Effect of Zirconia and Nickel Doping on the Reduction Behavior of Tungsten Oxide in Carbon Monoxide Atmosphere

Fairous Salleh, Tengku Shafazila Tengku Saharuddin, Alinda Samsuri, Rizafizah Othaman, and Mohd. Ambar Yarmo

Abstract—The reduction of undoped tungsten oxide (WO\(_3\)) and doped tungsten oxide has been studied by using temperature programmed reduction (TPR) and characterized by X-ray diffraction (XRD), Brunauer–Emmett–Teller (BET) and transmission electron microscope (TEM) analysis. Zirconia (Zr) and nickel (Ni) doped tungsten powder were prepared by impregnation method. The effect of Zr and Ni doping on reduction of WO\(_3\) and the effect of holding time on reduction were also studied. The reduction behavior were examined by nonisothermal reduction up to 900 °C then continued with isothermal reduction at 900 °C for 45 min under (40 %v/v) carbon monoxide in nitrogen (CO in N\(_2\)) atmosphere. The results show that, TPR spectra of doped powder slightly shift to a lower temperature (°C) as compared to the undoped WO\(_3\). The reduction steps involved in the undoped WO\(_3\), 10 mol% Zr and 10 mol% Ni to WO\(_3\) were found WO\(_3\) → WO\(_2\) and W, WO\(_3\) → WO\(_2\), W and W\(_2\)C and WO\(_3\) → WC and Ni\(_{0.96}\)O\(_{0.04}\) respectively. The carbide formation from reduction WO\(_3\) in this study revealed that WO\(_2\) and W could transform to carbide in excess of CO introduction. The ability to enhance the reducibility involved in WO\(_3\) may associate to the presence of zirconium tungsten (Zr(WO\(_3\))\(_2\)) compound and nickel tungsten oxide (NiWO\(_4\)).

Index Terms—Carbon monoxide, nickel, tungsten, tungsten oxide, zirconia.

I. INTRODUCTION

Tungsten can form as hard steel-grey metal that is often brittle and hard to work. Among other metal in pure form, tungsten has high melting point (3422 °C), high hardness (3.43 GPa), high boiling point, low evaporation rate at high temperature and low thermal expansion coefficient (4.5x10\(^{-6}\) K\(^{-1}\)) [1]. The demand for tungsten is increasing in industries due to its good mechanical, electrical, electro erosive properties. As a results, it is the most commonly used metal for high temperature applications such as filament in light bulbs, rocket nozzles in spacecraft [2].

However, about 60 % uses of tungsten in hard-metals industry as tungsten carbide (WC). It is due to their good in hardness which close to diamond and has great abrasion, low coefficient of thermal expansion and corrosion resistance. The properties is crucial in manufacturing industry for metal, forming tools and dies, mining and abrasive tools which can be employed in high pressure, temperature, and corrosion circumstances [3, 4].

Tungsten oxides are most frequently used as starting material for producing metal tungsten powder [5] whereas, tungsten carbide synthesized by a solid-state reaction between W metal and C at 1200 – 2000 °C under controlled atmosphere [6].

Several of method for reduction of WO\(_3\) has widely been studied. Reduction of WO\(_3\) powders by hydrogen is one of the widely used methods to obtain metallic tungsten of high purity. Reference [7] reported that WO\(_3\) is completely reduced to metallic at 800 °C in hydrogen atmosphere via formation of intermediate phases WO\(_{2.72}\) (~ 520 °C) and WO\(_2\) (~ 600 °C).

Moreover, carbon monoxide also can be used as a reducing agent [8] was studied the reduction of WO\(_3\) with carbon monoxide by using TGA. The intermediate phases W\(_{20}\)O\(_{49}\), W\(_{18}\)O\(_{40}\) and WO\(_3\) were observed in the reduction, and the final product is WC. Generally hydrogen reduction of tungsten oxide divided into two stages: (i) a low-temperature stage (< 777 °C) which can reduce WO\(_3\) → WO\(_2\) involving formation and reduction of three intermediate suboxide of (WO\(_2\))\(_{0.96}\), WO\(_{2.9}\) and WO\(_{2.72}\), and (ii) high temperature stage (> 777 °C) which reduce WO\(_2\) to WC[9].

Other than reducing agent, a foreign element could also influence WO\(_3\) reduction by altering the reaction sequence and/or by changing nucleation and growth [10]. Reference [11] explored the zirconia-supported tungsten oxide reduction by methane reforming. The reduction divided into three stages namely: the reduction of WO\(_3\) to WO\(_2\), reduction of WO\(_2\) to W and then significant methane decomposition. The optimal operating temperature range was 900 to 1000 °C [11]. Addition of ZrO\(_2\) to WO\(_2\) can enhance their catalytic activity and stability by improving their oxygen storage capacity, reducibility, and resistance to sintering effect [12].

The reduction and carburization of NiO-WO\(_3\) mixture was performed to prepare homogenous Ni-WC composite powders. Reduction of WO\(_3\) occurred at temperatures higher than 650 °C. It has been reported at temperatures above 900 °C, the carburization to WC take place, otherwise W\(_2\)C would be the primary carbide [3].

The reduction of WO\(_3\) was investigated under 40 % CO in N\(_2\) as a reducing agent by using the temperature programmed
reduction (TPR) and characterized by XRD. The objectives of this work are to enhance the reduction behavior by study the influence of different type of doping agents on reduction behavior and investigated the reduction product produced by varying holding reaction time.

II. MATERIALS AND METHODS

A. Chemical and Raw Materials

Powder of model (commercial) tungsten metal (IV) oxides WO₃ ≥ 99%, zirconyl chloride octahydrate, Cl₂OZr.8H₂O (98+%) from Acros Organics, nickel nitrate, Ni(NO₃)₂.6H₂O from Merck and ethanol, C₂H₅OH (99.5%) from Systerm® are pure and used as supplied.

B. Catalyst Preparation

Two different doped tungsten oxides: zirconia and nickel were prepared by impregnation method. The impregnation was prepared by using a zirconyl chloride octahydrate (Cl₂OZr.8H₂O) and tungsten trioxide (WO₃) powder. The amount of zirconia added was 10 mol% of total metal cation. Moreover, for 10 mol% of Ni-WO₃ was prepared by using nickel nitrate (Ni(NO₃)₂.6H₂O) and WO₃. The compounds were dissolved in water with additional of ethanol at 60°C with stirring for 4 hours, producing a viscous mixture. The solution was evaporated to dryness while stirring for 4 hours, then dried at 120 °C overnight followed by calcination in air at 600°C for 4 hours. The calcined solid was crushed and stored in a vial.

C. Temperature Programmed Reduction (TPR)

Reduction of the undoped WO₃, zirconia doped WO₃ and nickel doped WO₃ were performed by using a Micromeritics Autochem 2920 Chemisorption Analyzer apparatus. The completeness of the reduction of the powder was analysed using a temperature programmed reduction (TPR) method. 5 – 7 mg of the samples were carried out in nonisothermal mode up to 900 °C under streaming gas mixture of 40 % of CO in N₂ with a heating rate of 10 °C/min with flow gas carrier rates 20 ml/min. Then, the experiment continued for isothermal mode hold for 15, 30 and 45 min at 900 °C.

D. Characterization

XRD analysis of test samples was performed by using XRD’s Bruker AXS D8 Advance type with X-ray radiation source of Cu Kα (40kV, 40 mA) to record the 20 diffraction angle from 10° to 80° at wavelength (λ = 0.154 nm) of 1 g sample. For identification purposes of crystalline phase composition, diffraction pattern obtained were matched with standard diffraction data (JCPDS) files.

Nitrogen adsorption at 77 K (liquid nitrogen) was conducted using a Micromeritics ASAP 2010 instrument to obtain the adsorption isotherm of each sample. The Brunauer–Emmett–Teller (BET) surface area, micropores volume and micropores area were also calculated from the isotherms plot. Before analyses were done, samples were degassed at 200 °C for 4 hours.

The TEM analysis was performed using a Philips CM12 transmission electron microscope with an electron gun at 200 kV. Samples were dispersed in ethanol using supersonic waves and then placed on Cu grids under atmospheric condition.

III. RESULTS AND DISCUSSION

A. Characterization of Undoped and Doped WO₃ Using XRD

XRD spectra of as prepared undoped and doped WO₃ obtained after calcination at 600°C are shown in Fig. 1. All peaks in the diffraction pattern of undoped WO₃ were assigned to the stoichiometric monoclinic phase (JCPDS 1-072-0677). Addition of 10 mol% of Zr to WO₃ there is minimal change observed with respect to displays of zirconium oxide (ZrO₂) and zirconium tungsten (Zr(WO₄)₂) phase appear, indicating in a primarily WO₃ based structure. Moreover, addition of 10 mol% Ni there was a changes observed with respect to presence of complex oxide of nickel tungsten oxide (NiWO₄).

![Fig. 1. XRD patterns of the fresh undoped WO₃, 10 mol% Zr-WO₃ and 10 mol% Ni-WO₃ samples obtained after calcination at 600 °C for 4 hours.](image)

B. Physical Surface Analysis (BET)

BET surface area (S_{BET}) of the undoped WO₃ and Zr and Ni doped WO₃ catalysts are summarized in Table I. Surface area of undoped WO₃ was 2.20 m²/g. While, surface area of doped tungsten oxide for 10 mol% Zr and 10 mol% Ni doped tungsten oxide were 3.75 and 3.79 m²/g respectively. It was found the surface area was increase with addition of Zr and Ni to WO₃. This could suggest that there was more active sites that might be attributed to the lower temperature reduction of WO₃ after doping. Hence, the addition can significantly increase the surface area.

<table>
<thead>
<tr>
<th>Compounds</th>
<th>Surface Area (m²/g)</th>
<th>Pore Size (nm)</th>
<th>Pore Volume (cm³/g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Undoped WO₃</td>
<td>2.20</td>
<td>16.92</td>
<td>0.009</td>
</tr>
<tr>
<td>10% Zr-WO₃</td>
<td>3.75</td>
<td>12.89</td>
<td>0.012</td>
</tr>
<tr>
<td>10% Ni-WO₃</td>
<td>3.79</td>
<td>18.39</td>
<td>0.017</td>
</tr>
</tbody>
</table>

Pore size of undoped WO₃ was 16.92 nm, by addition of 10 mol% Zr and 10 mol% Ni Zr to WO₃ were 12.89 and 18.39 nm respectively. It was found that the pore size increasing by addition of Ni. Moreover the pore volume for undoped was 0.009 cm³/g, by addition of Zr and Ni the pore volume were increased to 0.012 and 0.017 cm³/g respectively. It could be due to more pore volume were filled with metal doping.
C. Surface Morphology by TEM

TEM analysis has shown the morphology of undoped and doped WO$_3$ shown in Fig. 2. By addition of Zr, the structure observed seems agglomerate and not clearly differentiating with TEM. However effect of addition of 10 mol% Zr resulted in presence of new peaks of zirconium tungsten oxide (Zr(WO$_4$)$_2$) and zirconium oxide (ZrO$_2$), whereas 10 mol% of Ni resulted in presence of complex oxide of nickel tungsten oxide, NiWO$_3$ which supported with XRD results shown in Fig. 1.

![TEM microstructures of (a)WO$_3$ powder (b) 10 mol% Zr-WO$_3$ and (c) 10 mol% Ni-WO$_3$ calcined at 600 °C for 4 hours.](image)

D. Temperature Programmed Reduction (TPR)

Nonisothermal TPR profiles obtained in a carbon monoxide atmosphere (40% CO in N$_2$) for the WO$_3$, 10 mol% Ni-WO$_3$, and 10 mol% Zr-WO$_3$ were compared. The TPR profile of nonisothermal reduction until 900 °C then continued with isothermal reduction at 900 °C for 45 min shown in Fig. 3. Generation of carbon dioxide (CO$_2$) as product gas was observed and measured by TCD signal.

The TPR profile (a) of undoped WO$_3$ is observed as a broad shoulder indicates that reduction does not commence detectably due to low rate of reaction occurred lead to low TCD signal. However, small reduction to suboxide WO$_{2.9}$ of undoped WO$_3$ begins at temperature 600 °C. After holding the temperature constants at 900 °C (78 min) for approximately 45 min, a new peak which denoted as I observed at 80 min. This peak attributed to the formation of suboxide W$_{18}$O$_{49}$(more) and WO$_2$(less). However reduction of WO$_3$ thus produced might be that responsible for the following incomplete peak commencing near holding time at 45 min. Reduction step WO$_3$ → WO$_{2.92}$ in undoped WO$_3$ sample was not detected due to low signal. It is comparable to previous literature reported [9] reduction WO$_3$ by (5% H$_2$/N$_2$) which give two peaks at 696 °C and 867°C which represent reduction of WO$_3$ to suboxide WO$_{2.9}$ and WO$_{2.5}$ to WO$_2$ respectively.

The shoulder and peak monitored in profile (b) were denoted as I and II at approximately 40 min and 87 min respectively for 10 mol% Zr-WO$_3$. The low peak I observed at 482 °C represents to reduction of WO$_3$ to WO$_{2.92}$ in agreement with previous study which small peak arising at ~ 600 °C which attributed to the WO$_3$ → WO$_{2.92}$ reduction step [13]. WO$_3$ first reduce to WO$_{2.92}$, after reached temperature 900 °C, the reaction continued for 45 min, peak detoned as II appears which represent for WO$_3$O$_{29}$ (less) to WO$_2$(more). The incomplete peak beginning near at holding time at 45 min might probably responsible for reduction of WO$_3$ to W.

It is clearly show that addition of Zr to WO$_3$ could give remarkable influence on the reduction process of the powder. TPR spectra of Zr doped powder had been shifted to a lower temperature, 482 °C compared to reduction of undoped WO$_3$ that reduce to WO$_{2.92}$ at temperature 600 °C.

The TPR profile (c) represents 10 wt% Ni-WO$_3$ assigned three reduction events (denoted I, II, and III). At early reduction time represent by event I owing to shoulder and small peak at 428 °C which may regarding to the reduction of WO$_3$ to W$_{18}$O$_{49}$. Event II and III were observed sharp peaks with high TCD signal compared to event I. Event II which belongs at peak 830 °C subsequent to reduction steps of W$_{18}$O$_{49}$ to partially WO$_2$ and W. After hold the reaction for 15 min, new peak appeared which denoted to peak III, which is attributed to the WO$_3$ reduce completely to WO$_2$ and start to form tungsten carbide, WC. The TPR results obviously show that the reduction peak of 10 mol% Ni doped WO$_3$ are slightly shifts to lower temperature (428 °C) by enhance the reduction to form W$_{18}$O$_{49}$ as compared with the pure WO$_3$. The interaction between Ni and W ions leads to this slightly decrease of the reduction temperature of Ni doped WO$_3$.

![TPR profile nonisothermal reduction of undoped WO$_3$, 10 mol% Zr-WO$_3$, and 10 mol%Ni-WO$_3$ at temperature 900 °C and maintained for 45 min under 40% (CO in N$_2$) atmosphere.](image)

E. Reduction Based on Crystallinity

Final product of the reduction composition of doped WO$_3$ was compared to undoped WO$_3$. The final product was under go reduction at temperature 900 °C, and maintained at different holding time as 15, 30, and 45 min. The reduction products obtained in different holding time were collected to study the x-ray diffraction pattern of the product of reaction.

XRD analysis in sample collected after nonisothermal reduction under 40% (CO in N$_2$) at 900 °C is shown in Fig 4. XRD analysis of reduced undoped WO$_3$ shows formation of suboxide W$_{18}$O$_{49}$ assigned (JCPDS 01-084-1516), small amount WO$_2$ (JCPDS 01-0871-0614), and some unreduced WO$_3$ (JCPDS 01-075-2072). As the addition 10 mol% of Zr to WO$_3$, the majority of WO$_3$ peaks reduced to suboxide W$_{18}$O$_{49}$ and some WO$_2$ peak observed. Peaks of ZrO$_2$ were also detected but almost undetected. Whereas, addition of 10 mol% Ni, the WO$_3$ phase were totally disappeared, but W$_{18}$O$_{49}$ was present as the dominant species, a few peak of WO$_3$ and new alloy peak of Ni$_4$W (JCPDS 03-065-2673) was detected. It was clearly can be concluded that addition of Zr and Ni enhanced the WO$_3$ reducibility. However reduction product by addition of Ni shown low intensity of crystalline phase of W$_{18}$O$_{49}$ due to further reduce to WO$_2$ in comparison.
of reduction product by addition of Zr which shown higher intensity.

Fig. 4. XRD patterns of non-isothermal reduction of undoped WO$_3$, 10 mol% Zr-WO$_3$ and 10 mol% Ni-WO$_3$ at temperature up to 900°C under 40% (CO in N$_2$) atmosphere.

Isothermal reduction was applied to further reduce the samples. The reaction was conducted at temperature 900°C and maintained at several holding time. Fig. 5 shows the XRD patterns of isothermal reduction for 15 min by comparing with undoped WO$_3$, 10 mol% Ni-WO$_3$, and 10 mol% Zr-WO$_3$. After hold for 15 min in reduction of undoped WO$_3$, remaining unreduced WO$_3$ in nonisothermal reduction was further reduce to W$_{18}$O$_{49}$, some of remaining W$_{18}$O$_{49}$ reduced to WO$_2$ and one peak with low intensity of W (JCPDS 04-0806) were observed. Moreover, reduction of 10 mol% Zr-WO$_3$ was completely reduced to WO$_2$ with one small peak of W$_{18}$O$_{49}$ observed by holding for 15 min at 900°C. Peaks of WO$_2$ were also observed in the XRD pattern for 10 mol% Ni-WO$_3$ as a result of further reduction for 15 min of remaining W$_{18}$O$_{49}$. However, there a few new peaks appeared such Ni$_3$W$_8$C$_2$ (JCPDS 20-0796), Ni$_3$W$_8$C (JCPDS 01-078-5006), Ni (JCPDS 1-077-9326), W (JCPDS 4-0806), and WC (JCPDS 051-093). After flowing with CO gas for 15 min lead to formation of tungsten carbide, WC. It is resulted from excess of CO supply to the samples, which converted WO$_2$ remained in nonisothermal to WC [14].

Fig. 5. XRD patterns of non-isothermal reduction of undoped WO$_3$, 10 mol% Zr-WO$_3$ and 10 mol% Ni-WO$_3$ at temperature up to 900°C and maintained at 900°C for 15 min under 40% (CO in N$_2$) atmosphere.

The reductions of samples were repeated with similar condition but increasing the holding reaction time to 45 min. From the XRD results in Fig. 6, the reduction product of undoped WO$_3$ identifying peaks predominantly WO$_2$ phase and three peaks of W metal. Prolong the reduction time to 45 min of 10 mol% Zr-WO$_3$ lead to increasing the formation of W$_7$C peaks and increasing the intensity of W$_7$C peak instead of remaining WO$_2$ peaks observed. Reference [3] have reported that carburization to WC takes place at temperatures above 900°C, otherwise W$_7$C would be the primary carbide formed.

The XRD pattern of reduced sample of 10 mol% Ni-WO$_3$ shows the structure comprised primarily of WC, two small peaks of Ni$_{0.98}$C$_{0.02}$ (JCPDS 1-074-5561) and no W phase observed. The formation of WC may also transform from W metal, it can be seen in the reduction of 10 mol% Ni-WO$_3$ where the intensity of W peak decrease sharply after hold for 45 min, compared to peak observed in reaction which hold for 30 min. It was in agreement with previous study [8], where the formation of WC may be either from WO$_3$ or W.

Furthermore, additions of Ni to WO$_3$ lead to a facilitated reduction and carburization which due to catalytic effect of Ni which enhances the CO adsorption [3]. However, addition of Zr to WO$_3$ enhanced the reducibility by lowering the reduction temperature.

The extent of reaction to 30 min for 10 mol% Ni-WO$_3$ lead to disappearance of WO$_2$ peak due to the reaction with excess CO to form high intensity of WC (JCPDS 51-0939), small peak of Ni (JCPDS 1-077-939) and W metal. Formation of phase of WC in reduction of 10 mol% Zr-WO$_3$ is probably due to transformation of WO$_2$ to WC [7].

Fig. 6. XRD patterns of non-isothermal reduction of undoped WO$_3$, 10wt% Zr-WO$_3$ and 10wt% Ni-WO$_3$ at temperature up to 900°C and maintained 900°C for 30 min under 40% (CO in N$_2$) atmosphere.

The reduction of sample was repeated with similar condition but increasing the holding reaction time to 45 min. From the XRD results in Fig. 7, the reduction product of undoped WO$_3$ identifying peaks predominantly WO$_2$ phase and three peaks of W metal. Prolong the reduction time to 45 min of 10 mol% Zr-WO$_3$ lead to increasing the formation of W$_7$C peaks and increasing the intensity of W$_7$C peak instead of remaining WO$_2$ peaks observed. Reference [3] have reported that carburization to WC takes place at temperatures above 900°C, otherwise W$_7$C would be the primary carbide formed.

The XRD pattern of reduced sample of 10 mol% Ni-WO$_3$ shows the structure comprised primarily of WC, two small peaks of Ni$_{0.98}$C$_{0.02}$ (JCPDS 1-074-5561) and no W phase observed. The formation of WC may also transform from W metal, it can be seen in the reduction of 10 mol% Ni-WO$_3$ where the intensity of W peak decrease sharply after hold for 45 min, compared to peak observed in reaction which hold for 30 min. It was in agreement with previous study [8], where the formation of WC may be either from WO$_3$ or W.

Furthermore, additions of Ni to WO$_3$ lead to a facilitated reduction and carburization which due to catalytic effect of Ni which enhances the CO adsorption [3]. However, addition of Zr to WO$_3$ enhanced the reducibility by lowering the reduction temperature.

Fig. 7. XRD patterns of non-isothermal reduction of undoped WO$_3$, 10 mol% Zr-WO$_3$ and 10 mol% Ni-WO$_3$ at temperature up to 900°C and maintained 900°C for 45 min under 40% (CO in N$_2$) atmosphere.
It can be concluded that, increasing the reaction time in the reduction process could improve the reducibility of the WO₃ [15]. Different holding time will produce different reduction products due to different interaction with reducing agents towards changes in reduction phases. Reduction at temperature 900 °C and hold for 45 min in undoped WO₃ and 10 mol% Zr, were completely reduced to WO₂ with low intensity of W metal peak. W₂C also form in 10 mol % Zr. However, by addition of 10 % mol Ni, the WO₃ was completely reduced to WC and Ni₀.96C₀.04.

IV. CONCLUSION

The reduction behaviour of undoped WO₃ and different doped WO₃ were investigated. It can be concluded that reduction WO₃ obeys the consecutive steps namely: as WO₃ → WO₂₉₂ → W₁₉₂O₉₉ → WO₂ → W→ W₂C → WC. The addition of Zr had a remarkable influence on the reduction process of the powder by improving their oxygen storage capacity and reducibility. Furthermore, addition of Ni for WO₃ reduction have tendency for the formation of WC due to the catalytic effect. Moreover by hold the reduction time could improve the reducibility of the sample oxide. The reducibility of unreduced WO₃ could be enhancing by increase the concentration of CO or increase the holding time of reduction.

ACKNOWLEDGMENT

The authors wish to thank Ministry of Higher Education (MOHE) and Universiti Kebangsaan Malaysia (UKM) for funding this project under research grant number BKB-P-FST-K003323-2014, FRGS/2/2013/TK06/UKM/02/3, ETP-2013-066, TD-2014-024 and Centre of Research and Innovation Management (CRIM) for the instruments facilities.

REFERENCES


Fairous Salleh was born on May 20, 1983 in Kuantan, Pahang, Malaysia. She obtained her bachelor of science with honours in resource chemistry from Universiti Malaysia Sarawak (UNIMAS), Malaysia in 2005, and her master of science by research from Universiti Teknologi Mara Malaysia (UiTM), Malaysia in 2011. She is currently a full time PhD candidate at School of Chemical Sciences and Food Technology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia (UKM). She experienced working as a lecturer in Kolek Tektonlogi Timur (KTT), Sepang, Malaysia for almost 2 years. Her research interests are in photocatalysis water splitting, thermocatalysis water splitting and electrolysis of water. She also interested in the catalytic gasification and pyrolysis, fuel and energy recovery from waste and waste-to-wealth. She had won several awards including silver medal in invention, innovation and design, R&D competition by Universiti Teknologi Maran Malaysia (UiTM) 2009.

Tengku Shafazila bt Tengku Saharuddin earned his BSc in petroleum chemistry from Universiti Putra Malaysia in 2005 and MSc degree in science from Universiti Teknologi Mara, Malaysia in 2012. She is currently a third year doctoral student at School of Chemical Science and Food Technology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia (UKM). She experienced working as a chemistry lecturer at Kolek Teknologi Timur, Sepang, Malaysia for 2 years. Her research interests are in areas of water splitting for hydrogen production, renewable energy, reaction kinetics, reaction mechanisms and heterogeneous catalysts development.

Alinda Samsuri earned her bachelor of science in analytical and environmental chemistry from Universiti Malaysia Terengganu (UMT), Malaysia in 2008 and her master of science in analytical chemistry and instrumental analysis from Universiti Malaya (UM), Malaysia in 2010. She has been a tutor of the Centre for Defence Foundation Studies, Universiti Pertahanan Nasional Malaysia (UPNM), Malaysia since 2011. She experienced working in product development technologies in Fonterra Brands Malaysia for 2 years. She currently a PhD candidate at School of Chemical Sciences and Food Technology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia (UKM), Malaysia. Her research interests are in field of hydrogen production as a renewable energy by photocatalysis water splitting, thermocatalysis water splitting and electrolysis of water. She also interested in the development of homogeneous catalyst for hydrogen production application.

393
Rizafizah Othaman obtained her bachelor in chemical engineering from Tokyo Institute of Technology, Japan in 1999, master degree in chemical engineering and process from Universiti Kebangsaan Malaysia in 2004 and Doctor of engineering from Tokyo Institute of Technology, Japan in 2010.

She is currently a senior lecturer and head of the chemical technology programme at School of Chemical Sciences and Food Technology, Faculty of Science and Technology, Universiti Kebangsaan Malaysia (UKM). She experienced working as a chemical engineer specialized in electroless NiP plating with Showa Aluminium Malaysia for 2 years before being offered as chemistry lecturer at Japanese Associate Degree programme (JAD), a twinning programme for higher education between YPM Malaysia and Japan Universities Consortium. Her research interests are in the field of polymeric membrane development for renewable energy applications, wastewater treatments and gas separation, process development via catalysis and chemistry outreach and education.

Dr. Rizafizah Othaman is also a fellow member of Polymer Research Center and the Centre for Water Research and Analysis (ALIR) at UKM. She is a registered engineer with Board of Engineers Malaysia. She was awarded with Monbukagakusho Scholarship from Japanese Government during her PhD study. She had won several awards including silver medal in Brussel INOVA 2013 Competition and Bronze in PECIPTA 2013.

Mohd. Ambar Yarmo received his BSc in chemistry from Universiti Kebangsaan Malaysia (UKM) and his Ph.D in analytical chemistry from University Of Wales, Cardiff, U.K. He was born at Johor, Malaysia.

His research interests are in conversion of CO₂ to Fuel, bio-ethanol derivatives and biofuel applications, upgrading of natural gas and palm oil to higher added value speciality chemicals using combinatorial technologies and catalysis. He has attended to Japanese scientific exchange programme under JSPS-VCC programme in 1988. He was a visiting scientist at Petronas Research and scientific services in 1995. He has research collaboration with Fritz Haber Institute, Max Planck Society, Berlin, Germany in 2002.

He was the outstanding UKM lecturer in research and teaching in 2000, 2002 and 2005. He is the chairman of Xapp-MNS (X-ray Application Society), Malaysian Nuclear Society. He is a senior member of International Zeolite Association (IZA, USA), Malaysian Analytical Member Society (ANALIST) and Malaysian Nuclear Society.