UNIVERSITI PUTRA MALAYSIA

SIMULTANEOUS REMOVAL OF CARBON DIOXIDE, SULPHUR DIOXIDE AND NITROGEN OXIDES USING ACTIVATED CARBON MODIFIED WITH METAL OXIDES

HAZIMAH BINTI MADZAKI

FK 2019 3

SIMULTANEOUS REMOVAL OF CARBON DIOXIDE, SULPHUR DIOXIDE AND NITROGEN OXIDES USING ACTIVATED CARBON MODIFIED WITH METAL OXIDES

By

HAZIMAH BINTI MADZAKI

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirements for the Degree of Master of Science

November 2018

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science

SIMULTANEOUS REMOVAL OF CARBON DIOXIDE, SULPHUR DIOXIDE AND NITROGEN OXIDES USING ACTIVATED CARBON MODIFIED WITH METAL OXIDES

By

HAZIMAH BINTI MADZAKI

November 2018

Chair : Assoc. Prof. Ir. Wan Azlina Wan Abdul Karim Ghani, PhD
Faculty : Engineering

Greenhouse gases act as a blanket to keep the Earth warm. However, excessive release of greenhouse gases in the atmosphere causes the Earth's temperature to rise above the threshold that led to many environmental problems. Carbon dioxide (CO_2) is the largest contributor to this problem, but other gases make a significant contribution. Malaysia's greenhouse gas emissions are mainly from power station industry that produces electricity through burning of fossil fuels. Coal-fired power plants emit high concentration of CO_2 as well as sulphur dioxide (SO_2) and oxides of nitrogen (NO_x), two of the most widespread and dangerous gases other than CO_2. These coal-fired power plants used many technologies to remove these gases from the flue gas stream. However, the technologies used are different for each gases; carbon capture and storage for CO_2 and flue gas desulphurization for SO_2 and low-NO_x burner for NO_x control. This multistage and complex removal processes can be very expensive due to high capital and operating cost. Hence, it is important to integrate the multistage process into a single step process for simultaneous removal of CO_2, SO_2 and NO_x to reduce the time and cost for flue gas cleaning.

This paper presents a simple way of modification of activated carbon surface using hydrothermal treatment and impregnation with metal oxides. The CO_2 adsorption performance of the modified activated carbon is evaluated by using a CO_2 adsorption unit while the simultaneous adsorption of CO_2, SO_2 and NO_x was done using flue gas adsorber unit with actual flue gas stream from combustion of coal in electrical furnace. Two types of metal oxides are used in this study which are cerium oxide (CeO_2) and copper oxide (CuO). The adsorption study consists of activated carbon hydrothermally treated with metal oxides (ACCe-HT, ACCu-HT and ACCeCu-HT) and also activated carbon

impregnated with metal oxides (ACCe-WI, ACCu-WI and ACCeCu-WI). The objectives of the research are to investigate the physical-chemical properties of modified activated carbon with various metal oxides and to investigate the adsorption capacity in simultaneous removal of carbon dioxide, sulphur dioxides and nitrogen oxides.

In this study, the performance of activated carbon modified by hydrothermal treatment and impregnation techniques was compared. The prepared samples were characterized by different techniques using Brunauer-Emmet-Teller (BET) surface area analysis, Scanning Electron Microscopy (SEM) and X-ray diffraction (XRD). From BET analysis, the surface area and pore volume of raw AC was 1,288 m^2/g and 0.38 cm^3/g respectively. After modification, these values decreased with ACCe-HT having the highest surface area among the other modified sample which was 1,169 m^2/g. This result corresponds to the SEM images that the surface of ACs were covered with metal oxides and peaks of metal oxides appear in XRD spectrum. The adsorption of CO_2 was investigated using a CO_2 adsorption unit, whereby 10% of CO_2 gas was passed through the samples until a breakthrough point was achieved. In the adsorption study, it was found that ACCe-HT had the highest adsorption capacity of 0.86 mmol/g with a breakthrough time of 19.33 min while ACCe-WI, ACCu-WI, ACCeCu-WI, ACCu-HT and ACCeCu-HT had the adsorption capacity of 0.12, 0.52, 0.06, 0.59 and 0.56 mmol/g respectively. In isotherm study using three isotherm models; Freundlich, Sips and Toth, it was also found that Toth Isotherm model shows good fit to the experimental data with correlation coefficient of 0.9910. In simultaneous adsorption from flue gas study using hydrothermal treated samples the adsorption capacity for ACCe-HT, ACCu-HT and ACCeCu-HT were 3.61, 1.16 and 0.50 mmol/g for CO_2, 0.43, 0.57 and 0.31 mmol/g for SO_2 and 0.82, 0.96 and 0.78 mmol/g for NO_x.

Overall, all objectives have been satisfied and it can be said that hydrothermally treated AC with CeO_2 has the potential to be used as adsorbent for CO_2 capture as well as SO_2 and NO_x and the ability is comparable to the carbon monolith. Therefore, it is suitable to be applied in industry particularly flue gas system for CO_2, SO_2 and NO_x adsorption.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Master Sains

PENYINGKIRAN SERENTAK KARBON DIOKSIDA, SULFUR DIOKSIDA DAN NITROGEN OKSIDA MENGGUNAKAN KARBON YANG DIAKTIFKAN YANG DIUBAH SUAI DENGAN LOGAM OKSIDA

Oleh

HAZIMAH BINTI MADZAKI

November 2018

Pengerusi : Profesor Madya Ir. Wan Azlina Wan Abdul Karim Ghani, PhD
Fakulti : Kejuruteraan

Gas rumah hijau berfungsi sebagai selimut untuk memastikan bumi hangat. Walau bagaimanapun, pelepasan gas rumah hijau yang berlebihan di atmosfera menyebabkan suhu bumi meningkat di atas ambang yang mengakibatkan banyak masalah alam sekitar. Karbon dioksida (CO_2) adalah penyumbang terbesar kepada masalah ini, tetapi gas lain juga turut menjadi penyumbang kepada masalah yang sama. Pelepasan gas rumah hijau yang utama di Malaysia adalah dari industri stesen janakuasa yang menghasilkan elektrik melalui pembakaran bahan api fosil. Loji kuasa arang batu mengeluarkan kepekatan CO_2 yang tinggi serta sulfur dioksida (SO2) dan oksida nitrogen (NOx), dua daripada gas yang paling banyak dan berbahaya selain daripada CO_2. Loji kuasa arang batu ini menggunakan banyak teknologi untuk menyingkirkan gas-gas ini dari aliran gas serombong. Walau bagaimanapun, teknologi yang digunakan adalah berbeza untuk setiap gas; penangkapan dan penyimpanan karbon untuk CO_2 dan desulfurisasi gas serombong untuk SO_2 dan pembakar NO_x rendah untuk kawalan NO_x. Proses penyingkiran yang pelbagai dan kompleks ini boleh menjadi sangat mahal disebabkan oleh modal dan kos operasi yang tinggi. Oleh itu, adalah penting untuk mengintegrasikan proses yang kompleks ini menjadi satu langkah tunggal untuk penyingkiran serentak CO_2, SO_2 dan NO_x untuk mengurangkan masa dan kos untuk pembersihan gas serombong.

Manuskrip ini memperkenalkan cara pengubahsuaian permukaan karbon aktif menggunakan rawatan hidrotermal dan impregnasi menggunakan logam oksida. Prestasi penjerapan CO_2 oleh karbon diaktifkan yang diubahsuai diuji dengan menggunakan unit penjerapan CO_2 sementara penyingkiran serentak CO_2, SO_2 dan NO_x dilakukan dengan menggunakan unit penjerapan gas serombong dengan aliran gas serombong yang sebenar dari pembakaran

arang batu dalam relau elektrik. Dua jenis oksida logam digunakan dalam kajian ini iaitu cerium oksida (CeO_2) dan tembaga oksida (CuO). Kajian penjerapan terdiri daripada karbon aktif hidroterma dirawat dengan oksida logam (ACCe-HT, ACCu-HT dan ACCeCu-HT) dan juga mengaktifkan karbon yang diresapi dengan oksida logam (ACCe-WI, ACCu-WI dan ACCeCu-WI). Objektif penyelidikan adalah untuk menyiasat sifat kimia fizikal karbon diaktifkan yang diubahsuai dengan pelbagai logam oksida dan untuk menyiasat kapasiti penjerapan dalam penyingkiran serentak karbon dioksida, sulfur dioksida dan nitrogen oksida.

Dalam kajian ini, prestasi karbon diaktifkan yang diubahsuai oleh rawatan hidrotermal dan teknik impregnasi telah dibandingkan. Sampel yang disediakan dicirikan oleh teknik-teknik yang berbeza menggunakan analisis permukaan permukaan *Brunauer-Emmet-Teller* (BET), *Scanning Electron Microscopy* (SEM) dan *X-ray Difraction* (XRD). Dari analisis BET, luas permukaan dan jumlah liang AC mentah ialah 1,288 m^2/g dan 0.38 cm^3/g.. Selepas pengubahsuaian, nilai-nilai ini berkurang dengan ACCe-HT yang mempunyai luas permukaan tertinggi di antara sampel yang diubahsuai yang lain iaitu 1,169 m^2/g. Keputusan ini sesuai dengan imej SEM bahawa permukaan AC dilitupi dengan logam oksida dan puncak logam oksida muncul dalam spektrum XRD. Penjerapan CO_2 diuji menggunakan unit penjerapan CO_2, di mana 10% gas CO_2 disalurkan melalui sampel sehingga titik terobosan dicapai. Melalui kajian penjerapan, ia didapati ACCe-HT mempunyai kapasiti penjerapan tertinggi iaitu 0.86 mmol/g dengan masa terobosan 19.33 min manakala ACCe-WI, ACCu-WI, ACCeCu-WI, ACCu-HT dan ACCeCu-HT mempunyai kapasiti penjerapan sebanyak 0.12, 0.52, 0.06, 0.59 dan 0.56 mmol/g. Dalam kajian isotherm menggunakan tiga model isoterm; Freundlich, Sips dan Toth, didapati bahawa model Toth Isotherm menunjukkan kesesuaian dengan data eksperimen dengan pekali korelasi 0.9910. Dalam penjerapan serentak dari kajian gas serombong menggunakan sampel rawatan hidrotermal, kapasiti penjerapan untuk ACCe-HT, ACCu-HT dan ACCeCu-HT adalah 3.61, 1.16 dan 0.50 mmol/g untuk CO_2, 0.43, 0.57 dan 0.31 mmol/g untuk SO_2 dan 0.82, 0.96 dan 0.78 mmol/g untuk NO_x.

Secara keseluruhannya, semua objektif telah dicapai dan dapat dikatakan bahawa AC yang diubahsuai dengan CeO_2 mempunyai potensi untuk digunakan sebagai penjerap untuk menangkap CO_2 serta SO_2 dan NO_x dan keupayaan adalah setanding dengan karbon monolit. Oleh itu, ia sesuai untuk digunakan dalam industri terutama sistem asap serombong untuk penjerapan CO_2, SO_2 dan NO_x.

ACKNOWLEDGEMENTS

In the name of Allah, the Most Gracious and the most Merciful.

Alhamdulillah, all praise to Allah SWT because of His blessing, I could complete this final project. In this occasion, I would like to thank all those involved.

First of all, I would like to express my appreciation and gratitude to my supervisor, Assoc. Prof. Ir. Dr. Wan Azlina Wan Ab Karim Ghani, for her support and invaluable advice with a continuous stream of suggestions, feedback, and encouragement that have guided me throughout the whole period of this project. I especially would like to thank her for always being accessible. All her sacrifices in serving my actions will not be forgotten.

Thank you also to Prof. Dr. Ir. Thomas Choong Shean Yaw and Pn. Noraziah Muda for their co-supervision and help in completing this work. I would like to express my gratitude to UPM/GP-IPB/9515201 and "Engineering and Physical Sciences Research Council" for partial funding of the research through the BEFEW project (Grant No. EP/P018165/1) for financial support. The help and assistance from various government and non-governmental organizations especially TNB Research is gratefully acknowledged.

I would like to thank the faculty and staffs in the Department of Chemical and Environmental Engineering for their continuous support and high quality education and cooperation during the session of project implementation, especially the Science Officer, Pn. Nor Hasni Zahari and all assistant engineers who have taken the trouble to give guidance for the success of my experiment especially En. Adli Nazri Mohd Kassim, Pn. Shafizah Masuri, Pn, Norhasliza Hasan, En. Ismail Abdul Ghani, En. Ismail Abdullah and En Joha Muhsidi Abdul Wahab.

My sincere warm hearted gratitude goes to my father, Madzaki bin Ab Ghani and other family members for their endless love, understanding, patience, support, prayers and encouragement. Without them, none of my accomplishments would have been possible. To them, I dedicate this thesis.

Finally, I would like to thank my friends, Syahin Mohamad Saleh, Nur Izzati Md Saleh, Falil Nisa Abdul Jalil, Ili Syazwani Mohd Rosley, Jack, Silas Kiman and Ramin Khezri for their friendship and help in completing this project. Thanks to all students in Faculty of Chemical Engineering for creating supportive environment. Alhamdullillah. Wassalam.

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree of Master of Science. The members of the Supervisory Committee were as follows:

Wan Azlina Binti Wan Ab Karim Ghani, PhD
Associate Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Thomas Choong Shean Yaw, PhD
Professor, Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Noraziah Muda
Principal Researcher
Tenaga Nasional Berhad Research
Malaysia
(Member)

_____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: _____ Date: _____

Name and Matric No.: Hazimah binti Madzaki, GS44195

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____
Name of Chairman of Supervisory Committee: Assoc. Prof. Ir. Dr. Wan Azlina Wan Ab Karim Ghani

Signature: _____
Name of Member of Supervisory Committee: Prof. Dr. Ir. Thomas Choong Shean Yaw

Signature: _____
Name of Member of Supervisory Committee: Puan Noraziah Muda

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURESS

LIST OF ABBREVIATIONS

1/n	system heterogeneity
AC	activated carbon
ACCeCu-HT	activated carbon hydrothermal treated with cerium oxide and copper oxide
ACCeCu-WI	activated carbon impregnated with cerium oxide and copper oxide
ACCe-HT	activated carbon hydrothermal treated with cerium oxide
ACCe-WI	activated carbon impregnated with cerium oxide
ACCu-HT	activated carbon hydrothermal treated with copper oxide
ACCu-WI	activated carbon impregnated with copper oxide
AEE	2-2-aminoethylamino ethanol
$AEPDNH_2$	N-2-aminoethyl 1,3-propanediamine
AlO	aluminium oxide
AMP	2-amino 2- methyl 1-propanol
ARG-C	argan fruit shell activated carbon
BET	Brunauer-Emmett-Teller
C	outlet concentration
C_0	initial concentration
Ca	calcium
$CaCO_3$	calcium carbonate
CCS	carbon capture and storage/sequestration
CDM	Clean Development Mechanism
Ce	cerium
CeO_2	cerium oxide
CM	carbon monolith
CMC	carboxymethylcellulose
CNT	carbon nanotube
Co	cobalt
CO	carbon monoxide
CO_2	carbon dioxide
COP21	Conferences of Parties 21
Cr	chromium
CS	raw coconut shell biochar
Cu	copper
CuO	copper oxide
C_xH_y	hydrocarbon
DEA	diethanol amine
DGA	diglycol- amine
DIPA	di-2-propanolamine
DOE	Department of Environmental
ESA	electrical swing adsorption

EU	European Union
F	feed flow rate
Fe	iron
FGD	flue gas desulphurization
GA	glucosamine
GHG	greenhouse gases
H_2	hydrogen
H_2O	water
H_3PO_4	phosphoric acid
HCL	hydrochloric acid
He	helium
HNO_3	nitric acid
HP5	persian ironwood was activated by h_3po_4
HT	hydrothermal treatment
IPCC	Intergovernmental Panel on Climate Change
IUPAC	International Union of Pure and Applied Chemistry
K	potassium
K_2CO_3	potassium carbonate
k_F	Freundlich adsorption constant
KOH	potassium hydroxide
k_S	adsorption constant
k_T	Toth adsorption constant
m	heterogeneity parameter
MDEA	N-methyldiethanolamine
MEA	monoethanol amine
Mg	magnesium
MgO	magnesium oxide
MO	metal oxide
MWCNT	multi-walled carbon nanotube based
N	nitrogen
N/A	not available
Na_2CO_3	sodium carbonate
NaOH	sodium hydroxide
N-CS	amine treated coconut shell biochar
NH_3	ammonia
Ni	nickel
NiO	nickel oxide
NO	nitrogen oxide
NO_2	nitrogen dioxide
NO_x	oxides of nitrogen
NRE	Ministry of Natural Resources and Environment
O_2	oxygen
P123	poly(ethylene glycol)-block-poly(propylene glycol)-block-poly(ethylene glycol)

PAH	polycyclic aromatic hydrocarbon
PEI	polyethylenimine
PSA	pressure swing adsorption
PSAC	palm shell activated carbon
PSAC-Ce	palm shell activated carbon activated by cerium
PZ	piperazine
q	adsorption capacity
q_F	amount of adsorbed CO_2
$q_{m,S}$	maximum adsorption capacity
$q_{m,T}$	maximum adsorption capacity
q_S	absolute amount adsorbed
q_T	amount of adsorbed CO_2
R^2	correlation coefficient
S	sulphur
S	system heterogeneity
SEM	Scanning Electron Microscopy
SM	silica monolith
SO_2	Sulphur dioxide
SO_x	oxides od sulphur
t	reaction time
TEA	triethanol amine
TETA	triethylene tetra amine
TNB	Tenaga Nasional Berhad
TNBR	Tenaga Nasional Berhad Research
TSA	temperature swing adsorption
US	United States
UTP	Universiti Teknologi Petronas
VOCs	volatile organic compounds
W	amount of adsorbent
WI	wet impregnation
XRD	X-ray Diffraction

CHAPTER 1

INTRODUCTION

1.1 Background

Global warming is an alarming issue faced globally. Since the industrial revolution, humans have been altering this process by adding more carbon dioxide and other harmful gases to the atmosphere. Global atmospheric concentration of the greenhouse gases (GHG) show significant seasonal and year-to year variability, but all show on going upward trends. Figure 1.1 shows the global mean GHG concentrations from the year 1978 to 2015.

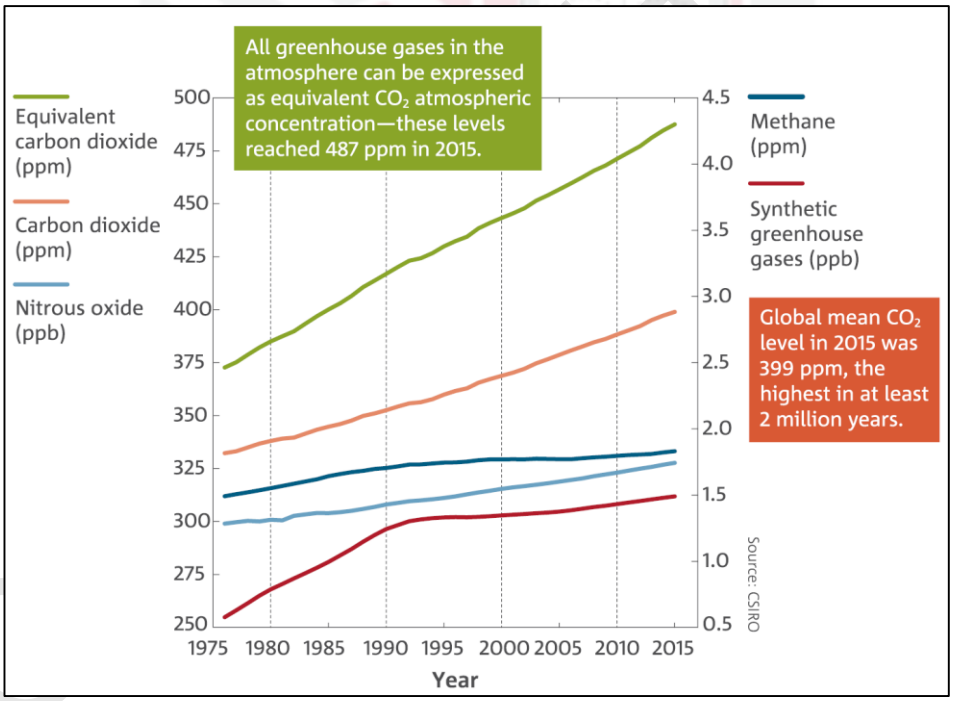

Figure 1.1: Global mean GHG concentrations from the year 1978 to 2015 (CSIRO, 2016)**.**

The world leaders have decided to take actions to reduce emissions to avoid 2 °C of earth warming, which is the level outlined as a safe threshold for climate change. It is forecasted that, if no action is taken to reduce the emission, the earth temperature will increase to three to six degree Celsius. Figure 1.2 shows

the world greenhouse gases, GHG emissions projection of baseline scenario (no action taken) versus targeted GHG concentration level which is 450 ppm.

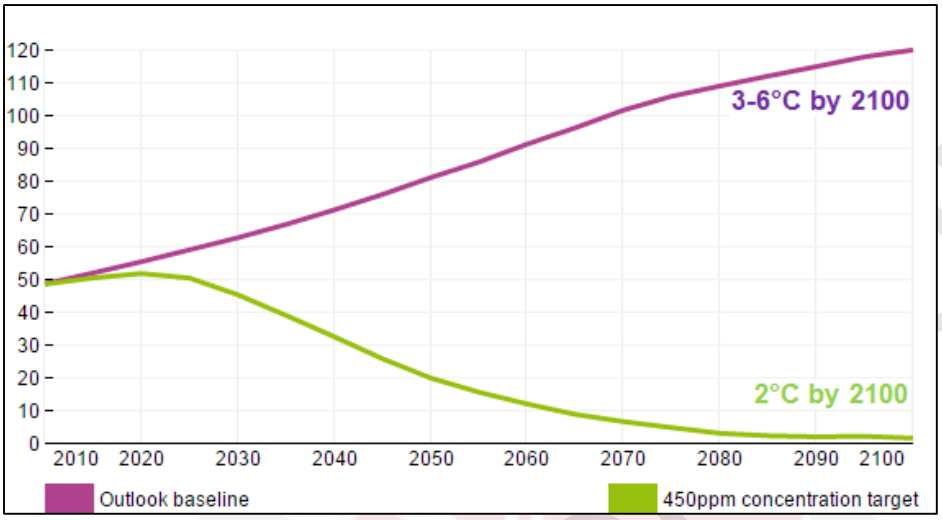

Figure 1.2: The world GHG emissions projection, 2010- 2100 (OECD, 2012)**.**

There are two causes of global warming which are categorized into natural and anthropogenic forcing. Natural forcing is the tilt of the earth axis that have time scales of thousands of years and variation in interaction between the ocean and atmosphere can result in climate variations of yearly, decadal and century time scales while anthropogenic forcing is human induced activities which lead to increasing of the concentration of GHG into the atmosphere (MET, 2009). Greenhouse effect is the process in which the infrared radiation was absorbs by water vapor, carbon dioxide (CO_2), methane and other atmospheric gases to warms the Earth's surface (Chiang & Juang, 2017; Yaumi *et al.*, 2017; Mondal *et al.* , 2012). However, excessive greenhouse gases in the atmosphere cause rises in earth's temperature that led to various environmental problems such as continuous rise of water-level in sea, the increasing number of ocean storms and floods (Hamza *et al.*, 2016; Mondal *et al.*, 2012).

Since 1990s, the economic growth in Malaysia has been increased in parallel with urbanization, stimulating in high energy demand. As stated in Tenth Malaysia Plan (EPU, 2010), by 2020, it is predicted that three quarters of the Malaysia population will be living in the urban areas. Bekhet & Othman (2017) studied on the theory of urbanization affects the environmental transition and concluded that as Malaysia is developing at a fast rate of urbanization with huge numbers of industrial areas and well-planed housing settlements has leads to higher level of atmospheric pollution. As the numbers of wealthier citizens increases, the demand for energy intensive products also increases. Hence, Malaysian government is trying to reduce the energy used through

transportation industry by focusing on urban transportation network (Bekhet & Othman, 2017; Zhang *et al.*, 2017; Shahbaz *et al*., 2016; Lau *et al*, 2014).

The Malaysian Department of Environmental (DOE) has reported in 2010 the air pollution in the country main contributors includes power stations industry, motor vehicles industry and open burnings. Production of electricity in Malaysia is mainly from burning of fossil fuel such as oil, coal or natural gas that has huge consequences for the environment. Malaysia used petroleum and other liquids and natural gas as the main energy sources followed by coal, hydroelectricity and biomass. Since Malaysia relies so much on the oil and natural gas to sustain its economic growth, it has cause many environmental problem such air pollution and global warming. The concern to the environment has caused the government to find an alternative energy sources from the used of coal to renewable energy (EIA, 2017).

Fossil fuel power plants have the highest CO_2 emission and coal-fired power plant is the main contributor among them. Coal has become much more competitive with natural gas-fired power because of the low fuel price and has gained a larger portion of power generation in Peninsula Malaysia in the past few years. There are several coal-fired power plants in Peninsular Malaysia which are Jimah Power Station in Negeri Sembilan, Manjung Power Station in Perak, Sultan Salahuddin Abdul Aziz Shah Power Station in Selangor and Tanjung Bin Power Station in Johor (Wikipedia, 2017). Among all this coal-fired power plant, Manjung Power Station is owned by Tenaga Nasional Berhad (TNB), the largest electric utility company in Malaysia.

CO_2 is one of the major pollutants in the atmosphere, which contribute to greenhouse effect. The rise in concern towards the earth climate has attracted extensive effort to introduce efficient and cost-effective technologies for capturing or reducing CO_2 from large point sources like coal-fired power plant. One of the main technologies in reducing greenhouse gases is post-combustion capture of CO_2 because it has the potential to be retrofitted to existing coal-fired power plant without requiring substantial changes to the combustion process (Hajari, 2017; Rackley, 2017; Thiruvenkatachari *et al.*, 2015). Technologies such as absorption, cryogenic and membrane separation have been proposed to capture CO_2 from the flue gases (Keller *et al*., 2018; Mohshim *et al.*, 2018; Singh *et al.*, 2018; Querejeta *et al.*, 2017; Lee & Park, 2015; Ruiz *et al.*, 2013; Choi *et al.*, 2009; Zhou *et al.*, 2012). However, these technologies have some disadvantages. For example in absorption, solvent degradation and corrosion may occur and affects the CO_2 removal efficiency (Liang *et al.*, 2016; Shakerian *et al*., 2015; Fytianos *et al.*, 2014). For cryogenic process, the H_2O must be completely removed to prevent corrosion, fouling and plugging which leads to higher cost (Kang *et al*, 2017). In membrane separation, multiple stages of separation or recycling is needed since it cannot always give high separation degrees which makes the cost of membranes reactor is high (Nakhjiri *et al.*, 2018; Mondal *et al*., 2012; Olajire, 2010).

Adsorption was considered as one of the most promising technologies in the commercial and industrial applications because of the low energy requirement, cost advantage, and ease of applicability over a relatively wide range of temperatures and pressures (Yue *et al.*, 2018; Serafin *et al.*, 2017; Kongnoo *et al.*, 2016; Younas *et al.*, 2016; Thiruvenkatachari *et al.*, 2009; Duffy *et al.*, 2006; Song, 2006). CO_2 capture by adsorption technology had drawn much research effort recently and had done lots of work to improve capture performance (Dassanayake & Jaroniec, 2018; Pan *et al.*, 2018; Irani *et al.*, 2017; Querejeta *et al.*, 2017; Kwiatkowski *et al.*, 2016). Activated carbon (AC) as an agent for adsorption has been used for many years in many field because this amorphous material has large surface area and pore volume. Gas-phase adsorption by activated carbon is a separation process in which adsorbate molecules are transferred to the pore surface of solid activated carbon (Sumathi *et al.*, 2010).

ACs as suitable candidates for CO_2 capture are highly anticipated, however, there is some restriction which is the low selectivity of AC towards CO_2. It has been known that the surface chemistry of AC can affect the adsorption chemistry which can be enhanced greatly using chemical modification like introducing the basic groups to the surface of AC (Chiang & Juang, 2016). To this day, many metal oxides have been used to further improve the CO_2 capture capacity. Still, one major problem for metal oxide modification is that the CO_2 adsorption capacity is still too moderate (Wang *et al*., 2014). Loading metal oxides onto the surface of the AC cause a reduction in the surface area as well as pore volume. This is due to the deposition of the metal particles into the interior structures and blocks some parts of the micropores and mesopores (Rashidi & Yusup, 2016).

Other technique that can modify AC physically is hydrothermal treatment. Hydrothermal treatment is commonly used in application like biodiesel production, activation of chars and carbonation of biomass (Breulmann *et al.*, 2017; Ding *et al.*, 2018; Jain *et al.*, 2016; Lagazzo *et al.*, 2016; Soltani *et al.*, 2017). There are only a few works devoted to hydrothermal treatment of carbon materials with the purpose of modification of their porous and surface structure (Hlaing et al., 2014; Wu, Li, Liu, & Jin, 2016; Xiao, Guo, Zhao, & Han, 2016). The chemical and physical properties, high speed, high yield, low cost and being eco-friendly (due to sealed system condition) are some of the characteristic of hydrothermal treatment (Deng *et al*., 2016). Hence hydrothermal treatment can enhanced the pore structure of an absorbent for better adsorption.

Coal-fired flue gas stream which also contains oxides of nitrogen NO_x and sulphur oxides SO_x, two of the most widespread and dangerous gases other CO_2 (Sumathi *et al*., 2010b), hence, the removal of these gases should also be taken into consideration. Many technologies have been used to remove these gases from flue gas. However, the process applied can only remove one gas at a time; flue gas desulphurization of SO_2, NO_x control and carbon capture and storage for CO_2. This multistage and complex removal processes can be very

expensive due to high capital and operating cost (Hajari, 2017; Yi, Huang, et al., 2014). Hence, it is important to integrate the multistage process into single step process for the simultaneous removal of CO_2, SO_2 and NO_x from flue gas.

This paper focus on modification of activated carbon surface using wet impregnation and hydrothermal treatment with metal oxides. The adsorption performance of the modified activated carbon is evaluated by using a CO_2 and flue gas adsorption unit. Recent study on doping of various oxides of metals; magnesium (Mg), calcium (Ca), copper (Cu), cobalt (Co), nickel (Ni), iron (Fe) and chromium (Cr), onto AC enhance the adsorption capacity of CO_2 and among all, it is reported that AC impregnated with CuO results in higher CO_2 percentage removal (Rashidi and Yusup, 2016; Hosseini *et al*., 2015; Kim *et al*., 2010; Moradi, 2014; Fenrong *et al*., 2010; Yong and Mata, 2001). A study by Sumathi *et al*. (2010b) on selection of best impregnated AC for removal of SO_2 and NO_x shows that AC impregnated with cerium oxide (CeO_2) has the best removal compare to other metal oxides; nickel (Ni), iron (Fe), vanadium (V). The study of simultaneous capture of CO_2, SO_x and NO_x reported is very limited. Currently, the removals only focus on CO_2 or SO_x and/or NO_x. Hence, in this study, two types of metal oxides which are cerium oxide and copper oxide are used for modification of AC to allow simultaneous adsorption of CO_2, SO_x and NO_x from flue gas stream.

1.2 Problem Statement

At present, research in the field of adsorbents had made rapid progress for adsorbing pollutant in flue gas. AC is preferred as CO_2 adsorbent due to its environmentally friendly nature, low cost, high porous structure, high surface area and good mechanical properties. However, other than CO_2 coal-fired flue gas stream also contains traces of oxides of nitrogen NO_x and sulphur oxides SO_x. Hence, the removal of these gases simultaneously is also considered in order to save cost and time compare to when they are captured separately.

A lot of attention is given in modification of the surface chemistry of existing carbon sorbents so that adsorption capacity is increased and selectivity is improved. Since CO_2 is an acidic gas, the basicity properties of metal oxides can increase the adsorption capacity of CO_2 since metal oxides is an electron donor that can attract CO_2 molecules. However, impregnating metal oxides onto the surface of the AC cause a reduction in the surface area as well as pore volume. This is due to the deposition of the metal particles into the interior structures and blocks some parts of the pores. Hence hydrothermal treatment is also introduced in modification of AC to alter the porous and surface structure as well as loading the metal oxides particles onto AC surface.

Copper oxide (CuO) and cerium oxide (CeO_2) are selected to be loaded to AC surface by the two modification methods; wet impregnation and hydrothermal treatment. Based on previous study, CuO has better CO_2 adsorption while

CeO_2 gave higher adsorption capacity for SO_2 and NO_x compared to other metal oxides. Hence, these metal oxides are used in this study for simultaneous adsorption of CO_2, SO_2 and NO_x.

1.3 Research Objectives

The objectives of the research are:

1. To investigate the physical-chemical properties of raw and modified activated carbon (AC) with various metal oxides.
2. To analyse adsorption capacity of simultaneous removal of carbon dioxide (CO_2), sulphur dioxide (SO_2) and nitrogen oxides (NO_x).

1.4 Scope and Limitation of Research

The scope of the research includes preparing AC modified with metal oxides via hydrothermal treatment and impregnation. The modified activated carbons were then characterized by using BET analysis to estimate the surface area, pore size, pore volume, pore diameter and pore distribution. The surface morphology of the samples is determined by Scanning Electron Microscopy (SEM). Determinations of the structure and fingerprint characterization of crystalline materials were done by using X-ray Diffraction (XRD). The performance of the modified AC in capturing CO_2 is tested using a CO_2 adsorption unit. The method that gives better adsorbent performance for CO_2 capture will be screened for simultaneous removal of CO_2 and SO_2/NO_x from flue gas testing. It is expected that the adsorption study of these modified AC will provide a new insight on their ability as simultaneous CO_2 and SO_2/NO_x adsorbent.

There are some notable limitations in this research. There is lack of previous studies on modification of AC with metal oxides via hydrothermal treatment. Therefore, the literatures that have similar aim that is to enhance the pore structure of the AC using the same type of precursors are being referred to. Other than that, the measure used to collect the data is restricted. The inlet and outlet concentration of the adsorption of gases need to be done using different batch of coal combustion due to the lack of gas analyzer. Hence the breakthrough curve and adsorption capacity cannot be calculated accurately. Thus, it is important to ensure the combustion of coal is done using the same parameter throughout the experiment.

REFERENCES

Abdulrasheed, A. A., Jalil, A. A., Triwahyono, S., Zaini, M. A. A., Gambo, Y., & Ibrahim, M. (2018). Surface modification of activated carbon for adsorption of SO_2 and NO_X: A review of existing and emerging technologies. *Renewable and Sustainable Energy Reviews*, *94*, 1067–1085.

Acar, B., Başar, M. S., Eropak, B. M., Caglayan, B. S., & Aksoylu, A. E. (2018). CO_2 adsorption over modified AC samples: A new methodology for determining selectivity. *Catalysis Today*, *301*, 112–124.

Adelodun, A. A., Lim, Y. H., & Jo, Y. M. (2014). Journal of Analytical and Applied Pyrolysis Stabilization of potassium-doped activated carbon by amination for improved CO_2 selective capture. *Journal of Analytical and Applied Pyrolysis*, *108*, 151–159.

Adeyemi, I., Abu-Zahra, M. R. M., & Alnashef, I. (2017). Novel green solvents for CO_2 capture. *Energy Procedia*, *114* (November 2016), 2552–2560.

Agren, C. (2012). China: New emission standards for power plants. Retrieved March 3, 2018, from http://www.airclim.org/acidnews/china-new-emission-standards-power-plants

Ahmadi, H., Hashemifard, S. A., & Ismail, A. F. (2017). A research on CO_2 removal via hollow fiber membrane contactor: The effect of heat treatment. *Chemical Engineering Research and Design*, *120*, 218–230.

Al Aiti, M., Jehnichen, D., Fischer, D., Brünig, H., & Heinrich, G. (2018). On the morphology and structure formation of carbon fibers from polymer precursor systems. *Progress in Materials Science*, *In Press*.

Amran, A., Zainuddin, Z., Hanim, S., & Zailani, M. (2013). Carbon trading in Malaysia: Review of policies and practices. *Sustainable Development*, *192*, 183–192.

An, L., Yu, X., Yang, J., Tu, S. T., & Yan, J. (2015). CO_2 capture using a superhydrophobic ceramic membrane contactor. *Energy Procedia*, *75*, 2287–2292.

Anas, M., Göktu, A., Bozbag, S. E., & Erkey, C. (2017). Thermodynamics of adsorption of carbon dioxide on various aerogels, *21*(August), 82–88.

Ayawei, N., Ebelegi, A. N., & Wankasi, D. (2017). Modelling and interpretation of adsorption isotherms. *Journal of Chemistry*, Volume 2017, 1-11.

Bai, B. C., Lee, C. W., Lee, Y. S., & Im, J. S. (2017). Modification of textural properties of CuO-supported activated carbon fibers for SO_2 adsorption

based on electrical investigation. *Materials Chemistry and Physics*, *200*, 361–367.

Basfar, A. A., Fageeha, O. I., Kunnummal, N., Al-Ghamdi, S., Chmielewski, A. G., Licki, J. & Zimek, Z. (2008). Electron beam flue gas treatment (EBFGT) technology for simultaneous removal of SO_2 and NO_x from combustion of liquid fuels. *Fuel*, *87*(8–9), 1446–1452.

Bekhet, H. A., & Othman, N. S. (2017). Impact of urbanization growth on Malaysia CO_2 emissions: Evidence from the dynamic relationship. *Journal of Cleaner Production*, *154*, 374–388.

Bernhardsen, I. M., & Knuutila, H. K. (2017). A review of potential amine solvents for CO_2 absorption process: Absorption capacity, cyclic capacity and pKa. *International Journal of Greenhouse Gas Control*, *61*, 27–48.

Bhuvaneshwari, S., & Gopalakrishnan, N. (2016). Hydrothermally synthesized Copper Oxide (CuO) superstructures for ammonia sensing. *Journal of Colloid and Interface Science*, *480*, 76–84.

Boujibar, O., Souikny, A., Ghamouss, F., Achak, O., Dahbi, M., & Chafik, T. (2018). CO_2 capture using N-containing nanoporous activated carbon obtained from argan fruit shells. *Journal of Environmental Chemical Engineering*, *6*, 1995–2002.

Breulmann, M., Afferden, M. van, Muller, R. A., Schulz, E., & Fuhner, C. (2017). Process conditions of pyrolysis and hydrothermal carbonization affect the potential of sewage sludge for soil carbon sequestration and amelioration. *Journal of Analytical and Applied Pyrolysis*, *124*, 256–265.

CAIT Climate Data Explorer. (2017). Historical Emissions. World Resource Institute. Retrieved March 3, 2018, from http://cait.wri.org/

Cha, J. S., Park, S. H., Jung, S. C., Ryu, C., Jeon, J. K., Shin, M. C., & Park, Y. K. (2016). Production and utilization of biochar: A review. *Journal of Industrial and Engineering Chemistry*, *40*, 1–15.

Chiang, Y., & Juang, R. (2017). Surface modifications of carbonaceous materials for carbon dioxide adsorption: A review. *Journal of the Taiwan Institute of Chemical Engineers*, *71*, 214–234.

Choi, S., Drese, J. H., & Jones, C. W. (2009). Adsorbent Materials for Carbon Dioxide Capture from Large Anthropogenic Point Sources. *ChemSusChem*, *2*, 796–854.

Córdoba, P. (2015). Status of flue gas desulphurisation (FGD) systems from coal-fired power plants: Overview of the physic-chemical control processes of wet limestone FGDs. *Fuel*, *144*, 274–286.

Creamer, A. E., Gao, B., & Wang, S. (2016). Carbon dioxide capture using

various metal oxyhydroxide – biochar composites. *Chemical Engineering Journal*, *283*, 826–832.

Creamer, A. E., Gao, B., & Zhang, M. (2014). Carbon dioxide capture using biochar produced from sugarcane bagasse and hickory wood. *Chemical Engineering Journal*, *249*, 174–179.

CSIRO, (2016). Greenhouses gases. State of the Climate 2016. Retrieved on December 9, 2018 from http://www.csiro.au/en/Research

Dai, Q., Wang, J., Chen, J., & Chen, J. (2014). Ozonation catalyzed by cerium supported on activated carbon for the degradation of typical pharmaceutical wastewater. *Separation and Purification Technology*, *127*, 112–120.

Damartzis, T., Papadopoulos, A. I., & Seferlis, P. (2016). Process flowsheet design optimization for various amine-based solvents in post-combustion CO_2 capture plants. *Journal of Cleaner Production*, *111*, 204–216.

Das, D., & Meikap, B. C. (2018). Comparison of adsorption capacity of mono-ethanolamine and diethanolamine impregnated activated carbon in a multi-staged fluidized bed reactor for carbon-dioxide capture. *Fuel*, *224*(March), 47–56.

Dassanayake, A. C., & Jaroniec, M. (2018). Activated polypyrrole-derived carbon spheres for superior CO_2 uptake at ambient conditions. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *549*(February), 147–154.

Deng, H., Yi, H., Tang, X., Liu, H., & Zhou, X. (2013). Interactive effect for simultaneous removal of SO_2 , NO, and CO_2 in flue gas on ion exchanged zeolites. *Industrial & Engineering Chemistry Research*, *52*, 6778–6784.

Deng, Z. L., Liang, M. N., Li, H. H., & Zhu, Z. J. (2016). Advances in preparation of modified activated carbon and its applications in the removal of chromium (VI) from aqueous solutions. *IOP Conference Series: Earth and Environmental Science*, *39*(1).

Dinda, S. (2013). Sepa ration and Purification Techn ology Development of solid adsorbent for carbon dioxide capture from flue gas. *Separation and Purification Technology*, *109*, 64–71.

Ding, B., Wang, X., Xu, Y., Feng, S., Ding, Y., Pan, Y., & Wang, H. (2018). Hydrothermal preparation of hierarchical ZIF-L nanostructures for enhanced CO_2 capture. *Journal of Colloid and Interface Science*, *519*, 38–43.

DOE, Department of Environment. (2017). Air pollution control infomation. Retrieved January 7, 2017, from https://www.doe.gov.my/portalv1/en/

Duffy, A., Walker, G. M., & Allen, S. J. (2006). Investigations on the adsorption of acidic gases using activated dolomite, *117*(November 2005), 239–244.

EIA, Energy Information Administration. (2017). Malaysia - International - Analysis - U.S. Energy Information Administration (EIA). Retrieved January 7, 2018, from https://www.eia.gov/beta/international/analysis.php?iso=MYS

El Hadri, N., Quang, D. V., Goetheer, E. L. V., & Abu Zahra, M. R. M. (2017). Aqueous amine solution characterization for post-combustion CO_2 capture process. *Applied Energy*, *185*, 1433–1449.

Elsom, D. M. (1992). *Atmospheric Pollution: A Global Problem* (2nd Edition). Blackwell Publishers.

EPA, Environmental Protection Agency. (2015). *Emission Control Technologies*. Retrieved January 7, 2017, from https://www.epa.gov/sites/production/files/ 2015-07/documents/chapter_5_emission_control_technologies.pdf

EPA, Environmental Protection Agency. (2017). Causes of Climate Change. Retrieved January 7, 2017, from https://archive.epa.gov/epa/climate-change-science/causes-climate-change.html#main-content

EPU, Economic Planing Unit. (2010). *Tenth Malaysia Plan*. *The Economic Planning Unit Prime Minister's Department*.

Fenrong, L. I., Honghong, Y. I., Xiaolong, T., Ping, N., Qiongfen, Y. U., & Dongjuan, K. (2010). Adsorption of carbon dioxide by coconut activated carbon modified with Cu/Ce. *Journal of Rare Earths*, *28*(10), 334–337.

Fiuza-jr, R. A., Andrade, R. C., Martins, H., & Andrade, C. (2016). CO_2 capture on KOH-activated carbons derived from yellow mombin fruit stones. *Journal of Environmental Chemical Engineering*, *4*, 4229–4236.

Fytianos, G., Grimstvedt, A., Knuutila, H., & Svendsen, H. F. (2014). Effect of MEA's degradation products on corrosion at CO_2 capture plants. *Energy Procedia*, *63*(1876), 1869–1875.

Gadkaree, K. P. (1998). Carbon honeycomb structures for adsorption applications. *Carbon*, *36*(7–8), 981–989.

Gaigward, R., & Boward, W. L. (2003). Wet flue gas desulfurization technology evaluation. *Sargent and Lundy Report Project No. 11311-000*, (January), 1–50.

Gao, X., Liu, S., Zhang, Y., Luo, Z., & Cen, K. (2011). Physicochemical properties of metal-doped activated carbons and relationship with their performance in the removal of SO_2 and NO. *Journal of Hazardous Materials*, *188*(1–3), 58–66.

Gąsior, D., & Tic, W. J. (2017). Application of the biochar-based technologies as the way of realization of the sustainable development strategy. *Economic and Environmental Studies*, *17*(3), 597–611.

Ghani, W. A. W. A. K., Rebitanim, N. Z., Salleh, M. A. M., & Alias, A. B. (2015). Carbon Dioxide Adsorption on Coconut Shell Biochar. In *Progress in Clean Emergy* (Vol. 1, pp. 683–693). Springer International Publishing.

Gibbins, J., & Chalmers, H. (2008). Carbon capture and storage. *Energy Policy*, *36*, 4317–4322.

Global CCS Institute. (2013). Malaysian program supports CCS R&D. Retrieved March 3, 2018, from https://www.globalccsinstitute.com/institute/news/ malaysian-program-supports-ccs-rd

Global CCS Institute. (2015). A conversation with TNB's Noraziah Muda on CCS in Malaysia. Retrieved March 3, 2018, from https://www.globalccsinstitute.com/ insights/authors/AliceGibson/2015/01/03/conversation-tnbs-noraziah-muda-ccs-malaysia

Gómez, A., Fueyo, N., & Tomás, A. (2007). Detailed modelling of a flue-gas desulfurisation plant. *Computers and Chemical Engineering*, *31*(11), 1419–1431.

González, A. S., Plaza, M. G., Rubiera, F., & Pevida, C. (2013). Sustainable biomass-based carbon adsorbents for post-combustion CO_2 capture. *Chemical Engineering Journal*, *230*, 456–465.

Gosu, V., Dhakar, A., Sikarwar, P., Arun Kumar, U. K., Subbaramaiah, V., & Zhang, T. C. (2018). Wet peroxidation of resorcinol catalyzed by copper impregnated granular activated carbon. *Journal of Environmental Management*, *223*, 825–833.

Haber, J. (1991). IUPAC Standard: Manual on Catalyst Characterization. *Pure and Applied Chemistry*, *63*, 1227–1246.

Hajari, A. N. (2017). Combined flue gas cleanup process for simultaneous removal of SO_x, NO_x , and CO_2 - A techno-economic analysis. *Master T*hesis, Missouri University of Science and Technology.

Hakim, A., Tahari, M. N. A., Marliza, T. S., Isahak, W. N. R. W., Yusop, M. R., Hisham, M. W. M., & Yarmoa, M. A. (2015). Study of CO_2 adsorption and desorption on activated carbon supported iron oxide by temperature programmed desorption. *Jurnal Teknologi (Sciences & Engineering)*, *77*(33), 75–84.

Hamza, U. D., Nasri, N. S., & Abd.Majid, Z. (2016). CO_2 adsorption on sustainable biomass derived activated carbon: A mini review.

International Journal of Advances in Science Engineering and Technology, *4*(1), 104–108.

Harsha, K. R. S., Murthy, M., Udayasimha, L., Dharmaprakash, & Rangappa, D. (2017). Synthesis and characterization of activated carbon coated alumina as nano adsorbent. *Materials Today: Proceedings*, *4*, 12321–12327.

Hidayu, A. R., & Muda, N. (2016). Preparation and characterization of impregnated activated carbon from palm kernel shell and coconut shell for CO_2 capture. *Procedia Engineering*, *148*, 106–113.

Hidayu, A. R., & Muda, N. (2017). Impregnated Palm Kernel Shell Activated Carbon for CO_2 Adsorption by Pressure Swing Adsorption. *Indian Journal of Science and Technology*, *10*(January).

Hinkov, I., Lamari, F. D., Langlois, P., Pentchev, I., Langlois, P., Dicko, M. & Pentchev, I. (2016). Carbon dioxide capture by adsorption (Review). *Journal of Chemical Technology and Metallurgy*, *51*(6), 609–626.

Hlaing, N. N., Othman, R., Hinode, H., Kurniawan, W., Thant, A. A., Mohamed, A. R., & Sreekantan, S. (2014). The influence of hydrothermal temperature on CaO-based adsorbents synthesized by sol-gel-hydrothermal method. *Procedia Environmental Sciences*, *20*, 71–78.

Hornbostel, M. D., Bao, J., Krishnan, G., Nagar, A., Jayaweera, I., Kobayashi, T., & Dubois, L. (2013). Characteristics of an advanced carbon sorbent for CO_2 capture. *Carbon*, *56*, 77–85.

Hosseini, S., Bayesti, I., Marahel, E., & Eghbali, F. (2015). Adsorption of carbon dioxide using activated carbon impregnated with Cu promoted by zinc. *Journal of the Taiwan Institute of Chemical Engineers*, *52*, 109–117.

Hosseini, S., Eghbali, F., & Masoudi, S. (2017). Carbon dioxide adsorption on nitrogen-enriched gel beads from calcined eggshell/sodium alginate natural composite. *Process Safety and Environmental Protection*, *109*, 387–399.

Hsu, S.-C., Lu, C., Su, F., Zeng, W., & Chen, W. (2010). Thermodynamics and regeneration studies of CO_2 adsorption on multiwalled carbon nanotubes. *Chemical Engineering Science*, *65*, 1354–1361.

IPCC. (2013). Intergovernmental Panel on Climate Change. Retrieved January 7, 2017, from http://www.ipcc.ch/

Irani, M., Jacobson, A. T., Gasem, K. A. M., & Fan, M. (2017). Modified carbon nanotubes/tetraethylenepentamine for CO_2 capture. *Fuel*, *206*, 10–18.

Jain, A., Balasubramanian, R., & Srinivasan, M. P. (2015). Production of high surface area mesoporous activated carbons from waste biomass using

hydrogen peroxide-mediated hydrothermal treatment for adsorption applications. *Chemical Engineering Journal*, *273*, 622–629.

Jain, A., Balasubramanian, R., & Srinivasan, M. P. (2016). Hydrothermal conversion of biomass waste to activated carbon with high porosity: A review. *Chemical Engineering Journal*, *283*, 789–805.

Jain, A., Xu, C., Jayaraman, S., & Balasubramanian, R. (2015). Microporous and mesoporous materials mesoporous activated carbons with enhanced porosity by optimal hydrothermal pre-treatment of biomass for supercapacitor applications. *Microporous and Mesoporous Materials*, *218*, 55–61.

Jang, D., & Park, S. (2012). Influence of nickel oxide on carbon dioxide adsorption behaviors of activated carbons. *Fuel*, *102*, 439–444.

Jang, E., Choi, S. W., Hong, S., Shin, S., & Lee, K. B. (2018). Development of a cost-effective CO_2 adsorbent from petroleum coke via KOH activation. *Applied Surface Science*, *429*, 62–71.

Jin, D. S., Deshwal, B. R., Park, Y. S., & Lee, H. K. (2006). Simultaneous removal of SO_2 and NO by wet scrubbing using aqueous chlorine dioxide solution. *Journal of Hazardous Materials*, *135*(1–3), 412–417.

Kaithwas, A., Prasad, M., Kulshreshtha, A., & Verma, S. (2012). Chemical engineering research and design industrial wastes derived solid adsorbents for CO_2 capture: A mini review. *Chemical Engineering Research and Design*, *90*(10), 1632–1641.

Kang, G., Chan, Z. P., Saleh, S. M., & Cao, Y. (2017). Removal of high concentration CO_2 from natural gas using high pressure membrane contactors. *International Journal of Greenhouse Gas Control*, *60*, 1–9.

Keller, L., Ohs, B., Lenhart, J., Abduly, L., Blanke, P., & Wessling, M. (2018). High capacity polyethylenimine impregnated microtubes made of carbon nanotubes for CO_2 capture. *Carbon*, *126*, 338–345.

Kim, B., Cho, K., & Park, S. (2010). Copper oxide-decorated porous carbons for carbon dioxide adsorption behaviors. *Journal of Colloid And Interface Science*, *342*, 575–578.

Kongnoo, A., Intharapat, P., Worathanakul, P., & Phalakornkule, C. (2016). Diethanolamine impregnated palm shell activated carbon for CO_2 adsorption at elevated temperatures. *Journal of Environmental Chemical Engineering*, *4*, 73–81.

Kudinalli, L., Bhatta, G., Subramanyam, S., Chengala, M. D., Olivera, S., & Venkatesh, K. (2015). Progress in hydrotalcite like compounds and metal-based oxides for CO_2 capture : a review. *Journal of Cleaner Production*, *103*, 171–196.

Kumara, N. T. R. N., Hamdan, N., Petra, M. I., Tennakoon, K. U., & Ekanayake, P. (2014). Equilibrium isotherm studies of adsorption of pigments extracted from kuduk-kuduk (Melastoma malabathricum L.) pulp onto TiO_2 nanoparticles, *Journal of Chemistry*, Volume 2014.

Kundu, P. K., Chakma, A., & Feng, X. (2014). Effectiveness of membranes and hybrid membrane processes in comparison with absorption using amines for post-combustion CO_2 capture. *International Journal of Greenhouse Gas Control*, *28*, 248–256.

Kwiatkowski, M., Policicchio, A., Seredych, M., & Bandosz, T. J. (2016). Evaluation of CO_2 interactions with S-doped nanoporous carbon and its composites with a reduced GO: Effect of surface features on an apparent physical adsorption mechanism. *Carbon*, *98*, 250–258.

Lagazzo, A., Finocchio, E., Petrini, P., Ruggiero, C., & Pastorino, L. (2016). Hydrothermal synthesis of pectin derived nanoporous carbon material. *Materials Letters*, *171*, 212–215.

Laginhas, C., Nabais, J. M. V., & Titirici, M. M. (2016). Activated carbons with high nitrogen content by a combination of hydrothermal carbonization with activation. *Microporous and Mesoporous Materials*, *226*, 125–132.

Lahijani, P., Mohammadi, M., & Mohamed, A. R. (2018). Metal incorporated biochar as a potential adsorbent for high capacity CO_2 capture at ambient condition. *Journal of CO_2 Utilization*, *26*, 281–293.

Lau, L., Choong, C., & Eng, Y. (2014). Carbon dioxide emission , institutional quality , and economic growth : Empirical evidence in Malaysia. *Renewable Energy*, *68*, 276–281.

Lavoie, R. (2017). Biochar - What's good, not so good and what's not fully understood. Retrieved May 11, 2018, from https://www.airterra.ca/uncategorized/biochar-whats-good-not-good-whats-not-fully-understood/

Lee, M., Lee, S., & Park, S. (2015). Preparation and characterization of multi-walled carbon nanotubes impregnated with polyethyleneimine for carbon dioxide capture. *International Journal of Hydrogen Energy*, *40*(8), 3415–3421.

Lee, S., & Park, S. (2015). A review on solid adsorbents for carbon dioxide capture. *Journal of Industrial and Engineering Chemistry*, *23*, 1–11.

Leslie, S. A., & Mitchell, J. C. (2007). Removing gold coating from sem samples. *Palaeontology*, *50*(6), 1459–1461.

Li, M., Huang, K., Schott, J. A., Wu, Z., & Dai, S. (2017a). Effect of metal oxides modification on CO_2 adsorption performance over mesoporous carbon. *Microporous and Mesoporous Materials*, *249*, 34–41.

Li, M., Huang, K., Schott, J. A., Wu, Z., & Dai, S. (2017b). Effect of metal oxides modification on CO_2 adsorption performance over mesoporous carbon. *Microporous and Mesoporous Materials*, *249*, 34–41.

Liang, Z., Fu, K., Idem, R., & Tontiwachwuthikul, P. (2016). Review on current advances, future challenges and consideration issues for post-combustion CO_2 capture using amine-based absorbents. *Chinese Journal of Chemical Engineering*, *24*(2), 278–288.

Liu, H., Li, M., Idem, R., (PT) Tontiwachwuthikul, P., & Liang, Z. (2017). Analysis of solubility, absorption heat and kinetics of CO_2 absorption into 1-(2-hydroxyethyl) pyrrolidine solvent. *Chemical Engineering Science*, *162*, 120–130.

Liu, J. (2017). Process design of aqueous ammonia-based post-combustion CO_2 capture. *Journal of the Taiwan Institute of Chemical Engineers*, *78*, 240–246.

Liu, S. (2015). Cooperative adsorption on solid surfaces. *Journal of Colloid and Interface Science*, *450*, 224–238.

Liu, S. H., & Huang, Y. Y. (2018). Valorization of coffee grounds to biochar-derived adsorbents for CO_2 adsorption. *Journal of Cleaner Production*, *175*, 354–360.

Lizzio, A. a, & Debarr, J. a. (1997). Mechanism of SO_2 Removal by Carbon. *Energy*, *11*, 284–291.

Ludwinowicz, J., & Jaroniec, M. (2015). Potassium salt-Assisted synthesis of highly microporous carbon spheres for CO_2 adsorption. *Carbon*, *82*, 297–303.

Madzaki, H., Ghani, W. A. W. A. K., Rebitanim, N. Z., & Alias, A. B. (2016). Carbon Dioxide Adsorption on Sawdust Biochar. In *Procedia Engineering* (Vol. 148, pp. 718–725).

Maleki, N., & Motahari, K. (2018). Absorption performance of carbon dioxide in 4-Hydroxy-1-methylpiperidine + aminoethylethanolamine aqueous solutions: Experimental measurement and modeling. *Journal of Natural Gas Science and Engineering*, *56*(January), 1–17.

Maroto-valer, M. M., Tang, Z., & Zhang, Y. (2005). CO_2 capture by activated and impregnated anthracites. *Fuel Processing Technology*, *86*, 1487–1502.

Masoumi, S., Rahimpour, M. R., & Mehdipour, M. (2016). Removal of carbon dioxide by aqueous amino acid salts using hollow fiber membrane contactors. *Journal of CO2 Utilization*, *16*, 42–49.

MEIH. (2018). Malaysia Energy Information Hub: Statistic. Retrieved from

March, 7, 2017, http://meih.st.gov.my

MET, Malayisa Meteorological Department. (2009). Climate Change Scenarios for Malaysia 2001 - 2009. Retrieved January 7, 2017 from http://www.met.gov.my/.

Mohshim, D. F., Mukhtar, H., & Man, Z. (2018). A study on carbon dioxide removal by blending the ionic liquid in membrane synthesis. *Separation and Purification Technology*, *196*, 20–26.

Mondal, M. K., Balsora, H. K., & Varshney, P. (2012). Progress and trends in CO_2 capture/separation technologies : A review. *Energy*, *46*(1), 431–441.

Moradi, S. E. (2014). Low-cost metal oxide activated carbon prepared and modified by microwave heating method for hydrogen storage. *Korean Journal of Chemical Engineering*, *31*(9), 1651–1655.

Mulukutla, T., Chau, J., Singh, D., Obuskovic, G., & Sirkar, K. K. (2015). Novel membrane contactor for CO_2 removal from flue gas by temperature swing absorption. *Journal of Membrane Science*, *493*, 321–328.

Nakhjiri, A. T., Heydarinasab, A., Bakhtiari, O., & Mohammadi, T. (2018). The effect of membrane pores wettability on CO_2 removal from CO_2/CH_4 gaseous mixture using NaOH, MEA and TEA liquid absorbents in hollow fiber membrane contactor. *Chinese Journal of Chemical Engineering*, *In Press*.

Nanoscience. (2018). CNT Technology Overview. Retrieved March 5, 2018, from https://www.nanoscience.com

Nguyen, T. T. H., Le, V. K., Minh, C. Le, & Nguyen, N. H. (2017). A theoretical study of carbon dioxide adsorption and activation on metal-doped (Fe, Co, Ni) carbon nanotube. *Computational and Theoretical Chemistry*, *1100*, 46–51.

Nowrouzi, M., Younesi, H., & Bahramifar, N. (2018). Superior CO_2 capture performance on biomass-derived carbon/metal oxides nanocomposites from Persian ironwood by H_3PO_4 activation. *Fuel*, *223*, 99–114.

Nugraha, Saputro, A. G., Agusta, M. K., Yuliarto, B., Dipojono, H. K., & Maezono, R. (2016). Density functional study of adsorptions of CO_2, NO_2 & SO_2 mole-cules on Zn(0002) surfaces. *Journal of Physics:Conference Series*, *739*, 1–8.

Nygaard, H. G., Kiil, S., Johnsson, J. E., Jensen, J. N., Hansen, J., Fogh, F., & Dam-Johansen, K. (2004). Full-scale measurements of SO_2 gas phase concentrations and slurry compositions in a wet flue gas desulphurisation spray absorber. *Fuel*, *83*(9), 1151–1164.

OECD, Organization for Economic Cooperation and Development. (2012).

OECD Environmental Outlook to 2050: The Consequences of Inaction. *Outlook*, (March), 353.

Olajire, A. A. (2010). CO_2 capture and separation technologies for end-of-pipe applications - A review. *Energy*, *35*, 2610–2628.

Pan, F., Zhao, H., Deng, W., Feng, X., & Li, Y. (2018). A novel N,Fe-Decorated carbon nanotubecarbon nanosheet architecture for efficient CO_2 reduction. *Electrochimica Acta*, *273*, 154–161.

Park, S. J., & Seo, M. K. (2011). Element and Processing. In *Interface Science and Technology* (Vol. 18, pp. 431–499).

Peavy, H. S., Rowe, D. R., & Tchobanoglous, G. (1985). *Environmental Engineering* (7th Editio). McGraw-Hill.

Pillai, C. K., Chung, S. J., Raju, T., & Moon, I. S. (2009). Experimental aspects of combined NO_x and SO_2 removal from flue-gas mixture in an integrated wet scrubber-electrochemical cell system. *Chemosphere*, *76*(5), 657–664.

Pires, J. C. M., Martins, F. G., & Simões, M. (2011). Chemical engineering research and design recent developments on carbon capture and storage : An overview. *Chemical Engineering Research and Design*, *89*(9), 1446–1460.

Pohlmann, J., Bram, M., Wilkner, K., & Brinkmann, T. (2016). Pilot scale separation of CO_2 from power plant flue gases by membrane technology. *International Journal of Greenhouse Gas Control*, *53*, 56–64.

Querejeta, N., Plaza, M. G., Rubiera, F., Pevida, C., Avery, T., & Tennisson, S. R. (2017). Carbon monoliths in adsorption-based post-combustion CO_2 capture. *Energy Procedia*, *114*, 2341–2352.

Rackley, S. A. (2017). *Carbon Capture and Storage* (2nd Editio). Butterworth-Heinemann.

Raganati, F., Alfe, M., Gargiulo, V., Chirone, R., & Ammendola, P. (2018). Isotherms and thermodynamics of CO_2 adsorption on a novel carbon-magnetite composite sorbent. *Chemical Engineering Research and Design*, *134*, 540–552.

Rashidi, N. A., & Yusup, S. (2016). An overview of activated carbons utilization for the post-combustion carbon dioxide capture. *Biochemical Pharmacology*, *13*, 1–16.

Rashidi, N. A., & Yusup, S. (2017). Potential of palm kernel shell as activated carbon precursors through single stage activation technique for carbon dioxide adsorption. *Journal of Cleaner Production*, *168*, 474–486.

Ratanakuakangwan, S., & Tangjitsitcharoen, S. (2017). Comparison of

metallurgical coke and lignite coke for power generation in Thailand. *IOP Conference Series: Materials Science and Engineering*, *191*, 1–6.

Raymundo-Piñero, E., Cazorla-Amorós, D., & Linares-Solano, A. (2001). Temperature programmed desorption study on the mechanism of SO_2 oxidation by activated carbon and activated carbon fibres. *Carbon*, *39*, 231–242.

Rezaei, F., & Jones, C. W. (2014). Stability of Supported Amine Adsorbents to SO_2 and NO_x in Postcombustion CO_2 Capture. 2. Multicomponent Adsorption. *Industrial & Engineering Chemistry Research*, *53*, 12103–12110.

Rubin, E., & Rao, A. B. (2002). A Technical , Economic and Environmental Assessment of Amine-based CO2 Capture Technology for Power Plant Greenhouse Gas Control*. Annual Technical Progress Report Reporting Period October 2000 – October 2001 Anand B*.

Ruiz, E., Sánchez, J. M., Maroño, M., & Otero, J. (2013). CO_2 capture from PCC power plants using solid sorbents : Bench scale study on synthetic gas. *Fuel*, *114*, 143–152.

Sandru, M., Kim, T. J., Capala, W., Huijbers, M., & Hägg, M. B. (2013). Pilot scale testing of polymeric membranes for CO_2 capture from coal fired power plants. *Energy Procedia*, *37*, 6473–6480.

Sarker, A. I., Aroonwilas, A., & Veawab, A. (2017). Equilibrium and kinetic behaviour of CO_2 adsorption onto zeolites, carbon molecular sieve and activated carbons. *Energy Procedia*, *114*, 2450–2459.

Serafin, J., Narkiewicz, U., Morawski, A. W., Wróbel, R. J., & Michalkiewicz, B. (2017). Highly microporous activated carbons from biomass for CO_2 capture and effective micropores at different conditions. *Journal of CO_2 Utilization*, *18*, 73–79.

Shafeeyan, M. S., Daud, W. M. A. W., Houshmand, A., & Shamiri, A. (2010). A review on surface modification of activated carbon for carbon dioxide adsorption. *Journal of Analytical and Applied Pyrolysis*, *89*(2), 143–151.

Shahbaz, M., Loganathan, N., Taneem, A., Ahmed, K., & Ali, M. (2016). How urbanization affects CO_2 emissions in Malaysia ? The application of STIRPAT model. *Renewable and Sustainable Energy Reviews*, *57*, 83–93.

Shahkarami, S., Dalai, A. K., & Soltan, J. (2016). Enhanced CO2 adsorption using MgO-impregnated activated carbon: Impact of Preparation Techniques. *Industrial & Engineering Chemistry Research*, 1–26.

Shakerian, F., Kim, K. H., Szulejko, J. E., & Park, J. W. (2015). A comparative review between amines and ammonia as sorptive media for post-

combustion CO_2 capture. *Applied Energy*, *148*, 10–22.

Shimabuku, Q. L., Ueda-Nakamura, T., Bergamasco, R., & Fagundes-Klen, M. R. (2018). Chick-Watson kinetics of virus inactivation with granular activated carbon modified with silver nanoparticles and/or copper oxide. *Process Safety and Environmental Protection*, *117*, 33–42.

Shiue, A., Hu, S., Chang, S., Ko, T., Hsieh, A., & Chan, A. (2017). Adsorption kinetics and breakthrough of carbon dioxide for the chemical modified activated carbon filter used in the building. *Sustainability*, *9*(1533), 1–13.

Singh, J., Bhunia, H., & Basu, S. (2018a). CO_2 adsorption on oxygen enriched porous carbon monoliths: Kinetics, isotherm and thermodynamic studies. *Journal of Industrial and Engineering Chemistry*, *60*, 321–332.

Singh, J., Bhunia, H., & Basu, S. (2018b). Synthesis of porous carbon monolith adsorbents for carbon dioxide capture: Breakthrough adsorption study. *Journal of the Taiwan Institute of Chemical Engineers*, *89*, 140–150.

Six, J. (2014). Biochar: is there a dark side? Retrieved May 11, 2018, from https://www.ethz.ch/en/news-and-events/eth-news/news/2014/04/biochar-is-there-a-dark-side.html

Skubiszewska-Zieba, J., Sydorchuk, V. V, Gun'ko, V. M., & Leboda, R. (2011). Hydrothermal modification of carbon adsorbents. *Adsorption*, *17*, 919–927.

Slostowski, C., Marre, S., Dagault, P., Babot, O., Toupance, T., & Aymonier, C. (2017). CeO_2 nanopowders as solid sorbents for efficient CO_2 capture/release processes. *Journal of CO_2 Utilization*, *20*(January), 52–58.

Soltani, S., Rashid, U., Al-resayes, S. I., & Arbi, I. (2017). Recent progress in synthesis and surface functionalization of mesoporous acidic heterogeneous catalysts for esterification of free fatty acid feedstocks : A review. *Energy Conversion and Management*, *141*, 183–205.

Soltani, S., Rashid, U., Al-resayes, S. I., & Nehdi, I. A. (2017). Sulfonated mesoporous ZnO catalyst for methyl esters production. *Journal of Cleaner Production*, *144*, 182–491.

Song, C. (2006). Global challenges and strategies for control, conversion and utilization of CO2 for sustainable development involving energy, catalysis, adsorption and chemical processing. *Catalysis Today*, *115*, 2–32.

Songolzadeh, M., Ravanchi, M. T., & Soleimani, M. (2012). Carbon dioxide capture and storage: A general review on adsorbents. *International Journal of Chemical and Molecular Engineering*, *6*(10), 900–907.

Sumathi, S., Bhatia, S., Lee, K. T., & Mohamed, A. R. (2010a). Adsorption

isotherm models and properties of SO_2 and NO removal by palm shell activated carbon supported with cerium (Ce/PSAC). *Chemical Engineering Journal*, *162*(1), 194–200.

Sumathi, S., Bhatia, S., Lee, K. T., & Mohamed, A. R. (2010b). Cerium impregnated palm shell activated carbon (Ce/PSAC) sorbent for simultaneous removal of SO_2 and NO — Process study. *Chemical Engineering Journal*, *162*(1), 51–57.

Sumathi, S., Bhatia, S., Lee, K. T., & Mohamed, A. R. (2010c). Performance of an activated carbon made from waste palm shell in simultaneous adsorption of SO_x and NO_x of flue gas at low temperature.pdf. *Journal of Applied Science*, *10*(12), 1052–1059.

Sumathi, S., Bhatia, S., Lee, K. T., & Mohamed, A. R. (2010d). Selection of best impregnated palm shell activated carbon (PSAC) for simultaneous removal of SO_2 and NO_x. *Journal of Hazardous Materials*, *176*, 1093–1096.

Sun, N., Tang, Z., Wei, W., Snape, C. E., & Sun, Y. (2015). Solid adsorbents for low-temperature CO_2 capture with low-energy penalties leading to more effective integrated solutions for power generation and industrial processes. *Frontiers in Energy Research*, *3*(March), 1–16.

Thiruvenkatachari, R., Su, S., An, H., & Yu, X. X. (2009). Post combustion CO_2 capture by carbon fibre monolithic adsorbents. *Progress in Energy and Combustion Science*, *35*(5), 438–455.

Thiruvenkatachari, R., Su, S., Yu, X. X., & Jin, Y. (2015). A site trial demonstration of CO_2 capture from real flue gas by novel carbon fibre composite monolith adsorbents. *International Journal of Greenhouse Gas Control*, *42*(x), 415–423.

TNB. (2015). Typical flue gas composition and properties at exhaust stack TNB. Tenaga Nasional Berhad, TNB.

UNFCCC, United Nation Framework Convention on Climate Change. (2015). COP21. Retrieved January 7, 2017, from https://unfccc.int/process-and-meetings/conferences/past-conferences/paris-climate-change-conference-november-2015/cop-21

Unur, E. (2013). Functional nanoporous carbons from hydrothermally treated biomass for environmental purification. *Microporous and Mesoporous Materials*, *168*, 92–101.

Valdés-Solís, T., Marbán, G., & Fuertes, A. B. (2003). Low-temperature SCR of NO_x with NH_3 over carbon-ceramic supported catalysts. *Applied Catalysis B: Environmental*, *46*(2), 261–271.

Vargas, D. P., Giraldo, L., & Moreno-piraján, J. C. (2012). CO_2 adsorption on

activated carbon honeycomb-monoliths : A comparison of Langmuir and Tóth models. *International Journal of Molecular Sciences*, *13*, 8388–8397.

Vaughn, P. (2011). Carbon nanotubes: Advantages and Disadvantages. Retrieved March 5, 2018, from http://pvaughn.blogspot.com/2011/02/carbon-nanotubes-advantages-and.html

Vergunst, T., Kapteijn, F., & Moulijn, J. A. (2001). Monolithic catalysts - Non-uniform active phase distribution by impregnation. *Applied Catalysis A: General*, *213*, 179–187.

Wang, J., Huang, L., Yang, R., Zhang, Z., Wu, J., Gao, Y., & Zhong, Z. (2014). Recent advances in solid sorbents for CO_2 capture and new development trends. *Energy Environ. Sci.*, *7*(11), 3478–3518.

Wang, L., Rao, L., Xia, B., Wang, L., Yue, L., Liang, Y., & Hu, X. (2018). Highly efficient CO_2 adsorption by nitrogen-doped porous carbons synthesized with low-temperature sodium amide activation. *Carbon*, *130*, 31–40.

Wang, M., Joel, A. S., Ramshaw, C., Eimer, D., & Musa, N. M. (2015). Process intensification for post-combustion CO_2 capture with chemical absorption: A critical review. *Applied Energy*, *158*, 275–291.

Wang, Q., Luo, J., Zhong, Z., & Borgna, A. (2011). CO_2 capture by solid adsorbents and their applications : current status and new trends. *Energy & Environmental Science*, *4*, 42–55.

Wikipedia. (2017). List of power stations in Malaysia. Retrieved January 7, 2017, from https://en.wikipedia.org/wiki/List_of_power_stations_in_Malaysia

Wu, Q., Li, W., Liu, S., & Jin, C. (2016). Hydrothermal synthesis of N-doped spherical carbon from carboxymethylcellulose for CO_2 capture. *Applied Surface Science*, *369*, 101–107.

Xiao, P. W., Guo, D., Zhao, L., & Han, B. H. (2016). Soft templating synthesis of nitrogen-doped porous hydrothermal carbons and their applications in carbon dioxide and hydrogen adsorption. *Microporous and Mesoporous Materials*, *220*, 129–135.

Xu, G., Liang, F., Wu, Y., Yang, Y., Zhang, K., & Liu, W. (2015). A new proposed approach for future large-scale de-carbonization coal- fi red power plants. *Applied Thermal Engineering*, *87*, 316–327.

Yang, T., & Lua, A. C. (2003). Characteristics of activated carbons prepared from pistachio-nut shells by physical activation. *Journal of Colloid and Interface Science*, *267*(2), 408–417.

Yang, W., Wang, H., Zhang, M., Zhu, J., Zhou, J., & Wu, S. (2016). Fuel

properties and combustion kinetics of hydrochar prepared by hydrothermal carbonization of bamboo. *Bioresource Technology*, *205*, 199–204.

Yaumi, A. L., Bakar, M. Z. A., & Hameed, B. H. (2017). Recent advances in functionalized composite solid materials for carbon dioxide capture. *Energy*, *124*, 461–480.

Yi, H., Huang, B., Tang, X., Li, K., Yuan, Q., Lai, R., & Wang, P. (2014). Simultaneous adsorption of SO_2, NO, and CO_2 by K_2CO_3-modified γ-Alumina. *Chemical Engineering Technology*, *37*(6), 1049–1054.

Yi, H., Wang, Z., Liu, H., Tang, X., Ma, D., Zhao, S., & Zuo, Y. (2014). Adsorption of SO_2, NO, and CO_2 on activated carbons: Equilibrium and thermodynamics. *Journal of Chemical Engineering Data*, *59*, 1556–1563.

Yi, H., Zuo, Y., Liu, H., Tang, X., Zhao, S., Zhang, B., & Gao, F. (2015). Study on coadsorption of SO_2, NO and CO_2 over copper-supported activated carbon sorbent in different operating condition. *Environmental Progress & Sustainable Energy*, *34*(4), 1044–1049.

Yin, C. Y., Aroua, M. K., & Wan Daud, W. M. A. (2007). Review of modifications of activated carbon for enhancing contaminant uptakes from aqueous solutions. *Separation and Purification Technology*, *52*, 403–415.

Ying, J., Knutsen, A. R., & Eimer, D. A. (2017). Mass transfer kinetics of CO_2 in loaded aqueous MEA solutions. *Energy Procedia*, *114*(November 2016), 2088–2095.

Yong, Z. O. U., & Mata, V. G. (2001). Adsorption of carbon dioxide on chemically modified high surface area carbon-based adsorbents at high temperature. *Adsorption, 7*, 41–50.

Yoshikawa, K., Kaneeda, M., & Nakamura, H. (2017). Development of novel CeO_2-based CO_2 adsorbent and analysis on its CO_2 adsorption and desorption mechanism. *Energy Procedia*, *114*, 2481–2487.

Yoshikawa, K., Sato, H., Kaneeda, M., & Kondo, J. N. (2014). Synthesis and analysis of CO_2 adsorbents based on cerium oxide. *Journal of CO_2 Utilization*, *8*, 34–38.

Younas, M., Sohail, M., Leong, L. K., Bashir, M. J., & Sumathi, S. (2016). Feasibility of CO_2 adsorption by solid adsorbents: a review on low-temperature systems. *International Journal of Environmental Science and Technology*, 1–22.

Yu, Y., Zhang, C., Yang, L., & Paul Chen, J. (2017). Cerium oxide modified activated carbon as an efficient and effective adsorbent for rapid uptake of arsenate and arsenite: Material development and study of performance and mechanisms. *Chemical Engineering Journal*, *315*, 630–638.

Yuan, Y., & Rochelle, G. T. (2018). CO_2 absorption rate in semi-aqueous monoethanolamine. *Chemical Engineering Science*, *182*, 56–66.

Yue, L., Xia, Q., Wang, L., Wang, L., Dacosta, H., Yang, J., & Hu, X. (2018). CO_2 adsorption at nitrogen-doped carbons prepared by K_2CO_3 activation of urea-modified coconut shell. *Journal of Colloid And Interface Science*, *511*, 259–267.

Zhang, N., Yu, K., & Chen, Z. (2017). How does urbanization affect carbon dioxide emissions? A cross-country panel data analysis. *Energy Policy*, *107*(March), 678–687.

Zhang, W., Chen, J., Luo, X., & Wang, M. (2017). Modelling and process analysis of post-combustion carbon capture with the blend of 2-amino-2-methyl-1-propanol and piperazine. *International Journal of Greenhouse Gas Control*, *63*(March), 37–46.

Zhou, X., Yi, H., Tang, X., Deng, H., & Liu, H. (2012). Thermodynamics for the adsorption of SO_2, NO and CO_2 from flue gas on activated carbon fiber. *Chemical Engineering Journal*, *200–202*(2), 399–404.

Zhu, J. L., Wang, Y. H., Zhang, J. C., & Ma, R. Y. (2005). Experimental investigation of adsorption of NO and SO_2 on modified activated carbon sorbent from flue gases. *Energy Conversion and Management*, *46*, 2173–2184.

BIODATA OF STUDENT

Hazimah binti Madzaki is a master's student in Chemical Engineering under the supervision of Assoc. Prof. Dr. Wan Azlina Wan Ab Karim Ghani. Her interest is in environment engineering, sustainable energy and gas cleaning. Prior to enrolling at Universiti Putra Malaysia (UPM), she worked as research assistance under the same supervision for one month. She graduated from Universiti Teknologi MARA (UiTM) with Diploma in Chemical Engneering and Bachelor of Engineering (Hons) Chemical and Process in 2011 and 2014 respectively. In February of 2015, he pursued his Master's degree in Chemical and Environmental Engineering under the supervision of Associate Professor Dr Wan Azlina in UPM.

LIST OF PUBLICATIONS

Madzaki, H., Ghani, W. A. W. A. K., Yaw, T. C. S., and Muda, N. (2017). Carbon dioxide adsorption using activated carbon impregnated with carbon dioxide. *Proceedings of the 4th Postgraduate Colloquium for Environmental Research* 2017 (POCER 2017), 44-45.

Madzaki, H., Ghani, W. A. W. A. K., Yaw, T. C. S., and Muda, N. (2018). Carbon Dioxide Adsorption on Activated Carbon Hydrothermally Treated and Impregnated with Metal Oxides. *Jurnal Kejuruteraan, 30*(1), 31-38.

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : _____

TITLE OF THESIS / PROJECT REPORT :

SIMULTANEOUS REMOVAL OF CARBON DIOXIDE, SULPHUR DIOXIDE AND NITROGEN OXIDES USING ACTIVATED CARBON MODIFIED WITH METAL OXIDES

NAME OF STUDENT : HAZIMAH BINTI MADZAKI

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

☐	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
☐	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
☐	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

☐	**PATENT**	Embargo from_____ until _____ (date) (date)

Approved by:

_____ (Signature of Student)
New IC No/ Passport No.:

Date :

_____ (Signature of Chairman of Supervisory Committee)
Name:

Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]