SYNTHESIS OF MODIFIED RICE HUSK ACTIVATED CARBON AND STUDY ON THEIR CARBON DIOXIDE (CO_2) ADSORPTION CAPACITY.

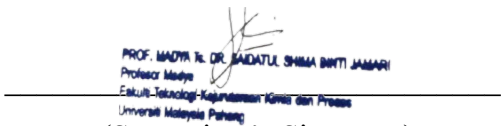
SITI NORAISHAH BINTI MASOUM RAMAN

MASTER OF SCIENCE

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

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

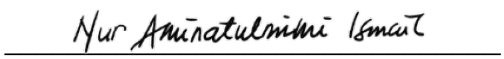


(Supervisor's Signature)

Full Name : DR. SAIDATUL SHIMA BINTI JAMARI

Position : SENIOR LECTURER

Date : 1st JUNE 2021



(Co-supervisor's Signature)

Full Name : NUR AMINATULMIMI BINTI ISMAIL

Position : LECTURER

Date : 1st JUNE 2021

STUDENT'S DECLARATION

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

_____

(Student's Signature)

Full Name : SITI NORAISHAH BINTI MASOUM RAMAN

ID Number : MKC15009

Date : 1st JUNE 2021

SYNTHESIS OF MODIFIED RICE HUSK ACTIVATED CARBON AND STUDY ON THEIR CARBON DIOXIDE (CO_2) ADSORPTION CAPACITY

SITI NORAISHAH BINTI MASOUM RAMAN

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

Faculty of Chemical and Process Engineering Technology

UNIVERSITI MALAYSIA PAHANG

JUNE 2021

ACKNOWLEDGEMENTS

I would first like to thank my thesis advisor, Dr. Saidatul Shima Jamari of the Faculty of Chemical and Process Engineering Technology at Universiti Malaysia Pahang. She was really helpful and helps a lot in my research and writing. She consistently allowed this paper to be my own work, but steered me in the right the direction whenever she thought I needed it.

I would also like to acknowledge Madam Nur Aminatulmimi Ismail of the Faculty of Chemical and Process Engineering Technology at Universiti Malaysia Pahang as the second reader of this thesis, and I am gratefully indebted to her for her very valuable comments on this thesis.

Finally, I must express my very profound gratitude to my family and friends for providing me with unfailing support and continuous encouragement throughout my years of study and through the process of researching and writing this thesis. This accomplishment would not have been possible without them. Thank you.

ABSTRAK

Kajian analisis sampel karbon aktif yang diresapi dengan monoethanolamine (MEA), diethanolamine (DEA), dan piperazine sebagai penjerap karbon dioksida (CO_2) berpotensi dilakukan. Kapasiti penjerapan karbon aktif dapat ditingkatkan dengan memperkenalkan kumpulan amina pada permukaan penjerap. MEA, DEA, dan piperazine dipilih sebagai sebatian amino untuk proses pengikatan pada permukaan karbon aktif. Sintesis karbon aktif yang diresapi dibuat mengikut nisbah kepekatan dan campuran. Sifat fizikokimia karbon aktif yang diresapi dicirikan oleh difraksi sinar-x (XRD), Brunauer, Emmett dan Teller (BET), spektroskopi inframerah transformasi Fourier (FTIR) dan mikroskop elektron pengimbas pancaran medan (FESEM). Analisis XRD digunakan untuk menentukan jenis kehadiran sebatian di permukaan karbon aktif. Hasilnya menunjukkan bahawa sudut difraksi sekitar 21.54º hingga 22.18º dihubungkan untuk pirazol, etanolamina, dietanolamin, dan benzalazin yang membuktikan adanya hidrokarbon dan amina pada permukaan karbon aktif. Dari analisis BET, jumlah luas permukaan dan isi pori menurun dengan peningkatan kepekatan alkanolamin. Kehadiran kumpulan fungsional amida dalam analisis FTIR pada jalur 3288 cm-1 dan 1651 cm-1 untuk karbon aktif yang diresapi membuktikan bahawa terdapat tindak balas yang berlaku antara kumpulan karboksil pada permukaan karbon aktif dengan ikatan amina. Bagi analisis FESEM, ditunjukkan bahawa morfologi karbon aktif yang tidak diresapi mengandung banyak liang di permukaannya sementara pori-pori pada karbon aktif yang diresapi dengan alkanolamin diisi dengan amina sesuai dengan kepekatan yang dipilih. Kajian kapasiti penjerapan CO_2 menunjukkan bahawa keadaan terbaik untuk proses penjerapan adalah pada suhu tempat tidur 25°C dan kadar aliran gas suapan 20 ml / minit. Sampel yang dipilih untuk kajian kapasiti penjerapan CO_2 adalah pada nisbah berat dan konsentrasi piperazin yang tertinggi, masing-masing pada 75% berat dan 1:2 nisbah karbon aktif kepada piperazin. Pengambilan CO_2 paling tinggi pada suhu dan kadar aliran ini untuk karbon aktif yang diresapi oleh piperazine diikuti oleh sampel regenerasi dan karbon aktif yang tidak diresapi iaitu masing-masing 145.42, 95.81, dan 42.00 mg-CO_2 / g-adsorben. Pemulihan regenerasi untuk karbon aktif yang diresapi oleh piperazine adalah lebih daripada 65%.

ABSTRACT

Characterization studies of impregnated activated carbon with monoethanolamine (MEA), diethanolamine (DEA), and piperazine as potential carbon dioxide (CO_2) adsorbent were conducted. The adsorption capacity of the activated carbon can be increased by introducing amine group on the surface of the adsorbent. MEA, DEA, and piperazine were selected as amino compounds for the binding process on activated carbon surface. The synthesis of impregnated activated carbon was prepared according to concentration and mixture ratio. The physicochemical properties of impregnated activated carbon were characterized by x-ray diffraction (XRD), Brunauer, Emmett and Teller (BET), fourier transform infrared spectroscopy (FTIR) and field emission scanning electron microscopy (FESEM). The XRD analysis was used to determine the type of compound present on the activated carbon surface. The result revealed that the diffraction angles around 21.54º to 22.18º were linked for pyrazole, ethanolamine, diethanolamine, and benzalazine which prove the presence of hydrocarbon and amine on the activated carbon surfaces. From the BET analysis, the total surface area and pore volume decreased with increase in concentration of alkanolamine. The presence of amide functional groups in FTIR analysis at 3288 cm^{-1} and 1651 cm^{-1} band for the impregnated activated carbon proved that a reaction occured between carboxyl groups on the activated carbon surfaces with amine bonded. As for FESEM analysis, it was shown that the morphology of the non-impregnated activated carbon contained many pores on its surface while the pores on the impregnated activated carbon with alkanolamine were filled with amines according to the selected concentration. The sample chosen for CO_2 adsorption capacity study was of the highest concentration and mixture ratio of piperazine, namely 75 wt.% and 1:2 activated carbon to piperazine ratio, respectively. The CO_2 adsorption capacity studies show that the best condition for adsorption process to take place was at bed temperature of 25°C and feed gas flow rate of 20 ml/min. The CO_2 uptake was highest at this temperature and flow rate for piperazine impregnated activated carbon followed by the regenerated sample and non-impregnated activated carbon which were 145.42, 95.81, and 42.00 mg-CO_2/g-adsorbent respectively. The regeneration recovery for the piperazine impregnated activated carbon was more than 65%.

TABLE OF CONTENT

REFERENCES

Abd Mutalib, Z. (2019). Ministry: Rice production to be increased to 75 percent. *New Straits Times*.

Abioye, A. M., Nasir Ani, F., & Bahru, J. (2017). Jurnal Teknologi Full Paper Advancement in the Production of Activated Carbon from Biomass Using Microwave Heating. *Sciences & Engineering)*, *79*, 2180–3722.

Ali, P. I., Asim, M., & Khan, T. A. (2012). Low Cost Adsorbents for Removal of Organic Pollutants from Wastewater. *Journal of Environmental Management*, *113C*, 170–183. https://doi.org/10.1016/j.jenvman.2012.08.028

Alkhatib, A. J., & Zailaey, K. Al. (2015). Medical and environmental applications of activated charcoal: review article. *European Scientific Journal*, *11*(3), 50–56.

Anderson, T. R., Hawkins, E., & Jones, P. D. (2016). CO2, the greenhouse effect and global warming: from the pioneering work of Arrhenius and Callendar to today's Earth System Models. *Endeavour*, *40*(3), 178–187. https://doi.org/10.1016/j.endeavour.2016.07.002

Arjmandi, R., Hassan, A., Majeed, K., & Zakaria, Z. (2015). Rice Husk Filled Polymer Composites. *International Journal of Polymer Science*, *2015*. https://doi.org/10.1155/2015/501471

Aroua, M., Daud, W., Yin, C., & Adinata, D. (2008). Adsorption Capacities of Carbon Dioxide, Oxygen, Nitrogen and Methane on Carbon Molecular Basket Derived from Polyethyleneimine Impregnation on Microporous Palm Shell Activated Carbon. *Separation and Purification Technology*, *62*, 609–613. https://doi.org/10.1016/j.seppur.2008.03.003

Bakar, R. A., Yahya, R., & Gan, S. N. (2016). Production of High Purity Amorphous Silica from Rice Husk. *Procedia Chemistry*, *19*, 189–195. https://doi.org/10.1016/j.proche.2016.03.092

Bezerra, D. P., Oliveira, R. S., Vieira, R. S., Cavalcante, C. L., & Azevedo, D. C. S. (2011). Adsorption of CO2 on nitrogen-enriched activated carbon and zeolite 13X. *Adsorption*, *17*(1), 235–246. https://doi.org/10.1007/s10450-011-9320-z

Binkley, R. W. (1969). Reexamination of the effect of benzophenone on benzalazine photochemistry. *The Journal of Organic Chemistry*, *34*(10), 3218–3219. https://doi.org/10.1021/jo01262a103

Brotzel, F., Mayr, H., & Baidya, M. (2010). Nucleophilicities of Amines , Amino Acids and Pyridines. *Org. Biomol. Chem.*, *8*, 1929–1935.

Chen, Y., Zhu, Y., Wang, Z., li, Y., Wang, L., Ding, L., Gao, X., Ma, Y., & Guo, Y. (2011). Application Studies of Activated Carbon Derived from Rice Husk

Produced by Chemical-Thermal Process – a Review. *Advances in Colloid and Interface Science*, *163*, 39–52. https://doi.org/10.1016/j.cis.2011.01.006

Conference, I., & Sciences, E. (2012). *Characteristics of Micro- and Mesoporous Structure and Surface Chemistry of Activated Carbons Produced by Oil Palm Shell*.

Correa, C. R., & Kruse, A. (2018). Biobased functional carbon materials: Production, characterization, and applications-A review. *Materials*, *11*(9). https://doi.org/10.3390/ma11091568

Dali, A., Saadi, A., & Hadi, A. (2012). *The Study Of Carbon Dioxide Adsorption On Activated Carbon In Single And Multi Fixed Bed Column*.

Das, D., Samal, D. P., & BC, M. (2015). Preparation of Activated Carbon from Green Coconut Shell and its Characterization. *Journal of Chemical Engineering & Process Technology*, *06*(05). https://doi.org/10.4172/2157-7048.1000248

de Souza, L. K. C., Wickramaratne, N. P., Ello, A. S., Costa, M. J. F., da Costa, C. E. F., & Jaroniec, M. (2013). Enhancement of CO2 adsorption on phenolic resin-based mesoporous carbons by KOH activation. *Carbon*, *65*, 334–340. https://doi.org/https://doi.org/10.1016/j.carbon.2013.08.034

Dhage S, S., & Kulkarni S, K. (2015). Adsorption of Carbon Dioxide on Adsorbents Synthesized by Microwave Technique. *Journal of Chemical Engineering & Process Technology*, *06*(05). https://doi.org/10.4172/2157-7048.1000259

Dindi, A., Quang, D. V., Nashef, E., & Zahra, M. R. M. A. (2017). Effect of PEI Impregnation on the CO2 Capture Performance of Activated Fly Ash. *Energy Procedia*, *114*(November 2016), 2243–2251. https://doi.org/10.1016/j.egypro.2017.03.1361

Element Materials Technology. (2021). *X-Ray Diffraction Analysis (XRD)*.

Fang, H., Kamakoti, P., Zang, J., Cundy, S., Paur, C., Ravikovitch, P. I., & Sholl, D. S. (2012). Prediction of CO 2 adsorption properties in zeolites using force fields derived from periodic dispersion-corrected DFT calculations. *Journal of Physical Chemistry C*, *116*(19), 10692–10701. https://doi.org/10.1021/jp302433b

Giraldo, L., Vargas, D. P., & Moreno-Piraján, J. C. (2020). Study of CO2 Adsorption on Chemically Modified Activated Carbon With Nitric Acid and Ammonium Aqueous. *Frontiers in Chemistry*, *8*(November), 1–11. https://doi.org/10.3389/fchem.2020.543452

Gonzalez, M. ., Susial, P., Peña Perez, J., & Rodriguez, D. (2013). Chemical activation with phosphoric acid. adsorption of methylene blue. *Revista Mexicana de Ingeniería Química*, *12*(3), 595–608.

Granados-Pichardo, A., Granados-Correa, F., Sánchez-Mendieta, V., & Hernández-

Mendoza, H. (2020). New CaO-based adsorbents prepared by solution combustion and high-energy ball-milling processes for CO2 adsorption: Textural and structural influences. *Arabian Journal of Chemistry*, *13*(1), 171–183. https://doi.org/10.1016/j.arabjc.2017.03.005

Gregg, S. J., & Sing, K. S. W. (1991). *Adsorption, surface area, and porosity*. Academic Press.

Hair, M. L., & Tripp, C. P. (1995). Alkylchlorosilane reactions at the silica surface. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *105*(1), 95–103. https://doi.org/https://doi.org/10.1016/0927-7757(95)03298-5

Hauchhum, L., & Mahanta, P. (2014). *Kinetic , Thermodynamic and Regeneration Studies for CO 2 Adsorption onto Activated Carbon*. *4*(1), 27–32.

He, X., Chu, Y., Lindbråthen, A., Hillestad, M., & Hägg, M. B. (2018). Carbon molecular sieve membranes for biogas upgrading: Techno-economic feasibility analysis. *Journal of Cleaner Production*, *194*, 584–593. https://doi.org/10.1016/j.jclepro.2018.05.172

Hieu, N. M., Korobochkin, V. V., & Tu, N. V. (2015). A Study of Silica Separation in the Production of Activated Carbon from Rice Husk in Viet Nam. *Procedia Chemistry*, *15*, 308–312. https://doi.org/10.1016/j.proche.2015.10.049

Holló, G., Quaranta, L., Cvenkel, B., Astakhov, Y. S., Teus, M. A., Kóthy, P., Miglior, S., Riva, I., Akopov, E. L., Gros, J., Stewart, J. A., Kristoffersen, M. S., Nelson, L. A., & Stewart, W. C. (2012). Risk factors associated with progression in exfoliative glaucoma patients. *Ophthalmic Research*, *47*(4), 208–213. https://doi.org/10.1159/000332081

Houshmand, A., Daud, W., Lee, M.-G., & Shafeeyan, M. S. (2011). Carbon Dioxide Capture with Amine-Grafted Activated Carbon. *Water, Air, & Soil Pollution*, *223*, 827–835. https://doi.org/10.1007/s11270-011-0905-7

Huertas, J. I., Gomez, M. D., Giraldo, N., & Garzón, J. (2015). CO2 absorbing capacity of MEA. *Journal of Chemistry*, *2015*(2). https://doi.org/10.1155/2015/965015

Jahangiri, M., Adl, J., Shahtaheri, S. J., Rashidi, A., Ghorbanali, A., Kakooe, H., Rahimi Forushani, A., & Ganjali, M. R. (2013). Preparation of a new adsorbent from activated carbon and carbon nanofiber (AC/CNF) for manufacturing organic-vacbpour respirator cartridge. *Journal of Environmental Health Science and Engineering*, *10*(1), 1–8. https://doi.org/10.1186/1735-2746-10-15

Jamnongchob, A., Duangphakdee, O., & Hanpattanakit, P. (2017). CO2 emission of tourist transportation in Suan Phueng Mountain, Thailand. *Energy Procedia*, *136*, 438–443. https://doi.org/10.1016/j.egypro.2017.10.300

Javed, S., Naveed, S., Feroze, N., Zafar, M., & Shafaq, M. (2010). crystal and amorphous silica from KMnO4 treated and untreated ricehusk. *Journal of Quality*

and Technology Management, *6*(1), 81–90.

Kangwanwatana, W., Saiwan, C., & Tontiwachwuthikul, P. (2013). Study of CO2 Adsorption Using Adsorbent Modified with Piperazine. In *Chemical Engineering Transactions* (Vol. 35). https://doi.org/10.3303/CET1335067

Kasikamphaiboon, P., & Khunjan, U. (2018). CO 2 Adsorption from Biogas Using Amine-Functionalized MgO. *International Journal of Chemical Engineering*, *2018*. https://doi.org/10.1155/2018/1706405

Khalil, S. (2011). *Impregnation of commercial palm shell activated carbon with monoethanolamine for adsorbing co2 from gas mixture*.

Kim, Y., Lim, J., Jeong, S., Yoon, Y., Bae, S., & Nam, S. (2013). Comparison of carbon dioxide absorption in aqueous MEA, DEA, TEA, and AMP solutions. *Bulletin of the Korean Chemical Society*, *34*. https://doi.org/10.5012/bkcs.2013.34.3.783

Kishore, R., Bhikshma, V., & Jeevana Prakash, P. (2011). Study on strength characteristics of high strength Rice Husk Ash concrete. *Procedia Engineering*, *14*, 2666–2672. https://doi.org/10.1016/j.proeng.2011.07.335

Kohli, R., & Mittal, K. L. (2016). *Developments in Surface Contamination and Cleaning*. Developments in Surface Contamination and Cleaning. https://doi.org/10.1016/C2009-0-64377-4

Kongnoo, A., Intharapat, P., Worathanakul, P., & Phalakornkule, C. (2014). CO2 Adsorption at Thermophilic Temperature on Alkanolamine Impregnated Activated Carbon. *International Journal of Advances in Chemical Engineering and Biological Sciences*, *1*(1), 143–148. https://doi.org/10.15242/ijacebs.c0114030

Kumar, A., Mohanta, K., Kumar, D., & Parkash, O. (2011). Properties and industrial applications of rice husk: A review. *Int J Emerg Technol Adv Eng*, *2*, 86–90.

Kumar, B. S., & Preethi, T. V. (2014). Behavior of Clayey Soil Stabilized with Rice Husk Ash & Lime. *International Journal of Engineering Trends and Technology*, *11*(1), 44–48. https://doi.org/10.14445/22315381/ijett-v11p209

Le Van, K., & Luong Thi, T. T. (2014). Activated carbon derived from rice husk by NaOH activation and its application in supercapacitor. *Progress in Natural Science: Materials International*, *24*(3), 191–198. https://doi.org/10.1016/j.pnsc.2014.05.012

Lee, I. Y., Kwak, N. S., Lee, J. H., Jang, K. R., & Shim, J. G. (2013). Oxidative degradation of alkanolamines with inhibitors in CO2 capture process. *Energy Procedia*, *37*, 1830–1835. https://doi.org/10.1016/j.egypro.2013.06.061

Lei, L., Bai, L., Lindbråthen, A., Pan, F., Zhang, X., & He, X. (2020). Carbon membranes for CO 2 removal : Status and perspectives from materials to

processes. *Chemical Engineering Journal*, *401*(June), 126084. https://doi.org/10.1016/j.cej.2020.126084

Lin, Y., Yan, Q., Kong, C., & Chen, L. (2013). Polyethyleneimine Incorporated Metal-Organic Frameworks Adsorbent for Highly Selective CO2 Capture. *Scientific Reports*, *3*, 1859. https://doi.org/10.1038/srep01859

Lucideon Materials Development and Commercialization. (2021). *Brunauer-Emmett-Teller (BET) Surface Area Aalysis and Barrett-Joyner-Halenda (BJH) Pore Size and Volume Analysis*.

Madzaki, H., Karimghani, W. A. W. A. B., Nurzalikharebitanim, & Azilbaharialias. (2016). Carbon Dioxide Adsorption on Sawdust Biochar. *Procedia Engineering*, *148*, 718–725. https://doi.org/10.1016/j.proeng.2016.06.591

Mahmood, A. (2000). *Reproduced with permission of the copyright owner. Further reproduction prohibited without permission.*

Mai, T. T., Vu, D. L., Huynh, D. C., Wu, N. L., & Le, A. T. (2019). Cost-effective porous carbon materials synthesized by carbonizing rice husk and K2CO3 activation and their application for lithium-sulfur batteries. In *Journal of Science: Advanced Materials and Devices* (Vol. 4, Issue 2, pp. 223–229). https://doi.org/10.1016/j.jsamd.2019.04.009

Martín, C. F., Sweatman, M. B., Brandani, S., & Fan, X. (2016). Wet impregnation of a commercial low cost silica using DETA for a fast post-combustion CO2 capture process. *Applied Energy*, *183*, 1705–1721. https://doi.org/10.1016/j.apenergy.2016.09.081

Masoud, M. S., El-Saraf, W. M., Abdel - Halim, A. M., Ali, A. E., Mohamed, E. A., & Hasan, H. M. I. (2016). Rice husk and activated carbon for waste water treatment of El-Mex Bay, Alexandria Coast, Egypt. *Arabian Journal of Chemistry*, *9*, S1590–S1596. https://doi.org/10.1016/j.arabjc.2012.04.028

Mdoe, J., & Mkayula, L. (2004). Preparation and characterization of activated carbons from rice husks and shells of palm fruits. *Tanzania Journal of Science*, *28*. https://doi.org/10.4314/tjs.v28i2.18361

Meng, L., Cho, K.-S., & Park, S.-J. (2009). CO2 Adsorption of Amine Functionalized Activated Carbons. *Carbon Letters*, *10*. https://doi.org/10.5714/CL.2009.10.3.221

Mohammad-Khah, A., & Ansari, R. (2009). Activated charcoal: Preparation, characterization and applications: A review article. *International Journal of ChemTech Research*, *1*(4), 859–864.

Muhammad, B., & Khan, S. (2019). Effect of bilateral FDI, energy consumption, CO2 emission and capital on economic growth of Asia countries. *Energy Reports*, *5*, 1305–1315. https://doi.org/10.1016/j.egyr.2019.09.004

Nagrale, S. D., Hajare, H., & Modak, P. R. (2012). Utilization Of Rice Husk Ash. *International Journal of Engineering Research and Applications (IJERA)*, *2*(4), 1–5.

Ndi Nsami, J., & Ketcha Mbadcam, J. (2013). The adsorption efficiency of chemically prepared activated carbon from cola nut shells by ZnCl2 on methylene blue. *Journal of Chemistry*, *2013*. https://doi.org/10.1155/2013/469170

Noor Syuhadah, S., & Rohasliney, H. (2012). Rice Husk as biosorbent: Areview. *Health and the Environment Journal*, *3*(1), 89–95.

Oginni, O., Singh, K., Oporto, G., Dawson-Andoh, B., McDonald, L., & Sabolsky, E. (2019). Effect of one-step and two-step H3PO4 activation on activated carbon characteristics. *Bioresource Technology Reports*, *8*(August), 100307. https://doi.org/10.1016/j.biteb.2019.100307

Ogungbenro, A. E., Quang, D. V., Al-Ali, K., & Abu-Zahra, M. R. M. (2017). Activated Carbon from Date Seeds for CO2 Capture Applications. *Energy Procedia*, *114*(November 2016), 2313–2321. https://doi.org/10.1016/j.egypro.2017.03.1370

Okoli, C. A., Onukwuli, O.D., O.-O., & C. F. and Okoye, C. C. (2015). Adsorptive removal of dyes from synthetic wastewater using activated carbon from tamarind seed. *European Scientific Journal*, *11*(18), 190–221.

Okumura, T., Yoshizawa, K., Nishibe, S., Iwasaki, H., Kazari, M., & Hori, T. (2017). Parametric Testing of a Pilot-scale Design for a Moving-bed CO2 Capture System Using Low-temperature Steam. *Energy Procedia*, *114*(November 2016), 2322–2329. https://doi.org/10.1016/j.egypro.2017.03.1369

Olawale, O., & Oyawale, F. (2012). Characterization of rice husk via atomic absorption spectrophotometer for optimal silica production. *International Journal of Science and Technology*, *2*(4), 210–213.

Olusegun, A., Makun, H. A., Ogara, I. M., Edema, M., Idahor, K. O., Oluwabamiwo, B. F., & Eshiett, M. E. (2012). We are IntechOpen , the world ' s leading publisher of Open Access books Built by scientists , for scientists TOP 1 %. *Intech*, *i*(tourism), 38. https://doi.org/10.1016/j.colsurfa.2011.12.014

Omatola, K. M., & Onojah, A. D. (2009). Elemental analysis of rice husk ash using X - Ray fluorescence technique. *International Journal of Physical Sciences*, *4*(4), 189–193.

P. Dantas, T. L., E., A., & M. Moreir, R. F. P. (2012). Separation of Carbon Dioxide from Flue Gas Using Adsorption on Porous Solids. *Greenhouse Gases - Capturing, Utilization and Reduction*. https://doi.org/10.5772/31917

P. J. Naik, D. V. P. and P. S. D. (2013). Pelagia Research Library. *Der Chemica Sinica*, *4*(4), 68–72.

Parise, J. B., Chen, X., Plonka, A. M., Woerner, W. R., Banerjee, D., Connors, D., & Goroff, N. (2019). XRD-DSC: A screening tool for identifying effective MOFs for selective gas sorption from humid gas streams. In *Powder Diffraction* (Vol. 34, Issue 1, pp. 3–12). Cambridge University Press. https://doi.org/10.1017/S088571561900006X

Patil, B. S., & Kulkarni, K. S. (2012). Development of High Surface Area Activated Carbon From Waste Material. *International Journal of Advanced Engineering Research and Studies*, *I*(II), 2249–8974.

Pedroso, G., Philippsen, M., Saldanha, L., Araujo, R., & Martins, A. (2019). Strategies for Fermentable Sugar Production by Using Pressurized Acid Hydrolysis for Rice Husks. *Rice Science*, *26*, 319–330. https://doi.org/10.1016/j.rsci.2019.08.006

Planas, N., Dzubak, A. L., Poloni, R., Lin, L.-C., McManus, A., McDonald, T. M., Neaton, J. B., Long, J. R., Smit, B., & Gagliardi, L. (2013). The Mechanism of Carbon Dioxide Adsorption in an Alkylamine-Functionalized Metal–Organic Framework. *Journal of the American Chemical Society*, *135*(20), 7402–7405. https://doi.org/10.1021/ja4004766

Qi, G., Wang, Y., Estevez, L., Duan, X., Anako, N., Park, A.-H., Li, W., Jones, C., & Giannelis, E. (2011). High efficiency nanocomposite sorbents for CO2 capture based on amine-functionalized mesoporous capsules. *Energy Environ. Sci.*, *4*, 444–452. https://doi.org/10.1039/C0EE00213E

Quang, D. V., Dindi, A., Rayer, A. V., El Hadri, N., Abdulkadir, A., & Abu-Zahra, M. R. M. (2014). Impregnation of amines onto porous precipitated silica for CO2 capture. *Energy Procedia*, *63*, 2122–2128. https://doi.org/10.1016/j.egypro.2014.11.229

Rashidi, N. A., Yusup, S., & Loong, L. H. (2013). Kinetic studies on carbon dioxide capture using activated carbon. *Chemical Engineering Transactions*, *35*, 361–366. https://doi.org/10.3303/CET1335060

Saiwan, C., Muchan, P., De Montigny, D., & Tontiwachwutikul, P. (2014). New poly(vinylbenzylchloride/divinylbenzene) adsorbent for carbon dioxide adsorption. Ii. Effect of amine functionalization. *Energy Procedia*, *63*(November 2015), 2317–2322. https://doi.org/10.1016/j.egypro.2014.11.251

Sangeetha, A., & Amudha, T. (2018). A Novel Bio-Inspired Framework for CO2 Emission Forecast in India. *Procedia Computer Science*, *125*, 367–375. https://doi.org/10.1016/j.procs.2017.12.048

Sarena Che Omar, Ashraf Shaharudin, & Siti Aiysyah Tumin. (2019). The Status of the Paddy and Rice Industry in Malaysia. In *Khazanah Research Institute*. http://www.krinstitute.org/assets/contentMS/img/template/editor/20190409_RiceReport_Full Report_Final.pdf

Saxena, R., Singh, V. K., & Kumar, E. A. (2014). Carbon dioxide capture and

sequestration by adsorption on activated carbon. *Energy Procedia*, *54*, 320–329. https://doi.org/10.1016/j.egypro.2014.07.275

Scaglioni, P. T., & Badiale-Furlong, E. (2016). Rice husk as an adsorbent: A new analytical approach to determine aflatoxins in milk. *Talanta*, *152*, 423–431. https://doi.org/10.1016/j.talanta.2016.02.042

Sekar, S., Ahmed, T. A., Inamdar, A. I., Lee, Y., Im, H., Kim, D. Y., & Lee, S. (2019). Activated carbon-decorated spherical silicon nanocrystal composites synchronously-derived from rice husks for anodic source of lithium-ion battery. *Nanomaterials*, *9*(7). https://doi.org/10.3390/nano9071055

Sekifuji, R., & Tateda, M. (2019). Study of the feasibility of a rice husk recycling scheme in Japan to produce silica fertilizer for rice plants. *Sustainable Environment Research*, *1*(1), 1–9. https://doi.org/10.1186/s42834-019-0011-x

Shafeeyan, M. S., Daud, W., Houshmand, A., & Sh, A. (2010). A review on surface modification of activated carbon for carbon dioxide adsorption. *Journal of Analytical and Applied Pyrolysis*, *89*, 143–151. https://doi.org/10.1016/j.jaap.2010.07.006

Shiue, A., Hu, S. C., Chang, S. M., Ko, T. Y., Hsieh, A., & Chan, A. (2017). Adsorption kinetics and breakthrough of carbon dioxide for the chemical modified activated carbon filter used in the building. *Sustainability (Switzerland)*, *9*(9). https://doi.org/10.3390/su9091533

Sindhu, R., Binod, P., & Pandey, A. (2015). Microbial Poly-3-Hydroxybutyrate and Related Copolymers. In *Industrial Biorefineries and White Biotechnology* (pp. 575–605). Elsevier. https://doi.org/10.1016/B978-0-444-63453-5.00019-7

Singh, V. K., & Anil Kumar, E. (2016). Measurement and analysis of adsorption isotherms of CO2 on activated carbon. *Applied Thermal Engineering*, *97*, 77–86. https://doi.org/10.1016/j.applthermaleng.2015.10.052

Singo, M. C., Molepo, X. C., Oluwasina, O. O., & Daramola, M. O. (2017). Chitosan-impregnated Sod-Metal Organic Frameworks (Sod-ZMOF) for CO2 Capture: Synthesis and Performance Evaluation. *Energy Procedia*, *114*(November 2016), 2429–2440. https://doi.org/10.1016/j.egypro.2017.03.1390

Solutions, R., & Handheld, U. (2016). *Measuring Amine Strength in Absorption and Regeneration Solutions Using Handheld Raman*. 1–11.

Speakman, S. (2019). *Crystallite Size Broadening*. Seoul National University.

Spigarelli, B., & Kawatra, S. (2013). Opportunities and challenges in carbon dioxide capture. *Journal of CO2 Utilization*, *1*, 69–87. https://doi.org/10.1016/j.jcou.2013.03.002

Starkie, C. M., Amieiro-Fonseca, A., Rigby, S. P., Drage, T. C., & Lester, E. H. (2014).

Surfactant mediated CO2 adsorption; the role of the coimpregnation species. *Energy Procedia*, *63*(0), 2323–2330. https://doi.org/10.1016/j.egypro.2014.11.252

Steele, G. (2019). *Activated Carbon Thermal Regeneration*. Acarbons.Com.

Tadda, M. ., Ahsan, A., Shifu, A., ElSergany, M., Arunkumar, T., Jose, B., Razzaque, Abdur, M., & Daud, Nik, N. . (2018). A Review on Activated Carbon from Biowaste : Process , Application and Prospects. *Journal of Advanced Civil Engineering Practice and Research*, *5*(3), 82–83.

Taku, J. K., Amartey, Y., & Kassar, T. (2016). Comparative Elemental Analysis of Rice Husk Ash Calcined at Different Temperatures Using X-ray Flourescence (XRF) Technique. *American Journal of Civil Engineering and Architecture*, *4*(1), 28–31. https://doi.org/10.12691/ajcea-4-1-4

Tang, Z., Maroto-Valer, M., & Zhang, Y. (2004). CO2 capture using anthracite based sorbents. *Prepr Pap-Am Chem Soc Div Fuel Chem*, *49*.

Tanzio, M. (2020). *Adsorption of Activated Carbon - Part 2*. Process Engineering Associates, LLC.

Ugheoke, B., & Mamat, O. (2012). A critical assessment and new research directions of rice husk silica processing methods and properties. *Maejo International Journal of Science and Technology*, *6*, 430–448. https://doi.org/10.14456/mijst.2012.31

Ünveren, E. E., Monkul, B. Ö., Sarıoğlan, Ş., Karademir, N., & Alper, E. (2017). *Solid amine sorbents for CO2 capture by chemical adsorption: A review*. *3*(1), 37–50. https://doi.org/10.1016/j.petlm.2016.11.001

Vargas, D. P., Giraldo, L., & Moreno-Piraján, J. C. (2013). Carbon dioxide and methane adsorption at high pressure on activated carbon materials. *Adsorption*, *19*(6), 1075–1082. https://doi.org/10.1007/s10450-013-9532-5

Wang, J., Chen, H., Zhou, H., Liu, X., Qiao, W., Long, D., & Ling, L. (2013). Carbon dioxide capture using polyethylenimine-loaded mesoporous carbons. *Journal of Environmental Sciences (China)*, *25*, 124–132. https://doi.org/10.1016/S1001-0742(12)60011-4

William, D., & Skord, J. L. (1989). *United States Patent (19). 19*.

Xue, Q., Wu, D., Zhou, Y., & Zhou, L. (2012). Improvement of amine-modification with piperazine for the adsorption of CO2. *Applied Surface Science*, *258*(8), 3859–3863. https://doi.org/https://doi.org/10.1016/j.apsusc.2011.12.046

Yacob, A. R., & Al Swaidan, H. M. (2012). Phosphoric Acid Effect on Prepared Activated Carbon from Saudi Arabia's Date Frond Waste. *Applied Mechanics and Materials*, *110–116*, 2124–2130. https://doi.org/10.4028/www.scientific.net/AMM.110-116.2124

Yang, M. W., Chen, N. C., Huang, C. H., Shen, Y. T., Yang, H. S., & Chou, C. T. (2014). Temperature swing adsorption process for CO2 capture using polyaniline solid sorbent. *Energy Procedia*, *63*, 2351–2358. https://doi.org/10.1016/j.egypro.2014.11.256

Yang, Q., Gao, C., Wu, Z. X., Liang, S. N., & Liu, M. H. (2018). Activated carbon clogging analysis in an integration of constructed wetland with microbial fuel cell. *E3S Web of Conferences*, *53*, 10–13. https://doi.org/10.1051/e3sconf/20185301025

Yii, K. J., & Geetha, C. (2017). The Nexus between Technology Innovation and CO2 Emissions in Malaysia: Evidence from Granger Causality Test. *Energy Procedia*, *105*, 3118–3124. https://doi.org/10.1016/j.egypro.2017.03.654

Yin, C., Aroua, M., & Daud, W. (2007). Impregnation of palm shell activated carbon with polyethyleneimine and its effects on Cd2+ adsorption. *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, *307*, 128–136. https://doi.org/10.1016/j.colsurfa.2007.05.012

Yu, C. H., Huang, C. H., & Tan, C. S. (2012). A review of CO2 capture by absorption and adsorption. *Aerosol and Air Quality Research*, *12*(5), 745–769. https://doi.org/10.4209/aaqr.2012.05.0132

Zedalis, R. J. (2017). International energy law: Rules governing future exploration, exploitation and use of renewable resources. *International Energy Law: Rules Governing Future Exploration, Exploitation and Use of Renewable Resources*, 1–341. https://doi.org/10.4324/9781315252056

Zhang, C., Khaqqi, K. N., Hadinoto Ong, K., Romagnoli, A., & Kraft, M. (2017). Assessment of biodiesel plant waste heat recovery with respect to economics and CO2 emission. *Energy Procedia*, *142*, 1100–1105. https://doi.org/10.1016/j.egypro.2017.12.363