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Hydrometallurgical Recovery of Lithium Oxide from Mud Sidoarjo

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Abstract: One of the efforts to meet the limited supply of fossil fuels is to replace the use of electric vehicles. Lithium batteries are one of the energy storage media that are environmentally friendly and cost-effective. Lithium batteries contain lithium ions. There are two sources for obtaining lithium ions as raw materials for batteries: used and natural resources. A natural resource that can potentially contain lithium ions is Sidoarjo mud. This research aims to determine the percentage efficiency of lithium extraction by the hydrometallurgical method. Factors affecting the extraction process include temperature, extraction time, solid-liquid ratio, and concentration of lactic acid solvent. The best leaching conditions were obtained at a temperature of 90oC and a concentration of 0.9 M lactic acid of 69.82%..

Keywords: hydrometallurgical; recovery; lithium; mud Sidoarjo; sustanaible

1. Prerequisites for the publication

The crisis of dominant primary energy sources such as fossil fuels, which are the basis of welfare[1)], economic movement and community development[2–4)]. In addition, the detrimental impacts that occur due to the use of fossil fuels are global climate change, health impacts, and soil and water contamination[5,6)]. Development to produce comprehensive green energy and recycling continues to be a basis for sustainable development[7–9)]. One of the ways to overcome the demand for fuel and have environmentally friendly energy is by using lithium-ion batteries[10–12)]. A lithium battery, which is one of the media that functions as a potential energy store, is efficient, has a long service life, has high energy stability at high and low temperatures, and has superior performance[12,13)].

The development of lithium-ion batteries and demand continue to increase significantly[14)]. The electronics industry applies lithium-ion batteries to electronic devices, electric vehicles and large-scale energy storage[15,16)]. Production of lithium-ion batteries is expected to reach 50 million units in 2025 and almost close to 140 million in 2030, with an average growth of nearly 30%[17,18)]. However, with the increase in consumption comes an increase in lithium battery waste[19,20)]. These used batteries can cause a waste of energy if they are still used and pose an environmental hazard if disposed of[19,21)]. These used batteries contain many valuable metals, including Co, Ni, Li, and C[22,23)]. Therefore, these used lithium batteries must be processed to make them clean and efficient[24,25)].

Several methods are generally used to recycle metals in batteries and mineral rocks, namely pyrometallurgy[26)], hydrometallurgy[27)], and biometallurgy[28,29)]. Generally, what is done chiefly to recover metals is hydrometallurgy[30)]. However, these three methods have the advantages for hydrometallurgy of low energy use, high selectivity[31)], and producing high-purity metals[32)]. Pyrometallurgical methods can be used more profitably on an industrial scale (for large capacities)[32,33)]. As for biometallurgy, only a little is used because the reaction rate is low, requires particular microorganisms, and is challenging to develop[34–36)].

In the hydrometallurgical method, there are two types of solvents used, namely inorganic solvents such as HCl[37)], HNO_3[38)], H_2SO_4[39)], H_3PO_4[40)] and organic solvents such as citric acid[41)], oxalate, and lactate[42)]. Most of the metal extraction focus leads to environmentally friendly processes[31)]. Lactic acid is one of the organic solvents that can extract lithium.

Sidoarjo mud is a geothermal fluid containing high amounts of minerals[43,44)], especially lithium[45,46)]. The results show that the lithium content in Sidoarjo mud reaches five ppm (mg/litre)[47,48)]. So, the total lithium content in the Sidoarjo mud is estimated to be 10 tons annually[49,50)]. This is an alternative to being used as a source of raw materials for lithium batteries and can support the needs of lithium batteries[24,51].

Lithium extraction from Sidoarjo mud needs to be done because, in addition to being an alternative source[52,53] of raw material for lithium batteries, it can also increase the economic value of the Sidoarjo mud. The processing and use of environmentally friendly solvents are chosen to save costs and be efficient. This paper will review lithium leaching with the effects of operating variables such as leaching temperature, leaching time, solid-liquid ratio, lactic acid concentration, and stirring speed to obtain the best leaching process operating conditions for the highest percentage leaching efficiency.

2. Method

Material

The Sidoarjo mud used is shown in Fig. 1 with the ordinate point 7º31'53,472"5 on March 5, 2023, at 09.51. The mud is dried to ±10% and then reduced in size to 100 mesh. Mud with 100 mesh is sampled using the coning quartering method, which aims to homogenize the mineral metals in the mud. This representative sample was pre-analyzed with an Inductively Coupled Plasma Mass Spectrometer (ICP-MS)[54]. In addition to mineralogical analysis, samples were subjected to powder X-ray diffraction (XRD)[55] and SEM-EDX analysis[56]. Lactic acid, which functions as a solvent with an analytical class, is diluted using distilled water.

Leaching Experiments

The sample used for the extraction process was 10 grams in 100 mL of solvent. The mixture of sludge and acid solution is put into a closed beaker to avoid water loss caused by high temperatures and placed on a hot plate with a magnetic stirrer for stirring. The leaching solution was stirred at 300 rpm for 2 hours. The operating variables discussed are as follows: lactic acid concentration (0.1 – 0.9 M), solid/liquid ratio (S/L), temperature (30 – 90 ºC) and reaction time (hours). The extraction results obtained were separated by filter paper. ICP-MS analyzed the resulting filtrate to determine the metal concentration after the extraction process[57]. The research steps are shown in Fig. 2 while calculating the extraction efficiency using equation (1)[58]:

$$\eta = \frac{CVD}{C_0 m} \times 100\% \quad (1)$$

Where C is the Li concentration in the leachate (mg/L), V is the volume of the leachate (L), D is the dilution factor, C_0 is the Li content in the initial sample (mg/kg), and m is the mass of the lake sediment sample (kg).

3. Results and Discussion

Characteristics of Sidoarjo Mud

An analysis was carried out using ICP-MS to determine the initial content of Sidoarjo mud. The initial lithium content in the Sidoarjo mud was 99.3 ppm. The second characteristic is XRD, which is shown in Fig. 3. XRD analysis was carried out to show the crystallographic properties of the Sidoarjo mud. Based on the results of a simple quantitative analysis using Match 3 calculations[59], it shows that the quartz SiO_2 (silicate) phase dominates, namely 81%, then magnesium ferrite 25%, Albit 3%, and Fluorohectorite 1%[60,61]. The XRD pattern shows that the sample has high crystallinity as indicated by the peak 2θ = 24.97º for SiO_2, which dominates according to JCPDS 00-021-127. At 20º – 30º, there is a maximum distribution peak, which means the SiO_2 is in an amorphous state. The second largest content is hematite (Fe_2O_3), with JCPDS No.00-036- 1296 occurring at a peak of 20º.

Fig. 1: The coordinate point for taking the Sidoarjo mud

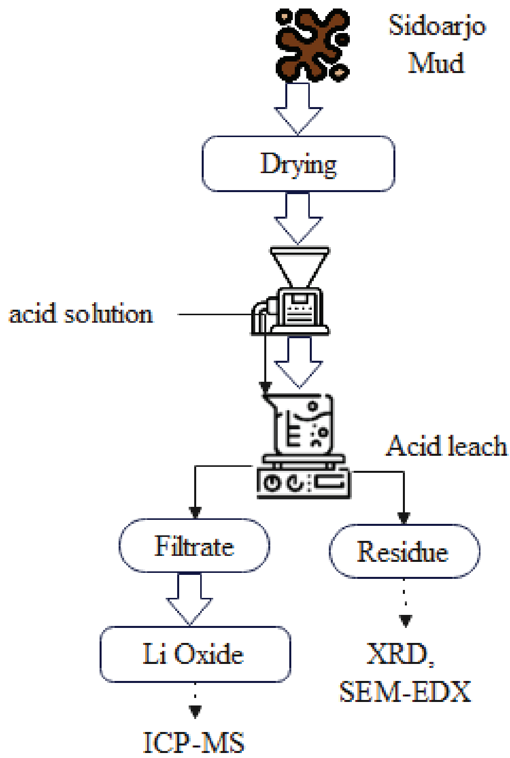


Fig. 2: Lithium leaching steps

Figure 4. a shows the results of the initial SEM-EDX analysis of the Sidoarjo mud at 5000 x magnification, which shows that the morphology is lumpy like clay[62,63].

The shape of the agglomerates in Sidoarjo mud is irregular and has a rough surface. Rough surfaces can absorb alkaline solutions and cause reduction. The main phase in the sample is quartz, where lithium can exist as physisorbed ions in this clay mud. This is also confirmed by Fig. 4. b with Si, Al and O peaks. The highest composition is the same as shown by the quantitative XRD analysis, namely Si (silicate).

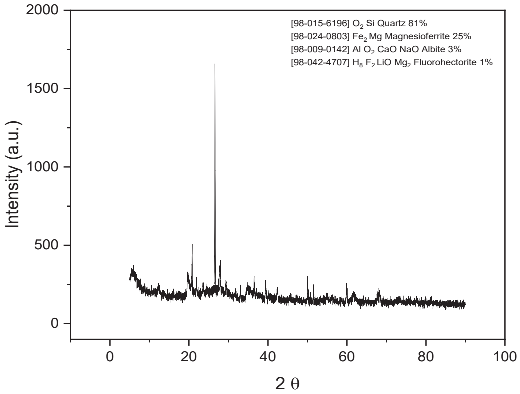
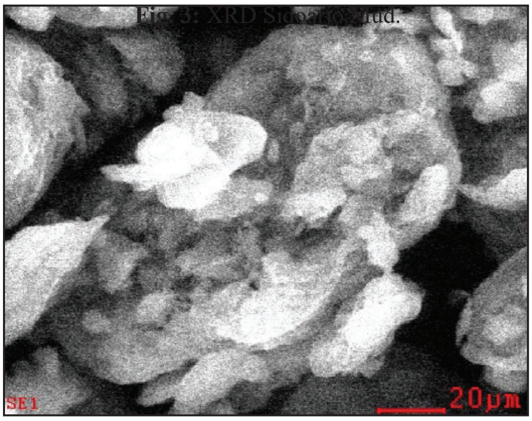
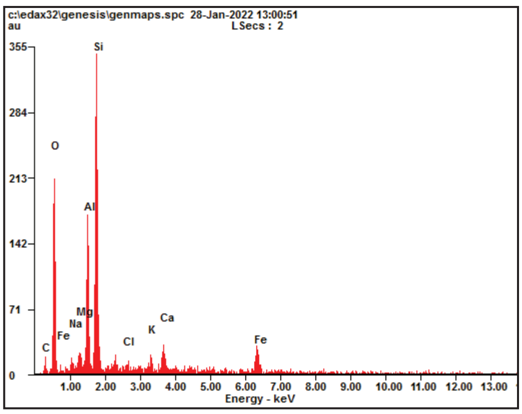


Fig. 3: XRD Sidoarjo mud.



(a)



(b)

Fig. 4: SEM-EDX Sidoarjo Mud (a), morphology (b), composition.

Effect of Concentration of Lactit Acid on Leaching

The effect of lactic acid concentration on leaching efficiency is shown in Fig. 5. Lactic acid concentration was varied from 0.3 M to 0.9 M, solid/liquid ratio 1:10 (gr/mL), stirring speed 300 rpm, reaction temperature from 30°C to 90°C , and reaction time for 2 hours. When the lactic acid concentration increased from 0.1 M to 0.9 M, the leaching efficiency increased, although not significantly. The lowest leaching efficiency was 48.77% at a temperature of 30°C with a concentration of 0.3 M lactic acid, while the highest occurred at a temperature of 90°C with a concentration of 0.9 M containing 69.82%. When the concentration of lactic acid is high, H^+ ions increase and can bind with Li^+ to form stable complex compounds[64,65]. In the leaching process, hydrogen ions attack the metal and dissolve it into a solution. Therefore, optimal leaching efficiency occurs at a concentration of 0.9 M. Lactic acid is included in organic acids, which can act as a leaching agent in the leaching process. In addition, organic acids have the advantage that they are more thermally stable compared to inorganic acids and play an essential role as complexing agents[66,67].

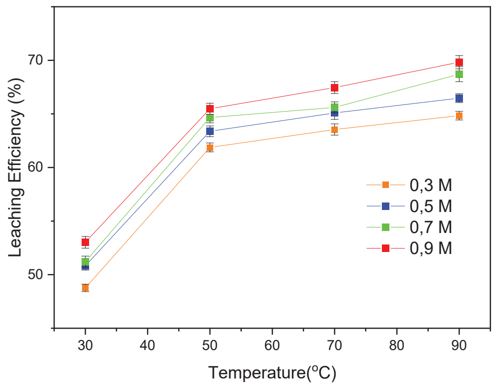


Fig. 5: Leaching Efficiency Lithium.

Effect of the Temperature on Leaching

The effect of temperature on leaching efficiency in the range of 30°C – 90°C is presented in Fig. 5. It is clear that when the leaching temperature increases, the leaching efficiency curve also increases. It can be explained that increasing the reaction temperature can accelerate the leaching reaction rate[68,69]. So, a higher leaching reaction rate can increase the leaching efficiency[70,71]. The best conditions for lithium leaching efficiency were used at 90°C, which was 69.82%. High temperatures can melt mud particles so that the lithium metal contained in the mud is easily extracted[43,72]. Besides that, this is because the Li metal leaching process is an endothermic reaction[73,74]. Temperature also produces activation energy, impacting the chemical reaction between Li ions and hydrogen ions. So, the existence of high temperatures can provide benefits in leaching efficiency. However, temperature has positive and negative influences, determined by another parameter, time[77]. In the leaching process, the maximum temperature is limited to less than 100oC, this is related to preventing the evaporation of water in the leaching solution.

4. Conclusion

This work proposes an environmentally friendly hydrometallurgical process to extract lithium from the Sidoajo mud, which can impact economic value. This leaching process is much more straightforward by direct contact of lactic acid with Sidoarjo mud without pre-treatment, such as soaking or calcining. The results show that lactic acid concentration and temperature are essential in increasing leaching efficiency. Leaching efficiency reached 69.82% under 0.9 M lactic acid conditions at 90ºC temperature. The proposed process can realize lithium recovery in Sidoarjo mud, which is clean, efficient and inexpensive, so it has broad industrial prospects. However, it is necessary to study further the role of stirring speed, solid/liquid ratio, and reaction time to obtain a higher leaching efficiency value.

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References

1) A.A.S. Gheidan, M.B.A. Wahid, O.A. Chukwunonso, and M.F. Yasin, "Impact of internal combustion engine on energy supplyand its emission reduction via sustainable fuel source," *Evergreen*, 9 (*3*) 830–844 (2022). https://doi.org/10.5109/4843114
2) W.S. Chai, Y. Bao, P. Jin, G. Tang, and L. Zhou, "A review on ammonia, ammonia-hydrogen and ammonia-methane fuels," *Renew. Sustain. Energy Rev.*, 147 (*April*) 111254 (2021). doi:10.1016/j.rser.2021.111254.
3) J. Rogelj, O. Geden, A. Cowie, and A. Reisinger, "Three ways to improve net-zero emissions targets," *Nature*, 591 365–368 (2021). https://www.nature.com/articles/d41586-021-00662-3.
4) F. Wang, W. Li, W. Bao, and Z. Lv, "Gauss–seidel method with oblique direction," *Results Appl. Math.*, 12 100180 (2021). doi:10.1016/j.rinam.2021.100180.
5) A. Sepehri, and M.H. Sarrafzadeh, "Effect of nitrifiers community on fouling mitigation and nitrification efficiency in a membrane bioreactor," *Chem. Eng. Process. - Process Intensif.*, 128 (*March*) 10–18 (2018). doi:10.1016/j.cep.2018.04.006.
6) M.S. Guney, and Y. Tepe, "Classification and assessment of energy storage systems," *Renew. Sustain. Energy Rev.*, 75 (*October 2016*) 1187–1197 (2017). doi:10.1016/j.rser.2016.11.102.
7) A. Alimujiang, and P. Jiang, "Synergy and co-benefits of reducing co2 and air pollutant emissions by promoting electric vehicles—a case of shanghai," *Energy Sustain. Dev.*, 55 181–189 (2020). doi:10.1016/j.esd.2020.02.005.
8) Y.W. Mirzayanti, B. Bhismoko, M.Q. Fathurrahman, and E. Ningsih, "Parameter variation of microwave torrefaction time of blotong and bagasse briquettes," *J. Phys. Conf. Ser.*, 2117 (*1*) (2021). doi:10.1088/1742-6596/2117/1/012022.
9) G. Ayuningtiyas, F. Harditya, and E. Ningsih, "Production of briquette made of sugarcase bagasse and dry leaves mixture by microwave torrefaction using tapioca flour as adhesive," 2020 140–144 (2020). doi:10.11594/nstp.2020.0521.
10) M.A. Santoso, Y. Wijayanti, R.B. Prasetyo, O. Setyandito, Nizam, Aprijanto, A. Subandriya, A.T. Kurniawan, A. Sudaryanto, and B. Sutejo, "A mini review: wave energy converters technology, potential applications and current research in indonesia," *Evergreen*, 10 (*3*) 1642–1650 (2023). doi:10.5109/7151712.
11) S. Natarajan, and V. Aravindan, "Burgeoning prospects of spent lithium-ion batteries in multifarious applications," *Adv. Energy Mater.*, 8 (*33*) 1–16 (2018). doi:10.1002/aenm.201802303.
12) X. Zhang, Z. Qin, T. Aldahri, S. Ren, and W. Liu, "Solvent extraction of rubidium from a sulfate solution with high concentrations of rubidium and potassium using 4-tert-butyl-2-(α-methylbenzyl)-phenol," *J. Taiwan Inst. Chem. Eng.*, 116 43–50 (2020). doi:10.1016/j.jtice.2020.11.014.
13) K.M. Winslow, S.J. Laux, and T.G. Townsend, "A review on the growing concern and potential management strategies of waste lithium-ion batteries," *Resour. Conserv. Recycl.*, 129 (*November 2017*) 263–277 (2018). doi:10.1016/j.resconrec.2017.11.001.
14) A. Nojima, A. Sano, H. Kitamura, and S. Okada, "Electrochemical characterization, structural evolution, and thermal stability of livopo4 over multiple lithium intercalations," *Evergreen*, 6 (*4*) 267–274 (2019). doi:10.5109/2547346.
15) B. Scrosati, J. Hassoun, and Y. kook Sun, "Environmental science lithium-ion batteries . a look into the future," 3287–3295 (2011). doi:10.1039/c1ee01388b.
16) Y. Chen, Y. Wang, Y. Bai, M. Feng, F. Zhou, Y. Lu, Y. Guo, Y. Zhang, and T. Mu, "Mild and efficient recovery of lithium-ion battery cathode material by deep eutectic solvents with natural and cheap components," *Green Chem. Eng.*, (*February*) (2022). doi:10.1016/j.gce.2022.06.005.
17) H. Bae, and Y. Kim, "Technologies of lithium recycling from waste lithium ion batteries: a review," *Mater. Adv.*, 2 (*10*) 3234–3250 (2021). doi:10.1039/d1ma00216c.
18) G.M. Larocca, "Global value chains: lithium in lithium-ion batteries for electric vehicles," (*July*)

(2020).

19) C.P. Makwarimba, M. Tang, Y. Peng, S. Lu, L. Zheng, Z. Zhao, and A. gang Zhen, "Assessment of recycling methods and processes for lithium-ion batteries," *IScience*, 25 (*5*) 104321 (2022). doi:10.1016/j.isci.2022.104321.
20) B. Priyono, B. Rifky, F. Zahara, and A. Subhan, "Enhancing performance of li4ti5o12 with addition of activated carbon from recycled pet waste as anode battery additives," *Evergreen*, 9 (*2*) 563–570 (2022). doi:10.5109/4794188.
21) T. Nshizirungu, M. Rana, Y.T. Jo, and J.H. Park, "Rapid leaching and recovery of valuable metals from spent lithium ion batteries (libs) via environmentally benign subcritical nickel-containing water over chlorinated polyvinyl chloride," *J. Hazard. Mater.*, 396 (*April 2020*) 122667 (2020). doi:10.1016/j.jhazmat.2020.122667.
22) X. Sun, H. Hao, F. Zhao, and Z. Liu, "Tracing global lithium flow: a trade-linked material flow analysis," *Resour. Conserv. Recycl.*, 124 (*January*) 50–61 (2017). doi:10.1016/j.resconrec.2017.04.012.
23) R.E. Ciez, and J.F. Whitacre, "Examining different recycling processes for lithium-ion batteries," *Nat. Sustain.*, 2 (*2*) 148–156 (2019). doi:10.1038/s41893-019-0222-5.
24) M. Nizam, M.R.A. Putra, and Inayati, "Heat management on lifepo4 battery pack for eddy current brake energy storage on rapid braking processes," *Evergreen*, 9 (*2*) 451–456 (2022). doi:10.5109/4794171.
25) E. Djubaedah, Riza, A. Kurniasari, S.N.E. Eny, and A. Nurrohim, "Projection of the demand for charging stations for electric passenger cars in indonesia," *Evergreen*, 10 (*3*) 1744–1752 (2023). doi:10.5109/7151723.
26) X. Zhang, Z. Chen, S. Rohani, M. He, X. Tan, and W. Liu, "Simultaneous extraction of lithium, rubidium, cesium and potassium from lepidolite via roasting with iron(ii) sulfate followed by water leaching," *Hydrometallurgy*, 208 (*July 2021*) 105820 (2022). doi:10.1016/j.hydromet.2022.105820.
27) Z. Liang, C. Cai, G. Peng, J. Hu, H. Hou, B. Liu, S. Liang, K. Xiao, S. Yuan, and J. Yang, "Hydrometallurgical recovery of spent lithium ion batteries: environmental strategies and sustainability evaluation," *ACS Sustain. Chem. Eng.*, 9 (*17*) 5750–5767 (2021). doi:10.1021/acssuschemeng.1c00942.
28) S.K. Chaerun, B.A. Prabowo, and R. Winarko, "Bionanotechnology: the formation of copper nanoparticles assisted by biological agents and their applications as antimicrobial and antiviral agents," *Environ. Nanotechnology, Monit. Manag.*, 18 (*September 2021*) 100703 (2022). doi:10.1016/j.enmm.2022.100703.
29) K. Oyama, "Applicability estimation of bioleaching into copper mining industry: comparison between mining-developed and developing countries," *Evergreen*, 7 (*2*) 195–201 (2020). doi:10.5109/4055216.
30) A. Fauzi, L.H. Lalasari, N. Sofyan, A. Ferdiansyah, D. Dhaneswara, and A.H. Yuwono, "Titanium dioxide nanosheets derived from indonesian ilmenite mineral through post-hydrothermal process," *Evergreen*, 9 (*2*) 470–475 (2022). doi:10.5109/4794174.
31) B. Xie, A. Kitajou, S. Okada, W. Kobayashi, M. Okada, and T. Takahara, "Cathode properties of na3mpo4co3 (m = co/ni) prepared by a hydrothermal method for na-ion batteries," *Evergreen*, 6 (*4*) 262–266 (2019). doi:10.5109/2547345.
32) A. Ashiq, J. Kulkarni, and M. Vithanage, "Hydrometallurgical recovery of metals from e-waste," Elsevier Inc., 2019. doi:10.1016/B978-0-12-816190-6.00010-8.
33) A.S. Rini, Y. Rati, R. Fadillah, R. Farma, L. Umar, and Y. Soerbakti, "Improved photocatalytic activity of zno film prepared via green synthesis method using red watermelon rind extract," *Evergreen*, 9 (*4*) 1046–1055 (2022). doi:10.5109/6625718.
34) G. Calvert, A.H. Kaksonen, K.Y. Cheng, J. Van Yken, B. Chang, and N.J. Boxall, "Recovery of metals from waste lithium ion battery leachates using biogenic hydrogen sulfide," *Minerals*, 9 (*9*) 1–19 (2019). doi:10.3390/min9090563.
35) D. Kim, H. Kil, K. Nakabayashi, and S. Yoon, "Improvement of electric conductivity of non-graphitizable carbon material via breaking-down and merging of the microdomains improvement of electric conductivity of non-graphitizable carbon material via breaking-down and merging of the microdomains," 4 (*1*) 16–20 (2017).
36) K. Ibadurrohman, I. Gusniani, D.M. Hartono, and N. Suwartha, "The potential analysis of food waste management using bioconversion of the organic waste by the black soldier fly (hermetia illucens) larvae in the cafeteria of the faculty of engineering , universitas indonesia the potential analysis of food waste mana," 7 (*1*) 61–66 (2020).
37) A.C. Ni'am, Y.F. Wang, S.W. Chen, and S.J. You, "Recovery of rare earth elements from waste permanent magnet (wpms) via selective leaching using the taguchi method," *J. Taiwan Inst. Chem. Eng.*, 97 137–145 (2019). doi:10.1016/j.jtice.2019.01.006.
38) J. Guan, Y. Li, Y. Guo, R. Su, G. Gao, H. Song, H. Yuan, B. Liang, and Z. Guo, "Mechanochemical process enhanced cobalt and lithium recycling from wasted lithium-ion batteries," *ACS Sustain. Chem. Eng.*, 5 (*1*) 1026–1032 (2017). doi:10.1021/acssuschemeng.6b02337.
39) X. Chen, Y. Chen, T. Zhou, D. Liu, H. Hu, and S. Fan, "Hydrometallurgical recovery of metal values from sulfuric acid leaching liquor of spent lithium-ion

batteries," *Waste Manag.*, 38 (*1*) 349–356 (2015). doi:10.1016/j.wasman.2014.12.023.

40) X. Chen, H. Ma, C. Luo, and T. Zhou, "Recovery of valuable metals from waste cathode materials of spent lithium-ion batteries using mild phosphoric acid," *J. Hazard. Mater.*, 326 77–86 (2017). doi:10.1016/j.jhazmat.2016.12.021.

41) L. Li, Y. Bian, X. Zhang, Y. Guan, E. Fan, F. Wu, and R. Chen, "Process for recycling mixed-cathode materials from spent lithium-ion batteries and kinetics of leaching," *Waste Manag.*, 71 362–371 (2018). doi:10.1016/j.wasman.2017.10.028.

42) L. Li, E. Fan, Y. Guan, X. Zhang, Q. Xue, L. Wei, F. Wu, and R. Chen, "Sustainable recovery of cathode materials from spent lithium-ion batteries using lactic acid leaching system," *ACS Sustain. Chem. Eng.*, 5 (*6*) 5224–5233 (2017). doi:10.1021/acssuschemeng.7b00571.

43) H. Kausarian, Lady Redyafry, J.T.S. Sumantyo, A. Suryadi, and M.Z. Lubis, "Structural analysis of the central sumatra basin using geological mapping and landsat 8 oli/tirs c2 l1 data," *Evergreen*, 10 (*2*) 792–804 (2023). doi:10.5109/6792830.

44) K.C. Anil, Kumaraswamy, M. Reddy, and K.M. Mamatha, "Air jet erosion studies on aluminum - red mud composites using taguchi design," *Evergreen*, 10 (*1*) 130–138 (2023). doi:10.5109/6781059.

45) H.T. Wibowo, B. Pratisho, C. Prasetyadi, and F. Yudiantoro, "Potensi unsur tanah jarang (rare earth elements) di lumpur panas," 533–539 (2022).

46) D.S. Agustawijaya, K. Karyadi, B.D. Krisnayanti, and S. Sutanto, "Rare earth element contents of the lusi mud: an attempt to identify the environmental origin of the hot mudflow in east java – indonesia," *Open Geosci.*, 9 (*1*) 689–706 (2017). doi:10.1515/geo-2017-0052.

47) N.A. Sari, I.W. Warmada, and F. Anggara, "The potential of lithium enrichment in lapindo brantas, mount anyar, and buncitan mud volcanoes, sidoarjo district, east java province," *IOP Conf. Ser. Earth Environ. Sci.*, 851 (*1*) (2021). doi:10.1088/1755-1315/851/1/012040.

48) L. Noerochim, G.A. Satriawangsa, and A. Widodo, "Recovery of lithium from geothermal fluid at lumpur sidoarjo by adsorption method," 48 (*2*) 200–206 (2016). doi:10.5614/j.eng.technol.sci.2016.48.2.6.

49) N.R. Caesar, U. Yanuhar, M. Musa, G. Ciptadi, H. Suryanto, Y.A. Wahyudi, and R.N. Soelistyoadi, "Heavy metals contamination and their impacts on fish responses in porong river, east java, indonesia," *Evergreen*, 10 (*3*) 1218–1230 (2023). doi:10.5109/7148443.

50) S. Silviana, A.G. Hasega, A.R. Nur Hanifah, and A.N. Saadah, "Synthesis of silica coating derived from geothermal solid waste modified with 3-aminopropyl triethoxysilane (aptes) and silver nano particles (agnps)," *Evergreen*, 9 (*4*) 1224–1230 (2022). doi:10.5109/6625733.

51) K.F.A. Sukra, A. Sukmono, L. Shalahuddin, A. Maswan, S. Yubaidah, D.T. Wibowo, M. Yusuf, and M.P. Helios, "Effects of battery state of charge on fuel economy of hybrid electric vehicles: an analysis using the un ece r101 method," *Evergreen*, 10 (*3*) 1770–1775 (2023). doi:10.5109/7151726.

52) M.M. Rahman, S. Saha, M.Z.H. Majumder, T.T. Suki, M.H. Rahman, F. Akter, M.A.S. Haque, and M.K. Hossain, "Energy conservation of smart grid system using voltage reduction technique and its challenges," *Evergreen*, 9 (*4*) 924–938 (2022). doi:10.5109/6622879.

53) A. Wahid, D.R. Mustafida, and Y.A. Husnil, "Exergy analysis of coal-fired power plants in ultra supercritical technology versus integrated gasification combined cycle," *Evergreen*, 7 (*1*) 32–42 (2020). doi:10.5109/2740939.

54) S. Montayev, N. Montayeva, A. Taudaeva, M. Ryskaliyev, and S. Zharylgapov, "Investigation of the compositional raw mixtures for preparation of the sintered microporous material and mineral feed additives," *Evergreen*, 10 (*3*) 1296–1306 (2023). https://doi.org/10.5109/7151675

55) N. Siregar, Motlan, and M. Sirait, "Synthesis of zno thin film by electroplating: effect of zinc concentration on the structural and optical properties," *Evergreen*, 10 (*2*) 715–721 (2023). doi:10.5109/6792820.

56) Y. Adityawardhana, A.Z. Syahrial, and B. Adjiantoro, "Characteristic of aa 7075-reinforced nano-sic composites produced by stir-squeeze casting and open die cold forging as an armor material candidate," *Evergreen*, 10 (*2*) 722–730 (2023). doi:10.5109/6792821.

57) A. Islam, S.P. Dwivedi, V.K. Dwivedi, and R. Yadav, "Extraction of chromium oxide from cclw to develop the aluminium based composite by fsp as reinforcement alongwith alumina," *Evergreen*, 9 (*4*) 993–1002 (2022). doi:10.5109/6625714.

58) N.P. Dushyantha, N.P. Ratnayake, H.M.R. Premasiri, I.M.S.K. Ilankoon, P.V.A. Hemalal, C.L. Jayawardena, R. Chandrajith, L.P.S. Rohitha, A.M.K.B. Abeysinghe, D.M.D.O.K. Dissanayake, P.G.R. Dharmaratne, A.S. Ratnayake, and N.M. Batapola, "Leaching of rare earth elements (rees) from lake sediments around eppawala phosphate deposit, sri lanka: a secondary source for rees," *Hydrometallurgy*, 205 (*May*) 105751 (2021). doi:10.1016/j.hydromet.2021.105751.

59) M. Haikal, R. Utomo, M. Haikal, R. Utomo, R.M. Ulum, and A.B. Prasetyo, "Ferronickel slag roasting to produce raw materials for refractory roasting to produce raw materials for refractory," 9 (*2*) 519–523 (2022).

60) E. Ciptawati, M. Hilfi Azra Dzikrulloh, M. Oki

Septiani, V. Rinata, D. Ainur Rokhim, N. Azfa Fauziyyah, and D. Sribuana, "Analisis kandungan mineral dari lumpur panas sidoarjo sebagai potensi sumber silika dan arah pemanfaatannya," *IJCA (Indonesian J. Chem. Anal.*, 5 (*1*) 18–28 (2022). doi:10.20885/ijca.vol5.iss1.art3.

61) R. Junaidi, A. Hasan, and M. Zamhari, "Karakteristik dan kalsinasi lumpur sidoarjo (lusi)," (*1998*) 192–196 (2018).

62) Y. Guo, F. Li, H. Zhu, G. Li, J. Huang, and W. He, "Leaching lithium from the anode electrode materials of spent lithium-ion batteries by hydrochloric acid (hcl)," *Waste Manag.*, 51 227–233 (2016). doi:10.1016/j.wasman.2015.11.036.

63) A.B. Prasetyo, A. Maksum, J.W. Soedarsono, and F. Firdiyono, "Thermal characteristics of ferronickel slag on roasting process with addition of sodium carbonate thermal characteristics of ferronickel slag on roasting process with addition of sodium carbonate (na 2 co 3)," (2019). doi:10.1088/1757-899X/541/1/012037.

64) L. Zhuang, C. Sun, T. Zhou, H. Li, and A. Dai, "Recovery of valuable metals from lini 0.5 co 0.2 mn 0.3 o 2 cathode materials of spent li-ion batteries using mild mixed acid as leachant," *Waste Manag.*, 85 175–185 (2019). doi:10.1016/j.wasman.2018.12.034.

65) M. Yu, Z. Zhang, F. Xue, B. Yang, G. Guo, and J. Qiu, "A more simple and efficient process for recovery of cobalt and lithium from spent lithium-ion batteries with citric acid," *Sep. Purif. Technol.*, 215 (*January*) 398–402 (2019). doi:10.1016/j.seppur.2019.01.027.

66) H. Ruan, M. Nishibori, T. Uchiyama, K. Kamitani, and K. Shimanoe, "Soot oxidation activity of ag / hzsm-5 (si / al = 40) catalyst soot oxidation activity of ag / hzsm-5 (si / al = 40) catalyst," 5 7–11 (2017).

67) Y. Furutani, K. Norinaga, and S. Kudo, "Current situation and future scope of biomass gasification in japan current situation and future scope of biomass gasification in japan," 4 (*4*) 24–29 (2017).

68) R. Tao, P. Xing, H. Li, Z. Sun, and Y. Wu, "Recovery of spent licoo2 lithium-ion battery via environmentally friendly pyrolysis and hydrometallurgical leaching," *Resour. Conserv. Recycl.*, 176 (*September 2021*) 105921 (2022). doi:10.1016/j.resconrec.2021.105921.

69) H. Rezaei, S. Ziaedin Shafaei, H. Abdollahi, A. Shahidi, and S. Ghassa, "A sustainable method for germanium, vanadium and lithium extraction from coal fly ash: sodium salts roasting and organic acids leaching," *Fuel*, 312 (*September 2021*) 122844 (2022). doi:10.1016/j.fuel.2021.122844.

70) C. Yang, J. Zhang, G. Liang, H. Jin, Y. Chen, and C. Wang, "An advanced strategy of 'metallurgy before sorting' for recycling spent entire ternary lithium-ion batteries," *J. Clean. Prod.*, 361 (*30*) (2022). doi:10.1016/j.jclepro.2022.132268.

71) M. Wang, K. Liu, S. Dutta, D.S. Alessi, J. Rinklebe, Y.S. Ok, and D.C.W. Tsang, "Recycling of lithium iron phosphate batteries: status, technologies, challenges, and prospects," *Renew. Sustain. Energy Rev.*, 163 (*May*) (2022). doi:10.1016/j.rser.2022.112515.

72) W. Yu, Y. Guo, Z. Shang, Y. Zhang, and S. Xu, "A review on comprehensive recycling of spent power lithium-ion battery in china," *ETransportation*, 11 100155 (2022). doi:10.1016/j.etran.2022.100155.

73) L. Li, W. Qu, X. Zhang, J. Lu, R. Chen, F. Wu, and K. Amine, "Succinic acid-based leaching system: a sustainable process for recovery of valuable metals from spent li-ion batteries," *J. Power Sources*, 282 544–551 (2015). doi:10.1016/j.jpowsour.2015.02.073.

74) E. Ningsih, S.R. Juliastuti, R. Darmawan, N. Hendrianie, and O. Rachmaniah, "Initial extraction of sodium silicate from sidoarjo mud by alkaline fusion and water leaching," *Heliyon*, 9 (*6*) e17095 (2023). doi:10.1016/j.heliyon.2023.e17095.

75) M. Egiza, H. Naragino, A. Tominaga, and K. Murasawa, "Si and cr doping effects on growth and mechanical properties of ultrananocrystallinediamond / amorphous carbon composite films deposited on cemented carbide substrates by coaxial arc plasma deposition si and cr doping effects on growth and mechanical prop," 3 (*1*) 32–36 (2016).

76) K. Nakamoto, R. Sakamoto, and A. Kitajou, "Cathode properties of sodium manganese hexacyanoferrate in aqueous electrolyte cathode properties of sodium manganese hexacyanoferrate in aqueous electrolyte," 4 (*1*) 6–9 (2017).

77) A. Zhumadilova, and S. Zhigitova, "Features of modern areas of solid waste disposal," *Evergreen*, 10 (*2*) 640–648 (2023). doi:10.5109/6792809.