

## Supplementary Material

### BIO-BASED PRODUCTION FROM WASTE STREAMS UNDER ACIDIC CONDITIONS

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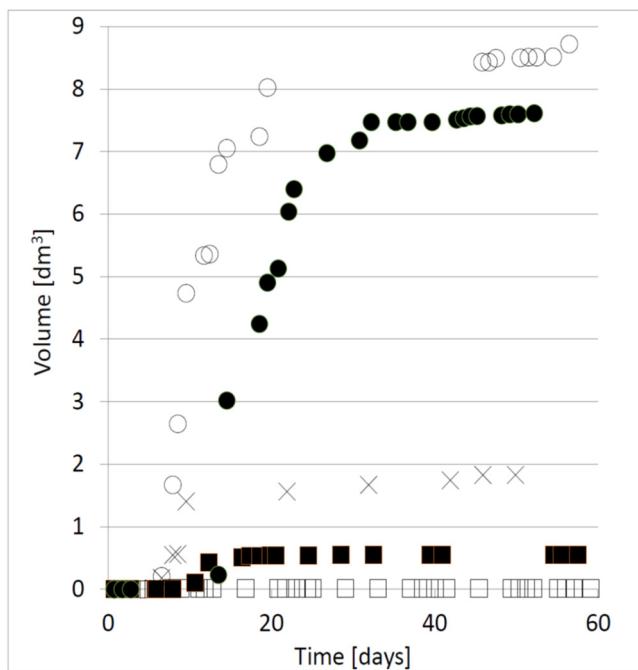
**Figure S1.** Cumulative hydrogen production from: cotton with pH 6 ■ or without pH control □ and from sour cabbage with pH 6 (OFR = 0) ● and (OFR = 2 ml/h) ○ and without pH control ×; VSS 40 g/L

**Figure S2.** Cumulative methane production from sour cabbage under pH 6 control conditions (OFR = 0) ● and (OFR = 2 ml/h) ○; VSS 40 g/L

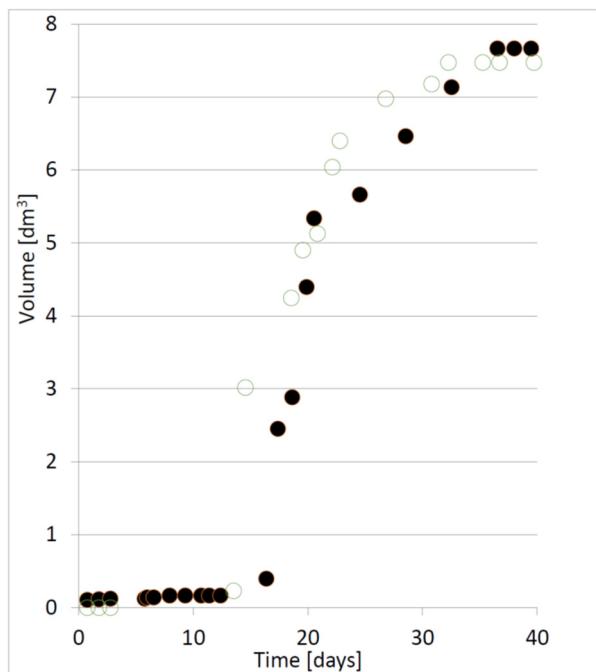
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**Table S2.** Bioleaching by inorganic acid producers.



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**Figure S2.** Cumulative methane production from sour cabbage under pH 6 control conditions (OFR = 0) ● and (OFR = 2 ml/h) ○; VSS 40 g/L.

**Table S1.** Bioleaching by organic acid producers.

Microorganism	Waste material	Produced acids	Pulp density	pH	Time (day)	Efficiency (%)	Reference
<i>Aspergillus foetidus</i>	Spent fluid catalytic cracking catalyst	Citric acid	0.8%	5.5	20	Al 88	Das et al 2019
<i>Aspergillus niger</i>	Spent fluid catalytic cracking catalyst	Citric acid (main)	1%	5	21	La 63	Mouna, Baral, 2019
<i>Aspergillus niger</i>	Red mud	n.d.	2%	1.8	30	Ge 63, Yb 59, Ga 50, Sc 44, V 40, Eu 33, La 31	Qu et al, 2015
<i>Aspergillus niger</i>	Spent refinery catalyst	Gluconic acid	3%	7	30	Mo 99.5, Ni 46, Al 14	Amiri et al 2012
<i>Aspergillus niger</i>	Red mud	Oxalic and citric acid	4 g/l	2	7	Al 45	Urik et al. 2015
<i>A. niger</i> indirect bioleaching	LCD	Oxalic acid	1%	4	90 min (70°C)	In 100	Cui et al 2020
<i>A. niger</i>	Li-ion batteries	Gluconic acid	1%	5	30	Li 100, Cu 94, Mn 72, Al 62, Ni 45, Co 38	Bahaloo-Horeh et al 2018

<i>A. niger</i> MXPE6, <i>A. niger</i> MX7	Mobil phone PCB	n.d.	13 g/l	4.4	14	Au 87, Cu 0.2	Madrigal-Arias et al 2015
<i>A. niger</i> MXPE6, <i>A. niger</i> MX7	PCB (computer)	n.d.	13 g/l	4.4	14	Au 28, Cu 29	Madrigal-Arias et al 2015
<i>Gluconobacter oxydans</i>	Spent fluid catalytic cracking catalyst	Gluconic acid	1.5%	n.d.	1	REE 49	Reed et al, 2016
<i>Penicillium expansum</i>	Electrical and electronical waste	n.d.	Powder in agar plate	5.5	21	REE 99	Di Piazza et al 2017
<i>Penicillium crustosum</i>	Red mud	Oxalic and citric acid	4 g/l	4	7	Al 41	Urik et al 2015
<i>Penicillium simplicissimum</i>	Mobile phone PCB		1%	2-7	n.d.	Cu 90, Ni 89	Arshadi et al 2019
<i>Penicillium tricolor</i> RM-10 (indirect bioleaching)	Red mud	Gluconic and citric acids	10%	2 - 4	10	REE 22 – 67, Th 27, U 45	Qu, Lian, 2013

n.d. not determined

**Table S2.** Bioleaching by inorganic acid producers.

<b>Microorganism</b>	<b>Waste material</b>	<b>Pulp density</b>	<b>Additional chemicals/process conditions</b>	<b>pH</b>	<b>Time (day)</b>	<b>Efficiency (%)</b>	<b>Reference</b>
<i>A. ferrooxidans</i>	PCB (0.075-1 mm)	7,5 g/l	Lemon juice (0.2M citric acid)	2.5	18	Cu 94, Zn 92, Pb 64, Ni 81	Priya, Hait, 2018
<i>A. ferrooxidans</i>	Ni-Cd batteries	10 g/l	Shaking flasks	1.5	28	Ni 45, Cd 100 (cathode); Ni 5.4, Cd 98 (anode)	Velgosová et al, 2013; Velgosová et al, 2014
<i>A. ferrooxidans</i>	Electroplating slugde after acid leaching	8%	Combined with bioelectrical reactor	2.2	9 hours	Cu 75.8, Zn 84.4, Cr 80.9, Ni 65.8	Wu et al 2020
<i>A. ferrooxidans</i>	LED	20 g/l	Shaking flasks	2	30	Cu 84, Ni 96, Ga 60	Pourhossein, Mousavi 2018
<i>A. ferrooxidans</i>	PCB	20 g/l	Mechanical activation	n.d.	9	Cu 94, Zn 91, Ni 91, Pb 10, Cr 75, Cd 54	Gu et al 2019
<i>A. ferrooxidans</i> ( <i>1<sup>st</sup></i> step), <i>E. coli</i> ( <i>2<sup>nd</sup></i> step)	Hydrodesuphurization spent catalyst	1%		2/9	25	Mo 99	Vyas, Ting, 2016
<i>A. ferrooxidans</i> ( <i>1<sup>st</sup></i> step)	Hydrodesuphurization spent catalyst	1%		2	15	Ni 89, Mo 21, Al 13	Vyas, Ting, 2016
<i>A. ferrooxidans</i>	Waste magnets	10 g/l	Shaking flasks	1.8	14	Al 96, B 93, Co 91, Cu 71, Nd 86, Pr 100	Auerbach et al, 2019a
<i>A. ferrooxidans</i>	e-waste	10%	Shaking flasks	2	20	Cu, Fe 100, Ni 54	Arshadi et al 2019 b
<i>A. ferrooxidans</i> (indirect bioleaching)	LCD	20 g/l	Shaking flasks	2	15	Cu 83, Ni 97, Ga 84	Pourhossein, Mousavi 2019
<i>A. ferrooxidans</i>	Metal-plating sludge	9 g/l	Shaking flasks	1	7	Cr 56, Ni 58	Rastegar et al. 2014
<i>A. ferrooxidans</i>	Mobile phone PCB	8.5 g/l		1	20	Cu, Ni 100	Arshadi, Mousavi, 2015
<i>A. ferrooxidans</i> + nitrogen-doped carbon nanotubes modified electrode	PCB	20 g/l	Shaking flasks	2	9	Cu 99	Gu et al 2017
<i>A. thiooxidans</i>	Spent coin cells	30 g/l		2	16	Li 99, Co 60, Mn 20	Nasseri et al 2019
<i>A. thiooxidans</i>	Waste magnets	10 g/l	Shaking flasks	1.8	14	Al 86, B 92, Co 26, Cu 49, Nd 77, Pr 100	Auerbach et al, 2019a
<i>A. thiooxidans</i>	WEEE shredding dust	0.5%	Shaking flasks	1	8	Cd, Ni, Zn 100, Al 92, Cu 81, Ce, Eu, Nd >99 La, Y 80	Marra et al 2018
<i>A. thiooxidans</i>	Lead metallurgical slag	1%	Shaking flasks	2.5	28	Co 88, Mo 40, REE 83, V 55	Mikoda et al, 2019
<i>A. thiooxidans</i>	Copper metallurgical slag (shaft furnace slag)	1%	Shaking flasks	2.5	28	Co 100, Mo 44, REE 70, V 70	Mikoda et al, 2019

<i>A. thiooxidans</i>	Copper metallurgical slag (granulated slag)	1%	Shaking flasks	2.5	28	Co 95, Mo 70, REE 99, V 93	Mikoda et al, 2019
<i>A. thiooxidans</i>	petroleum refinery spent hydroprocessing catalyst	n.d.	Column bioleaching	3.3	13	Ni 83, Al 33, Mo 23, V 54	Pathak et al 2019
<i>A. thiooxidans</i>	LCD	1.6%	Shaking flasks	2.6	14	In 100, Sr10	Jowkar et al 2018
<i>A. thiooxidans, A. ferrooxidans</i>	Incineration slag	1%	Shaking flasks	2.2	7	Al 82, Cu 94, Mn 71, Cd 74, Cr 14, Ni 70, Zn 85	Auerbach et al, 2019b
<i>A. ferrooxidans, A. thiooxidans</i>	PCB (1 mm – 1 cm)	10 g/l	Shaking flasks	1.5	14-35	Cu 88, Zn 100, Ni 100, Al 56	Sedlakova-Kadukova et al., 2017
<i>A. ferrooxidans, A. thiooxidans</i>	Zn-Mn batteries	10 g/l	Shaking flasks	1.5	7-28	Zn 98, Mn 80	Ubaldini et al, 2014 Sedlakova-Kadukova et al., 2017
<i>A. ferrooxidans, A. thiooxidans</i>	Li-ion batteries	10 g/l	Shaking flasks	1.5	14-21	Li 80; Co 67	Marcincakova et al. 2016
<i>A. ferrooxidans, L. ferrooxidans</i> (indirect bioleaching)	PCB	5%	Shaking flasks	1.6	9	Cu 94, Zn 70	Becci et al 2020
<i>A. ferrooxidans, A. thiooxidans, L. ferriphilum</i>	Brake pad waste	4%	Low-temperature thermal pre-treatment	1	9	Cu 98, Zn 100	Zhang et al 2019
<i>L. ferriphilum</i>	PCB (pre-treatment with NaCl)	10 g/l	Shaking flasks	2	2-6	Cu 94, Zn 100, Ni 98	Shah et al 2015
<i>L. ferriphilum</i> (indirect bioleaching)	PCB (plates)	125 g/l	aeration	1.8	2	Cu 99	Sodha et al 2020
<i>L. ferrooxidans</i>	Waste magnets	10 g/l	Shaking flasks	1.8	14	Al 100, B 95, Co 94, Cu 100, Nd 100, Pr 100	Auerbach et al, 2019a
<i>L. ferrooxidans</i>	Incineration slag	1%	Shaking flasks	2.2	7	Al 57, Cu 81, Mn 28, Cr 17, Ni 59, Zn 96, Co 49, Er 100, La 54, Nd 95, Ce 55	Auerbach et al, 2019b
<i>Sulfolobacillus thermosulfidooxidans</i>	PCB (20 mm)	25 g/l	Rotating-drum reactor (50°C)	1.75	8	Cu 85	Rodriguez et al 2015
<i>Sulfolobacillus thermosulfidooxidans</i>	PCB (20 mm)	10 g/l	Shaking flasks	1.75	6	Cu 99	Rodriguez et al 2015
Consortium of acidophilic chemotrophic bacteria	Electroplating sludge	15%	Fe <sup>2+</sup> (9 g/l)	2	1	Cu, Zn, Ni > 95,6, Cr 90.3	Zhang et al., 2020
Consortium of moderately thermophilic bacteria	Electroplating sludge	250 g/l	Stirred reactor (Semi-pilot scale)	1.5	5 hours	99% (Cu, Zn, Ni, Cr)	Zhou et al 2019
Consortium of thermophilic	Sewage sludge	1.5%	Bioreactor (pilot-scale)	2	14	Mn 100, Zn 60, Ni 41,	Chen, Cheng, 2019

sulphur-oxidising bacteria						Cu 39, Cr 38	
Consortium of moderately thermophilic iron and sulphur-oxidising bacteria	Mixture of Cu-Ni-Co sulfidic tailing and PCB waste	10%	50 l stirred tank reactor	1.5	90	Cu 92, Zn 67, Al 65	Akbari, Ahmadi, 2019
Bacterial consortium from acid mine drainage ( <i>Acidithiobacillus sp.</i> , <i>Gallionella sp.</i> , <i>Leptospirillum sp.</i> )	PCB	20 g/l	Shaking flasks	1.5	5	Cu 95	Xiang et al. 2010
Bacterial consortium from acid mine drainage	PCB concentrate	12 g/l	Shaking flasks	2	2	Cu 97, Al 88, Zn 92	Zhu et al 2011
Consortium of moderately thermophilic iron and sulphur-oxidising bacteria	High pressure acid leaching residue	50 g/l	Shaking flasks	1.4	15	Co 88, Cu 56	Liu et al., 2020a
Consortium of acid tolerant bacteria (mainly <i>L. ferriphilum</i> , <i>Sulfobacillus thermosulfidooxidans</i> , <i>Ferroplasma thermophilum</i> )	Resin powder	20%	2 l Static tank	0.7	1.5	Cu 99.9, Al 100	Liu et al 2020 b
Fe-oxidising bacteria	PCB	10 g/l	Bioelectrica 1 reactor, direct current electric field	2	3	Cu 100	Wei et al 2020
Consortium of Fe and S-oxidising bacteria dominated by <i>A. ferrooxidans</i>	Mobile phone PCB	15 %	1 l flask	1.5	12	Cu 99, Ni 48,	Garg et al 2019

n.d. not defined

## References

1. Akbari, S., Ahmadi, A. 2019. Recovery of copper from a mixture of printed circuit boards (PCBs) and sulphidic tailings using bioleaching and solvent extraction processes. Chemical Engineering & Processing: Process Intensification 142, 107584.
2. Amiri, F., Mousavi, S.M., Yaghmaei, S., Barati, M. 2012. Bioleaching kinetics of a spent refinery catalyst using *Aspergillus niger* at optimal conditions. Biochem. Eng. J. 67, 208– 217.
3. Arshadi, M., Mousavi, S.M. 2015. Multi-objective optimization of heavy metals bioleaching from discarded mobile phone PCBs: Simultaneous Cu and Ni recovery using *Acidithiobacillus ferrooxidans*, Sep. Purif. Technol. 147, 210–219.
4. Arshadi, M., Nili, S., Yaghmaei, S. 2019. Ni and Cu recovery by bioleaching from the printed circuit boards of mobile phones in non-conventional medium, J. Environ. Manage. 250, 109502.

5. Auerbach, R., Bokelmann, K., Stauber, R., Gutfleisch, O., Schnell, S., Ratering, S. 2019a. Critical raw materials – Advanced recycling technologies and processes: Recycling of rare earth metals out of end of life magnets by bioleaching with various bacteria as an example of an intelligent recycling strategy. Miner. Eng. 134, 104–117.
6. Auerbach, R., Ratering, S., Bokelmann, K., Gellermann, C., Bramer, T., Baumann, R., Schnell, S., 2019b. Bioleaching of valuable and hazardous metals from dry discharged incineration slag. An approach for metal recycling and pollutant elimination. J. Environ. Manage. 232, 428–437
7. Bahaloo-Horeh, N., Mousavi, S.M., Baniasadi, M. 2018. Use of adapted metal tolerant *Aspergillus niger* to enhance bioleaching efficiency of valuable metals from spent lithium-ion mobile phone batteries. J. Clean. Prod. 197, 1546-1557.
8. Becci, A., Amato, A., Fonti, V., Karaj, D., Beolchini, F. 2020. An innovative biotechnology for metal recovery from printed circuit boards. Resources, Conservation & Recycling 153, 104549
9. Cui, J., Zhu, N., Li, Y., Luo, D., Wu, P., Dang, Z. 2020. Rapid and green process for valuable materials recovery from waste liquid crystal displays. Resources, Conservation & Recycling 153, 104544.
10. Das, S., Deshavath, N.N., Goud, V.V. Dasu, V.V. 2019. Bioleaching of Al from spent fluid catalytic cracking catalyst using *Aspergillus* species. Biotechnol. Reports 23, e00349.
11. Di Piazza, S., Cecchi, G., Cardinale, A.M., Carbone, C., Mariotti, M.G., Giovine, M., Zotti, M. 2017. *Penicillium expansum* Link strain for a biometallurgical method to recover REEs from WEEE. Waste Manag. 60, 596–600.
12. Garg, H., Nagar, M.N., Ellamparuthy, G., Angadi, S.I., Gahan, C.S. 2019. Bench scale microbial catalysed leaching of mobile phone PCBs with an increasing pulp density. Heliyon 5, e02883.
13. Gu, W., Bai, J., Dong, B., Zhuang, X., Zhao, J., Zhang, C., Wang, J., Shih, K. 2017. Enhanced bioleaching efficiency of copper from waste printed circuit board driven by nitrogen-doped carbon nanotubes modified electrode. Chem. Eng. J. 324, 122–129.
14. Gu, W., Bai, J., Lu, L., Zhuang, X., Zhao, J., Yuan, W., Zhang, C., Wang, J. 2019. Improved bioleaching efficiency of metals from waste printed circuit boards by mechanical activation. Waste Manag. 98, 21–28
15. Chen, S-Y., Cheng, Y-K. 2019. Effects of sulfur dosage and inoculum size on pilot-scale thermophilic bioleaching of heavy metals from sewage sludge. Chemosphere 234, 346-355.

16. Jowkar, M.J., Bahaloo-Horeh, N., Mousavi, S.M., Pourhossein, F. 2018. Bioleaching of indium from discarded liquid crystal displays. *J. Clean. Prod.* 180, 417-429.
17. Liu, R. Mao, Z., Liu, W., Wang, Y., Cheng, H., Zhou, H., Zhao, K. 2020a. Selective removal of cobalt and copper from Fe (III)-enriched high-pressure acid leach residue using the hybrid bioleaching technique. *J. Hazard. Mater.* 384, 121462.
18. Liu, R., Wang, W., Zhou, W., Cheng, H., Zhou, H. 2020b. Acid catalysis coupling bioleaching for enhancement of metals removal from waste resin powder. *J. Clean Prod.* 247, 119130
19. Madrigal-Arias, J.E., Argumedo-Delira, R., Mendoza-Lopez, A.A., Garcia-Barradas, O., Cruz-Sánchez, J.S., Ferrera-Cerrato, R., Jiménez-Fernandez, M. 2015. Bioleaching of gold, copper and nickel from waste cellular phone PCBs and computer goldfinger motherboards by two *Aspergillus niger* strains, *Braz. J. Microbiol.* 46, 3, 707-713.
20. Marcinčáková, R., Kaduková, J., Mražíková, A., Velgosová, O., Luptáková, A., Ubaldini, S. 2016. Metal bioleaching from spent lithium-ion batteries using acidophilic bacterial strains, *Inżynieria Mineralna*, 37, 1, 117-120.
21. Marra, A., Cesaro, A., Rene, E.R., Belgiorno, V., Lens, P.N.L. 2018. Bioleaching of metals from WEEE shredding dust. *J. Environ. Manage.* 210, 180-190.
22. Mikoda, B., Potysz, A., Kmiecik, E. 2019. Bacterial leaching of critical metal values from Polish copper metallurgical slags using *Acidithiobacillus thiooxidans*. *J. Environ. Manag.* 236, 436–445
23. Mouna, H.M., Baral, S.S. 2019. A bio-hydrometallurgical approach towards leaching of lanthanum from the spent fluid catalytic cracking catalyst using *Aspergillus niger*. *Hydrometallurgy* 184, 175–182
24. Naseri, T., Bahaloo-Horeh, N., Mousavi, S.M. 2019. Environmentally friendly recovery of valuable metals from spent coin cells through two-step bioleaching using *Acidithiobacillus thiooxidans*. *J. Environ. Manag.* 235, 357–367
25. Pathak, A., Scrichandan, H., Kim, D.J. 2019. Column bioleaching of metals from refinery spent catalyst by *Acidithiobacillus thiooxidans*: Effect of operational modifications on metal extraction, metal precipitation, and bacterial attachment. *J. Environ. Manag.* 242, 372–383.
26. Pourhossein, F. Mousavi, S.M. 2019. A novel step-wise indirect bioleaching using biogenic ferric agent for enhancement recovery of valuable metals from waste light emitting diode (WLED), *J. Hazard. Mat.* 378, 120648.
27. Pourhossein, F., Mousavi, S.M. 2018. Enhancement of copper, nickel, and gallium recovery from LED waste by adaptation of *Acidithiobacillus ferrooxidans*. *Waste Manag.* 79, 98–108.

28. Priya, A., Hait, S. 2018. Extraction of metals from high grade waste printed circuit board by conventional and hybrid bioleaching using *Acidithiobacillus ferrooxidans*. Hydrometallurgy 177, 132–139
29. Qu, Y., Li, H., Tian, W., Wang, X., Wang, X., Jia, X., Shi, B., Song, G., Tang, Y. 2015. Leaching of valuable metals from red mud via batch and continuous processes by using fungi. Miner. Eng. 81, 1–4.
30. Qu, Y., Lian, B. 2013. Bioleaching of rare earth and radioactive elements from red mud using *Penicillium tricolor* RM-10. Bioresour. Technol. 136, 16–23.
31. Rastegar, S.O., Mousavi, S.M., Shojaosadati, S.A. 2014. Cr and Ni recovery during bioleaching of dewatered metal-plating sludge using *Acidithiobacillus ferrooxidans*. Bioresour. Technol. 167, 61–68
32. Reed, D.W., Fujita, Y., Daubaras, D.L., Jiao, Y., Thompson, V.S. 2016. Bioleaching of rare earth elements from waste phosphors and cracking catalysts. Hydrometallurgy 166, 34–40
33. Rodrigues, M.L.M., Leao, V.A., Gomes, O., Lambert, F., Bastin, D., Gaydardzhiev, S. 2015. Copper extraction from coarsely ground printed circuit boards using moderate thermophilic bacteria in a rotating-drum reactor. Waste Manag. 41, 148–158.
34. Sedlakova-Kadukova, J., Marcincakova, R., Mrazikova, A., Willner, J., Fornalczyk, A. 2017. Closing the Loop: Key Role of Iron in Metal-Bearing Waste Recycling. Arch. Metall. Mater. 62, 3, 1459–1466.
35. Shah, M.B., Tipre, D.R., Purohit, M.S., Dave, S.R. 2015. Development of two-step process for enhanced biorecovery of Cu-Zn-Ni from computer printed circuit boards. J. Biosci. Bioeng. 120, 2, 167–173.
36. Sodha, A.B., Tipre, D.R., Dave, S.R. 2020. Optimisation of biohydrometallurgical batch reactor process for copper extraction and recovery from non-pulverized waste printed circuit boards. Hydrometallurgy 191, 105170
37. Ubaldini, S., Kadukova, J., Mrazikova, A., Fornaria, P., Luptakova, A., Marcincakova, R., Pizzichemi, P.: Application of Innovative Processes for the Valorisation of Spent Alkaline Batteries, Chemical Engineering Transactions, 39, 2014, 1609-1614.
38. Urík, M., Bujdoš, M., Milová-Žiaková, B., Mikušová, P., Slovák, M., Matúš, P. 2015. Aluminium leaching from red mud by filamentous fungi. J. Inorg. Biochem. 152, 154–159.
39. Velgosová, O., Kaduková, J., Marcinčáková, R., Mráziková, A., Fröhlich, L. 2014. The Role of Main Leaching Agents Responsible for Ni Bioleaching from spent Ni-Cd Batteries, Separ. Sci. Technol. 49, 3, 438-444.

40. Velgosová, O., Kaduková, J., Marcinčáková, R., Palfy, P., Trpčevská, J. 2013. Influence of H<sub>2</sub>SO<sub>4</sub> and ferric iron on Cd bioleaching from spent Ni-Cd batteries, *Waste Manag.* 33, 456–461.
41. Vyas, S., Ting, Y-P. 2020. Microbial leaching of heavy metals using *Escherichia coli* and evaluation of bioleaching mechanism. *Bioresour. Technol. Reports* 9, 100368.
42. Wei, X., Li, J., Huang, W., Zheng, X., Li, S., Chen, X., Liu D. 2020b. Comparative Study of Iron-Oxidizing and Sulfur-Oxidizing Bioleaching Processes for Heavy Metal Removal and Nutrient Leaching from Pig Manure. *Water Air Soil Pollut* 231, 34.
43. Wu, P., Zhang, L., Lin, C., Xie, X., Yong, X., Wu, X., Zhou, J., Jia, H., Wei, P. 2020. Extracting heavy metals from electroplating sludge by acid and bioelectrical leaching using *Acidithiobacillus ferrooxidans*. *Hydrometallurgy* 191, 105225.
44. Xiang, Y., Wu, P., Zhu, N., Zhang, T., Liu, W., Wu, J., Li, P. 2010. Bioleaching of copper from waste printed circuit boards by bacterial consortium enriched from acid mine drainage. *J. Hazard. Mater.* 184, 812–818.
45. Zhang, L., Zhou, W., Liu, Y., Jia, H., Zhou, J., Wei, P., Zhou, H. 2020. Bioleaching of dewatered electroplating sludge for the extraction of base metals using an adapted microbial consortium: Process optimization and kinetics. *Hydrometallurgy* 191, 105227.
46. Zhang, M., Guo, X., Tian, B., Wang, J., Qi, S., Yang, Y., Xin, B. 2019. Improved bioleaching of copper and zinc from brake pad waste by low-temperature thermal pretreatment and its mechanisms. *Waste Manag.* 87, 629–635.
47. Zhu, N., Xiang, Y., Zhang, T., Wu, P., Dang, Z. Li, P., Wu, J. 2011. Bioleaching of metal concentrates of waste printed circuit boards by mixed culture of acidophilic bacteria. *J. Hazard. Mater.* 192, 614– 619.