MESO-SUBSTITUTED ANIONIC METALLOPORPHYRIN CATALYSTS IMMOBILIZED ON IONIC LIQUID-FUNCTIONALIZED MESOPOROUS SILICA IN OXIDATION OF TRIMETHYLPHENOL

NURLIANA BINTI ROSLAN

A thesis submitted in fulfilment of the
requirements for the award of the degree of
Doctor of Philosophy (Chemistry)

Faculty of Science
Universiti Teknologi Malaysia

FEBRUARY 2018

Special dedicated to;

My beloved parents,
Roslan Othman and Asnani Asmar for their love and care, continuous prayer, endless support and encouragement they have provided all these years for me.
My wonderful sister and brothers,
Rusnita, Aidil, Azreen, Azrul and Aiman who supported me on this journey.
My adorable nephews,
Adam Zikry and Ammar Ziyyad who never fails to make me smile.
All my labmates, group members and dearest friends,
For standing by my side when times get hard and always making me happy.
And
Thank you ALLAH for the countless blessing.

ACKNOWLEDGEMENT

Bismillaahirrahmaanirrahim

In the name of Allah, the most Gracious; the most Merciful

First and foremost, all praise to Allah SWT, the Almighty God, for His gracious mercy and blessing for giving me an opportunity, strength and endurance to complete my PhD study. There are a number of people behind this journey who deserve to be both acknowledged and thanked here. I would like to express my outmost gratitude and deepest appreciation to my supervisors, Prof. Dr. Salasiah Endud and Assoc. Prof. Dr. Zainab Ramli for their time, sufficient guidance and continuous commitment throughout this project. Not to forget my co-supervisors, Dr. Hendrik Oktendy Lintang and Dr. Mohd Bakri Bakar for all the assistance and guidance provided all this while. It was a great pleasure for me to do my PhD studies under their supervisions and gained a lot of thoughtful knowledge, advice as well as suggestions which are to the great benefit of this project.

A special gratitude goes to all lecturers, research and laboratory officers from the Department of Chemistry and Physics, University Industry Research Laboratory and Ibnu Sina Institute for Scientific and Industrial Research, UTM. I am also greatly indebted to the Ministry of Education Malaysia for the financial support through Research University Grant and scholarship provided under MyBrain15 (MyPhd).

A million thanks to my beloved parents and my siblings for their love, encouragements, understanding and continuous pray that makes me stronger each and every day on completing this study. Not forgotten, a special thanks also to all my labmates, group members and close friends, whose names are too numerous to mention for their invaluable assistance and support encouragement along this study.

ABSTRACT

Synthetic metalloporphyrins have been extensively studied as biomimetic models for cytochrome P-450 oxidative enzymes in catalysis of different substrates. Despite the advantages of superior activity and selectivity, as well as mild reaction temperatures, difficulties in catalyst recovery and purification of products still constitute the major drawbacks of homogeneous processes. This research aimed to develop new heterogeneous catalysts of *meso*-tetra-(4-sulfonatophenyl)porphyrinato metal complexes (MTSPP) immobilized in ionic liquid-functionalized mesoporous silica SBA-15. Hence, positively charged ionic liquid, 1-methyl-3-(3-triethoxysilylpropyl) imidazolium chloride (C_3mimCl, denoted as ImIL) was explored as an interface linker for immobilization of the anionic MTSPP complexes onto the mesoporous silica support by electrostatic interactions. A series of ImIL-functionalized SBA-15 (ImIL@SBA) materials with different loadings of ImIL (1.0-10.0 mmol) were prepared via the post-synthesis covalent grafting method. The immobilization of MTSPP complexes on the ImIL@SBA with different MTSPP loading (5, 10 and 25 μmol) was carried-out via the post-synthesis ion-exchange method to afford the MTSPP-ImIL@SBA (M: Mn, Fe, Cu and Zn) nanocomposites. The TGA results showed the relative stability of the MTSPP-ImIL@SBA catalysts decreased in the order of strength of metal ion binding: Cu(II) > Mn(II) > Zn(II) > Fe(II), which correlated directly with metal core electronegativity effect. The DRUV-Vis spectroscopy confirmed that FeTSPP could form iron porphyrin μ-oxo-dimeric species upon immobilization onto the surface of mesoporous silica support, which would cause the thermal stability of FeTSPP-ImIL@SBA to become very low. The catalytic properties of MTSPP-ImIL@SBA was tested in the one-step oxidation of 2,3,6-trimethylphenol (TMP) to 2,3,5-trimethylbenzoquinone (TMBQ) as a model reaction. Factors influencing the reaction were studied systematically, and a possible reaction mechanism was then proposed. The catalytic activity trend of the MTSPP-ImIL@SBA increased in the order of metal ion: Cu(II) > Mn(II) > Zn(II) > Fe(II). Under the optimum condition, CuTSPP-ImIL@SBA showed excellent performance with 80-100% conversions of TMP and 100% selectivity for TMBQ. Furthermore, MTSPP-ImIL@SBA catalysts were highly stable and reusable up to four cycles without a significant loss of activity, with a high TON value of 1302 after 24 hours and TOF up to 54 h^{-1}, which were readily attainable under mild reaction conditions. As a conclusion, the cationic ImIL linker in the MTSPP-ImIL@SBA seemed to play a pivotal role in the catalytic mechanism by enhancing the chemical stability of the anionic MTSPP complexes. Therefore, the MTSPP-ImIL@SBA nanocomposites emerged as potential heterogeneous catalysts for the production of TMBQ, the chemical intermediate for the industrial production of Vitamin E.

ABSTRAK

Metaloporfirin sintetik telah dikaji secara meluas sebagai model biomimetik untuk enzim oksidatif sitokrom P-450 dalam pemangkinan substrat yang berlainan. Meskipun mempunyai kelebihan seperti aktiviti dan kepilihan yang tinggi serta suhu tindak balas yang sederhana, namun pemisahan mangkin dan penulenan produk yang rumit masih merupakan kelemahan utama proses homogen. Penyelidikan ini bertujuan membangunkan mangkin heterogen baharu yang terdiri daripada kompleks logam *meso*-tetra-(4-sulfonatofenil)porfirin (MTSPP) yang dipegunkan pada silika mesoliang SBA-15 berfungsikan-cecair ionik. Maka, cecair ionik bercas positif, iaitu 1-metil-3-(3-trietoksisililpropil) imidazolium klorida (C_3mimCl, disimbolkan sebagai ImIL) telah diteroka sebagai pemaut antara muka untuk pemegunan kompleks anionik MTSPP kepada penyokong silika mesoliang secara kaedah interaksi elektrostatik. Siri bahan SBA-15 berfungsikan-ImIL (ImIL@SBA) dengan muatan ImIL yang berbeza-beza (1.0-10.0 mmol) telah disediakan menggunakan kaedah pencangkukan kovalen pasca-sintesis. Pemegunan kompleks MTSPP pada ImIL@SBA dengan muatan MTSPP berlainan (5, 10 dan 25 μmol) telah dijalankan melalui kaedah penukaran ion pasca-sintesis bagi menghasilkan nanokomposit MTSPP-ImIL@SBA (M: Mn, Fe, Cu dan Zn). Keputusan TGA menunjukkan bahawa kestabilan relatif mangkin MTSPP-ImIL@SBA berkurang mengikut tertib kekuatan penambatan ion logam: Cu(II) > Mn(II) > Zn(II) > Fe(II), yang berkorelasi langsung dengan kesan elektronegativiti logam pusat. Spektroskopi DRUV-Vis mengesahkan bahawa FeTSPP mampu membentuk dimer μ-okso ferum porfirin ketika dipegunkan pada permukaan penyokong silika mesoliang, yang mungkin mengakibatkan kestabilan terma FeTSPP-ImIL@SBA menjadi sangat rendah. Sifat pemangkinan MTSPP-ImIL@SBA telah diuji dalam pengoksidaan satu langkah 2,3,6-trimetilfenol (TMP) kepada 2,3,5-trimetilbenzokuinon (TMBQ) sebagai model tindak balas. Faktor yang mempengaruhi tindak balas telah dikaji secara sistematik, dan mekanisme tindak balas yang munasabah kemudiannya dicadangkan. Kecenderungan aktiviti pemangkinan MTSPP-ImIL@SBA bertambah mengikut tertib ion logam: Cu(II) > Mn(II) > Zn(II) > Fe(II). Dalam keadaan optimum, CuTSPP-ImIL@SBA menunjukkan prestasi yang cemerlang dengan penukaran 80-100% untuk TMP dan kepilihan 100% untuk TMBQ. Tambahan lagi, mangkin MTSPP-ImIL@SBA adalah sangat stabil dan dapat diguna semula sehingga empat kitaran tanpa kehilangan aktiviti yang signifikan, dengan TON yang tinggi bernilai 1302 selepas 24 jam dan TOF sehingga 54 h^{-1}, yang mudah tercapai pada keadaan tindak balas sederhana. Sebagai kesimpulan, pemaut ImIL kationik dalam MTSPP-ImIL@SBA kelihatan memainkan peranan penting dalam mekanisme pemangkinan dengan mempertingkatkan kestabilan kimia kompleks anionik MTSPP. Oleh kerana itu, nanokomposit MTSPP-ImIL@SBA muncul sebagai mangkin heterogen berpotensi untuk penghasilan TMBQ, bahan kimia perantaraan bagi penghasilan industri Vitamin E.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

^{13}C CP-MAS NMR	-	Carbon-13 Cross Polarization-Magic Angle Spinning Nuclear Magnetic Resonance
^{1}H-NMR	-	Proton Nuclear Magnetic Resonance
^{29}Si MAS NMR	-	Silicon-29 Magic Angle Spinning Nuclear Magnetic Resonance
ac-SBA-15	-	After calcination SBA-15
as-SBA-15	-	As-synthesized SBA-15
ase-SBA-15	-	After Soxhlet extraction SBA-15
BET	-	Brunauer-Emmet-Teller
BJH	-	Barret-Jouner-Halenda
C_3mimCl	-	1-Methyl-3-(3-triethoxysilylpropyl) imidazolium chloride
$CDCl_3$		Chloroform
CPTES	-	(3-chlororopyl)triethoxysilane
CuTSPP-ImIL@SBA	-	CuTSPP immobilized onto ImIL@SBA
CuTSPP	-	(*meso*-tetra-(4-sulfonatophenyl)porphyrinato) Cu(II)
DMSO		Dimethyl sulfoxide
DR UV-Vis	-	Diffuse Reflectance Ultraviolet-Visible
EB	-	Ethyl benzoate
EDX	-	Energy Dispersive X-Ray
FDU	-	Fudan University
FeTSPP-ImIL@SBA	-	FeTSPP immobilized onto ImIL@SBA
FeTSPP	-	(*meso*-tetra-(4-sulfonatophenyl)porphyrinato) Fe(II)
FESEM	-	Field Emission Scanning Electron Microscope

FSM	-	Folding Sheet Materials
FTIR	-	Fourier Transform Infrared Spectroscopy
GC-FID	-	Gas chromatography-flame ionization detector
GC-MS	-	Gas chromatography-mass spectrometry
H_2TPP	-	*meso*-tetraphenylporphyin
H_2TSPP	-	*meso*-tetra-(4-sulfonatophenyl)porphyrin
HOM	-	Highly Ordered Mesoporous Silica
HMS	-	Hexagonal Mesoporous Silica
HOMO	-	Highest occupied molecular orbital
ICP-OES	-	Inductively Coupled Plasma-Optical Emission Spectroscopy
IL	-	Ionic liquid
ImIL	-	Ionic liquid C_3mimCl
ImIL@SBA	-	ImIL-functionalized SBA-15
KIT	-	Korean Institute of Science and Technology
LUMO	-	Lowest unoccupied molecular orbital
MALDI-TOF MS	-	Matrix Assisted Laser Desorption/Ionization Time-of-Flight Mass Spectrometry
MCM	-	Mobil Composition Matter
MTSPP	-	Metalloporphyrin Complexes of H_2TSPP
MTSPP-ImIL@SBA	-	MTSPP complexes immobilized onto ImIL@SBA
MnTSPP	-	(*meso*-tetra-(4-sulfonatophenyl)porphyrinato) Mn(II)
MnTSPP-ImIL@SBA	-	MnTSPP immobilized onto ImIL@SBA
MSU	-	Michigan State University
Pluronic P123	-	(Poly(ethylene glycol)-block-poly(propylene glycol)-block-poly(ethylene glycol) copolymer
SBA	-	Santa Barbara Amorphous
SAXS	-	Small Angle X-Ray Scattering
TBHP	-	*tert*-butyl hydroperoxide
TEM	-	Transmission Electron Microscopy
TEOS	-	Tetraethyl orthosilicate

TGA	-	Thermogravimetric analysis
TMP	-	2,3,6-Trimethylphenol
TMBQ	-	2,3,5-Trimethylbenzoquinone
TOF	-	Turnover frequency
TON	-	Turnover number
UV-Vis	-	Ultraviolet-Visible
ZnTSPP	-	(*meso*-tetra-(4-sulfonatophenyl)porphyrinato) Zn(II)
ZnTSPP-ImIL@SBA	-	ZnTSPP immobilized onto ImIL@SBA

LIST OF SYMBOLS

A	-	Absorbance
a_o	-	Unit cell parameter
d_{100}	-	d-spacing at (1 1 0) lattice
D_{BJH}	-	Pore diameter based on BJH model
2θ	-	Bragg angle
δ	-	Chemical shift
Da	-	Daltons
J	-	Coupling constant
Hz	-	Hertz
λ	-	Wavelength
nm	-	Nanometer
q	-	Scattering vector
Si-OH	-	Silanol
S_{BET}	-	Total specific surface area
S_{Meso}	-	Mesoporous surface area
S_{Micro}	-	Microporous surface area
V_{Total}	-	Total pore volume
V_{Meso}	-	Pore volume of mesopore
V_{Micro}	-	Pore volume of micropore
W	-	Pore wall thickness

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the past few years, there have been some rapid developments of metalloporphyrin systems which mimic the Cytochrome P-450 enzymes. Cytochrome P-450, a member of the monooxygenase family of heme enzymes, have an iron protoporphyrin IX as the prosthetic group that acts as a catalytic intermediate in several oxygenations of organic substrates (Nakagaki *et al.,* 2014; Nakagaki *et al.,* 2013; Bolzon *et al.,* 2013; Palaretti *et al.,* 2012). Furthermore, there are a large number of published studies (Barona-Castaño *et al.,* 2016; Notonier *et al.,* 2016; Krest *et al.,* 2013) that describe the application of Cytochrome P-450 as catalyst in different chemical processes, including alkene epoxidation, *n*-dealkylation of secondary and tertiary amines, *o*-dealkylation, and hydroxylation of aromatic compounds and oxidations of amines, sulfides, alcohols and aldehydes.

Recently, a considerable amount of literature has been published on synthetic metalloporphyrins with transition metals such as iron, manganese and ruthenium rhodium, cobalt, nickel, copper and zinc (Huang *et al.,* 2017; Castro *et al.,* 2017; Lü *et al.,* 2017; Carrie *et al.,* 2016; Silva Martins *et al.,* 2016; Tabor *et al.,* 2016; Barbosa *et al.,* 2016; Chan *et al.,* 2015). Besides, the studies demonstrated the metalloporphyrins as useful biomimetic catalysts for various oxidation reactions (Zhao *et al.,* 2017; Zhou *et al.,* 2016; Santos da Silva *et al.,* 2014; Rayati *et al.,* 2013). Biomimetic catalysts are known to have several advantages such as high activity, selectivity, efficiency and turnover catalytic system under mild reaction

conditions (Hajian *et al.,* 2016; Jondi *et al.,* 2016; Che and Huang, 2009). Despite its many advantages and wide range of applications, the metalloporphyrin does present certain drawbacks such as the low solubility in organic solvents. This major problem is due to the relatively high energy of their molecular lattice and their moderate energies of solvation with the low polarity chemical bonding of the macrocycle (Mamardashvili *et al.,* 2000). In addition, the use of metalloporphyrins as homogeneous catalysts have some drawbacks such as thermal decomposition during the reaction and difficulty of recovery after the reaction (Kolahdoozan *et al.,* 2013).

It has been reported that heterogenization of homogeneous catalysts is a technique that involves the immobilization of homogeneous catalysts on inorganic solid materials (Bolzon *et al.,* 2013). To date, a variety of methods have been developed and introduced to support the metalloporphyrins. Immobilization of metalloporphyrins or active metal species onto imidazolium-based IL grafted silica has been employed as an alternative method to combine the advantages of ILs (non-volatility, immiscible with non-polar solvent, good thermal stability, low vapour pressure and simple functionality) with those of metalloporphyrins. This concept of catalyst system can be achieved in many different approaches, such as simple impregnation, coordination, electrostatic interactions, covalent binding or grafting, polymerization sol-gel and encapsulation or pore trapping techniques (Rostamnia *et al.,* 2016a; Bolzon *et al.,* 2013; Gustafsson *et al.,* 2012; Nohair *et al.,* 2008; Beakley *et al.,* 2005).

One of the favoured approaches that can be used is electrostatic interactions between an ionic metalloporphyrins and counter ionic groups on the surface of silica. In other words, electrostatic interaction involves the opposite charges. Even though this method is limited only to ionic metalloporphyrins, it has been reported that the leaching of metal complexes from the support during the reactions was avoided due to the existence of strong ionic interaction (Hajian *et al.,* 2016; Gandini *et al.,* 2008; Zhao *et al.,* 2006). Imidazolium-based IL could be functionalized onto the surface of silica supports via a chemical covalent grafting method which is used as the cation in the formation of the ionic group. Therefore, in this research, imidazolium-based IL is

covalently bonded to the silica and then act as the linkers between silica and the anionic metalloporphyrins.

Many recent studies have demonstrated the use of mesoporous silica materials, in particular, SBA-15 as inorganic solid support due to their characteristic textural properties, such as a large specific surface area and pore volume, high ordered channel structures with narrow and uniform pore diameter between 3 and 30 nm (Rostamnia *et al.,* 2016b; Lei *et al.,* 2015; Rostamnia *et al.,* 2014; Xiong *et al.,* 2014). In addition, the SBA-15 silica displays dense silanol (Si−OH) groups on the surface which can readily be reacted for organic functionalization. Owing to the favourable physicochemical properties, SBA-15 had been chosen as suitable supports for the immobilization of metalloporphyrins.

Catalytic oxidation is one of the widely used processes in the chemical production of many commercial compounds (Xu *et al.,* 2015; Ali *et al.,* 2014; Guo *et al.,* 2014). In this regard, the selective oxidation of phenols to the desired quinones has been a great interest in organic synthesis. Quinones are used as intermediate in the synthesis of fine chemicals and pharmaceuticals such as perfume aromas, vitamins and drugs (Saux *et al.,* 2013; Çimen and Türk, 2008). Previous studies revealed that compounds having a benzoquinone structure displayed biologically important properties such as cardiovascular, antibacterial, antigerminative, antitumor and antiprotozoan activities (Palacio *et al.,* 2012; Li *et al.,* 2009). On the other hand, Vitamin E is the one of the most important fat-soluble biological antioxidant that has been used in food, medical treatments and cosmetics (Gao *et al.,* 2017; Kholdeeva *et al.,* 2009). Notably, the precursor in the synthesis of Vitamin E is, 2,3,5-trimethylbenzoquinone (TMBQ) which is currently produced in the industry via oxidation of 2,3,6-trimethylphenol (TMP).

So far, however, the conventional method for producing TMBQ is the oxidation of sulfonated TMP using oxidant MnO_2 which brings a large amount of waste by-products (Wang *et al.,* 2009; Guan *et al.,* 2008; Sun *et al.,* 2005). Therefore, an environmentally friendly catalytic method based on the one-step oxidation of TMP to TMBQ has been established using hydrogen peroxide or *tert*-

butyl hydroperoxide (TBHP) as “clean” oxidants (Saux *et al.*, 2013; Çimen and Türk, 2008).

Generally, the use of solid heterogeneous catalysts in liquid phase oxidation reactions is considered as a promising alternative that offer several advantages such as ease of product separation, easy catalyst recycling, easier to prepare and handle, enhance the catalytic efficiency and selectivity as well as to minimize the side product of reactions (Zanardi *et al.*, 2016; Choi *et al.*, 2015; Kolahdoozan *et al.*, 2013; Pires *et al.*, 2009; Zois *et al.*, 2007). In the past, copper halides or other copper salts, cobalt complexes with Schiff bases, ruthenium salts and heteropoly acids have been extensively reported as catalysts for the oxidation of TMP (Wang *et al.*, 2009; Li *et al.*, 2009; Guan *et al.*, 2008; Çimen and Türk, 2008; Sun *et al.*, 2005). Nevertheless, the homogeneous catalysts as mentioned above posed significant drawbacks that related to the separation, recycling and purification of products (Gao *et al.*, 2017; Kholdeeva *et al.*, 2009). To address these issues, the development of more efficient heterogeneous catalysts for such oxidation reactions is highly desired.

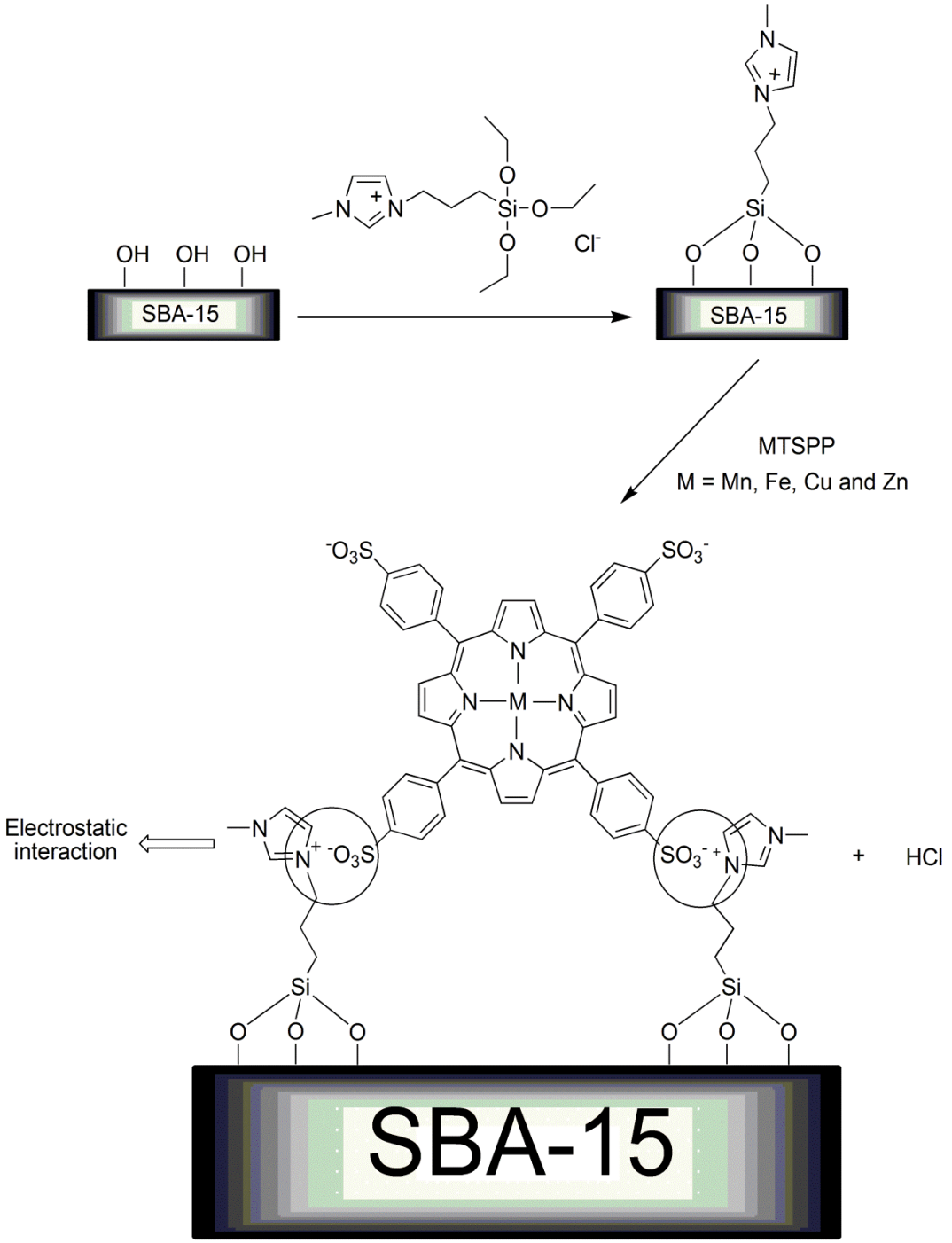
1.2 Problem Statement

One of the most attractive and significant transformation in organic reactions is oxidation of TMP to TMBQ. The TMBQ represents a key intermediate in the industrial production of vitamin E (*α*-tocopherol) (Möller *et al.*, 2011; Palacio *et al.*, 2012). Traditionally, TMBQ production in the industry involves two different steps; *para*-sulfonation of TMP, and chemical oxidation with an inorganic oxidizing agent such as manganese oxide (MnO_2). Still, the major problems associated with this approach are the high capital cost and the safe disposal of solids and liquid wastes, due to high consumption of sulfuric acid and the use of stoichiometric amounts of solid oxidants, and reductants (Çimen and Türk, 2008).

An alternative one-step oxidation of TMP to TMBQ has been demonstrated using several homogeneous transition-metal-based catalysts such as cobalt

complexes with Schiff bases, copper complexes, Fenton's reagent, hetero-polyacids, iron halides and metallophthalocyanines with clean oxidizing agents (Li *et al.*, 2009; Li and Liu, 2004; Sorokin and Tuel, 2000). Nevertheless, the low conversion of TMP was mainly due to the poor selectivity, recovery and deactivation of the catalysts (Wang *et al.*, 2009; Guan *et al.*, 2008). Therefore, in order to resolve these drawbacks, heterogeneous metalloporphyrin catalysts can be developed as a promising new catalytic system for selective oxidation of TMP.

At present, metalloporphyrins which can act as homogeneous catalysts to mimic the reactions of the cytochrome P-450 enzymes have aroused great attention in the literature. These compounds are able to catalyze several reactions of organic and inorganic substrates including styrene, cyclohexene, *N*,*N*-dimethylaniline, cyclohexane, *n*-hexane and benzyl alcohol under mild conditions (Omagari *et al.*, 2016; Sakthipriya and Ananthi, 2016; Agarwal and Bhat, 2016; Da Silva *et al.*, 2017; Wang *et al.*, 2016; Rahimi *et al.*, 2011; Ren *et al.*, 2010). While homogeneous catalytic systems provide high product yields, metalloporphyrins have the tendency to quickly degrade their ligands due to the self-aggregation by π-π stacking interactions (Nakagaki *et al.*, 2014; Adam and Ooi, 2012; Guo *et al.*, 2011). Likewise, the introduction of electron-withdrawing substituents such as the sulfonatophenyl group in the *meso*-position of metalloporphyrins generally helps to improve their stability and enhance the catalytic efficiency (Castro *et al.*, 2017; Tabor *et al.*, 2016; Feng *et al.*, 2015). Consequently, a synthetic approach based on the electrostatic binding of ionic metalloporphyrin molecules to positively charged imidazolium-based ILs is presented in the current study by using anionic metalloporphyrin complexes of *meso*-tetra-(4-sulfonatophenyl)porphyrin (MTSPP) and the functionalized imidazolium cationic-based ILs of 1-(3-triethoxysilylpropyl)-3-methylimidazolium chloride salt. The proposed immobilization of IL on the mesoporous silica SBA-15 support is as shown schematically in Figure 1.1.



Figures 1.1 Immobilization of MTSPP complexes on ionic liquid-functionalized SBA-15

Immobilization of metalloporphyrins onto functionalized imidazolium-based ILs represents a technique that combines the solvent properties of ILs with the robust nature of the solid support, and the biomimetic properties of the metalloporphyrin catalysts. In this approach, the ionic metalloporphyrin is introduced in the

imidazolium-based IL supported on mesoporous silica SBA-15 via electrostatic interaction. Therefore, the main role of the IL in the catalyst system is to improve the dispersion of the anionic metalloporphyrin molecules on the silica nanoparticles, while promoting the diffusion of reactants over the catalytic surface of the pores, and allowing for the reaction products to be released efficiently into the reaction medium. In the present study, immobilization of metalloporphyrins onto functionalized imidazolium-based ILs for the one-step oxidation of TMP is expected to facilitate the reactant access to the catalytic sites, prevent rapid catalyst deactivation, enhance catalyst stability as well as improve the yield of TMBQ. Most importantly, the SBA-15 supported ILs catalysts can be recycled and reused, which promotes green catalytic processes for the production of TMBQ.

1.3 Research Hypothesis

Based on the above problem statements, the following hypotheses have been formulated:

i. Introduction of sulfonatophenyl groups as electron withdrawing substituents in the *meso*-position of supported metalloporphyrin complexes (MTSPP) can tune the energy level and have an effect on the electronic structure leading to superior performance of heterogenous catalysts.

ii. Functionalized imidazolium cationic-based IL (ImIL) as a chemical linker can greatly improve the dispersion and solubility of the MTSPP on silica support. The strong interactions between MTSPP and the ImIL@SBA-15 silica surface might induce a synergistic effect of improving the catalytic activity of MTSPP-ImIL@SBA-15.

iii. Homogeneous MTSPP complex species leached from the support are insignificant and does not contribute to the overall catalytic activity.

iv. Iron and manganese are known biomimetics of the heme enzymes, including cytochrome P-450. Anionic MTSPP species containing the first row transition metals consisting of Fe, Mn, Cu or Zn are

hypothesized to be the main catalyst for the formation of the main product in the oxidation of TMP.

1.4 Objectives of Study

The main objectives of the research are as follows:

i. To synthesize anionic metalloporphyrin complexes of *meso*-tetra-(4-sulfonatophenyl)porphyrin (MTSPP).
ii. To synthesize imidazolium cationic-based IL-functionalized onto mesoporous SBA-15 support (ImIL@SBA nanocomposites).
iii. To immobilize MTSPP complexes on ImIL@SBA nanocomposites.
iv. To characterize the physicochemical properties of the ImIL@SBA and MTSPP immobilized on ImIL@SBA nanocomposites.
v. To optimize the catalytic activity of MTSPP immobilized on ImIL@SBA in the oxidation of TMP to produce TMBQ.

1.5 Scope of Study

The scopes of this research focused on the synthesis of free-base porphyrin, anionic *meso*-tetra-(4-sulfonatophenyl)porphyrin (H_2TSPP). Then, H_2TSPP was coordinated to the first row transition metals including Mn(II), Fe(II), Cu(II) and Zn(II). The physicochemical properties of prepared metalloporphyrin complexes (MTSPP) were characterized using FT-IR, ^{1}H-NMR, UV-Vis spectroscopy and MALDI-TOF-MS spectrometry.

On the other hand, ImIL@SBA nanocomposites were synthesized via post-grafing method between imidazolium cationic-based IL of 1-(3-triethoxysilylpropyl)-3-methylimidazolium chloride salt, C_3mimCl (ImIL) and mesoporous silica SBA-15. The physicochemical properties of the ImIL@SBA nanocomposites were

characterized using FTIR, SAXS, nitrogen adsorption-desorption isotherm analysis, TGA, FESEM, TEM, ^{29}Si MAS NMR and ^{13}C CP-MAS NMR spectroscopy. Next, the prepared MTSPP complexes, was immobilized onto ImIL@SBA nanocomposite by post-synthesis ion-exchange method and the resulting organic-inorganic hybrid materials, MTSPP-ImIL@SBA were characterized using FTIR, nitrogen adsorption-desorption isotherm analysis, SAXS, DR UV-Vis spectroscopy, TGA, FESEM, EDX, TEM and ICP-OES spectrometry.

Finally, the catalytic performances of the prepared MTSPP-ImIL@SBA were tested in the oxidation of TMP. The catalytic oxidation reaction was monitored by using GC-FID and GC-MS. Oxidation of TMP over blank reactions have also been carried out by using MTSPP complexes, imidazolium cationic-based IL (C_3mimCl), SBA-15, and without catalyst for the comparison. Reusability, leaching test, effect of reaction parameters (temperature, time, solvent and catalyst loading) and reaction mechanism were also studied.

1.6 Outline of Study

Figure 1.2 represents the outline for this research which includes the synthesis, characterizations and application of immobilized MTSPP complexes onto ImIL@SBA nanocomposite in the catalytic oxidation of TMP.

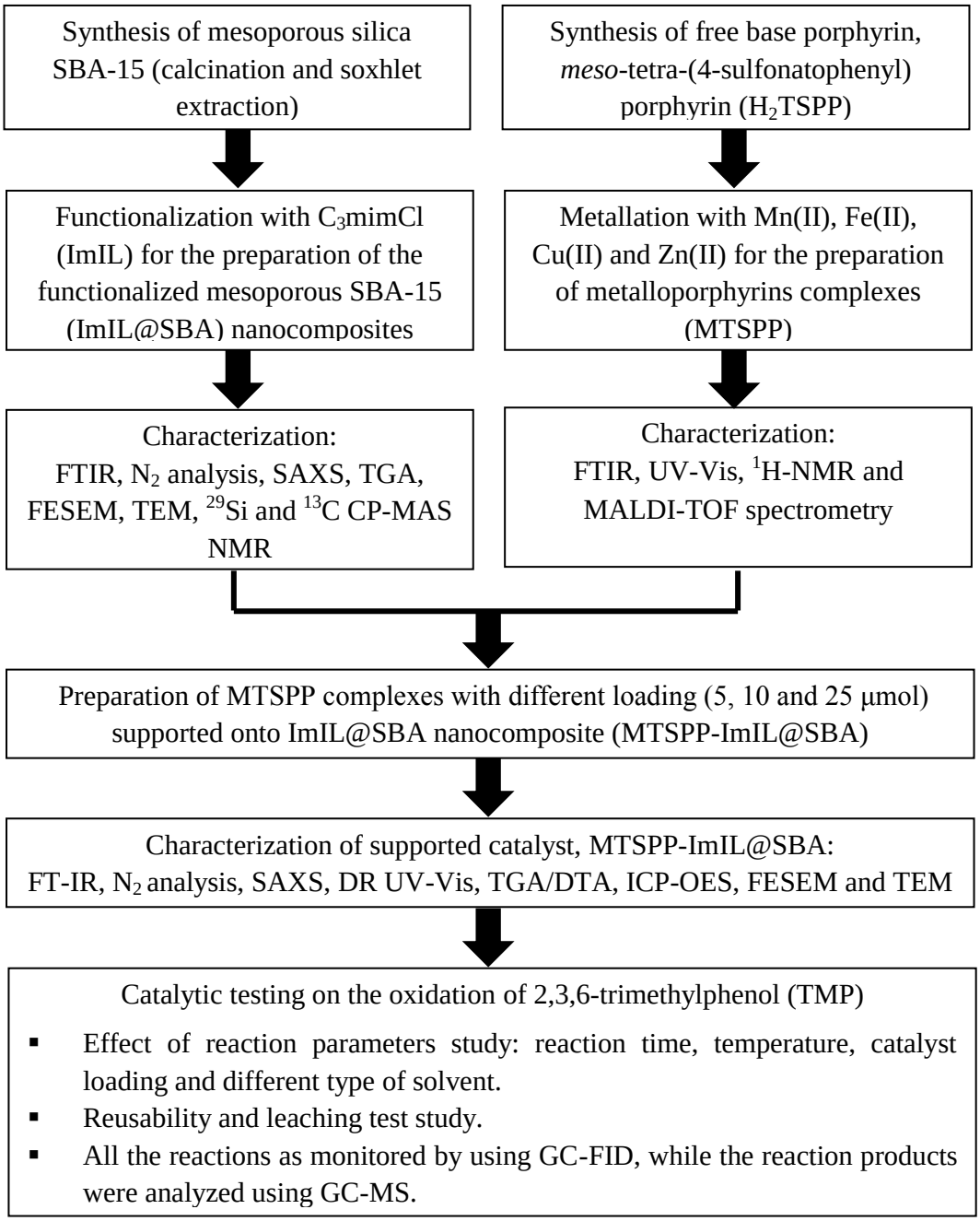


Figure 1.2 Outline of study

REFERENCES

Abdolmohammad-Zadeh, H. and Sadeghi, G.H. (2009). A Novel Microextraction Technique Based on 1-Hexylpyridinium Hexafluorophosphate Ionic Liquid for the Preconcentration of Zinc in Water and Milk Samples. *Analytica Chimica Acta.* 649: 211-217.

Adam, F. and Ooi, W-T. (2012). Selective Oxidation of Benzyl Alcohol to Benzaldehyde over Co-Metalloporphyrin Supported on Silica Nanoparticles. *Applied Catalysis A: General.* 445-446: 252-260.

Adler, A.D., Longo, F.R., Finarelli, J.D., Goldmacher, J., Assour, J. and Korsakoff, L. (1967). A Simplified Synthesis for *meso*-Tetraphenylporphyrin. *Journal Organic Chemistry.* 32(2): 476.

Agarwal, D.D. and Bhat, D. (2016). Substituted Tetraphenyl Porphyrin Catalyzed Oxidative N-dealkylation of Tertiary Amine using Molecular Oxygen. *Journal of Porphyrins and Phthalocyanines.* 20(6): 689-693.

Agarwal, M., Chauhan, G., Chaurasia, S.P. and Singh, K. (2012). Study of Catalytic Behavior of KOH as Homogeneous and Heterogeneous Catalyst for Biodiesel Production. *Journal of the Taiwan Institute of Chemical Engineers.* 43(1): 89-94.

Aghabali, A. and Safari, N. (2010). Effects of Methoxy-Substituted Metalloporphyrins in Catalytic Alkene Epoxidation by *n*-Bu_4NHSO_5. *Journal of Porphyrins and Phthalocyanines*. 14: 335-342.

Ali, M.E., Rahman, M.M., Sarkar, S.M. and Abd Hamid, S.B. (2014). Review Article Heterogeneous Metal Catalysts for Oxidation Reactions. *Journal of Nanomaterials.* 2014: 1-23.

Anthony, J.L., Brennecke, J.F., Holbrey, J.D., Maginn, E.J., Mantz, R.A., Rogers, R.D., Trulove, P.C., Visser, A.E. and Welton T. (2002). Synthesis and Purification of Ionic Liquids. In Wasserscheid, P. and Welton, T. (Eds.). *Ionic Liquids in Synthesis.* (pp. 41-55). Weinheim: Wiley-VCH Verlag.

Antipas, A., Buchler, J.W., Gouterman, M. and Smith, P.D. (1978). Porphyrins. 36.1 Synthesis and Optical and Electroniv Properties of Some Ruthenium and Osmium Octaethylporphyrins. *American Chemical Society.* 100(10): 3015-3024.

Armstrong, R.S., Foran, G.J., Hough, W.A., D'Alessandro, D.M., Lay, P.A. and Crossley, M.J. (2006). Spectroelectrochemical Evidence for Communication within a Laterally-Bridged Dimanganese(III) Bis-Porphyrin. *Dalton Transactions.* 40: 4805-4813.

Atilhan, M., Jacquemin, J., Rooney, D., Khraisheh, M. and Aparicio, S. (2013). Viscous Behavior of Imidazolium-Based Ionic Liquids. *Industrial and Engineering Chemistry Research.* 52(47): 16774-16785.

Ávila, S.G., Silva, L.C.C and Matos, J.R. (2016). Optimisation of SBA-15 Properties using Soxhlet Extraction for Template Removal. *Microporous and Mesoporous Materials.* 234: 277-286.

Azimov, F., Markova, I., Stefanova, V. and Sharipov, Kh. (2012). Synthesis and Characterization of SBA-15 and Ti-SBA-15 Nanoporous Materials for DME Catalysts. *Journal of the University of Chemical Technology and Metallurgy.* 47(3): 333-340.

Badiei, A., Mirahsani, A., Shahbazi, A., Younesi, H. and Alizadeh, M. (2014). Adsorptive Removal of Toxic Dye From Aqueous Solution and Real Industrial Effluent by Tris(2-aminoethyl)amine Functionalized Nanoporous Silica. *Environmental Progress & Sustainable Energy*. 1-9.

Bagheri, S., Muhd Julkapli, N. and Abd Hamid, S.B. (2014). Titanium Dioxide as a Catalyst Support in Heterogeneous Catalysis. *The Scientific World Journal.* 727496: 1-21.

Bagshaw, S.A., Prouzet, E. and Pinnavaia, T.J. (1995). Templating of Mesoporous Molecular Sieves by Nonionic Polyethylene Oxide Surfactant. *Science.* 1(269): 1242-1244.

Bajju, G.D., Kundan, S., Kapahi, A. and Gupta, D. (2013). Synthesis and Spectroscopic Studies of Axially Ligated Zn(II)5,10,15,20-meso-tetra(p-chlorophenyl)porphyrin with Oxygen and Nitrogen Donors. *Journal of Chemistry.* 2013: 1-14.

Balcar, H. and Cejka, J. (2007). Mesoporous Molecular Sieves as Supports for Metathesis Catalysts. Imamoglu, Y. and Dragutan, V. (Eds). *Metathesis*

Chemistry: From Nanostructure Design to Synthesis of Advanced Materials. (pp. 151-166). The Netherlands: Springer.

Balcar, H. and Roth, W.J. (2013). Hybrid Catalysts for Olefin Metathesis and Related Polymerization. In Suib, S.L. (Ed.). *New and Future Developments in Catalysis: Hybrid Materials, Composites, and Organocatalysts.* (pp. 1-26). Poland: Elsevier B.V.

Ball, R. H., Dorough, G.D. and Calvin, M. A. (1946). Further Study of the Porphine-like Products of the Reaction of Benzaldehyde and Pyrrole. *Journal American Chemical Society.* 68(11): 2278-2281.

Bandgar, B.P. and Gujarathi, P.B. (2008). Synthesis and Characterization of New Meso-substituted Unsymmetrical Metalloporphyrins. *Journal Chemical Science.* 120(2): 259-266.

Barbosa, I.A., Sousa Filho, P.C.D., Silva, D.L.D., Zanardi, F.B., Zanatta, L.D., Oliveira, A.J.A.D., Serra, O.A. and Iamamoto, Y. (2016). Metalloporphyrins Immobilized in $Fe_3O_4{}^{@}SiO_2$ Mesoporous Submicropheres: Reusable Biomimetic Catalysts for Hydrocarbon Oxidation. *Journal of Colloid and Interface Science.* 469: 296-309.

Barona-Castaño, J.C., Carmona-Vargas, C.C., Brocksom, T.J. and Oliceira, K.T.D. (2016). Review Porphyrins as Catalysts in Scalable Organic Reactions. *Molecules.* 21(310): 1-27.

Barrett, E.P., Joyner, L.G. and Halenda, P.P. (1951). The Determination of Pore Volume and Area Distribution in Porous Substances. I. Computations from Nitrogen Isotherms. *Journal of the American Chemical Society*. 73(1): 373-380.

Barros, V.P., Faria, A.L., MacLeod, T.C.O, Moraes, L.A.B. and Assis, M.D. (2008). Ironporphyrin Immobilized onto Montmorillonite as a Biomimetical Model for Azo Dye Oxidation. *International Biodeterioration and Biodegradation.* 61: 337-344.

Bastos, F.S., Lima, O.A., Filho, C.R. and Fernandes, L.D. (2011). Mesoporous Molecular Sieve MCM-41 Synthesis from Fluoride Media. *Brazilian Journal of Chemical Engineering.* 28:4: 649-658.

Beakley, L.W., Yost, S.E., Cheng, R. and Chandler, B.D. (2005). Nanocomposites Catalysts: Dendrimers Encapsulated Nanoparticles Immobilized in Sol-Gel Silica. *Applied Catalysis A: General.* 292(1-2): 124-129.

Benamor, T., Michelin, L., Lebeau, B. and Marichal, C. (2012). Flash Induction Calcination: A Powerful Tool for Total Template Removal and Fine Tuning of the Hydrophobic/Hydrophilic Balance in SBA-15 Type Silica Mesoporous Materials. *Microporous and Mesoporous Materials.* 147: 334-342.

Berthomieu, C and Hienerwadel, R. (2009). Fourier Transform Infrared (FTIR) Spectroscopy. *Photosynthesis Research*. 101(2-3): 157-170.

Bérubé, F. and Kaliaguine, S. (2008). Calcination and Thermal Degradation Mechanisms of Triblock Copolymer Template in SBA-15 Materials. *Microporous and Mesoporous Materials.* 115: 469-479.

Bérubé, F., Nohair, B., Kleitz, F. and Kaliaguine, S. (2010). Controlled Postgrafting of Titanium Chelates for Improved Synthesis of Ti-SBA-15 Epoxidation Catalysts. *Chemistry of Materials.* 22: 1988-2000.

Bhaduri, S. and Mukesh, D. (2014). Homogeneous Catalysis: Mechanism and Industrial Applications. (pp. 1-22). New Jersey: John Wiley and Sons, Inc.

Bhuiyan, T.I., Arudra, P., Akhtar, M.N., Aitani, A.M., Abudawoud, R.H., Al-Yami, M.A. and Al-Khattaf, S.S. (2013). Metathesis of 2-Butene to Propylene over W-Mesoporous Molecular Sieves: A Comparative Study Between Tungsten Containing MCM-41 and SBA-15. *Applied Catalysis A: General*. 467: 224-234.

Binetti, E., Pannielo, A., Triggiani, L., Tommasi, R., Agostiano, A., Curri, M.L. and Striccoli, M. (2012). Spectroscopic Study on Imidazolium-Based Ionic Liquids: Effect of Alkyl Chain Length and Anion. *The Journal of Physical Chemistry B*. 116: 3512-3518.

Blümel, J. (2008). Review Linkers and Catalysts Immobilized on Oxide Supports: New Insights by Solid-State NMR Spectroscopy. *Coordination Chemistry Reviews*. 252: 2410-2423.

Blusch, L.K. (2013). The Siamese-Twin Porphyrin and Its Copper and Nickel Complexes: A Non-Innocent Twist. (pp.1-21). Germany: Springer.

Bohström, Z., Härelind, H., Gevert, B., Andersson, S-I. and Holmberg, K. (2014). Comparison of Microporous/Mesoporous and Microporous HZSM-5 as Catalysts for Friedel-Crafts Alkylation of Toluene with Ethene. *RSC Advances*. 4: 28786-28793.

Bolzon, L.B., Airoldi, H.R., Zanardi, F.B., Granado, J.G. and Iamamoto, Y. (2013). Metalloporphyrin-Functionalized Hexagonal Mesoporous Silica: Synthesis,

Structural Properties and Catalytic Activity as Cytochrome P450 Model. *Microporous and Mesoporous Materials.* 168: 37-45.

Bonnett, R. (1978). Chapter 1 Nomenclature. In Dolphin, D. (Ed). T*he Porphyrins Volume 1 Structure and Synthesis, Part A.* (pp. 1-27). New York: Academic Press, A Harcourt Science and Technology Company.

Bonrath, W. and Netscher, T. (2005). Catalytic Processes in Vitamins Synthesis and Production. *Applied Catalysis A: General*. 280: 55-73.

Bonrath, W., Dittel, C., Giraudi, L., Netscher, T. and Pabst, T. (2007**a**). Rare Earth Triflate Catalysts in the Synthesis of Vitamin E and Its Derivatives. *Catalysis Today.* 121: 65-70.

Bonrath, W., Eggersdorfer, M. and Netscher, T. (2007**b**). Catalysis in the Industrial Preparation of Vitamins and Nutraceuticals. *Catalysis Today*. 121: 45-57.

Bordoloi, A., Sahoo, S., Lefebvre, F. and Halligudi, S.B. (2008). Heteropoly Acid-Based Supported Ionic Liquid-Phase Catalyst for the Selective Oxidation of Alcohols. *Journal of Catalysis.* 259: 232-239.

Boucher, L.J. (1968). Manganese Porphyrin Complexes. I. Synthesis and Spectroscopy of Manganese(III) Protoporphyrin IX Dimethyl Ester Halides. *Journal of the American Chemical Society.* 90(24): 6640-6645.

Boucher, L.J. (1972). Manganese Porphyrin Complexes. *Coordination Chemistry Reviews*. 7: 289-329.

Bouchoucha, M., Côté, M-F., -Gaudreault, R.C., Fortin, M-A. and Kleitz, F. (2016). Size-Controlled Functionalized Mesoporous Silica Nanoparticles for Tunable Drug Release and Enhanced Anti-Tumoral Activity. *Chemistry of Materials.* 28(12): 4243-4258.

Brown, P., Butts, C.P., Eastoe, J., Fermin, D., Grillo, I., Lee, H-C., David, P., Plana, D. and Richardson, R.M. (2012). Anionic Surfactant Ionic Liquids with 1-Butyl-3-Methylimidazolium Cations: Characterizations and Applications. *Langmuir*. 28(5): 2502-2509.

Brunauer, S., Emmett, P.H. and Teller, E. (1938). Adsorption of Gases in Multimolecular Layers. *Journal of the American Chemical Society.* 60(2): 309-319.

Bui, T.X., Kang, S-Y., Lee, S-H. and Choi, H. (2011). Organically Functionalized Mesoporous SBA-15 as Sorbents For Removal of Selected Pharmaceuticals From Water. *Journals of Hazardous Materials.* 193: 156-163.

Burba, C.M., Rocher, N.M., Frech, R. and Powell, D.R. (2008). Cation-Anion Interactions in 1-Ethyl-3-Methylimidazolium Trifluoromethanesulfonate-Based Ionic Liquid Electrolytes. *The Journal of Physical Chemistry.* 112(10): 2991-2995.

Cai, Y., Liu, Y., Lu, Y., Gao, G. and He, M. (2008). Ionic Manganese Porphyrins with S-containing Counter Anions: Mimicking Cytochrome P450 Activity for Alkene Epoxidation. *Catalysis Letters*. 124: 334-339.

Calvete, M.J.F., Silva, M., Pereira, M.M. and Burrows, H.D. (2013). Inorganic Helping Organic: Recent Advances in Catalytic Heterogeneous Oxidations by Immobilised Tetrapyrrolic Macrocycles in Micro and Mesoporous Supports. *RSC Advances*. 2: 22774-22789.

Campestrini, S. and Meunier, B. (1992). Olefin Epoxidation and Alkane Hydroxylation Catalyzed by Robust Sulfonated Manganese and Iron Porphyrins Supported on Cationic Ion-Exchange Resins. *Inorganic Chemistry.* 31(11): 1999-2006.

Canales, R.I. and Brennecke, J.F. (2016). Review Comparison of Ionic Liquids to Conventional Organic Solvents for Extraction of Aromatics from Aliphatics. *Journal of Chemical and Engineering Data.* 61(5): 1685-1699.

Cang, R., Lu, B., Li, X. Niu, R., Zhao, J. and Cai, Q. (2015). Iron-Chloride Ionic Liquid Immobilized on SBA-15 for Solvent-Free Alcohol of Benzyl Alcohol to Benzaldehyde with H_2O_2. *Chemical Engineering Science*. 137: 268-275.

Cao, L. and Kruk, M. (2014). Short Synthesis of Ordered Silicas with Very Mesopores. *RSC Advances.* 4: 331-339.

Cardiano, P., Mineo, P.G., Neri, F., Schiavo, S.L. and Piraino, P. (2008). A New Application of Ionic Liquids: Hydrophobic Properties of Tetraalkylammonium-Based Poly(ionic liquids)s. *Journal of Materials Chemistry.* 18: 1253-1260.

Carrasco, C.J., Montilla, F., Bobadilla, L., Ivanoca, S., Odriozola, J.A. and Galindo, A. (2015). Oxodiperoxomolybdenum Complex Immobilized onto Ionic Liquid Modified SBA-15 as an Effective Catalysis for Sulfide Oxidation to Sulfoxides using Hydrogen Peroxide. *Catalysis Today.* 255: 102-108.

Carriazo, J.G., Montoya-González, E.A. and Vanoy-Villamil, M.N. (2013). Preparation and Immobilization of diNOsarcobalt(III) Complex in Zeolite Y

for the Catalyzed Production of Hydrogen Peroxide. *Quimica Nova.* 36(9): 1318-1322.

Carrie, D., Srour, H., Maux, P.L. and Simonneaux, G. (2016). Synthesis and Chemical Reactivity of New Zinc Porphyrin Diazoacetates Catalyzed by Ruthenium and Iron Porphyrins. *Tetrahedron Letters*. 57: 1179-1182.

Casella, G., Causin, V., Rastrelli, F. and Saielli, G. (2014). Viologen-Based Ionic Liquid Crystals: Induction of a Smectic A Phase by Dimerisation. *Physical Chemistry Chemical Physics.* 16: 5048-5051.

Castro, K.A.D.F., Halma, M., Machado, G.S., Ricci, G.P., Ucoski, G.M., Ciuffi, K.J. and Nakagaki, S. (2010). Preparation of Catalysts based on Iron(III) Porphyrins Heterogenized on Silica Obtained by the Sol-Gel Process for Hydroxylation and Epoxidation Reactions. *Journal of the Brazilian Chemical Society*. 21(7): 1329-1340.

Castro, K.A.D.F., Lima, F.H.C.D., Simões, M.M.Q., Neves, M.G.P.M.S., Paz, F.A.A., Mendes, R.F., Nakagaki, S. and Cavaleiro, J.A.S. (2017). Synthesis, Characterization and Catalytic Activity under Homogeneous Conditions of Ethylene Glycol Substituted Porphyrin Manganese(III) Complexes. *Inorganica Chimica Acta*. 455: 575-583.

Cattaneo, A.S., Ferrara, C., Villa, D.C., Angioni, S., Milanese, C., Capsoni, D., Grandi, S., Mustarelli, P., Allodi, V., Mariotto, G., Brutti, S. and Quartarone, E. (2016). SBA-15 Mesoporous Silica Highly Functionalized with Propylsulfonic Pendants: A Thorough Physico-chemical Characterization. *Microporous and Mesoporous Materials.* 291: 219-229.

Celer, E.B., Kruk, M., Zuzek, Y. and Jaroniec, M. (2006). Hydrothermal Stability of SBA-15 and Related Ordered Mesoporous Silicas with Plugged Pores. *Journal of Materials Chemistry.* 16: 2824-2833.

Chaban, V. (2016). Halogenation of Imidazolium-Based Ionic Liquids: Thermodynamic Perspective. *The Journal of Chemical Thermodynamics*. 98: 81-85.

Chaban, V.V. (2016). Acetone as a Polar Cosolvent for Pyridinium-Based Ionic Liquids. *RSC Advances*. 6: 8906-8912.

Chaban, V.V. and Prezhdo, O.V. (2016). Ionic Vapor Composition in Pyridinium-Based Ionic Liquids. *The Journal of Physical Chemistry B.* 120(2): 4661-4667.

Chaban, V.V., Voroshylova, I.V., Kalugin, O.N. and Prezhdo, O.V. (2012). Acetonitrile Boots Conductivity of Imidazolium Ionic Liquids. *The Journal of Physical Chemistry B.* 116(26): 7719-7727.

Chan, K.S., Liu, C.R. and Wong, K.L. (2015). Cobalt Porphyrin Catalyzed Hydrodehalogenation of Aryl Bromides with KOH. *Tetrahedron Letters.* 56: 2728-2731.

Chaudhary, R.G., Juneja, H.D., Pagadala, R., Gandhare, N.V. and Gharpure, M.P. (2015). Synthesis, Characterization and Thermal Degradation Behavior of Some Coordination Polymer by using TG-DTG and DTA Techniques. *Journal of Saudi Chemical Society.* 19: 442-453.

Chauhan, S.M.S. and Kumari, P. (2007). Biomimetic Oxidation of Metribuzin with Hydrogen Peroxide by 5,10,15,20-Tetraarylporphyrinatoiron(III) Chlorides. *Tetrahedron Letters.* 48: 5035-5038.

Che, C-M. and Huang, J-S. (2009). Metalloporphyrin-Based Oxidation System: From Biomimetic Reactions to Application in Organic Synthesis. *Chemical Communications.* (27): 3996-4015.

Che, M. and Védrine, J.C. (2012). Characterization of Solid Materials and Heterogeneous Catalysts- From Structure to Surface Reactivi*ty.* Volume 2. Weinheim: Wiley-VCH.

Chen, C.-Y., Li, H.-X. and Davis, M.E. (1993). Studies on Mesoporous Material: I. Synthesis and Characterization of MCM-41. *Microporous Material*s. 2: 17-26.

Chen, J. (2014). Homogeneous and Heterogeneous Catalysis: Teachings of the Thermal Energy and Power Engineering Course. *International Journal of Social, Behavior, Educational, Economic, Business and Industrial Engineering.* 8(12): 3891-3894.

Chen, Y., Cao, Y., Zhang, Y. and Mu, T. (2014). Hydrogen Bonding Between Acetate-Based Ionic Liquids and Water: Three Types of IR Absorption Peaks and NMR Chemical Shifts Change upon Dilution. *Journal of Molecular Structure.* 1058: 244-251.

Chiappe, C. and Pieraccini, D. (2005). Review Commentary Ionic Liquids: Solvent Properties and Organic Reactivity. *Journal of Physical Organic Chemistry.* 18: 275-297.

Chin, T.K. (2010). *Oxidative Coupling of Ortho-Aminophenol over Mesoporous Silica Containing Copper(II) Diethylamino-Substituted Salen Complex*. Master Thesis, Universiti Teknologi Malaysia, Skudai.

Choi, J., Han, Y., Park, S., Park, J. and Kim, H. (2014). Research Article Pore Characteristics and Hydrothermal Stability of Mesoporous Silica: Role of Oleic Acid. *Journal of Nanomaterials*. 2014: 1-9.

Choi, P-G., Ohno, T., Masui, T. and Imanaka, N. (2015). Catalytic Liquid-Phase Oxidation of Acetaldehyde to Acetic Acid over a Pt/CeO_2-ZrO_2-SnO_2/γ-Alumina Catalyst. *Journal of Environmental Sciences.* 36: 63-66.

Chorghade, M.S., Hill, D.R., Lee, E.C. and Pariza, R.J. (1996). Metalloporphyrins as Chemical Mimics of Cytochrome P-450 Systems. *Pure & Applied Chemistry.* 68(3): 753-756.

Chorkendorff, I and Niemantsverdriet, J.W. (2007). Concepts of Modern Catalysis and Kinetics, Second Edition. (pp. 1-22). Weinheim: Wiley-VCH Verlag.

Christian, G.D. (2004). Analytical Chemistry. (6^{th} ed.). New York: John Wiley & Sons. Inc.

Çimen, Y. and Türk, H. (2008). Oxidation of 2,3,6-Trimethylphenol with Potassium Peroxymonosulfate Catalyzed by Iron and Cobalt Phthalocyanine Tetrasulfonates in a Methanol-Water Mixture. *Applied Catalysis A: General*. 340: 52-58.

Ciuffi, K.J., Sacco, H.C., Biazzotto, J.C., Vidoto, E.A., Nascimento, O.R., Leite, C.A.P., Serra, O.A and Iamamoto, Y. (2000). Synthesis of Fluorinated Metalloporphyrinosilica Imprinted with Templates Through Sol-Gel Process. *Journal of Non-Crystalline Solids*. 73: 100-108.

Clare, B., Sirwardana, A. and MacFarlane, D.R. (2009). Synthesis, Purification and Characterization of Ionic Liquids. In Kirchner, P.B. (Ed.). *Topic Current in Chemistry Ionic Liquids* 1^{st} Edition. (pp. 1-40). Germany: Springer-Verlag Berlin Heidelberg.

Comănesu, C and Guran, C. (2011). Influence of NaCl Addition on the Synthesis of SBA-15 Mesoporous Silica. *UPB Scientific Bulletin Series B.* 73(4): 95-104.

Corrêa, R.J., Salomão, G.C., Olsen, M.H.N., Filho, L.C., Drago, V., Fernandes, C. and Antunes, O.A.C. (2008). Catalytic Activity of Mn^{III}(Salen) and Fe^{III}(Salen) Complexes Encapsulated in Zeolite Y. *Applied Catalysis A: General.* 336(1-2): 35-39.

Costa, A.A., Ghesti, G.F., De Macedo, J.L., Braga, V.V., Santos, M.M., Dias, J.A. and Dias, S.C.L. (2008). Immobilization of Fe, Mn and Co Tetraphenylporphyrin Complexes in MCM-41 and their Catalytic Activity in Cyclohexene Oxidation Reaction by Hydrogen Peroxide. *Journal of Molecular Catalysis A: Chemical.* 282: 149-157.

Cotea, V.V., Luchian, C.E., Bilba, N. and Niculaua, M. (2012). Mesoporous Silica SBA-15, A New Adsorbent for Bioactive Polyphenols from Red Wine. *Analytica Chimica Acta.* 732: 180 – 185.

Cruz, P., Pérez, Y., Del Hierro, I., Fernández-Galán, R. and Fajardo, M. (2016). ε-Caprolactone Polymerization using Titanium Complexes Immobilized onto Silica Based Materials Functionalized with Ionic Liquids: Insights into Steric Electronic and Support Effects. *RSC Advances.* 6(24): 19723-19733.

Cruz, P., Pèrez, Y., Hierro, I.D., Fajardo, M. (2016). Copper, Copper Oxide Nanoparticles and Copper Complexes Supported on Mesoporous SBA-15 as Catalysts in the Selective Oxidation of Benzyl Alcohol in Aqueous Phase. *Microporous and Mesoporous Materials.* 220: 136-147.

Da Silva,V.S., Santos Vieira, W.C.D., Meireles, A.M., Ucoski, G.M., Nakagaki, S., Idemori, Y.M. and DeFreitas-Silva, G. (2017). Biomimetic Oxidation of Cyclic and Linear Alkanes: High Alcohol Selectivity Promoted by a Novel Manganese Porphyrin Catalyst. *New Journal of Chemistry.* 41: 997-1006.

Daeid, N.N., Atkinson, S.T. and Nolan, K.B. (1993). Synthetic Porphyrins/Metalloporphyrins which Mimic States in Catalytic Cycle of Cytochrome P-450 and Peroxidases. *Pure and Applied Chemistry*. 65(7): 1541-1548.

Dai, Y-M., Lu, C-Y. and Chang, C-J. (2016). Catalytic Activity of Mesoporous Ni/CNT, Ni/SBA-15 and (Cu, Ca, Mg, Mn, Co)- Ni/SBA-15 Catalysts for CO_2 Reforming of CH_4. *RSC Advances*. 6(77): 73887-73896.

Dalla Costa, B.O., Legnoverde, M.S., Lago, C., Decolatti, H.P. and Querini, C.A. (2016). Sulfonic Functionalization SBA-15 Catalysts in the Gas Phase Glycerol Dehydration. Thermal Stability and Catalyst Deactivation. *Microporous and Mesoporous Materials.* 230: 66-75.

Dan-Hua, S., Lin-Tao, J., Ling-Ling, F., Xu-Long, D., Zhi-Gang, L., Qiang, L. and Shi-Min, L. (2015). Immobilization of Metalloporphyrins on CeO_2@SiO_2 with a Core-Shell Structure Prepared via Microemulsion Method for Catalytic

Oxidation of Ethylbenzene. *Journal of Central South University*. 22(3): 862-867.

Darvis, J.H., Gardon, C.M., Hilgers, C. and Wasserscheid, P. (2002). Synthesis and Purification of Ionic Liquids. In Wasserscheid, P. and Welton, T. (Eds.). *Ionic Liquids in Synthesis.* Weinheim: Wiley-VCH Verlag.

De la Iglesia, O., Pedernera, M., Mallada, R., Lin, Z., Rocha, J., Coronas, J. and Santamaría, J. (2006). Synthesis and Characterization of MCM-48 Tubular Membranes. *Journal of Membrane Science.* 280: 867-875.

De Paula, R., Simões, M.M.Q., Neves, M.G.P.M.S. and Cavaleiro, J.A.S. (2008). Homogeneous Olefin Epoxidation Catalyzed by An Imidazolium-based Manganese Porphyrin. *Catalysis Communications*. 10: 57-60.

Dean, P.M., Golding, J.J., Pringle, J.M., Forsyth. M., Skelton, B.W., White, A.H. and MacFarlane, D.R. (2009). The Effect of Alkyl Chain Length in A Series of Novel N-Aklyl-3-benzylimidazolium Iodide Salts. *CrystEngComm.* 11: 2456-2465.

Decker, H., Schweikardt, T. and Tuczek, F. (2006). The First Crystal Structure of Tyrosinase: All Questions Answered? *Angewandte Chemie International Edition.* 45: 4546-4550.

Dharaskar, S.A., Varma, M.N., Shende, D.Z., Yoo, C.K. and Wasewar, K.L. (2013). Synthesis, Characterization and Application of 1-Butyl-3 Methylimidazolium Chloride as Green Material for Extractive Desulfurization of Liquid Fuel. *The Scientific World Journal.* 2013: 1-9.

Dinarés, I., de Miguel, C.G., Ibánez, A., Mesquida, N. and Alcalde, E. (2009). Imidazolium Ionic Liquids: A Simplr Anion Exchange Protocol. *Green Chemistry.* 11: 1507-1510.

Ding, W., Zhu, W., Xiong, J., Yang, L., Wei, A., Zhang, M. and Li, H. (2015). Novel Heterogeneous Iron-Based Redox Ionic Liquid Supported on SBA-15 for Deep Oxidative Desulfurization of Fuels. *Chemical Engineering Journal.* 266: 213-221.

Ding, Y., Zhang, B., Gupta, N. and Su, D.S. (2015). Heterogenization of Homogeneous Reaction System on Carbon Surface with Ionic Liquid as Mediator. *Green Chemistry.* 17(2): 1107-1112.

Doherty, S. (2014). Chapter 3 Homogeneous Catalysis in Ionic Liquids. In Hardacre, C. and Parvulescu, V. *Catalysis in Ionic Liquids from Catalyst Synthesis to Application.* (pp. 44- 280). Cambridge: The Royal Society of Chemistry.

Doro, F.G., Smith, J.R.L., Ferreira, A.G., Assis, M.D. (2000). Oxidation of Alkanes and Alkenes by Iodosylbenzene and Hydrogen Peroxide Catalysed by Halogenated Manganese Porphyrins in Homogeneous Solution and Covalently Bound to Silica. *Journal of Molecular Catalysis A: Chemical.* 164: 97-108.

Dorough, G.D. and Huennekens, F.M. (1952). The Spectra of α,β,γ,δ-Tetraphenylporphine and its Metallo-derivatives. *Journal American Chemical Society.*74(16): 3974-3976.

Dorough, G.D., Miller, J.R. and Huennekens, F.M. (1951). Spectra of the Metallo-derivatives of α,β,γ,δ-Tetraphenylporphine. *Journal American Chemical Society.* 73(9): 4315-4320.

Dos Santos, J.S., Faria, A.L., Da Silva Amorin, P.M., La Luna, F.M., Caiado, K.L., Silva, D.O.C., Sartoratto, P.P.C. and Assis, M.D. (2012). Iron(III) Porphyrin Covalently Supported onto Magnetic Amino-Functionalized Nanospheres as Catalyst for Hydrocarbon and Herbicide Oxidations. *Journal of the Brazilian Chemical Society*. 23(8): 1411-1420.

Dos Santos, S.M.L., Nogueira, K.A.B., De Souza Gama, M., Lima, J.D.F., Da Silva Júnior, I.J. and De Azevedo, D.C.S. (2013). Synthesis and Characterization of Ordered Mesoporous Silica (SBA-15 and SBA-16) for Adsorption of Biomolecules. *Microporous and Mesoporous Materials.* 180: 284-292.

Du, P.D., Khieru, D.Q. and Hoa, T.T. (2011). Removal of Organic Template from Mesoporous MCM-41. *Journal of Science*. 69(6): 35-41.

Dybowski, C., Gaffney, E.J., Sayir, A., Rabinowitz, M.J. (1996). Solid-sate ^{13}C and ^{29}Si MAS NMR Spectroscopy of Silicon Carbide. *Colloids and Surfaces A: Physicochemical and Engineering Aspect.* 118: 171-181.

Dymon, J., Wibby, R., Kleingardner, J., Tanski, J.M., Guzei, I.A., Holbrey, J.D. and Larsen, A.S. (2008). Designing Ionic Liquids with Boron Cluster Anions: Alkylpyridinium and Imidazolium [*nido*-$C_2B_9H_{11}$] and [*closo*-$CB_{11}H_{12}$] Carborane Salts. *Dalton Transactions*. (22): 2999-3006.

Dyson, P.J. and Jessop, P.G. (2016). Solvent Effects in Catalysis: Rational Improvements of Catalysts via Manipulation of Solvent. *Catalysis Science and Technology.* 6(10): 3302-3316.

Dziedzic-Kocurek, K., Byrne, H.J., Świderski, A. and Stanek, J. (2009). Spectroscopic Study of the Dimerization Process of Iron Protoporphyrin IX. *Acta Physica Polinica A.* 115(2): 552-555.

Elhamifar, D., Badin, P. and Karimipor, G. (2017). Alkyl-Imidazolium based Organosilica Supported Fe/Porphyrin Complex: As Novel, Highly Efficient and Reusable Catalyst for the Unsymmetrical Hantzsch Reaction. *Journal of Colloid and Interface Science.* 499: 120-127.

El-Safty, S.A. (2003). Monolithic Nanostructured Silica Family Templated by Lyotropic Liquid-Crystalline Nonionic Surfactant Mesophases. *Chemistry of Materials.* 15(15): 2892-2902.

El-Safty, S.A. (2008). A Review on the Key Controls of Designer Copolymer-Silica Mesophase Monoliths (HOM-type) with Large Particle Morphology, Ordered Geometry and Uniform Pore Dimension. *Journal of Porous Materials.* 15: 369-387.

Espinosa, M., Pacheco, S. and Rodriguez, R. (2007). Synthesis and Characterization of NH_2-Porphyrins Covalently Immobilized on Modified-SBA-15. *Journal of Non-Crystalline Solid.* 353: 2573-2581.

Everett, D.H. (1972). Definitions, Terminology and Symbols in Colloid and Surface Chemistry: Part I. In IUPAC Manual of Symbols and Terminology of Physiochemical Quantites and Units: Appendix II. Butterworths, London. 31(4): 578-638.

Fadagar-Cosma, G., Fadagar-Cosma, E., Popa, I. and Taranu, I. (2007). Electrochemical and Spectroscopic Studies of 5,10,15,20-Tetrakis(4-hydroxyphenyl)-21H,23H-porphine. *Chemical Bulletin of Politechnica University of Timisoara.* 53(66): 109-112.

Falbe, J. and Bahrmann, H. (2004). Homogeneous Catalysis- Industrial Applications. *Journal of Chemical Education.* 61(11): 961-967.

Falvo, R.E. and Mink, L.M. (1999). Microscale Synthesis and ^{1}H NMR Analysis of Tetraphenylporphyrins. *Journal of Chemical Education*. 76: 237-239.

Farnetti, E., Di Monte, R. and Kaŝpar, J. (2009). *Homogeneous and Heterogeneous Catalysi*s. In Bertin, I. (Ed.). *Inorganic and Bio-Inorganic Chemistry*- Volume II (6). (pp. 50-86). Italy: Encyclopedia of Life Support Systems.

Feng, Y., Chen, S., Guo, W., Zhang, Y. and Liu, G. (2007). Inhibition of Iron Corrosion by 5,10,15,20-tetraphenylporphyrin and 5,10,15,20-tetra-(4-chlorophenyl)porphyrin Adlayers in 0.5 M H_2SO_4. *Journal of Electroanalytical Chemistry.* 602: 115-122.

Feng, Z., Xie, Y., Hao, F., Liu, P. and Luo, H. (2015). Catalytic Oxidation of Cyclohexane by Substituted Metalloporphyrins: Experimental and Molecular Stimulation. *RSC Advances.* 5: 101593-101598.

Fernández, A., Garcia, J., Torrecilla, J.S., Oliet, M. and Rodríguez, F. (2008). Volumetric Transport and Surface Properties of [bmim][$MeSO_4$] and [emim][$EtSO_4$] Ionic Liquids As a Function of Temperature. *Journal of Chemical and Engineering Data.* 53(7): 1518-1522.

Fernandez, A.A. and Kouwer, P.H.J. (2016). Review Key Developments in Ionic Liquids Crystals. *International Journal of Molecular Sciences.* 17(731): 1-31.

Ferreira, A.D.Q., Vinhado, F.S. and Iamamoto, Y. (2006). Characterization of Mn(III)porphyrin Immobilized on Modified Silica Surfaces by EXAFS Spectroscopy: A Promising Tool for Analysis of Supported Metalloporphyrin Catalysts. *Journal of Molecular Catalysis A: Chemical*. 243: 111-119.

Finn, M., An, N. and Voutchkova-Kostal, A. (2015). Immobilization of Imidazolium Ionic Liquids on Hydrotalcites using Silane Linkers: Retardation of Memory Effect. *RSC Advances.* 5: 13016-13020.

Fleischer, E.B. (1970). Structure of Porphyrins and Metalloporphyrins. *Accounts of Chemical Research*. 3 (3): 105-112.

Forsyth, S.A., Pringle, J.M. and MacFarlane, D.R. (2004). Ionic Liquids- An Overview. *Australian Journal of Chemistry*. 57: 113-119.

Frei, R.W. and MacNeil, J.D. (1973). Diffuse Reflectance Spectroscopy in Environmental Problem-Solving. Cleveland, Ohio: CRC Press.

Freire, C. and Silva A.S. (2009). Carbon- Anchored Metal Complex Catalyst. In Serp, P. and Fifueiredo, J.L. (Eds.). *Carbon Materials for Catalysis.* (pp. 267-399). New Jersey: John Wiley and Sons, Inc.

Fu, B., Yu, H-C., Huang, J-W., Zhao, P. and Ji, L-N. (2008). Synthesis and Catalytic Activities in Cyclohexane Hydroxylation of Metalloporphyrins Supported on

Styrene-Methylacrylic Acid Copolymer Microspheres. *Transition Metal Chemistry.* 33(7): 803-807.

Fu, W., Zhang, L., Wu, D., Xiang, M., Zhuo, Q., Huang, K., Tao, Z. and Tang, T. (2015). Mesoporous Zeolite-Supported Metal Sulfide Catalysts with High Activities in the Deep Hydrogenation of Phenanthrene. *Journal of Catalysis.* 330: 423-433.

Gallo, J.M.R., Alamillo, R. and Dumesic, J.A. (2016). Acid-Functionalized Mesoporous Carbons for the Continuous Production of 5-Hydroxymethylfurfural. *Journal of Molecular Catalysis A: Chemical.* 422: 13-17.

Gandini, M.E.F., Neri, C.R., Vinhado, F.S., Minorin, T.S., Nascimento, O.R., Serra, O.A. and Iamamoto, Y. (2008). Modified Silicas Covalently Bounded to 5,10,15,20-Tetrakis(2-hydroxy-5-nitrophenyl)Porphyrinato Iron(III). Synthesis, Spectroscopic and EPR Characterization. Catalytic Studies. *Journal of the Brazilian Chemical Society.* 19(2): 344-351.

Gao, X., An, J., Gu, J., Li, L. and Li, Y. (2017). A Green Template-Assisted Synthesis of Hierarchical TS-1 with Excellent Catalytic Activity and Recyclability for the Oxidation of 2,3,6-Trimethylphenol. *Microporous and Mesoporous Materials.* 239: 381-389.

García-Verdugo, E., Altava, B., Burguete, M.I., Lozano, P. and Luis, S.V. (2015). Ionic Liquids and Continuous Flow Processes: A Good Marriage to Design Sustainable Processes. *Green Chemistry.* 17: 2693-2713.

Ghandi, K. (2014). A Review of Ionic Liquids, Their Limits and Applications. *Green and Sustainable Chemistry*. 4: 44-53.

Gibson, L.T. (2013). Mesosilica Materials and Organic Pollutant Adsorption: Part A Removal form Air. *Chemical Society Reviews.* 43: 5163-5172.

Giernoth, R. (2007). *Homogeneous in Ionic Liquids*. In Bargon, J. and Kuhn, L.T. (Eds). *Topics in Current Chemistry.* (pp. 2-20). New York: Springer Berlin-Heidelberg.

Gomes Jr., Z.A., Cardoso, L.A.M., Gonzaga, A.R.E., Aguiar, L.G. and Andrade, H.M.C. (2005). Influence of the Extraction Methods to Remove Organic Templates from Al-MCM-41 Molecular Sieves. *Materials Chemistry and Physics.* 93: 133 – 137.

Gonfa, G., Bustam, M.A., Muhammad, N. and Khan, A.S. (2015). Evaluation of Thermophysical Properties of Functionalized Imidazolium Thiocyanate Based Ionic Liquids. *Industrial and Engineering Chemistry Research.* 54(49): 12428-12437.

González, B., Gómez, E., Domíngues, Á., Vilas, M. and Tojo, E. (2011). Physicochemical Characterization of New Sulfate Ionic Liquids. *Journal of Chemical and Engineering Data.* 56(1): 14-20.

Gouterman, M. (1961). Spectra of Porphyrins. *Journal of Molecular Spectroscopy.* 6: 138-163.

Groen, J.C., Peffer, L.A.A. and Pérez-Ramírez, J. (2003). Pore Size Determination in Modified Micro- and Mesopores Materials. Pitfalls and Limitations in Gas Adsorption Data Analysis. *Microporous and Mesoporous Materials.* 60: 1-17.

Groves, J.T., Nemo, T.E. and Myers, R.S. (1979). Hydroxylation and Epoxidation Catalyzed by Iron-Porphine Complexes, Oxygen Transfer from Iodosylbenzene. *Journal of the American Chemical Society.*101: 032-1033.

Gruber-Woelfler, H., Radaschitz, P.F., Feenstra, P.W., Haas, W. and Khinast, J.G. (2012). Synthesis, Catalytic Activity, and Leaching Studies of a Heterogeneous Pd-Catalyst Including an Immobilized Bis(oxazoline) Ligand. *Journal of Catalysis.* 286: 30-40.

Grünberg, A., Breitzke, H. and Buntkowsky, G. (2012). *Solid State NMR of Immobilized Catalysts and Nanocatalysts.* In Yarwood, J., Douthwaite R. and Duckett, S.B. (Eds). Spectroscopic Properties of Inorganic and Organometallic Compounds: Techniques, Materials and Applications, Volume 43. (pp. 289-323). Cambridge: The Royal Society of Chemistry.

Guan, W., Wang, C., Yun, X., Hu, X., Wang, Y. and Li, H. (2008). A Mild and Efficient Oxidation of 2,3,6-Trimethylphenol to Trimethyl-1,4-benzoquinone in Ionic Liquids. *Catalysis Communications.* 9: 1979-1981.

Guilard, R., Tabard, A., Caemelbecke, E.V. and Kadish, K.M. (2000). Synthesis, Spectroscopy and Electrochemical Properties of Porphyrins with Metal-Carbon Bonds. In Kadish, K.M., Smith, K.M. and Guilard, T. (Eds.). *The Porphyrin Handbook: Inorganic, Organometallic and Coordination Chemistry Volume 3.* (pp. 295-338). United States of America: Academic Press.

Guli, M., Zhang, L., Yao, J. and Li, X. (2012). Effect of Template-Removing Methods and Modification to Mesoporous Blank Silica and Composited Silica. *Powder Technology*. 219: 271-275.

Guo, X., Shen, D-H., Li, Y-Y., Tian, M., Liu, Q., Guo, C-C. and Liu, Z-G. (2011). Immobilization of Metalloporphyrin on Organosilicon Microsphere Mixed with Ceria as A New Catalyst for Oxidation of Cyclohexane. *Journal of Molecular Catalysis A: Chemical.* 351: 174-178.

Guo, Z., Liu, B., Zhang, Q., Deng, W., Wang, Y. and Yang, Y. (2014). Recent Advances in Heterogeneous Selective Oxidation Catalysis of Sustainable Chemistry. *Chemical Society Reviews.* 43: 3480-3524.

Gustafsson, H., Johansson, E.M., Barrabino, A., Odén, M. and Holmberg, K. (2012). Immobilization of Lipase from Mucor Miehei and Rhizopus Oryzae into Mesoporous Silica-The Effect of Varied Particle Size and Morphology. *Colloids and Surfaces B: Biointerfaces.* 100: 22-30.

Hagen, J. (2006). *Industrial Catalysis: A Practice Approach*. Second, Completely Revised and Extended Edition. (pp. 1-14). Weinheim: Wiley-VCH.

Hajian, R., Tangestaninejad, S., Moghadam, M., Mirkhani, V. and Mohammadpoor-Baltork, I. (2016). [Mn(TPPS)] Immobilized on Ionic Liquid-Modified Silica as A Heterogeneous and Reusable Catalyst for Epoxidation of Alkenes with $NaIO_4$ under Ultrasonic Irradiation. *Journal of the Iranian Chemical Society.* 13(6): 1061-1067.

Hajipour, A.R. and Refiee, F. (2015). Recent Progress in Ionic Liquids and their Applications in Organic Synthesis. *Organic Preparations and Procedures International*. 47: 249-308.

Halma, M., Taviot-Gueho, C., Prevot, V. and Forano, C. (2008). Synthesis, Characterization, and Catalytic Activity of Anionic Iron (III) Porphyrins Intercalated into Layered Double Hydroxides. *Journal of Catalysis*. 257: 233-243.

Hamid, H. (2005). *Iron(III)-Porphyrin Immobilized on Mesoporous Al-MCM-41 and Polymethacrylic Acid as Catalysts for the Single-Step Synthesis of Phenol from Benzene.* Master Thesis, Universiti Teknologi Malaysia, Skudai.

Han, L., Park, S-W. and Park, D-W. (2009). Silica Grafted Imidazolium-based Ionic Liquids: Efficient Heterogeneous Catalysts for Chemical Fixation of CO_2 to a Cyclic Carbonate. *Energy and Environmental Science.* 2: 1286-1292.

Han, P., Zhang, H., Qiu, X., Ji, X. and Gao, L. (2008). Palladium within Ionic Liquid Functionalized Mesoporous Silica SBA-15 and Its Catalytic Application in Room-Temperature Suzuki Coupling Reaction. *Journal of Molecular Catalysis A: Chemical.* 295: 57-67.

Hartley, F.R. (1985). Supported Metal Complexes (Catalysis by Metal Complexes). In Ugo, R. and James, B.R. (Eds.). (pp.1-33). Holland: D. Reidel Publishing Company.

Hasanpour, M., Eshghi, H., Bakavoli, M. and Mirzaei, M. (2015). A Novel Ionic Liquid on Imidazolium Cation as an Efficient and Reusable Catalyst for the One-Pot Synthesis of Benzoxazoles, Benzthiazoles, Benzimidazoles and 2-Arylsubstituted Benzimidazoles. *Journal of the Chinese Chemical Society*. 52: 1-8.

Hasanzadeh, M., Shadjou, N., de la Guardia, M., Eskandani, M. and Sheikhzadeh, P. (2012). Mesoporous Silica-Based Materials for Use in Biosensors. *Trends in Analytical Chemistry*. 33: 117-129.

Hazra, M., Dolai, T., Pandey, A., Kumar Dey, S. and Patra, A. (2014). Synthesis and Characterisation of Copper(II) Complexes with Tridentate NNO Functionalized Ligand: Density Function Theory Study, DNA Binding Mechanism, Optical Properties, and Biological Application. *Bioinorganic Chemistry and Applications*. 1-13.

He, W., Yao, Y., He, M., Kai, Z., Long, L., Zhang, M., Qin, S. and Yu, J. (2013**a**). Influence of Reaction Conditions on the Grafting Pattern of 3-Glycidoxypropyl trimetthoxysilane on Montmorillonite. *Bulletin of the Korean Chemical Society*. 34(1): 112-116.

He. W., Wu, D., Li, J., Zhang, K., Xiang, Y., Long, L., Qin, S., Yu, J. and Zhang, Q. (2013**b**). Surface Modification of Colloidal Silica Nanoparticles: Controlling the Size and Grafting Process. *Bulletin of the Korean Chemical Society*. 34(9): 2747-2752.

Heng, S., Lau, P.P.S., Yeung, K.L., Djafer, M. and Schrotter, J-C. (2004). Low-Temperature Ozone Treatment for Organic Template Removal from Zeolite Membrane. *Journal of Membrane Science.* 234: 69-78.

Hirsh, S.L., Bilek, M.M.M., Nosworthy, N.J., Kondyurin, A., Dos Remedios, C.G. and McKenzie, D.R. (2010). A Comparison of Covalent Immobilization and

Physical Adsorption of a Cellulase Enzyme Mixture. *Langmuir*. 26(17): 14380-14388.

Hitz, S. and Prins, R. (1997). Influence of Template Extraction on Structure, Activity, and Stability of MCM-41 Catalysts. *Journal of Catalysis.* 168(2): 194 – 206.

Hodala, J.L., Halgeri, A.B. and Shanbhag, G.V. (2016). Enhancement in Activity and Shape Selectivity of Zeolite BEA by Phosphate Treatment for 2-Methoxynaphthaene Acylation. *RSC Advances.* 6(93): 90579-90586.

Hodgson, M.J. (2005). *Preparation, Structure and Spectra of Meso-metalloporphyrins.* Master Thesis, Queensland University of Technology, Brisbane.

Hollingsworth, J.V., Kumar Bhupathiraju, N.V.S.D., Sun, J., Lochner, E., Vicente, M.G.H. and Russo, P.S. (2016). Preparation of Metalloporphyrin-Bound Supermagnetic Silica Particels via "Click" Reaction. *ACS Applied Materials and Interfaces*. 8(1): 792-801.

Horváth, T., Kaizer, J. and Speier, G. (2004). Functional Phenoxazinone Synthase Models Kinetic Studies on the Copper-Catalyzed Oxygenation of 2-Aminophenol. *Journal of Molecular Catalysis A: Chemical*. 215: 9-15.

Huang, G., Liu, Y., Cai, J.L., Chen, X.F., Zhao, S.K., Guo, Y.A., Wei, S.J. and Li, X. (2017). Heterogeneous Biomimetic Catalysis using Iron Porphyrin for Cyclohexane Oxidation Promoted by Chitosan. *Applied Surface Science*. 402: 436-443.

Huang, Z., Li, H-S., Miao, H., Guo, Y-H. and Teng, L-J. (2014). Modified Supercritical CO_2 Extraction of Amine Template from Hexagonal Mesoporous Silica (HMS) Materials: Effects of Template Identity and Matrix Al/Si Molar Ratio. *Chemical Engineering Research and Design*. 92: 1371-1380.

Huo, Q. (2011). Synthetic Chemistry of the Inorganic Ordered Porous Materials. In Xu, R., Pang, W. and Huo, Q. (Eds.). *Modern Inorganic Synthetic Chemistry*. (pp.339-373). The Netherlands: Elsevier Science B.V.

Huo, Q., Margolese, D.I., Ciesla, U., Demuth, D.G., Feng, P., Gier, T.E., Sieger, P., Firouzi, A., Chmelka, B.F., Schuth, F. and Stucky, G.D. (1994). Organization of Organic Molecules with Inorganic Molecular Species into Nanocomposites Biphase Arrays. *Chemistry of Materials.* 6:1176-1191.

Ide, M., El-Roz, M., Canck, E.D., Vicente, A., Planckaert, T., Bogaerts, T., Driessche, I.V., Lynen, F., Speybroeck, V.V., Thybault-Starzyk, F. and Voort, V.D. (2013). Quantification of Silanol Sites for the Most Common Mesoporous Ordered Silicas and Organosilicas: Total versus Accessible Silanols. *Physical Chemistry Chemical Physics.* 15: 642-650.

Innocenzi, P. and Falcaro, P. (2003). Order-Disorder Transition and Evolution of Silica Structure in Self-Assembled Mesostructured Silica Films through FTIR Spectroscopy. *Journal Physical Chemistry B.* 107: 4711-4717.

Irge, D.D. (2016). Review Article Ionic Liquids: A Review on Greener Chemistry Applications, Quality Ionic Liquid Synthesis and Economical Vialibity in a Chemical Processes. *American Journal of Physical Chemistry.* 5(3): 74-79.

Islam, R.U., Taher, A., Choudhary, M., Siwal, S. and Mallick, K. (2015). Polymer Immobilized Cu(I) Formation and Azide-Alkyne Cycloaddition: A One Pot Reaction. *Scientific Reports.* 5(9632): 1-8.

Ito, S., Aihara, K and Matsumoto, M. (1983). Ruthenium-Catalyzed Oxidation of Phenols with Hydrogen Peroxide. *Tetrahedron Letters.* 24(27): 5249-5252.

Ivanov, A.S. and Boldyrev, A.I. (2014). Deciphering Aromaticity in Porphyrinoids via Adaptive Natural Density Partitioning. *Organic and Biomolecular Chemistr.* 12: 6145-6150.

Jacob, C.R., Varkey, S.P. and Ratnasamy, P. (1998). Selective Oxidation over Copper and Manganese Salens Encapsulated in Zeolites. *Microporous and Mesoporous Material*s. 22: 465-474.

Jadhav, A.H., Thorat, G.M., Lee, K., Lim, A.C., Kang, H. and Seo, J.G. (2016). Effect of Anion Type of Imidazolium Based Polymer Supported Ionic Liquids on the Solvents Free Synthesis of Cycloadditon of CO_2 into Epoxide. *Catalysis Today*. 265: 56-67.

Jalali, A.M., Taromi, F.A., Atai, M. and Solhi, L. (2016). Effect of Reaction Conditions on Silanation of Sepiolite Nanoparticles. *Journal of Experimental Nanoscience.* 11(15): 1171-1183.

Jensen, K.P. and Ryde, U. (2003). Comparison of the Chemical Properties of Iron and Cobalt Porphyrins and Corrins. *ChemBioChem.* 4: 413-424.

Ji, H., Fan, Y., Jin, W., Chen, C. and Xu, N. (2008). Synthesis of Si-MCM-48 Membrane by Solvent Extraction of the Surfactant Template. *Journal of Non-Crystalline Solids.* 354(18): 2010 – 2016.

Jiang, T., Wu, D., Song, J., Zhou, X., Zhao, Q., Ji, M. and Yin, H. (2011). Synthesis and Characterization of Mesoporous ZrMCM-48 Molecular Sieves with Good Thermal and Hydrothermal Stability. *Powder Technology.* 207: 422-427.

Jiang, X., Nie, Y., Li, C. and Wang, Z. (2008). Imidazolium-Based Alkylphosphate Ionic Liquids- A Potential Solvent for Extractive Desulfurization of Fuel. *Fuel.* 87: 79-84.

Jin, J., Dong, Z., He, J., Li, R. and Ma, J. (2009). Synthesis of Novel Porphyrin and its Complexes Covalently Linked to Multi-Walled Carbon Nanotubes and Study of their Spectroscopy. *Nanoscale Research Letters*. 4: 578-583.

Jin, Y., Fang, S., Chai, M., Yang, L. and Hirano, S-I. (2012). Ether-Functionalized Trialkylimidazolium Ionic Liquids: Synthesis, Characterization, and Properties. *Industrial and Engineering Chemistry Research.* 51(34): 11011-11020.

Jondi, W., Zyoud, A., Mansour, W., Hussein, A.Q. and Hilal, H.S. (2016). Highly Active and Selective Catalysts for Olefin Hydrosilylation Reactions using Metalloporphyrins Intercalated in Natural Clays. *Reaction Chemistry and Engineering.* 1: 194-203.

Kameyama, H., Narumi, F., Hattori, T. and Kameyama, H. (2006). Oxidation of Cyclohexene with Molecular Oxygen Catalyzed by Cobalt Porphyrin Complexes Immobilized on Montmorillonite. *Journal of Molecular Catalysis A: Chemical.* 258: 172-177.

Kang, H., Zhu, Y., Shen, J., Yang, X., Chen, C., Cao, H. and Li, C. (2010). Preparation of Silica-Sustained Electrospun Polyvinylpyrrolidone Fibers with Uniform Mesopores via Oxidative Removal of Template Molecules by H_2O_2 Treatment. *Materials Research Bulleti*n. 45: 830-837.

Karas, M. and Hillenkamp, F. (1988). Laser Desorption Ionization of Proteins with Molecular Masses Exceeding 10,000 Daltons. *Analytical Chemistry.* 60(20): 2299-2301.

Karasek, F.W. and Clement, R.E. (1988). Basic Gas Chromatography- Mass Spectrometry, Principles and Techniques. The Netherlands: Elsevier Science B.V.

Kärkkäinen, J. (2007). *Preparation and Characterization of Some Ionic Liquids and Their Use in the Dimerization Reaction of 2-Methylpropene.* Doctor Philosophy, University of Oulu, Finland.

Katsuka, S., Shiozawa, Y., Imai, K., Kudo, Y. and Takeda, Y. (2010). Stability of Ion Pairs of Bis(trifluoromethanesulfonyl)amide-Based Ionic Liquids in Dichloromethane. *Journal of Chemical and Engineering Data.* 55(4): 1588-1593.

Keene, M.T.J., Denoyel, R. and Llewellyn, P.L. (1998). Ozone Treatment for the Removal of Surfactant to Form MCM-41 Type Materials. *Chemical Communications.* (20): 2203 – 2204.

Keppeler, M., Holzbock, J., Akbarzadeh, J., Peterlik, H. and Hüsing, N. (2011). Inorganic-Organic Hybrid Materials Through Post-Synthesis Modification: Impact of the Treatment with Azides on the Mesopore Structure. *Beilstein Journal of Nanotechnology.* 2: 486-498.

Kermanioryani, M., Abdul Mutalib, M.I., Dong, Y., Lethesh, K.C., Ben Ghanem, O.B.O., Kurnia, K.A., Aminuddin, N.F. and Leveque, J-M. (2016). Physicochemical Properties of New Imidazolium-Based Ionic Liquids Containing Aromatic Group. *Journal of Chemical and Engineering Data.* 61: 2020-2026.

Kervinen, K., Korpi, H., Leskalä, M. and Repo, T. (2003). Oxidation of Veratryl Alcohol by Molecular Oxygen in Aqueous Solution Catalyzed by Cobalt Salen-Type Complexes: The Effect of Reaction Conditions. *Journal of Molecular Catalysis A: Chemical*. 203: 9-19.

Keskin, S., Kayrak-Talay, D., Akman, U. and Hortaçsu, Ö. (2007). A Review of Ionic Liquids Towards Supercritical Fluid Applications. *Journal of Supercritical Fluids.* 43: 150-180.

Khalili, N.R., Rahimi, R. and Rabbani, M. (2013). Immobilized Metalloporphyrins in Mesoporous MCM-48 as Efficient and Selective Heterogeneous Catalysts for Oxidation of Cyclohexane. *Monatshefte fur Chemie.* 144(5): 597-603.

Khokhlov, A.G., Valiullin, R.R., Stepovich, M.A. and Kärger, J. (2008). Characterization of Pore Size Distribution in Porous Silicon NMR Spectroscopy and Adsorption Methods. *Colloid Journal.* 70(4): 507-514.

Kholdeeva, O.A., Ivanchikova, I.D., Guidotti, M. and Ravasio, N. (2007). Highly Efficient Production of 2,3,5-Trimethyl-1,4-benzoquinone using Aqueous H_2O_2 and Grafted $Ti(IV)/SiO_2$ Catalyst. *Green Chemistry*. 9: 731-733.

Kholdeeva, O.A., Ivanchikova, I.D., Guidotti, M., Ravasio, N., Sgobba, M. and Barmatova. M.V. (2009). How to Reach 100% Selectivity in H_2O_2-Based Oxidation of 2,3,6-Trimethylphenol to Trimethyl-*p*-benzoquinone over Ti, Si-Catalysts. *Catalysis Today*. 141: 330-336.

Khupse, N.D. and Kumar, A. (2010). Ionic Liquids: New Materials with Wide Applications. *Indian Journal of Chemistry*. 49A: 635-648.

Kim, H-J., Yang, H-C., Chung, D-Y., Yang, I-H., Choi, Y.J. and Moon, J-K. (2015). Review Article Functionalized Mesoporous Silica Membranes for CO_2 Separation Applications. *Journal of Chemistry*. 2015: 1-9.

Kim, Y-S., Guo, X-F. and Kim, G-J. (2009). Highly Active New Chiral Co(III) Salen Catalysts Immobilized by Electrostatic Interaction with Sulfonic Acid Linkages on Ordered Mesoporous SBA-16 Silica. *Chemical Communications.* (28): 4296-4298.

Kolahdoozan, M., Kalbasi, R.J. and Hossaini, M. (2013). Synthesis of Heterogeneous Copper Catalyst Based on Amino-Functionalized Triazine Rings Supported by Silica-Gel for Oxidation of Alcohols. *Journal of Chemistry*. 1-7.

Kresge, C.T. and Roth, W.J. (2013). The Discovery of Mesoporous Molecular Sieves from the Twenty Year Perspective. *Chemical Society Reviews.* 42: 3663-3670.

Kresge, C.T., Vartuli, J.C., Roth, W.J. and Leonowicz, E. (2004). The Discovery of Exxon Mobil's M41S Family of Mesoporous Molecular Sieves. *Studies in Surface and Catalysis.* 148: 53 -72.

Krest, C.M., Onderko, E.L., Yosca, T.H., Calixto, J.C., Karp, R.F., Livada, J., Rittle, J. and Green, M.T. (2013). Reactive Intermediates in Cytochrome P450 Catalysis. *Journal of Biological Chemistry.* 288(24): 17074-17081.

Krężel, A. and Maret, W. (2016). The Biologival Inorganic Chemistry of Zinc Ions. *Achieves of Biochemistry and Biophysics*. 611: 3-19.

Krishnamurthy, M. (1977). Kinetics of Anation Reactions of a Water-Soluble Rh(III)-Porphyrin. *Inorganic Chimica Acta.* 25(C): 215-218.

Kruk, M., Celer, E.B., Matos, J.R., Pikus, S. and Jaroniec, M. (2005). Synthesis of FDU-1 Silica with Narrow Pore Size Distribution and Tailorable Pore

Entrance Size in the Presence of Sodium Chloride. *The Journal of Physical Chemistry B.* 109(9): 3838-3843.

Kumar, J., Jha, R. and Modhera, B.K. (2013). Applications of Zeolite with Additives in Petroleum Refinery. *International Journal of Chemistry and Chemical Engineering.* 3(2): 75-80.

Kumar, P., Ida, J., Kim, S., Guliants, V.V. and Lin, J.Y.S. (2006). Ordered Mesoporous Membranes: Effects of Support and Surfactant Removal Conditions on Membrane Quality. *Journal of Membrane Science*. 279: 539-547.

Kumar, R., Chen, H-T., Escoto, J.L.V., Lin, V.S-Y. and Pruski, M. (2006). Template Removal and Thermal Stability of Organically Functionalized Mesoporous Silica Nanoparticles. *Chemistry of Materials.* 18(18): 4319 – 4327.

Kumar, S. and Jain, S.L. (2013). Non-Symmetrical Dialkyl Carbonate Synthesis Promoted by 1-(3-trimethoxysilylpropyl)-3-methylimidazolium Chloride. *New Journal of Chemistry.* 37(10): 3057-3061.

Kurnia, K.A., Sintra, T.E., Neves, C.M., Shimizu, K., Lopes, J.N.C., Gonçalves, F., Ventura, S.P.M., Freire, M.G., Santos, L.M. and Coutinho, J.A.P. (2014). The Effect of the Cation Alkyl Chain Branching on Mutual Solubilites with Water and Toxicities. *Physical Chemistry Chemical Physics.* 16(37): 19952-19963.

Lall-Ramnarine, S.I., Castano, S., Subramaniuam, G., Thomas, M.F. and Wishart, J.F. (2009). Synthesis, Characterization and Radiolytic Properties of Bis(oxalate)borate Containing Ionic Liquids. *Radiation Physics and Chemistry*. 78: 1120-1125.

Lau, S.C. (2009). *Iron(III) Porphyrin Dendrimer-Mesoporous Silica as Biomimetic Catalyst for Selective Oxidation of Trimethylphenol.* Master Thesis, Universiti Teknologi Malaysia, Skudai.

Lawrence, G., Baskar, A.V., El-Newehy, M.H., Cha, W.S., Al-Deyab, S.S. and Vinu, A. (2015). Quick High-Temperature Hydrothermal Synthesis of Mesoporous Materials with Cubic Structure for the Adsorption of Lysozyme. *Science and Technology of Advanced Materials.* 16: 1-11.

Lazar, A., Thiel, W.R. and Singh, A.P. (2014). Synthesis and Characterization of 3-[N,N'-bis-3-(salicylidenamino)ethyltriamine] $Mo^{(VI)}O_2$@SBA-15: A Highly Stable and Reusable Catalyst for Epoxidation and Sulfoxidation Reactions. *RSC Advances.* 4: 14063-14073.

Lazar, A., Vinid, C.P. and Singh, A.P. (2016). A Simple, Phosphine Free, Reusable Pd(II)-2,2'-Dihydroxybenzophenone-SBA-15 Catalyst for Arylation and Hydrogenation Reactions of Alkenes. *New Journal of Chemistry.* 40: 2423-2432.

Le Roux, E., Mallmann, A.D., Merle, N., Taoufik, M. and Anwander, R. (2015). Immobilization of Heteroleptic Bis(Oxazoline) Zinc Catalysts on SBA-15 for Asymmetric Hydrosilylation. *Organometallics.* 34(20): 5146-5154.

Lee, S-G. (2006). Functionalized Imidazolium Salts for Task-Specific Ionic Liquid Applications. *Chemical Communications.* (10): 1049-1063.

Lei, D., Zheng, Q., Wang, Y. and Wang, H. (2015). Preparation and Evaluation of Aminopropyl-Functionalized Manganese-Loaded SBA-15 for Copper Removal from Aqueous Solution. *Journal of Environmental Sciences.* 28: 118-127.

Leonard, D.R. and Lindsay Smith, J.R. (1990). Model Systems for Cytochrome P450 Dependent Mono-Oxygenase. Part 7. Alkene Epoxidation by Iodosylbenzene Catalysed by Ionic Iron(III) Tetraarylporphyrins Supported on Ion-Exchange Resins. *Journal of the Chemistry Society Perkin Transactions.* 2: 1917-1923.

Leones, R., Costa, C.M., Machado, A.V., Esperança, J.M.S.S., Silva, M.M. and Lanceros-Méndez, S. (2015). Effect of Ionic Liquid Anion Type in the Performance of Solid Polymer Electrolytes Based on Poly(Vinylidene fluoride-trifluoroethylene). *Electronanalysis*. 27: 457-464.

Li, Hu., Bhadury, P.S., Song, B. and Yang, S. (2012). Immobilized Functional Ionic Liquids: Efficient, Green, and Reusable Catalysts. *RSC Advances.* 2: 12525-12551.

Li, H., Endres, F. and Atkin, R. (2013). Effect of Alkyl Chain Length and Anion Species on the Interfacial Nanostructure of Ionic Liquids at the Au(111)-Ionic Liquid Interface as a Function of Potential. *Physical Chemistry Chemical Physics.* 15: 14624-14633.

Li, H., She, Y. and Wang, T. (2012). Advances and Perspectives in Catalysts for Liquid-Phase Oxidation of Cyclohexane. *Frontiers of Chemical Science and Engineering.* 6(3): 356-368.

Li, H., Yang, M., Zhang, X., Yan, L., Li, J. and Qi, Y. (2013). Mesoporous Silica-Supported Copper-Catalysts for Homocoupling Reaction of Terminal Alkynes at Room Temperature. *New Journal of Chemistry*. 37: 1343 – 1349.

Li, K-T. and Liu, P-Y. (2004). Oxidation of 2,4,6-Trimethylphenol using Iron-Based Catalysts. *Applied Catalysis A: General.* 272: 167-174.

Li, Q., Wu, Z., Tu, B., Park, S.S., Ha, C-S. and Zhao, D. (2010). Highly Hydrothermal Stability of Ordered Mesoporous Aluminosilicates Al-SBA-15 with High Si/Al Ratio. *Microporous and Mesoporous Materials*. 135: 95 – 104.

Li, Q-F., Yue, D., Lu, W., Zhang, X., Li, C. and Wang, Z. (2015). Hybrid Luminescence Materials Assembled by $[Ln(DPA)_3]^{3-}$ and Mesoporous Host Through Ion-Pairing Interactions with High Quantum Efficiencies and Long Lifetime. *Science Reports*. 5(8385): 1 -9.

Li, X., Wu, X., Kim, J.M., Kim, S.S., Jin, M. and Li, D. (2009). MALDI-TOF-MS Analysis of Small Molecules using Modified Mesoporous Material SBA-15 as Assisted Matrix. *American Society for Mass Spectrometry*. 20: 2167-2173.

Li, Y., Sun, N., Li, L., Zhao, N., Xiao, F., Wei, W., Sun, Y. and Huang, W. (2013). Grafting of Amines on Ethanol-Extracted SBA-15 for CO_2 Adsorption. *Materials.* 6: 981-999.

Li, Y., Zhang, P., Wu, M., Liu, W., Yi, Z., Yang, M., Zhang, J., Zhang, G. and Bai, Z. (2009). An Effective Oxidation of 2,3,6-Trimethylphenol to 2,3,5-Trimethylbenzoquinone using Fenton's Reagent under Mild Conditions. *Chemical Engineering Journal.* 146: 270-274.

Li, Z., Xia, C.-G. and Zhang, X.-M. (2002). Preparation and Catalysis of DMY and MCM-41 Encapsulated Cationic Mn(III)–porphyrin Complex. *Journal of Molecular Catalysis A: Chemical*. 185: 47-56.

Liévano, J.F.P and Díaz, L.A.C (2016). Synthesis and Characterization of 1-Methyl-3-Methoxysilyl Propyl Imidazolium Chloride-Mesoporous Silica Composite as Adsorbent for Dehydration in Industrial Processes. *Materials Research.* 19(3): 534-541.

Lignier, P. (2015). Size Control of Monodisperse Metal Nanocrystals in Ionic Liquids. In Dupont, J. and Kollár, L. (Eds.). *Ionic Liquids (ILs) in Organometallic.* (pp. 55-78). Switzerland: Springer International Publishing.

Lin, H-Y. and Chen, Y-W. (2005). Preparation of Spherical Hexagonal Mesoporous Silica. *Journal of Porous Materials.* 12: 95-105.

Linares, N., Silvestre-A;bero, A.M., Serrano, E., Silvestre-Albero, J. and García-Martínez, J. (2014). Mesoporous Materials for Clean Energy Technologies. *Chemical Society Reviews.* 43: 7681-7717.

Lindsey, J.S. (2009). Synthetic Routes to *Meso*-Patterned Porphyrins. *Accounts of Chemical Research.* 43(2): 300-311.

Liu, P., Zhou, C-Y., Xiang, S. and Che, C-M. (2010). Highly Efficient Oxidative Carbon-Carbon Coupling with SBA-15 Support Iron Terpyridine Catalyst. *Chemical Communications*. 46: 2739-2741.

Liu, X., Chang, F., Xu, L., Yang, Y., Tian, P., Qu, L. and Liu, Z. (2005). Preparation of Ordered Carbon/Silica Hybrid Mesoporous Materials with Specific Pore Size Expansion. *Microporous and Mesoporous Materials.* 79: 269-273.

Liu, Y., Peng, J., Zhai, S., Li, J., Mao, J., Li, M., Qiu, H. and Lai, G. (2006). Synthesis of Ionic Liquid Functionalized SBA-15 Mesoporous Materials as Heterogeneous Catalyst toward Knoevenagel Condensation under Solvent-Free Conditions. *European Journal of Inorganic Chemistry.* 2947-2949.

Livi, S., Gérard, J-F. and Duchet-Rumeau, J. (2015). Ionic Liquids as Polymer Additives. In Mecerreyes, D. (Ed.). *Applications of Ionic Liquids in Polymer Science and Technology*. (pp. 1-21). New York: Springer.

Loll, B., Biesiadka, J. and Saenger, W. (2004). Metal Ions in Cyanobacterial Photosystem II. In Messerschmidt, A., Bode, W. and Cygler, M. (Eds). *Handbook of Metalloproteins Volume 3.* (pp. 1-17). United Kingdom; John Wiley & Sons Ltd.

Losch, P., Kolb, J.F., Astafan, A., Daou, T.J., Pinard, L., Pale, P. and Louis, B. (2016). Eco-Compatible Zeolite-Catalysed Continuous Halogenation of Aromatics. *Green Chemistry.* 18(17): 4714-4724.

Lowell, S., Shields, J.E., Thomas, M.A. and Thommes, M. (2004). *Characterization of Porous Solids and Powders: Surface Area, Pore Size and Density: Chapter 4 Adsorption Mechanism.* Dordrecht, Netherlands: Kluwer Academic Publishers.

Lu, A-H., Li, W-C., Schmidt, W. and Schüth, F. (2006). Low Temperature Oxidative Template Removal from SBA-15 using MnO_4^- Solution and Carbon Replication of the Mesoporous Silica Product. *Journal of Materials Chemistry*. 16: 3396-3401.

Lu, Q.S. and Zhao, X.S. (2004). Nanoporous Materials Science and Engineering: Chapter 11 Physical Adsorption Characterization of Ordered and Amorphous Mesoporous Materials. London: Imperial College Press.

Lu, X-B., Zhang, W-H., Xiu, J-H., He, R., Chen, L-G. and Li, X. (2003). Removal of the Template Molecules from MCM-41 with Supercritical Fluid in a Flow Apparatus. *Industrial and Engineering Chemistry Research.* 42(3): 653 – 656.

Lü, X-F., Qian, H., Mele, G., Riccardis, A.D., Zhao, R., Chen, J., Wu, H. and Hu, N-J. (2017). Impact of Different TiO_2 Samples and Porphyrin Sunstituents on the Photocatalytic Performance of TiO_2@Copper Porphyrin Composites. *Catalysis Today*. 281: 45-52.

Luo, J., Conrad, O. and Vankelecom, I.F.J. (2012). Physicochemical Peoperties of Phosphonium-Based and Ammonium-Based Protic Ionic Liquids. *Journal of Materials Chemistry*. 22: 20574-20579.

Luque, R. Balu, A.M., Campelo, J.M., Gracia, M.D., Losada, E., Pineda, A., Romero, A.A. and Serrano-Ruiz, J.C. (2012). Catalytic Applications of Mesoporous Silica-Based Materials. In Spivey, J.J. and Gupta, M. (Eds.). *Catalysis Volume 24* (pp.253-280). Cambridge: The Royal Society of Chemistry.

Machado, G.S., De Freitas Castro, K.A.D., Wypych, F. and Nakagaki, S. (2008). Immobilization of Metalloporphyrins into Nanotubes of Natural Halloysite Toward Selective Catalyst for Oxidation Reactions. *Journal of Molecular Catalysis A: Chemical*. 283: 99-107.

Machado, G.S., José de Lima, O., Ciuffi, K.J., Wypych, F. and Nakagaki, S. (2012**a**). Iron(III) Porphyrin Supported on Metahalloysite: An Efficient and Reusable Catalyst for Oxidation Reactions. *Catalysis Science and Technology*. 3: 1094-1101.

Machado, G.S., Wypych, F. and Nakagaki, S. (2012**b**). Anionic Iron(III) Porphyrins Immobilized on Zinc Hydroxide Chloride as Catalysts for Heterogeneous Oxidation Reactions. *Applied Catalysis A: General*. 413-414: 94-102.

Madadi, M. and Rahimi, R. (2012). Zeolite-Immobilized Mn(III), Fe(III) and Co(III) Complexes with 5,10,15,20-Tetra(4-Methoxyphenyl)Porphyrin as Heterogeneous Catalysts for the Epoxidation of (R)-(+)-Limonene: Synthesis,

Characterization and Catalytic Activity. *Reaction Kinetics, Mechanisms and Catalysis*. 107(1): 215-229.

Majda, D., Napruszewska, B.D., Zimowska, M. and Makowski,W. (2016). Porosity of SBA-15 After Functionalization of the Surface with Aminosilanes. *Microporous and Mesoporous Materials.* 243: 98-106.

Makhoukhi, B., Villemin, D. and Didi, M.A. (2016). Synthesis of Bismidazolium-Ionic Liquids: Characterization, Thermal Stability and Application to Bentonite Intercalation. *Journal of Taibah University for Science.* 10: 168-180.

Mamardashvili, G.M., Mamardashvili, N.Z. and Berezin, B.D. (2000). Solubility of Alkylporphyrins. *Molecules.* 5: 762-766.

Manassen, J. and Bar-Ilan, A. (1970). Metal Complexes of Phthalocyanine and α, β, γ, δ-Tetraphenyl Porphyrin as Heterogeneous Catalysts in Oxidative Dehydrogenation. Correlation between Catalytic Activity and Redox Potential. *Journal of Catalysis.* 17: 86-92.

Mantri, S., Pradhan, C., Maharana, T. and Sutar, A.K. (2017). Schiff Base Transition Metal Complexes for ROP of L-Lactide. *International Journal of Chemical Engineering and Applications.* 8(2): 122-126.

Marchetti, L. and Levine, M. (2011). Biomimetic Catalysis. *American Chemical Society.* 1: 1090-1118.

Marcus, Y. (2016). Room Temperature Ionic Liquids. In Marcus, Y. (Ed). *Ionic Liquid Properties from Molten Salts to RTILs.* (pp. 123-196) Switzerland: Springer.

Maria Chong, A.S. and Zhao, X.S. (2003). Functionalization of SBA-15 with APTES and Characterization of Functionalized Materials. *The Journal of Physical Chemistry B.* 107: 12650-12657.

Martin, A. (2016). Zeolite Catalysis. *Catalysts.* 6(118): 1-3.

Martínez, A.V., Mayoral, J.A. and García, J.I. (2014). Pd Nanoparticles Immobilized in [Bmim][PF_6] Supported on Laponite Clay as Highly Recyclable Catalysts for the Mizoroki-Heck Reaction. *Applied Catalysis A: General.* 472: 21-28.

Martins, M.A.R., Neves, C.M.S.S., Kurnia, K.A., Carvalho, P.J., Rocha, M.A.A., Santos, L.M.N.B.F., Pinho, S.P. and Freire, M.G. (2015). Densities, Viscosities and Derived Thermophysical Properties of Water-Saturated Imidazolium-Based Ionic Liquids. *Fluid Phase Equilibria*. 407: 188-196.

Matei, D., Cursaru, D.L. and Mihai, S. (2016). Preparation of MCM-48 Mesoporous Molecular Sieve Influence of Preparation Conditions on the Structural Properties. *Digest Journal of Nanomaterials and Biostructures*. 11(1): 271-276.

Matos, J.R., Kruk, M., Mercuri, L.P., Jaroniec, M., Zhao, L., Kamiyama, T., Terasaki, O., Pinnavaia, T.J. and Liu, Y. (2003). Ordered Mesoporous Silica with Large Cage-Like Pores: Structural Identification and Pore Connectivity Design by Controlling the Synthesis Temperature and Time. *Journal of the American Chemical Society.* 125: 821-8219.

Matsumoto, H., Sakaebe, H. and Tatsumi, K. (2005). Preparation of Room Temperature Ionic Liquids Based on Aliphatic Onium Cations and Asymmetric Amide Anions and Their Electrochemical Properties as a Lithium Battery Electrolyte. *Journal of Power Sources.* 146: 45-50.

Maurya, M.R., Kumar, A. and Pessoa, J.C. (2011). Vanadium Complexes Immobilized on Solid Supports and their use as Catalysts for Oxidation and Functionalization of Alkanes and Alkenes. *Coordination Chemistry Reviews.* 255(19-20): 2315-2344.

McDanel, W.M., Cowan, M.G., Carlisle, T.K., Swanson, A.K., Noble, R.D. and Gin, D.L. (2014). Cross-linked Ionic Resins and Gels from Epoxide-Functionalized Imidazolium Ionic Liquid Monomers. *Polymer.* 55: 3305-3313.

McNair, H.M. and Miller, J.M. (1998). Basic Gas Chromatography, Techniques in Analytical Chemistry. New York: John Wiley & Sons. Inc.

Melník, M., Kabešova, M., Koman, M., Macáškova, L. and Holloway, C.E. (1999). Review Copper(II) Coordiantion Compounds: Classification and Analysis of *Journal of Coordination Chemistry* Crystallographic and Structural Data IV. Trimeric and Oligomeric Compounds. 48(3): 271-374.

Meunier, B., De Visser, S.P. and Shaik, S. (2004). Mechanism of Oxidation Reactions Catalyzed by Cytochrome P450 Enzymes. *Chemical Reviews.* 104(9): 3947-3980.

Milgrom, L.R. (1997). The Colours of Life: An Introduction to the Chemistry of Porphyrins and Related Compounds. United States: Oxford University Press Inc.

Mohapatra, P.K. (2017). Actinide Ion Extraction Using Room Temperature Ionic Liquids: Opportunities and Challenges for Nuclear Fuel Cycle Applications. *Dalton Transactions.* 46: 1730-1747.

Mondal, S.S., Bhunia, A., Demeshko, S., Kelling, A., Schilde, U., Janiak, C. and Holdt, H-J. (2014). Synthesis of a Co(II)-Imidazolate Framework from an Anionic Linker Precursor: Gas-Sorption and Magnet Properties. *CrystEngComm*. 16: 39-42.

Moritz, M. and Łaniecki, M. (2012). SBA-15 Mesoporous Material Modified with APTES as the Carrier for 2-(3-Benzoylphenyl)propionic Acid. *Applied Surface Science.* 258: 7523-7529.

Mustacich, D.J., Bruno, R.S. and Traber, M.G. (2007). Vitamin E. In Litwack, G. (Ed.). Vitamins and Hormones. (pp. 1-21). The United States of America: Elsevier Academic Press.

Möller, K., Weinhöfer, G., Westerhaus, F., Junge, K. and Beller, M. (2011). Oxidation of 1,2,4-Trimethylbenzene (TMB), 2,3,6-Trimethylphenol (TMP) and 2-Methylnaphthalene to 2,3,5-Trimethylbenzoquinone (TMBQ) and Menadione (Vitamin K_3). *Catalysis Today.* 173: 68-75.

Möller, K., Wienhöfer, G., Schröder, K., Join, B., Junge, K. and Beller, M. (2010). Selective Iron-Catalyzed Oxidation of Phenols and Arenes with Hydrogen Peroxide: Synthesis of Vitamin E Intermediates and Vitamin K_3. *Chemistry- A European Journal.* 16: 10300-10303.

Nabid, M.R., Sedghi, R., Jammat, P.R., Safari, N. and Enrezami, A.A. (2006). Synthesis of Conducting Water-Soluble Polyanaline with Iron(III) Porphyrin. *Journal of Applied Polymer Science.* 102(3): 2929-2934.

Najafian, A., Rabbani, M., Rahimi, R., Deilamkamar, M. and Maleki, A. (2015). Synthesis and Characterization of Copper Porphyrin into SBA-16 through "Ship in a Bottle" Method: A Catalyst for photo Oxidation Reaction under Visible light. *Solid State Science*. 46: 7-13.

Nakagaki, S., Castro, K.A.D.F., Ucoski, G.M., Halma, M., Prévot, V., Forano, C. and Wypych, F. (2014). Anionic Iron(III) Porphyrin Immobilized on/Into Exfoliated Macroporous Layered Double Hydroxides as Catalyst for Oxidation Reactions. *Journal of the Brazilian Chemical Society*. 25(12): 2329-2338.

Nakagaki, S., Ferreira, G.K.B., Marçal, A.L. and Ciuffi, K.J. (2014). Metalloporphyrins Immobilized on Silica and Modified Silica as Catalysts in Heterogeneous Processes. *Current Organic Synthesis.* 11: 67-88.

Nakagaki, S., Ferreira, G.K.B., Ucoski, G.M. and Dias de Freitas Castro, K.A. (2013). Review Chemical Reactions Catalyzed by Metalloporphyrin-Based Metal-Organic Frameworks. *Molecules.* 18: 7279-7308.

Nakagaki, S., Mantovani, K.M., Machado, G.S., de Freitas Castro, K.A. and Wypych, F. (2016). Review Recent Advances in Solid Catalysts Obtained by Metalloporphyrins Immobilization on Layered Anionic Exchangers: A Short Review and Some New Catalytic Results. *Molecules*. 21(3): 1-25.

Nam, W. and Valentine, J.S. (1990). Zinc(II) Complexes and Aluminium(III) Porphyrin Complexes Catalyze the Epoxidation of Olefins by Iodosylbenzene. *Journal of the American Chemical Society.* 112(12): 4977-4979.

Nam, W., Kim, I., Kim, Y. and Kim, C. (2001). Biomimetic Aklane Hydroxylation by Cobalt(III) Porphyrin Complex and *m*-Chloroperbenzoic Acid. *Chemical Communications.* 14: 1262-1263.

Narsimhan, K., Iyoki, K., Dinh, K. and Román-Leshkov, Y. (2016). Catalytic Oxidation of Methane into Methanol over Copper-Exchanged Zeolites with Oxygen at Low Temperature. *ACS Central Science.* 2(6): 424-429.

Nasab, M.J. and Kiasat, A.R. (2015). Covalently Anchored 2-amino ethyl-3-propyl Imidazolium Bromideon SBA-15 as A Green, Efficient and Reusable Brønsted Basic Ionic Liquid Nanocatalyst for One-Pot Solvent-Free Synthesis of Benzopyranopyrimidines Under Ultrasonic Irradiation. *RSC Advances.* 5: 75491-75499.

Nefedieva, M., Lebedeva, O., Kultin, D., Kustov, L., Borisenkova, S. and Krasovskiy, V. (2010). Ionic Liquids Based on Imidazolium Tetrafluoroborate for The Removal of Aromatic Sulfur-Containing Compounds from Hydrocarbon Mixtures. *Green Chemistry.* 12: 346-349.

Neouze, M-A. (2010). About the Interactions Between Nanoparticles and Imidazolium Moieties: Emergence of Original Hybrid Materials. J*ournal of Materials Chemistry*. 20: 9593-9607.

Niedermeyer, H., Hallett, J.P., Villar-Garcia, I.J., Hunt, P.A. and Welton, T. (2012). Mixtures of Ionic Liquids. *Chemical Society Reviews* 41, 7780-7802.

Niessen, W.M.A. (2001). Current Practice of Gas Chromatography-Mass Spectrometry. New York: Marcel Dekker, Inc.

Nockemann, P., Binnemans, K. and Driesen, K. (2005). Purification of Imidazolium Ionic Liquids for Spectroscopic Applications. *Chemical Physical Letters.* 415: 131-136.

Nohair, B., MacQuarrie, S., Crudden, C.M. and Kaliaguine, S. (2008). Functionalized Mesostructured Silicates as Supports for Palladium Complexes: Synthesis and Catalytic Activity for the Suzuki-Miyaura Coupling Reaction. *Journal of Physical Chemistry C.* 112(15): 6065-6072.

Notonier, S., Meyers, A. and Jayakody, L.N. (2016). An Overview of P450 Enzymes: Opportunities and Challenges in Industrial Applications. *Enzyme Engineering.* 5(3): 1-5.

Nur, H., Hamid, H., Endud, S., Hamdan, H. and Ramli, Z. (2006). Iron-Porphyrin Encapsulated in Poly(Methacrylic Acid) and Mesoporous Al-MCM-41 as Catalysts in the Oxidation of Benzene to Phenol. *Materials Chemistry and Physics.* 96(2-3): 337-342.

Nuzzo, A. and Piccolo, A. (2013). Enhanced Catechol Oxidation by Heterogeneous Biomimetic Catalysts Immobilized on Clay Minerals. *Journal of Molecular Catalysis A: Chemical.* 371: 8-14.

Obondi, C. and Rodriguez, A.A. (2010). NMR Studies into the Potential Interactions of Fullerence C_{60} with Tetraphenylporphyrin and Some of Its Derivatives. *Advances in Physical Chemistry.* 2010: 1-9.

Olea, A., Sanz-Pérez, E.S., Areancibia, A., Sanz, R. and Calleja, G. (2013). Amino-Functionalized Pore-Expanded SBA-15 for CO_2 Adsorption. *Adsorption*. 19(2): 589-600.

Oliveira, F.S., Cabrita, E.J., Todorovic, S., Bernardes, C.E.S., Canongia Lopes, J.N., Hodgson. J.L., MacFarlane, D.R., Rebelo, L.P.N. and Marrucho, I.M. (2016). Mixtures of the 1-Ethyl-3-Methylimidazolium Acetate Ionic Liquid with Different Inorganic Salts: Insights into Their Interactions. *Physical Chemistry Chemical Physics.* 18: 2756-2766.

Olivier-Bourbigou, H., Magna, L. and Morvan, D. (2010). Review Ionic Liquids and Catalysis: Recent Progress from Knowledge to Applications. *Applied Catalysis A: General.* 373: 1-56.

Omagari, T., Suzuki, A., Akita, M. and Yoshizawa, M. (2016). Efficient Catalytic Epoxidation in Water by Axial N-Ligand-Free Mn-Porphyrins within A Micellar Capsule. *Journal of the American Chemical Society*. 138(2): 499-502.

Opanasenko, M., Štěpnička, P. and Čejka, J. (2014). Heterogeneous Pd Catalysts Supported on Silica Matrices. *RSC Advances*. 4: 65137-65162.

Osterholm., H., Kumar, N., Lindblad, M., Tiitta, M., Salmi, T. and Murzin, D. (2012). Characterization Of MFI And BEA Embedded In Mesoporous Molecular Sieve – Thermal Stability. *Microporous and Mesoporous Materials.* 154: 124 -132.

Pal, N. and Bhaumik, A. (2015). Mesoporous Materials: Versatile Supports in Heterogeneous Catalysis for Liquid Phase Catalytic Transformations. *RSC Advances.* 5: 24363-24391.

Palacio, M., Villabrille, P.I., Romanelli, G.P., Vázquez, P.G. and Cáceres, C.V. (2012). Preparation, Characterization and Use of V_2O_5-TiO_2 Mixed Xerogels as Catalysts for Sustainable Oxidation with Hydrogen Peroxide of 2,3,6-Trimethylphenol. *Applied Catalysis A: General.* 417-418: 273-280.

Palaretti, V., Santamalvina dos Santos, J., Costa Guedes, D.F., Beraldo de Moraes, L.A. and Assis, M.D.D. (2012). Metalloporphyrins as Cytochrome P450 Models for Chlorhexidine Metabolite Prediction. *Applied Catalysis A: General.* 447-448: 7-13.

Papaiconomou, N., Salminen, J., Lee, J-M. and Prausnitz, J.M. (2007). Physicochemical Properties of Hydrophobic Ionic Liquids Containing 1-Octylpyridinium, 1-Octyl-2-methylpyridinium, or 1-Octyl-4-methylpyridinium Cations. *Journal of Chemical and Engineering Data.* 52(3): 833-840.

Papancea, A., Paţachia, S. and Porzsolt, A. (2015). Conductivity Studies of Imidazolium-Based Ionic Liquids in Aqueous Solution. *Bulletin of the Transilvania University of Braşov*. 8(57): 67-72.

Pardal, F., Lapinte, V. and Robin, J.J. (2009). Modification of Silica Nanoparticles by Grafting of Copolymers Containing Organosilane and Fluorine Moities. *Journal of Polymer Science Part A: Polymer Chemistry*. 47: 4617-4628.

Pavlov, M.L., Shavaleev, D.A., Kutepov, B.I., Travkina, O.S., Pavlova, I.N., Basimova, R.A., Ershtein, A.S. and Gerzeliev, I.M. (2016). Synthesis and

Investigation of ZSM-5 Zeolite-Based Catalysts for Benzene Alkylation with Ethylene. *Petroleum Chemistry.* 56(2): 151-157.

Pérez, Y., del Hierro, I., Zazo, L., Fernáandez-Galán, R. and Fajardo, M. (2015). The Catalytic Performance of Metal Complexes Immobilized on SBA-15 in the Ring Opening Polymerization of ε-Caprolactone with Different Metals (Ti, Al, Zn and Mg) and Immobilization Procedures. *Dalton Transactions.* 44: 4088-4101.

Pérez-Romo, P., Guzmán-Castillo, M.D.L., Armendáriz-Herrera, H., Navarrete, J., Acosta, D.R. and Montoya, J.A. (2003). Synthesis of FSM-16 Mesoporous Materials: Effect of the Anion (F^-, Cl^-, SO_4^{2-}) in the Ion Exchange Process on the Thermal Stability. *Langmuir.* 19(8): 3446-3452.

Pires, S.M.G., Paula, R.D., Simoes, M.Q., Neves, M.G., Santos, C.M.S., Tome, A.C. and Cavaleiro, J.A.S. (2009). A New Silica-supported Manganese Chlorine as A Biomimetic Oxidation Catalyst. *Catalysis Communications.* 11: 24-28.

Pires, S.M.G., Simões, M.M.Q., Santos, I.C.M.S., Rebelo, S.L.H., Pereira, M.M., Neves, M.G.P.M.S. and Cavaleiro, J.A.S. (2012). Biomimetic Oxidation of Organosulfur with Hydrogen Peroxide Catalyzed by Manganese Porphyrins. *Applied Catalysis A: General.* 439-440: 51-56.

Pizzoccaro, M-A., Drobek, M., Petit, E., Guerrero, G., Hesemann, P. and Julbe, A. (2016). Design pf Phosphonated Imidazolium-Based Ionic Liquids Grafted on γ-Alumina: Potential Model for Hybrid Membranes. *International Journal of Molecular Sciences.* 17(1212): 1-13.

Plechkova, N.V. and Seddon, K.R. (2008). Applications of Ionic Liquids in the Chemical Industry. *Chemical Society Reviews*. 37(1): 123-150.

Połtowicz, J., Pamin, K. and Haberm J. (2006). Influence of Manganese Tetraarylporphyrins Substituents on the Selectivity of Cycloalkanes Oxidation with Magnesium Monoperoxyphthalate. *Journal of Molecular Catalysis A: Chemical.* 257: 154-157.

Pu, H., Han, C., Wang, H., Xu, S., Zhang, L., Zhang, Y. and Luo, Y. (2012). Characterization and Investigation Mechanism of Hydrothermal Stability for Micropore-Free Ordered Mesoporous Molecular Sieves. *Applied Surface Science.* 258: 8895-8901.

Qureshi, Z.S., Deshmukh, K.M. and Bhanage, B.M. (2014). Applications of Ionic Liquids in Organic Synthesis and Catalysis. *Clean Technologies Environmental Policy.* 16(8): 1487-1513.

Rad, A.M., Moosavi-Movahedi, A.A., Ghourchian, H., Safari, N., Hong, J., Moosavi-Movahedi,VZ., Nazari, K., Saboury, A.A. and Jamat P.R. (2007). Effect of Substituted Metal-Free Porphyrins in Apo-Horseradish Peroxidase. *Journal of Porphyrins & Phthalocyanines.* 11: 836-845.

Ragupathi, C., Vijaya, J.J. and Kennedy, L.J. (2017). Preparation, Characterization and Catalytic Properties of Nickel Aluminate Nanoparticles: A Comparison between Conventional and Microwave Method. *Journal of Saudi Chemical Society*. 21: 231-239.

Rahiman, A.K., Rajesh, K., Bharathi, K.S., Sreedaran, S. and Narayanan, V. (2006). Manganese(III) Porphyrin-Encapsulated Ti,Si-Mesoporous Molecular Sieves as Heterogeneous Catalysts for the Epoxidation of Alkenes. *Applied Catalysis A: General.* 314: 216-225.

Rahimi, R., Gholamrezapor, E., Naimi-Jamal, M.R. (2011). Oxidation of Benzyl Alcohols to the Corresponding Carbonyl Compounds Catalyzed by Copper (II) Meso-tetraphenylporphyrin as Cyctochrome P-450 Model Reaction. *Inorganic Chemistry Communications.* 14: 1561-1568.

Rahimi, R., Ghoreishi, S.Z. and Dekamin, M.G. (2012). Immobilized Metalloporphyrins on 3-aminopropyl-Functionalized Silica Support as Heterogeneous Catalysts for Selective Oxidation of Primary and Secondary Alcohols. *Monatshefte für Chemie.*143: 1031-1038.

Ramli, Z., Bakar, M.B., Endud, S., Lintang, H.O. and Roslan, N. (2016). Synthesis of Mesoporous SBA-15/Ionic Liquid Nanocomposites for the Selective Oxidation of 2,3,6-Trimethylphenol. *Malaysian Journal of Catalysis.* 1: 27-31.

Ramos, J.M., Wang, J.A., Chen, L.F., Arellano, U., Ramírez, S.P., Sotelo, R. and Schachat, P. (2015). Synthesis and Catalytic Evaluation of CoMo/SBA-15 Catalysts for Oxidative Removal of Dibenzothiophene from a Model Diesel. *Catalysis Communication.* 72: 57-62.

Rana, U.A., Vijayaraghavan, R., Walther, M., Sun, J., Torriero, A.A.J., Forsyth, M. and MacFarlane, D.R. (2011). Protic Ionic Liquids Based on Phosphonium

Cations: Comparison with Ammonium Analogues. *Chemical Communications.* 47: 11612-11614.

Ratti, R. (2014). Review Article Ionic Liquids: Synthesis and Applications in Catalysis. *Advanced in Chemistry.* 2014: 1-16.

Rayati, S., Jafarzadeh, P. and Zakavi, S. (2013). Catalytic Activity of Carbon Nanotube Supported Iron(III) and Manganese (III)Porphyrins in Oxidation of Olefins with Tert-Butyhl Hydroperoxide: Higher Activity of the Iron(III) Porphyrin. *Inorganic Chemistry Coomunications.* 29: 40-44.

Rebelo, L.P.N., Canongia Lopes, J.N., Esperança, J.M.S.S. and Filipe, E. (2005). On the Critical Temperature, Normal Boiling Point, and Vapor Pressure of Ionic Liquids. *The Journal of Physical Chemistry B Letters.* 109: 6040-6043.

Ren, Q-G., Chen, S-Y., Zhou, X-T. and Ji, H-B. (2010). Highly Efficient Controllable Oxidation of Alcohols to Aldehydes and Acids with Sodium Periodate C atalyzed by Water-Soluble Metalloporphyrins as Biomimetic Catalyst. *Bioorganic and Medicinal Chemistry.* 18: 8144-8149.

Ren, Q-Z., Yao, Y., Ding, X-J., Hou, Z-S. and Yan, D-Y. (2009). Phase-transfer of Porphyrin by Polypeptide-Containing Hyperbranched Polymers and A Novel Iron (III) Porphyrin Biomimetic Catalyst. *Chemical Communications*. 4732-4734.

Ribeiro, M.C.C. (2012). High Viscosity of Imidazolium Ionic Liquids with the Hydrogen Sulfate Anion: A Raman Spectroscopy Study. *The Journal of Physical Chemistry B.* 116(24): 7281-7290.

Ricoux, R., Allard, M., Dubuc, R., Dupont, C., Marechal, J-D. and Mahy, J-P. (2009). Selective Oxidation of Aromatic Sulfide Catalyzed by An Artificial Metalloenzyme: New Activity of Hemozymes. *Organic and Biomolecular Chemistry.* 7: 3208-3211.

Rodikova, Y.A. and Zhizhina, E.G. (2013). Trimethyl-1,4-Benzoquinone Synthesis via 2,3,6-Trimethylphenol Catalytic Oxidation by Oxygen in the Presence of Non-Keggin-Type Mo-V-Phosphoriv Heteropoly Acid Solutions. *Journal of Chemical and Chemical Engineering*. 7: 808-820.

Rostamnia, S., Doustkhah, E. and Zeynizadeh, B. (2016**a**). Cationic Modification of SBA-15 Pore Walls for Pd Supporting: Pd@SBA-15/IL_{DABCO} as A Catalyst for Suzuki Coupling in Water Medium. *Microporous and Mesoporous Materials.* 222: 87-93.

Rostamnia, S., Gholipour, B. and Hosseini, H.G. (2016**b**). Metal- and Halogen-Free Hydrogensulfate Ionic Liquid/SBA-15 as Catalyst in Clean Oxidation of Aromatic and Aliphatic Organic Sulfides with Aqueous Hydrogen Peroxide. *Process Safety and Environmental Protection.* 100: 74-79.

Rostamnia, S., Hassankhani, A., Hossieni, H.G., Gholipour, B. and Xin, H. (2014). Brønsted Acidic Hydrogensulfate Ionic Liquid Immobilized SBA-15: [MPIm][HSO_4]@SBA-15 as An Environmentally Friendly, Metal- and Halogen-Free Recyclable Catalyst for Knoevenagel-Michael-Cyclization Processes. *Journal of Molecular Catalysis A: Chemical*. 395: 463-469.

Rostamnia, S., Nouruzi, N., Xin, H. and Luque, R. (2015). Efficient and Selective Copper-Grafted Nanoporous Silica in Aqueous Conversion of Aldehydes to Amides. *Catalysis Science and Technology.* 5: 199-205.

Rothemund, P. (1935). Formation of Porphyrins from Pyrrole and Aldehydes. *Journal American Chemical Society.* 57(10): 2010-2011.

Rouquerol, F., Rouquerol, J. and Sing K. (1999). Adsorption by Powders and Porous Solids with Principles, Methodology and Applications; Chapter 7: Assessment of Mesoporosity. (pp. 191-217), London: Academic Press.

Ryoo, R., Kim, J.M., Ko, C.H. and Shin, C.H. (1996). Disordered Molecular Sieve with Branched Mesoporous Channel Network. *The Journal of Physical Chemistry.* 100(45): 17718-17721.

Saadon, N., Endud, S., Bakar, M.B., Lintang, H.O. and Roslan, N. (2016). SAXS, FESEM and BET Studies of Mesoporous Catalyst SBA-15 Containing Zinc Porphyrin for Epoxidation of Limonene. *Jurnal Teknologi.* 78(3-2): 7-13.

Sacco, H.C., Iamamoto, Y. and Smith, J.R.L. (2001). Alkene Epoxidation with Iodosylbenzene Catalysed by Polyionic Manganese Porphyrins Electrostatically Bound to Counter-Charged Supports. *Journal of the Chemical Society, Perkin Transactions*. 2: 181-190.

Sahoo, S., Kumar, P., Lefebvre, F. and Halligudi, S.B. (2008). A Chiral Mn(II) Salen Complex Immobilized onto Ionic Liquid Modified Mesoporous Silica for Oxidative Kinetic Resolution of Secondary Alcohols. *Tetrahedron Letters.* 49: 4865-4868.

Sakthipriya, P. and Ananthi, N. (2016). Asymmetric Epoxidation of Alkenes Catalyzed by Novel Chiral Porphyrin Metal Complexes. *Journal of Porphyrins and Phthalocyanines.* 20(6): 730-737.

Santos da Silva, V., Teixeira, L.I., Do Nascimento, E., Idemori, Y.M. and Defreitas-Silva, G. (2014). New Manganese Porphyrin as Biomimetic Catalyst of Cyclohexane Oxidation: Effect of Water or Imidazole as Additives. *Applied Catalysis A: General*. 460: 124-131.

Sareen, S., Mutreja, V., Pal, B. and Singh, S. (2015). Homogeneous Dispersion of Au Nanoparticles into Mesoporous SBA-15 Exhibiting Improved Catalytic Activity for Nitroaromatic Reduction. *Miroporous and Mesoporous Materials*. 202: 219 – 225.

Sarkar, S.M., Rahman, M.L. and Mohd Yusoff, M. (2015). Highly Active Thiol-Functionalized SBA-15 Supported Palladium Catalyst for Sonogashira and Suzuki-Miyaura Cross-Coupling Reactions. *RSC Advances.* 5(2): 1295-1300.

Satake, A., Shoji, O. and Kobuke, Y. (2007). Supramolecular Array of Imizazolylethynyl-Zinc-Porphyrin. *Journal of Organometallic Chemistry*. 692: 635-644.

Saux, C., Pizzio, L.R. and Pierella, L.B. (2013). 2,3,5-Trimethylphenol Oxidation over Co-based Solid Catalysts. *Applied Catalysis A: General.* 452: 17-23.

Schrekker, H.S., Silva, D.O., Gelesky, M.A., Stracke, M.P., Schrekker, C.M.I., Gonçalves, R.S. and Dupont, J. (2008). Preparation, Cation-Anion Interactions and Physicochemical Properties of Ether-Functionalized Imidazolium Ionic Liquids. *Journal of the Brazilian Chemical Society.* 19(3): 426-433.

Seftel, E-M., Cool, P., Lloyd-Spetz, A. and Lutic, D. (2014). Pt-Doped Semiconductive Oxides Loaded on Mesoporous SBA-15 for Gas Sensing. *Comptes Rendus Chimie.* 17: 717 – 724.

Seliem, M.K., Komarneni, S., Parette, R., Katsuki, H., Cannon, F.S., Shahien, M.G., Khalil, A.A. and Abd El-Gaid, I.M. (2010). Composites of MCM-41 Silica with Rice Husk: Hydrothermal Synthesis, Characterization and Application for Perchlorate Separation. *Materials Research Innovation*. 14(5): 351-354.

Selvaraj, M. and Kawi, S. (2007). Effect of Tin Precursors and Crystallization Temperatures on the Synthesis of SBA-15 with High Levels of Tetrahedral Tin. *Journal of Materials Chemistry*.17: 3610-3621.

Serp, P. and Machado, B. (2015). Surface Chemistry of Nanostructured Carbon Materials and Preparation of Nanocarbon Supported Catalysts. In Hardacre, C., Gebbink. B.K. and Rodriguez, J. (Eds.). *Nanostructured Carbon*

Materials for Catalysis. (pp.165-222). United Kingdom: The Royal Society of Chemistry.

Sharma, P. and Singh, A.P. (2014). A Covalently Anchored 2,4,6-triallyloxy-1,3,5-triazine Pd(II) Complex over A Modified Surface of SBA-15: Catalytic Application in Hydrogenation Reaction. *RSC Advances.* 4: 58467-58475.

Shen, S., Fang, S., Qu, L., Luo, D., Yang, L. and Hirano, S-I. (2015). Low-Viscosity Ether-Functionalized Pyrazolium Ionic Liquids Based on Dicyanamide Anions: Properties and Application as Electrolyte for Lithium Metal Batteries. *RSC Advances*. 5: 93888-93899.

Sheng, X., Zhou, Y., Yang, Y., Zhang, Y., Zhang, Z., Zhou, S., Fu, X. and Zhao, S. (2014). Synthesis of Immobilized Heteropolyanion-based Ionic Liquids on Mesoporous Silica SBA-15 as a Heterogeneous Catalyst for Alkylation. *RSC Advances.* 4(58): 30697-30703.

Sheng, X., Zhou, Y., Zhang, Y., Duan, Y., Zhang, Z. and Yang, Y. (2012). Immobilization of 12-Tungstophosphoric Acid in Alumina-Grafted Mesoporous LaSBA-15 and its Catalytic Activity for Alkylation of *o*-Xylene with Styrene. *Microporous and Mesoporous Materials.* 161: 25-32.

Shimizu, M., Watanabe, Y. and Hideo Orita. (1992). Synthesis of Alkyl Substituted p-Benzoquinones from the Corresponding Phenols using Molecular Oxygen Catalyzed by Copper(II) Chloride-Amine Hydrochloride Systems. *Bulletin of the Chemical Society of Japan.* 65(6) 1522-1526.

Shinde, T., Varga, V., Polášek, M., Horáček, M., Žilková, N. and Balcar, H. (2014). Metathesis of Cardanol over Ru Catalysts Supported on Mesoporous Molecular Sieve SBA-15. *Applied Catalysis A: General*. 478: 138- 145.

Shirokopoyas, S.1., Baranova, S.V., Maksimov, A.L., Kardashev, S.V., Kulikov, A.B., Naranov, E.R., Vinokurov, V.A., Lysensko, S.V. and Karakhanov, E.A. (2014). Hydrogenation of Aromatic Hydrocarbons in the Presence of Dibenzothiophene over Platinum-Palladium Catalysts Based on Al-SBA-15 Aluminosilicates. *Petroleum Chemistry*. 52(4): 94-99.

Shmukler, L.E., Gruzdev, M.S., Kudryakova, N.O., Fadeeva, Y.A., Kolker, A.M. and Safonova, L.P. (2016). Thermal Behavior and Electrochemistry of Protic Ionic Liquids Based on Triethylamine with Different Acids. *RSC Advance.* 6: 109664-109671.

Shukla, M. and Saha, S. (2013). A Comparative Study of Piperidinium and Imidazolium Based Ionic Liquids: Thermal, Spectroscopic and Theoretical Studies. In Kadokawa, J-I. (Ed.). *Ionic Liquids – New Aspects For The Future*. (pp. 61-84). Croatia: InTech Open Access Publisher.

Shylesh, S. and Singh, A.P. (2004). Synthesis, Characterization, and Catalytic Activity of Vanadium-Incorporated, -Grafted, and Immobilized Mesoporous MCM-41 in the Oxidation of Aromatics. *Journal of Catalysis*. 228: 333-346.

Silva Martins, D.C.D., Silva, F.S., Meireles, A.M., Rodrigues Soares, É.A., Fátima Silva, G.D., Vieira-Filho, S.A., Duarte, L.P., Rebouças, J.S. and Idemori, Y.M. (2016). Selective Oxidation of Lupeol by Iodosylbenzene Catalyzed by Manganese Porphyrins. *Catalysis Communications.* 86: 104-107.

Silva, A.R., Freitas, M.M.A., Freire, C., De Castro, B. and Figueiredo, J.L. (2002). Heterogenization of a Functionalized Copper(II) Schiff Base Complex by Direct Immobilization onto an Oxidized Activated Carbon. *Langmuir*. 18(21): 8017-8024.

Sing, K. (2001). Review: The Use of Nitrogen Adsorption for the Characterization of Porous Materials. *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 187-188: 3-9.

Sing, K., Ecerett, D., Haul, R., Moscou,L., Pierotti, R., Rouquerol, J. and Siemieniewska, T. (1985). Physical and Biophysical Chemistry Division Commission on Colloid and Surface Chemistry Including Catalyis. *Pure and Applied Chemistry.* 57: 603.

Sing, K.S.W., Everett, D.H., Haul, R.A.W., Moscou, L., Pierotti, R.A., Rouquérol, J. and Siemieniewska, T. (1985). Reporting Physisorption Data for Gas/Solid Systems with Special Reference to the Determination of Surface Area and Porosity. *Pure and Applied Chemistry*. 57(4): 603-619.

Singh, G. and Kumar, A. (2008). Ionic Liquids: Physico-chemical, Solvent Properties and Their Applications in Chemical Processes. *Indian Journal of Chemistry.* 47A: 495-503

Singh, R. and Geetanjali (2005). Novel Synthetic Methodology for Metalloporphyrins in Ionic Liquid. *Journal Brazilian Society*. 16(3B): 666-668.

Siriwardana, A.I. (2015). Chapter 20 Industrial Applications of Ionic Liquids. In Torriero, A.A.J. (Ed.). *Electrochemistry in Ionic Liquids Volume 2: Applications.* (pp. 563-603). Switzerland: Springer International Publishing.

Skrobot, F.C., Rosa, I.L.V., Marques, A.P.A., Martins, P.R., Rocha, J., Valente, A.A. and Iamamoto, Y. (2005). Asymmetric Cationic Methyl Pyridyl and Pentafluorophenyl Porphyrin Encapsulated in Zeolites: A Cyctochrome P-450 Model. *Journal of Molecular Catalysis A: Chemical*. 237: 86-92.

Song. M., Zou, C., Niu, G. and Zhao, D. (2012). Improving the Hydrothermal Stability of Mesoporous Silica SBA-15 by Pre-treatment with $(NH_4)_2SiF_6$. *Chinese Journal of Catalysis*. 33(1): 140 – 151.

Sonwane, C.G. and Ludovice. (2005). A Note on Micro- and Mesopores in the Walls of SBA-15 and Hysteresis of Adsorption Isotherms. *Journal of Molecular Catalysis A: Chemical.* 238: 135-137.

Sorokin, A.B and Tuel, A. (2000). Metallophthalocyanine Functionalized Silicas: Catalysts for the Selective Oxidation of Aromatic Compounds. *Catalysis Today.* 57: 45-59.

Sowmiah, S., Srinivasadesikan, V., Tseng, M-C. and Chu, Y-H. (2009). Review On the Chemical Stabilities of Ionic Liquids. *Molecules*. 14: 3780-3813.

Srinivas, D. and Sivasanker, S. (2003). Biomimetic Oxidations using Transition Metal Complexes Encapsulated in Zeolites. *Catalysis Surveys from Asia*. 7(2-3): 121-132.

Srivastava, N., Shukla, M. and Saha, S. (2010). An Unusal Effect of Charcoal on the Purification of Alkylimidazolium Iodide Room Temperature Ionic Liquids. *Indian Journal of Chemistry.* 49A: 757-761.

Stephenson, N.A. and Bell, A.T. (2007). Effects of Porphyrin Composition on the Activity and Selectivity of the Iron(III) Porphyrin Catalysts for the Epoxidation of Cyclooctene by Hydrogen Peroxide. *Journal of Molecular Catalysis A: Chemical.* 272: 108-117.

Storck, S., Bretinger, H. and Maier, W.F. (1998). Characterization of Micro- and Mesoporous Solids Physisorption Methods and Pore-Size Analysis. *Applied Catalysis A: General.* 174: 137-146.

Sun, H., Li, X. and Sundermeyer, J. (2005). Aerobic Oxidation of Phenol to Quinone with Copper Chloride as Catalyst in Ionic Liquid. *Journal of Molecular Catalysis A: Chemical.* 240: 119-122.

Sun, L-B., Liu, X-Q., and Zhou, H-C. (2015). Design and Fabrication of Mesoporous Heterogeneous Basic Catalysts. *Chemical Society Reviews.* 44: 5092-5147.

Sun, Q., Li, L., Yan, H., Hong, X., Hui, K.S. and Pan, Z. (2014). Influence of the Surface Hydroxyl Groups of MnO_x/SBA-15 on Heterogeneous Catalytic Ozonation of Oxalic Acid. *Chemical Engineering Journal.* 242: 348-356.

Sun, Z-C., She, Y-B., Zhou, Y., Song, X-F. and Li, K. (2011). Synthesis, Characterization and Spectral Properties of Substituted Tetraphenylporphyrin Iron Chloride Complexes. *Molecules.* 16: 2960-2970.

Suslick, K.S. and Watson, R.A. (1992). The Photochemistry of Chromium, Manganese, and Iron Porphyrin Complexes. *New Journal of Chemistry.* 16: 633-642.

Tabor, E., Połtowicz, J., Pamin, K., Basąg, S. and Kubiak, W. (2016). Influence of Substituents in Meso-Aryl Groups on Iron μ-oxo Porphyrins on their Catalytic Activity in the Oxidation of Cycloalkanes. *Polyhedron.* 119: 342-349.

Taghavimoghaddam, J., Knowles, G.P. and Chaffee, A.L. (2012). Mesoporous Silica SBA-15 Supported Co_3O_4 Nanorods as Efficient Liquid Phase Oxidative Catalysts. *Topics in Catalysis.* 55: 571-579.

Takamuku, T., Shimomura, T., Sadakane, K., Koga, M. and Seto, H. (2012). Aggregation of 1-Dodecyl-3-methylimidazolium Nitrate in Water and Benzene Studied by SANS and ^{1}H NMR. *Physical Chemistry Chemical Physics.* 14: 11070-11080.

Tan, R., Liu, C., Feng, N., Xiao, J., Zheng, W., Zheng, A. and Yin, D. (2012). Phosphotungstic Acid Loaded on Hydrophilic Ionic Liquid Modified SBA-15 for Selective Oxidation of Alcohols with Aqueous H_2O_2. *Microporous and Mesoporous Materials.*158: 77-87.

Tanaka, K., Waki, H., Ido, Y., Akita, S., Yoshida, Y. and Yoshida, T. (1988). Protein and Polymer Analyses up to *m/z* 100,000 by Laser Ionization Time-of-flight Mass Spectrometry. *Rapid Communications in Mass Spectrometry.* 2(8): 151-153.

Tao, R., Tamas, G., Xue, L., Simon, S.L. and Quitevis, E.L. (2014). Thermophysical Properties of Imidazolium-Based Ionic Liquids: The Effect of Aliphatic Versus Aromatic Functionality. *Journal of Chemical and Engineering Data.* 59(9): 2717-2724.

Taylor, R.E. (2004). Setting Up ^{13}C CP/MAS Experiments. In Traficante, D.D. (Ed). *Concepts in Magnetic Resonance Part A*, Volume 22A(1). (pp. 37-49). Wiley Interscience.

Thommes, M. (2010). Physical Adsorption Characterization of Nanoporous Materials. Chemie Ingenieur Technik, 82(7): 1059-1073. Weinheim: Wiley-VCH Verlag GmbH & Co. KGaA.

Tian, B., Liu, X., Yu, C., Gao, F., Luo, Q., Xie, S., Tu, B. and Zhao, D. (2002). Microwave Assisted Template Removal of Siliceous Porous Materials. *Chemical Communications.* (11): 1186 – 1187.

Tietze, L.F., Sommer, K.M., Zinngrebe, J. and Stecker, F. (2005). Palladium-Catalyzed Enantioselective Domino Reaction for the Efficient Synthesis of Vitamin E. *Angewandte Chemie International Edition*. 44: 257-259.

Trindade, F.J., Queiruga Rey, J.F. and Brochsztain, S. (2012). Modification of Molecular Sieves MCM-41 and SBA-15 with Covalently Grafted Pyromellitimide and 1,4,5,8-Naphthalenediimide. *Journal of Colloid and Interface Science*. 368: 34-40.

Tsai, C-L., Chou, B., Cheng, S. and Lee, J-F. (2001). Synthesis of TMBQ using Cu(II)-Substituted MCM-41 as the Catalyst. *Applied Catalysis A: General*. 208: 279-289.

Ucoski, G.M., Nunes, F.S., DeFreitas-Silva, G., Idemori, Y.M. and Nakagaki, S. (2013). Metalloporphyrins Immobilized on Silica-Coated Fe_3O_4 Nanoparticels: Magnetically Recoverable Catalysts for the Oxidation of Organic Substrates. *Applied Catalysis A: General*. 459: 121-130.

Van Grieken, R., Calleja, G., Stucky, G.D., Melero, J.A., García, R.A. and Iglesias, J. (2003). Supercritical Fluid Extraction of a Nonionic Surfactant Template from SBA-15 Materials and Consequences on the Porous Structure. *Langmuir*. 19: 3966-3973.

Veisi, H., Sedrpoushan, A., Fraji, A.R., Heydari, M., Hemmati, S. ans Fatahi, B. (2015). A Mesoporous SBA-15 Silica Catalyst Functionalized with Phenylsulfonic Acid Groups (SBA-15-Ph-SO_3H) as a Novel Hydrophobic Nanoreactor Solid Acid Catalyst for a One-Pot Three-Component Synthesis of 2*H*-indazolo[2,1-b]phthalazine-triones and triazolo[1,2-a]indazole-triones. *RSC Advances*. 5: 68523-68530.

Vekariya, R.L. (2017). A Review of Ionic Liquids: Application Towards Catalytic Organic Transformations. *Journal of Molecular Liquids.* 227: 44-60.

Vilarrasa-García, E., Cecilia, J.A., Santos, S.M.L., Cavalcante Jr, C.L., Jiménez-Jiménez, J., Azevedo, D.C.S. and Rodríguez-Castellón, E. (2014). CO_2 Adsorption on APTES Functionalized Mesocellular Foams Obtained From Mesoporous Silicas. *Microporous and Mesoporous Materials.* 187: 125-134.

Vita Damasceno, J., Maroneze, C.M., Strauss, M., Sigoli, F.A. and Mazali, I.O. (2016). Preparation of Supported AuPd Nanoalloys Mediated by Ionic Liquid-like Functionalized SBA-15: Structural Correlations Concerning Its Catalytic Activity. *New Journal of Chemistry.* 40(8): 6636-6642

Vrancken, K.C., Van Der Voort, P. and Vansant, E.F. (1995). Characterization and Chemical Modification of the Silica Surface. Studies in Surface Science and Catalysis. 93. (pp. 79-91). The Netherlands: Elsevier.

Wan, X., Tian, M. and Row, K.H. (2010). Ionic Liquid-Modified Silica as a New Stationary Phase for Chromatographic Separation. *Journal of Analytical Chemistry.* 65(8): 798-802

Wan, Y. and Zhao, D. (2007). On the Controllable Soft-Templating Approach to Mesoporous Silicates. *Chemical Reviews.* 107(7): 2821 – 2860.

Wang, C., Guan, W., Xie, P., Yun, X., Li, H., Hu, X. and Wang, Y. (2009). Effects of Ionic Liquids on the Oxidation of 2,3,6-Trimethylphenol to Trimethyl-1,4-benzoquinone under Atmospheric Oxygen. *Catalysis Communications.* 10: 725-727.

Wang, D.H., Pan, J.N., Li, H.H., Liu, J.J., Wang, Y.B., Kang, L.T. and Yao, J.N. (2016). A Pure Organic Heterostructure of μ-oxo Dimeric Iron(III) Porphyrin and Graphitic-C_3H_4 for Solar H_2 Production from Water. *Journal of Materials Chemistry A.* 4(1): 290-296.

Wang, J-G., Xiao, Q., Zhou, H-J., Sun, P-C., Ding, D-T. and Chen, T-H. (2008). Anionic Surfactant-Templated Mesoporous Silica (AMS) Nano-Spheres with Radially Oriented Mesopores. *Journal of Colloid and Interface Science.* 323: 332-337.

Wang, L. and Yang, R.T. (2011). Increasing Selective CO_2 Adsorption on Amine-Grafted SBA-15 by Increasing Silanol Density. *The Journal of Physical Chemistry C*. 115: 21264 – 21272.

Wang, P.F., Jin, H.X., Jin, D.F., Hong, B., Ge, H.I., Gong, J., Peng, L., Zhang, H., Liu, Z.Y. and WanG X.Q. (2012). Research Article Microstructure and Magnetic Properties of Highly Ordered SBA-15 Nanocomposites Modified with Fe_2O_3 and Co_3O_4 Nanoparticles. *Journal of Nanomaterials.* 2012: 1-7.

Wang, T., She, Y., Fu, H. and Li, H. (2016). Selective Cyclohexane Oxidation Catalyzed by Manganese Porphyrins and Co-Catalysts. *Catalysis Today.* 264: 185-190.

Wang, W., Qi, R., Shan, W., Wang, X., Jia, Q., Zhao, J., Zhang, C. and Ru, H. (2014). Synthesis of KIT-6 Type Mesoporous Silicas with Tunable Pore Sizes, Wall Thickness and Particle Sizes via the Partitioned Cooperative Self-Assembly Process. *Microporous and Mesoporous Materials*. 194: 167-173.

Wang, X., Bu, X. and Feng, P. (2011). Porous Inorganic Materials. In Scott, R.A. (Ed.). *Encyclopedia of Inorganic and Bioinorganic Chemistry.* The United States of America: John Wiley and Sons, Ltd.

Wang, Y., Zhu, T. and Row, K.H. (2010). Preparation and Evaluation of Silica-Based Ionic Liquid-Modified Stationary Phase for HPLC. *Journal of Chromatographic Science.* 48: 690-693.

Wasserscheid, P (2000). Potential to Apply Ionic Liquids in Industry. In Rogers, R.D., Seddon, K.R. and Volkov, S. (Eds.) *Green Industrial Applications of Ionic Liquids.* (pp. 29-48). Greece: Kluwer Academic Publishers.

Wasserscheid, P. and Joni, J. (2010). Green Organic Synthesis in Ionic Liquids. In Anastas, P.T., Wasserscheid, P. and Stark, A. (Eds.). *Handbook of Green Chemistry Green Solvents Volume 6: Ionic Liquids.* (pp.41-63). Weinheim: Wiley-Vch Gmbh and Co.

Weckhuysen, B.M. and Yu, J. (2015). Recent Advances in Zeolite Chemistry and Catalysis. *Chemical Society Reviews.* 44(20): 7022-7024.

Welton, T. (2004). Review Ionic Liquids in Catalysis. *Coordination Chemistry Reviews.* 248: 2459-2477.

Wijesekera, T.P. and Dolphin, D. (1994). Synthetic Aspects of Porphyrin and Metalloporphyrin Chemistry. In Sheldon, R.A (Ed). *Metalloporphyrin Catalytic Oxidation.* (pp. 193-239). New York: Marcel Dekker Inc.

Wilkes, J.S. (2004). Properties of Ionic Liquid Solvents for Catalysis. *Journal of Molecular Catalysis A: Chemical.* 214: 11-17.

Wilkes, J.S. and Zaworotko, M.J. (1992). Air and Water Stable 1-Ethyl-methylimidazolium Based Ionic Liquids. *Journal of the Chemical Society, Chemical Communications.* 13: 965-967.

Wilkes, J.S., Levisky, J.A., Wilson, R.A. and Hussey, C.L. (1982). Dialkylimidazolium Chloroaluminate Melts: A New Class of Room-Temperature Ionic Liquids for Electrochemistry, Spectroscopy, and Synthesis. *Inorganic Chemistry*. 21(3): 1263-1264.

Willows, R.D. and Hansson, M. (2013). Mechanism, Structure, and Regulation of Magnesium Chelatase. In Kadish, K.M., Smith, K.M. and Guilard, R. (Eds.). *The Porphyrin Handbook Volume 13 Chlorophylls and Bilins: Biosynthesis, Synthesis, and Degradation.* (pp. 1-43). California: Elsevier Science.

Witoon, T. and Chareonpanich, M. (2009). Effect of Acidity on the Formation of Silica-Chitosan Hybrid Materials and Thermal Conductive Property. *Journal of Sol-Gel Science and Technology*. 51: 146-152.

Witoon, T., Tatan, N., Rattanavichian, P. and Chareonpanich, M. (2011). Preparation of Silica Xerogel with High Silanol Content from Sodium Silicate and its Application as CO_2 Adsorbent. *Ceramic Internationals.* 37: 2297-2303.

Wolberg, A. and Manassen, J. (1970). Electrochemical and Electron Paramagnetic Resonance Studies of Metalloporphyrins and Their Electrochemical Oxidation Products. *Journal of the American Chemical Society.* 92(10): 2982-2991.

Wu, H., Zhang, J., Liu, Y., Zheng, J. and Wei, Q. (2014). Biodiesel Production from Jatropha Oil using Mesoporous Molecular Sieves Supporting K_2SiO_3 as Catalyst for Transesterification. *Fuel Processing Technology.* 119: 114 – 120.

Xin, B. and Hao, J. (2014). Imidazolium-Based Ionic Liquids Grafted n Solid Surfaces. *Chemical Society Reviews.* 43: 7171-7187.

Xinhua, Z., Jiesheng, H. and Panwen, S. (1996). A New Method of Preparation of Iron(II) Porphyrin Complexes-Isolation and Characterization of Amine Complxes of Ferrous Porphyrin. *Polyhedron.* 15(16): 2677-2679.

Xiong, J., Zhu, W., Ding, W., Yang, L., Chao, Y., Li, H., Zhu, F. and Li, H. (2014). Phosphotungstic Acid Immobilized on Ionic Liquid-Modified SBA-15: Efficient Hydrophobic Heterogeneous Catalyst for Oxidative Desulfurization in Fuel. *Industrial and Engineering Chemistry Research.* 53: 19895-19904.

Xiong, J., Zhu, W., Li, H., Xu, Y., Jiang, W., Xun, S. and Liu, H. (2013). Immobilized Fenton-Like Ionic Liquid: Catalytic Performance for Oxidative Desulfurization. *American Institute of Chemical Engineers Journal.* 59: 4696 – 4704.

Xu, C., Zhang, C., Li, H., Zhao, X., Song, L. and Li, X. (2015). An Overview of Selective Oxidation of Alcohols: Oxidants and Reaction Mechanisms. Catalysis *Surveys from Asia – Springer.* 20(1): 13-22.

Xu, L-W., Yang, M-S., Jiang, J-X., Qiu, H-Y. and Lai, G-Q. (2007). Ionic Liquid-Functionalized SBA-15 Mesoporous Materials: Efficient Heterogeneous Catalyst in Versatile Organic Reactions. *Central European Journal of Chemistry.* 5(4): 1073 – 1083

Yadav, G.D. and Singh, S. (2016). (L)-Prolinamide Imidazolium Hexafluorophosphate Ionic Liquid as An Efficient Reusable Organocatalyst for Direct Asymmetric Aldol Reaction in Solvent-Free Condition. *RSC Advances*. 6: 100459-100466.

Yang, L.M., Wang, Y.J., Luo, G.S. and Dai, Y.Y. (2005). Simultaneous Removal of Copolymer Template from SBA-15 in the Crystallization Process. *Microporous and Mesoporous Materials.* 81: 107-114.

Yang, P., Gai, S. and Lin, J. (2012). Functionalized Mesoporous Silica Materials for Controlled Drug Delivery. *Chemical Society Reviews.* 41: 3679-3698.

Yang, T., Du, M., Zhu, H., Zhang, M. and Zou, M. (2015). Immobilization of Pt Nanoparticles in Carbon Nanofibers: Bifunctional Catalyst for Hydrogen Evolution and Electrochemical Sensor. *Electrochimica Acta.* 167: 48-54.

Yao, S.A., Hansen, C.B. and Berry, J.F. (2013). A Convenient, High-Yielding, Chromatography-Free Method for the Insertion of Transition Metal Acetates into Porphyrins. *Polyhedron*. 58: 2-6.

Yasmin, T. and Müller, K. (2011). Synthesis and Characterization of Surface Modified SBA-15 Silica Materials and their Application in Chromatography. *Journal of Chromatography A*. 1218: 6464-6475.

Yethiraj, A. (2016). Structure of Room Temperature Ionic Liquids. *Journal of Physics: Condensed Matter*. 28: 1-6.

Yingwei, Z., Zhen, L. and Chungu, X. (2011). Alkyl Sulfonate Functionalized Ionic Liquids: Synthesis, Properties, and Their Application in Esterification. Chinese *Journal of Catalysis.* 32(3): 440-445.

Yu, J., Shen, A., Cao, Y. and Lu, G. (2016). Article Praparation of Pd-Diimine$^{@}$SBA-15 and Its Catalytic Performance for the Suzuki Coupling Reaction. *Catalysts.* 6(181): 1-17.

Yuan, C., Huang, Z. and Chen, J. (2012). Basic Ionic Liquid Supported on Mesoporous SBA-15: An Efficient Heterogeneous Catalyst for Epoxidation of Olefins with H_2O_2 as Oxidant. *Catalysis Communications*. 24: 56-60.

Yuan, P., Liu, J., Li, Y., Shi, G., Liu, H. and Bao, X. (2014). Effect of Pore Diameter and Structure of Mesoporous Sieve Supported Catalysts on Hydrodesulfurization Performance. *Chemical Engineering Science.* 111: 381-389.

Zaki, A., Xu, J., Stoclet, G., Casale, S., Dacquin, J-P. and Granger, P. (2015). Tunable Hierarchical Porous Silica Materials Using Hydrothermal Sedimentation-Aggregation Technique. *Microporous and Mesoporous Materials.* 208: 140 - 151.

Zanardi, F.B., Barbosa, I.A., Sousa Filho, P.C.D., Zanatta, L.D., Silva, D.L.D., Serra, O.A. and Iamamoto, Y. (2016). Manganese Porphyrin Functionalized on Fe_3O_4@*n*SiO_2@MCM-41 Magnetic Composite: Structural Characterization and Catalytic Activity as Cytochrome P450 Model. *Microporous and Mesoporous Materials.* 219: 161-171.

Zhang, H. and Cui, H. (2009). Synthesis and Characterization of Functionalized Ionic Liquid-Stabilized Metal (Gold and Platinum) Nanoparticles and Metal Nanoparticle/Carbon Nnanotube Hybrids. *Langmuir.* 25(5): 2604-2612.

Zhang, J., Zhao, G.F., Popović., Lu, Y. and Liu, Y. (2010). Pd-Porphyrin Functionalized Ionic Liquid-Modified Mesoporous SBA-15: An Efficient and Recyclable Catalyst for Solvent-Free Heck Reaction. *Materials Research Bulletin*. 45: 1648-1653.

Zhang, S., Lu, X., Zhou, Q., Li, X., Xhang, X. and Li, S. (2009). Ionic Liquids Physicochemical Properties. Hungary: Elsevier B.V.

Zhang, X., Liu, X., Peng, J., Zhao, Y. and Yang, Q. (2014). Highly Efficient Solid Catalysts for Asymmetric Hydrogenation Fabricated via Facile Adsorption of Rh-MonoPhos on Porous Silicas. *Catalysis Science and Technology*. 4(4): 1012-1016.

Zhang, Y. and Maginn, E.J. (2014). Molecular Dynamics Study of the Effect of Alkyl Chain Length on Melting Points of $[C_nMIM][PF_6]$ Ionic Liquids. *Physical Chemistry Chemical Physics.* 16: 13489-13499.

Zhang, Z., Yin, J., Heeres, H.J. and Melián-Cabrera, I. (2013). Thermal Detemplation of SBA-15 Mesophases. Effect of the Activation Protocol on the Framework Contraction. *Microporous and Mesoporous Materials.* 176: 103-111.

Zhao, D., Huo, Q., Feng, J., Chmelka, B.F. and Stucky, G.D. (1998). Nonionic Triblock and Star Diblock Copolymer and Oligomeric Surfactant of Highly Ordered, Hydrothermally Stable, Mesoporous Silica Structures. *Journal of the American Chemical Society*. 120(24): 6024-6036.

Zhao, D., Huo, Q., Feng, J., Chmelka, B.F. and Stucky, G.D. (1998). Nonionic Triblock and Star Diblock Copolymer and Oligomeric Surfactant of Highly Ordered, Hydrothermally Stable, Mesoporous Silica Structures. *Journal of the American Chemical Society.* 120(24): 6024 – 6036.

Zhao, D., Wan, Y. and Zhou, W. (2013). Ordered Mesoporous Materials 1st Edition. (pp: 24-29). Germany: Wiley-VCH Verlag GmbH & Co. KGaA.

Zhao, R., Wang, J., Zhang, D., Sun, Y., Han, B., Tang, N., Wang, N. and Li, K. (2017). Biomimetic Oxidative Desulfurization of Fuel Oil in Ionic Liquids Catalyzed by Fe(III) Porphyrins. *Applied Catalysis A: General.* 532: 26-31.

Zhao, S., Chen, Y. and Liu, Z. (2015). Immobilization of Metalloporphyrin on a Silica Shell with Bimetallic Oxide Core for Ethylbenzene Oxidation. *RSC Advances.* 5: 33299-33305.

Zhao, X.S., Bao, X.Y., Guo, W. and Lee, F.Y. (2006). Immobilizing Catalysts on Porous Materials. *Materials Today.* 9(3): 32-39.

Zheng, W., Shan, N., Yu, L. and Wang, X. (2008). UV-Visible, Fluorescence and EPR Properties of Porphyrins and Metalloporphyrins. *Dyes and Pigment.* 77: 153-157.

Zheng, W., Tan, R., Yin, S., Zhang, Y., Zhao, G., Chen, Y. and Yin, D. (2015). Ionic Liquid-Functionalized Graphene Oxide as an Efficient Support for the Chiral Salen Mn(II) Complex in Asymmetric Epoxidation of Unfunctionalized Olefins. *Catalysis Science and Technology*. 5: 2092-2102.

Zhou, Q., Lu, X., Zhang, S. and Guo, L. (2014). Physicochemical Properties of Ionic Liquids. In Plechkova, N.V. and Seddon, K.R. (Eds.). *Ionic Liquids Further*

Uncoiled Critical Expert Overviews. (pp. 275-307). New Jersey: John Wiley and Sons, Inc.

Zhou, W-Y., Tian, P., Sun, F., He, M-Y. and Chen, Q. (2016). Highly Efficient Transformation of Alcohol to Carbonyl Compounds under a Hybrid Bifunctional Catalyst Originated from Metalloporphyrins and Hydrotalcite. *Journal of Catalysis.* 335: 105-116.

Zhou, X., Duan, A., Zhao, Z., Gong, Y., Wu, H., Wei, Y., Jiang, G. and Liu, J. (2014). The Influence of Cosurfactants on the Synthesis of Hierarchically Porous Silica Materials in a P123/Cosurfactant/1,3,5-Trimethylbenzene/Water Four-Component Microemulsion System. *Materials Letters.* 133: 228 - 231.

Zhu, Q., Maeno, S., Nishimoto, R., Miyamoto, T. and Fukushima, M. (2014). Oxidative Degradation of Pentabromophenol in the Presence of Humic Substances Catalyzed by a SBA-15 Supported Iron-Porphyrin Catalyst. *Journal of Molecular Catalysis A: Chemical.* 385: 31-37.

Zhu, Y. and Silverman, R.B. (2007). Electronic Effects of Peripheral Substituents at Porphyrin Meso-Positions. *Journal Organic Chemistry*.72(1): 233-3239.

Zhuang, X., Qian, X., Lv, J. and Wan, Y. (2010). An Alternative Method to Remove PEO-PPO-PEO Template in Organic-Inorganic Mesoporous Nanocomposites by Sulfuric Acid Extraction. *Applied Surface Science.* 256: 5343-5348.

Zhuravlev, L.T. (1987). Concentration of Hydroxyl Groups on the Surface of Amorphous Silicas. *Langmuir.* 3(3): 316-318.

Zhuravlev, L.T. (2000). The Surface Chemistry of Amorphous Silica. Zhuravlev Model. *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 173:1-38.

Ziarani, G.M., Lashgari, N. and Badiei, A. (2015). Sulfonic Acid-Functionalized Mesoporous Silica (SBA-Pr-SO_3H) as Solid Acid Catalyst in Organic Reactions. *Journal of Molecular Catalysis A: Chemical.* 397: 166 – 191.

Zielinski, W., Kukawka, R., Maciejewski, H. and Smiglak, M. (2016). Ionic Liquids as Solvents for Rhodium and Platinum Catalysts Used in Hydrosilylation Reaction. *Molecules.* 21(1115): 2-11.

Ziolek, M. (2004). Catalytic Liquid-Phase Oxidation in Heterogeneous System as Green Chemistry Goal-Advantages and Disadvantages of MCM-41 used as Catalyst. *Catalysis Today.* 90(1-2): 145-150.

Zois, D., Vartzouma, C., Deligiannakis, Y., Hadjiliadis, N., Casella, L., Monzani, E. and Louloudi, M. (2007). Active Catalytic Centers in Silica-supported Cu(II) and Mn(II) Biomimetic Complexes: Correlation Between Catalytic and EPR Data. *Journal of Molecular Catalysis A: Chemical.* 261: 306-317.

Zuo, C., Sha, G., Gu, H., Huang, Y. and Niu, G. (2015). Facile Solvothermal Post-Treatment to Improve Hydrothermal Stability of Mesoporous SBA-15 Zeolite. *Chinese Journal of Catalysis*. 36: 1350-1357.

Zuo, D., Lane, J., Culy, D., Schultz, M., Pullar, A. and Waxman, M. (2013). Sulfonic Acid Functionalized Mesoporous SBA-15 Catalysts for Biodiesel Production. *Applied Catalysis B: Environmental*. 129: 342-350.