CATALYTIC METHANATION ON CONVERSION OF CARBON DIOXIDE OVER ALUMINA-SUPPORTED MANGANESE OXIDE CATALYSTS

THANWA FILZA NASHRUDDIN

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

School of Civil Engineering
Faculty of Engineering
Universiti Teknologi Malaysia

JUNE 2021

DEDICATION

First and Foremost, Thankful to Allah The Almighty

To my beloved husband Sabri Abd Rashid

my son Muhammad Thalhah and my daughter Hafsah Husna

Also, not to be forgotten,

To my father (Hj. Nashruddin Md Salim) and mother (Hjh Hamidah Abdullah), my mother in law(Hjh. Che Yam), my late father in laws(Hj.Abd Rashid Md Noor), all family members and my respected friends

thank you for all your kindness and endless support

ACKNOWLEDGEMENT

First and foremost, thanks to Allah SWT for His blessing that gave me a strength, healthy, highly patient and passions in completing my thesis. All praises to Allah SWT, the Most Merciful, who is All Knower for all my words and prayers.

I am truly thankful to Allah SWT for bestow me my beloved husband, Sabri Abd Rashid, who is most compassionate and understanding persons. Thank you for your patience in waiting me until the completion this study. Your support, advice, cooperation in collecting the data, proofread the writing thesis and nursery, our kids are so given me courage to complete this study. May Allah SWT blessing for all your Amal and Ikram.

To my father and my mother, sincerely grateful to both of you, thank you for not skipping a day to pray for me. Both of you still take care of me until now. Al-fatihah, to my late father in law, and to my lovely mother in law, thank you patiently listening to my problems. I am appreciated for your limitless of kindness, support and consideration.

In addition, I was in contact with many people, researchers, academics, and professionals in the preparation of this study. In particular, I would like to express my sincere gratitude to Dr. Md. Maniruzzaman A.Aziz, my main thesis supervisor for encouragement, guidance, critics, fully support the financial to complete this thesis and thank you very much for your friendship and father characters. I am also very indebted to my co-supervisor Professor Dr Wan Azelee Wan Abu Bakar and to Professor Khairul Anuar Kassim for his guidance, advice and support. Without their continued support and participation, this thesis would not be the same as what presented here.

I am also indebted to My Ph.D. and Universiti Teknologi Malaysia (UTM) for funding my PhD studied. To all the UTM staff in the Faculty of Science and the Central Lab, thank you for your cooperation. Also, Dr. Syed Anuar, Mr. Jamal, Mr. Hafiz, thank you for all the equipment on-site. Thank you to Dr You, for borrowing your thermometer. Thank you to Prof Musa for your financially support in characterize section. To Mr Daie, thank you for sharing the info, for lent the gas pump, plastic gas and thermometer laser. To all staff of HMA plants (Mr. Vik, Mr. Alfred, Mr. Tham and Mr. Sulaiman), thank you for all your assistance in helping to collect the gas sample.

As well, my fellow graduate student, Ms. Amira, Ms. Has, Ms Suhaila, Ms Nurul Hidayah and Mrs. Nadhirah, and all my chemical lab members should be respected for their support. Not even forgotten, to my gorgeous best friend, Ms Farahiyah, for being patiently together and 100% supportive with the idea and discussions for our projects. Thank you so much for your amazing support. I am truly indebted to you. May Allah give you a great Jannah and bestow you a good and pious of future husband.

Then, I truly apologize, to all those who have provided assistance on various occasions, opinions and recommendations that are valuable in this research that are not included in this column. Unfortunately, it is not possible to mention all of them in this limited space. Million thanks to all of you.

ABSTRACT

In this study, the catalytic methanation conversion system is introduced to convert CO_2 to methane (CH_4). Hot mix asphalt (HMA) plants include of heating, drying and mixing processes contributed to carbon dioxide (CO_2) emissions. The first stage of the study is the analysis of flue gases emissions from the chimney in HMA plant by on-site gas analysis and laboratory. The flue gas emission analysis shows that CO_2 produced from HMA plant operating is between 1.30-7.33%. For second stage, the optimization and characterization of potential catalyst was conducted to determine the factor contributed to the catalytic activity. The results from optimization of catalyst revealed that the parameters catalyst loading with 65wt.% of manganese (Mn), 30wt.% of nickel (Ni), and 5wt.% of ruthenium (Ru) at calcination 500°C and aging of 90°C produced the optimum values in term of CO_2 conversion and CH_4 formation during the reaction. For characterization analysis, the X-ray diffractograms (XRD) has observed the well-defined sharp peaks for elements of alumina (Al_2O_3), manganese oxide (MnO), nickel oxide (NiO), and ruthenium oxide (RuO) in a crystalline shape. The Brunauer-Emmett-Teller (BET) theory of surface area of Ru/Ni/Mn (5:30:65)/Al_2O_3 catalyst are decreased along with the increasing of calcination temperature. The Nitrogen adsorption (NA) found that more characteristic of mesopores resembled the typical shape of Type IV isotherm. Field emission scanning electron microscopy with energy-dispersive X-ray spectroscopy (FESEM-EDX) revealed the morphology of catalyst was break into pieces with planes surfaces. Also, the presence of crystallite images in rhombic and diamond shape as the calcination temperature increased. At last stages, the effect of gas mixture of CO_2/H_2 methanation with compressed air (N_2O_2), nitrogen (N_2), propane (C_3H_8) and nitrous dioxide (NO_2) that present in HMA plants towards the catalyst were not deactivate the catalytic activity. The results show that, less significant different (10%) of CO_2 conversion produces compared to the optimum CO_2 conversion. In addressing environmental issues, the introduction of catalyst technology in the HMA plants is therefore highly recommended to preserve sustainable environmental.

ABSTRAK

Kajian ini memperkenalkan penukaran metanasi pemangkin untuk menukarkan CO_2 kepada gas metana (CH_4). Loji asfalt campuran panas (HMA) yang memerlukan proses pemanasan, pengeringan dan pencampuran menyumbang kepada pembebasan karbon dioksida (CO_2). Peringkat pertama kajian adalah analisis pelepasan gas serombong dari cerobong asap HMA menggunakan analisis gas secara langsung dan juga analisis di makmal. Daripada analisis pelepasan gas serombong menunjukkan bahawa CO_2 yang dihasilkan dari loji HMA adalah antara 1.30-7.33%. Untuk peringkat kedua, pengoptimuman dan pencirian pemangkin berpotensi telah dilakukan untuk menentukan faktor yang menyumbang kepada aktiviti pemangkin. Hasil pengoptimuman pemangkin menunjukkan bahawa parameter yang menggunakan muatan asas sebanyak 65wt.% manganese (Mn), 30wt.% nikel (Ni) dan 5wt.% ruthenium (Ru) pada suhu 500°C pengkalsinan dan 90°C penuaan telah menghasilkan nilai optimum dari segi penukaran CO_2 dan pembentukan CH_4 semasa tindak balas. Berdasarkan analisis pencirian, Belauan sinar-X (XRD) telah mendapati bahawa elemen alumina (Al_2O_3), mangan oksida (MnO), nikel oksida (NiO) dan ruthenium oksida (RuO) hadir dalam bentuk kristal melalui takrifan puncak tajam Teori Brunauer-Emmett-Teller (BET) luas permukaan pemangkin Ru/Ni/Mn(5:30:65)/Al_2O_3 menurun seiring dengan peningkatan suhu kalsinasi. Penyerapan Nitrogen (NA) mendapati bahawa lebih banyak ciri mesopori menyerupai bentuk khas jenis isotherm IV. Mikroskopi imbasan elektron pancaran medan dan tenaga serapan sinar-X (FESEM-EDX) menunjukkan zarah berpecah pada permukaan satah pemangkin. Selain itu, kehadiran gambar kristal dalam bentuk rombik dan berlian ketika suhu kalsinasi meningkat. Pada peringkat terakhir, kesan campuran gas metanasi CO_2/H_2 dengan udara termampat (N_2O_2), nitrogen(N_2), propana (C_3H_8), dan nitrat dioksida (NO_2) yang hadir pada loji HMA terhadap pemangkin tidak menyahaktifkan aktiviti pemangkin. Keputusan menunjukan hasil penukaran CO_2 tidak begitu berbeza apabila dibandingkan dengan penukaran CO_2 yang optimum. Dalam menangani isu alam sekitar, pengenalan teknologi pemangkin di loji HMA sangat disyorkan untuk memelihara alam sekitar yang mampan.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AFR	-	Air Fuel Ratio
ANOVA	-	Analysis of Variance
AIWI	-	Aqueous Incipient Wetness Impregnation
BBD	-	Box Behnken design
EPA	-	Environmentally Protected Agency
FESEM-EDX	-	Field Emission Scanning Electron Microscopy - Energy Dispersive X-Ray
FTIR	-	Fourier Transform Infrared
GHG	-	Greenhouse gas
HMA	-	Hot Mix Asphalt
NA	-	Nitrogen Adsorption Analysis
PGA	-	Portable Exhaust Gas Analyser
RGA	-	Residual Gas Analyser
RSM	-	Response Surface Methodology
SNG	-	Synthetic Natural Gas
TEM	-	High Transmission Electron Microscopy
TPR	-	Temperature Programmed Reduction
TPD MS	-	Temperature Programmed Desorption and Mass Spectrometer
TWA	-	Time-Weighted Average
TPM	-	Total Particulate Matter
TOC	-	Total Organic Compound
XRD	-	X-Ray Diffraction Spectroscopy
XRF	-	X-ray Fluorescent
VOC	-	Volatile Organic Compounds

LIST OF SYMBOLS

%	-	percentage
ppm	-	Part per million
°C	-	degree celsius
L	-	litres
MJ	-	million joules
km	-	kilometre
kWh	-	kilo watt hour
h	-	hour
CO_2	-	carbon dioxide
O_2	-	oxygen
NO_2	-	nitrous dioxide
SO_x	-	sulfur oxide
CO	-	carbon monoxide
CH_4	-	methane
P	-	pressure
m	-	meter
K	-	Kelvin
C	-	concentration
g	-	gram
R	-	standard ideal gas law (0.08205 L atm mol^{-1} K)
T	-	room temperature (27°C)
mL	-	mililitre
Å	-	angstrom
θ	-	theta
µ	-	micro
°	-	degree
mm	-	milimetre
mg	-	miligram
m^3	-	metre cube

LIST OF APPENDICES

CHAPTER 1

INTRODUCTION

1.1 Background

Recently, greenhouse gases (GHG) are considered as the most important environmental challenge due to the human activities and combustion of fuels in growing industry (Martire *et al.*, 2018). The carbon dioxide (CO_2) emissions have changed atmospheric concentrations and effect the planet warmed (Nda *et al.*, 2018). The concentrations of CO_2 have reached 400 parts per million (ppm) on 2013 and increase until 405 ppm in 2018. The percentage increments in concentrations of CO_2 start from the pre-industrial era of 1750 (280 ppm) until now was about 48% (NOAA, 2018). If the combustion of fossil fuel keeps continue at a high level, CO_2 emissions have brought the global temperature close to limit of global warming that is 2°C (Xu and Ramanathan, 2017).

Therefore, capture and utilization of CO_2 formed during combustion of fossil fuels for transformation of valuable chemical product, such as methane (CH_4), is one of the alternatives can promote the sustainability of environmental. To mitigate the emissions from combustion fuels in Hot Mix Asphalt (HMA) plants, the chemical conversion techniques have been introduced as the potential to control the environment pollution by converting the CO_2 to the new value product of methane (CH_4). Generally, the operation of the HMA plant entails a high demand for electricity and fuel such as diesel, light fuel oil and heavy oil for the complete combustion process (Chiu *et al.,* 2008). The energy is consumed mostly by flame. The fuel combustion process is used to dry the aggregates and heat the asphalt binder for the next coating process (Rubio *et al.,* 2012).

For this reason, a new technology to remove CO_2 by using catalytic of CO_2 methanation has been defined, which is one of the most efficient and green technology process (Zamani *et al.,* 2015). The CO_2 methanation is also called the Sabatier reaction (Sabatier and Senderens, 1902) and moderately exothermic, $H^{O}\Delta$ = -165 kJ/mol. The reaction process shown as Equations 1.1:

$$CO_2(g) + 4H_2(g) \xrightarrow{catalyst} CH_4(g) + H_2\,O(liq) \tag{1.1}$$

The methanation reaction is the catalytic reaction where carbon dioxide reacts with hydrogen to produce methane and water. The catalysis is certainly playing a critical role in the methanation of CO_2 to provide an efficient process to produces the value of starting materials like CH_4. The metal based catalysts have been of huge importance in a wide range of diverse catalytic applications with high efficiency (De *et al.,* 2016). Moreover, methanation of CO_2 is a well-known reaction that is of interest as a renewable energy by substitute or synthetic natural gas (SNG) production. The active, selective and stable catalysts are the most crucial of the CO_2 methanation process. Novel, heterogeneous catalysts gave significant in the CO_2 methanation process increases their productivity.

In addition, the catalyst is necessary for the reaction to take place to increase the effectiveness of the process. By increasing such effectiveness of an industrial process, it gives a lot of benefit for the environment, since it utilizes the reactants more efficiently and lower the temperatures as well as energy (Fred, 2008). Moreover, the catalysis can be used as a direct mean to protect the environment and reduce the pollution of many harmful compounds (Clark and Macquarrie, 2002).

The valuable methane gas produced which has been described in Equations 1.1, can becomes the main element in the Synthetic Natural Gas (SNG) and also can be used as a fuel to generate electricity (Zain and Mohamed, 2018). Moreover, CH_4 is a colourless and odourless gas with a broad distribution in nature. Since, the CH_4 is the main element of natural gas, therefore it is more environmental friendly. Also, the catalyst designed is easy to prepare and can be recycled using the appropriate of parameter (Salmiah *et al.,* 2015)

1.2 Problem Statement

Growing energy consumption and released of the flue gas from combustion of fuels in HMA plants contains carbon dioxide, the major GHG. As the level of CO_2 increases, the temperature of the earth's surface will also increase. This phenomenon is called greenhouse effect thus causes global warming eventually. Therefore, the CO_2 gas is necessary to be removed to prevent or minimize the release of this gas into the environment.

One solution is the chemical conversion of such green hydrogen and easily available carbon dioxide into methane. An alternative to the capture and sequestration of CO_2 is its conversion to higher value-added products, such as hydrocarbons, by reacting CO_2 in the presence of hydrogen and heterogeneous catalysts (Giglio *et al.*, 2015). In this study, the CO_2 methanation has been investigated using alternative suitable catalytic systems based on group 8-10 metals. Attention more to Manganese (Mn) catalyst seem to be potential in their catalytic activity. Mn catalyst is less to be explored for its ability as a base catalyst for the CO_2 methanation reaction. However, it has received attention from researchers as a dopant material for metal oxide (Abu Bakar *et al.*, 2010). In this study, Mn used as the based catalyst cooperation with other transition-metal like nickel (Ni), ruthenium (Ru), cobalt (Co), Vanadium (V) and titanium (Ti) are being investigated because of their superior catalytic activity.

The role of a support material is also crucial in designing an efficient methanation catalyst to ensure enhanced metal dispersion and stability (Al-Fatesh *et al.*, 2019). Also, it is necessary to find the catalyst which is active in low operating temperature and resistance under poison gases present from flue gases like nitrous dioxide which may lead to the catalyst deactivation.

1.3 Research Objectives

There are three main objectives need to be fulfill:

(a) To determine the compositions of flue gas from the HMA plants;
(b) To develop and characterize a novel catalyst for conversion of CO_2 to CH_4;
(c) To determine the effect of gas mixture towards the sturdiness of catalyst for CO_2 conversion and formation of CH_4.

1.4 Scope and Limitation of Research

The scope and limitation of the research has been focused in the following:

(a) The data of flue gas onsite is collected at two HMA plants at district Kulai areas, Johor Bahru;
(b) The data flue gas was analysed using several of methods, there are Portable Gas Analyser (PGA), Residual Gas Analyser (RGA) and Fourier transform Infrared (FTIR);
(c) The design of catalyst was focused on transitional metal group in term of based catalyst, bi-metallic catalyst and tri-metallic catalyst;
(d) The preparation of catalyst using Aqueous Incipient Wetness Impregnation (AIWI) method;
(e) The conversion of CO_2 was measured using house-built micro reactor coupled with FTIR;
(f) The formation of CH_4 was measured using TQ Analyst software;
(g) Response Surface Methodology (RSM) through Box-Behnken Design (BBD) validated the optimum conditions of the potential catalysts;
(h) The optimum condition of catalyst was used in characterization using various X-ray Diffraction spectroscopy (XRD), Nitrogen Adsorption (NA), High Transmission Electron Microscopy (HRTEM), Field Emission Scanning Electron Microscopy - Energy Dispersive X-ray (FESEM-EDX), X-ray Fluorescent (XRF), H_2-temperature Programmed Reduction (H_2-TPR) and

CO_2-Temperature Programmed Desorption and Mass Spectrometer (CO_2-TPD MS);

(i) In laboratory, the effect of gas mixture used in CO_2/H_2 methanation are compressed air, nitrogen, propane and nitrous dioxides;

(j) Study are limited to CO_2 conversion and CH_4 formation only, no further test for the by-product presence after finishing the experiment.

1.5 Significance of the Research

The significance of this research is to utilize the CO_2 released from combustion fuels of HMA plants to a new value product of CH_4. Hence, the catalytic methanation conversion system becomes the potential techniques that has been applied in this study. In the past, the CO_2 methanation processes was discovered in 1902 by Paul Sabatier and Jean-Baptiste Senderens, this techniques representing as a promising solution for reducing anthropogenic gas emissions (Frontera *et al.,* 2017; Stangeland *et al.,* 2017b; Müller *et al.,* 2013a). Figure 1.1 shown the basic flow of methanation process and its application usage into another product.

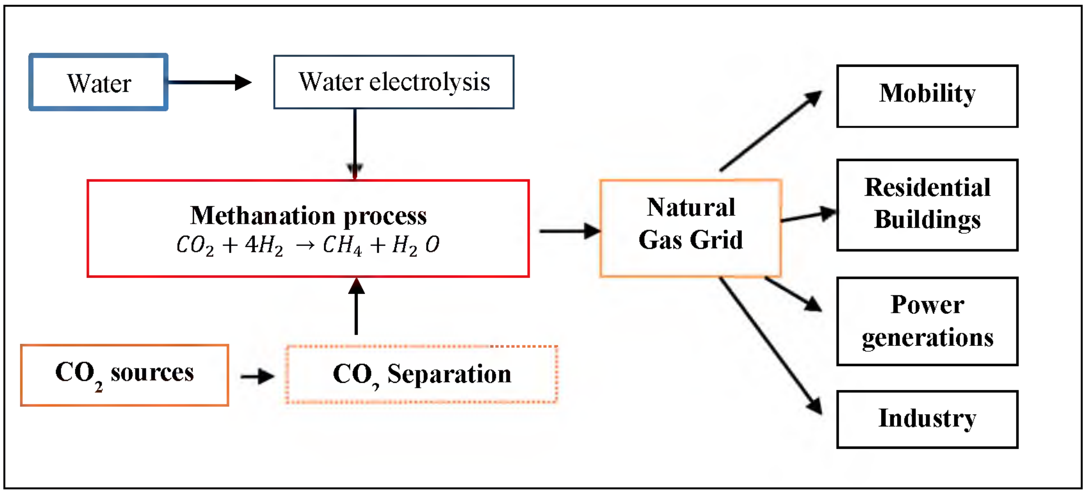

Figure 1.1 Flow methanation process and its applications (Ghaib and Fares, 2018a)

Moreover, methane is the main component of natural gas (Burkart and Lothar, 2004; Daniel, 2013). It would great interest if plants and factories come out with carbon capture and storage technology facilities that able to produce electricity that is powered by methane and natural gas which converts from CO_2 emissions. Additionally, methane can be used as a fuel for mobility in the residential sector for electricity production at times when the energy consumption overbalances the electricity supply and as raw resources in industry.

1.6 Thesis Structure and Organization

This thesis is divided into 7 chapters. Chapter 1 comprises an overview of the research background, the problem statement, the objectives with the related scope and the significance of the research.

Chapter 2 include the literature review of the catalytic methanation conversion system, its basic and application. Also, the sources of emissions from HMA plants is discuss in detail.

Chapter 3 presented the methods of the flue gas analysis in HMA plants. Meanwhile, the preparation and design of catalyst using AIWI methods has been explained in detail. Furthermore, RSM software with BBD was used to verify the experimental results. The characterization techniques for the CO_2/H_2 methanation reaction has been listed in detail.

Chapter 4 presented the data flue gas obtained from HMA plants. Also, the results analysis using PGA, RGA and FTIR has been discussed in detail.

Chapter 5 presented the findings of screening and catalytic optimization. The effects of loading, calcination and aging temperature of the potential catalyst on the CO_2 conversions are discussed in detail. Next, the findings on the potential catalyst on the highest reading of CO_2 conversions has been optimized in terms of replicate, reproducibility, regeneration and stability. Meanwhile, the formation of CH_4 for the highest conversion of CO_2 is quantified using TQ Analyst.

Moreover, RSM findings explain the expected values of the RSM optimization parameters obtained with the values acquired from the experimental outcomes. The selectivity and yield of CH_4 are discussed in the GA and TQ analyst findings. Finally, the findings over the XRD, NA, HTEM, FESEM-EDX, XRF H_2-TPR and CO_2-TPD was explained the chemical characteristics of potential catalyst that influenced the results of CO_2 conversions.

Chapter 6 discusses the results and findings on the effects of gas mixture towards CO_2/H_2 methanation reactions.

Chapter 7 concludes the research objectives and provides relevant recommendations for future studies.

REFERENCES

Abdullah, F., Rahim, A., Yusoff, M., Azelee, W., Bakar, W. A., Ismail, R. and and Hadiyanto, D. P. (2014) 'Removal of Selected Heavy Metals From Green Mussel Via Catalytic Oxidation', *The Malaysian Journal of Analytical Sciences*, 18(2), pp. 271–283.

Abdullah, B., Abd Ghani, N. A. and Vo, D. V. N. (2017) 'Recent advances in dry reforming of methane over Ni-based catalysts', *Journal of Cleaner Production*, 162, pp. 170–185.

Abdulra'Uf, L. B., Sirhan, A. Y. and Tan, G. H. (2015) 'Applications of experimental design to the optimization of microextraction sample preparation parameters for the analysis of pesticide residues in fruits and vegetables', *Journal of AOAC International*, 98(5), pp. 1171–1185.

Abu Bakar, W. A. W., Ali, R., Sulaiman, N. and Abd Rahim, H. F. (2010) 'Manganese oxide doped noble metals supported catalyst for carbon dioxide methanation reaction', *Scientia Iranica*, 17(2), pp. 115–123.

Abu Bakar, W. A. W., Ali, R. and Toemen, S. (2012) 'Catalytic methanation reaction over supported nickel-ruthenium oxide base for purification of simulated natural gas', *Scientia Iranica*. 19(3), pp. 525–534.

Abu Bakar, W. A W., Ali, R. and Mohammad, N. S. (2015a) 'The effect of noble metals on catalytic methanation reaction over supported Mn/Ni oxide based catalysts', *Arabian Journal of Chemistry*. King Saud University, 8(5), pp. 632–643.

Abu Bakar, W. A. W., Ali, R. and Mohammad, N. S. (2015b) 'The effect of noble metals on catalytic methanation reaction over supported Mn/Ni oxide based catalysts', *Arabian Journal of Chemistry*, 8(5), pp. 632–643.

Abu Bakar W.A.W and Ali R., (2010) *Natural Gas*, *InTech*, Department of Chemistry, Universiti Teknologi Malaysia.

Adamski, P., Nadziejko, M., Komorowska, A., Sarnecki, A., Albrecht, A. and Moszynski, D. (2019) 'Chromium-modified cobalt molybdenum nitrides as catalysts for ammonia synthesis', *Open Chemistry*, 17(1), pp. 127–131.

Ahmad, I., Sm, S., Khan, H., Khan, R. and Ahmad, W. (2018) 'Characterization of Petroleum Crude Oils by Fourier Transform Infrared (FT-IR) and Gas Chromatography-Mass Spectrometerys', *Petroleum & Petrochemical Engineering*, pp. 1–7.

Akrami HA, Yardim MF, Akar A, E. E. (1997) 'FTIR characterization of pitches derived from Avgamasya asphaltite and Raman–Dincer heavy crude.', *Fuel*, (76), pp. 1389–1394.

Aldana, P. A., Ocampo, F., Kobl, K., Louis, B., Thibault-Starzyk, F., Daturi, M., Bazin, P., Thomas, S. and Roger, A. C. (2013) 'Catalytic CO_2 valorization into CH4 on Ni-based ceria-zirconia. Reaction mechanism by operando IR spectroscopy', *Catalysis Today*, 215, pp. 201–207.

Al-Fatesh, A. S., Kasim, S. O., Ibrahim, A. A., Fakeeha, A. H., Abasaeed, A. E., Alrasheed, R., Ashamari, R. and Bagabas, A. (2019) 'Combined magnesia, ceria and nickel catalyst supported over γ-alumina doped with titania for dry reforming of methane', *Catalysts*, 9(2), p. 188

Almeida-Costa, A. and Benta, A. (2016) 'Economic and environmental impact study of warm mix asphalt compared to hot mix asphalt', *Journal of Cleaner Production*, 112, pp. 2308–2317.

ALmix Asia (2013) *Asphalt Mixing Plants*, *Asphalt Equipment Company Inc.*

Alonso, D. M., Bond, J. Q. and Dumesic, J. A. (2010) 'Catalytic conversion of biomass to biofuels', *Green Chem.* The Royal Society of Chemistry, 12(9), pp. 1493–1513.

Amadine, O., Essamlali, Y., Fihri, A., Larzek, M. and Zahouily, M. (2017) 'Effect of calcination temperature on the structure and catalytic performance of copper-ceria mixed oxide catalysts in phenol hydroxylation', *RSC Advances*, 7(21), pp. 12586– 12597.

Ambursa, M. M. (2018) '*Development of Ti-MCM-41 Supported Bi- Metallic Catalyst For Hydrodeoxygenation of Lignin Derived Bio Oil Model Compounds.*' Phd dissertation, University of Malaya.

American Conference of Governmental Industrial Hygienists (ACGIH) (2010) 'TLVs and BEIs. Based on the documentation of the threshold limit values for chemical substances and physical agents & biological exposure indices.', *Cincinnati (OH)*, p. 272.

Androjic I, K. G. (2016) 'Usage of solar aggregate stockpiles in the production of hot mix asphalt.', *Applied Thermal Engineering*, 108(131–139).

Ang, B.W., Fwa, T.F. and Ng, T. T. (1993) 'Analysis of process energy use of asphalt-mixing plants', *Energy*, 18(7), pp. 769–777.

Archer, D. (2005) 'Chapter 4: Greenhouse Gases', *Global Warming: understanding the forecast*.

Argyle, M. D. and Bartholomew, C. H. (2015) 'Heterogeneous catalyst deactivation and regeneration: A review', *Catalysts*, 5(1), pp. 145–269.

Ashok, J., Ang, M. L. and Kawi, S. (2017) 'Enhanced activity of CO_2 methanation over Ni/CeO_2-ZrO_2 catalysts: Influence of preparation methods', *Catalysis Today*, 281, pp. 304–311.

Asiltürk, I. and Neşeli, S. (2012) 'Multi response optimisation of CNC turning parameters via Taguchi method-based response surface analysis', *Measurement*, *45*(4), pp.785-794.

Aske, N., Kallevik, H., and Sjöblom, J. (2001) 'Determination of saturate, aromatic, resin, and asphaltenic (SARA) components in crude oils by means of infrared and near-infrared spectroscopy', *Energy & Fuels*, 15(5), pp. 1304-1312.

Aydar, A.Y., (2018) 'Utilization of response surface methodology in optimization of extraction of plant materials', *Statistical approaches with emphasis on design of experiments applied to chemical processes*, pp.157-169.

Aydın, H. and İlkılıç, C. (2018) 'Air pollution, pollutant emissions and harmfull effects', *Journal of Engineering and Technology*, 1(1), pp. 8–15.

Aziz, M. A. A., Jalil, A. A., Triwahyono, S. and Ahmad, A. (2015) 'CO_2 methanation over heterogeneous catalysts: Recent progress and future prospects', *Green Chemistry*. Royal Society of Chemistry, 17(5), pp. 2647–2663.

Bakar, W. A. W. A., Othman, M. Y. and Ali, R. (2009) 'The investigation of active sites on nickel oxide based catalysts towards the in-situ reactions of methanation and desulfurization', *Modern Applied Science*, 3(001), pp. 35–43.

Barbarossa, V., an Vanga, G. (2011) 'Methanation of carbon dioxide', *In XXXIV Meeting of the Italian Section of the Combustion Institute Rome.*

Bartholomew, C. H. (2001) 'Mechanisms of catalyst deactivation', *Applied Catalysis A: General*, 212(1–2), pp. 17–60.

Bartholomew, C. H. and Farrauto, R. J. (2010) '*Fundamentals of industrial catalytic processes*', 2nd Edition, John Wiley & Sons.

Bartholomew, C. H., Farrauto, R. J. and Wiley, C. J. (2006) 'Part One : Introduction and Fundamentals', *Fundamental of Industrial Catalytic Processes*, p. 2006.

Baskar, P., and Senthilkumar, A. (2016) 'Effects of oxygen enriched combustion on pollution and performance characteristics of a diesel engine', *Engineering Science and Technology, an International Journal*, 1(19), pp. 438-443.

Basim A. H and Ahmed H. (2012) *Rehabilitation of Expressway No.1 Section (R7) Nasiriya–Rymaila Project: Environmental and Social Management Plan (ESMP) for Section R7 Asphalt plant*, Iraq.

Behrenbruch, Peter and Dedigama, T. (2007) 'Classification and characterisation of crude oils based on distillation properties', *Journal of Petroleum Science and Engineering*, 57(1-2), 166-180.

Beuls, A., Swalus, C., Jacquemin, M., Heyen, G., Karelovic, A. and Ruiz, P. (2012) 'Methanation of CO_2: Further insight into the mechanism over Rh/γ-Al_2O_3 catalyst', *Applied Catalysis B: Environmental*. Elsevier B.V., 113–114, pp. 2–10.

Box, G. E. P. and Wilson, K. B. (1951) 'On the Experimental Attainment of Optimum Conditions', *Journal of the Royal Statistical Society: Series B (Methodological)*, pp.270-230

Brander, M. (2012) 'Greenhouse gases, CO_2, CO2e, and carbon: What do all these terms mean.', *Ecometrica*, (August), pp. 2–4.

Budget, G. E. and Earth, T. (2010) 'Greenhouse Gases and Climate Change', pp. 181–204.

Burch, R., Urbano, F. J. and Loader, P. K. (1995) 'Methane combustion over palladium catalysts: The effect of carbon dioxide and water on activity', *Applied Catalysis A, General*, 123(1), pp. 173–184.

Burns, J. R. and Ramshaw, C. (1999) 'Development of a microreactor for chemical production', *Chemical Engineering Research and Design*, 77(3), pp. 206–211.

Burtin, P., Brunelle, J. P., Pijolat, M. and Soustelle, M. (1987) 'Influence of surface area and additives on the thermal stability of transition alumina catalyst supports. II: Kinetic model and interpretation', *Applied Catalysis*, *34*, pp.239-254.

Calado, D. G. and V. M. de A. (2014) *The use and importance of design of experiments (DOE) in process modelling in food science and technology*. 1st editio, *Mathematical and Statistical Methods in Food Science and Technology*. 1st editio. Edited by Daniel Granato and Gaston Ares. John Wiley & Sons.

Cao, G., Zhang, X., Gong, S. and Zheng, F. (2008) 'Investigation on emission factors of particulate matter and gaseous pollutants from crop residue burning', *Journal of Environmental Sciences,* 20(1), pp.50-55.

Chang, F. W., Kuo, M. S., Tsay, M. T. and Hsieh, M. C. (2003) 'Hydrogenation of CO_2 over nickel catalysts on rice husk ash-alumina prepared by incipient wetness impregnation', *Applied Catalysis A: General*, 247(2), pp. 309–320.

Chang FW, Kuo MS, Tsay MT, H. M. (2003) 'Hydrogenation of CO_2 over nickel catalysts on rice husk ash-alumina prepared by incipient wetness impregnation.', *Applied Catalysis A: General*, 247(2), pp. 309–320.

Chappat, M. and Bilal, J. (2003) 'The environmental road of the future: Life cycle analysis', *Colas Group.*, pp. 1–34.

Chiche, D., Chanéac, C., Revel, R. and Jolivet, J. P. (2006) 'Size and shape control of γ-AlOOH boehmite nanoparticles, a precursor of γ-Al_2O_3 catalyst', *Studies in Surface Science and Catalysis*, 162, pp. 393–400.

Ching Kuan Yong (2008) *Nickel oxide based catalysts for the in-situ reactions of methanation and desulfurization in the removal of sour gases from simulated natural gas*. Universiti Teknologi Malaysia, Skudai, Malaysia.

Chiu, C., Hsu, T. and Yang, W. (2008) 'Life cycle assessment on using recycled materials for rehabilitating asphalt pavements', 52, pp. 545–556.

Chou, J. C. S. W. & C. (2009) 'Bimetallic Rh-Ni/BN catalyst for methane reforming with CO_2', *Chemical Engineering Journal*, 148(2–3), pp. 539–545.

Keches, C. and LeBlanc, A., (2007) 'Reducing greenhouse gas emissions from asphalt materials', *Project Number: MQP-RBM-0601, Worcester Polytechnic Institute, Worcester, MA*.

Cimbola, Z. and Dolaček-Alduk, Z. (2018) 'Managing thermal energy of exhaust gases in the production of asphalt mixtures', *Tehnicki Vjesnik*, 25, pp. 444–451.

Coates, J. (2004) 'Encyclopedia of Analytical Chemistry -IInterpretation of Infrared Spectra, A Practical Approach', pp. 1–23.

Commons, W. (2019) 'Asphalt Batching Plant Structure.', *Wikimedia*.

Cong, X. C., Yang, S. L., Cao, S. Q., Chen, Z. L., Dai, M. X. and Peng, S. T. (2012) 'Effect of aggregate stockpile configuration and layout on dust emissions in an open yard', *Applied Mathematical Modelling*. Elsevier Inc., 36(11), pp. 5482–5491.

Cui, P., Cui, Q. and Green, H. (2019) 'Estimating VOC emissions from asphalt pavement', in El-Badawy, S. and Abd El-Hakim, R. (eds) *Recent Developments in Pavement Design, Modeling and Performance*. Cham: Springer International Publishing, pp. 84–93.

Cychosz, K. A. and Thommes, M. (2018) 'Progress in the Physisorption Characterization of Nanoporous Gas Storage Materials', *Engineering*, 4(4), pp. 559–566.

De Richter, R., Ming, T., Davies, P., Liu, W. and Caillol, S. (2017) 'Removal of non-CO_2 greenhouse gases by large-scale atmospheric solar photocatalysis', *Progress in Energy and Combustion Science*, 60, pp. 68–96.

Daniel Jacob Goodman (2013) *Methanation of Carbon Dioxide*. Phd dissertation, UCLA.

Davidson, R., (2011) 'Pre-combustion capture of CO_2 in IGCC plants', *IEA Clean Coal Centre*, 571(98), p.572.

De, S., Zhang, J., Luque, R. and Yan, N. (2016) 'Ni-based bimetallic heterogeneous catalysts for energy and environmental applications', *Energy and Environmental Science*. Royal Society of Chemistry, 9(11), pp. 3314–3347.

Deane, J. P., Ó Gallachóir, B. P. and McKeogh, E. J. (2010) 'Techno-economic review of existing and new pumped hydro energy storage plant', *Renewable and Sustainable Energy Reviews*, 14(4), pp.1293-1302.

Deutschmann, O. (2015) 'Modeling of the Interactions Between Catalytic Surfaces and Gas-Phase', *Catalysis Letters*, 145(1), pp. 272–289.

Dey, S., Dhal, G. C., Mohan, D. and Prasad, R. (2019) 'Application of hopcalite catalyst for controlling carbon monoxide emission at cold-start emission conditions', *Journal of Traffic and Transportation Engineering (English Edition)*, 6(5), pp. 419-440.

Ding, M., Tu, J., Zhang, Q., Wang, M., Tsubaki, N., Wang, T. and Ma, L. (2016) 'Enhancement of methanation of bio-syngas over CeO_2-modified Ni/Al_2O_3 catalysts', *Biomass and Bioenergy*, 85, pp. 12–17.

Dixit, M., Mishra, M., Joshi, P. A. and Shah, D. O. (2013) ‘Study on the catalytic properties of silica supported copper catalysts’, *Procedia Engineering*. 51, pp. 467–472.

Dokandari, P. A. and Topal, A. (2015) ‘Effects of warm mix asphalt additives on aging characteristics of bituminous mixtures’, *Periodica Polytechnica Civil Engineering*, 59(4), pp. 475–486.

Doukkali, M., Iriondo, A., Cambra, J. F., Gandarias, I., Jalowiecki-Duhamel, L., Dumeignil, F. and Arias, P. L. (2014) ‘Deactivation study of the Pt and/or Ni-based γ-Al_2O_3 catalysts used in the aqueous phase reforming of glycerol for H2 production’, *Applied Catalysis A: General*, 472, pp. 80–91.

Douvartzides, S. L., Charisiou, N. D., Papageridis, K. N. and Goula, M. A. (2019) ‘Green diesel: Biomass Feedstocks, Production Technologies, Catalytic Research, Fuel Properties and Performance in Compression Ignition Internal Combustion Engines’, *Energies*, 12(5), pp. 809.

Dufour, J., Martos, C., Ruiz, A. and Ayuela, F. J. (2013) ‘Effect of the precursor on the activity of high temperature water gas shift catalysts’, *International Journal of Hydrogen Energy,* 38(18), pp. 7647-7653.

Dushyant Shekhawat, ,J.J. SpiveyDavid A. B. (2011) ‘Oxidative Steam Reforming’, in*Fuel Cells: Technologies for Fuel Processing*. pp. 129-190. Elsevier, 2011.

Eckle Stephan. (2012) *‘Investigations of the kinetics and mechanism of the selective methanation of CO in CO_2 and H_2-rich reformates over Ru supported catalysts’,* PhD diss., Verlag nicht ermittelbar.

Eckle, S. and Science, S. (2010) ‘Carriers Selective Methanation of CO in CO_2 – rich feed gases on supported Ru catalysts’, *Fuel Cells*, 78, pp. 1–5.

Ehrfeld, W., Hessel, V. and Löwe, H. (2000) ‘State of the art of microreaction technology’, *Microreactors: New Technology for Modern Chemistry*, pp.1-14.

El Sibai, A., Rihko Struckmann, L. K. and Sundmacher, K. (2017) ‘Model-based Optimal Sabatier Reactor Design for Power-to-Gas Applications’, *Energy Technology*, 5(6), pp. 911–921.

EPA (1999) ‘Nitrogen oxides (NOx), why and how they are controlled’, *Epa-456/F-99-006R*, (November), p. 48.

EPA (2008) Air Poluttion Control Equipment, MACT EEE Training Workshop.

EPA (2016) 'U.S. Environmental Protection Agency Office of Resource Conservation and Recovery Documentation for Greenhouse Gas Emission and Energy Factors Used in the Waste Reduction Model (WARM) Construction and Demolition Materials Chapters', (February).

EPA, (2000) Hot mix asphalt plants - emission assessment report, North Carolina.

EPA (2004) 'Emission Factor Documentation for AP-42 Hot Mix Asphalt Plants Final Report', (08682).

EPA (2017) 'U.S. Greenhouse Gas Emissions and Sinks', *Decision Support Systems*, 38(4), pp. 557–573.

EPA (2015) 'Sulfur Dioxide Emissions', (SOx).

EPA (2019) 'NAAQS Table', *United States Environmental Protection Agency*, (2), pp. 2017–2019.

Ernst, B., Hilaire, L. and Kiennemann, A. (1999) 'Effects of highly dispersed ceria addition on reductibility, activity and hydrocarbon chain growth of a Co/SiO_2 Fischer-Tropsch catalyst', *Catalysis Today*, 50(2), pp. 413–427.

Eurotron (2006) 'Combustion and Flue Gas Analysis', (December), pp. 1–37.

Federal Aviation (2000) *Section 9:Parallel-Flow Drum-Mix Plants*. Hot-mix asphalt paving handbook.

Felder, R. and Rousseau, R. W. (1986) *Elementary Principles of Chemical Processes*. 2nd edn. John Wily & Sons.

Feng, Y., Yang, W. and Chu, W. (2015) 'A Study of CO Methanation over Ni-Based Catalysts Supported by CNTs with Various Textural Characteristics', *International Journal of Chemical Engineering*, 2015, pp. 167-173.

Finch, J.N. and Ripley, D. L. (1976) 'United States Patent 3988334.' Retrieved on October 26 (1976).

Fisher RA (1935) *The design of experiments.* 1st edn. Edinburgh: Oliver and Boyd; 1935.

Fisher RA (1990) *Statistical methods, experimental design and scientific interference*. Oxford: Oxford University Press.

Fletcher, P., and Haswell, S. (1999) 'Downsizing synthesis', *Chemistry in Britain*, 35(11), pp. 38–41.

Foger, K. (1984) 'Dispersed metal catalysts', *In Catalysis,* pp. 227-305.

Forzatti, P. and Lietti, L. (1999) 'Catalyst deactivation', 52, pp. 165–181.

Fowler, D., Amann, M., Anderson, R., Ashmore, M. R., Depledge, M., Derwent, D., Grennfelt, P., Hewitt, C. N., Hov, O., Jenkin, M., Kelly, F. J., Liss, P., Pilling, M. J., Pyle, J., Slingo, J. and Stevenson, D. (2008) *Ground-level ozone in the 21st century: future trends , impacts and policy implications Science Policy, Science Policy Report - The Royal Society.*

Frontera, P., Macario, A., Ferraro, M. and Antonucci, P. L. (2017) 'Supported catalysts for CO_2 methanation: A review', *Catalysts*, 7(2), pp. 1–28.

Furimsky, E., Massoth, F. E. (1993) 'Introduction of regeneration of hydroprocessing catalyst', *Catalysis Today*, 17(4), pp. 537–659.

Gao, J., Jia, C., Li, J., Zhang, M., Gu, F., Xu, G., Zhong, Z. and Su, F. (2013) 'Ni/Al_2O_3 catalysts for CO methanation: Effect of Al_2O_3 supports calcined at different temperatures', *Journal of Energy Chemistry*, 22(6), pp. 919–927.

Garbarino, G., Bellotti, D., Riani, P., Magistri, L. and Busca, G. (2015) 'Methanation of carbon dioxide on Ru/Al_2O_3 and Ni/Al_2O_3 catalysts at atmospheric pressure: Catalysts activation, behaviour and stability.', *International Journal of Hydrogen Energy*, 40(30), pp. 9171–9182.

Garbis, P., Kern, C. and Jess, A. (2019) 'Kinetics and reactor design aspects of selective methanation of CO over a Ru/γ-Al_2O_3 catalyst in CO_2/H_2 rich gases', *Energies*, 12(3), pp. 1–15.

Ghaib, K. and Ben-Fares, F. Z. (2018b) 'Power-to-Methane: A state-of-the-art review', *Renewable and Sustainable Energy Reviews*, 81, pp. 433–446.

Giglio, E., Lanzini, A., Santarelli, M. and Leone, P. (2015) 'Synthetic natural gas via integrated high-temperature electrolysis and methanation: Part I-Energy performance', *Journal of Energy Storage*, 1(1), pp. 22–37.

Gillespie, I. (2012) 'Quantifying the Energy Used in an Asphalt Coating Plant', *University of Strachclyde: Glasgow, Scotland* , 164.

Götz, M., Lefebvre, J., Mörs, F., McDaniel Koch, A., Graf, F., Bajohr, S., Reimert, R. and Kolb, T. (2016a) 'Renewable Power-to-Gas: A technological and economic review', *Renewable Energy*, 85, pp. 1371–1390.

Guettel, R. and Turek, T. (2009) 'Comparison of different reactor types for low temperature Fischer-Tropsch synthesis: A simulation study', *Chemical Engineering Science*, 64(5), pp. 955–964.

Hans-Christian Schneider (2017) *4 Ways to Reduce Moisture and Fuel Costs, Ammann Group.*

Harris, J. M., Roach, B., Harris, J. M. and Roach, B. (2018) '*Global Climate Change: Science and Economics, Environmental and Natural Resource Economics: A contemporary approach*',4th Edn., Routledge.

Hassan, S. M. N. (2005) '*Techno-economic study of CO_2 capture process for cement plants*', Master's thesis, University of Waterloo.

He, Z., Wang, X., Gao, S. and Xiao, T. (2015) 'Effect of reaction variables on CO methanation process over NiO–La_2O_3–MgO/Al_2O_3 catalyst for coal to synthetic natural gas', *Applied Petrochemical Research*, 5(4), pp. 413–417.

Heck, R. M. and Farrauto, R. J. (2001) 'Automobile Exhaust Catalysts', *Applied Catalysis A: General*, 221(1–2), pp. 443–457.

Herman A. Szymanski Ronald E. Erickson (1970) Infrared Absorption Bands. In *Infrared Band Handbook* (pp. 1-754). Springer, Boston, MA.

Herranz, T., Rojas, S., Perez-Alonso, F.J., Ojeda, M., Terreros, P. and Fierro, J. L. G. (2006) 'Hydrogenation of carbon oxides over promoted Fe-Mn catalysts prepared by the microemulsion methodology', *Applied Catalysis A: Generaleral*, 311, pp. 66–75.

Himmelblau, D. M. (1982) *Basic Principles and Calculations in Chemical Engineering*. 4th edn. Prentice Hall, New Jersey.

Hu, J., Brooks, K. P., Holladay, J. D., Howe, D. T. and Simon, T. M. (2007) 'Catalyst development for microchannel reactors for martian in situ propellant production', *Catalysis Today*, 125(1-2), pp.103-110.

Hu, Y., Naito, S., Kobayashi, N. and Hasatani, M. (2000) 'CO_2, NOx and SO_2 Emissions from the Combustion of Coal with high Oxygen Concentration Gases', *Fuel*, 79(15), pp. 1925–1932.

Huang, T. X. and X. (2010) 'Study on combustion mechanism of asphalt binder by using TG–FTIR technique', *Fuels*, (89), pp. 2185–2190.

Huang, X., Yang, J., Fang, H., Cai, Y., Zhu, H. and Lv, N. (2019) 'Energy Consumption Analysis and Prediction of Hot Mix Asphalt', *IOP Conference Series: Materials Science and Engineering*, 490(3), pp. 032029.

Huang, Y., Yuan, Y., Zhou, Z., Liang, J., Chen, Z. and Li, G. (2014) 'Optimization and evaluation of chelerythrine nanoparticles composed of magnetic multiwalled carbon nanotubes by response surface methodology', *Applied Surface Science*. 292, pp.378-386.

Hwang S, Lee J, Hong UG, Jung JC, Baik JH, Koh DJ, Lim H, S. I. (2012) ‘Hydrogenation of CO to methane over mesoporous nickel-iron-alumina xerogel nano-catalysts’, *Journal Nanoscience and Nanotechnology*, 12(7), pp. 6051–7.

Inoue, T., Ohtaki, K., Kikutani, Y., Sato, K., Nishioka, M., Hamakawa, S., Mawatari, K., Hibara, A., Mizukami, F. and Kitamori, T. (2010) ‘Direct synthesis of hydrogen peroxide based on microreactor technology’, *Fuel processing technology*, *108*, pp.8-11.

Inui, T. (1996) ‘Highly effective conversion of carbon dioxide to valuable compounds on composite catalysts’, *Catalysis Today*, 29(1–4), pp. 329–337.

Irvine, W. M. (2015) ‘Langmuir-Hinshelwood Mechanism’, in *Encyclopedia of Astrobiology*, pp.1360-1360.

Jacquemin, M., Beuls, A. and Ruiz, P. (2010) ‘Catalytic production of methane from CO_2 and H_2 at low temperature: Insight on the reaction mechanism’, *Catalysis Today*, 157(1–4), pp. 462–466.

Jiajian, G., Wang, Y., Ping, Y., Hu, D., Xu, G., Gu, F. and Su, F. (2012) ‘A thermodynamic analysis of methanation reactions of carbon oxides for the production of synthetic natural gas’, *RSC Adv.*, 2, pp. 2358–2368.

Jing Si, Guilong Liu, Jingge Liu, Lin Zhao, Shuangshuang Li, Y. G. and Y. L. (2016) ‘Ni nanoparticles highly dispersed on ZrO_2 and modified with La_2O_3 for CO methanation’, *Royale Society of Chemistry Advances*, 6(15), pp. 12699-12707

Jullien, A., Gaudefroy, V., Ventura, A., De La Roche, C., Paranhos, R., & Monéron, P. (2010) ‘Airborne emissions assessment of hot asphalt mixing: methods and limitations.’, *Road Materials and Pavement Design*, 11(1), pp. 149–169.

Jyethi, D. S. (2016) ‘Air Quality: Global and Regional Emissions of Particulate Matter, SOx, and NOx.’, *In Plant Responses to Air Pollution*, Springer, pp. 5–19.

Karelovic, A. and Ruiz, P. (2013) ‘Mechanistic study of low temperature CO_2 methanation over Rh/TiO_2 catalysts’, *Journal of Catalysis*. Elsevier Inc., 301, pp. 141–153.

Kawi, S., Kathiraser, Y., Ni, J., Oemar, U., Li, Z. and Saw, E. T. (2015) ‘Progress in Synthesis of Highly Active and Stable Nickel-Based Catalysts for Carbon Dioxide Reforming of Methane’, *ChemSusChem*, 8(21), pp. 3556–3575.

Khuri, A. I. (2017) ‘Response Surface Methodology and Its Applications In Agricultural and Food Sciences’, *Biometrics & Biostatistics International Journal*, 5(5), pp.1-11.

Kikkawa, S., Teramura, K., Asakura, H., Hosokawa, S., & Tanaka, T. (2020) ‘Ni–Pt Alloy Nanoparticles with Isolated Pt Atoms and Their Cooperative Neighboring Ni Atoms for Selective Hydrogenation of CO_2 Toward CH_4 Evolution: In Situ and Transient Fourier Transform Infrared Studies.’, *ACS Applied Nano Materials*, 3(10), pp. 9633–9644.

Kirk, N. B. and Wood, J. V. (1995) ‘The effect of the calcination process on the crystallite shape of sol-gel cerium oxide used for glass polishing’, *Journal of Materials Science*, 30(8), pp. 2171–2175.

Kitto AM, Pirbazari M, Badriyha BN, Ravindran V, Tyner R, S. C. (1997) ‘Emissions of volatile and semivolatile organic compounds and particulate matter from hot asphalts.’, *Enviroment Technology*, 18, pp. 121–138.

Kiwi-Minsker, L., Renken, A., Hessel, V. S. (2008) ‘*Structured Catalytic Microreactors and Catalysts*’, in Wirth, T. (ed.), Wiley-VCH.

Klemm, E., Dietzsch, E., Schwarz, T., Kruppa, T., De Oliveira, A. L., Becker, F., Markowz, G., Schirrmeister, S., Schütte, R., Caspary, K. J., Schüth, F. and Hönicke, D. (2008) ‘Direct gas-phase epoxidation of propene with hydrogen peroxide on TS-1 zeolite in a microstructured reactor’, *Industrial and Engineering Chemistry Research*. 47(6), pp.2086-2090.

Klemm, E. and Schirrmeister, S. (2008) ‘Microstructured reactors for the production of commodities by heterogeneously catalysed gas phase reactions: Potentials and limits’, in *Conference Proceedings - 2009 AIChE Spring National Meeting and 5th Global Congress on Process Safety*.

Kok, E., Scott, J., Cant, N. and Trimm, D. (2011) ‘The impact of ruthenium, lanthanum and activation conditions on the methanation activity of alumina-supported cobalt catalysts’, *Catalysis Today*, 164(1), pp. 297–301.

Kopyscinski, J., Schildhauer, T. J. and Biollaz, S. M. A. (2010) ‘Production of synthetic natural gas (SNG) from coal and dry biomass - A technology review from 1950 to 2009’, *Fuel*, 89(8), pp.1763-1783.

Kriech, A.J., Osborn, L. V. (2014) ‘Review and implications of IARC monograph 103 outcomes for the asphalt pavement industry.’, *Road Materials and Pavement Design*, 15(2), pp. 406–419.

Krier, C., Hackel, M., Hägele, C., Urtel, H., Querner, C. and Haas, A. (2013) 'Improving the methanation process', *Chemie-Ingenieur-Technik*, 85(4), pp. 523–528.

Kumar, J. and Bansal, A. (2013) 'Photocatalytic degradation in annular reactor: Modelization and optimization using computational fluid dynamics (CFD) and response surface methodology (RSM)', *Journal of Environmental Chemical Engineering*, 1(3), pp.398-405.

Kuznecova, I. and Gusca, J. (2017) 'Property based ranking of CO and CO_2 methanation catalysts', *Energy Procedia*, 128, pp. 255–260.

Lau, L., Choong, C. and Ng, C. (2018) 'Role of Institutional Quality on Environmental Kuznets Curve: A Comparative Study in Developed and Developing Countries.', *Advances in Pacific Basin Business, Economics and Finance*, 6, pp. 223–247.

Leclercq, G., Dathy, C., Mabilon, G. and Leclercq, L. (1991) 'Influence of Rh and CeO_2 addition on the activity and selectivity of a Pt/Al_2O_3 catalyst in the CO + NO and CO + NO + O_2 reactions', in *Studies in Surface Science and Catalysis*, pp. 181–194.

Lee, H. V., Juan, J. C., Yun Hin, T. Y. and Ong, H. C. (2016) 'Environment-friendly heterogeneous alkaline-Based mixed metal oxide catalysts for biodiesel production', *Energies*, 9(8), p.611.

Li, L., Wang, Y., Xu, Z. P. and Zhu, Z. (2013) 'Catalytic ammonia decomposition for CO-free hydrogen generation over Ru/Cr_2O_3 catalysts', *Applied Catalysis A: General*, 467, pp. 246–252.

Li, S. and Gong, J. (2014) 'Strategies for improving the performance and stability of Ni-based catalysts for reforming reactions', *Chemical Society Reviews*. Royal Society of Chemistry, 43(21), pp. 7245–7256.

Li, X., Wang, Y., Zhang, G., Sun, W., Bai, Y., Zheng, L., Han, X. and Wu, L. (2019) 'Influence of Mg-promoted Ni-based Catalyst Supported on Coconut Shell Carbon for CO_2 Methanation', *ChemistrySelect*, 4(3), pp.838-845.

Liew, S. C. (2014) '*Impacts of Vanadium and Coke Deposition on CO_2 Gasification of Nickel Catalysts Supported on Activated Carbon from Petroleum Coke*', Master's thesis, Graduate Studies.

Lindsey, R. and Dlugokencky, E. (2017) *Climate Change: Atmospheric Carbon Dioxide*, *Climate.Gov*.

Linping, Q., Bin, Y., Supeng, P., Li, Z., Lin, Y., Jifang, C., Shik Chi, T. and Heyong, H. (2010) 'Reforming of CH4 with CO_2 over Rh/H-Beta : Effect of rhodium dispersion on the catalytic activity and coke resistance', *Chinese Journal of Chemistry*, 28(10), pp. 1864–1870.

Liu, J. Y., Qiu, Z. S., Huang, W. A., Luo, Y. and Song, D. D. (2014) 'Nano-pore structure characterization of shales using gas adsorption and mercury intrusion techniques', *Journal of Chemical and Pharmaceutical Research*, 6, pp.850-857.

Liu, Q., Gu, F., Lu, X., Liu, Y., Li, H., Zhong, Z., Xu, G. and Su, F. (2014) 'Enhanced catalytic performances of Ni/Al_2O_3 catalyst via addition of V_2O_3 for CO methanation', *Applied Catalysis A: General*, 488, pp. 37–47.

Liu, Q., Zhong, Z., Gu, F., Wang, X., Lu, X., Li, H., Xu, G. and Su, F. (2016) 'CO methanation on ordered mesoporous Ni-Cr-Al catalysts: Effects of the catalyst structure and Cr promoter on the catalytic properties', *Journal of Catalysis*, 337, pp. 221–232.

Liu, Q., Bian, B., Fan, J. and Yang, J. (2018) 'Cobalt doped Ni based ordered mesoporous catalysts for CO2 methanation with enhanced catalytic performance', *International Journal of Hydrogen Energy*. Elsevier Ltd, 43(10), pp. 4893–4901.

Liu, X., Cui, Q. and Schwartz, C. (2014) 'Performance Benchmark of Greenhouse Gas Emissions from Asphalt Pavement in the United States', In *ICSI 2014: Creating Infrastructure for a Sustainable World*, 301, pp. 678-689.

Liu, Z., Chu, B., Zhai, X., Jin, Y. and Cheng, Y. (2012) 'Total methanation of syngas to synthetic natural gas over Ni catalyst in a micro-channel reactor', *Fuel*, 95, pp. 599–605.

Lohitharn, N., Goodwin, J. G. and Lotero, E. (2008) 'Fe-based Fischer-Tropsch synthesis catalysts containing carbide-forming transition metal promoters', *Journal of Catalysis*, 255(1), pp.104-113.

Lopez-Ruiz, H. G. and Crozet, Y. (2010) 'Sustainable Transport in France Is a 75% Reduction in Carbon Dioxide Emissions Attainable?', *Transportation Research Record*, (2163), pp. 124–132.

Luisetto, I., Tuti, S., Battocchio, C., Lo Mastro, S. and Sodo, A. (2015) 'Ni/CeO2-Al2O3 catalysts for the dry reforming of methane: The effect of $CeAlO_3$

content and nickel crystallite size on catalytic activity and coke resistance', *Applied Catalysis A: General*, 500, pp. 12–22.

Lunde, P. J. and Kester, F. L. (1974) 'Carbon Dioxide Methanation on a Ruthenium Catalyst', *Industrial and Engineering Chemistry Process Design and Development*, 13(1), pp.27-33.

M. Bankmann, R. Brand, B. H. Engler, and J. O. (1992) 'Forming of High Surface Area $Ti0_2$', 14, pp. 225–242.

M. Sol-Sánchez, F. Moreno-Navarro, G. García-Travé, M.C.R.-G. (2016) 'Analysing Industrial Manufacturing in-plant and in-service Performance of Asphalt Mixtures Cleaner Technologies', *Journal of Cleaner Production*, 121, pp. 56–63.

Mäkelä, M. (2017) 'Experimental design and response surface methodology in energy applications: A tutorial review', *Energy Conversion and Management*, 151, pp. 630–640.

Managamuri, U., Vijayalakshmi, M., Indupalli, M. D., Ganduri, V. S. R. K., Rajulapati, S. B. and Poda, S. (2018) 'Improved bioactive metabolite production by saccharopolyspora halotolerans VSM-2 using response surface methodology and unstructured kinetic modelling', *Pharmacognosy Journal*, 10(5), pp. 833–840.

Martínez, J., Hernández, E., Alfaro, S., Medina, R. L., Aguilar, G. V., Albiter, E. and Valenzuela, M. A. (2019) 'High selectivity and stability of nickel catalysts for CO2 Methanation: Support effects', *Catalysts*, 9(1).

Marwood, M., Doepper, R. and Renken, A. (1996) 'Modeling of Surface Intermediates under Forced Periodic Conditions Applied to CO_2 Methanation', *Canadian Journal of Chemical Engineering*, 74(5), pp.660-663.

Marwood, M., Doepper, R. and Renken, A. (1997) 'In-situ surface and gas phase analysis for kinetic studies under transient conditions: The catalytic hydrogenation of CO_2', *Applied Catalysis A: General*, 151(1), pp. 223–246.

Matthischke, S., Roensch, S. and Güttel, R. (2018) 'Start-up Time and Load Range for the Methanation of Carbon Dioxide in a Fixed-Bed Recycle Reactor', *Industrial and Engineering Chemistry Research*, 57(18), pp. 6391–6400.

Meg Postle, Philip Holmes, Marco Camboni, Anthony Footitt, Nigel Tuffnell, Mark Blainey, Gary Stevens, A. P. (2012) 'Final Report Part A: Polymers', (December).

Mebrahtu, C., Krebs, F., Abate, S., Perathoner, S., Centi, G. and Palkovits, R. (2019) 'CO_2 methanation: principles and challenges.', *Studies in surface science and catalysis*, 178, pp. 85–103.

Mierczynski, P., Mierczynska, A., Ciesielski, R., Mosinska, M., Nowosielska, M., Czylkowska, A., Maniukiewicz, W., Szynkowska, M. I. and Vasilev, K. (2018) 'High active and selective Ni/Ceo_2 –Al_2O_3 and Pd–Ni/Ceo_2–Al_2O_3 catalysts for oxy-steam reforming of methanol', *Catalysts*, 8(9), pp. 13–16.

Miller TD, B. H. (2009) *Sustainable asphalt pavements: technologies, knowledge gaps and opportunities.* Madison, USA: Modified Asphalt Research Center and University of Wisconsin; 2009.

Mills, G. A. and Steffgen, F. W. (1974) 'Catalytic methanation', *Catalysis Reviews*, *8*(1), pp.159-210.

Misono, M. (2013) 'Chemistry and catalysis of mixed oxides', In *Studies in Surface Science and Catalysis*, 176, pp. 25-65.

Moka, S., Pande, M., Rani, M., Gakhar, R., Sharma, M., Rani, J. and Bhaskarwar, A. N. (2014) 'Alternative fuels : An overview of current trends and scope for future', *Renewable and Sustainable Energy Reviews*, 32, pp. 697–712.

Müller, K., Fleige, M., Rachow, F. and Schmeißer, D. (2013) 'Sabatier based CO_2-methanation of flue gas emitted by conventional power plants', *Energy Procedia*, 40, pp. 240–248.

Murata, K., Okabe, K., Inaba, M., Takahara, I. and Liu, Y. (2009) 'Mn-modified Ru catalysts supported on carbon nanotubes for Fischer-Tropsch synthesis', *Journal of the Japan Petroleum Institute*, 52(1), pp. 16–20.

Muroyama, H., Tsuda, Y., Asakoshi, T., Masitah, H., Okanishi, T. and Matsui, T. (2016) 'Carbon dioxide methanation over Ni catalysts supported on various metal oxides', *Journal of Catalysis*. Elsevier Inc., 343, pp. 178–184.

Murray, K. K., Boyd, R. K., Eberlin, M. N., John Langley, G., Li, L. and Naito, Y. (2013) 'Definitions of terms relating to mass spectrometry (IUPAC Recommendations 2013)', *Pure and Applied Chemistry*.

Najam, T., Shah, S. S. A. and , Ding, W., Jiang, J., Li, J., Wang, Y., Li, L. and Wei, Z. (2018) 'An Efficient Anti-poisoning catalyst against SOx, NOx and POx:

P, N-doped Carbon for Oxygen Reduction in Acidic Media', *Chemistry International*, 57(46), pp. 1–8.

NCHRP (2013) 'National Cooperative Highway Research Program Synthesis 435:Recycled Materials and By products in Highway Applications', in *The National Acedemies of Science Engineering Medicines*, p. 2.

Nguyen, T. T. M., Wissing, L. and Skjøth-Rasmussen, M. S. (2013) 'High temperature methanation: Catalyst considerations', *Catalysis Today*, 215, pp. 233–238.

NOAA (2018) *Trends in Atmospheric Carbon Dioxide*, *Global Monitoring Laboratory*, pp. 3

NPTEL (2015) 'Lecture 1: Introduction to catalysis', *Chemical Engineering: Catalyst Science and Technology*, pp. 1–30.

NPTEL (2018) 'Combustion Technology and Combustion air calculation', *Indian Institutes of Technology*, pp. 1- 45.

Nurunnabi, M., Murata, K., Okabe, K., Inaba, M. and Takahara, I. (2008) 'Performance and characterization of Ru/Al_2O_3 and Ru/SiO_2 catalysts modified with Mn for Fischer-Tropsch synthesis', *Applied Catalysis A: General*, 340(2), pp. 203–211.

Ocampo, F., Louis, B., Kiennemann, A. and Roger, A. C. (2011) 'CO_2 methanation over Ni-Ceria-Zirconia catalysts: Effect of preparation and operating conditions',*IOP Conference Series: Materials Science and Engineering*, 19, pp. 1–11.

Oh, S. W., Bang, H. J., Bae, Y. C. and Sun, Y. K. (2007) 'Effect of calcination temperature on morphology, crystallinity and electrochemical properties of nano-crystalline metal oxides (Co_3O_4, CuO, and NiO) prepared via ultrasonic spray pyrolysis', *Journal of Power Sources*, 173(1), pp. 502–509.

OSHA (2019) *Occupational Safety and Health Administration*, *U.S Department of Labour*.

Panagiotopoulou, P., Kondarides, D.I. and Verykios, X. E. (2009) 'Selective methanation of CO over supported Ru catalysts', *Applied Catalysis B: Environmental*, 88(3–4), pp. 470–478.

Panagiotopoulou, P., Kondarides, D. and Verykios, X. (2009) 'Selective methanation of CO over supported Ru catalysts', *Applied Catalysis B Environmental*, 88(3-4), pp.470-478.

Panahi, P. N., Salari, D., Niaei, A. and Mousavi, S. M. (2013) 'NO reduction over nanostructure M-Cu/ZSM-5 (M: Cr, Mn, Co and Fe) bimetallic catalysts and optimization of catalyst preparation by RSM', *Journal of Industrial and Engineering Chemistry*. The Korean Society of Industrial and Engineering Chemistry, 19(6), pp. 1793–1799.

Paranhos, R. S. and Petter, C. O. (2013a) 'Multivariate data analysis applied in Hot-Mix asphalt plants', *Resources, Conservation and Recycling*, 73, pp. 1–10.

Paranhos, R. S. and Petter, C. O. (2013b) 'Multivariate data analysis applied in Hot-Mix asphalt plants', *Resources, Conservation and Recycling*, 73, pp. 1–10.

Park, J. H., Lee, D., Lee, H. C. and Park, E. D. (2010) 'Steam reforming of liquid petroleum gas over Mn-promoted Ni/γ-Al_2O_3 catalysts', *Korean Journal of Chemical Engineering*, 27(4), pp. 1132–1138.

Peinado, D., de Vega, M., García-Hernando, N. and Marugán-Cruz, C. (2011) 'Energy and exergy analysis in an asphalt plant's rotary dryer', *Applied Thermal Engineering*, 31(6–7), pp. 1039–1049.

Peinado, D, Vega, M. De, García-hernando, N. and Marugán-cruz, C. (2011) 'Energy and exergy analysis in an asphalt plant ' s rotary dryer', *Applied Thermal Engineering*, 31(6–7), pp. 1039–1049.

Peng, B., Cai, C., Yin, G., Li, W. and Zhan, Y. (2015) 'Evaluation System for CO_2 Emission of Hot Asphalt Mixture', *Journal of Traffic and Transportation Engineering (English Edition)*, 2(2), pp. 116–124.

Perego, Carlo and Villa, P. (1997) 'Catalyst preparation methods', *Catalysis Today*, 34, pp. 281-305.

Pérez-Ramírez, J., Mondelli, C., Schmidt, T., Schlüter, O. F. K., Wolf, A., Mleczko, L. and Dreier, T. (2011) 'Sustainable chlorine recycling via catalysed HCl oxidation: From fundamentals to implementation', *Energy and Environmental Science*, 4(12), pp. 4786–4799.

Perkas, N., Amirian, G., Zhong, Z., Teo, J., Gofer, Y., Gedanken, A. (2009) 'Methanation of carbon dioxide on Ni catalysts on mesoporous ZrO_2 doped with rare earth oxides.', *Catalysis Letters*, 130(3–4), pp. 455–462.

Popova, N. M., Salakhova, R. K., Dosumov, K., Tungatarova, S. A., Sass, A. S., Zheksenbaeva, Z. T., Komashko, L. V, Grigor'eva, V. P. and Shapovalov, A. A. (2009) 'Nickel-copper-chromium catalyst for selective methane oxidation to synthesis gas at short residence times', *Kinetics and Catalysis*, 50(4), pp. 567–576.

Popovicheva, O. B., Irimiea, C., Carpentier, Y., Ortega, I. K., Kireeva, E. D., Shonija, N. K., Schwarz, J., Vojtíšek-Lom, M. and Focsa, C. (2017) 'Chemical composition of diesel/biodiesel particulate exhaust by FTIR spectroscopy and mass spectrometry: Impact of fuel and driving cycle', *Aerosol and Air Quality Research*, 17(7), pp. 1717–1734.

Powell, J. B. and Langer, S. H. (1985) 'Low-temperature methanation and Fischer-Tropsch activity over supported ruthenium, nickel, and cobalt catalysts', *Journal of Catalysis*, 94(2), pp.566-569.

Puga, A. V (2018) 'On the nature of active phases and sites in CO and CO_2 hydrogenation catalysts', *Catal. Sci. Technol.* The Royal Society of Chemistry, 8(22), pp. 5681–5707.

Qiu, J., van de Ven, M. and Molenaar, A. (2013) 'Crack-Healing Investigation in Bituminous Materials', *Journal of Materials in Civil Engineering*, 25(7), pp.864-870.

Rahman, F. A. (2020) *Conversion of carbon dioxide emission using catalytic methanation method in hot mix asphalt plant*. Universiti Teknologi Malyasia.

Rao, C. N. R. (2010) 'Chemical Reactions', *Understanding Chemistry*, 461(S 11), pp. 225–274.

Rauf Razzaq, Hongwei ZhuLi Jiang, Usman Muhammad, Chunshan Li, S. Z. (2013) 'Catalytic Methanation of CO and CO_2 in Coke Oven Gas over Ni–Co/ZrO_2–CeO_2', *American Chemical Society*, 52(6), pp. 2247–2256.

Razza, S., Heidig, T., Bianchi, E., Groppi, G., Schwieger, W., Tronconi, E. and Freund, H. (2016) 'Heat transfer performance of structured catalytic reactors packed with metal foam supports: Influence of wall coupling', *Catalysis Today*, 273, pp. 187–195.

Razzaq, R., Li, C., Usman, M., Suzuki, K. and Zhang, S. (2015) 'A highly active and stable Co_4N/γ-Al_2O_3 catalyst for CO and CO_2 methanation to produce synthetic natural gas (SNG)', *Chemical Engineering Journal*, 262, pp. 1090–1098.

Read, J. & Whiteoak, D. (2003) *The Shell Bitumen Handbook*. 5th ed. London, UK: Thomas Telford.

Ren, J., Qin, X., Yang, J. Z., Qin, Z. F., Guo, H. L., Lin, J. Y. and Li, Z. (2015) 'Methanation of carbon dioxide over Ni-M/ZrO_2 (M = Fe, Co, Cu) catalysts: Effect of addition of a second metal', *Fuel Processing Technology*, 137, pp. 204–211.

Rengarajan, T., Rajendran, Peramaiyan, Nandakumar, N., Lokeshkumar, B., Rajendran, Palaniswami and Nishigaki, I. (2015) 'Exposure to polycyclic aromatic hydrocarbons with special focus on cancer', *Asian Pacific Journal of Tropical Biomedicine*, 5(3), pp. 182–189.

Rönsch, S., Schneider, J., Matthischke, S., Schlüter, M., Götz, M., Lefebvre, J., Prabhakaran, P. and Bajohr, S. (2016) 'Review on methanation – From fundamentals to current projects', *Fuels,* 166, pp. 276–296.

Rosid, S. J. M., Bakar, W. A. W. A. and Ali, R. (2015) 'Optimization of praseodymium oxide based catalysts for methanation reaction of simulated natural gas using Box-Behnken design', *Jurnal Teknologi*, 75(1), pp. 55–65.

Rosid, M.S. J., Wan Abu Bakar, W. A. and Ali, R. (2015) 'Catalytic CO_2 Methanation Reaction over Alumina Supported Manganese/Cerium Oxide Based Catalysts', *Advanced Materials Research*, 1107, pp. 67–72.

Rosid, S. J. M., Toemen, S., Wan Abu Bakar, W. A., Zamani, A. H. and Wan Mokhtar, W. N. A. (2018) 'Physicochemical characteristic of neodymium oxide-based catalyst for in-situ CO_2/H_2 methanation reaction', 23(3), pp.284-293.

Rostrup-Nielsen, J. . (1997) 'Industrial relevance of coking.', *Catalysis Today*, 37(3), pp. 225–232.

Rostrup-Nielsen, J. R., Pedersen, K. and Sehested, J. (2007) 'High temperature methanation. Sintering and structure sensitivity', *Applied Catalysis A: General*, 330, pp.134-138.

Rubio, M., Martínez, G., Baena, L. and Moreno, F. (2012) 'Warm Mix Asphalt: An overview', *Journal of Cleaner Production*, 24, pp. 76–84.

Russell, A. T. (2013). Combustion emissions. *Air pollution and cancer*, *161*.

Ryder, A. G., Glynn, T. J. and Feely, M. (2003) 'Influence of chemical composition on the fluorescence lifetimes of crude petroleum oils', *Opto-Ireland 2002: Optics and Photonics Technologies and Applications*, 4876, p. 1188.

Rynkowski, J. M., Paryjczak, T. and Lenik, M. (1995) 'Characterization of alumina supported nickel-ruthenium systems', *Applied Catalysis A, General*, 126(2), pp. 257–271.

Sabatier, P. and Senderens, J. B. (1902) 'New Synthesis of Methane', *Comptes Rendus*, 134, pp.514-516.

Sadollah, A., Ghadimi, A., Metselaar, I. H. and Bahreininejad, A. (2013) 'Prediction and optimization of stability parameters for titanium dioxide nanofluid using response surface methodology and artificial neural networks', *Science and Engineering of Composite Materials*, 20(4), pp. 319–330.

Sakata, Y., Tamaura, Y., Imamura, H. and Watanabe, M. (2006) 'Preparation of a new type of CaSiO3 with high surface area and property as a catalyst support', In *Studies in surface science and catalysis*, 162, pp. 331-338.

Salmiah Jamal Mat Rosid. (2015) '*Design and Optimization of Lanthanide Oxides Based Catalysts for Carbon Dioxide Methanation*', Phd dissertation, Universiti Teknologi Malaysia.

Santero, N. J. and Horvath, A. (2009) 'Global warming potential of pavements', *Environmental Research Letters*, 034011.

Satein, H. (2009) 'Chemical Relationships between Greenhouse Gases and Air Pollutants in Biomass Energy Production', *Oregon Toxics Alliance*, 1(1), pp. 1–5.

Saxena, A. K. (2009) 'Greenhouse gas emissions: Estimation and Reduction', *Asian Productivity Organization.*

Schild, C., Wokaun, A. and Baiker, A. (1990) 'On the mechanism of CO and CO_2 hydrogenation reactions on zirconia-supported catalysts: a diffuse reflectance FTIR study. Part I. Identification of surface species and methanation reactions on palladium/zirconia catalysts', *Journal of Molecular Catalysis*, 63(2), pp.243-254.

Schlereth, D. and Hinrichsen, O. (2014) 'A fixed-bed reactor modeling study on the methanation of CO2', *Chemical Engineering Research and Design*. Institution of Chemical Engineers, 92(4), pp. 702–712.

Schwarz, J. A., Contescu, C. and Contescu, A. (1995) 'Methods for Preparation of Catalytic Materials', *Chemical Reviews*, 95(3), pp. 477–510.

Scire` S, Crisafulli C, Maggiore R, Minico` S, G. S. (1981) ‘Influence of the support on CO2 methanation over Ru catalysts: an FT-IR study.’, *Catalysis Letters*, 51, pp. 41–45.

Sehested, J. (2006) ‘Four challenges for nickel steam-reforming catalysts.’, *Catalysis Today Today*, 111(1–2), pp. 103–110.

Seinfled, J. A. M. and J. H. (1985) ‘Control System Design for a Fixed-Bed Methanation Reactor’, 41(6), pp. 1577–1597.

Serra, D., (2010) ‘Moisture in Asphalt Production-The importance of accurate moisture measurement and control’, *Quarry Management*, *37*(1), p.19.

Seung-Ho Seok, Sung Hwan Han, J. S. L. (2001) ‘The role of MnO in Ni/MnO-Al2O3 catalysts for carbon dioxide reforming of methane’, *Applied Catalysis A, General*, 215(1–2), pp. 31–38.

Shahsavari, A. and Akbari, M. (2018) ‘Potential of solar energy in developing countries for reducing energy-related emissions’, *Renewable and Sustainable Energy Reviews*, 90, pp. 275–291.

Shan, W., Yang, L., Ma, N. and Yang, J. (2012) ‘Catalytic activity and stability of K/CeO 2 catalysts for diesel soot oxidation’, *Chinese Journal of Catalysis*, 33(4–6), pp. 970–976.

Shang, Z., Li, S., Li, L., Liu, G. and Liang, X. (2017) ‘Highly active and stable alumina supported nickel nanoparticle catalysts for dry reforming of methane’, *Applied Catalysis B: Environmental*, 201, pp. 302–309.

Sharma, S. B., Jain, S., Khirwadkar, P. and Kulkarni, S. (2013) ‘The effects of air pollution on the environment and human health’, *Indian Journal of Research in Pharmacy and Biotechnology*, 1(3), pp. 2320–3471.

Sharma, S., Hu, Z., Zhang, P., McFarland, E. W. and Metiu, H. (2011) ‘CO2 methanation on Ru-doped ceria’, *Journal of Catalysis*, 278(2), pp. 297–309.

Environmental Sciences, 20(1), pp. 50–55.

Singh, D., Subramanian, K.A. and Singal, S.K., (2015) 'Emissions and fuel consumption characteristics of a heavy duty diesel engine fueled with hydroprocessed renewable diesel and biodiesel' *Applied Energy*, 155, pp.440-446.

Siti Fadziana (2016) *Synthesis, Catalytic Activity and Characterization of Alumina Supported Ceria Catalyst for Carbon Dioxide Methanation*. Master's Thesis, Universiti Teknologi Malaysia, Skudai.

Słomkiewicz, P. M. (2004) 'Determination of the Langmuir-Hinshelwood kinetic equation of synthesis of ethers', *Applied Catalysis A: General*, 269(1-2), pp.33-42.

Sorrels, J. L., Randall, D. D., Schaffner, K. S. and Fry, C. R. (2016) 'Chapter 2: Selective Catalytic Reduction', *Economic and Cost Analysis for Air Pollution Regulations*, (May 2016).

Speight, J. G. (2019) 'Combustion of hydrocarbons', in *Handbook of Industrial Hydrocarbon Processes*. 2nd edn, pp. 421–463.

Stangeland, K., Kalai, D., Li, H. and Yu, Z. (2017) 'CO_2 Methanation: the effect of catalysts and reaction conditions', *Energy Procedia*, 105(1876), pp. 2022–2027.

Stern, A. C. (1964) 'Summary of existing air pollution standards', *Journal of the Air Pollution Control Association*, 14(1), pp. 5–15.

Stout, D., Douglas, P. E., & Carlson, D. (2003) 'Stack emissions with asphalt rubber a synthesis of studies.', in *Proceedings of Asphalt Rubber*. Brasília, Brazil.

Susilawati Toeman (2015) *'Preparation, Characterization and Mechanism of catalytic Methanation of Cerium, Strontium, Nickel and Tin Oxides Catalysts'*, Phd dissertation, Universiti Teknologi Malaysia, Skudai.

Tada S, Shimizu T, Kameyama H, Haneda T, K. R. (2012) 'Ni/CeO_2 catalysts with high CO_2 methanation activity and high CH_4 selectivity at low temperatures', *International Journal of Hydrogen Energy,* 37(7), pp. 5527–5531.

Tada, S., James, O. and Kikuchi, R. (2014) 'Promotion of CO_2 methanation activity and CH_4 selectivity at low temperatures over Ru/CeO_2/Al_2O_3 catalysts', *International Journal of Hydrogen Energy*, 39(19), pp. 10090–10100.

Tada, S. and Kikuchi, R. (2015) 'Mechanistic study and catalyst development for selective carbon monoxide methanation', *Catalysis Science and Technology*, 5(6), pp. 3061–3070.

Takafumi S, Tadafumi A, Kunio A, Garry LR, F. T. (2003) 'Upgrading of asphalt with and without partial oxidation in supercritical water.', *Fuel*, (82), pp. 1231–1239.

Thives, L. P. and Ghisi, E. (2017) 'Asphalt mixtures emission and energy consumption: A review', *Renewable and Sustainable Energy Reviews*, 72, pp. 473–484.

Thommes, M., Kaneko, K., Neimark, A.V., Olivier, J.P., Rodriguez-Reinoso, F., Rouquerol, J. and Sing, K.S. (2015) 'Physisorption of Gases, with Special Reference to the Evaluation of Surface Area and Pore Size Distribution (IUPAC technical report).', *Pure Applied Chemical*, 87(9–10), pp. 1051–69.

Thommes, M. (2016) 'Physisorption of gases, with special reference to the evaluation of surface area and pore size distribution (IUPAC Technical Report)', *Chemistry International*, 38(1), pp. 25–25.

Türks, D., Mena, H., Armbruster, U. and Martin, A. (2017) 'Methanation of CO_2 on Ni/Al_2O_3 in a structured fixed-bed reactor—A scale-up study', *Catalysts*, 7(5), p.152..

Turner, James. M; Mckenna, J. (1998) 'Particulate Matter Controls', *EPA/452/B-02-001*, pp. 1–60.

UN Data (2015) *Energy and Environment: Bitumen asphalt*, *Factfish*.

UNEP (2006a) 'Energy Efficiency Guide for Industry in Asia - Thermal Energy Equipment: Furnaces and Refractories', pp. 1–36.

UNEP (2006b) 'Fuel and Combustion'.

US Army Corps of Engineers (2001) 'Hot-Mix Asphalt Paving (AC 150/5370-14A Appendix 1)', *Hot Mix Asphalt Paving Handbook (AC 150/5370-14A Appendix 1)*.

Vahid Shadravan, Eric Kennedy, M. S. (2018) 'An experimental investigation on the effects of adding a transition metal to Ni/Al_2O_3 for catalytic hydrogenation of CO and CO_2 in presence of light alkanes and alkenes', *Catalysis Today*, 307, pp. 277– 285.

Vahid Shadravan, Vanessa J. Bukas, G. T. Kasun Kalhara Gunasooriya, J. W., Matthew Drewery, Joel Karibika, Jamie Jones, Eric Kennedy, Adesoji Adesina, J. K. N. and Stockenhuber, and M. (2020) 'Effect of Manganese on the Selective Catalytic Hydrogenation of COx in the Presence of Light Hydrocarbons Over Ni/Al_2O_3: An Experimental and Computational Study', *ACS Catalysis*, 10, pp. 1535–1547.

Vannice, M. A. (1976) 'The Catalytic Synthesis of Hydrocarbons from Carbon Monoxide and Hydrogen', *Catalysis Reviews*, 14(1), pp. 153–191.

Ventura, A., Lorino, T., Le Guen, L. (2015) 'Modeling of Polycyclic Aromatic Hydrocarbons stack emissions from a hot mix asphalt plant for gate-to-gate Life Cycle Inventory.', *Journal of Cleaner Production*, 93, pp. 151–158.

Veser, G. (2001) 'Experimental and theoretical investigation of H_2 oxidation in a high-temperature catalytic microreactor', *Chemical Engineering Science*, 56(4), pp.1265-1273.

Wachs, E. I. (2005) 'Recent conceptual advances in the catalysis science of mixed metal oxide catalytic materials', *Catalysis Today*, 100(1–2), pp. 79–94.

Wang, H.T., Xiao, T.C., Su, J.X., Liu, W.X. and Lu, Y. L. (1999) 'Catalytic purification of flue gas from civil-used stove', *Catalysis Today*, 53, pp. 661–667.

Wang, S. and Lu, G. Q. M. (1998) 'Role of CeO2 in Ni/CeO_2-Al_2O_3 catalysts for carbon dioxide reforming of methane.', *Applied Catalysis B: Environmental.*, 19, pp. 267–277.

Wang, N., Chu, W., Zhang, T. and Zhao, X. S. (2011) 'Manganese promoting effects on the Co-Ce-Zr-Ox nano catalysts for methane dry reforming with carbon dioxide to hydrogen and carbon monoxide', *Chemical Engineering Journal*, 170(2–3), pp. 457–463.

Wang, P., Means, N., Shekhawat, D., Berry, D. and Massoudi, M. (2015) 'Chemical-looping combustion and gasification of coals and oxygen carrier development: A brief review', *Energies*, 8(10), pp. 10605–10635.

Watts, P., Wiles, C., Haswell, S. J., Pombo-Villar, E. and Styring, P. (2001) 'The synthesis of peptides using micro reactors', In *Microreaction Technology*, pp. 508-517.

Wei, J. and Iglesia, E. (2004) 'Structural requirements and reaction pathways in methane activation and chemical conversion catalyzed by rhodium', *Journal of Catalysis*, 225, pp. 116–127.

WHO (2003) 'Health Aspects of Air Pollution with Particulate Matter , Ozone and Nitrogen Dioxide', *Report on a WHO Working Group Bonn, Germany 13–15 January 2003. EUR/03/5042688*, (January), p. 98.

Xu, J., Su, X., Duan, H., Hou, B., Lin, Q., Liu, X., Pan, X., Pei, G., Geng, H., Huang, Y. and Zhang, T. (2016) 'Influence of pretreatment temperature on catalytic performance of rutile TiO 2 -supported ruthenium catalyst in CO_2 methanation', *Journal of Catalysis*, 333, pp. 227–237.

Xu, L., Wang, F., Chen, M., Zhang, J., Yuan, K., Wang, L., Wu, K., Xu, G. and Chen, W. (2016) 'CO_2 methanation over a Ni based ordered mesoporous catalyst for the production of synthetic natural gas', *RSC Advances*. Royal Society of Chemistry, 6(34), pp. 28489–28499.

Yan, X., Liu, Y., Zhao, B., Wang, Z., Wang, Y. and Liu, C. J. (2013) 'Methanation over Ni/SiO 2 : Effect of the catalyst preparation methodologies', *International Journal of Hydrogen Energy*, 38(5), pp. 2283–2291.

Yang, S., Wu, Y. M. (2000) 'One Step Synthesis of Methyl isobutyl Ketone over Palladium Supported on AlPO4-11 and SAPO-11.', *Applied Catalysis A: General.*, 192, pp. 211–220.

Yanrong Li, Gongxuan Lu, J. M. (2014) 'Highly active and stable nano NiO-MgO catalyst encapsulated by silica with core-shell structure for CO_2 methanation', *Royale Society of Chemistry Advances*, pp. 1–10.

Yener, E. and Hinislioglu, S. (2011) 'A new energy saving for the determination of mixing temperature in hot mix asphalts', *Energy Education Science and Technology Part A: Energy Science and Research*, 26(2), pp.103-17.

Yeniay, Ö. (2014) 'Comparative study of algorithms for response surface optimization', *Mathematical and Computational Applications*, 19(1), pp. 93–104.

Younas, M., Loong Kong, L., Bashir, M.J., Nadeem, H., Shehzad, A. and Sethupathi, S., (2016) 'Recent advancements, fundamental challenges, and opportunities in catalytic methanation of CO_2', *Energy & Fuels*, *30*(11), pp.8815-8831.

Yuliwati, E., Ismail, A. F., Lau, W. J., Ng, B. C., Mataram, A. and Kassim, M. A. (2012) 'Effects of process conditions in submerged ultrafiltration for refinery wastewater treatment: Optimization of operating process by response surface methodology', *Desalination*, 287, pp.350-361.

Zain, M. M. and Mohamed, A. R. (2018) 'An overview on conversion technologies to produce value added products from CH_4 and CO_2 as major biogas constituents', *Renewable and Sustainable Energy Reviews*, 98, pp. 56–63.

Zamani, A. H., Ali, R. and Bakar, W.A.W.A. (2014) 'The investigation of Ru/Mn/Cu-Al_2O $_3$ catalysts for CO_2/H_2 methanation in natural gas', *Journal of the Taiwan Institute of Chemical Engineers*, 45(1), pp.143-152.

Zamani, A. H., Ali, R., Azelee, W. A.W.A., (2015) 'Green Technology purification of nature gas via CO_2/H_2 methanation by using trimetallic Ru/Mn/Fe-Al_2O_3 oxide catalyst', 1107, pp. 85–90.

Zhang, J., Xin, Z., Meng, X., Lv, Y. and Tao, M. (2013) 'Effect of MoO_3 on structures and properties of Ni-SiO_2 methanation catalysts prepared by the hydrothermal synthesis method.', *Industrial and Engineering Chemistry Research*, 52(41), pp. 14533–14544.

Zhang, X., Li, H., Lv, X., Xu, J., Wang, Y., He, C., and Wang, Y. (2018) 'Facile synthesis of highly efficient amorphous Mn-MIL-100 catalysts: formation mechanism and structure changes during application in CO oxidation.', *Chemistry–A European Journal*, 24(35), pp. 8822–8832.

Zhang, C., Liu, B., Wang, Y., Zhao, L., Zhang, J., Zong, Q., Gao, J. and Xu, C. (2017) 'The effect of cobalt promoter on the CO methanation reaction over MoS_2 catalyst: a density functional study', *RSC Advances*. Royal Society of Chemistry, 7(20), pp. 11862–11871.

Zhao, A., Ying, W., Zhang, H., Ma, H., Fang, D. (2012) 'Ni/Al_2O_3 Catalysts for Syngas Methanation: Effect of Mn promoter.', *Journal of Natural Gas Chemical*, 21, pp. 170–177.

Zhao, K., Li, Z. and Bian, L. (2016) 'CO_2 methanation and co-methanation of CO and CO_2 over Mn-promoted Ni/Al_2O_3 catalysts', *Frontiers of Chemical Science and Engineering*, 10(2), pp. 273–280.

Zhao, K., Wang, W. and Li, Z. (2016) 'Highly efficient Ni/ZrO_2 catalysts prepared via combustion method for CO_2 methanation', *Journal of CO_2 Utilization*, 16, pp. 236–244.

Zhou, G., Liu, H., Cui, K., Jia, A., Hu, G., Jiao, Z., Liu, Y. and Zhang, X. (2016) 'Role of surface Ni and Ce species of Ni/CeO_2 catalyst in CO_2 methanation', *Applied Surface Science*, 383, pp. 248–252.

Zhu, H., Razzaq, R., Li, C., Muhmmad, Y. and Zhang, S., (2013) 'Catalytic Methanation of Carbon Dioxide by Active Oxygen Material $Ce_xZr_{1-x}O_2$ Supported Ni/Co Bimetallic Nanocatalysts', *American Institute of Chemical Engineers*, 59(7), pp. 2567–2576.

LIST OF PUBLICATIONS

Book

1. **Thanwa Filza Nashruddin** and Maniruzzaman (2019). Chapter 3: Greenhouse Gases solution in Roads and Transportation. Fossil Free Fuels Trends in Renewable Energy. *CRC Press Taylor & Francis Group,* Edited by Maniruzzaman A. Aziz, Khairul Anuar Kassim, Wan Azelee Wan Abu Bakar, Aminaton Marto, and Syed Anuar Faua'ad Syed Muhammad, *CRC Press Taylor & Francis Group*

Conference Paper

1. **Thanwa Filza Nashruddin**, Md.Maniruzzaman A.Aziz, Wan Azelee Wan Abu Bakar, Syed Anuar Faua'ad Syed Muhammad, You Kok Yeow and Musa Mailah. (2018). Overview of catalytic methanation in hot mixing asphalt plants towards greenhouse gas emissions. *International Conference of Innovation and Sustainable Material Engineering (ISME 2018)*, 15-17 August 2018, Hilton Hotel Kuching, Sarawak.
2. **Thanwa Filza Nashruddin**, Md.Maniruzzaman A.Aziz, Wan Azelee Wan Abu Bakar, Syed Anuar Faua'ad Syed Muhammad, You Kok Yeow, and Musa Mailah. (2018). Green roads and highway: introduction of catalytic methanation in highway industry to utilize greenhouse gas emissions. 7th International Graduate Conference on Engineering Science & Humanities 2018 (IGCESH2018), 13-15 August 2018, Universiti Teknologi Malaysia, Johor Bahru, Malaysia.
3. **Thanwa Filza Nashruddin**, Md.Maniruzzaman A. Aziz,Ramadhansyah Putrajaya, Wan Azelee Wan Abu Bakar, R.Saidur. (2016). Green road action: sequestering greenhouse gas (GHGs) emissions associated with road constructions activities – a review. *Conference on Emerging Energy and Process Technology (CONCEPT2016),* 07 - 08 December, 2016, Ancasa Residences, Port Dickson.

4. **Thanwa Filza Nashruddin**, Ramadhansyah Putra Jaya, Norhidayah Abdul Hassan, Hasanan Md Nor, Md. Maniruzzaman A. Aziz, Che Norazman Che Wan (2013). Evaluation of Binder Absorption in Asphalt Mixture with Various Aging Conditions Using Rice Method. *The 9th International Conference of Geotechnical & Transportation Engineering (GEOTROPIKA) and the 1st International Conference on Construction and Building Engineering (ICONBUILD) – GEOCON2013*, 28-30 October, 2013, Persada Johor International Convention Centre, Johor Bahru.

Journal Paper

1. **Thanwa Filza Nashruddin**, Md. Maniruzzaman A. Aziz, Wan Azelee Wan Abu Bakar, Syed Anuar Faua'ad Syed Muhammad, You Kok Yeow and Musa Mailah."Overview of Catalytic Methanation in HotMixing Asphalt Plants Towards Greenhouse Gas Emissions", (2018), *IOP Conference Series: Materials Science and Engineering*, 429, 012092.
2. **Thanwa Filza Nashruddin**, Ramadhansyah Putra Jaya, Norhidayah Abdul Hassan, Hasanan Md Nor, Md. Maniruzzaman A. Aziz, Che Norazman Che Wan (2014). Evaluation of Binder Absorption in Asphalt Mixture with Various Aging Conditions Using Rice Method. *Jurnal Teknologi,* 71:3, 53–56, eISSN 2180–3722.
3. Yusuf Babangida Attahiru, Md. Maniruzzaman A.Aziz, Khairul Anuar Kassim Shamsuddin Shahid, Wan AzeleeWan Abu Bakar, **Thanwa Filza Nashruddin**, Farahiyah Abdul Rahman, Mohd Imran Ahamed. (2019). A review on green economy and development of green roads and highways using carbon neutral materials. *Renewable and Sustainable Energy Reviews*, 101, 600-613.