UTILIZATION OF PALM OIL FUEL ASH (POFA) AS SILICA SOURCE OF Ni/SBA-15 FOR CO_2 REFORMING OF CH_4

NORNASUHA BINTI ABDULLAH

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Master of Science.

(Supervisor's Signature)

Full Name : DR. NURUL AINI BINTI MOHAMED RAZALI

Position : SENIOR LECTURER

Date : 16 MAY 2019

(Co-supervisor's Signature)

Full Name : DR. HERMA DINA BT SETIABUDI

Position : SENIOR LECTURER

Date : 16 MAY 2019

Universiti Malaysia PAHANG
Engineering • Technology • Creativity

STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

____

(Student's Signature)

Full Name : NORNASUHA BINTI ABDULLAH

ID Number : MKC16030

Date : 16 MAY 2019

UTILIZATION OF PALM OIL FUEL ASH (POFA) AS SILICA SOURCE OF Ni/SBA-15 FOR CO_2 REFORMING OF CH_4

NORNASUHA BINTI ABDULLAH

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Master of Science

Faculty of Chemical and Natural Resources Engineering

UNIVERSITI MALAYSIA PAHANG

MAY 2019

ACKNOWLEDGEMENTS

Alhamdulillah to Allah S.W.T for granting me with good health and golden chances to explore His knowledge and guided me to the right path in completing this Master project. I would like to say thank you so much to my parents, Mr. Abdullah bin Mat Dris and Madam Rosnah binti Zainun, my family members and my supervisors, Dr Nurul Aini binti Mohamed Razali and Dr Herma Dina binti Setiabudi for guiding me through this project at every stage with clarity and also for their willingness to share their valuable ideas as well as their knowledge with me.

Besides, my honest appreciation also to staffs of Faculty of Chemical Engineering and Natural Resources who have put in great effort to assist and guide me with valuable advices. To my dear colleagues whom openhandedly guided, assisted, supported and encouraged me to make this project successful, my deepest thanks. Lastly, my deep appreciation for the financial assistance by Research Acculturation Grant Scheme (RDU151414) and UMP Research Grant Scheme (RDU170330 & RDU1803184).

ABSTRAK

Karbon dioksida (CO_2) dan metana (CH_4) adalah penyumbang utama kepada gas rumah hijau (GRH) dengan komposisi 81% dan 10% yang membawa kepada pemanasan global. CO_2 pembentukkan semula CH_4 adalah proses yang sesuai untuk menukar CO_2 dan CH_4 kepada sintesis gas. Penghasilan sintesis gas daripada CO_2 pembentukkan semula CH_4 menggunakan pemangkin berasaskan Ni telah menarik perhatian ramai di seluruh dunia kerana aktiviti pemangkinnya yang baik, kos rendah, dan mudah didapati. Walau bagaimanapun, pemangkin berasaskan Ni menghadapi kelemahan yang serius dalam penyahaktifan permukaan pemangkin disebabkan oleh pembentukan kok. Pemilihan bahan sokongan yang bersesuaian didapati menjadi satu cara yang berkesan mengurangkan pembentukan kok yang tinggi pada permukaan pemangkin. Dalam kajian ini, SBA-15 telah dipilih sebagai bahan sokongan kerana sifat teksturnya yang menarik. SBA-15 boleh disintesiskan menggunakan templet dan pelbagai sumber silika seperti tetraetil orto silikat dan natrium silikat. Walau bagaimanapun, jenis prekursor silika ini tidak mesra alam dan memerlukan kos yang tinggi. Oleh itu, penggunaan bahan buangan abu minyak kelapa sawit (AMKS) sebagai sumber silika alternatif akan mengurangkan kos pengeluaran. Penyediaan POFA sodium silikat (POFA-Na_2SiO_3) telah dilakukan dengan menggunakan natrium hidroksida (NaOH) di bawah beberapa parameter termasuk nisbah jisim NaOH/POFA, suhu perlakuran, dan nisbah jisim H_2O/NaOH-POFA terlakur. Keadaan optimum telah dicapai pada nisbah NaOH/POFA jisim 2:1, suhu gabungan 550^{o}C, dan nisbah jisim H_2O/NaOH-POFA terlakur dari 4:1, dengan kandungan silika maksimum 40570 ppm. Hasil SiO_2 daripada POFA ialah 35 %. SBA-15 telah berjaya disintesis dan dibuktikan dengan keputusan XRD sudut rendah, N_2 penjerapan isoterma dan imej TEM, dengan ciri struktur meso bagi SBA-15. 3 peratus Ni telah dimuatkan pada SBA-15 menggunakan pelbagai jenis kaedah penyediaan seperti kaedah pengisitepuan (Ni/SBA-15 (IM)), kaedah bantuan penyejat berputar (Ni/SBA-15 (RE)), kaedah bantuan penggoncang (Ni/SBA-15 (SH)) dan kaedah bantuan ultrasonik (Ni / SBA-15 (US)). CO_2 pembentukkan semula CH_4 (CRM) telah disiasat dalam keluli tahan karat dengan dibungkus di katil reaktor pada 800°C dengan tekanan ambien dan suapan komposisi CO_2/CH_4 bersamaan dengan 1/1. Prestasi pemangkin tertinggi dicapai melalui Ni/SBA-15(US) dengan 81% penukaran CO_2 dan 90% penukaran CH_4. Ini disebabkan oleh penyebaran baik Ni pada permukaan pemangkin dengan beberapa Ni terletak di dalam kerangka SBA-15, interaksi Ni-O-Si yang kuat, dan asas pemangkin yang lebih tinggi. Pembentukan karbon grafit yang paling rendah pada Ni/SBA-15 (US) telah dikaitkan dengan penyebaran baik zarah Ni yang lebih kecil yang mampu menyekat pembentukan kok. Kewujudan penyinaran ultrasonik menawarkan kesan peronggaan untuk memusnahkan aglomerasi lembut zarah Ni dan dengan itu membawa kepada penyebaran Ni yang lebih baik daripada pengisitepuan konvensional (IM), kaedah bantuan penyejat berputar (RE), dan kaedah bantuan penggoncang (SH) . Kajian ini memberikan idea untuk menyediakan sifat pemangkin Ni/SBA-15 yang lebih baik untuk meningkatkan aktiviti dan kestabilan dalam proses CO_2 pembentukkan semula CH_4.

ABSTRACT

Carbon dioxide (CO_2) and methane (CH_4) are the major greenhouse gases (GHGs) with 81% and 10 %, respectively, leading to global warming. CO_2 reforming of CH_4 is a promising route to convert CO_2 and CH_4 to synthesis gas. Production of synthesis gas by CO_2 reforming of CH_4 over Ni-based catalyst has been attracted extensive attention worldwide due to its good catalytic activity, low cost, and readily available. However, Ni-based catalyst faces a serious drawback in catalyst surface deactivation by coke formation. Selection of suitable support material was found to be an effective way to reduce the coke formation on catalyst surfaces. In this study, SBA-15 has been chosen as support material due to its interesting textural properties. SBA-15 can be synthesized using templates and variety of silica sources such as tetraethyl ortosilicate and sodium silicate. However, these types of silica precursors are non-eco-friendly and high cost. Therefore, the utilization of palm oil fuel ash (POFA) waste material as an alternative silica source would minimize the cost of SBA-15 production. The preparation of POFA sodium silicate (POFA-Na_2SiO_3) was done via sodium hydroxide (NaOH) fusion method by investigating several parameters including NaOH/POFA mass ratio, fusion temperature and H_2O/NaOH-fused POFA mass ratio. The optimum condition was achieved at NaOH/POFA mass ratio of 2:1, fusion temperature of 550°C, and H_2O/NaOH-fused POFA mass ratio of 4:1, with maximum silica content of 40570 ppm. The yield of SiO_2 from POFA was 35%. The successful synthesized of SBA-15 was proved by the results of XRD low angle, N_2 adsorption-desorption isotherm, and TEM image, corresponding to the SBA-15 mesostructure characteristic. 3wt % of Ni was loaded on the synthesized SBA-15 using various preparation method including conventional impregnation (Ni/SBA-15(IM)), rotary evaporator-assisted impregnation (Ni/SBA-15(RE)), shaker-assisted impregnation (Ni/SBA-15(SH)) and ultrasonic-assisted impregnation (Ni/SBA-15(US)). CO_2 reforming of CH_4 (CRM) were investigated in a stainless steel fixed bed reactor at 800°C, atmospheric pressure and CO_2/CH_4 feed composition =1/1. The highest catalytic performance was achieved over Ni/SBA-15(US) with 81 % of CO_2 conversion and 90 % of CH_4 conversion. This is due to the well Ni distribution on the catalyst surfaces with some of the Ni were located inside the SBA-15 framework, stronger Ni-O-Si interaction, and higher catalyst basicity. Lowest formation of graphite carbon on Ni/SBA-15(US) was correlated to the well dispersion of smaller Ni particles that able to suppress the coke formation. The existence of ultrasonic irradiation offers a cavitation effect to destroy the soft agglomeration of Ni particles and thus lead to a better Ni distribution than conventional impregnation (IM), rotary evaporator-assisted impregnation (RE), and shaker-assisted impregnation (SH) methods. This study provides an idea in preparing a better properties of Ni/SBA-15 catalyst to enhance the activity and stability of CO_2 reforming of CH_4.

TABLE OF CONTENT

LIST OF TABLES

LIST OF FIGURES

LIST OF SYMBOLS

θ	Half-Braggs's angle
^{o}C	Degree Celsius
g	gram
h	hour
kg	kilogram
kJ/mol	kilo Joule per mol
kV	kilo Volt
m^2/g	meter cube per gram
Mt/year	Metric tonne per year
µm	micrometer
mg	milligram
mL	milli Liter
min	minute
nm	nanometer

LIST OF ABBREVIATIONS

Al_2O_3	Aluminium Oxide
APOFA	Acid leached –Palm Oil Fuel Ash
BET	Brunauer–Emmett–Teller
CaO	Calcium Oxide
Ce	Cerium
Comm.	Commercial
CRM	CO_2 Reforming of CH_4
CO_2-TPD	Carbon dioxide-Temperature Programed Desorption
Cu	Copper
DRM	Dry Reforming of Methane
F_{CO2}	Molar Flow Rate of Carbon Dioxide
GC	Gas Chromatography
GHGs	Greenhouse Gases
HCl	Hydrochloric Acid
HNO_3	Nitric Acid
H_2SO_4	Sulfuric Acid
ICP-OES	Inductively Coupled Plasma Optical Emission Spectrometry
IE	Ion Exchange
Ir	Iridium
MCM-41	Mobil Composition of Matter No. 41
MCM-48	Mobil Composition of Matter No. 48
MgO	Magnesium Oxide
Na_2SiO_3	Sodium Silicate
NaOH	Sodium Hydroxide
Ni	Nickel
NiO	Nickel Oxide
Ni/SBA-15(IM)	Ni/SBA prepared by Impregnation
Ni/SBA-15(RE)	Ni/SBA prepared by Rotary evaporator
Ni/SBA-15(SH)	Ni/SBA prepared by Shaker
Ni/SBA-15(US)	Ni/SBA prepared by Ultrasound
P123	Triblock copolymer pluronic 123

Pd	Palladium
PM	Physical Mixing
POFA	Palm Oil Fuel Ash
POM	Partial Oxidation of Methane
Pt	Platinum
RHA	Rice Husk Ash
Rh	Rhodium
Ru	Ruthenium
SBA-15	Santa Barbara Amorphous 15
SiO_2	Silicon Dioxide
S.S	Sodium Silicate
TCD	Thermal Conductivity Detector
TEOS	Tetraethyl ortosilicate
TEM	Transmission Electron Microscopy
TGA	Thermogravimetric Analysis
TOS	Time on Stream
XRD	X-Ray Diffraction
XRF	X-Ray Fluorescence
Wt.%	Weight percentage

REFERENCES

Abdullah, A. Z., Razali, N., & Lee, K. T. (2010). Influence of the Silica-to-Surfactant Ratio and the pH of Synthesis on the Characteristics of Mesoporous SBA-15. *Journal of Physical Science*, *21*(2), 13–27.

Al-fatesh, A., Kumar, S., Kanade, G. S., Atia, H., Fakeeha, A. H., Ibrahim, A. A., … Labhasetwar, N. K. (2018). Rh promoted and ZrO_2 /Al_2O_3 supported Ni/Co based catalysts : High activity for CO_2 reforming, steam-CO_2 reforming and oxy- CO_2 reforming of CH_4. *International Journal of Hydrogen Energy*, *43*(27), 12069–12080.

Al-mulali, M. Z., Awang, H., Khalil, H. P. S. A., & Shaker, Z. (2015). Cement & Concrete Composites The incorporation of oil palm ash in concrete as a means of recycling : A review. *Cement and Concrete Composites*, *55*, 129–138.

Albarazi, A., Beaunier, P., & Da Costa, P. (2013). Hydrogen and syngas production by methane dry reforming on SBA-15 supported nickel catalysts: On the effect of promotion by $Ce_{0.75}Zr_{0.25}O_2$ mixed oxide. *International Journal of Hydrogen Energy*, *38*, 127-139.

Albarazi, A., Gálvez, M. E., & Costa, P. Da. (2015). Synthesis strategies of ceria – zirconia doped Ni/SBA-15 catalysts for methane dry reforming. *Catalysis Communication*, *59*, 108–112.

Albayati, T. M., & Doyle, A. M. (2014). SBA-15 Supported bimetallic catalysts for enhancement isomers production during n-heptane decomposition. *International Journal of Chemical Reactor Engineering*, *12*(1), 1-10.

Alihosseinzadeh, A., Nematollahi, B., Rezaei, M., & Lay, E. N. (2015). CO methanation over Ni catalysts supported on high surface area mesoporous nanocrystalline γ-Al_2O_3 for CO removal in H_2-rich stream. *International Journal of Hydrogen Energy*, *40*(4), 1809–1819.

Altwair, N. M., Johari, M. A. M., & Hashim, S. F. S. (2012). Flexural performance of green engineered cementitious composites containing high volume of palm oil fuel ash. *Construction and Building Materials*, *37*, 518–525.

Amin, M. H., Tardio, J., & Bhargava, S. K. (2012). A Comparison Study on Carbon Dioxide Reforming of Methane Over Ni Catalysts Supported on Mesoporous SBA-15, MCM-41, KIT-6 and g-Al_2O_3. *Material*, *37*, 1454–1464.

Arbag, H., Yasyerli, S., Yasyerli, N., & Dogu, G. (2010). Activity and stability enhancement of Ni-MCM-41 catalysts by Rh incorporation for hydrogen from dry reforming of methane. *International Journal of Hydrogen Energy*, *35*(6), 2296–2304.

Awal, A. S. M. A., & Hussin, M. W. (2011). Effect of Palm Oil Fuel Ash in Controlling Heat of Hydration of Concrete. *Procedia Engineering*, *14*, 2650–2657.

Assaf, O, O., Jacobs, M., Lima, G., De, S. M., Adriana, M., Davis, B. H., & Mattos, L. V. (2010). Evaluation of the performance of Ni/La_2O_3 catalyst prepared from $LaNiO_3$ perovskite-type oxides for the production of hydrogen through steam reforming and oxidative steam reforming of ethanol. *Applied Catalysis A : General*, *377*, 181–190.

Bhagiyalakshmi, M., & Ji, Æ. L. (2010). Synthesis of chloropropylamine grafted mesoporous MCM-41, MCM-48 and SBA-15 from rice husk ash : their application to CO_2 chemisorption. *Journal Porous Maaterial*, *17*, 475–484.

Bhagiyalakshmi, M., Yun, L. J., Anuradha, R., & Jang, H. T. (2010). Utilization of rice husk ash as silica source for the synthesis of mesoporous silicas and their application to CO_2 adsorption through TREN/TEPA grafting. *Journal of Hazardous Materials*, *175*(1–3), 928–938.

Boerrigter, H., & Rauch, R. (2006). Review of applications of gases from biomass gasification. *ECN Biomass, Coal and Environmental …*, 1-33.

Cai, W., Ye, L., Zhang, L., Ren, Y., Yue, B., Chen, X., & He, H. (2014). Highly dispersed nickel-containing mesoporous silica with superior stability in carbon dioxide reforming of methane: The effect of anchoring. *Materials*, *7*(3), 2340–2355.

Chandrasekar, G., Son, W. J., & Ahn, W. S. (2009). Synthesis of mesoporous materials SBA-15 and CMK-3 from fly ash and their application for CO_2 adsorption. *Journal of Porous Materials*, *16*(5), 545–551.

Chandrasekar, G., You, K. S., Ahn, J. W., & Ahn, W. S. (2008). Synthesis of hexagonal and cubic mesoporous silica using power plant bottom ash. *Microporous and Mesoporous Materials*, *111*(1–3), 455–462.

Chandrasekhar, S., Pramada, P. N., & Majeed, J. (2006). Effect of calcination temperature and heating rate on the optical properties and reactivity of rice husk ash. *Journal of Materials Science*, *41*, 7926-7933.

Chindaprasirt, P. (2008). Resistance to chloride penetration of blended Portland cement mortar containing palm oil fuel ash, rice husk ash and fly ash, *Construction and Building Materials*, *22*, 932–938.

Chong, C. C, Abdullah, N., Bukhari, S. N., Ainirazali N., Teh, L. P., & Setiabudi, H. D. (2018). Hydrogen production via CO_2 reforming of CH_4 over low-cost Ni / SBA-15 from silica-rich palm oil fuel ash (POFA) waste. *International Journal of Hydrogen Energy*, 1–11.

Choudhary, T. V., & Choudhary, V. R. (2008). Energy-efficient syngas production through catalytic oxy-methane reforming reactions. *Angewandte Chemie - International Edition*, *47*(10), 1828–1847.

Christensen, K. O., Chen, D., Lødeng, R., & Holmen, A. (2006). Effect of supports and Ni crystal size on carbon formation and sintering during steam methane reforming. *Applied Catalysis A: General*, *314*(1), 9–22.

Da Silva, R. J. F., Dutra, A. J. B., & Afonso, J. C. (2012). Alkali fusion followed by a two-step leaching of a Brazilian zircon concentrate. *Hydrometallurgy*, *117-118*, 93-100.

Dai, A. (2011). Drought under global warming: A review. *Wiley Interdisciplinary Reviews: Climate Change*, *2*(1), 45-65.

Das, S., Thakur, S., Bag, A., Gupta, M. S., Mondal, P., & Bordoloi, A. (2015). Support interaction of Ni nanocluster based catalysts applied in CO_2 reforming. *Journal of Catalysis*, *330*, 46–60.

Della, V., Kuhn, I., & Hotza, D. (2002). Rice husk ash as an element source for active silica production. *Mater. Lett. 57*(4), 818–821.

Di Cosimo, J. I., Díez, V. K., Xu, M., Iglesia, E., & Apesteguía, C. R. (1998). Structure and surface and catalytic properties of Mg-Al basic oxides. *Journal of Catalysis*, *178*(2), 499–510.

Dou, B., Zhang, H., Cui, G., Wang, Z., Jiang, B., Wang, K. … Xu, Y. (2017). Hydrogen production and reduction of Ni-based oxygen carriers during chemical looping steam reforming of ethanol in a fixed-bed reactor. *International Journal of Hydrogen Energy*, *42*(42), 26217–26230.

Du, G., Lim, S., Pinault, M., Wang, C., Fang, F., Pfefferle, L., & Haller, G. L. (2008). Synthesis, characterization, and catalytic performance of highly dispersed vanadium grafted SBA-15 catalyst. *Journal of Catalysis*, *253*, 74-90.

El-Mogazi, D., Lisk, D. J., & Weinstein, L. H. (1988). A Review of Physical, Chemical, And Biological Properties of Fly Ash and Effects on Agricultural Ecosystems. *The Science of the Total Environment*, *74*, 1–37.

Elsayed, N. H., Roberts, N. R. M., Joseph, B., & Kuhn, J. N. (2015). Applied Catalysis B : Environmental Low temperature dry reforming of methane over Pt – Ni – Mg / ceria – zirconia catalysts. *'Applied Catalysis B, Environmental'*, *179*, 213–219.

Faizul, C. P., Abdullah, C., & Fazlul, B. (2013). Extraction of silica from palm ashvia citric acid leaching treatment. *Advances in Environmental Biology*, *7* (12), 3690–3695.

Fan, M., Abdullah, A. Z., & Bhatia, S. (2009). Catalytic Technology for Carbon Dioxide Reforming of Methane to Synthesis Gas, *1*, 192–208.

Gadalla, A. M., & Bower, B. (1988). The Role of Catalyst Support on the Activity for Reforming Methane With CO_2, *Chemical Engineering Science*, *43*(11), 3049–3062.

Ghelamallah, M., & Granger, P. (2012). Impact of barium and lanthanum incorporation to supported Pt and Rh on α-Al_2O_3 in the dry reforming of methane. *Fuel*, *97*, 269–276.

Ghorbani, F., Younesi, H., Mehraban, Z., Çelik, M. S., Ghoreyshi, A. A., & Anbia, M. (2013). Preparation and characterization of highly pure silica from sedge as agricultural waste and its utilization in the synthesis of mesoporous silica MCM-41. *Journal of the Taiwan Institute of Chemical Engineers*, *44*(5), 821–828.

Habeeb, G. A., & Mahmud, H. Bin. (2010). Study on properties of rice husk ash and its use as cement replacement material. *Materials Research*, *13*(2), 185–190.

Han, J. W., Park, J. S., Choi, M. S., & Lee, H. (2017). Uncoupling the size and support effects of Ni catalysts for dry reforming of methane. *Applied Catalysis B: Environmental*, *203*, 625–632.

Han, Y., Kim, H., Park, J., Lee, S. H., & Kim, J. Y. (2012). Influence of Ti doping level on hydrogen adsorption of mesoporous Ti-SBA-15 materials prepared by direct synthesis. *International Journal of Hydrogen Energy*, *37*(19), 14240–14247.

Hao, Z., Zhu, Q., Jiang, Z., Hou, B., & Li, H. (2008). Characterization of aerogel Ni /Al_2O_3 catalysts and investigation on their stability for CH_4-CO_2 reforming in a fluidized bed. *Fuel Processing Technology*, *90*(1), 113-121.

Hassan, M., Putla, S., Abd, S. B., & Bhargava, S. K. (2015). Applied Catalysis A : General Understanding the role of lanthanide promoters on the structure – activity of nanosized Ni/ɤ -Al_2O_3 catalysts in carbon dioxide reforming of methane. *'Applied Catalysis A, General'*, *492*, 160–168.

He, S., Mei, Z., Liu, N., Zhang, L., Lu, J., Li, X., … Luo, Y. (2017). Ni/SBA-15 catalysts for hydrogen production by ethanol steam reforming: Effect of nickel precursor. *International Journal of Hydrogen Energy*, *42*(21), 14429–14438.

Hoon, J., & Kim, Y. (2013). Ultrasonics Sonochemistry Ultrasound-assisted copper deposition on a polymer membrane and application for methanol steam reforming. *Ultrasonics - Sonochemistry*, *20*(1), 472–477.

Hosseini, S. E., Abdul, M., & Aghili, N. (2013). The scenario of greenhouse gases reduction in Malaysia. *Renewable and Sustainable Energy Reviews*, *28*, 400–409.

Hou, Z., Chen, P., Fang, H., Zheng, X., & Yashima, T. (2006). Production of synthesis gas via methane reforming with CO_2 on noble metals and small amount of noble-(Rh-) promoted Ni catalysts, *31*, 555–561

Huang, J., Ma, R., Huang, T., Zhang, A., & Huang, W. (2011). Carbon dioxide reforming of methane over Ni/Mo/SBA-15-La_2O_3 catalyst: Its characterization and catalytic performance. *Journal of Natural Gas Chemistry*, *20*(5), 465–470.

Huang, Z., Xu, C., Liu, C., Xiao, H., Chen, J., Zhang, Y., and Lei, Y. (2013). Glycerol steam reforming over Ni/γ-Al_2O_3 catalysts modified by metal oxides. *Korean J. Chem. Eng.*, *30*(3), 587–592.

Hui, K. S., & Chao, C. Y. H. (2006). Synthesis of MCM-41 from coal fly ash by a green approach : Influence of synthesis pH, *Journal of Hazardous Materials, 137*, 1135–1148.

Huirache-Acuña, R., Nava, R., Peza-Ledesma, C., Lara-Romero, J., Alonso-Núez, G., Pawelec, B., & Rivera-Muñoz, E. (2013). SBA-15 Mesoporous Silica as Catalytic Support for Hydrodesulfurization Catalysts—Review. *Materials*, 6, 4139-4167.

IPCC. (2014). *Climate Change 2014: Mitigation of Climate Change*. *Working Group III Contribution to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*, 1545.

Irfan Khan, M., Azizli, K., Sufian, S., Man, Z., & Khan, A. S. (2015). Simultaneous preparation of nano silica and iron oxide from palm oil fuel ash and thermokinetics of template removal. *RSC Adv.*, *5*(27), 20788–20799.

Jang, H. T., Park, Y., Ko, Y. S., Lee, J. Y., & Margandan, B. (2009). Highly siliceous MCM-48 from rice husk ash for CO_2 adsorption. *International Journal of Greenhouse Gas Control*, *3*(5), 545–549.

Johari, M. A. M., Zeyad, A. M., Bunnori, N. M., & Ariffin, K. S. (2012). Engineering and transport properties of high-strength green concrete containing high volume of ultrafine palm oil fuel ash. *Construction and Building Materials*, *30*, 281–288.

Kathiraser, Y., Oemar, U., Saw, E. T., Li, Z., & Kawi, S. (2015). Kinetic and mechanistic aspects for CO_2 reforming of methane over Ni based catalysts. *Chemical Engineering Journal*, *278*, 62–78.

Kaydouh, M. N., El Hassan, N., Davidson, A., Casale, S., El Zakhem, H., & Massiani, P. (2016). Highly active and stable Ni/SBA-15 catalysts prepared by a ‘two solvents’ method for dry reforming of methane. *Microporous and Mesoporous Materials*, *220*, 99–109.

Khankhaje, E., Warid, M., Mirza, J., Ra, M., Razman, M., Chin, H. … Warid, M. (2016). On blended cement and geopolymer concretes containing palm oil fuel ash, *Material and Design*, *89*, 385–398.

Khoshbin, R., & Haghighi, M. (2013). Direct syngas to DME as a clean fuel: The beneficial use of ultrasound for the preparation of CuO-ZnO-Al_2O_3/HZSM-5 nanocatalyst. *Chemical Engineering Research and Design*, *91*(6), 1111–1122.

Kim, J.-H., Suh, D. J., Park, T.-J., & Kim, K.-L. (2000). Effect of metal particle size on coking during CO_2 reforming of CH_4 over Ni–alumina aerogel catalysts. *Applied Catalysis A: General*, *197*(2), 191–200.

Kuprianov, V. I., Janvijitsakul, K., & Permchart, W. (2006). Co-firing of sugar cane bagasse with rice husk in a conical fluidized-bed combustor. *Fuel*, *85*(4), 434–442.

Li, B., Su, W., Lin, X., & Wang, X. (2017). Catalytic performance and characterization of Neodymium-containing mesoporous silica supported nickel catalysts for methane reforming to syngas. *International Journal of Hydrogen Energy*, *42*(17), 12197–12209.

Lin, Y. (2013). Catalytic valorization of glycerol to hydrogen and syngas. *Int. J. Hydrogen Energy*, *38*(6), 2678–2700.

Liu, D., Lau, R., Borgna, A., & Yang, Y. (2009). Carbon dioxide reforming of methane to synthesis gas over Ni-MCM-41 catalysts. *Applied Catalysis A*: General, 358, 110-118.

Liu, H., & He, D. (2011). Properties of Ni/Y_2O_3 and its catalytic performance in methane conversion to syngas. *International Journal of Hydrogen Energy*, *36*(22), 14447–14454.

Liu, H., Li, Y., Wu, H., Miyake, T., & He, D. (2013). CO_2 reforming of methane over Ni/SBA-15 prepared with β-cyclodextrin - Role of β-cyclodextrin in Ni dispersion and performance. *International Journal of Hydrogen Energy*, *38*(35), 15200–15209.

Liu, Q., & Tian, Y. (2017). One-pot synthesis of NiO/SBA-15 monolith catalyst with a three-dimensional framework for CO_2 methanation. *International Journal of Hydrogen Energy*, *42*(17), 12295–12300.

Lu, B., Ju, Y., & Kawamoto, K. (2014). Conversion of producer gas using NiO/SBA-15 obtained with different synthesis methods. *International Journal of Coal Science and Technology*, *1*(3), 315–320.

Manuscript, A., & Processes, T. (2013). NIH Public Access, *1693*, 258–264.

Martínez, A., López, C., Márquez, F., & Díaz, I. (2003). Fischer-Tropsch synthesis of hydrocarbons over mesoporous Co/SBA-15 catalysts: The influence of metal loading, cobalt precursor, and promoters. *Journal of Catalysis*, *220*(2), 486–499.

Moradi, G., Khezeli, F., & Hemmati, H. (2016). Syngas production with dry reforming of methane over Ni/ZSM-5 catalysts. *Journal of Natural Gas Science and Engineering*, *33*, 657-665.

Nava, R., Ledesma, C. L. P., Romero, J. L., & Nú, G. A. (2013). SBA-15 Mesoporous Silica as Catalytic Support for Hydrodesulfurization Catalysts. *Review*, *6*, 4139–4167.

Noor, Z. Z., Yusuf, R. O., Abba, A. H., Abu Hassan, M. A., & Mohd Din, M. F. (2013). An overview for energy recovery from municipal solid wastes (MSW) in Malaysia scenario. *Renewable and Sustainable Energy Reviews*, *20*, 378–384.

Norsuraya, S., Fazlena, H., & Norhasyimi, R. (2016). Sugarcane Bagasse as a Renewable Source of Silica to Synthesize Santa Barbara Amorphous-15 (SBA-15). *Procedia Engineering*, 148, 839-846.

Osmieri, L., Monteverde Videla, A. H. A., Armandi, M., & Specchia, S. (2016). Influence of different transition metals on the properties of Me–N–C (Me = Fe, Co, Cu, Zn) catalysts synthesized using SBA-15 as tubular nano-silica reactor for oxygen reduction reaction. *International Journal of Hydrogen Energy*, *41*(47), 22570–22588.

Paula, A., Peres, G., Lunelli, B. H., & Maciel FIlho, R. (2013). Application of Biomass to Hydrogen and Syngas Production. *Chem Eng Transactions*, *32*(2011), 589–594.

Pino, L., Vita, A., Cipitì, F., Laganà, M., & Recupero, V. (2011). Hydrogen production by methane tri-reforming process over Ni-ceria catalysts: Effect of La-doping. *Applied Catalysis B: Environmental*, *104*(1–2), 64–73.

Pudukudy, M., Yaakob, Z., & Akmal, Z. S. (2015). Direct decomposition of methane over Pd promoted Ni/SBA-15 catalysts. *Applied Surface Science*, *353*, 127–136.

Rahbar S. F., Rezaei, M., & Meshkani, F. (2017). The influence of Ni loading on the activity and coke formation of ultrasound-assisted co-precipitated Ni–Al_2O_3 nanocatalyst in dry reforming of methane. *International Journal of Hydrogen Energy*, *42*(7), 4155–4164.

Rahemi, N., Haghighi, M., Babaluo, A., Fallah Jafari, M., & Estifaee, P. (2013). Synthesis and Physicochemical Characterizations of Ni/Al_2O_3-ZrO_2 Nanocatalyst Prepared via Impregnation Method and Treated with Non-Thermal Plasma for CO_2 Reforming of CH_4. *Journal of Industrial and Engineering Chemistry*, *19*, 1566-1576.

Rahmani, F., Haghighi, M., Vafaeian, Y., & Estifaee, P. (2014). Hydrogen production via CO_2 reforming of methane over ZrO_2-Doped Ni/ZSM-5 nanostructured catalyst prepared by ultrasound assisted sequential impregnation method. *Journal of Power Sources*, *272*, 816–827.

Rahmat, N., Hamzah, F., Sahiron, N., Mazlan, M., & Zahari, M. M. (2016). Sodium silicate as source of silica for synthesis of mesoporous SBA-15. *IOP Conference Series: Materials Science and Engineering*, *133*(1), 1-9.

Rodrigues, J. J., André, F., Fernandes, N., Gláucia, M., & Rodrigues, F. (2013). Study of Co/SBA-15 catalysts prepared by microwave and conventional heating methods and application in Fischer–Tropsch synthesis. *'Applied Catalysis A, General'*, *468*, 32–37.

Sata, V., Jaturapitakkul, C., & Kiattikomol, K. (2004). Utilization of Palm Oil Fuel Ash in High-Strength Concrete, *Journal Material Civil Engineering*, *16*, 623–628.

Scafetta, N. (2010). Climate Change and Its Causes, A Discussion About Some Key Issues, *75*, 70–75.

Sener, C., Dogu, T., & Dogu, G. (2006). Effects of synthesis conditions on the structure of Pd incorporated MCM-41 type mesoporous nanocomposite catalytic materials with high Pd/Si ratios, *Microporous and Mesoporous Materials*, *94*, 89–98.

Setiabudi, H. D., Razak, N. S. A., Suhaimi, F. R. M., & Pauzi, F. N. (2016). CO_2 reforming of CH_4 over Ni/SBA-15: Influence of Ni-loading methods. *Malaysian Journal of Catalysis*, *1*, 1–6.

Shahid, S. (2012). Vulnerability of the power sector of Bangladesh to climate change and extreme weather events, 595–606.

Shahid, S., Minhans, A., & Che, O. (2014). Jurnal Teknologi Full paper Assessment of Greenhouse Gas Emission Reduction Measures in Transportation Sector of Malaysia, *4*, 1–8.

Sharifi, M., Haghighi, M., & Abdollahifar, M. (2014). Hydrogen production via reforming of biogas over nanostructured Ni/Y catalyst: Effect of ultrasound irradiation and Ni-content on catalyst properties and performance. *Materials Research Bulletin*, *60*, 328–340.

Sidik, S. M., Triwahyono, S., Jalil, A. A., Aziz, M. A. A., Fatah, N. A. A., & Teh, L. P. (2016). Tailoring the properties of electrolyzed Ni/mesostructured silica nanoparticles (MSN) via different Ni-loading methods for CO_2 reforming of CH_4. *Journal of CO_2 Utilization*, *13*, 71-80.

Siew, K. W., Lee, H. C., Gimbun, J., and Cheng, C. K. (2013). Hydrogen production via glycerol dry reforming over La- Ni/Al_2O_3 catalyst. *Bull. Chem. React. Eng. Catal.* *8*(2), 160–166.

Singha, R. K., Yadav, A., Agrawal, A., Shukla, A., Adak, S., Sasaki, T., & Bal, R. (2016). Synthesis of highly coke resistant Ni nanoparticles supported MgO/ZnO catalyst for reforming of methane with carbon dioxide. *Applied Catalysis B: Environmental*, *191*, 165–178.

Solymosi, F., Kutsán, G., & Erdöhelyi, A. (1991). Catalytic reaction of CH_4 with CO_2 over alumina-supported Pt metals. *Catalysis Letters*, *11*(2), 149–156.

Sousa, A. M. de, Visconte, L., Mansur, C., & Furtado, C. (2009). Silica sol obtained from rice husk ash. *Chemistry & Chemical Technology*, *3*(4), 321–326.

Sorensen, T. C. (2013). Global warming and its impacts on climate of India. *Climate Change and Global Warming*, 1–13.

Taherian, Z., Yousefpour, M., Tajally, M., & Khoshandam, B. (2017). Catalytic performance of Samaria-promoted Ni and Co/SBA-15 catalysts for dry reforming of methane. *International Journal of Hydrogen Energy*, *42*(39), 24811–24822.

Tan, M., Wang, X., Shang, X., Zou, X., Lu, X., & Ding, W. (2014). Template-free synthesis of mesoporous γ-alumina-supported Ni-Mg oxides and their catalytic properties for prereforming liquefied petroleum gas. *Journal of Catalysis*, *314*, 117–131.

Tangchirapat, W., Saeting, T., Jaturapitakkul, C., Kiattikomol, K., & Siripanichgorn, A. (2007). Use of waste ash from palm oil industry in concrete. *Waste Management*, 27, 81-88.

Taufiq-Yap, Y. H., Sudarno, Rashid, U., & Zainal, Z. (2013). CeO_2-SiO_2 supported nickel catalysts for dry reforming of methane toward syngas production. *Applied Catalysis A: General*, *468*, 359–369.

Therdthianwong, S., Siangchin, C., & Therdthianwong, A. (2008). Improvement of coke resistance of Ni/Al_2O_3 catalyst in CH_4/CO_2 reforming by ZrO_2 addition. *Fuel Processing Technology*, *89*(2), 160–168.

Thielemann, J. P., Girgsdies, F., Schlögl, R., & Hess, C. (2011). Pore structure and surface area of silica SBA-15: influence of washing and scale-up. *Beilstein Journal of Nanotechnology*, *2*, 110–118.

Tingem, M., & Rivington, M. (2009). Adaptation for crop agriculture to climate change in Cameroon: Turning on the heat. *Mitigation and Adaptation Strategies for Global Change*, *14*(2), 153–168.

Tomishige, K., Chen, Y. G., & Fujimoto, K. (1999). Studies on carbon deposition in CO_2 reforming of CH_4 over nickel-magnesia solid solution catalysts. *Journal of Catalysis*, *181*(1), 91–103.

Tsang, S. C., Claridge, J. B., & Green, M. L. H. (1995). Recent advances in the conversion of methane to synthesis gas, *23*, 3–15.

Usman, M., Wan Daud, W. M. A., & Abbas, H. F. (2015). Dry reforming of methane: Influence of process parameters—A review. *Renewable and Sustainable Energy Reviews*, *45*, 710–744.

Vafaeian, Y., Haghighi, M., & Aghamohammadi, S. (2013). Ultrasound assisted dispersion of different amount of Ni over ZSM-5 used as nanostructured catalyst for hydrogen production via CO_2 reforming of methane. *Energy Conversion and Management*, 76, 1093-1113.

Vizcaíno, A. J., Carrero, A., & Calles, J. A. (2006). Pure silica SBA-15 supported Cu-Ni catalysts for hydrogen production by ethanol steam reforming, *WHEC*, *16*, 1–12.

Wang, H. Y., & Ruckenstein, E. (2001). CO_2 reforming of CH_4 over Co/MgO solid solution catalysts — effect of calcination temperature and Co loading, *209*, 207–215.

Wang, J., Fang, L., Cheng, F., Duan, X., & Chen, R. (2013). Hydrothermal synthesis of SBA-15 using sodium silicate derived from coal gangue. *Journal of Nanomaterials*, *2013*, 1-6.

Wang, K., Dou, B., Jiang, B., Song, Y., Zhang, C., Zhang, Q. … Xu, Y. (2016). Renewable hydrogen production from chemical looping steam reforming of ethanol using xCeNi/SBA-15 oxygen carriers in a fixed-bed reactor. *International Journal of Hydrogen Energy*, *41*(30), 12899–12909.

Wang, N., Chu, W., Zhang, T., & Zhao, X. S. (2012). Synthesis, characterization and catalytic performances of Ce-SBA-15 supported nickel catalysts for methane dry reforming to hydrogen and syngas. *International Journal of Hydrogen Energy*, *37*(1), 19–30.

Wang, N., Yu, X., Shen, K., Chu, W., & Qian, W. (2013). Synthesis, characterization and catalytic performance of MgO-coated Ni/SBA-15 catalysts for methane dry reforming to syngas and hydrogen. *International Journal of Hydrogen Energy*, *38*(23), 9718–9731.

Wang, N., Yu, X., Wang, Y., Chu, W., & Liu, M. (2013). A comparison study on methane dry reforming with carbon dioxide over $LaNiO_3$ perovskite catalysts supported on mesoporous SBA-15, MCM-41 and silica carrier. *Catalysis Today*, *212*, 98–107.

Worathanakul, P., Payubnop, W., & Muangpet, A. (2009). Characterization for Post-treatment Effect of Bagasse Ash for Silica Extraction, *International Journal of Chemical and Molecular Engineering*, 3(8), 398–400.

Xu, L., Zhao, H., Song, H., & Chou, L. (2012). Ordered mesoporous alumina supported nickel based catalysts for carbon dioxide reforming of methane. *International Journal of Hydrogen Energy*, *37*(9), 7497–7511.

Yan, Q. G., Weng, W. Z., Wan, H. L., Toghiani, H., Toghiani, R. K., & Pittman, C. U. (2003). Activation of methane to syngas over a Ni/TiO_2 catalyst, *Applied Catalysis A: General*, *239*, 43–58.

Yang, M., Guo, H., Li, Y., & Dang, Q. (2012). Modification of support using ion exchange resin method. *Journal of Natural Gas Chemistry*, *21*(1), 76–82.

Yang, W., Liu, H., Li, Y., Wu, H., & He, D. (2015). CO_2 reforming of methane to syngas over highly-stable Ni/SBA-15 catalysts prepared by P123-assisted method. *International Journal of Hydrogen Energy*, *41*(3), 1513–1523.

Yasyerli, S., Filizgok, S., Arbag, H., Yasyerli, N., & Dogu, G. (2011). Ru incorporated Ni-MCM-41 mesoporous catalysts for dry reforming of methane: Effects of Mg addition, feed composition and temperature. *International Journal of Hydrogen Energy*, *36*(8), 4863–4874.

Yılmaz, M. S., Pişkin, S., & Materials, A. (2013). Extraction of Silicon from Tailings Slurry of Gold Mine Treatment Plant by Alkali Fusion Technique, *Materials, 1*(2), 2–4.

York, A. P. E., Xiao, T., Green, M. L. H., Claridge, J. B., York, A. P. E., Xiao, T., … Claridge, J. B. (2007). Methane Oxyforming for Synthesis Gas Production. *Catalysis Reviews*, 49(4), 511-560.

Zhai, X., Ding, S., Liu, Z., Jin, Y., & Cheng, Y. (2011). Catalytic performance of Ni catalysts for steam reforming of methane at high space velocity. *International Journal of Hydrogen Energy*, *36*(1), 482–489.

Zhang, H., Li, M., Xiao, P., Liu, D., & Zou, C. J. (2013). Structure and Catalytic Performance of Mg-SBA-15-Supported Nickel Catalysts for CO_2 Reforming of Methane to Syngas. *Chemical Engineering & Technology*, *36*(10), 1701-1707.

Zhang, L., Li, L., Li, J., Zhang, Y., & Hu, J. (2014). Carbon dioxide reforming of methane over nickel catalyst supported on MgO(111) nanosheets. *Topics in Catalysis*, *57*(6–9), 619–626.

Zhang, M., Ji, S., Hu, L., Yin, F., Li, C., & Liu, H. (2006). Structural characterization of highly stable Ni/SBA-15 catalyst and its catalytic performance for methane reforming with CO_2. *Chinese Journal of Catalysis*, *27*(9), 777-782.

Zhang, Q., Wang, J., Ning, P., Zhang, T., Wang, M., Long, K., & Huang, J. (2017). Dry reforming of methane over Ni/SBA-15 catalysts prepared by homogeneous precipitation method. *Korean Journal of Chemical Engineering*, *34*(7), 1–9.

Zhang, S., Wang, J., Liu, H., & Wang, X. (2008). One-pot synthesis of Ni-nanoparticle-embedded mesoporous titania/silica catalyst and its application for CO_2-reforming of methane. *Catalysis Communications*, *9*(6), 995–1000.

Zhao, Y., Liu, B., & Amin, R. (2016). CO_2 Reforming of CH_4 over MgO-Doped Ni/MAS-24 with Microporous ZSM-5 Structure. *Industrial and Engineering Chemistry Research*, *55*(25), 6931–6942.

Zhu, J., Wang, T., Xu, X., Xiao, P., & Li, J. (2013). Pt nanoparticles supported on SBA-15: Synthesis, characterization and applications in heterogeneous catalysis. *Applied Catalysis B: Environmental*, *130–131*, 197–217.