Supplementary material

Optimization and Efficiency of Novel Magnetic Resin-Based-Approaches for Enchanced Nickel Removal form Water

Marija Maletin[1], Jasmina Nikić[1*], Vesna Gvoić[2], Jovana Pešić[1], Željka Cvejić[1], Aleksandra Tubić[1] and Jasmina Agbaba[1]


[1] University of Novi Sad, Faculty of Sciences, Trg Dositeja Obradovića 3, 21000 Novi Sad, Serbia

[2] University of Novi Sad, Faculty of Technical Sciences, Trg Dositeja Obradovića 6, 21000 Novi Sad, Serbia

*Corresponding author, e-mail: jasmina.nikic@dh.uns.ac.rs
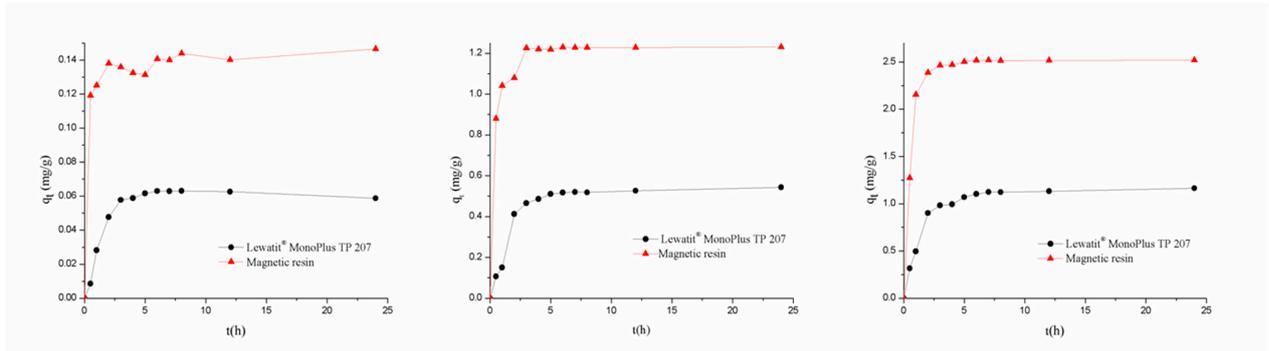
(a) **(b)** **(c)**

Figure S1. Adsorption of Ni(II) onto Lewatit® MonoPlus TP 207 and magnetic resin as a function of contact time under varying initial concentrations: (a) 0.05 mg/L, (b) 0.5 mg/L, and (c) 1 mg/L. Experimental conditions: resin dosage = 0.5 ml/l, solution volume = 500 mL (synthetic water matrix containing Ni(II)), pH = 7.0 ± 0.2, contact time = 30 min to 24 h, agitation speed = 120 rpm, temperature = 298 ± 2 K.
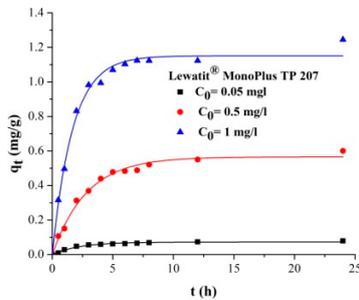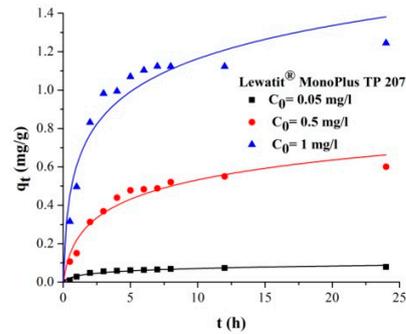
(a) **(b)**
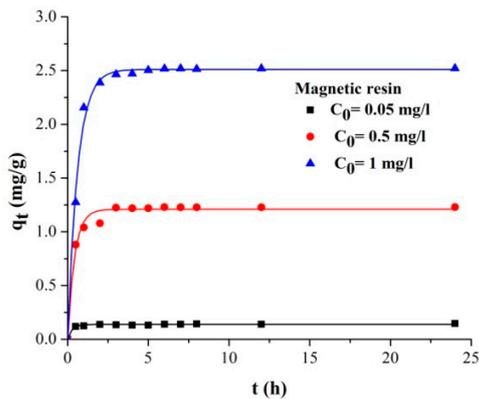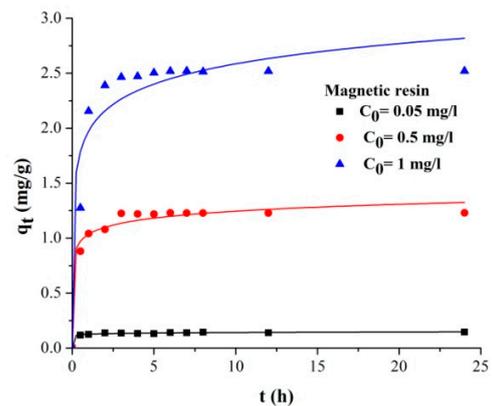
(c) **(d)**

Figure S2. Kinetic plots for Ni(II) adsorption onto Lewatit® MonoPlus TP 207 and magnetic resins under various kinetic models. (a) Pseudo-first-order model for Lewatit® MonoPlus TP 207 resin; (b) Elovich model for Lewatit® MonoPlus TP 207 resin; (c) pseudo-first-order model for magnetic resin; (d) Elovich model for magnetic resin. Experimental conditions: resin dosage = 0.5 ml/l mg, solution volume = 500 mL (synthetic water matrix containing Ni(II)), pH = 7.0 ± 0.2, contact time = 30 min to 24 h, agitation speed = 120 rpm, temperature = 298 ± 2 K.)
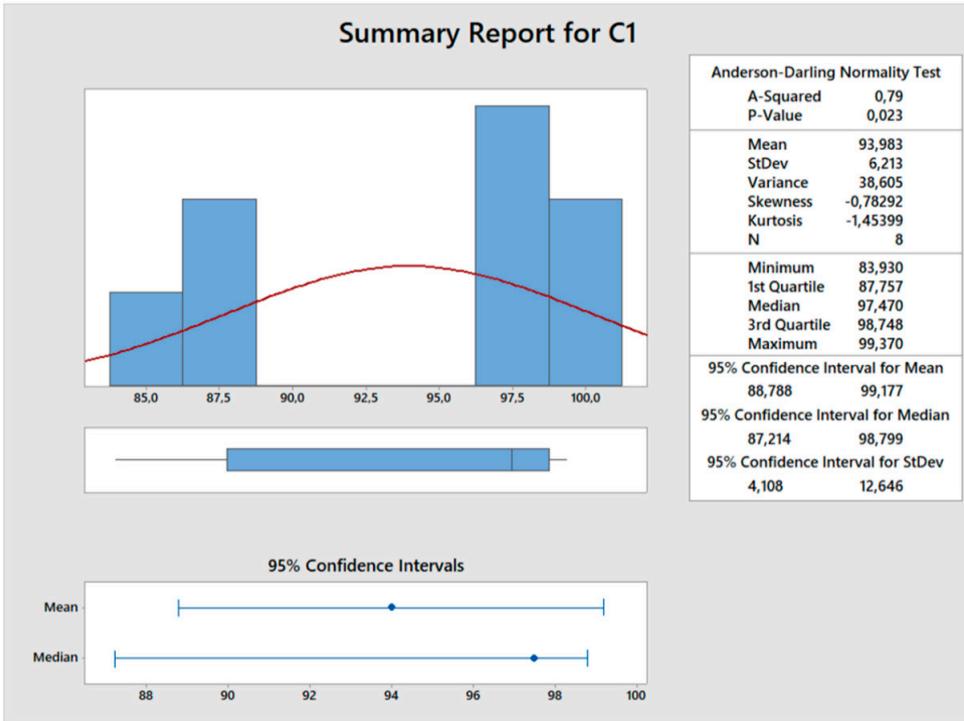
a)
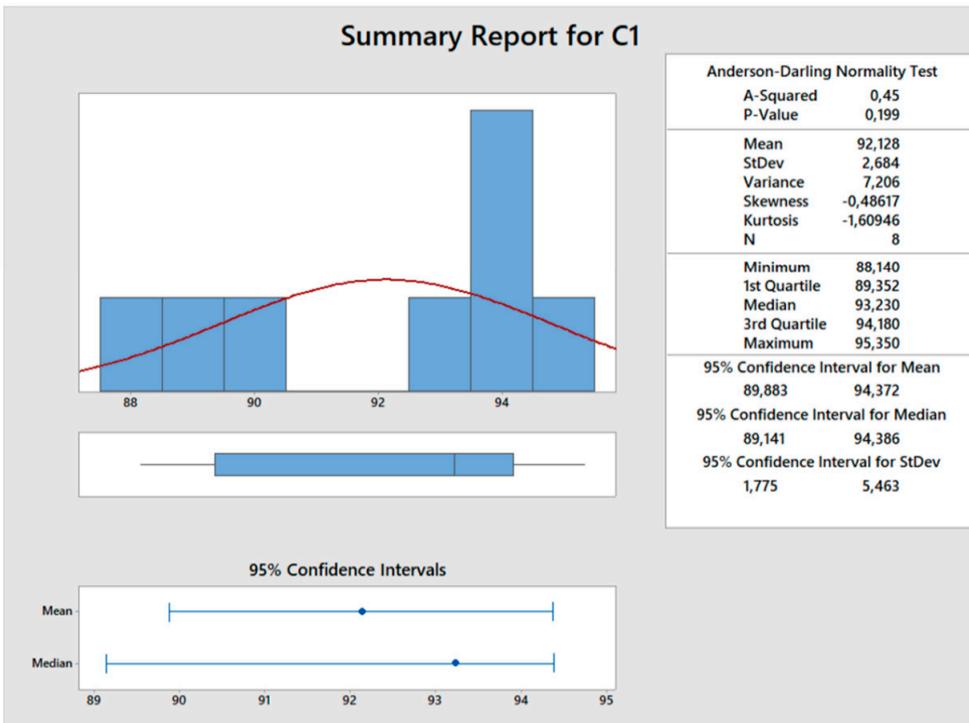
b)

Figure S3. Verification diagram for: (**a**) Lewatit® MonoPlus TP 207; (**b**) magnetic resin

Table S1. Mathematical models used for modelling data obtained in kinetic and isotherm adsorption experiments

Model	Non-linear form	Linear form	Parameters od model
Pseudo-first-order	$\dfrac{dq_t}{dt} = k_1(q_e - q_t)$	$\log(q_e - q_t) = \log q_e - \dfrac{k_1}{2.303}t$	k_1 – pseudo-first-order sorption rate constant (1/min) q_e - the amount of metal ion adsorbed (mg/g) q_t – sorption capacity at equilibrium conditions and at time t (mg/g) t – contact time between adsorbate and adsorbent (min)
Pseudo-second-order	$\dfrac{dq_t}{dt} = k_2(q_e - q_t)^2$	$\dfrac{t}{q_t} = \dfrac{1}{k_2 q_e^2} + \dfrac{1}{q_e}t$	k_2 – pseudo-second-order sorption rate constant (g/mg min)
Elovich	$\dfrac{dq_t}{dt} = \alpha\, exp(-\beta q_t)$	$q_t = \dfrac{1}{\beta}\ln(\alpha\beta) + \dfrac{1}{\beta}\ln t$	α – initial sorption rate constant (mg/g min) β – desorption constant (g/mg)
Freundlich	$q_e = K_F C_e^{n_F}$	$\log q_e = \log K_F + n_F \log C_e$	C_e - the concentration (mg/L) of metal ion in the solution atequilibrium K_F - Freundlich constant which predicts the quantity of metal ion per gram of resin at the unit equilibrium concentration ((mg/g)/(mg/L)^n) n_F - a measure of the nature and strength of the adsorption process and of the distribution of active sites
Langmuir	$q_e = \dfrac{q_{max}K_L C_e}{1 + K_L C_e}$	$\dfrac{C_e}{q_e} = \dfrac{\alpha_L}{K_L}C_e + \dfrac{1}{K_L}$	K_L - adsorption equilibrium constant (L/mg) α_L - saturated monolayer adsorption capacity constant

Table S2. Kinetic parameters for the sorption of Ni(II) onto Lewatit® MonoPlus TP 207 and magnetic resin

Lewatit® MonoPlus TP 207												
Concentration level (mg/l)	Pseudo first order				Pseudo second order				Elovich			
	k_1 (g/mg min)	q_e (mg/g)	R^2		k_2 (g/mg min)	q_e (mg/g)	R^2		α (mg/g min)	β (g/mg)	R^2	
0.05	0.441	0.0724	0.9740		5.94	0.085	0.9811		0.083	53.7	0.9462	
0.5	0.354	0.565	0.9895		0.61	0.674	0.9899		0.488	6.56	0.9587	
1	0.593	1.15	0.9897		0.562	1.324	0.9875		2.55	3.98	0.9398	
Magnetic resins												
Concentration level (mg/l)	Pseudo first order				Pseudo second order				Elovich			
	k_1 (g/mg min)	q_e (mg/g)	R^2		k_2 (g/mg min)	q_e (mg/g)	R^2		α (mg/g min)	β (g/mg)	R^2	
0.05	3.68	0.138	0.9811		66.9	0.1417	0.9898		1.26	150.8	0.9916	
0.5	2.34	1.21	0.9829		3.61	1.264	0.9943		8164	11.00	0.9736	
1	1.61	2.51	0.9937		1.01	2.6713	0.9735		447.4	3.76	0.9104	

Table S3. DSD experimental design layout and nickel removal efficiency

Run	pH	Contact time (min)	Resin dosage (mL/L)	Ni (µg/L)	Ca (mg/L)	Mg (mg/L)	Removal efficiency (%)	
							Lewatit® MonoPlus TP 207	Magentic resin
1	7	480	5	200	500	100	99.8	76.66
2	7	30	0.5	20	50	5	63.6	90.55
3	9	255	0.5	200	500	5	63.6	96.32
4	5	255	5	20	50	100	88.1	88.19
5	9	30	2.75	20	500	100	33.0	76.75
6	5	480	2.75	200	50	5	99.8	99.03
7	9	480	0.5	110	50	100	99.5	83.46
8	5	30	5	110	500	5	81.9	98.64
9	9	480	5	20	275	5	97.7	88.93
10	5	30	0.5	200	275	100	49.0	73.09
11	9	30	5	200	50	52.5	89.8	69.17
12	5	480	0.5	20	500	52.5	97.7	80.54
13	7	255	2.75	110	275	52.5	99.5	98.81
14	7	480	5	200	500	100	99.8	82.27
15	7	30	0.5	20	50	5	45.2	97.10
16	9	255	0.5	200	500	5	96.1	95.38
17	5	255	5	20	50	100	99.8	94.83
18	9	30	2.75	20	500	100	35.8	71.53
19	5	480	2.75	200	50	5	99.8	99.35
20	9	480	0.5	110	50	100	99.5	82.13
21	5	30	5	110	500	5	84.6	99.38
22	9	480	5	20	275	5	97.7	85.53
23	5	30	0.5	200	275	100	35.4	68.04
24	9	30	5	200	50	52.5	83.3	74.75
25	5	480	0.5	20	500	52.5	50.0	90.97
26	7	345	2.75	110	275	52.5	99.5	99.42
27	7	345	2.75	110	275	52.5	99.5	98.94
28	7	345	2.75	110	275	52.5	98.4	99.04

Table S4. Summary of fit

Descriptive factor	Lewatit® MonoPlus TP 207	Magentic resin
R^2	0.871	0.948
R^2adj	0.785	0.907
AIC	233.152	175.164
BIC	224.249	161.186
RMSE	11.209	3.241
Mean of response	80.365	86.955

Table S5. Analysis of variance and „lack of fit" test

Source	[a]DF	[b]SS	[c]MS	F ratio
Lewatit® MonoPlus TP 207				
Model	10	12751.32	1275.13	10.15
Error	15	1884.56	125.64	**Prob>F**
C. Total	25	14635.88		**<0.0001**
Magentic resin				
Model	11	2661.31	241.94	23.04
Error	14	147.03	10.50	**Prob>F**
C. Total	25	2808.34	-	**<0.0001**

[a]Degrees of freedom; [b]Sum of squares; [c]Mean square

Table S6. Estimated regression coefficients of the significant main and interaction effects

Parameter	Estimate	Std Error	t value	Prob >[t]
Lewatit® MonoPlus TP 207				
Contact time (min)	16.985	2.438	6.970	**<0.0001**
Calcium (mg/L)	-6.305	2.438	-2.590	**0.0181**
pH * Nickel (µg/L)	7.513	2.726	2.760	**0.0126**
Nickel (µg/L)	5.390	2.438	2.210	**0.0395**
Resin dosage (mL/L)	11.145	2.438	4.570	0.0682
Magnesium (mg/L)	-4.515	2.438	-1.850	0.0796
pH	0.495	2.438	0.200	0.8413
Magentic resin				
Magnesium (mg/L)	-7.663	0.725	-10.570	**<0.0001**
pH	-3.406	0.725	-4.700	**0.0003**
Contact time (min)	2.494	0.725	3.440	**0.0040**
pH * Magnesium (mg/L)	3.289	1.140	2.890	**0.0120**
Nickel (µg/L)	-1.543	0.725	-2.130	0.052
Resin dosage (mL/L) * Calcium (mg/L)	2.299	1.140	2.890	0.312

pH * Resin dosage (mL/L)	-1.096	1.323	-0.830	0.422
Calcium (mg/L)	-0.506	0.725	-0.700	0.496
Resin dosage (mL/L)	0.039	0.725	0.050	0.958

Table S7. Experimental verification of optimized ion exchange processes

Run	Lewatit® MonoPlus TP 207	Magnetic resin
1	83.93	88.14
2	87.44	89.21
3	97.64	93.76
4	99.37	95.35
5	97.30	93.57
6	98.76	89.78
7	88.71	94.32
8	93.71	92.89
95% confidence interval	88.79 - 99.18	89.89 - 94.37