Supplementary material to

Reciprocating plate column - fundamental research and application in Serbia from 1970 to 2020

Vlada B. Veljković[1,2], Ivana B. Banković Ilić[1] and Dejan U. Skala[3]

[1]University of Niš, Faculty of Technology, Leskovac, Serbia
[2]Serbian Academy of Sciences and Arts, Belgrade, Serbia
[3]University of Belgrade, Faculty of Technology and Metallurgy, Belgrade, Serbia

Hem. Ind. **78(3)** 187-203 (2024); https://doi.org/10.2298/HEMIND230320028V

Table S-1. Types of RPCs [1]

Plate type	Reciprocating element	Characteristics	Country
Karr (KRPC)	Plates with large openings (open type)	Column diameter up to 1.7 m Large fractional free plate surface (50-60 %) Large plate opening diameter (10-16 mm) Plate modification - with a central opening (Baird type) Inserted buffers along the column of larger diameter reduce the radial flow non-uniformity. Operating mode: homogeneous	USA, Canada, Western Europe, India, Serbia
Prochazka (PRPC)	Plates with downcomers or segmental passages	Column diameter up to 1.2 m Small fractional free plate surface (4-30 %) Small plate opening diameter (2-5 mm) With a drain in the form of a pipe or a segmental passage in the form of a cut-off part of the plate (free surface fraction of 10-25 %) Movement of plats: all in the same phase or every other with a phase shift of 180° Operating mode: segregated and homogeneous	Czech Republic, Canada
Tojo and Miyanami (VDC)	Vibrating discs	Discs without perforations The fractional free plate surface depends on the disk diameter-to-column diameter ratio (4-0.78 %) Static buffers between every two disks	Japan
Karpačeva and Gorodetskiy (KRIMZ, GIAP)	Plates with rectangular openings	Column diameter up to 1.5 m, height up to 11 m Fractional-free plate surface about 45 % Rectangular openings with bent ends that divert fluid flow radially to reduce axial mixing Plates without (KRIMZ) or with a drain (GIAP)	Former USSR

[a]GIAP - the plate with rectangular openings with a drain, KRIMZ - the plate with rectangular openings without a drain, KRPC - the Karr type RPC, PRPC - the Prochazka type RPC, and VDC - the vibrating disc column.

Table S-2. Overview of previous research on RPCs in Serbia (adapted according to [1])

System	Phase flow	D_c / cm	l_c / m	n_p	h / cm	d_o / cm	ε	A / mm	f / Hz	u_g / cm s^{-1}	Subject[a]	Ref.
Water	-	2.54		18			0.51				Δp, P	[2]
Water-toluene, water-*n*-butanol	Batch	2.54	2.11	78	2.54	0.8	0.51	5-19.6	0.5-3.5	-	Δp, P	[3]
Water-toluene	-	2.54	2.71	18	2.54	ND	0.51	20.5	0.275-2	-	Δp	[4]
Water, air-sulfite solution	↑↓	2.54	2.14	65	2.6	0.8/0.6	0.51	0.65-2	0.483-6.18	0.8-3.2	D_l, ε_g, a	[5]
Air-water	↑↓	2.54	2.14	32 64	2.54 5.08	0.8/0.6	0.51	0.65-1.5	1.83-6	0.8; 2.9	D_l,	[6]
Water, air-sucrose solution	↑↓	2.54	2	33 65	2.54	0.7/0.5 0.8/0.6	0.41 0.51	<10 and <20	<10	< 5	Δp. P, ε_g, k_la, a	[7]

System	Phase flow	D_c / cm	l_c / m	n_p	h / cm	d_o / cm	ε	A / mm	f / Hz	u_g / cm s^{-1}	Subject[a]	Ref.
Water, air-sucrose, sulfate, mixtures of sucrose, fructose, and dextran	↑↓	2.54	2.14	32 64	2.54 5.08	0.8/0.6	0.51	0.65-1.5	1.83-6	0.275 to 1.1	k_la, dextran sucrase production	[8]
Water, air-sucrose, air-water	Batch	2.54	2	65 33	2.5 5.0	0.7/0.5	0.41	1-10	1-10	0.275 to 2.75	Δp, P, ε_g	[9]
Air-water	↑↓	2.54	2	33 65	5.0 2.5	0.7/0.5	0.41	1-10	1-10		ε_g	[10]
Water, air-solutions of sucrose, sulfate, and mixtures of sucrose, fructose, and dextran	↑↓	2.54	2	65 33	5.08 2.54	0.8/0.6 0.7/0.5	0.51 0.41	<20	<6.2	<5	k_la	[11]
Water, air, N_2, O_2-sucrose and sulfite solutions	Batch or ↑↓	2.54	2	65 33	5.08 2.54	0.8/0.6	0.51	<20	<6.2	<5	a	[12]
Air-water	↑↓	2.54	2	65 32	2.54 5.08	0.8/0.6	0.51	0-20	0-6.25	0.8-3.1	ε_g	[13]
Water, air-sucrose solution, fermentation medium	↑↓	2.54	2	65 33	2.54 5.08	0.8/0.6 0.7/0.5	0.51 0.41	-	-	-	k_la, dextran sucrase production	[14]
Air-water-solid	↑↓	2.54	2	65	2.54	0.8	0.51	17	0-6.4	0.5-12.8	ε_g, d_b	[15]
Air-water	Batch	2.54	2	65	2.54	0.8/0.6	0.51	13-23.5	1-7.2	0.4-7.5	Δp, P, ε_g	[16, 17]
Water, butanol (0.5 %), glycerol (69 %, 64 %), sulfite (0.8 mol dm^{-3}) and CMC (1 and 2 %) solutions; 2-phase (gas-liquid; liquid-solid) and 3-phase systems	Batch	2.54 9.2	1.836 1.05	65 15	2.54 5	0.8 0.8	0.51 0.454	2.35 2.35	2-6 2-6	0.5-1.5 0.5-1.5	Δp, P, ε_g, d_b, k_la, a	[18-20]
Water, air-water, air-water-solid, air-CMC, air-CMC solution (1 %)-solid solution (1 %)-solid	Batch	9.2	1.05	15	5	0.8	0.263 0.319 0.454	2.35	2-6	0.5-1.5	Δp, P, ε_g, k_la, a	[21-26]
CMC solution	Batch	9.2	1.05	15	5	0.8	0.454	2.35	2-5.5	0.5-1.5	ε_g	[27-30]
Air-water-solid	↑↓	2.54 9.2	1.836 0.856	65 15	2.54 5.0	0.8 0.8	0.51 0.454	2.35;1 2.35;1	2-4.5 2-4.5	0-1.48 0-1.88	D_l, ε_g, alcoholic fermentation	[31-37]
Air-water, air-water-solid	↑↓	16.6	0.97	15	5	0.78	0.466	2.35	2-6	0.5-1.5	Δp, P, ε_g, k_la	[31-37]
Air-CMC solution (0.5 - 1.5 %)-solid	Batch	9.2	1.05	15	5	0.8/0.6	0,454	2.35	2-5,5	0.5-1.5	ε_g	[38-43]
Methanol-oil, methanol-KOH-oil	↑ ↑	2.54	2.0	63	2.54	0.8/0.6	0.51	1.0 2.35	2-5	-	Δp, P, d_b, a, biodiesel production	[44]
Methanol-KOH-oil	↑ ↑	2.54	2.0	63	2.54	0.8/0.6	0.51	1.0	2-4	-		[45]
		16.6	1.53	15	5	0.8	0.466	2.35	2	-		
Methanol-oil, methanol-KOH-oil	↑ ↑	2.54	2.0	63	2.54	0.8/0.6	0.51	1.0	2.0	-	d_b, biodiesel production	[46]
Methanol-KOH-waste lard	↑ ↑	2.54	2.0	63	2.54	0.8/0.6	0.51	1.0	2.0	-	Kinetic modeling of biodiesel production	[47]

[a]a - specific interfacial area, d_b, - bubble/drop size, D_l, - axial dispersion coefficient, k_l - liquid mass transfer coefficient, k_la - volumetric mass transfer coefficient, Δp - pressure variation at the column bottom, P - power consumption, ε_d - dispersed phase (methanol) holdup, and ε_g - gas holdup.

Table S-3. Worldwide applications of RPCs (adapted according to [1])

Plate type[a]	Application	Reference
KRPC	Copper extraction	[47]
	Lysine biosynthesis	[48]
	Treatment of wastewater	[49]
	Extraction of the product from the fermentation liquid	[50]
	Penicillin extraction	[51]
	Biosynthesis of dextransucrase	[6,3]
	Production of antibiotics, ethanol, and citric acid	[52]
	Fermentation processes	[53]
	Fermentation of pullulan	[54]
	Ester saponification reaction	[55]
	Rare earth separation and recovery	[56]
	Extraction of phenol from water	[57-59]
	Caffeine extraction	[60]
	Alcoholic fermentation with immobilized yeast cells	[33]
	Biodiesel production	[43-46]
	Extraction of natural alkaloids	[61]
PRPC	Production of ephedrine and erythromycin Extraction of phenol and nitro-aromatic derivatives from wastewater	Cited according to [62]
KRIMZ, GIAP	Caprolactam extraction with organic solvents Extraction of cyclohexanone and cyclohexanol with benzene	Cited according to [62]

[a]GIAP - the plate with rectangular openings with a drain, KRIMZ - the plate with rectangular openings without a drain, KRPC - the Karr type plate, and PRPC - the Prochazka type plate.

REFERENCE

[1] Banković-Ilić I, Veljković V, Skala D. Hidrodinamičke i masenoprenosne karakteristike kolone sa vibracionom mešalicom za sisteme gas-tečnost i gas-tečnost-čvrsta faza - monografija. Univerzitet u Nišu, Tehnološki fakultet, Leskovac; 2009. ISBN 978-86-82367-80-2 (in Serbian).

[2] Kažić N. Proučavanje promene pritiska u cilju definisanja hidromehaničkih sila u vibracionom ekstraktoru. Magistarska teza, Univerzitet u Beogradu, Mašinski fakultet, Beograd; 1979 (in Serbian).

[3] Stevanović R, Pavasović V, Simonović D, Nemoda S. The study of pressure variations at the bottom of a vibrating plate extraction column. In: Levec J, ed. *Proceedings of the 2nd Yugoslav-Italian-Austrian Chemical Engineering Conference*, Bled, Ljubljana, Slovenia, 1980, pp. 186-197.

[4] Skala D. Analiza sistema gas-tečnost u koloni sa vibracionom mešalicom. Doktorska disertacija, Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Beograd; 1980 (in Serbian).

[5] Skala D, Zubović S, Mićić J. Ispitivanje proticanja tečne faze u koloni sa vibracionom mešalicom pri suprotnostrujnom toku gas-tečnost. *Glasnik hemijskog društva.* 1981; 46: 513-525.

[6] Veljković V. Ispitivanje hidrodinamičkih i maseno-prenosnih karakteristika različitih reaktora i izbor optimalnog tipa za biosintezu dekstran-saharaze. Doktorska disertacija, Univerzitet u Beogradu, Tehnološko-metalurški fakultet, Beograd; 1985 (in Serbian).

[7] Veljković V, Skala D. Influence of different liquid flow models on the determination of oxygen mass transfer in a reciprocating plate column. *J Serb Chem Soc.* 1985; 50: 427-434.

[8] Veljković V, Skala D. Hydrodynamic investigation of gas-liquid contacting in a reciprocating plate column. *Can J Chem Eng*. 1986; 64: 906-914. https://doi.org/10.1002/cjce.5450640604

[9] Skala D, Veljković V. Zadržavanje gasa u trofaznoj koloni sa vibracionom mešalicom, In: *II Jugoslovenski kongres za hemijsko inženjerstvo i procesnu tehniku sa međunarodnim učešćem*, *Zbornik radova II.* Dubrovnik, Jugoslavija, 1987, pp. 56-59 (in Serbo-Croation).

[10] Skala D, Veljković V. Mass transfer characteristics in a gas-liquid reciprocating plate column. I. Liquid phase volumetric mass transfer coefficient. *Can J Chem Eng*. 1988; 66: 192-199. https://doi.org/10.1002/cjce.5450660203

[11] Veljković V, Skala D. Mass transfer characteristics in a gas-liquid reciprocating plate column. II. Interfacial area. *Can J Chem Eng*. 1988; 66: 200-210. https://doi.org/10.1002/cjce.5450660203

[12] Veljković VB, Skala DU. On the possibility of general prediction of gas holdup in reciprocating plate column. *Can J Chem Eng*. 1989; 67: 1015-1018. https://doi.org/10.1002/cjce.5450670622

[13] Veljković VB, Lazić ML, Rutić DJ, Jovanović SM, Skala DU. Selection of a bioreactor and the optimal aerobic conditions for dextransucrase fermentation by *Leuconostoc mesenteroides*. *J Serb Chem Soc*. 1990; 35: 483-490.

[14] Skala DU, Veljković VB, Janjić VV, Lazić M, Banković-Ilić IB. Gas holdup in a gas-liquid-solid reciprocating plate column. *Can J Chem Eng*. 1993; 71: 817-820. https://doi.org/10.1002/cjce.5450710521

[15] Banković-Ilić IB, Veljković VB, Lazić ML, Skala DU. Hydrodynamics of a gas-liquid-solid reciprocating plate column. In: *11th International Congress of Chemical and Process Engineering*, Prague, Czech Republic, 1993, E4.27.

[16] Banković-Ilić IB, Veljković VB, Lazić ML, Skala DU. Power consumption and gas holdup in a gas-liquid reciprocating plate column. *Chem Eng Comm*. 1995; 134: 17-32. https://doi.org/10.1080/00986449508936320

[17] Banković-Ilić I. Hidrodinamika i prenos mase u sistemima gas-tečnost-čvrsto u koloni sa vibracionom mešalicom. Doktorska disertacija, Univerzitet u Nišu, Tehnološki fakultet, Leskovac; 1999 (in Serbian).

[18] Banković-Ilić IB, Veljković VB, Lazić ML, Skala DU. Mass transfer in a multiphase vibration column. I. The volumetric mass transfer coefficient. *Hem Ind.* 2001; 55: 376-382.

[19] Banković-Ilić IB, Veljković VB, Lazić ML, Skala DU. Mass transfer in a multiphase vibration column. II. Interfacial area. *Hem Ind*. 2001; 55: 383-388.

[20] Aleksić M, Veljković VB, Banković-Ilić IB, Lazić ML, Skala DU. Uticaj Rašigovih prstenova i reoloških osobina tečnosti na promenu pritiska na dnu kolone sa vibracionom mešalicom. *Hem Ind*. 2002; 56:409-414. https://doi.org/10.2298/HEMIND0210409A (in Serbian)

[21] Aleksić M, Veljković VB, Banković-Ilić IB, Lazić ML, Skala DU. Gas holdup in a gassed reciprocating plate column with Rashig rings placed in interplate spaces. *Can J Chem Eng*. 2002: 80: 485-490. https://doi.org/10.1002/cjce.5450800318

[22] Aleksić M, Veljković VB, Banković-Ilić IB, Lazić ML, Skala DU. Uticaj Rašigovih i reoloških osobina tečnosti na promenu pritiska na dnu kolone sa vibracionom mešalicom. *Hem Ind*. 2003; 57: 107-113. https://doi.org/10.2298/HEMIND0210409A (in Serbian)

[23] Aleksić M, Veljković V, Banković-Ilić I, Lazić M, Skala D. The Effects of operating conditions on the gas holdup in a multiphase reciprocating plate column with Rashig rings placed in interplate spaces. In: *16th International Congress of Chemical and Process Engineering.* Prague, Czech Republic, 2004, CD ROM of Full Texts 0755.pdf.

[24] Aleksić M. Hidrodinamičke i maseno-prenosne karakteristike višefaznog reaktora sa vibracionom mešalicom. Doktorska disertacija, Univerzitet u Nišu, Tehnološki fakultet, Leskovac; 2006 (in Serbian).

[25] Aleksić M, Vasić L, Banković-Ilić I, Veljković V, Lazić M, Skala D. Correlation for volumetric mass transfer coefficient in a reciprocating plate column different diameter. In: *5th International Conference of the Chemical Societies of the Southeast European Countries*, Ohrid, Macedonia, 2006, 213.

[26] Naseva O. Uticaj reoloških osobina tečne faze na snagu mešanja u bioreaktoru sa vibracionom mešalicom. Magistarska teza, Univerzitet u Nišu, Tehnološki fakultet, Leskovac; 2002 (in Serbian).

[27] Naseva OS, Stamenković IS, Banković-Ilić IB, Lazić ML, Veljković VB, Skala DU. Sadržaj gasa u bioreaktoru sa vibracionom mešalicom - tečna faza je njutnovski fluid. *Hem Ind*. 2002; 56: 198-203. https://doi.org/10.2298/HEMIND0205198N (in Serbian)

[28] Stamenković I. Uticaj reoloških osobina tečne faze na sadržaj gasa i promenu pritiska na dnu reaktora sa vibracionom mešalicom. Magistarska teza, Univerzitet u Nišu, Tehnološki fakultet, Leskovac; 2005 (in Serbian)

[29] Stamenković IS, Stamenković OS, Banković-Ilić IB, Lazić ML, Veljković VB, Skala DU. The gas holdup in a multiphase reciprocating plate column filled with carboxymethylcellulose solutions. *J Serb Chem Soc*. 2005; 70: 1533-1544. https://doi.org/10.2298/JSC0512533S

[30] Nikolić L, Đoković N, Veljković V, Skala D. Aksijalno mešanje u koloni sa vibracionom mešalicom. *Hem Ind*. 1999; 53: 300-308.

[31] Nikolić L, Veljković V, Skala D. Analysis of liquid flow in a Karr reciprocating plate column. *Hem Ind*. 2001; 55: 249-254. http://www.ache.org.rs/HI/2001/No06/skala.pdf

[32] Nikolić LB, Veljković VB, Skala DU. Axial dispersion of the liquid flow in a Karr reciprocating plate column. *Hem Ind.* 2001; 55: 249-254. https://doi/10.2298/JSC0407581N

[33] Nikolić L. Povratno mešanje tečne faze i kinetika procesa alkoholne fermentacije u trofaznom bioreaktoru sa vibracionom mešalicom. Doktorska disertacija, Univerzitet u Nišu, Tehnološki fakultet, Leskovac; 2003. http://doiserbia.nb.rs/phd/fulltext/NI20031003NIKOLIC.pdf (in Serbian).

[34] Nikolić LB, Nikolić VD, Veljković VB, Lazić ML, Skala DU. Axial dispersion of the liquid phase in a three-phase Karr reciprocating plate column. *J Serb Chem Soc*. 2004; 69: 581-599. https://doi.org/10.2298/JSC0407581N

[35] Nikolić LB, Nikolić VD, Veljković VB, Skala DU. Gas hold-up in a three-phase reciprocating plate column. *J Serb Chem Soc*. 2005; 70: 1363-1371. http://www.doi.10.2298/JSC0511363N

[36] Nikolić L, Stojanović S, Veljković V, Skala D. The model of back-flow mixed tanks-in-series used for representing the liquid flow in a reciprocating plate column. *Hem Ind*. 2003; 57: 269-275. https://doi.org/10.2298/HEMIND0306269N

[37] Vasić Lj. Brzina prenosa mase kiseonika kao kriterijum za povećanje razmere kolone sa vibracionom mešalicom. Magistarska teza, Univerzitet u Nišu, Tehnološki fakultet, Leskovac; 2006 (in Serbian).

[38] Vasić Lj, Banković-Ilić IB, Lazić ML, Veljković VB, Skala DU. The effects of operating conditions on the pressure variation at the bottom of a 16.6 cm i.d. reciprocating plate column. *Chem Ind Chem Eng Q*. 2005; 11: 195-202. https://doi.org/10.2298/CICEQ0504195V

[39] Vasić LJ, Banković-Ilić IB, Lazić ML, Veljković VB, Skala DU. Sadržaj gasa u koloni sa vibracionom mešalicom prečnika 16,6 cm. *Hem Ind*. 2005; 59: 263-266. https://doi.org/10.2298/HEMIND0510263V

[40] Vasić LS, Banković-Ilić IB, Lazić ML, Veljković VB, Skala DU. Snaga mešanja nenjutnovskih tečnosti u višefaznoj koloni sa vibracionim mešanjem prečnika 16,6 cm. In: *19. Kongres o procesnoj industriji Procesing 2006*, *Zbornik rezimea radova.* Beograd, Srbija, 2006, CD verzija punog rada (in Serbian).

[41] Vasić LS, Banković-Ilić IB, Lazić ML, Veljković VB, Skala DU. The gas holdup in a 16.6 cm i.d. multiphase reciprocating plate column. In: *5th International Conference of the Chemical Societies of the Southeast European Countries.* Ohrid, Republic of Macedonia, 2006, p. 238.

[42] Vasić LS, Banković-Ilić IB, Lazić ML, Veljković VB, Skala DU. Oxygen mass transfer in a 16.6 i.d. multiphase reciprocating plate column. *J Serb Chem Soc*. 2007; 72: 523-531. https://doi.org/10.2298/JSC0705523V

[43] Stamenković IS, Banković-Ilić IB, Jovanić PB, Veljković VB, Skala D. Hydrodynamics of a cocurrent upflow liquid-liquid reciprocating plate reactor for homogeneously base-catalyzed methanolysis of vegetable oils. *Fuel.* 2010; 89: 3971-3984. http://www.doi:10.1016/j.fuel.2010.06.026

[44] Stamenković I. Kontinualna homogena bazno katalizovana alkoholiza biljnih ulja u reaktoru sa vibracionom mešalicom. Doktorska disertacija, Univerzitet u Nišu, Tehnološki fakultet, Leskovac; 2014 (in Serbian).

[45] Banković-Ilić IB, Todorović ZB, Avramović JM, Veličković AV, Veljković VB. The effect of tetrahydrofuran on the base-catalyzed sunflower oil methanolysis in a continuous reciprocating plate reactor. *Fuel Process Technol*. 2015; 137: 339-350. http://dx.doi.org/10.1016/j.fuproc.2015.03.023

[46] Miladinović MR, Stojković IS, Veličković AV, Stamenković OS, Banković-Ilić IB, Veljković VB. Optimization and kinetic modeling of waste lard methanolysis in a continuous reciprocating plate reactor. *Chin J Chem Eng*. 2019; 27: 2481-2490. https://doi.org/10.1016/j.cjche.2019.02.019

[47] Sharma RN, Baird MHI. Solvent extraction of copper in a reciprocating plate column. *Can J Chem Eng*. 1978; 56, 310-315. https://doi.org/10.1002/cjce.5450560307

[48] Šerbak V, Selga S, Sakse A. Ispîanie pnevmatičeskogo fermentatora s perforirovannîmi tarelkami primeniteľno k processam biosinteza lizina. In: *Tehnologija mikrobnogo sinteza*, Riga: Zinatne; 1978: 125-130.

[49] Brauer H, Sucker D. Biological waste water treatment in a high efficiency reactor. *Ger Chem Eng*. 1979; 2: 77-86.

[50] Karr AE, Gebert W, Wang M. Axial mixing and scale-up of reciprocating plate columns. *Can J Chem Eng*. 1987; 65: 373-381. https://doi.org/10.1002/cjce.5450650304

[51] Reschke M, Schügerl K. Continuous reactive extraction of penicillin-g in a Karr column. *Chem Eng J.* 1985; 31: B19-B26. https://doi.org/10.1016/0300-9467(85)80061-7

[52] Brauer H. Growth of fungi and bacteria in the reciprocating jet bioreactor. *Bioprocess Eng*. 1991; 6: 1-15. https://doi.org/10.1007/BF00369272

[53] Lounes M, Audet J, Thibault J, LeDuy A. Description and evaluation of a reciprocating plate bioreactors. *Bioprocess Eng*. 1995; 13, 1-11. https://doi.org/10.1007/BF00368758

[54] Audet J, Lounes M, Thibault J. Pullulan fermentation in a reciprocating plate bioreactor. *Bioprocess Eng*. 1996; 15: 209-214. https://doi.org/10.1007/BF00369484

[55] Harvey AP, Mackley MR, Seliger T. Process intensification of biodiesel production using a continuous oscillatory flow reactor. *J Chem Technol Biotech*. 2003; 78: 338-341. https://doi.org/10.1002/jctb.782

[56] Liao BQ, Wang J, Wan CR. Separation and recovery of rare earths in reciprocating extraction columns. *Sep Sci Technol*. 2005; 40: 1685-1700. http://dx.doi.org/10.1081/SS-200059604

[57] Yung KKL, Smith CD, Bowser T, Perera JM, Stevens GW. The use of an ionic liquid in a Karr reciprocating plate extraction column. *Chem Eng Res Des*. 2012; 90: 2034-2040. http://www.doi:10.1016/j.cherd.2012.03.006

[58] Yung KKL, Smith CD, Bowser TA, Perera JM, Stevens GW. The use of an ionic liquid in a Karr reciprocating plate extraction column: dispersed phase holdup prediction. *Sep Sci Technol*. 2012; 47: 346-353. http://www.doi:10.1080/01496395.2011.593604

[59] Yung KKL, Smith CD, Bowser TA, Perera JM, Stevens GW. The use of an ionic liquid in a Karr reciprocating plate extraction column: drop size distribution. *Sep Sci Technol*. 2012; 47: 1733-1739. http://www.doi: 10.1080/01496395.2012.681000

[60] Hu X, Wang X, Yang H. Caffeine extraction with a Karr reciprocating plate column. *Eng Life Sci*. 2003; 3(10): 416-423. http://www.doi:10.1002/elsc.200301798

[61] Wu Y, Vovers J, Lu HT, Li W, Stevens GW, Mumford KA. Investigation of the extraction of natural alkaloids in Karr reciprocating plate columns: fluid dynamic study. *Chem Eng Sci*. 2022; 264: 118090. https://doi.org/10.1016/j.ces.2022.118090

[62] Baird MHI, Rama Rao NV, Prochazka J, Sovova H. Reciprocating plate columns. In: Godfrey JC, Slater MJ, eds. *Liquid-liquid extraction equipment.* New York: John Wiley & Sons; 1994: 307-362.