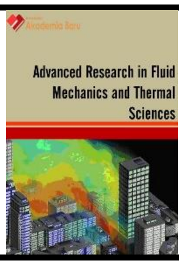
Penerbit Akademia Baru

Journal of Advanced Research in Fluid Mechanics and Thermal Sciences

Journal homepage: www.akademiabaru.com/arfmts.html
ISSN: 2289-7879



Screening of Long Chain Imidazolium Base Ionic Liquids for EPA and DHA Extraction from Microalgae Using COSMO-RS Model

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ARTICLE INFO

Article history:
Received 7 March 2019
Received in revised form 2 May 2019
Accepted 12 May 2019
Available online 6 June 2019

ABSTRACT

Omega-3 Poly Unsaturated Fatty Acids (Omega-3 PUFA) in various types including alpha-linolenic acid (ALA), eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) have many benefits for human health. The EPA and DHA from microalgae are favorable as the algal is farmed in a controlled environment that avoids harmful contamination such as methyl mercury and copper from the sea. Microalgae has the advantage of presenting neither an unpleasant odour nor a high amount of cholesterol. The presence of squalene and phytosterols in microalgae offer additional benefits to human health. The existing conventional methods of lipid extraction like soxhlet consume large amount of solvent and hence consider high toxic and energy intensive. Ionic liquids (ILs) are new classes of solvents that have the potential in extracting the microalgae lipid. ILs provide low vapor pressure, high thermal stability, non-toxicity and they can dissolve polar, non-polar and polymeric components. Very limited research has been conducted on extracting microalgae lipid especially PUFA using ILs therefore, this study aims to screen the potential ILs that can be used in the lipid extraction process. The screening was carried out using Continuum Solvation Models for Real Solvents (COSMO-RS) method to investigate the effect of different types of anions base ILs by calculate the activity coefficient value. It was found that the lowest activity coefficient has the best interaction between the solute and solvent. According to the results the lowest activity coefficient for EPA and DHA extraction belongs to [benzoate] as anion for the octyl-methyl imidazolium base ILs.

Keywords:
Lipid extraction; EPA; DHA; Ionic liquid; COSMO-RS

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1. Introduction

Omega-3 poly unsaturated fatty acid (PUFA) particularly eicosapentaenoic acid (EPA), and docosahexaenoic acid (DHA) has potential to reduce the risk of cancer, cardiovascular disease, autoimmune, inflammatory disorders, cystic fibrosis, disrupted neurological function, bowel disease and mental illness [1–3]. Therefore, the use of PUFA as health prospects has gained a great attention in last years. Fish is considered the main source of PUFA. The intake of fish oil for months may cause a deficiency of vitamin E due to the high level of vitamin A and D involve in fish lipids [4]. Many harmful contaminants such as methyl mercury, copper and organic pollutants as polychlorinated biphenyls (PCBs) or dioxins are also found in some species of fish especially in salmon, sardine, and tuna which may impose toxic effect to human health [4], therefore the alternative sources of omega-3 PUFA are required. Microalgae oil and fish oil have the same amount of omega-3 but microalgae oil has more advantages in terms of health and less toxicity compared to fish oil [5]. The microalgae oil does not have unpleasant smell and cholesterol, It contains squalene and phytosterols which has many benefits for human health [6]. Moreover, microalgae are easily cultivated which avoid differences in seasonal production.

There are several methods that have been used for lipid extraction including Soxhlet [7] and Bligh & Dyer as traditional methods [7] and non-traditional methods such as supercritical fluid extraction (SFE), Subcritical Water Extraction (SWE), Ultrasound-Assisted Extraction (UAE), Microwave-Assisted Extraction (MAE), Enzymatic-Assisted Extraction (EAE) and Ionic Liquids (ILs) [8]. Traditional methods involve large amount of toxic solvents, they are mostly time consuming and they demand a huge amount of energy as compared to non-traditional methods. Ionic Liquids (ILs) on the other hand has been observed to have high potential in extraction the microalgae lipids. The Ionic Liquids (ILs) are salts with low melting point and consist of organic cation and organic or inorganic anions [9]. The cations of ILs are generally composed of nitrogen contacting ring like imidazolium, pyrrolidinium to which a different functional groups can be added [10]. Furthermore, ILs are considered as green solvent due to the remarkable properties such as low vapor pressure, high thermal stability, non-toxicity, non-flammable and dissolve polar, non-polar organic, inorganic and polymeric components [11]. Pan *et al*., [8] investigated the microwave assisted extraction of lipid from *Nannochloropsis salina*, *Chlorella sorokiniana* and *Galdieria sulphuraria* by using [BMIM][HSO_4] as IL. They found that the selected IL had higher extraction yield than conventional methods of oil bath and organic solvent. ILs have prominent advantages over organic solvent like hexane in terms of extraction efficiency and green solvent, however there are only a few literatures available to use ILs for extraction of long chain fatty acid such as EPA (C20:5n-3) and DHA (C22:5n-3). The use of some types of ILs for experiment is costly, thus a reasonable screening study to choose an appropriate IL based on different cations and anions combination seems obligatory to ensure the highest extraction rate with minimum consumption of solvents [12; 13; 14; 15; 16]. ILs characteristics are required to be predicted during the screening prior to be used in experimental approaches. The activity coefficient (AC) measures the degree of nonideality of a compound in solution. The greatest degree of nonideality is at infinite dilution, when a single solute molecule is completely surrounded by solvent. The infinite-dilution activity coefficient (IDAC) can be used to predict the behavior of liquid-liquid or solid-liquid equilibrium [17]. Therefore, IL behaviour towards EPA and DHA can be predicted by AC at infinite dilution. Previously, also AC at infinite dilution have been used for the purpose of extraction process. Conductor like screening model for real solvent (COSMO-RS) is a model that can be used for calculate the infinite dilution AC in order to fast prior prediction [18]. A study has been conducted by Rezaei motlagh *et al.,* [19] investigated the effect of AC and capacity values at infinite dilution for EPA extraction and the highest capacity for EPA extraction among 352 screened cation/anion combinations belongs to [TMAm][SO_4]. Moreover, A study examined by Anantharaj and Banerjee [20] has been screened 28 anions and 6 cations resulting in 168 possible combinations via COSMO-RS Initially to predict the infinite dilution AC of thiophene in ionic liquids. They found that the cation without the aromatic ring combined with anions having sterical shielding effect such as [SCN], [CH_3SO_3], [CH_3COO], [Cl], and [Br] demonstrated to be the most suitable IL for desulphurization. Furthermore, the effect of AC at infinite dilution and solubility has been investigated in another study by Song *et al.,* [21] for extractive desulfurization process. The effects of anion and cation on the extractive performance of ILs are studied by COSMO-RS, and the IL [C4MIM][H2PO4] is designated based on the standard [21].

In this study, COSMO-RS has been used to select the most suitable ILs as a part of solid-liquid-liquid extraction of EPA and DHA from microalgae. This work is aimed to predict infinite activity coefficient values of imidazolium ILs ([OMIM]) for EPA and DHA as extractant.

2. Methodology

The molecules geometries were optimized by turbo mole 6.3 to generate COSMO files using BP functional with a triple-zeta valence with polarization (TZVP) as a basis set. Steps taken to perform the screening study are including the introduction of sample EPA and DHA properties to the software, calculation of AC values of cations and anions based ILs and finally the selection of ILs with minimum activity coefficient as the result.

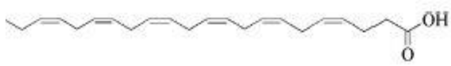
2.1 Computational Considerations

COSMO-RS is a theory with the purpose of quantum theory, surface interactions, dielectric continuum models, and statistical thermodynamic properties which has been described for first time in a work by [22]. At first, in 1998 the application of COSMO-RS was limited by calculation of the AC in infinite dilution for vapor-liquid equilibria of binary mixtures. Then the usage of COSMO-RS go further to calculate all kinds of phase equilibrium such as vapor-liquid, liquid-liquid, solid-liquid predictions [22–24].

2.2 Data Collection and Screening Process

The chemical structure of EPA and DHA is first optimized by TZVP according to thermodynamic properties and inserted to the data bank of COSMO-RS. Next, chosen the cations from imidazolium based ILs and hydrophilic and hydrophobic anions. The screened ILs was referred from the lipid extraction literature as a basis. Then, the software calculates the related activity coefficient for each ILs. The chemical structure of EPA and DHA are illustrated in Table 1.

Table 1
Structure of EPA and DHA

Shorthand Sign	Syntethic Name	Trivial Name	Formula	Chemical Structure
20:5	Eicosapentanoic acid	EPA	$C_{20}H_{30}O_2$	
22:6	Docosahexaenoic acid	DHA	$C_{22}H_{32}O_2$	

3. Results

The activity coefficient values represent the interaction between the chemical structure of ILs and EPA and DHA. Lower activity coefficient results in higher extraction capacity according to Eq. (1) hence the lowest activity coefficient is desired as the target of screening. The COSMO-RS method used to predict the behavior of different types of anions namely Benzoate, Toluene-4-sulfonate, Octhyl-SO_4, DCN, Buthyl-SO_4, Ethyl-SO_4, OTF, TF_2N, PF_3, HSO_4, BF_4 and PF_6. The screening was performed towards finding the behavior of anions in interaction with EPA and DHA in the case of long chain imidazolium base IL [OMIM]. Generally, the activity coefficient is a thermodynamic factor which shows the deviation from ideal behavior in a mixture [25]. The lowest activity coefficient values represent the highest interaction between solute and solvent as well as it shows the highest lipid extraction yield. Figure 1 and Figure 2 show the activity coefficient values of 1-octyl-3-methyl imidazolium ([OMIM]) cation based IL with different types of anions in order to screen the suitable one for EPA and DHA extraction respectively.

$$Capacity = \frac{1}{AC\ at\ infinite\ dilution} \quad (1)$$

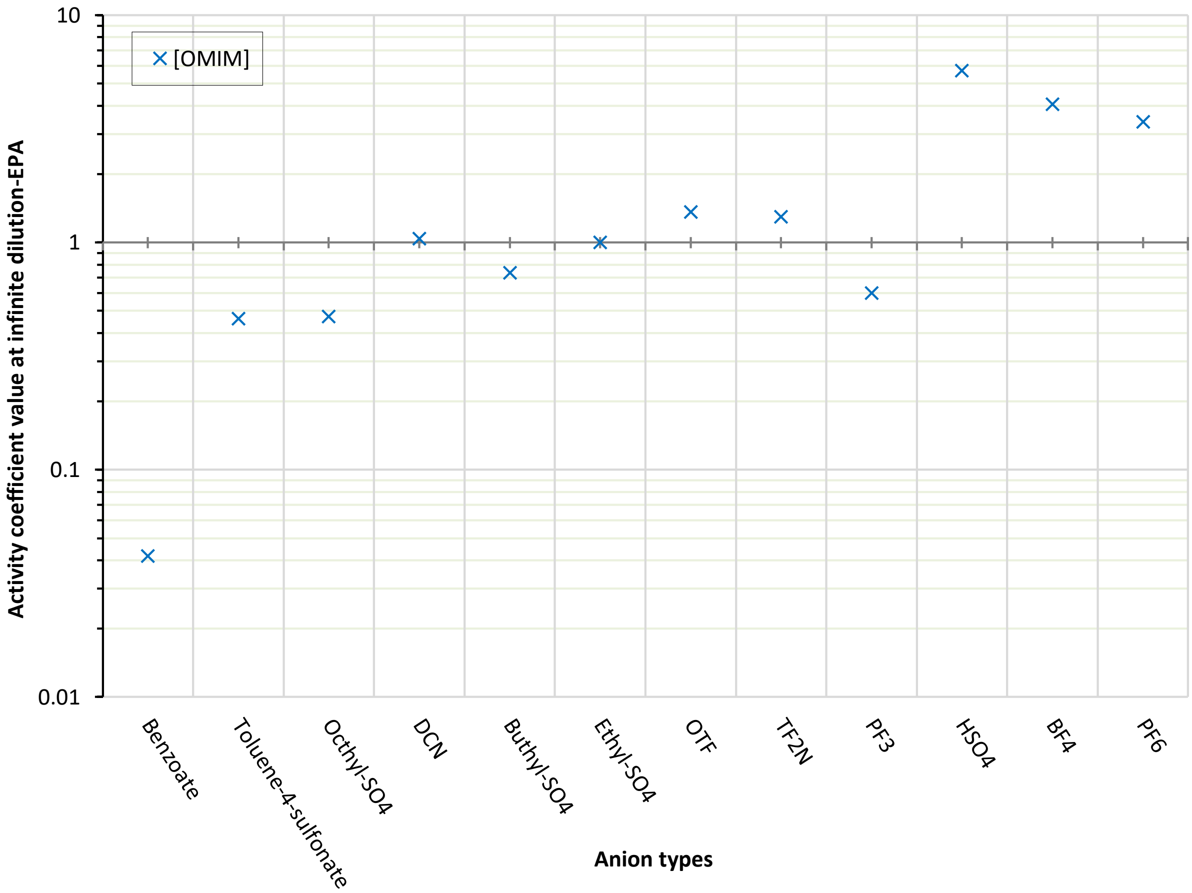


Fig. 1. The AC values of [OMIM] cation based ILs for EPA extraction at T=298.15 K

The lowest activity coefficient values of [OMIM] belongs to benzene as anion for both EPA and DHA extraction. The activity coefficient values of benzene for DHA is lower than EPA which means [OMIM]Benzoate IL can extract more DHA rather than EPA. The AC values for [OMIM]Toluene-4-sulfonate, OTF, Octhyl-SO_4, Buthyl-SO_4, Ethyl-SO_4, and DCN for DHA extraction and [OMIM]Toluene-4-sulfonate, OTF, Octhyl-SO_4, Buthyl-SO_4, Ethyl-SO_4, and PF_3 for EPA extraction are less than 1.

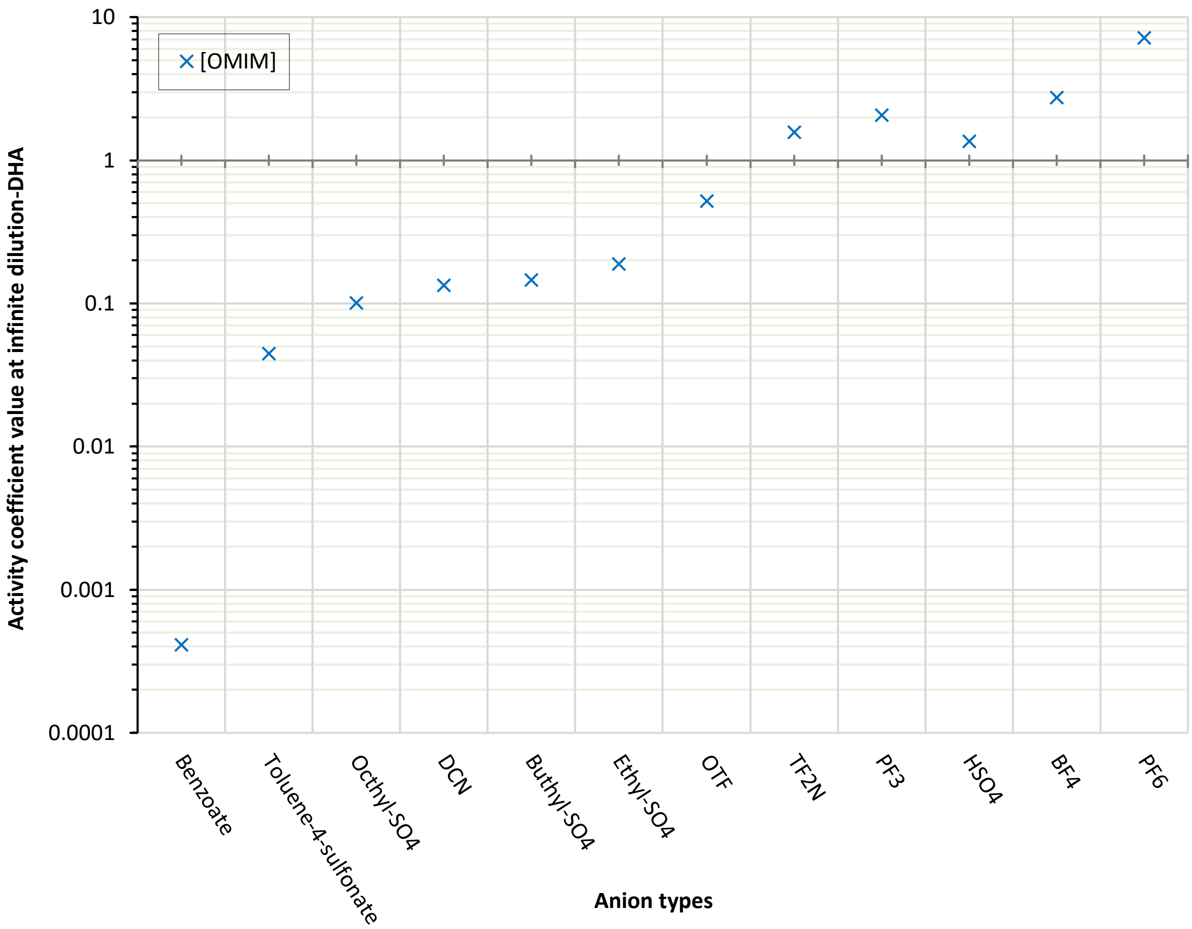


Fig. 2. The AC values of [OMIM] cation based ILs for DHA extraction at T=298.15 K

[OMIM]HSO_4 and [OMIM]PF_6 are observed to be inadequate ILs for EPA and DHA extraction respectively due to have the highest AC values at infinite dilution. The lowest to highest AC values for EPA extraction follow this order: [OMIM]Benzoate < Toluene-4-sulfonate < Octhyl-SO_4 < PF_3 < Buthyl-SO_4 < Ethyl-SO_4 < DCN < TF_2N < OTF < PF_6 < BF_4 < HSO_4 and for DHA: [OMIM]benzene < Toluene-4-sulfonate < Octhyl-SO_4 < DCN < Buthyl-SO_4 < Ethyl-SO_4 < OTF < HSO_4 < TF_2N < PF_3 < BF_4 < PF_6.

4. Conclusions

COSMO-RS method was used to evaluate the effect of anion changes on long chain of imidazolium cation [OMIM] base ILs for extraction of EPA and DHA. Several anions were selected for screening including Benzoate, Toluene-4-sulfonate, Octhyl-SO_4, DCN, Buthyl-SO_4, Ethyl-SO_4, OTF, TF_2N, PF_3, HSO_4, BF_4 and PF_6. The target of screening was to select an anion with lowest activity coefficient which lead to have highest capacity. The most favourable IL with lowest activity coefficient value was selected [OMIM]Benzoate for both EPA and DHA and is expected to result in desirable amount of yield when applies in microalgae lipid extraction.

Acknowledgement
This work has been supported by the Department of Chemical and Environmental Engineering, Universiti Putra Malaysia (UPM) and Centre of Ionic Liquids, Universiti Teknologi Petronas (UTP).

References

[1] Fabian, Carol J., Bruce F. Kimler, and Stephen D. Hursting. "Omega-3 fatty acids for breast cancer prevention and survivorship." *Breast cancer research* 17, no. 1 (2015): 62.
[2] Rubio-Rodríguez, Nuria, Sagrario Beltrán, Isabel Jaime, M. Sara, María Teresa Sanz, and Jordi Rovira Carballido. "Production of omega-3 polyunsaturated fatty acid concentrates: a review." *Innovative Food Science & Emerging Technologies* 11, no. 1 (2010): 1-12.
[3] Ruxton, C. H. S., Stephen C. Reed, M. J. A. Simpson, and K. J. Millington. "The health benefits of omega-3 polyunsaturated fatty acids: a review of the evidence." *Journal of Human Nutrition and Dietetics* 17, no. 5 (2004): 449-459.
[4] Davidson, Michael H., Julie H. Burns, Papasani V. Subbaiah, Meredith E. Conn, and Kathleen B. Drennan. "Marine oil capsule therapy for the treatment of hyperlipidemia." *Archives of internal medicine* 151, no. 9 (1991): 1732-1740.
[5] Khan, Muhammad Imran, Jin Hyuk Shin, and Jong Deog Kim. "The promising future of microalgae: current status, challenges, and optimization of a sustainable and renewable industry for biofuels, feed, and other products." *Microbial cell factories* 17, no. 1 (2018): 36.
[6] Kajikawa, Masataka, Seiko Kinohira, Akira Ando, Miki Shimoyama, Misako Kato, and Hideya Fukuzawa. "Accumulation of squalene in a microalga Chlamydomonas reinhardtii by genetic modification of squalene synthase and squalene epoxidase genes." *PLoS One* 10, no. 3 (2015): e0120446.
[7] Manirakiza, P., A. Covaci, and P. Schepens. "Comparative study on total lipid determination using Soxhlet, Roese-Gottlieb, Bligh & Dyer, and modified Bligh & Dyer extraction methods." *Journal of food composition and analysis* 14, no. 1 (2001): 93-100.
[8] Pan, Jingying, Tapaswy Muppaneni, Yingqiang Sun, Harvind K. Reddy, Jie Fu, Xiuyang Lu, and Shuguang Deng. "Microwave-assisted extraction of lipids from microalgae using an ionic liquid solvent [BMIM][HSO4]." *Fuel* 178 (2016): 49-55.
[9] Shimizu, Karina, M. Tariq, Luís PN Rebelo, and José N. Canongia Lopes. "Binary mixtures of ionic liquids with a common ion revisited: a molecular dynamics simulation study." *Journal of Molecular Liquids* 153, no. 1 (2010): 52-56.
[10] Keskin, Seda, Defne Kayrak-Talay, Uğur Akman, and Öner Hortaçsu. "A review of ionic liquids towards supercritical fluid applications." *The Journal of Supercritical Fluids* 43, no. 1 (2007): 150-180.
[11] Petkovic, Marija, Kenneth R. Seddon, Luis Paulo N. Rebelo, and Cristina Silva Pereira. "Ionic liquids: a pathway to environmental acceptability." *Chemical Society Reviews* 40, no. 3 (2011): 1383-1403.
[12] Amal Ahmed Elgharbawy, Md Zahangir Alam, Mohammed Moniruzzaman, Nassereldeen Ahmed Kabbashi, and Parveen Jamal. "Factors affecting the in-situ hydrolysis of empty fruit bunches in ionic liquid compatible cellulase system." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 52, no.1 (2018): 23–32.
[13] Sharikh, Atikah Mohamed, Sarina Sulaiman, and Azlin Suhaida Azmi. "A Review on Multiple Functions of Ionic Liquid in Biodiesel Production." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 39, no. 1 (2017): 26-35.
[14] Khairulazhar Jumbri, Nor Suzy Farahana Mah Noh, Nur Afiqah Ahmad, Mohd Basyaruddin Abdul Rahman, Haslina Ahmad. "Characterization of New Cholinium-based Ionic Liquids for Antimicrobial Application." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 42, no.1 (2018): 16-23.
[15] Rezaei Motlagh, Shiva, Razif Harun, Awang Biak, Dayang Radiah, Siti Aslina Hussain, Wan Azlina Wan Ab Karim Ghani, Ramin Khezri, Cecilia Devi Wilfred, and Amal AM Elgharbawy. "Screening of Suitable Ionic Liquids as Green Solvents for Extraction of Eicosapentaenoic Acid (EPA) from Microalgae Biomass Using COSMO-RS Model." *Molecules* 24, no. 4 (2019): 713.
[16] Motlagh, Shiva Rezaei, and Razif Harun. "Screening of Ionic liquids for PUFA extraction from microalgal biomass using COSMO-RS."
[17] Gerber, R.P.; Soares, R.D.P. COSMO-SAC Variants. **2010**, 7488–7496.
[18] Eckert, Frank, and Andreas Klamt. "Fast solvent screening via quantum chemistry: COSMO-RS approach." *AIChE Journal*48, no. 2 (2002): 369-385.
[19] Rezaei Motlagh, Shiva, Razif Harun, Awang Biak, Dayang Radiah, Siti Aslina Hussain, Wan Azlina Wan Ab Karim Ghani, Ramin Khezri, Cecilia Devi Wilfred, and Amal AM Elgharbawy. "Screening of Suitable Ionic Liquids as Green Solvents for Extraction of Eicosapentaenoic Acid (EPA) from Microalgae Biomass Using COSMO-RS Model." *Molecules* 24, no. 4 (2019): 713.
[20] Anantharaj, R., and Tamal Banerjee. "COSMO-RS based predictions for the desulphurization of diesel oil using ionic liquids: Effect of cation and anion combination." *Fuel processing technology* 92, no. 1 (2011): 39-52.
[21] Song, Zhen, Teng Zhou, Jianan Zhang, Hongye Cheng, Lifang Chen, and Zhiwen Qi. "Screening of ionic liquids for

solvent-sensitive extraction–with deep desulfurization as an example." *Chemical Engineering Science* 129 (2015): 69-77.
[22] Klamt, Andreas. "Conductor-like screening model for real solvents: a new approach to the quantitative calculation of solvation phenomena." *The Journal of Physical Chemistry* 99, no. 7 (1995): 2224-2235.
[23] Klamt, Andreas, Volker Jonas, Thorsten Bürger, and John CW Lohrenz. "Refinement and parametrization of COSMO-RS." *The Journal of Physical Chemistry A* 102, no. 26 (1998): 5074-5085.
[24] Lin, Shiang-Tai, and Stanley I. Sandler. "A priori phase equilibrium prediction from a segment contribution solvation model." *Industrial & engineering chemistry research* 41, no. 5 (2002): 899-913.
[25] Gamsjäger, Heinz, John W. Lorimer, Mark Salomon, David G. Shaw, and Reginald PT Tomkins. "The IUPAC-NIST Solubility Data Series: A Guide to Preparation and Use of Compilations and Evaluations." *Journal of Physical and Chemical Reference Data* 39, no. 2 (2010): 023101.