TITANIA-POLYSTYRENE TEXTILE AS PHASE BOUNDARY CATALYSIS

RASIDAH BINTI RAZALI

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

SEPTEMBER 2019

DEDICATION

‘Praise to Allah who created the heavens and the earth, and made the darkness and light’ (al-An’am 1)

Specially dedicated to my beloved
Husband
(Mohd Shahir Yaman)
Children
(Muhammad Ali Sufi Mohd Shahir)
Mother and Father
(Suleka Raghavan & Razali Samin)
Mother in law
(Halimah Abd Manap)

ACKNOWLEDGEMENT

First and foremost, I would like to thank Allah for His blessings and for the strength that He gave me while completing this research. Alhamdullillah, for His bounties and permission finally I could complete my study that I have been looking forward previously. I would like to express my heartfelt gratitude to my main supervisor, Prof.Dr.Hadi Nur, for his guidance, enthusiasm, immense knowledge and patient to me throughout this research. My gratitude also extended to Assist. Prof. Dr. Lai Sin Yuan for her priceless support, motivation, always stays positive and never give up for all this while. Her counsel and remark during group meetings as well as reviewing my draft thesis is one of the irreplaceable good deeds that I own her. I also have to thanks Dr Mohd Akmal Muhammad Sidek for his comments and advise along this research journey.Not to forget, all staffs and research members in Center for Sustainable Nanomaterial the Institute Ibnu Sina for Scientific and Industrial Research (IIS), Department of Chemistry of Faculty Science, UTM for being helpful and assisting during my research period. Special thanks also for PALAPES colleagues especially SEIRAMA group members for always teach me the meaning of real life and all the fun we had together during my study in UTM. I heavenly indebt my study life to my special buddies (Dr Ooi Yee Khai, Dr Nina Diana Nawi, Dr Nor Hidayah Ab Radzaz, Dr Mat Hussin Ab. Talib, Dr Afrooz Baharvand, Dr Shafiyah Pondi, Dr Farah Syuhada Ab. Halim, Norhayati Turiman, Nor Anisah Ab Kadar and Halimatulhusna Shahrudinbasri) for always with me. I would like to take this chance to thank everyone who did contributed either directly or indirectly along this research. I am gratefully indebted to MyBrain15 Scholarship by Ministry of Education Malaysia (KPM) for financial support given to me. Last but not least, my sincere thanks also go to my family members especially my husband, Mohd Shahir Yaman for his understanding and willing to sacrifice for me to complete my study. To both of my parent, the full support given by them throughout in my life in general will always in my mind forever. I could never have completed anything without them.

ABSTRACT

In the lights of the trending necessity towards clean and economical technology in chemical industry, heterogeneous catalysts are widely used due to their convenience of effortless separation methodology of catalysts from the products. Thus, this research proposes the establishment of a novel heterogeneous catalytic concept named "Phase-Boundary Catalysis System (PBC)", utilizing textile as the support of titania active sites and H_2O_2 as the oxidizing agent. The previous catalyst of PBC was in particulate form, indicating existence of challenges to evenly disperse and immobilize at the liquid-liquid interface for 1-octene oxidation reaction. Therefore, the aim in this study is to design layered catalysts that can immobilize steadily at the interface of liquid-liquid layers and hence, applying the PBC catalyst for potential applications. The layered catalyst was designed using cotton textile as the support and polystyrene (PS) as the binder between titania and cotton textile. It is worth noting that the hydrophobic environment is the main character imposed by layered catalyst, which assists the layered catalyst to be floating and located exactly at the interface of liquid-liquid boundary. The titanium propoxide was chosen as titanium precursor due to the aspect of susceptibility towards cotton textile. The six layered catalysts were prepared by styrene polymerization with varied time (minutes) and denoted as T30, T60, T90, T120, T150 and T180. It was discovered that the cotton textiles bearing titania were gradually covered by PS with time. A series of layered catalysts were investigated in application of oxidation reaction using H_2O_2 as oxidizing agent. In the oxidation reaction, the conversion of 1-octene increased by approximately 5%, 10% and 25%, for reaction temperatures of 30^oC, 60^oC and 90^oC, respectively. Reaction temperature 90^oC showed the highest conversion to products, but the catalysts were low in the selectivity towards 1,2-epoxyoctane. The high selectivity of the oxidation reaction is towards 2-octanone products. It was possibly due to the concentration of H_2O_2 used (30 mmol) was much higher compared to previous studies (10 mmol), resulting in the process of accelerating 1,2-epoxyoctane to open its oxirane ring, then forming 2-octanone. Amongst all the layered catalyst, layered catalyst T90 gave the highest catalytic activity. It was due to the catalytic active site of layered catalyst T90 that has the optimum condition where the catalytic active site was not surrounded by large amount of polystyrene while attaining the sufficient attachment of titania towards cotton textile. Thus, less energy was needed for the substance to reach the catalyst active site for the reaction. As a comparison from previous study which used particulate catalyst involving variable temperature reaction, layered catalyst improved the catalyst selectivity by giving no side product besides 1,2-epoxyoctane and 2-octanone. However, the conversion activity still remains below 25% as previous study. Despite some limitations, the aim was successfully achieved. Thus, further modification should be carried out to improve the integrity of layered catalyst for potential applications.

ABSTRAK

Dalam memacu keperluan ke arah corak teknologi yang bersih dan ekonomik dalam industri kimia, mangkin heterogen telah digunakan secara meluas kerana ia memberi kemudahan kaedah pemisahan mangkin dari produk. Dengan itu, kajian ini mencadangkan penubuhan konsep pemangkinan heterogen baharu yang dinamakan "Sistem Pemangkinan Sempadan Fasa (PBC)" menggunakan tekstil kapas sebagai penyokong tapak aktif titania dan H_2O_2 sebagai agen pengoksidaan. Pemangkin PBC yang sebelumnya adalah dalam bentuk zarahan yang menunjukkan ia mempunyai kekurangan untuk tersebar dengan seragam dan tidak bergerak di antara fasa cecair-cecair untuk tindak balas pengoksidaan 1-oktena. Oleh itu, matlamat kajian ini ialah untuk mereka bentuk mangkin berlapis yang tidak bergerak di antara muka lapisan cecair-cecair dan seterusnya boleh dipraktikkan dalam applikasi yang berpotensi. Mangkin berlapis telah direka bentuk menggunakan tekstil kapas sebagai penyokong dan polistirena (PS) sebagai pengikat di antara titania dan tekstil kapas. Harus ditekankan bahawa sifat persekitaran hidrofobik merupakan sifat utama mangkin berlapis yang membantu mangkin berlapis untuk terapung dan berada betul-betul di antara muka sempadan cecair-cecair. Titanium peroksida telah dipilih sebagai bahan pelopor titanium disebabkan aspek kepekaan terhadap tekstil kapas. Enam sampel mangkin berlapis telah disediakan melalui pempolimeran stirena dengan perbezaan masa pempolimeran yang dilabel T30, T60, T90, T120, T150 dan T180. Didapati, tekstil kapas yang mengandungi titania semakin dilitupi PS dengan pertambahan masa. Satu siri mangkin berlapis telah dikaji untuk aplikasi tindak balas pengoksidaan menggunakan H_2O_2 sebagai agen pengoksidaan. Dalam tindak balas pengoksidaan, penukaran 1-oktena didapati meningkat masing-masing sebanyak 5%, 10% dan 25% bagi suhu tindak balas 30^oC, 60^oC dan 90^oC. Suhu tindak balas 90^oC menunjukkan hasil penukaran tertinggi, tetapi mangkin berkepilihan rendah terhadap 1,2-epoksioktana. Kepilihan tinggi tindak balas pengoksidaan adalah terhadap produk 2-oktanon. Ini berkemungkinan kerana kepekatan H_2O_2 yang digunakan (30 mmol) adalah lebih tinggi berbanding kajian sebelum ini (10 mmol) yang mendorong 1,2-epoksioktana untuk membuka gegelang oksirana lalu membentuk 2-oktanon. Dari kesemua mangkin berlapis, mangkin berlapis T90 telah memberikan aktiviti pemangkinan tertinggi. Ini disebabkan tapak aktif mangkin berlapis T90 memiliki keadaan yang optimum di mana tapak aktif mangkin tidak dikelilingi oleh jumlah polistirena yang banyak sementara mencapai ikatan yang mencukupi antara titania dengan tekstil kapas. Dengan itu, kurang tenaga diperlukan untuk bahan mencapai tapak aktif mangkin untuk tindak balas. Sebagai perbandingan dengan kajian terdahulu yang menggunakan mangkin zarahan yang melibatkan tindak balas suhu berubah, mangkin berlapis telah meningkatkan kepilihan mangkin dengan tidak memberikan sebarang produk sampingan selain 1,2-epoksioktana dan 2-oktanon. Walau bagaimanapun, aktiviti penukaran masih di bawah 25% seperti kajian terdahulu. Walaupun terdapat kekangan, namun matlamat kajian telah berjaya dicapai. Dengan itu, pengubahsuaian pada masa hadapan perlu dilaksanakan untuk memperbaiki integriti mangkin berlapis untuk aplikasi yang berpotensi.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

APTS	-	Aminopropyltriethoxysilane
DRUV	-	Diffuse reflectance ultraviolet
EDX	-	Energy dispersive X-ray
FTIR-ATR	-	Fourier transform infrared with attenuated total reflection
GC	-	Gas chromatography
H_2O_2	-	Hydrogen peroxide
H_2O	-	Water
OTS	-	Octadecyltrichlorosilane
PBC	-	Phase boundary catalysis
PTC	-	Phase transfer catalysis
PS	-	Polystyrene
SEM	-	Scanning electron microscopy
TGA	-	Thermogravimetric analysis
Ti	-	Titanium
TS-1	-	Titanium silicate 1
XPS	-	X-ray photoelectron spectroscopy

LIST OF SYMBOLS

%	-	Percentage
▼	-	Negative gradient
●	-	Radical
°	-	Degree
e^-	-	Negative electron
g	-	Gram
g/L	-	Gram per liter
g/mol	-	Gram per mol
kV	-	Kilo volt
M	-	Molar
mg	-	Milligram
mL	-	Millimeter
mm	-	Millimeter
mM	-	Milimolar
mmol	-	Milimol
nA	-	Nano ampere
nm	-	Nanometer
rpm	-	Rotation per minute
s	-	Second
t	-	Time
wt	-	Weight

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Research Background

In the 21st century, the chemical industrial processes look forward in two major shifts: a continuing shift in reaction that produces little waste (Yamabe, 2005) and an easy way in handling which results in time and energy consumption. Energy and time are the dynamic factors to allow competitiveness and employment for industries. The faster economic growth pursues the research to be ventured into green chemistry, thus leading to the studies in the field of environmentally benign catalysts (Nur, 2006).

Presently, catalysts in the immiscible liquid-liquid reaction applied in most of the industries becomes a dime a dozen. Rational design of the conventional catalytic system requires vigorous stirring to remove the diffusion boundary layer and additional cosolvent to enhance mass transfer. Both of these approaches are to obtain homogeneous solution for reactions to take place. To minimize energy consumption in the process, a novel concept of phase boundary catalytic (PBC) system using solid catalysts has been proposed recently to solve the problem in immiscible liquid-liquid reaction (Nur *et al.*, 2000). With no stirring and cosolvent in the reaction, the solid catalyst was proven to have an outstanding catalytic activity in epoxidation reaction.

The location of the solid catalyst placed between aqueous and organic phase plays the main role towards the simplicity of reaction methodology since the mass transfer is not the rate determining step in PBC system. Conventional catalytic reaction requires seven steps for the catalytic reaction to take places. On the contrary, PBC reaction does not require any steps since the reaction take places at the boundary of the immiscible liquid-liquid phase. It is clearly elucidated that organic phase, aqueous phase and catalyst are contacted at a point, without involving multiple routes travelled by organic substrates to reach inner pore of solid catalysts.

The novel concept of PBC for liquid-liquid reaction has been well established since PBC concept was successfully tested in several reactions in previous studies (Nur *et al*., 2004a; Nur *et al*., 2004b; Nur *et al*., 2004c; Nur *et al*., 2012). A preliminary study of PBC concept was started by using NaY zeolite catalyst which has been modified to be partly alkylsilane-covered titanium dioxide. The primary stage of this study aimed to place the bifunctional particles acquiring features of hydrophobic and hydrophilic regions to function as a role of catalyst in epoxidation reaction for PBC system. A discovery has shown that partial modification of alkylsilyl-Ti-NaY led to significant epoxide yield in the PBC system compared to the conventional system. This finding has been published previously (Nur *et al*., 2000).

Despite of the PBC is endowed with the aforementioned advantages, some flaws are discovered though. The previous catalyst of phase boundary was in form of particulates. Particle form of solid catalyst leads to tedious methodology, which centrifugation for several times with high speed is required after the reaction. Unequivocally, it is less practical to be applied for the industries. To resolve the separation process of catalyst from liquid-liquid immiscible separation, hence emerging of this research to design and synthesize new catalyst for PBC system using layered concept. This layered catalyst immobilized in the system which could assist the PBC system to be practically applied in industries for huge batch of processes since the methodology of separating the catalyst from the reaction has been simplified. As illustrated in Figure 1.1, design of the layered catalyst involving choosing cotton textile as the layered platform while titanium(IV)-based materials as the solid active sites.

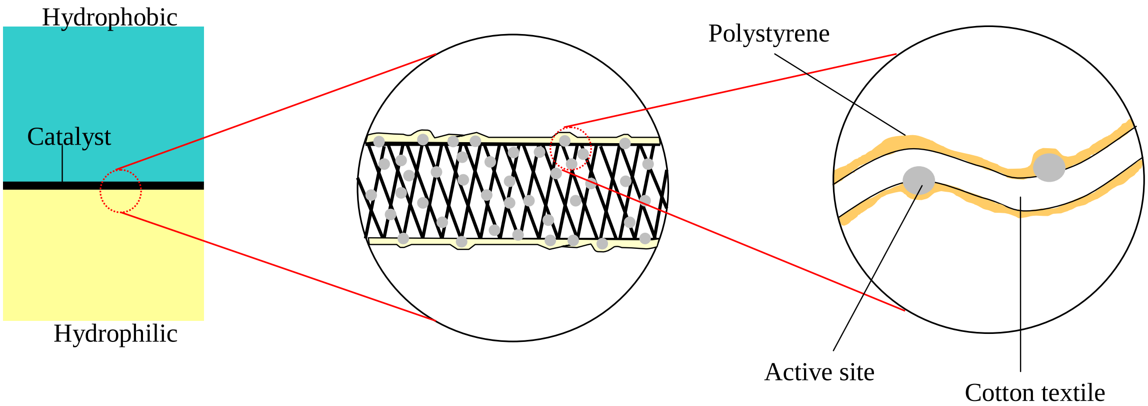

Figure 1.1 Schematic diagram of layered catalyst for PBC of liquid-liquid system.

In particularly, the cotton textile consists of cellulose which is the molecular ribbon shape structure of the cellulose allows the cellulose to be twisted and bent in any directions and makes the molecular moderately flexible (Agrawal, Nierstrasz, Klug-Santner, Gübitz, Lenting and Warmoeskerken, 2007). in any circumstances for designing layered catalyst. Titanium-based materials are utilized as active sites for the layered catalyst. In order to determine titanium(IV) precursor that are compatible with the cotton textile, various types of titanium(IV) precursors are tested including Ti(IV) sulphate, Ti(IV) chloride, Ti(IV) isopropoxide and Ti(IV) propoxide.

Subsequently, the polystyrene are strategically added to enhance binding of Ti(IV)-based materials onto the textile layered. This step also creates hydrophobic environment for the catalyst and simultaneously protect the catalyst from catalyst poisoning caused by water and hydrogen peroxide (H_2O_2). In order to observe the degree of success in designing and synthesizing new layered catalyst, the physicochemical properties of the new layered catalyst is studied in this thesis. Consequently, the layered catalyst is undergone an oxidation reaction of 1-octene with H_2O_2 which the reaction is carried out with varied temperatures starting from 30, 60 and 90°C.

1.2 Problem Statement

Emerging of PBC in particulate concept has been ventured for almost two decades. It is preponderance with its no stirring and no-co-solvent added into reaction system because of its reactivity is comparable to the conventional catalytic system. In spite of PBC system is on the horizon, a research is working on to overshadow the particulate concept of PBC. To meet the requirements of low energy consumption and easy separation of chemical processes in industries, it comes to a light with a newly designed PBC layered catalyst with titanium(IV)-based materials as active sites and light weight textile as floating material. The PBC layered catalyst can standalone in immiscible liquid-liquid system with immediate removal after the reaction is complete. The research question is listed in Figure 1.3.

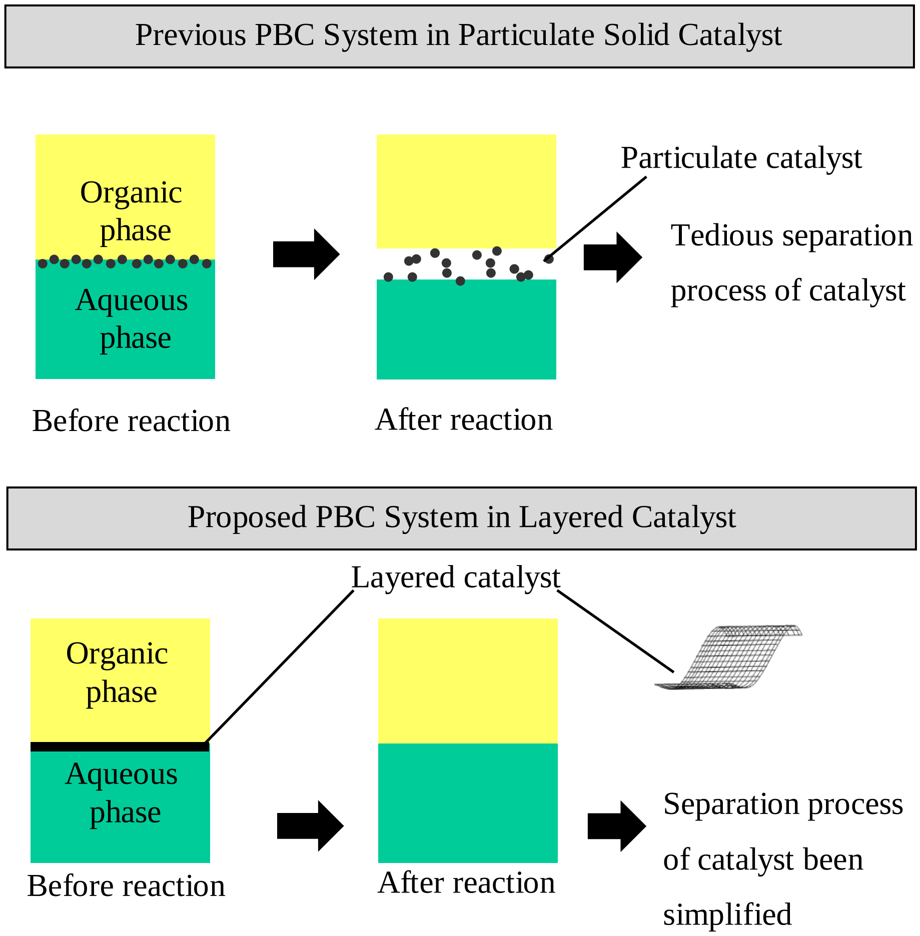

Figure 1.2 Schematic diagram of comparison between previous particulate solid catalyst and proposed new layered catalyst.

Strategies	Research questions
Design and synthesis layered catalyst	• How to design and synthesize the new layered catalyst for PBC system in immiscible reaction? • What are the physicochemical properties of new layered PBC catalyst?
Proofs of the concept	• Are the new layered catalysts can be located at the phase boundary of immiscible liquid-liquid system and active as catalyst?
Outcomes of the concept	• How are the performance of the catalytic activity and selectivity of layered catalyst compared to solid particulate catalyst? (a)

Figure 1.3 Schematic representation of strategies and research questions of the PBC system in immiscible liquid-liquid reaction.

1.3 Objectives of Study

The aims of this study are to provide a comprehensive study on preliminary design of new PBC layered catalyst, the effect of polymerization time on the changes in the properties of new PBC layered catalyst and the correlation between the series of layered catalyst to its catalytic activities and selectivity in order to identify the optimum condition to design enhanced layered catalyst. With the issues mentioned above, this research is conducted based on the following objectives;

- To design and synthesize layered catalyst with titanium(IV)-based materials.
- To investigate the physicochemical properties of new PBC layered catalyst
- To investigate the catalytic activity and selectivity of the layered catalyst in 1-octene oxidation reaction.

1.4 Scope of Study

This study is focused on the selection of titanium(IV) precursor that are compatible with the environment of cotton textile as a based of layered catalysts. The motivation is to study the enhancement of the attachment integrity on the new layered catalyst with different time of polymerization. This is also a study to understanding the changes in the physical and chemical properties of the cellulose-derived polystyrene-TiO_2 layered catalyst with the catalytic activity and selectivity relationship of the layered catalyst. In order to accomplish the research's objective, the scope of the study is divided into three parts, which are the designation and synthesizes of the new layered catalyst, the characterization of layered catalyst and the application of the layered catalyst in catalytic reaction.

The design and synthesize of new layered catalyst was done with the selection of cotton textile as the based for the layered of catalyst support. The cotton textile was first scoured in order to remove impurities. The scoured cotton textile was impregnated with compatible selection of titanium(IV) precursor that can adapt cotton textile environment. The selected titanium(IV) precursor was then been improved the integrity of attachment with cotton textile is assisted by styrene polymerization that been varied by time of polymerization of 30, 60, 90, 120, 150 and 180 minutes in order to study the effect of polymerization on the properties of layered catalyst.

The characterization of layered catalyst was conducted to study surface, physical and chemical properties of the layered catalyst. The properties of layered catalyst were the correlated to the catalytic activity and selectivity of the layered catalyst. The catalytic performance of layered catalyst was done by oxidation reaction of 1-octene with the hydrogen peroxide as the oxidant in the reaction with three different reaction temperature 30, 60 and 90°C.was investigated.

1.5 Significance of Study

The results from this study provide useful information of the new perspective of catalyst that can be used for PBC in immiscible liquid-liquid system. This study explores a new design of catalyst which is more practical to be applied either in small or huge batch processes. The simplicity of the methodology would benefit the industries in term of low consumption of energy and time which are favoured by the industries nowadays.

REFERENCES

Abidi, N., Hequet, E. & Cabrales L. (2011). Application of Fourier Transform Infrared Spectroscopy to Study Cotton Fibers. in Nikolic, G. *Fourier Transforms-New Analytical Approaches and FTIR Strategies*. IntechOpen.

Agrawal, P. B., Nierstrasz, V. A., Klug-Santner, B. G., Gübitz, G. M., Lenting, H. B. M. & Warmoeskerken, M. M. C. G. (2007). Wax Removal for Accelerated Cotton Scouring with Alkaline Pectinase. *Biotechnology Journal*. 2:306-315.

Agrawal. P. B., Nierstrasz, V. A., Bouwhuis, G. H. & Warmoeskerken, M. M. C. G. (2008), Cutinase and Pectinase in Cotton Bioscouring: An Innovative and Fast Bioscouring Process. *Biocatalysis and Biotransformation*. 26(5):412-421.

Akhtar, F., Andersson, L., Ogunwumi, S., Hedin, N. & Bergstorm, L. (2014) Structuring Adsorbent and Catalysts by Processing of Porous Powders. *Journal of European Ceramic Society*. 34:1643-1666.

Allen, T. (1997). (5^{th} ed) *Particle Size Measurement-Powder Sampling and Particle Size Measurement.* Great Britain. Chapman & Hall

Alotaibi, A. M., Sathasivam, S., Williamson, B. A., Kazas, A., Sotelo-Vazquez, C., Taylor, A., & Parkin, I. P. (2018). Chemical Vapor Deposition of Photocatalytically Active Pure Brookite TiO_2 Thin Films. *Chemistry of Materials*.

Anita K. Losonczi (2004) *Biscouring of Cotton Fabrics*. PhD Thesis. Budapest University of Technology and Economics, Hungary.

Arai, M. & Bhanage, B. M. (2013). Catalyst Product Separation Techniques in Heck Reaction. *Catalysis Review: Science and Engineering*. 43(3):315-344.

Armaroli, T., Busca, G., Carlini, C., Giuttari, M., Galletti, A.M.R. & Sbrana, G. (2000) Acid Sites Characterization of Niobium Phosphate Catalysts and Their Activity in Fructose Dehydration to 5-Hydroxymethyl-2-furaldehyde. *Journal of Molecular Catalysis A*. 151(1-2):233-243.

Au, C. K. & Holme, I. (1999). The Alkali Desizing of Woven Cotton Fabrics. *Research Journal of Textile and Apparel*. 3(1):16-30.

Bailie, J. E., Hutchings, G. J. & Leary, S. O. (2001) Supported Catalysts. (2^{nd} ed) *Encyclopedia of Material: Science and Technology*. pp. 8986-8990. Elsevier Ltd.

Baumann, K. & Muhlfriedel, K. (2001) Mass Transfer and Concentration Profile Near Phase Boundaries. *International journal of Thermal Sciences*. 40:425-436.

Binder, J. B. & Raines, R. T. (2010) Fermentable Sugars by Chemical Hydrolysis of Biomass. *Proceedings of the National Academy of Sciences*. 107(10): 4516-4521.

Bing-Huang, Y. & Fu, Y. (2013) Hydrolysis of Cellulose to Glucose by Solid Acid Catalysts. *Green Chemistry*. 15:1095-1111.

Bonelli, B., Cozzolino, M., Tesser, R., Serio, M.D., Piumetti, M., Garrone, E. & Santacesaria, E. (2007). FTIR Measurement of CO and NH_3 Adsorption. *Journal of Catalysis*. 246:293-300.

Boyle, T. J., Eilerts, N. W., Heppert, J. A. & Takusagawa, F. (1994) Structurally Well Characterized Binaphtholate TitaniumChloride Lewis Acids: Evidence for Active Dinuclear Catalysts in a Diels-Alder Process. *Organometallics*. 13(6):2218-2229.

Brink, G.J., Arends, I. W. C. E. & Sheldon, R.A. (2000). Green, Catalytic Oxidation of Alcohol in Water. *Sciences*. 287(5458): 1636-1639.

Brosse, J. C., Derouet, D., Epaillard, F., Soutif, J. C., Legeay, G. & Dušek, K. (1987) Hydroxyl-Terminated Polymers Obtained by Free Radical Polymerization-Synthesis, Characterization, and Applications. in: *Catalytical and Radical Polymerization. Advances in Polymer Science*, vol 81. Berlin, Heidelberg. Springer.

Buha, J. (2012) Solar Absorption and Microstructureof C-Doped and H-Doped TiO_2 Thin Films. *Journal of Physics D: Applied Physics.* 45(385305):1-15.

Bukur, D. B., Lang, X., Mukesh, D., Zimmerman, W. H., Rosynek, M. P. & Li, C. (1990) Binder/Support Effect on the Activity and Selectivity of Iron Catalysts in the Fisher-Tropsch Synthesis. *Industrial and Engineering Chemistry Research*. 29:1588-1599.

Chen, L.H. & Lee, Y.L. 2000. Adsorption Behavior Of Surfactants And Mass Transfer In Single-Drop Extraction. *American Institute of Chemical Engineers Journal*. 46:160–168.

Chigwada, G., Kandare, E., Wang, D., Majoni, S., Mlambo, D., Wilkie C.A. & Hossenlopp, J.M. (2008). Thermal Stability and Degradation Kinetics of Polystyrene / Organically-Modified. *Journal of Nanoscience and Nanotechnology*. 8:1927-1936.

Chinkap, C., Myunghee, L. & Eun-Kyung, C. (2004) Characterization of Cotton Fabric Scouring by FT-IR ATR Spectroscopy. *Carbohydrate Polymers*. 58(4):417-420.

Clayden, J., Greeves, N., Warren, S. & Wothers, P. (2000) *Organic Chemistry*. USA. Oxford University Press.

Corma, A. & Garcia, H. (2003). Lewis Acid: From Conventional Homogeneous to Green Homogeneous and Heterogeneous Catalysis. *Chemical Review*. 103:4307-4365.

Cornil, B., Hermann, W. A, Schlögl, R. & Wong, C. H. (2003). 2nd ed. *Catalysis from A to Z-A Concise Encyclopedia*. Wiley-VCH, Weinheim.

Cox, M. M. & Nelson D. L. (2013). How Enzymes Work. in (6th ed) *Lehninger Principles of Biochemistry*. New York, W.H. Freeman. pp. 195. ISBN 978-1464109621.

Dumesic, J. A., Huber, G. W. & Boudart, M. (2008). Principles of Heterogeneous Catalysis. in Ertl, G., Knoziger, H., Schuth, F. & Weitkamp, J. (2nd ed) *Handbook of Heterogeneous Catalysis*. Wiley-VCH. pp. 1-15.

Dupin, J., Gonbeau, D., Vinatier, P. & Levasseur, A. (2000) Systematic XPS Studies of Metal Oxides, Hydroxides and Peroxide. *Physical Chemistry Chemical Physics*. 2:1319-1324.

Ediati, R., Ulfa, M., Fansuri, H., Ramli, Z., Nur, H. & Prasetyoko, D. (2014). Influence of TiO2/TS-1 Calconation on Hydroxylation of Phenol. *Journal of Mathematical Fundamental Science*. 46(1):76-90.

Enomoto, N., Kawasaki, K., Yoshida, M., Li, X., Uehara, M., &Hojo, J. (2002). Synthesis of Mesoporous Silica Modified with Titania and Application to Gas Adsorbent. *Solid State Ionics*. 151(1-4): 171-175.

Fabiyi, J. S. & Ogunleye, B. M. (2015) Mid-Infrared Spectroscopy and Dynamic Mechanical Analysis of Heat-Treated Obeche (Triplochiton Scleroxylon) Wood. *Maderas. Ciencia Y Technologia*. 17(1):5-16.

Fan, T., Zhao, Z., Zhou, J., Li, L., Liu, Y. & Lu, M. (2018). Fabrication of Magnetic Cotton Fabric using Surface Micro-dissolving Technology in $ZnCl_2$ Aqueous Solution. *Cellulose*. 25:1437.

Fan, M., Dai, D.& Huang, B. (2012). Fourier Transform Infrared Spectroscopy for Natural Fibres, Fourier Transform. in Salih, M. S. *FourierTransform-Material Analysis.* IntechOpen.

Fujishima, A., Rao, T. N. & Tryk, D. A. (2000). Titanium Dioxide Photocatalysis. *Journal Photochemistry and Photobiology C.* 1(1): 1–21.

Fujishima, A., Zhang, X., & Tryk, D. A. (2008). TiO_2 Photocatalysis and Related Surface Phenomena. *Surface Science Reports*. 63:515–582.

Gallo, J. M. R., Paulino, I. S. & Schuchardt, U. (2004) Cyclooctene Epoxidation using Nb-MCM-41 and Ti-MCM-41 Synthesized at Room Temperature. *Applied Catalysis A*. 266(2):223-227.

George, S. M. (1995). Introduction: Heterogeneous Catalysis. *Chemical Reviews*. 95(3):475-476.

Ghaly, A. E., Ananthashankar, R., Alhattab, M. & Ramakrishnan, V. V. (2014). Production, Characterization and Treatment of Textile Effluents: A Critical Review. *Journal of Chemical Engineering and Process Technology*. 5(1):1-19.

Gibbs, J. W. (1928) The Collected Works Vol 1 , Yale University Press.

Gokani, S. J. & Thaker, V. S. (2002). Physiological and Biochemical Changes Associated with Cotton Fiber Development: IX. Role of IAA and PAA. *Field Crops Research*. 77(2-3):127-136.

Goldberg, Y. (1992). Basic Principle of Phase Transfer Catalysis. in *Phase Transfer Catalysis-Selected Problems and Applications*. pp. 1-23. Gordon and Breach Science Publishers.

Gonzalez-Cabriales, J. J., De Leon, J. A. R. & Vazquez, M. (2004) Effect of the Hydrochloric Acid Concentration on the Hydrolysis of Sorghum Straw at Atmospheric Pressure. *Journal of Food Engineering*. 63:103-109.

Gordon, S. & Hsieh, Y. L. (2007). Part 1: The structure and Properties of Cotton. *Cotton*: *Science and Technology*. Cambridge, England. Woodhead Publishing Limited.

Gouda, M. & Aljaafari, A. I. (2012) Augmentation of Multifunctional Properties of Cellulosic Cotton Fabric using Titanium Dioxide Nanoparticles. *Advances in Nanoparticles*. 1: 29-36.

Guyot, A. (1988) Polymer Supports with High Accessibility. *Pure and Applied Chemistry*. 60(3):365-376.

Grigopoulou, G., Clark, J.H. & Eling, J.A. (2003). Recent Developments on the Epoxidation of Alkenes using Hydrogen Peroxide as an Oxidant. *Green Chemistry*. 5:1-7.

Hachani, S.E., Alchekhwis, A., Necira, Z., Nebbache, N., Meghezzi, A. & Ozkoz, G. (2018). Effect of Magnesia Incorporation on Properties of Polystyrene/Magnesia Composites. *Acta Chimica SlovenicaI. 65:646-651.*

Hagen, J. (2006). *Industrial Catalysis: A Practical Approach*. 2^{nd} ed. Wiley-VCH, Weimheim. pp 339-345.

Haggerty, J. E., Schelhas, L. T., Kitchaev, D. A., Magnum, J. S., Garten, L. M., Sun, W., Stone, K. H., Perkin, J. D., Toney, M. F., Ceder, G., Ginley, D. S., Gorman, B. P., & Tate, J. (2017). High Fraction Brookite Films from Amorphous Precursors. *Scientific Reports*. 7(1).

Haji, A., Hashemizad, S. & Dehkani, S. (2016) Improved Attachment of Titanium Dioxide Nanoparticles on Cotton Fabrics using Plasma Treatment and Chitosan Coating. 24^{th} IFATCC International Congress. Czech Republic. University of Pardubice.

Harima, Y., Fujita, T., Kano, Y., Imae, I., Kmoguchi, K., Ooyama, Y. & Ohshita, J. (2013). Lewis-Acid Sites of TiO_2 Surface for Adsorption of Organic Dye Having Pyridyl Group as Anchoring Unit. *Journal of Physical Chemistry. C.* 117:16364-16370.

Hattori, H. (1995). Heterogeneous Basic Catalysis. *Chemical Review*. 95: 537-558.

He, Y., Wu, Z. & Mao, Z. (2007) The Resistance of Interphase Mass Transfer in Colloidal Liquid Aphron System. *Chemical Engineering Science*. 62:2803-28812.

Hosomi, A. & Sakurai, H. (1976) Syntheses of γ, δ-Unsaturated Alcohol from Allylsilanes and Carbonyl Compounds in the Presence of Titanium Tetrachloride. *Tetrahedron Letters*. 17(16):1295-1298.

Huang, X. & Zhang,W. (2010). Preparation of Cellulose Sulphate and Evaluation of its Properties. *Journal of Fiber Bioengineering and Informatics*. 3(1): 32-39.

Hutomo, G. S., Rahim, A. & Kadir, S. (2015) The Effect of Sulfuric and Hydrochloric Acid on Cellulose Degradation from Pod Husk Cacao. *International Journal of Current Microbiology and Applied Sciences*. 4(10):89-95.

Ikeda, S., Nur, H., Sawadaishi, T., Ijiro, K., Shimomura, M. & Ohtani, B. (2001). Direct Observation of Bimodal Amphiphilic Surface Structures of Zeolite Particles for a Novel Liquid-Liquid Phase Boundary Catalysis. *Langmuir*. 17(26): 6271-6275.

Ikeda, S., Nur, H., Wu, P., Tatsumi, T. & Ohtani, B. (2003). Effect of Titanium Active Site Location on Activity of Phase Boundary Catalyst Particles for Alkene Epoxidation with Aqueous Hydrogen Peroxide. in Anpo, M., Onaka, M. & Yamashita, H. *Science and Technology in Catalysis 2002- Proceedings of the Fourth Tokyo Conference on Advance Catalytic Science and Technology*. Tokyo. Kodansha Ltd. 145(50):251-254.

Ioelovich, M. (2012) Study of Cellulose Interaction with Concentrated Solution of Sulfuric Acid. *International Scholarly Research Network Chemical Engineering*. 428974:1-7.

Jinfeng, Z., Peng, Z., Jianjun, L., & Jiaguo, Y. (2014). New Understanding of The Difference of Photocatalytic Activity Among Anatase, Rutile and Brookite TiO_2.*Physical Chemistry Chemical Physics*.16:20382-20386.

Junjie, C. (2014). Homogeneous and Heterogeneous Catalysis: Teachings of The Thermal Energy and Power Engineering Course. *Journal of Educational and Pedagogical Sciences*. 8(12): 3923-3926.

Junyuan Yang (2017) *Manufacturing of Nanocrystalline Cellulose*. Master. Espoo, Finland.

Karapinar, E. & Sariisik, M. O. (2004). Scouring of Cotton with Cellulases, Pectinases and Proteases. *Fibres & Textiles in Eastern Europe*. 12(3):79-82.

Karimi, L., Yazdanshenas, M. E., Khajavi, R., Rashidi, A. & Mirjalili, M. (2016) Functional Finishing of Cotton Fabrics using Graphene Oxide Nanosheets Decorated with Titanium Dioxide Nanoparticles. *The Journal of The Textile Institute*. 107(9):1122-1134.

Kerber, S. J., Bruckner, J. J., Wozniak, K., Seal, S., Hardcastle, S. & Barr, T. L. (1996) The Nature of Hydrogen in X-Ray Photoelectron Spectroscopy:

General Pattern from Hydroxides to Hydrogen Bonding. *Journal of Vacuum Science and Technology A*. 14(3):1314-1320.

Kerstiens, G. (1996). Cuticular Water Permeability and Its Physiological Significance. *Journal of Experimental Botany*. 47(305):1813-1832.

Khajavi, R. & Berendjchi, A. (2014). Effect of Dicarboxylic Acid Chain Length on the Self-Cleaning Property of Nano-TiO_2-Coated Cotton Fabrics. *ACS Applied Materials & Interfaces*. 6:18795–18799.

Khan, M. M., Adil, S. F. & Al-Mayouf, A. (2015b). Metal Oxides as Photocatalysts. *Journal Saudi Chemical Society*. 19(5): 462-464.

Khataee, A. & Mansoori, G. A. (2012). Application of Nanostructured Titanium Dioxide. in *Nanostructured Titanium Dioxide Materials:Properties, Preparation and Applications*. Singapore. World Scientific Publishing.

Klaewkla, R., Arend, M. & Hoelderich, W. F. (2011) A Review of Mass Transfer Controlling the Reaction Rate in Heterogeneous Catalytic Systems. in Nakajima, H. *Mass Transfer IntechOpen,*

Kobayashi, T., Sakai, Y. & Lizuka, K. (1960) Hydrolysis of Cellulose in a Small Amount of Concentrated Sulfuric Acid. *Bulletin of Agricultural Chemical Society of Japan*. 24(5):443-449

Krishnamoorthy, K., Navaneethaiyer, U., Mohan, R., Lee, J. & Kim, S. (2012) Graphene Oxide Nanostructures Modified Multifunctional Cotton Fabrics. *Applied Nanosciences*. 2:119-126.

Krishnamurthi, P. P., Ramalingam, H. B. & Raju, K. (2015) FTIR Studies of Hydrogen Bonding Interaction Between the Hydroxyl and Carbonyl Liquids. *Advance Applied Science Research*. 6(12):44052.

Kunst, L. & Samuels, A. L. (2003). Biosynthesis and Secretion of Plant Cuticular Wax. *Progress in Lipid Research*. 42:51-80.

Labouriau, A., & Earl, W. L. (1997). Titanium Solid-state NMR in Anatase, Brookite and Rutile. *Chemical Physics Letters*. 270(3-4): 278-284.

Lamb, S.B. & Stuckey, D.C. 2000. Factors Influencing The Stability Of A Novel Enzyme Immobilization Support-Colloidal Liquid Aphrons (CLAs). *Journal of Chemical Technology and Biotechnology*.75:681–688.

Landmann, M., Rauls, E., & Schmidt, W. (2012). The Electronic Structure and Optical Response of Rutile, Anatase and Brookite TiO_2. *Journal of Physics: Condensed Matter*.24:3.

Lee, A. F., Gee, J. J. & Theyers, H. J. (2000). Aspect of Allylic Alcohol Oxidation - a Bimetallic Heterogeneous Selective Oxidation Catalyst. *Green Chemistry*. 2(6): 279-282.

Leng, D.E. & Calabrese, R.V. (2004). Immiscible Liquid-Liquid Systems. in Paul, E. L., Atiemo-Obeng, V. A. & Kresta, S. M. *Handbook of Industrial Mixing: Science and Practice*. pp. 639-753. John Wiley & Sons, Inc.

Lewin, E., Gorgoi, M., Schafers, F., Svensson, S. & Jansson, U. (2009) Influence of Sputter Damage on the XPS Analysis of Metastable Nanocomposite Coatings. *Surface and Coatings Technology*. 204:455-462.

Li, L., Xi, S., Xing, Y. & Shang, F. (2013) Preparation and Photocatalytic Activity of Yellow Titania. *Materials Science Forum*. 743-744:849-856.

Li, R., Jin., T. Z., Liu, Z.& Liu, L. (2018) Antimicrobial Double-Layer Coating Prepared from Pure or Doped-Titanium Dioxide and Binders. *Coatings*. 8(41):1-11.

Lignier, P., Mangematin, S., Morfin, F., Rousset, J.L. & Caps, V.(2008). Solvent and Oxidant Effect on the Au/TiO_2-Catalyzed Aerobic Epoxidation of Stilbene. *Catalysis Today*. 138:50-54.

Lin, J., Chang, Y. & Hsu, Y. (2009) Degradation of Cotton Cellulose Treated with Hydrochloric Acid either in Water or in Ethanol. *Food Hydrocolloids*. 23: 1548-1553.

Liu, Y. (2013). Recent Progress in Fourier Transform Infrared (FTIR) Spectroscopy Study of Compositional, Structural and Physical Attributes of Developmental Cotton Fibers. *Materials*. 6:299-313.

Lopez, G. P., Castner, D. G. & Ratner, B. D. (1991) XPS O1s Binding Energies for Polymers Containing Hydroxyl, Ether, Ketone and Ester Groups. *Surface and Interface Analysis*. 17:267-272.

Lubis, S., Yuliati, L., Lee, S. L., Sumpono, I. & Nur, H. (2012). Improvement of Catalytic Activity in Styrene Oxidation of Carbon-Coated Titania by Formation of Porous Carbon Layer. *Chemical Engineering Journal*. 209:486-493.

Ma, Z. & Zaera, F. (2014). Heterogeneous Catalysis by Metals, in Robert A. S. (2^{nd} ed) *Encyclopedia of Inorganic and Bioinorganic Chemistry, Online*. John Wiley & Sons, Ltd, pp.1-15.

Makosza, M. (2000). Phase-Transfer Catalysis. A General Green Methodology in Organic Synthesis. *Pure and Applied Chemistry*. 72(7):1399-1403.

Marko, I. E., Giles, P. R., Tsukazaki, M., Brown, S. M. & Urch, C. J. (1996). Copper-Catalyzed Oxidation of Alcohol to Aldehydes and Ketones: An Efficient, Aerobic Alternative. *Sciences*. (1996) 274(5295): 2044-2046.

Marquez, C., Rivera-Torrente, M., Paalanen, P. P., Weckhuysen, B. M., Cirujano, F. G., Vos, D. D. & Baerdemaeker, T. D. (2017) Increasing the Availability of Active Sites in Zn-Co Double Metal Cyanides by Dispersion onto a SiO2 Support. *Journal of Catalysis*. 354: 92-99.

Mayer-Gall, T., Lee, J., Opwis, K., List, B. & Gutmann, J. S. (2016). Textile Catalysts-An Unconventional Approach Towards Heterogeneous Catalysis. *ChemCatChem*. 8:1428-1436.

Merkus, H. G. (2009) Particle size, Size Distribution and Shape. in *Particle Size Measurements-Fundamentals, Practice, Quality*. Springer Science+Business Media B.V.

Mirjalili, M. & Karimi, L. (2011) Photocatalytic Degradation of Synthesized Colorant Stains on Cotton Fabric Coated with Nano TiO2. *Journal of Fiber Bioengineering and Informatics*. 3(4):208-215.

Modak, M. J. (2002). Haber Process for Ammonia Synthesis. *Resonance-Journal of Sciences Education*. 7(9):69-77.

Molto, J., Font, R., Conesa, J.A., Martin-Gullon, I. (2006). Thermogravimetric Analysis During the Decomposition of Cotton Fabrics in an Inert and Air Environment. *Journal of Analytical and Applied Pyrolysis*. 76:124-131.

Montazer, M., Behzadnia, A., Pakdel, E., Rahimi, M. K., & Moghadam, M. B. (2011). Photo Induced Silver on Nano Titanium Dioxide as an Enhanced Antimicrobial Agent for Wool. *Journal of Photochemistry and Photobiology B: Biology*. 103:207–214.

Montazer, M. & Pakdel, E.(2011). Functionality of Nano Titanium Dioxide on Textiles with Future Aspects: Focus on Wool. *Journal of Photochemisry and Photobiology C: Photochemistry Reviews*. 12:293-303.

Morais, J. P. S., Rosa, M. D. F., Filho, M. D. S. M. D. S., Nascimento, L. D., Nascimento, D. M. D. & Cassales, A. R. (2013). Extraction and Characterization of Nanocellulose Structures from Raw Cotton Linter. *Carbohydrate Polymers*. 91:229-235.

Moulijn, J. A., Van Leeuwen, P. W. N. M. & Van Santen, R. A. (1993). Heterogeneous Catalysis. *Studies in Surface Science and Catalysis*. 79(C): 159-197. Elsivier B. V.

Muralidhara, K. & Prabhunath, M. (2014). A Study on the Surface Properties of Transition Metal Oxides. *International Journal of Scientific Research and Management*. 2(12):1880-1883.

Naik, S. D. & Doraiswamy, L. K. (1998). Phase Transfer Catalysis: Chemistry and Engineering. *AIChE Journal*. 44(3): 612-646.

Nasef, M. M., Saidi, H., Nor, H. M. & Yarmo, M., A. (2000) Xps Studies of Radiation Grafted PTFE-g-polystyrene Sulfonic Acid Membranes. *Journal of Applied Polymer Sciences*. 76:336-349.

National Research Council (US)-Separation Technologies for the Industries of the Future. (1998) *NMAB-487*-3. Washington D.C. National Academies Press.

Nilghaz, A., Wicaksono, D. H. B., Gustiono, D., Majid, F. A. A., Supriyanto, E. & Kadir, M. R. A. (2012). Flexible Microfluid Cloth-Based Analytical Devices Using a Low-Cost Wax Patterning Technque. *Lab Chip*. 12:209-218.

Nur, H. (2006). Heterogeneous Chemocatalysis: Catalysis by Chemical Design (Selected Paper of Hadi Nur). Malaysia. Ibnu Sina Institute for Fundamental Science Studies UTM.

Nur, H., Ikeda, S. & Ohtani, B. (2000) Phase Boundary Catalysis: A New Approach in Alkene Epoxidation with Hydrogen Peroxide by Zeolite Loaded with Alkylsilane-Covered Titanium Oxide. *Chemical Communications*. (22):2235-2236.

Nur, H., Ikeda, S. & Ohtani, B. (2001). Phase-Boundary Catalysis of Alkene Epoxidation with Aqueous Hydrogen Peroxide Using Amphiphilic Zeolite Particles Loaded with Titanium Oxide. *Journal of Catalysis*. 204: 402-408.

Nur, H., Ikeda, S. & Ohtani, B. (2004a). Amphiphilic NaY Zeolite Particles Loaded with Niobic Acid: Materials with Applications for Catalysis in Immiscible Liquid-Liquid System. *Reaction Kinetics and Catalysis Letters*. 82(2):255-261.

Nur, H., Ng, Y. H., Muhid, M. N. M. & Hamdan, H. (2004b). Surface Structure of Alkylsilated HZSM-5 as Phase-Boundary Catalyst. *Physics Journal of the Indonesian Physical Society.* A7(0218):1-5.

Nur, H., Prasetyoko, D., Ramli, Z. & Endud, S. (2004c). Sulfation: A Simple Method to Enhance the Catalytic Activity of TS-1 in Epoxidation of 1-Octene with Aqueous Hydrogen Peroxide. *Catalysis Communication*. 5:725-728.

Nur, H., Ran, N. H. M., Attan, N., Ikeda, S. & Ohtani, B. (2012). On Effective Locations of Catalytic Active Sites in Phase Boundary Catalyst. *ITB Journal of Science*. 44(2):153-163.

Ochiai, T. & Fujishima, A. (2012). Photoelectrochemical Properties of TiO_2 Photocatalyst and its Applications for Environmental Purification. *Journal of Photochemistry and Photobiology C: Photochemistry* Reviews. 13:247–262.

Olayo, M. G., Gonzalez-Salgado, F., Cruz, G. J., Gomez, L. M., Garcia-Rosales, G., Gonzales-Torres, M. & Lopez-Gracia, O. G. (2013) Chemical Structure of TiO Organometallic Particles Obtained by Plasma. *Advances in Nanoparticles*. 2:229-235.

Opwis, K., Straube, T., Kiehl, K. & Gutmann, J. S. (2014). Various Strategies for the Immobilization of Biocatalysts on Textile Carrier Materials. *Chemical Engineering Transactions*. 38:223-228.

Pinazzi, C., Legeay, G. & Brosse J. (1973) Radical Initiated Synthesis of Hydroxyl Terminated Polymers Using Aqueous Hydrogen Peroxide as Initiator. *Journal of Polymer Science: Polymer Symposia*. 42(1):11-19.

Piradashvili, K., Alenxandrino, E. M., Wurn, F. R. & Landfester, K. (2016) Reactions and Polymerizations at the Liquid-Liquid Interface. *Chemical Reviews*. 116:2141-2169.

Poole, C., Mester, Z., Miro, M., Pedersen-Bjergaard, S. & Pawliszyn, J. (2016) Extraction for Analytical Scale Sample Preparation (IUPAC Technical Report). *Pure and Applied Chemistry*. 88(7): 649-687.

Pramodkumar Bhagwandas Agrawal. (2005). The Performance of Cutinase and Pectinase in Cotton Scouring PhD Thesis, University of Twente, Netherlands.

Prasetyoko, D., Ramli, Z., Endud, S. & Nur, H. (2005a). Enhancement of Catalytic Activity of Titanosilicalite-1 – Sulfated Zirconia Combination Toward Epoxidation of 1-Octene with Aqueous Hydrogen Peroxide. *Reaction Kinetics and Catalysis Letters*. 86(1):83-89.

Prasetyoko, D., Ramli, Z., Endud, S. & Nur, H. (2005b). Niobic Acid Dispersed on the Surface of TS-1: Acidity Study. *Akta Kimindo*. 1:11-16.

Prasetyoko, D., Ramli, Z., Endud, S. & Nur, H. (2005c). Preparation and Characterization of Bifunctional Oxidative and Acidic Catalysts Nb_2O_5/Ts-1 for Synthesis of Diols. *Materials Chemistry and Physics*. 93:443-449.

Prasetyoko, D., Ramli, Z., Endud, S. & Nur, H. (2005d). TS-1 Loaded with Sulfated Zirconia as Bifunctional Oxidative and Acidic Catalyst for Transformation of 1-Octene to 1,2-Octanediol. *Journal of Molecular Catalysis A: Chemical*. 241:118-125.

Rajendran, R., Sundaram, S. K., Radhai, R. & Rajapriya, P. (2011). Biscouring of Cotton Fabrics Using Pectinase Enzyme Its Optimization and Comparison with Conventional Scouring Process. *Pakistan Journal of Biological Sciences*. 14(9):519-525.

Rajeshwar, K., Osugi, M. E., Chanmanee, W., Chenthamarakshan, C. R., Zanoni, M., Kajitvichyanukul, P. & Krishnan-Ayer, R. (2008). Heterogeneous Photocatalytic Treatment of Organic Dyes in Air and Aqueous Media. *Journal Photochemistry and Photobiology C*. 9(4): 171–192.

Ran, N. H. M., Yuliati, L., Lee, S. L., Mahlia, T. M. I. & Nur, H. (2013). Liquid-Gas Boundary Catalysis by Using Gold/Polystyrene-Coated Hollow Titania. *Journal of Colloid and Interface Science*. 394:490-497.

Ranga, S. (2017). Comparative Analysis of Homogeneous and Heterogeneous Catalysis. *International Journal of Engineering Technology Science and Research*. 4(9):1496-1500.

Rehman, S., Ullah, R., Butt, A. M. & Gohar, N. D. (2009). Strategies of Making TiO2 and ZnO Visible Light Active. *Journal of Hazardous* Materials. 170(2–3): 560–569.

Rocky, A. M. K. B. P. (2012). Comparison of Effectiveness Between Conventional Scouring and Bio-Scouring on Cotton Fabrics. *International Journal of Scientific & Engineering Research*. 3(8):1-5.

Rouette, H. K. (2001) *Encyclopedia of Textile finishing.* English edn. Cambridge. UK: Woodhead Publishing.

Sameii, N., Mortazavi, S. M., Rashidi, A. S. & Sheikhzadah-Najar, S. (2008). An Investigation on the Effect of Hot Mercerization on Cotton Fabrics Made Up of Open-End Yarns. *Journal of Applied Sciences*. 8(22):4204-4209.

Sasson, Y. & Neumann, R. *Handbook of phase Transfer Catalysis*. 1st ed. United Kingdom: Chapmann & Hall. 1997.

Sebati, W. & Ray S. S. (2018) Advances in Nanostructured Metal-Encapsulated Porous Organic-Polymer Composite for Catalyzed Organic Chemical Synthesis. *Catalysts*. 8(11):492-519.

Shahidullah, M., Islam, M. R., Sayeed, M. M. A., Uddin, M. K. & Abdullah, A. B. M. (2007). Improvement of Light Fastness Properties of Dyed Jute Fabrics Through Pretreatment. *Journal of Applied Sciences*. 7(23):3791-3795.

Sharma, M.V., Durgakumari, V. Subrahmanyam, M. (2008). Degradation of Isoproturon Herbicide Over TiO_2/Al-MCM-41 Composite Systems using Solar Light. *Chemosphere*. 72:644-658.

Starks, C. (1971). Phase-Transfer Catalysis. I. Heterogeneous Reactions Involving Anion Transfer by Quaternary Ammonium and Phosphonium Salts. *Journal of the American Chemical Society*. 93(1):195-199.

Starks, C.M., Liotta, C.L. & Halpern, M. (1934). Basic Concept in Phase Transfer Catalysis. in *Phase Transfer Catalysis-Fundamentals, Applications and Industrial Perspectives*. pp. 1-21. Atlanta. Springer-Science + Business Media, B.V.

Su, W. F. (2013) Radical Chain Polymerization. in *Principle of Polymer Design and Synthesis*.Berlin, Heidelberg. Springer.

Sundaresan, K., Sivakumar, A., Vigneswaran, C. & Ramachandran, T. (2011) Influence of Nano Titanium Dioxide Finish, Prepared by Sol-Gel Technique, on the Ultraviolet Protection, Antimicrobial and Self-Cleaning Characteristics of Cotton Fabrics. *Journal of Industrial Textile*. 0(00): 1-19.

Timochenco, L., Grassi, V.G., Pizzol, M.D., Costa, J.M., Castellares, L.G., Sayer, C., Machado, R.A.F. & Araujo, P.H.H. (2010). Swelling of Organoclays in Styrene. Effect on Flammability in Polystyrene Nanocomposites. *Express Polymer Letter.* 4(8):500-508.

Tryk, D. A., Fujishima, A., & Honda, K. (2000) Recent Topics in Photoelectrochemistry: Achievements and Future Prospects. *Electrochimica Acta*. 45(15-16): 2363-2376.

UNCTAD secretariat, based on International Cotton Advisory Committee (ICAC) statistics. (2011). Washington D.C. Secretariat of the International Cotton Advisory Committee.

Wang, Y., Xue, X., & Yang, H (2014). Preparation and Characterization of Carbon or/and Boron-doped Titania Nano-materials with Antibacterial Activity. *Ceramics International*. 40 (8, Part A): 12533-12537.

Wasif, A. I. & Indi, Y. M. (2009). Combined Scouring-Bleaching of Cotton Using Potassium Persulphate. *Indian Journal of Fibre & Textile Research*. 35:353-357.

Wong, C. L., Tan, Y. N., & Mohamed A. R. (2011). A Review on The Formation of Titania Nanotube Photocatalysts by Hydrothermal Treatment. *Journal of Environment Management*. 92(7): 1669-1680.

Wu, H., Wu, S., Wu, I. & Chang, F. (2001). Novel determination of the crystallinity of syndiotactic polystyrene using FTIR spectrum. *Polymer*, 42(10):4719--4725.

Xin, J. H., Daoud, W. A. & Kong, Y. Y.(2004) A New Approach to UV-Blocking Treatment for Cotton Fabrics. *Textile Research Journal*. 74(2):97-100.

Yaghoubidoust, F., Wicaksono, D.H.B., Chandren, S. & Nur, H. (2014). Effect of Graphene Oxide on the Structural and Electrochemical Behaviour of Polypyrrole Deposited on Cotton Fabric. *Journal of Molecular Structure.* 1075:486-493.

Yeo, S. Y., Lee, H. J. & Jeong, S. H. (2003) Preparation of Nanocomposite Fibers for Permanent Antibacterial Effect. *Journal of Materials Science*. 38(10):2143-2147.

Yilmaz, B. & Muller, U. (2009). Catalytic Application of Zeolites in Chemical Industry. *Topics in Catalysis*. 52: 888-895.

Yuan, L. S., Razali, R. Efendi, J. Buang, N. A. & Nur, H. (2013). Temperature-Controlled Selectivity in Oxidation of 1-Octene by Using Aqueous Hydrogen Peroxide in Phase-Boundary Catalytic System. *Applied Catalysis A: General*. 460-461:21-25.

Zhang, X., Zhu, L. & Sun, R. (2014) Structure and Properties of Cotton Fibers Modified with Titanium Sulfate and Urea under Hydrothermal Conditions. *Journal of engineered Fibers and Fabrics*. 9(1):67-75.

Zheng, L., Zhang, X., Li, Q., Chikkannanavar, S. B., Li, Y., Zhao, Y., Liao, X., Jia, Q., Doorn, S. K., Peterson, D. E. & Zhu, Y. (2007). Carbon-Nanotube Cotton for Large-Scale Fibers. *Advanced Materials*. 19:2567-2570.

LIST OF CONFERENCES RELATED TO THIS RESEARCH

1. Razali, R., Yuan, L. S., Nur, H. & Buang, N. A. "Strategy of Attachment Catalyst Active Site on Cotton Textile by Layering Technique", poster presentation at The International Postgraduate Conference on Science and Mathematics (IPCSM), 5-6 October 2013, e-Leraning Building Universiti Pendidikan Sultan Idris, Tanjung Malim, Perak, Malaysia.

2. Razali, R., Yuan, L. S., Nur, H. & Buang, N. A. "Preparation of Gold-Loaded Textile as Catalyst in Phase-Boundary Catalytic System", poster presentation at Technology, Education and Science International Conference (TESIC), 20-21 November 2013, Universiti Teknologi Malaysia, Skudai, Johor, Malaysia.

3. Razali, R., Yuan, L. S., Nur, H. & Buang, N. A." New Layer Catalyst for Application of Phase Boundary Catalysis System" poster presentation at 8th Southest Asean Technical University Consortium Symposium (SEATUC), 3-5 March 2014, M-Suites Hotel, Johor Bahru , Malaysia.

4. Razali, R., Yuan, L. S., Chandren, S., Nur, H. & Buang, N. A. "Layer Catalyst As New Catalyst For Phase Boundary Catalysis System" poster presentation at Twelfth Regional Annual Fundamental Sciences Symposium (RAFSS), 8-10 September 2014, Persada Johor International Convention Centre, Johor Bahru, Malaysia.