83

S3: Doehlert's matrix design for Phosphates

Exp #	Ads dose (mg/mL)	Ci (ppm)	Time (min)	Absorbance @ 880 nm @ filter						Absorbance @ t=0			
				I		II		I		II			
1.00	6.00	50.25	25.00	0.49	0.49	0.48	0.50	0.50	0.51	0.54	0.55	0.55	
2.00	10.00	50.25	25.00	0.42	0.42	0.42	0.42	0.43	0.43	0.54	0.57	0.55	
3.00	2.00	50.25	25.00	0.44	0.54	0.55	0.54	0.49	0.54	0.52	0.56	0.54	
4.00	8.00	100.00	25.00	0.49	0.48	0.51	0.50	0.50	0.50	0.55	0.55	0.55	
5.00	4.00	0.50	25.00	0.11	0.12	0.12	0.13	0.13	0.12	0.56	0.56	0.55	
6.00	8.00	0.50	25.00	0.09	0.10	0.10	0.07	0.07	0.07	0.54	0.55	0.55	
7.00	4.00	100.00	25.00	0.54	0.56	0.56	0.56	0.55	0.54	0.55	0.56	0.55	

Exp #	Ads dose (mg/mL)	Final conc (ppm)			qt (mg/g)		Removal %		Ave	STD
		Zeros	I	II	I	II	I	II		
1.00	6.00	0.64	0.56	0.58	3.84	2.77	11.98	8.63	10.30	2.37
2.00	10.00	0.65	0.48	0.49	8.32	7.89	25.60	24.27	24.93	0.94
3.00	2.00	0.63	0.59	0.61	1.86	1.16	5.86	3.65	4.76	1.57
4.00	8.00	0.64	0.57	0.58	6.66	6.50	10.38	10.13	10.26	0.18
5.00	4.00	0.65	0.11	0.11	0.27	0.27	83.45	82.37	82.91	0.76
6.00	8.00	0.64	0.08	0.05	0.28	0.29	87.74	92.38	90.06	3.28
7.00	4.00	0.65	0.64	0.64	0.74	0.45	1.14	0.70	0.92	0.31

S4: Nitrates Kinetics data

Time (mins)	Final Conc.(mg/L)			Ave Conc. (mg/mL)	Qt (mg/g)	t/qt	ln(qe-qt)	NO ₃ Removal %		
	I	II	III							
0.00	5.50	5.50	5.50	5.50	0.00	0.00	-0.20	0.00	0.00	0.00
1.00	4.00	4.90	4.90	4.60	0.45	2.22	-1.00	16.36	27.27	10.91
2.50	3.80	4.60	4.60	4.33	0.58	4.29	-1.46	21.21	30.91	16.36
5.00	4.10	4.50	5.10	4.57	0.47	10.71	-1.05	16.97	25.45	18.18
10.00	4.10	4.60	4.80	4.50	0.50	20.00	-1.15	18.18	25.45	16.36
20.00	4.20	4.60	4.50	4.43	0.53	37.50	-1.26	19.39	23.64	16.36
30.00	4.10	4.40	4.70	4.40	0.55	54.55	-1.32	20.00	25.45	20.00
40.00	4.30	4.60	4.20	4.37	0.57	70.59	-1.39	20.61	21.82	16.36
50.00	4.30	4.70	4.10	4.37	0.57	88.24	-1.39	20.61	21.82	14.55
60.00	3.50	4.40	4.30	4.07	0.72	83.72	-2.30	26.06	36.36	20.00
70.00	3.10	4.40	4.40	3.97	0.77	91.30	-3.00	27.88	43.64	20.00
80.00	4.20	3.70	4.20	4.03	0.73	109.09	-2.48	26.67	23.64	32.73
90.00	3.90	4.10	4.60	4.20	0.65	138.46	-1.79	23.64	29.09	25.45

S5: Nitrates isotherm data

Ci (ppm)	Conc (mg/L)			qt (mg/g)			Ce (ppm)	1/Ce	Log Ce	Ln Ce	qe (mg/g)	1/qe	Log qe	Ce/qe
	I	II	III	I	II	III								
15.80	14.20	13.60	14.00	0.80	1.10	0.90	13.93	0.07	1.14	2.63	0.93	1.07	-0.03	14.93
13.80	12.10	11.70	12.30	0.85	1.05	0.75	12.03	0.08	1.08	2.49	0.88	1.13	-0.05	13.62
11.60	9.60	9.50	10.10	1.00	1.05	0.75	9.73	0.10	0.99	2.28	0.93	1.07	-0.03	10.43
7.30	5.90	5.90	5.70	0.70	0.70	0.80	5.83	0.17	0.77	1.76	0.73	1.36	-0.13	7.95
5.50	4.50	4.10	3.80	0.50	0.70	0.85	4.13	0.24	0.62	1.42	0.68	1.46	-0.17	6.05
3.60	2.80	2.90	3.00	0.40	0.35	0.30	2.90	0.34	0.46	1.06	0.35	2.86	-0.46	8.29

S6: Doehlert's matrix design for Nitrates

Adsorbent dose (mg/L)	Ci (mg/L)	Time (min)	Final conc (mg/L)		Removal %		Av. removal %	STD
			I	II	I	II		
6.00	13.55	25.00	9.50	8.90	29.89	34.32	32.10	3.13
10.00	13.55	25.00	7.20	5.70	46.86	57.93	52.40	7.83
2.00	13.55	25.00	12.00	11.50	11.44	15.13	13.28	2.61
8.00	24.10	25.00	16.70	17.80	30.71	26.14	28.42	3.23
4.00	3.00	25.00	1.90	2.00	36.67	33.33	35.00	2.36
8.00	3.00	25.00	0.60	0.80	80.00	73.33	76.67	4.71
4.00	24.10	25.00	19.30	18.40	19.92	23.65	21.78	2.64

S7: Doehlert's model data for phosphates and nitrates

Adsorbent dose (mg/mL)	Phosphate conc (mg/L)	Phosphate removal %	Nitrate conc (mg/L)	Nitrate removal %
2.00	0.50	81.51	3.00	17.78
2.00	10.45	60.75	5.11	15.27
2.00	20.40	42.75	7.22	13.41
2.00	30.35	27.52	9.33	12.20
2.00	40.30	15.06	11.44	11.65
2.00	50.25	5.37	13.55	11.75
2.00	60.20	-1.55	15.66	12.51
2.00	70.15	-5.71	17.77	13.92
2.00	80.10	-7.10	19.88	15.99
2.00	90.05	-5.72	21.99	18.71
2.00	100.00	-1.57	24.10	22.08
2.80	0.50	81.55	3.00	25.24
2.80	10.45	60.83	5.11	22.02
2.80	20.40	42.88	7.22	19.46
2.80	30.35	27.70	9.33	17.55
2.80	40.30	15.28	11.44	16.30
2.80	50.25	5.63	13.55	15.70
2.80	60.20	-1.25	15.66	15.76
2.80	70.15	-5.36	17.77	16.47
2.80	80.10	-6.71	19.88	17.84
2.80	90.05	-5.28	21.99	19.86
2.80	100.00	-1.09	24.10	22.53
3.60	0.50	81.96	3.00	32.75
3.60	10.45	61.28	5.11	28.84
3.60	20.40	43.37	7.22	25.57
3.60	30.35	28.23	9.33	22.97
3.60	40.30	15.86	11.44	21.01

3.60	50.25	6.25	13.55	19.72
3.60	60.20	-0.58	15.66	19.07
3.60	70.15	-4.65	17.77	19.08
3.60	80.10	-5.95	19.88	19.75
3.60	90.05	-4.49	21.99	21.07
3.60	100.00	-0.25	24.10	23.04
4.40	0.50	82.73	3.00	40.33
4.40	10.45	62.09	5.11	35.71
4.40	20.40	44.23	7.22	31.75
4.40	30.35	29.13	9.33	28.44
4.40	40.30	16.80	11.44	25.78
4.40	50.25	7.24	13.55	23.79
4.40	60.20	0.45	15.66	22.44
4.40	70.15	-3.58	17.77	21.75
4.40	80.10	-4.84	19.88	21.72
4.40	90.05	-3.33	21.99	22.33
4.40	100.00	0.95	24.10	23.61
5.20	0.50	83.86	3.00	47.96
5.20	10.45	63.27	5.11	42.64
5.20	20.40	45.45	7.22	37.98
5.20	30.35	30.39	9.33	33.97
5.20	40.30	18.11	11.44	30.61
5.20	50.25	8.59	13.55	27.92
5.20	60.20	1.84	15.66	25.87
5.20	70.15	-2.14	17.77	24.48
5.20	80.10	-3.36	19.88	23.74
5.20	90.05	-1.80	21.99	23.66
5.20	100.00	2.52	24.10	24.23
6.00	0.50	85.35	3.00	55.65
6.00	10.45	64.81	5.11	49.63
6.00	20.40	47.03	7.22	44.27
6.00	30.35	32.02	9.33	39.56

6.00	40.30	19.78	11.44	35.50
6.00	50.25	10.30	13.55	32.10
6.00	60.20	3.60	15.66	29.36
6.00	70.15	-0.34	17.77	27.27
6.00	80.10	-1.51	19.88	25.83
6.00	90.05	0.09	21.99	25.05
6.00	100.00	4.45	24.10	24.92
6.80	0.50	87.21	3.00	63.40
6.80	10.45	66.71	5.11	56.68
6.80	20.40	48.97	7.22	50.62
6.80	30.35	34.01	9.33	45.21
6.80	40.30	21.81	11.44	40.45
6.80	50.25	12.38	13.55	36.35
6.80	60.20	5.72	15.66	32.90
6.80	70.15	1.82	17.77	30.11
6.80	80.10	0.70	19.88	27.98
6.80	90.05	2.34	21.99	26.49
6.80	100.00	6.75	24.10	25.66
7.60	0.50	89.43	3.00	71.21
7.60	10.45	68.97	5.11	63.79
7.60	20.40	51.28	7.22	57.02
7.60	30.35	36.36	9.33	50.91
7.60	40.30	24.20	11.44	45.46
7.60	50.25	14.82	13.55	40.66
7.60	60.20	8.20	15.66	36.51
7.60	70.15	4.35	17.77	33.02
7.60	80.10	3.27	19.88	30.18
7.60	90.05	4.95	21.99	28.00
7.60	100.00	9.41	24.10	26.47
8.40	0.50	92.02	3.00	79.08
8.40	10.45	71.60	5.11	70.96
8.40	20.40	53.95	7.22	63.49

8.40	30.35	39.08	9.33	56.68
8.40	40.30	26.96	11.44	50.52
8.40	50.25	17.62	13.55	45.02
8.40	60.20	11.05	15.66	40.18
8.40	70.15	7.24	17.77	35.98
8.40	80.10	6.20	19.88	32.44
8.40	90.05	7.93	21.99	29.56
8.40	100.00	12.43	24.10	27.33
9.20	0.50	94.96	3.00	87.00
9.20	10.45	74.59	5.11	78.18
9.20	20.40	56.99	7.22	70.02
9.20	30.35	42.15	9.33	62.51
9.20	40.30	30.09	11.44	55.65
9.20	50.25	20.79	13.55	49.45
9.20	60.20	14.26	15.66	43.90
9.20	70.15	10.49	17.77	39.01
9.20	80.10	9.50	19.88	34.77
9.20	90.05	11.27	21.99	31.18
9.20	100.00	15.81	24.10	28.25
10.00	0.50	98.28	3.00	94.99
10.00	10.45	77.95	5.11	85.47
10.00	20.40	60.39	7.22	76.60
10.00	30.35	45.60	9.33	68.39
10.00	40.30	33.57	11.44	60.83
10.00	50.25	24.32	13.55	53.93
10.00	60.20	17.83	15.66	47.68
10.00	70.15	14.11	17.77	42.09
10.00	80.10	13.16	19.88	37.15
10.00	90.05	14.98	21.99	32.86
10.00	100.00	19.56	24.10	29.23