

**PELARUT *DEEP EUTECTIC* ETALIN SEBAGAI AGEN PELINDIAN  
LOGAM PERAK DARI LIMBAH PRINTED CIRCUIT BOARDS (*PCB*)**

**SKRIPSI**

Diajukan untuk memenuhi salah satu syarat  
memperoleh sajana sains pada Program Studi Kimia



Disusun oleh :  
Muhammad Yunus Firdaus  
1704850

**PROGRAM STUDI KIMIA  
DEPARTEMEN PENDIDIKAN KIMIA  
FAKULTAS PENDIDIKAN MATEMATIKA DAN ILMU PENGETAHUAN ALAM  
UNIVERSITAS PENDIDIKAN INDONESIA  
BANDUNG  
2021**

**PELARUT *DEEP EUTECTIC* ETALIN SEBAGAI AGEN PELINDIAN  
LOGAM PERAK DARI LIMBAH PRINTED CIRCUIT BOARDS (PCB)**

disetujui dan disahkan oleh pembimbing:

Pembimbing I



Dr. Soja Siti Fatimah, M.Si.

NIP. 196802161994022001

Pembimbing II

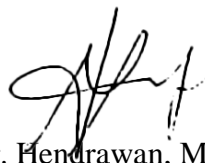


Dr. rer. nat. H. Ahmad Mudzakir, M.Si.

NIP. 196611211991031002

Mengetahui,

Kepala Departemen Pendidikan Kimia FPMIPA UPI



Dr. Hendrawan, M.Si.

NIP. 196309111989011001

2021

**PELARUT *DEEP EUTECTIC* ETALIN SEBAGAI AGEN PELINDIAN  
LOGAM PERAK DARI LIMBAH PRINTED CIRCUIT BOARDS (PCB)**

Oleh:

Muhammad Yunus Firdaus

1704850

Sebuah skripsi yang diajukan untuk memenuhi salah satu syarat memperoleh gelar  
Sarjana Sains pada Program Studi Kimia Departemen Pendidikan Kimia

Fakultas Pendidikan Matematika dan Ilmu Pengetahuan Alam

© Muhammad Yunus Firdaus

Universitas Pendidikan Indonesia

Agustus 2021

Hak Cipta dilindungi undang-undang.

Skripsi ini tidak boleh diperbanyak seluruhnya atau sebagian, dengan dicetak  
ulang, difotokopi, atau cara lainnya tanpa izin penulis.

## ABSTRAK

*Deep eutectic solvent* (DES) merupakan pelarut yang akhir-akhir ini menjadi perhatian dalam pelindian logam dari berbagai limbah industri. Penelitian ini berbasis *review* jurnal mengkaji penggunaan pelarut *deep eutectic* Etalin berbasis kolin klorida/ChCl sebagai akseptor ikatan hidrogen dan etilen glikol donor ikatan hidrogen sebagai agen pelindian logam perak dari limbah printed circuit boards (*pcb*). Model penelitian yang digunakan adalah *traditional narrative review*. Tahapan penelitian yang dilakukan dengan mengidentifikasi masalah terkait sintesis dan karakterisasi, juga aplikasi dalam penggunaan pelarut *deep eutectic* Etalin dalam pelindian logam perak. Seleksi jurnal dilakukan melalui penelusuran dengan kata kunci sintesis dan karakterisasi, DES Etalin, pelindian logam perak, limbah *PCB*. Selanjutnya hasil seleksi jurnal dirangkum berdasarkan temuan yang ada. Hasil *review* jurnal menunjukkan bahwa sintesis DES Etalin dapat dilakukan dengan rasio molar ChCl dan etilen glikol (1:2) pada temperatur 50-100°C dengan pengadukan hingga terbentuk suatu campuran yang homogen. Hasil karakterisasi DES Etalin dengan FTIR mengindikasikan adanya pergeseran bilangan gelombang OH dan TGA DES mengalami dekomposisi pada temperatur 354- 582K. DES Etalin dapat diaplikasikan pada pelindian logam perak dengan persen kemurnian 99%. Karakterisasi perak hasil pelindian menunjukkan perak yang terbentuk berwarna abu-abu muda dengan bentuk kristal mikro dendritik dan data logam perak sesuai dengan JCPDS File No. 04-0783 melalui analisis XRD.

**Kata kunci:** Sintesis dan karakterisasi, DES Etalin, Pelindian Logam Perak, Limbah *PCB*

## ABSTRACT

*Deep eutectic solvent (DES) is a solvent that has recently become a concern in the leaching of metals from various industrial wastes. This research is based on a journal review examining the use of the deep eutectic solvent Ethalin based on choline chloride/ChCl as a hydrogen bond acceptor and ethylene glycol as a hydrogen bond donor as a leaching agent for silver metal from printed circuit boards (pcb) waste. The research model used is a traditional narrative review. The research steps were carried out by identifying problems related to synthesis and characterization, as well as the application of the deep eutectic solvent Ethaline in leaching silver metal. Journal selection was carried out by searching with the keywords synthesis and characterization, DES Ethalin, silver metal leaching, PCB waste. Furthermore, the results of the journal selection are summarized based on the existing findings. The results of the journal review show that the synthesis of DES Ethaline can be carried out with a molar ratio of ChCl and ethylene glycol (1:2) at a temperature of 50-100°C with stirring until a homogeneous mixture is formed. The results of Ethaline DES characterization with FTIR indicated a shift in the OH and TGA wave numbers. DES decomposed at a temperature of 354-582K. DES Ethaline can be applied to the leaching of silver metal with a purity percent of 99%. The characterization of the leached silver showed that the silver formed was light gray in color with dendritic microcrystals and the silver metal data was in accordance with JCPDS File No. 04-0783 via XRD analysis.*

**Keywords:** *Synthesis and characterization, DES Ethaline, Silver Leach, PCB Waste.*

## DAFTAR ISI

LEMBAR PERNYATAAN .....	iii
KATA PENGANTAR .....	iv
UCAPAN TERIMAKASIH .....	v
ABSTRAK .....	vi
ABSTRACT .....	vii
DAFTAR ISI .....	viii
DAFTAR GAMBAR .....	x
DAFTAR TABEL .....	xii
<b>BAB I PENDAHULUAN .....</b>	<b>1</b>
1.1 Latar Belakang Penelitian.....	1
1.2 Rumusan Masalah Penelitian .....	3
1.3 Tujuan Penelitian.....	3
1.4 Manfaat Penelitian.....	3
1.5 Struktur Organisasi Skripsi.....	4
<b>BAB II TINJAUAN PUSTAKA.....</b>	<b>5</b>
2.1. Deep Eutectic Solvents (DES).....	5
2.1.1 Sifat Fisikokimia DES berbasis $\text{ChCl}$ .....	8
2.2. Pelarut DES berbasis kolin dan beberapa donor ikatan hidrogen (HBD)	
11	
2.2.1 Etilen glikol.....	11
2.2.2 Asam levulinat .....	12
2.2.3 Asam sitrat .....	12
2.3. Pelindian Logam.....	13
2.3.1 Perak.....	14
2.3.2 Tembaga.....	15
2.3.3 Emas.....	16
2.4. Limbah industri unsur logam.....	16
2.4.1 Baterai litium.....	16
2.4.2 Zinc plant residue dari sfalerit.....	17
2.4.3 PCB (Printed Circuit Board) .....	17
2.5. Pelindian logam dengan DES Etalin .....	18

2.5.1	Suhu Pelindian .....	19
2.5.2	Waktu pelindian .....	19
2.5.3	Rasio padat-cair.....	19
2.6.	Kelarutan logam dalam DES Etalin .....	19
BAB III METODE PENELITIAN.....		21
3.1.	Deskripsi Penelitian.....	21
3.2.	Tahapan Penelitian .....	21
3.2.1.	Identifikasi masalah melalui jurnal-jurnal bereputasi .....	21
3.2.2.	Penelaahan jurnal terpilih.....	21
3.2.3.	Seleksi jurnal.....	25
3.2.4.	Pengumpulan Data .....	27
3.2.5.	Pengolahan Data.....	27
3.2.6.	Penarikan Kesimpulan .....	28
3.3.	Tahapan Penelitian .....	28
BAB IV HASIL DAN PEMBAHASAN .....		29
4.1.	Sintesis DES Etalin.....	29
4.1.1	Mekanisme reaksi DES Etalin .....	31
4.1.2	Rasio molar HBA dan HBD.....	33
4.1.3	Karakterisasi DES Ethalin.....	37
4.2.	Aplikasi Pelindian Logam Perak dengan menggunakan DES Etalin dari Limbah PCB .....	41
4.2.1	Kondisi Optimum DES Etalin dalam Pelindian Logam Perak dari Limbah PCB .....	42
4.2.2	Mekanisme Reaksi DES Etalin dalam Pelindian Logam Perak.....	50
4.3.	Pelindian logam perak dari limbah PCB dengan DES Etalin.....	52
4.3.1	Karakterisasi Hasil Pelindian Logam Perak dari Limbah PCB dengan DES Etalin.....	54
BAB V KESIMPULAN.....		57

## DAFTAR GAMBAR

<b>Gambar 2.1</b> HBA dan HBD yang umum digunakan dalam sintesis DES.....	6
<b>Gambar 2.2</b> Perbandingan sintesis utama IL dan DES.....	6
<b>Gambar 2.3</b> Mekanisme reaksi pembentukan DES berbasis ChCl dan alkohol.....	8
<b>Gambar 2.4</b> Struktur molekul kolin klorida. ....	11
<b>Gambar 2.5</b> Penggambaran struktur kimia etilen glikol.....	12
<b>Gambar 2.6</b> Struktur molekul asam levulinat.....	12
<b>Gambar 2.7</b> Struktur molekul asam sitrat.....	13
<b>Gambar 3.1</b> Bagan Alir Penelitian.....	28
<b>Gambar 4.1</b> Tahapan Pembuatan DES secara umum.....	29
<b>Gambar 4.2</b> Reaksi yang terlibat dalam persiapan DES Etalin.....	31
<b>Gambar 4.3</b> Efektifitas Rasio Molar Ethaline terhadap Densitas dalam DES.....	33
<b>Gambar 4.4</b> Struktur molekul DES Etalin dengan perhitungan DFT.....	33
<b>Gambar 4.5</b> Efektifitas Rasio Molar Ethaline terhadap Densitas dalam DES.....	36
<b>Gambar 4.6</b> Efektifitas Rasio Molar Ethaline terhadap Viskositas dalam DES...37	37
<b>Gambar 4.7</b> Spektrum FTIR komponen murni dan DES Etalin.....	38
<b>Gambar 4.8</b> Kurva TGA dinamis dengan laju pemanasan 10 K · menit <sup>-1</sup> untuk Etalin.....	40
<b>Gambar 4.9</b> Pengaruh Variasi Suhu terhadap Efisiensi Pelindian Logam Perak dengan DES ChCl-Air dari Limbah Residu Perak.....	43
<b>Gambar 4.10</b> Pengaruh Variasi Suhu terhadap Efisiensi Pelindian Logam Seng dengan DES ChCl-Asam levulinat dari Limbah Residu Goetit.....	43
<b>Gambar 4.11</b> Pengaruh Variasi Suhu terhadap Efisiensi Pelindian Logam Kobalt dengan DES ChCl-Asam sitrat dari Limbah Katoda Baterai Litium.....	44
<b>Gambar 4.12</b> Pengaruh Variasi waktu terhadap Efisiensi Pelindian Logam Perak dengan DES ChCl-Air dari Limbah Residu Perak.....	45
<b>Gambar 4.13</b> Pengaruh Variasi Suhu terhadap Efisiensi Pelindian Logam Seng dengan DES ChCl-Asam levulinat dari Limbah Residu Goetit.....	45
<b>Gambar 4.14</b> Pengaruh Variasi Suhu terhadap Efisiensi Pelindian Logam Kobalt dengan DES ChCl-asam sitrat dari Limbah Baterai Litium Bekas...46	46
<b>Gambar 4.15</b> Pengaruh Variasi Rasio Padat-Cair terhadap Efisiensi Pelindian Logam Perak dengan DES ChCl-Air dari Limbah Residu Perak.....	47



<b>Gambar 4.16</b> Pengaruh Variasi Rasio Padat-Cair terhadap Efisiensi Pelindian Logam Seng dengan DES ChCl-Asam levulinat dari Limbah Residu Goetit .....	47
<b>Gambar 4.17</b> Pengaruh Variasi Rasio Padat-Cair terhadap Efisiensi Pelindian Logam Kobalt dengan DES ChCl-asam sitrat dari Limbah Baterai Litium Bekas.....	48
<b>Gambar 4.18</b> Gambaran mekanisme reaksi yang diusulkan pada pelindian logam perak dengan DES Etalin.....	49
<b>Gambar 4.19</b> Prediksi Orde Reaksi 1 DES Etalin yang terjadi dalam pelindian perak.....	49
<b>Gambar 4.20</b> Prediksi Orde Reaksi 0 DES Etalin yang terjadi dalam pelindian perak.....	51
<b>Gambar 4.21</b> Bagan alir tiga pelarutan anodik yang digunakan untuk mendapatkan sampel S1.....	52
<b>Gambar 4.22</b> Mikrograf optik untuk pelapis Ag yang diendapkan dari ChCl-EG-I <sub>2</sub> pada substrat .....	54
<b>Gambar 4.23</b> Pola XRD untuk deposit Ag diperoleh dari sampel S1 dalam ChCl-EG-I <sub>2</sub> .....	55
<b>Gambar 4.24</b> SEM dari Ag yang dielektrodeposisi dari ChCl-EG-I <sub>2</sub> .....	56

## DAFTAR TABEL

<b>Tabel 2.1</b> Perbedaan dan Persamaan DES dengan ILs.....	7
<b>Tabel 2.2</b> Titik leleh DES berbasis kolin dengan variasi HBD pada beberapa rasio molar.....	9
<b>Tabel 2.3</b> Densitas HBA ChCl dengan variasi HBD dan rasio molar.....	10
<b>Tabel 2.4</b> Viskositas DES berbasis kolin pada rasio molar 1:2 untuk beberapa jenis HBD.....	10
<b>Tabel 2.5</b> Komposisi logam dalam ZPR (Massa fraksi,% ).....	17
<b>Tabel 2.6</b> Komposisi Kimia PCB.....	18
<b>Tabel 2.7</b> Kelarutan Logam dalam pelindi DES Etalin.....	20
<b>Tabel 3.1</b> Hasil Penelusuran Jurnal.....	21
<b>Tabel 3.2</b> Hasil Seleksi Jurnal.....	25
<b>Tabel 4.1</b> Penggunaan DES Etalin (1:2) dan suhu sintesis pada beberapa penelitian.....	30
<b>Tabel 4.2</b> Pengukuran densitas dan viskositas DES Etalin terhadap rasio molar HBA:HBD.....	33
<b>Tabel 4.3</b> Daerah Serapan FTIR Etilen Glikol.....	39
<b>Tabel 4.4</b> Daerah Serapan FTIR Etalin.....	39

## DAFTAR PUSTAKA

- Abbott, A. P., Boothby, D., Capper, G., Davies, D. L., & Rasheed, R. K. (2004). Deep eutectic solvents formed between choline chloride and carboxylic acids: versatile alternatives to ionic liquids. *Journal of the American Chemical Society*, 126(29), 9142-9147.
- Abbott, A. P., Capper, G., Davies, D. L., Munro, H. L., Rasheed, R. K., & Tambyrajah, V. (2001). Preparation of novel, moisture-stable, Lewis-acidic ionic liquids containing quaternary ammonium salts with functional side chains. *Chemical Communications*, (19), 2010–2011.
- Abbott, A.P., Capper, G., Davies, D.L., McKenzie, K.J., Obi, S.U. (2006). *Solubility of Metal Oxides in Deep Eutectic Solvents Based on Choline Chloride*. *J. Chem. Eng.* 51, 1280–1282.
- Abbott, A. P., McKenzie, K. J., & Ryder, K. S. (2007). Electropolishing and Electroplating of Metals Using Ionic Liquids Based on Choline Chloride. *Ionic Liquids IV*, 186–197.
- Abbott, A. P., Harris, R. C., Holyoak, F., Frisch, G., Hartley, J., & Jenkin, G. R. T. (2015). Electrocatalytic recovery of elements from complex mixtures using deep eutectic solvents. *Green Chemistry*, 17(4), 2172–2179.
- Alcanfor, A. A. C., dos Santos, L. P. M., Dias, D. F., Correia, A. N., & de Lima-Neto, P. (2017). Electrodeposition of indium on copper from deep eutectic solvents based on choline chloride and ethylene glycol. *Electrochimica Acta*, 235, 553–560
- Alcanfor, A. A. C., dos Santos, L. P. M., Dias, D. F., Correia, A. N., & de Lima-Neto, P. (2017). Electrodeposition of indium on copper from deep eutectic solvents based on choline chloride and ethylene glycol. *Electrochimica Acta*, 235, 553–560
- Anonim. (2019). Lembaran Data Keselamatan Bahan: Perak. [Online] Diakses melalui : [https://www.merckmillipore.com/ID/id/product/msds/MDA\\_CHEM-101506?ReferrerURL=https%3A%2F%2Fwww.google.com%2F](https://www.merckmillipore.com/ID/id/product/msds/MDA_CHEM-101506?ReferrerURL=https%3A%2F%2Fwww.google.com%2F) (10 Maret 2021).
- Arslan, V., Ucurum, M., Vapur, H. and Bayat, O., 2011. Recovery of silver from waste radiographic films by chemical leaching. *Asian Journal of Chemistry*, 23(1), p.67.
- Atia, T.A. and Spoooren, J., 2020. Microwave assisted chloride leaching of zinc plant residues. *Journal of Hazardous Materials*, 398, p.122814.
- Bagh, F.S.G., Shahbaz, K., Mjalli, F.S., AlNashef, I.M., Hashim, M.A. (2013). *Electrical Conductivity of Ammonium and Phosphonium Based Deep Eutectic Solvents: Measurements and Artificial Intelligence-Based Prediction*. *Fluid Phase Equilibria*, 356, 30–37.

- Bakkar, A., & Neubert, V. (2018). Recycling of cupola furnace dust: Extraction and electrodeposition of zinc in deep eutectic solvents. *Journal of Alloys and Compounds*.
- Bernasconi, R., Panzeri, G., Firtin, G., Kahyaoglu, B., Nobili, L., & Magagnin, L. (2020). Electrodeposition of ZnNi Alloys from Choline Chloride/Ethylene Glycol Deep Eutectic Solvent and Pure Ethylene Glycol for Corrosion Protection. *The Journal of Physical Chemistry B*.
- Binnemans, K., & Jones, P. T. (2017). Solvometallurgy: An Emerging Branch of Extractive Metallurgy. *Journal of Sustainable Metallurgy*, 3(3), 570–600.
- Brindley, K. (2011). Soldering. *Starting Electronics*, 205–257.
- Britannicakids. (2020). Copper. [Online] diakses melalui : <https://kids.britannica.com/students/article/copper/273804> (27 Juli 2021).
- Brusas, J. R. & Pena, E. M. B. D. (2021). *Hygroscopicity of 1:2 Choline Chloride:Ethylene Glycol Deep Eutectic Solvent: A Hindrance to its Electroplating Industry Adoption. J. Electrochem. Sci. Technol. jecst.2020.01522*
- Chen, Z., Greaves, T. L., Warr, G. G., & Atkin, R. (2017). *Mixing cations with different alkyl chain lengths markedly depresses the melting point in deep eutectic solvents formed from alkylammonium bromide salts and urea. Chemical Communications*, 53(15), 2375–2377.
- CDC. (2019). Sulfuric Acid. [Online] Diakses melalui : <https://www.cdc.gov/niosh/topics/sulfuric-acid/default.html> (19 Mei 2021).
- Clark, C. (2019). Sulfuric Acid. [Online] Diakses melalui : <http://www.gcesystems.com/sulfuric-acid/> (10 Maret 2021).
- Delgado-Mellado, N., Larriba, M., Navarro, P., Rigual, V., Ayuso, M., García, J., & Rodríguez, F. (2018). *Thermal stability of choline chloride deep eutectic solvents by TGA/FTIR-ATR analysis. Journal of Molecular Liquids*, 260, 37–43.
- Dochea, M., Mandroyana, A., Mourad-Mahmoudb, M., Moutarliera, V., Hihn, J. (2016). A Sonochemical Process for Copper Leaching and Electrochemical Re-Deposition in a Des Solvent.
- Dorella, G., & Mansur, M. B. (2007). A study of the separation of cobalt from spent Li-ion battery residues. *Journal of Power Sources*, 170(1), 210–215
- Eurocircuit. (2013). What is a PCB or Printed Circuit Board. [Online] Diakses melalui : <https://www.eurocircuits.com/pcb-printed-circuit-board/> (27 Juli 2021).
- Fan, Y., Liu, Y., Niu, L., Zhang, W., & Zhang, T. (2020). Leaching of silver from silver-bearing residue by a choline chloride aqueous solution and the sustained deposition of silver on copper. *Hydrometallurgy*, 105454

- Ferré, E.C. (2017). The Many Uses of Silver. [Online] Diakses melalui: <https://geology.com/articles/uses-of-silver/> (29 Mei 2021).
- Frisch, G., Hartley, J., Abbott, A. P., Karim, W. O., & Ryder, K. S. (2015). Anodic dissolution of metals in ionic liquids. *Progress in Natural Science: Materials International*, 25(6), 595–602.
- García, G., Aparicio, S., Ullah, R., & Atilhan, M. (2015). Deep Eutectic Solvents: Physicochemical Properties and Gas Separation Applications. *Energy & Fuels*, 29(4), 2616–2644.
- Haghighbakhsh, R., & Raeissi, S. (2020). A study of non-ideal mixtures of ethanol and the (1 choline chloride + 2 ethylene glycol) deep eutectic solvent for their volumetric behaviour. *The Journal of Chemical Thermodynamics*, 106219.
- Hartley, J. M., Ip, C.-M., Forrest, G. C. H., Singh, K., Gurman, S. J., Ryder, K. S., Frisch, G. (2014). EXAFS Study into the Speciation of Metal Salts Dissolved in Ionic Liquids and Deep Eutectic Solvents. *Inorganic Chemistry*, 53(12), 6280–6288.
- Hsieh, L.-Y., Fong, J.-D., Hsieh, Y.-Y., Wang, S.-P., & Sun, I.-W. (2018). Electrodeposition of Bismuth in a Choline Chloride/Ethylene Glycol Deep Eutectic Solvent under Ambient Atmosphere. *Journal of The Electrochemical Society*, 165(9), D331–D338.
- Javanshir, S., Saei Qashoqchi, S. and Heidari Mofrad, Z., 2020. Silver production from spent zinc–silver oxide batteries via leaching–cementation technique. *Separation Science and Technology*, pp.1-9.
- Jiang, G., Peng, B., Liang, Y., Chai, L., Wang, Q., Li, Q., & Hu, M. (2017). Recovery of valuable metals from zinc leaching residue by sulfate roasting and water leaching. *Transactions of Nonferrous Metals Society of China*, 27(5), 1180–1187.
- Joda, N.N. and Rashchi, F., 2012. Recovery of ultrafine grained silver and copper from PC board scraps. *Separation and Purification Technology*, 92, pp.36-42.
- Jordilabs. (2020). What is Thermal Gravimetric Analysis?. [Online] Diakses melalui : <https://jordilabs.com/blog/what-is-thermal-gravimetric-analysis/> (27 Juli 2021).
- Kalhor, P., & Ghandi, K. (2019). Deep Eutectic Solvents for Pretreatment, Extraction, and Catalysis of Biomass and Food Waste. *Molecules*, 24(22), 4012.
- Libretext. Hydrogen Bonding. (2020) Diakses melalui : <https://chem.libretexts.org> (27 Juli 2021).
- Li, X., dan Binnemas, K. (2021). Oxidative Dissolution of Metals in Organic Solvents. *Chemical Reviews* 2021 121 (8), 4506-4530.

- Lim, C. Y., Majid, M. F., Rajasuriyan, S., Mohd Zaid, H. F., Jumbri, K., & Chong, F. K. (2020). *Desulfurization Performance of Choline Chloride-Based Deep Eutectic Solvents in the Presence of Graphene Oxide*. *Environments*, 7(11), 97.
- Manurung, R., Simanjuntak, G. C., Perez, R. N., Syahputra, A., Alhamdi, M. A., Siregar, H., & Syahputri Zuhri, R. R. (2019). Production of Choline Chloride-Based Deep Eutectic Solvent with Hydrogen Bond Donor D-Glucose and Ethylene Glycol. *IOP Conference Series: Materials Science and Engineering*, 505, 012134.
- Medchemexpress. (2021). Choline Chloride. [Online] Diakses melalui : <https://www.medchemexpress.com/Choline-chloride.html> (10 Maret 2020).
- Mishra, G., Jha, R., Rao, M.D., Meshram, A., Singh, K.K. (2021). Recovery of Silver from Waste Printed Circuit Boards (WPCBs) through Hydrometallurgical Route: A Review. *Environmental Challenges*, 100073.
- National Center for Biotechnology Information. (2021). PubChem Compound Summary [Online] diakses melalui: <https://pubchem.ncbi.nlm.nih.gov/compound> (28 Maret 2021).
- Ntengwe, F. (2010). The Leaching of Dolomitic-Copper Ore Using Sulphuric Acid Under Controlled Conditions. *The Open Mineral Processing Journal*, 3.
- Peeters, N., Binnemans, K., & Riaño, S. (2020). Solvometallurgical recovery of cobalt from lithium-ion battery cathode materials using deep-eutectic solvents. *Green Chemistry*.
- Plotka-Wasyłka, J., de la Guardia, M., Andruch, V., & Vilková, M. (2020). *Deep eutectic solvents vs ionic liquids: Similarities and differences*. *Microchemical Journal*, 105539.
- Popescu, A.M., Soare, V., Demidenko, O., Moreno, J, M, C., Neacsu, E, I., Donath, D., Burada, M., Constantin, i., Constantin, V. (2020). *Recovery of silver and gold from elektronik waste by electrodeposition in ethaline ionic liquid*. *Rev Chim*, 71, 122-132.
- Pubchem. (2021). Choline Chloride. [Online] Diakses melalui : <https://pubchem.ncbi.nlm.nih.gov/compound/Choline-chloride> (27 Juli 2021).
- Pubchem. (2021). 1,2-Ethandiol. [Online] Diakses melalui : [https://pubchem.ncbi.nlm.nih.gov/compound/1\\_2-Ethandiol](https://pubchem.ncbi.nlm.nih.gov/compound/1_2-Ethandiol) (27 Juli 2021).
- Qiao, H., & Wei, Q. (2012). Functional nanofibers in lithium-ion batteries. *Functional Nanofibers and Their Applications*, 197–208. doi:10.1533/9780857095640.2.197
- Rodriguez Rodriguez, N., Machiels, L., Onghena, B., Spooren, J., & Binnemans, K. (2020). *Selective recovery of zinc from goethite residue in the zinc industri using deep-eutectic solvents*. *RSC Advances*, 10(12), 7328–7335.

- RSC. (2017). Periodic Table. [Online] Diakses melalui: <https://www.rsc.org/periodic-table/>. (11 Maret 2021)
- Rusen, A., & Ali Topcu, M. (2017). Investigation of Various Metal Recoveries from Zinc Plant Leach Residue by Choline-Chloride Agent. *Current Physical Chemistry*, 7(4), 273-280.
- Sánchez-Viesca, F. and Gómez, R., 2020. *On the Sabanin-Laskowski Test for Citric Acid. World*, 8(1), pp.5-6.
- Sathaiyan, N., Nandakumar, V., & Ramachandran, P. (2006). *Hydrometallurgical recovery of silver from waste silver oxide button cells. Journal of Power Sources*, 161(2), 1463–1468.
- Sivaguru, P., & Bi, X. (2018). *Introduction to Silver Chemistry. Silver Catalysis in Organic Synthesis*, 1–32.
- Sethurajan, M., & van Hullebusch, E. D. (2019). *Leaching and Selective Recovery of Cu from Printed Circuit Boards. Metals*, 9(10), 1034.
- Sethurajan, M., Lens, P. N. L., Horn, H. A., Figueiredo, L. H. A., & van Hullebusch, E. D. (2017). *Leaching and Recovery of Metals. Environmental Chemistry for a Sustainable World*, 161–206.
- Shahbaz, K., Baroutian, S., Mjalli, F.S., Hasyim, M.A., AlNashef, I.M. (2012). *Densities of Ammonium and Phosphonium Based Deep Eutectic Solvents: Prediction Using Artificial Intelligence and Group Contribution Techniques. Thermochimica Acta*, 527, 59– 66.
- Shekaari, Hemayat., Taghi Zafarani-Moattar, Mohammed., Shayanfar, Ali., Mokhtarpour, Masumeh. (2018). *Effect of choline chloride/ethylene glycol or glycerol as deep eutectic solvents on the solubility and thermodynamic properties of acetaminophen. Journal of Molecular Liquids* 249, 1222–1235.
- Sivrikaya, S. (2019). *A novel vortex-assisted liquid phase microextraction method for parabens in cosmetic oil products using deep eutectic solvent. International Journal of Environmental Analytical Chemistry*, 1–11.
- Smith, E. L., Abbott, A. P., & Ryder, K. S. (2014). *Deep Eutectic Solvents (DESs) and Their Applications. Chemical Reviews*, 114(21), 11060–11082.
- Spathariotis, S., Peeters, N., Ryder, K. S., Abbott, A. P., Binnemans, K., & Riaño, S. (2020). *Separation of iron(iii), zinc(ii) and lead(ii) from a choline chloride–ethylene glycol deep eutectic solvent by solvent extraction. RSC Advances*, 10(55), 33161–33170.
- Swerim. (2017). *Metal recovery and recycling*. [Online] Diakses melalui : <https://www.swerim.se/en/areas-of-expertise/materials-sciences-raw-materials/metals/metal-recycling> (29 Mei 2021).
- Tang, B., Zhang, H., Row, K.H. (2015). *Application Of Deep Eutectic Solvents Intheextraction And Separation Of Target Compounds From Various Samples. Journal of Separation Science*, 402-751.

- TCIchemicals. (2021). *Product Number: L0042 Levulinic Acid*. [Online] Diakses melalui : <https://www.tcichemicals.com/AT/en/p/L0042#documentsSectionPDP> (10 Maret 2021).
- Tim Dosen Kimia UB. (2012). *Kinetika Reaksi Kimia*. Malang: Kimia FMIPA UB.
- Tran, M.K., Rodrigues, M.T.F., Kato, K., Babu, G. (2019). *Deep Eutectic Solvents for Cathode Recycling of Li-ion Batteries*. *Nat Energy* 4, 339–345.
- Turan, M. D., Altundoğan, H. S., & Tümen, F. (2004). *Recovery of zinc and lead from zinc plant residue*. *Hydrometallurgy*, 75(1-4), 169–176.
- Wang, D., Lu, A.Z., Yang, M.O., Guoa, A.H., Yang, Z. (2020). *A Choline Chloride-Ethylene Glycol Deep Eutectic Solvent Based on Magnetic Polydopamine with Preconcentration and Determination for Sulfonylurea Herbicides in Water Samples*. *J. Braz. Chem. Soc.*, Vol. 31, No. 7, 1509-1517.
- Wang, Y., Ma, C., Liu, C., Lu, X., Feng, X., & Ji, X. (2020). *Thermodynamic Study of Choline Chloride-Based Deep Eutectic Solvents with Water and Methanol*. *Journal of Chemical & Engineering Data*.
- Yadav, A., Kar, J. R., Verma, M., Naqvi, S., & Pandey, S. (2015). *Densities of aqueous mixtures of (choline chloride+ethylene glycol) and (choline chloride+malonic acid) deep eutectic solvents in temperature range 283.15–363.15K*. *Thermochimica Acta*, 600, 95–101.
- Yusof, R., Abdulmalek, E., Sirat, K., Basyaruddin, M., Rahman, A. (2014). *Tetrabutylammonium Bromide (TBABr)-Based Deep Eutectic Solvents (DESS) and Their Physical Properties*. *Molecules*, 19, 8011-8026.
- Zhang, Q., Vigier, K.D.O., Royer, S., Jerome, F. (2012). *Deep Eutectic Solvents: Syntheses, Properties and Applications*. *Chem. Soc. Rev.* 41, 7108– 7146 .
- Zürner, P., & Frisch, G. (2019). *Leaching and selective extraction of indium and tin from zinc flue dust using an oxalic acid based deep eutectic solvent*. *ACS Sustainable Chemistry & Engineering*.