Production of Activated Carbon, Bio Oil and Syngas From Coconut Shells- A Review

Mr. Tejpal C Parshiwanikar
Department of Mechanical Engineering,
KDK College of Engineering, Nagpur, India

Dr. Chandrahas C Handa
Department of Mechanical Engineering,
KDK College of Engineering, Nagpur, India

Abstract- This review paper bring together the work done by different research scholars on production of activated carbon, bio oil and syngas from coconut shells. The generalize process for production of activated carbon, bio oil and syngas are deliberated. The influence of thermal pyrolysis i.e. carbonization and activation parameters viz. temperature, heating medium, heating rate, fume flow rate, activating reagent, and dwelling time toward properties of activated carbon were reviewed. The various pyrolysis methods for production of other byproducts also studied and their application is reviewed.

Keywords— Activated carbon, Bio oil, Syngas, Carbonization, Activation

I. Introduction

Deployment of coconut shells for production of activated carbon, bio oil and syngas is an important approach to convert waste in to some value added products that could solve environmental issues like water pollution and air pollution, large collection of agricultural waste. Also, instead of using other fossil fuel sources such as coal, using coconut shells biomass based activated carbon will reduce global warming's effects. As coconut shells based activated carbon, bio oil & syn gas is sourced from agricultural sector wastes and it is abundantly available so it will be more economical.

Activated carbon is non-graphite form of carbon which could be produced from any carbonaceous material, one of the most important micro porous adsorbent due to its tremendous adsorptive capacity. A number of studies on numerous applications of activated carbon have been published by various researchers [1–7]. Activated carbon derived from coconut shell is widely used for pollutant removal. Various industrial sectors use activated carbon in operations such as in waste water treatment, water & gas purification, desulphurization and mercury removal, refining and bleaching of vegetable oils, volatile organic compounds (VOC) adsorption [48], recovery of gold, solvents and other vapours, in gas masks & in filters for protection against warm & toxic gases etc. Activated carbon also used as an effective means for purification, storage, separation, deodorization and catalysis in gas phase applications [49]. Activated carbon is a well-known adsorbent due to its tremendous and versatile properties due to its high degree of surface reactivity that allow the accessible gas/liquid into its internal pore surface. The main properties of activated carbon are that it is comprised of developed microporous structure with high surface area and favorable pore size of the prepared material. Activated carbon with high adsorption capacity can be produced from numerous sources of biomass, such as coconut shell [8-12], wood [13,14], rice husk [15-17], walnut shell [18,19], durian shell [20–23], rubber- seed shell [24], almond shell [25-28], hazelnut shell [29–31], palm kernel shell [32–43], pistachio-nut shell [44,45], plum stones [46], and cotton stalks [47].

Another byproduct is bio oil which is extracted from coconut and consists of over 80% saturated fat. It is typically used in cosmetics as well as in baking and cooking. The very first step in preparing activated carbon & bio oil is preparing biochar from raw coconut shell with pyrolysis process viz. carbonization [1]. In this step, moisture content and volatile matters are removed from the coconut shells [1]. From this coconut shell charcoal, activated carbon & bio oil is produced by using steam activation of shell charcoal in a high temperature reactor. Fast pyrolysis process was carried out prior in fluidized bed reactor to produce char before activation process. Pyrolysis oil or Bio oil, sometimes also known as bio crude or bio oil is a synthetic fuel under investigation as substitute for petroleum. Liquid products can be refined to produce liquid fuels or value-added products, and can also be used as a chemical raw material. Paralytic oil (or bio-oil) is a kind of tar and normally contains levels of oxygen too high to be considered as hydrocarbon. The syngas product contains methane, which is widely present in natural gas, biogas, and coal mine gases.

The present study is focused on the process of production of activated carbon, bio oil & syngas from coconut shells and its various applications. The whole process study can be divided into two parts. In the first part, productions of activated carbon, bio oil & syngas from coconut shells based on different methods are reviewed in details. The second part described the various application of activated carbon, bio oil & syngas which is derived from coconut shells.

II. STAGES OF PRODUCTION PROCESS.

In general, two main stages are concerned in production of activated carbon, bio oil & syngas from coconut shells. The first stage is started with thermal pyrolysis / carbonization of raw coconut shell biomass at a temperature of around 600^0C in the inert atmosphere that is exclusion of oxygen for getting biochar/charcoal [1,8,12,58,60]. The first stage is then followed by second stage of activation process for the enlargement of pore volume and generation of large surface area of activated carbon. In general, activation process is divided into two separate methods, unlikely first one is physical activation and second one is chemical activation. During both the stages, syn gases are produced which can be condensed to get bio oil.

Carbonization/Thermal Pyrolysis

Carbonization/thermal pyrolysis process is a phase to enrich carbon content in coconut shell material by eliminating non-carbon species using thermal decomposition. Initial porosity of biochar even though comparatively low, it could be developed in this stage before undergoes further development in activation process. Careful selection of carbonization parameters is important because this process leaves a significant effect on the final product [44,45].

In this process, the carbonization temperature has the most prominent effect, followed by heating rate and residence time [7,37]. Normally, higher carbonization temperature (500–600^0C) result in reduced yield of char while increasing the liquid and gases release rate [7]. Higher temperature will also increase ash and fixed carbon content and lower amount of volatile matter [7,37,47]. Thus, high temperatures result in better quality char but also decrease yield. This is due to the primary decomposition of coconut shell at higher temperatures and also secondary decomposition of char residue [7]. Thus, as the temperature of primary decomposition increased or the residence times of primary vapors inside the cracked particle is shorter, the char yields decrease [47]. According to Ioannidoue and Zabaniotou [7], higher carbonization temperatures also increase ash and fixed carbon content due to the decrease in volatile matter. As a result, a higher temperature yields char with improved quality.

In order to obtain low volatilization and a high char yield, low heating rates (10–15^0 C/min) should be used. Char has a high fixed carbon content which is important for producing activated carbon. Lower heating rate will increase dehydration and improve the stabilization of the polymeric components [6,7]. However, the microporosity of char has been found to be independent of the precursor composition and the carbonization heating rate [6]. Table 1 presents the proximate and ultimate analysis of several biomass materials.

Table 1

Ultimate and Proximate Analysis of various biomass used for production.

Biomass type	Ultimate analysis (db, % w/w)					Proximate analysis (db, % w/w)				
	C	H	O	N	S	A sh	Volatile	Fixed carbon	Moisture	Refs.
Coconut shell	51.38	5.	30.76	0.13	0.	0.	85.36	20.26		
Rice straw	41.8	8	36.6	0.7	01	69	69.3	–	11.26	[58]
Cotton stalks	41.2	4.	34.0	2.6	0.	13	–	–	25	[7]
Durian shell	60.3	6	28.1	3.1	1	.4	69.6	22.4	6.0	[7]
		5.			0.	13			5.5	
		0			0	.3				[22]
		8.			0.	2.5				
		5			1					

Corn stalks	45.5	6.2	41.1	0.9	0.13	6.4	—	—	0	[7]
Corn cobs	46.3	5.6	42.2	0.6	0.0	5.3	—	—	7.1	[7]
Almond shell	51.4	6.1	41.6	0.3	0.6	1.3	82.3	—	—	[25]
Palm shell	50.1	6.9	41.2	1.9	—	1.1	72.5	18.7	8.0	[34]
Plum stones	46.4	5.5	48.0	0.1	—	0.4	80.6	—	—	[46]

Carbonization parameters have high impact in the development of initial pore structure in the char, mainly through the release of volatile compounds. Since pore development in the char has a great influence on the pore characteristics of subsequently produced activated carbon, carbonization parameters should be taken into account prior to activation stage.

Activation

The aim of activation process is to increase the porosity of activated carbon material & enhance the pore volume. Activation process can be carried out by two different methods. They are named as physical activation and chemical activation. Physical activation usually uses steam or CO_2 while for chemical activation; various chemicals are used [62,63]. Table 2 represents various activation conditions for preparation of activated carbon from several biomass materials.

Table 2
Various activation conditions for production of Activated Carbon.

Activation method	Biomass	Activation Medium	Refs.
Physical	Durian peel-based, palm shell, almond shell, pistachio-nut shell	CO_2	[21,33,37,42,44,64]
	Rubber-seed shell, palm shell, nut shell, coconut shell	Steam	[24,34,39,43,65,66]
Chemical	Durian shell, pistachio nut shell, plum stones, coconut shell, palm shell	KOH	[20,36,46,44,67]
	Corn cob	$ZnCl_2$	[49]
	Coconut shell	Strong base	[68]
	Coconut shell	$Cu(NO_3)_2$	[69]
	Wood	H_3PO_4	[70]

During the activation process, unorganized carbon is removed, exposing the char to the action of activating agents and lead to the development of microporous structure [6]. In this phase, existing pores are widened or large- size pores are formed when walls between the pores are completely burnt-off. This results in the increasing transitional pores and macroporosity, whereas the volume of micropores decreases. Thus, the extent of burn-off carbon material or the degree of activation is an important measure in activated carbon production [71].

During activation the temperature is set between 800 and 950^0 C to develop the porosity and surface area of carbon. For physical activation, steam is more effective than CO_2, because activated carbon with a relatively higher surface area can be produced. The smaller molecule size of water is responsible to facilitate diffusion within the char's porous structure effectively [43]. On the other hand, various chemicals such as $ZnCl_2$, H_3PO_4, NaOH and KOH have been used for chemical activation [29,46,18,72,73]. These chemical agents develop the porosity based on dehydration and degradation. Generally, chemical activation (300–500^0 C) takes place at lower temperature than physical activation [29,72,73]. This improves the development of pore in carbon structure due to the effect of chemical agent [74]. One of the most important advantages of chemical activation over physical activation is the lower treatment temperature and shorter treatment time. In addition, the activated carbon obtained by the chemical activation possesses larger surface area and well controlled microporosity in smaller ranges [41,42,72]. Further- more, the carbon yield of chemical activation is also higher than that of physical activation [74]. The disadvantages of chemical activation is the high cost of production due to higher cost of various chemical & contaminated activated carbon is produced. Also purity of other product like quality of bio oil & syngas is also get affected.

III. PRODUCTION METHODOLOGY

Figure 3.1 represents the production process layout for production of activated carbon, bio oil & syngas.

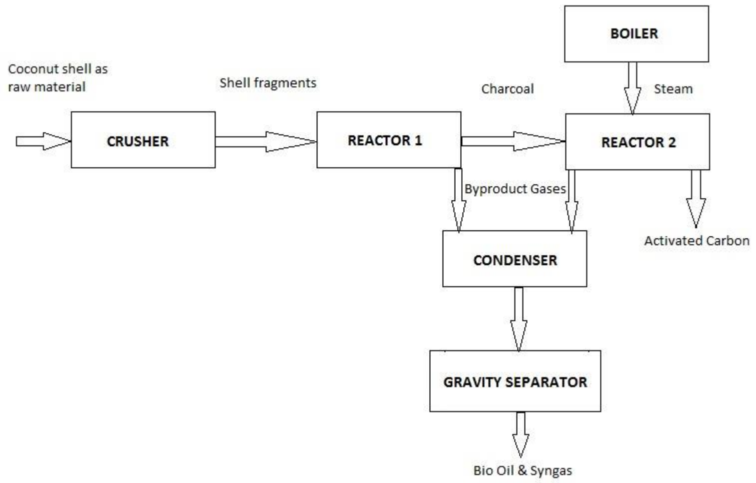

Figure 3.1

The various components used for production of activated carbon, bio oil & syngas are as follows.

Crusher

Coconut shells are hard and abrasive as the shell fragments can have rough edges and sharp points. A jaw crusher is chosen to crush the shells because it is suitable for hard and abrasive materials. The jaw crusher will have higher crushing capacity and is capable of reducing the shell fragments to the desired size.

Reactor

The shells are heated to 600°C at a rate of 20°C/min in a reactor. For slow pyrolysis, a lower heating rate is required for higher char yield. Faster heating rates result in higher gas yields and lower char yields. However, the heating rate should not be too slow that it would just waste time when a higher heating rate would have also resulted in the same char yield [32,51,61].

Condenser

A condenser is an apparatus or equipment used to condense gases (change the physical state of a substance from its gaseous to its liquid state). In simplest form, condenser consists of a tube through which hot gases are passed with outside water providing cooling.

Gravity Separator

The vertical knock-out drum is assumed to be a vertical vessel with sieve plates functioning as mesh pads. As the gas flows up through the vessel, gravity separates the liquid from the gas. The vessel will be made out of low alloy steel because the syngas contains hydrogen. The plates are made out of stainless steel since the gas is corrosive.

IV. APPLICATIONS OF PRODUCT

Water and air pollution has emerged as one of the major problems caused by substantial population growth and rapid development in industrial activities. Therefore, in order to achieve a sustainable development for future, water and air pollution control is a crucial. Currently, scrubbing pollutants using the adsorption method is widely applied [2–5,20,25,27]. Nevertheless, technological development using adsorption processes is also gaining considerable attention. Adsorption using adsorbents such as activated carbon has been studied [2–5,20,25,27]. Due to the fact that activated carbon provides a suitable pore size for adsorption and large surface area for rapid reaction, utilization of activated carbon offers great potential in water and air pollution control [2–5,20,25,27].

V. RESULT AND DISCUSSION

Production of coconut shell activated carbon, bio oil and syngas would enhance the conversion of waste into value added products. The production of activated carbon, bio oil and syngas has been studied for decades. This supports the theoretical study that coconut shell materials are suitable precursors for the production of activated carbons, bio oil and syngas with very high surface area and pore volume comparable to the best commercial activated carbon. Successful application of coconut shell based activated carbon in water and air pollution control depends strongly on the adsorption capacity of activated carbon. For that, activated carbon needs to undergo modification through either controlling the conditions of activation or by post-activation surface treatments.

VI. CONCLUSION

For production of the activated carbon, bio oil along with syngas, two optimal process i.e. carbonization / thermal pyrolysis and activation conditions are carried out by using various equipment's like pyrolysis reactors, condenser, oil & gas separator etc. Conclusively, the use of waste as adsorbent is an economic alternative and contributes to reduce the environmental contamination. Coconut shell can be converted into high economic value products by applied technology.

ACKNOWLEDGMENT

The authors gratefully acknowledge Mr. Ajay Padole, Director, Parth Enterprizes, Nagpur for their financial supports.

REFERENCES

[1] A.A. Ahmad, A. Idris, "Preparation and characterization of activated carbons derived from bio-solid: a review", Desalination and Water Treatment www.deswater.com, doi: 10.1080/19443994.2013.808797.

[2] S.Gueu, B. Yao, K. Adouby, G. Ado, "Heavy Metals Removal in Aqueous Solution by Activated Carbons Prepared from Coconut Shell and Seed Shell of the Palm Tree", Journal of Applied Sciences 6(13):2789-2793, 2006.

[3] Donni Adinata, Wan Mohd Ashri Wan Daud, Mohd Kheireddine Aroua, "Removal of heavy metal from industrial wastewater using modified activated coconut shell carbon", Biochemical Engineering Journal 36 (2007) 174–181 Received 1 September 2006; received in revised form 11 February 2007; accepted 12 February 2007.

[4] Olugbenga Solomon Bello & Mohd Azmier Ahmad, "Coconut (Cocos nucifera) Shell Based Activated Carbon for the Removal of Malachite Green Dye from Aqueous Solutions ", Separation Science and Technology Accepted author version posted online: 14 Dec 2011. Published online: 18 Apr 2012.

[5] Sandhya Babel, Tonni Agustiono Kurniawan, "Cr(VI) removal from synthetic wastewater using coconut shell charcoal and commercial activated carbon modified with oxidizing agents and/or chitosan", Chemosphere 54 (2004) 951–967 Received 10 December 2002; received in revised form 4 June 2003; accepted 6 October 2003.

[6] P.J.M. Suhas, M.M.L. Carrott, R. Carrott, "Lignin – from natural adsorbent to activated carbon: a review", Bioresource Technology 98 (2007) 2301–2312.

[7] O. Ioannidou, A. Zabaniotou, "Agricultural residues as precursors for activated carbon production – a review", Renewable and Sustainable Energy Reviews 11 (2007) 1966–2005.

[8] M.K.B. Gratuito, T. Panyathanmaporn, R. A. Chumnanklang, N. Sirinuntawittaya, A. Dutta, "Production of activated carbon from coconut shell: Optimization using response surface methodology / Bioresource Technology" 99 (2008) 4887–4895 Received 16 May 2007; received in revised form 11 September 2007; accepted 15 September 2007 Available online 13 November 2007

[9] Zhonghua Hu, M.P. Srinivasan, "Preparation of high-surface-area activated carbons from coconut shell, Microporous and Mesoporous Materials" 27 (1999) 11–18 Received 29 December 1997; received in revised form 19 May 1998; accepted 26 May 1998

[10] J. Laine, A. Calafat, M. Labady, "Preparation and characterization of activated carbons from coconut shell impregnated with phosphoric acid, Carbon" Vol. 27.No. 2, pp. 191-195,1989.

[11] W. Li, K. Yang, J. Peng, L. Zhang, S. Guo, H. Xia, "Effects of carbonization tempera- tures on characteristics of porosity in coconut shell chars and activated carbons derived from carbonized coconut shell chars", Industrial Crops and Products 28 (2008) 190–198.

[12] W. Li, J. Peng, L. Zhang, K. Yang, H. Xia, S. Zhang, S.H. Guo, "Preparation of activated carbon from coconut shell chars in pilot-scale microwave heating equipment at 60 kW", Waste Management 29 (2009) 756–760.

[13] Shakuntala Ojha, G. Raghavendra, S.K. Acharya, "A Comparative Investigation of Bio Waste Filler (Wood Apple-Coconut) Reinforced Polymer Composites", Polymer Composites-2014, pp 180-185

[14] M.C. Macías-Pérez, A. Bueno-López, M.A. Lillo-Ródenas, C. Salinas-Martínez deLecea, A. Linares-Solano, SO_2 retention on CaO/activated carbon sorbents. Part I: importance of calcium loading and dispersion, Fuel 86 (2007) 677–683.

[15] N. Yalcın, V. Sevinc, "Studies of the surface area and porosity of activated carbons prepared from rice husks", Carbon 38 (2000) 1943–1945.

[16] I. Dahlan, K.T. Lee, A.H. Kamaruddin, A.R. Mohamed, "Key factor in rice husk ash/ CaO sorbent for high flue gas desulfurization activity", Environmental Science & Technology 40 (2006) 6032–6037.

[17] Mandy Su Zan Gui, Seyed Amirmostafa Jourabchi, Hoon Kiat Ng and Suyin Gan, "Comparison of the yield and properties of bio-oil produced by slow and fast pyrolysis of rice husks and coconut shells", Applied Mechanics and Materials Vol. 625, pp 626-629 Online: 2014-09-12

[18] P. Nowicki, R. Pietrzak, H. Wachowska, "Sorption properties of active carbons obtained from walnut shells by chemical and physical activation", Catalysis Today 150 (2010) 107–114.

[19] Jin-Wha Kima, Myoung-Hoi Sohna, Dong-Su Kima, Seung-Man Sohnb, Young-Shik Kwon, "Production of granular activated carbon from waste walnut shell and its adsorption characteristics for Cu2+ ion", Journal of Hazardous Materials B85 (2001) 301–315.

[20] T.C. Chandra, M.M. Mirna, Y. Sudaryanto, S. Ismadji, "Adsorption of basic dye onto activated carbon prepared from durian shell: studies of adsorption equilibrium and kinetics", Chemical Engineering Journal 127 (2007) 121–129.

[21] K. Nuithitikul, S. Srikhun, S. Hirunpraditkoon, "Influences of pyrolysis condition and acid treatment on properties of durian peel-based activated carbon", Bior- esource Technology 101 (2010) 426–429.

[22] T.C. Chandra, M.M. Mirna, Y. Sudaryanto, S. Ismadji, "Activated carbon from durian shell: preparation and characterization", Journal of the Taiwan Institute of Chemical Engineers 40 (2009) 457–462.

[23] Y.J. Tham, P.A. Latif, A.M. Abdullah, A. Shamala-Devi, Y.H. Taufiq-Yap, "Performances of toluene removal by activated carbon derived from durian shell", Bioresource Technology 9 (2010), In Press, Corrected Proof.

[24] K. Sun, J.C. Jiang, "Preparation and characterization of activated carbon from rubber-seed shell by physical activation with steam", Biomass and Bioenergy 34 (2010) 539–544.

[25] M.G. Plaza, C. Pevida, C.F. Martı´n, J. Fermoso, J.J. Pis, F. Rubiera, "Developing almond shell-derived activated carbons as CO_2 adsorbents", Separation and Purification Technology 71 (2010) 102–106.

[26] A. Marcilla, S. Garcıa-Garcıa, M. Asensio, J.A. Conesa, "Influence of thermal treatment regime on the density and reactivity of activated carbons from almond shells, Carbon 38 (2000) 429–440.

[27] R.R. Bansode, J.N. Losso, W.E. Marshall, R.M. Rao, R.J. Portier, "Adsorption of volatile organic compounds by pecan shell and almond shell-based granular activated carbons", Bioresource Technology 90 (2003) 175–184 Received 18 October 2002; received in revised form 24 March 2003; accepted 25 March 2003.

[28] E. Demirbas, M. Kobya, A.E.S. Konukmanc, "Error analysis of equilibrium studies for the almond shell activated carbon adsorption of Cr(VI) from aqueous solutions", Journal of Hazardous Materials 154 (2008) 787–794 Received 22 May 2007; received in revised form 3 October 2007; accepted 25 October 2007 Available online 4 November 2007.

[29] E. Sayan, "Ultrasound-assisted preparation of activated carbon from alkaline impregnated hazelnut shell: an optimization study on removal of Cu^{2+} from aqueous solution", Chemical Engineering Journal 115 (2006) 213–218.

[30] D.D. Milenkovic, P.V. Dasic, V.B. Veljkovic, "Ultrasound-assisted adsorption of copper(II) ions on hazelnut shell activated carbon", Ultrasonics Sonochemistry 16 (2009) 557–563.

[31] M. Kobya, "Removal of Cr(VI) from aqueous solutions by adsorption onto hazelnut shell activated carbon: kinetic and equilibrium studies", Bioresource Technology 91 (2004) 317–321.

[32] T. Vitidsant, T. Suravattanasakul, S. Damronglerd, "Production of activated carbon from palm-oil shell by pyrolysis and steam activation in a fixed bed reactor", Science Asia 25 (1999) 211–222.

[33] J. Guo, A.C. Lua, "Experimental and kinetic studies on pore development during CO_2 activation of oil palm shell char", Journal of Porous Materials 8 (2001) 149–157.

[34] W.M.A.W. Daud, W.S.W. Ali, M.Z. Sulaiman, "The effects of carbonization temperature on pore development in palm-shell-based activated carbon", Carbon 38 (2000) 1925–1932.

[35] W.M.A.W. Daud, W.S.W. Ali, M.Z. Sulaiman, "Effect of activation temperature on pore development in activated carbon produced from palm shell", Journal of Chemical Technology & Biotechnology 78 (2003) 1–5.

[36] J. Guo, Y. Luo, A.C. Lua, R. Chi, Y. Chen, X. Bao, S. Xiang, "Adsorption of hydrogen sulphide (H_2S) by activated carbons derived from oil-palm shell", Carbon 45 (2007) 330–336.

[37] A.C. Lua, F.Y. Lau, J. Guo, "Influence of pyrolysis conditions on pore development of oil-palm-shell activated carbons", Journal of Analytical and Applied Pyrolysis 76 (2006) 96–102.

[38] A.C. Lua, Q. Jia, "Adsorption of phenol by oil-palm-shell activated carbons in a fixed bed", Chemical Engineering Journal 150 (2009) 455–461.

[39] Q. Jia, A.C. Lua, "Effects of pyrolysis conditions on the physical characteristics of oil- palm-shell activated carbons used in aqueous phase phenol adsorption", Journal of Analytical and Applied Pyrolysis 83 (2008) 175–179.

[40] B.K. Hamad, A.M. Noor, A.R. Afida, M.N. Mohd Asri, "High removal of 4-chlor- oguaiacol by high surface area of oil palm shell-activated carbon activated with NaOH from aqueous solution", Desalination 257 (2010) 1–7.

[41] S. Sumathi, S. Bhatia, K.T. Lee, A.R. Mohamed, "Optimization of microporous palm shell activated carbon production for flue gas desulphurization: experimental and statistical studies", Bioresource Technology 100 (2009) 1614–1621.

[42] S. Sumathi, S. Bhatia, K.T. Lee, A.R. Mohamed, "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", Science in China, Series E: Technological Sciences 52 (2009) 198–203.

[43] S. Mak, B. Tey, K. Cheah, W. Siew, K. Tan, "The effect of mechanical grinding on the mesoporosity of steam-activated palm kernel shell activated carbons", Journal of Chemical Technology & Biotechnology 84 (2009) 1405–1411.

[44] T. Yang, A.C. Lua, "Characteristics of activated carbons prepared from pistachio-nut shells by potassium hydroxide activation", Microporous and Mesoporous Materials 63 (2003) 113–124.

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

[46] P. Nowicki, H. Wachowska, R. Pietrzak, "Active carbons prepared by chemical activation of plum stones and their application in removal of NO_2", Journal of Hazardous Materials 181 (2010) 1088–1094.

[47] A.E. Putun, N. Ozbay, E.P. Onal, E. Putun, "Fixed-bed pyrolysis of cotton stalk for liquid and solid products", Fuel Process Technology 86 (2005) 1207–1219.

[48] M. Yates, J. Blanco, P. Avila, M.P. Martin, "Honeycomb monoliths of activated carbons for effluent gas purification", Microporous and Mesoporous Material 37 (2000) 201–208.

[49] W.T. Tsai, C.Y. Chang, S.L. Lee, "A low cost adsorbent from agricultural waste corn cob by zinc chloride activation", Bioresource Technology 64 (1998) 211–217.

[50] Wookeun Bae, Jongho Kim & Jinwook Chung,"Production of granular activated carbon from food-processing wastes (walnut shells and jujube seeds) and its adsorptive properties", Journal of the Air & Waste Management Association, ISSN: 1096-2247 (2014)

[51] J.O Otulana, O.O. Oluwole, M.B Adeleke, "A Reactor Plant for Activated Carbon Production", International Journal of Novel Research in Engineering and Science Vol. 2, Issue 2, pp: (20-26), Month: September 2015 - February 2016.

[52] G. L. Mcconnachie, A.M. Warhurst, S.J. Pollard, UK and V. Chipofya, Malawi, "Activated carbon from Moringa husks and pods", 22nd WEDC Conference, Reaching The Unreached: Challenges For The 21st Century, New Delhi, India, 1996

[53] F. Rulz Bevia, D. Prats Rico and A. F. Marcilla Gomis, "Activated Carbon from Almond Shells. Chemical Activating Reagent Selection and Variables Influence" , Ind. Eng. Chem. Prod. Res. Dev. 1984, 23, 266-269

[54] M.Shireesha, M.Prem Kumar, K.Naresh, L.Suresh Kumar "Research Planning and Experimental Procedure for Production of Bio-Oil by using Renewable Sources", International Journal of Engineering Technology Science and Research, ISSN 2394 – 3386,Volume 4, Issue1I, November 2017

[55] Radhakrishnan C, Karunaraja Natarajan, Azhagendran K, Mohanlal K, Ponraj P, Nivas R, "Experimental Analysis of Bio-Oil from Coconut Shell and Front by Continuous Pyrolysis Process", International Journal of Innovative Research in Science Engineering and Technology ISSN : 2319-8753, Vol. 5, Issue 4, April 2016.

[56] D. S. Fardhyanti, A. Damayanti, "Analysis of Bio-Oil Produced by Pyrolysis of Coconut Shell", International Journal of Chemical and Molecular Engineering,Vol:11, No:9, 2017.

[57] Supaat zakaria, A.M. Leman, Dafit Feriyanto, "Burner Characteristics for Activated Carbon Production", MATEC Web of Conferences, ENCON 2016 .

[58] Puttiphon Kongnum, and Sukritthira Ratanawilai ,"Catalytic Pyrolysis of Coconut Shell for Bio-oil", Int'l Journal of Advances in Chemical Engg., & Biological Sciences (IJACEBS) Vol. 1, Issue 1(2014).

[59] Sodha R., Gaonkar S., Kolte S. and Padmanabha P., "Antibacterial and Antifungal Activity of Crude Coconut Shell Oil", International Research Journal of Biological SciencesVol. 4(11), 16-20, November (2015).

[60] Mandy Su Zan Gui1, Seyed Amirmostafa Jourabchi, Hoon Kiat Ng and Suyin Gan, "Comparison of the yield and properties of bio-oil produced by slow and fast pyrolysis of rice husks and coconut shells", Applied Mechanics and MaterialsVol. 625, pp 626-629Online: 2014-09-12.

[61] P. M. Satya Sai, K. Krishnaiah, "Development of the Pore-Size Distribution in Activated Carbon Produced from Coconut Shell Char in a Fluidized-Bed Reactor", Ind. Eng. Chem. Res. 2005, 44, 51-60

[62] V.K. Gupta, P.J.M. Suhas, "Application of low-cost adsorbents for dye removal – a review", Journal of Environmental Management 90 (2009) 2313–2342.

[63] G. Crini, "Non-conventional low-cost adsorbents for dye removal: a review", Bioresource Technology 97 (2006) 1061–1085.

[64] R.C. Bansal, J.B. Donnet, F.F. Stoeckli, Active Carbon, Marcel Dekker Inc., New York, 1988.

[65] O.N. Baklanova, G.V. Plaksin, V.A. Drozdov, V.K. Duplyakin, N.V. Chesnokov, B.N. Kuznetsov, "Preparation of microporous sorbents from cedar nutshells and hy- drolytic lignin", Carbon 42 (2003) 1793–1800.

[66] F. Cosnier, A. Celzard, G. Furdin, D. Bégin, J.F. Marêché, "Influence of water on the dynamic adsoprtion of chlorinated VOCs on active carbon: Relative humidity of the gas phase versus pre-adsorbed water", Adsorption Science and Technology 24 (2006) 215–228.

[67] Y.W. Lee, H.J. Kim, J.W. Park, B.U. Choi, D.K. Choi, "Adsorption and reaction behavior for the simultaneous adsorption of NO–NO_2 and SO_2 on activated carbon im- pregnated with KOH", Carbon 41 (2003) 1881–1888.

[68] Y. Elsayed, M. Seredych, A. Dallas, T.J. Bandosz, "Desulfurization of air at high and low H_2S concentrations", Chemical Engineering Journal 155 (2009) 594–602.

[69] C.C. Huang, C.H. Chen, S.M. Chiu, "Effect of moisture on H_2S adsorption by copper impregnated activated carbon", Journal of Hazardous Materials 136 (2006) 866–873.

[70] M.C. Maciás-Pérez, A. Bueno-López, M.A. Lillo-Ródenas, C. Salinas-Martínez de Lecea, A. Linares-Solano, "SO_2 retention on CaO/activated carbon sorbents. Part I: importance of calcium loading and dispersion", Fuel 86 (2007) 677–683.

[71] A.R. Reed, P.T. William, "Thermal processing of biomass natural fiber wastes by pyrolysis", International Journal Energy Resources 28 (2003) 131–145.

[72] S. Sumathi, S. Bhatia, K.T. Lee, A.R. Mohamed, "Cerium impregnated palm shell activated carbon (Ce/PSAC) sorbent for simultaneous removal of SO_2 and NO- process study", Chemical Engineering Journal 162 (2010) 51–57.

[73] N. Bhadusha, T. Ananthabaskaran, "Adsorptive removal of methylene blue onto $ZnCl_2$ activated carbon from wood apple outer shell: kinetics and equilibrium studies", E-Journal of Chemistry 8 (2011) 1696–1707.

[74] Y. Sudaryanto, S.B. Hartono, W. Irawaty, H. Hindarso, S. Ismadji, "High surface area activated carbon prepared from cassava peel bychemical activation", Bioresource Technology 97 (2006) 734.

[75] Ami Cobb, Mikell Warms,Dr. Edwin P. Maurer, "Low-Tech Coconut Shell Activated Charcoal Production", International Journal for Service Learning in Engineering Vol. 7, No. 1, pp. 93-104, Spring 2012.

[76] Yun Gao, Yi Yang, Zhanbin Qin and Yi Sun, "Factors affecting the yield of bio-oil from the pyrolysis of coconut shell",Springer Plus (2016).

[77] Juan Carlos Moreno-Piraján· Vanessa S. Garcia-Cuello·Liliana Giraldo, "The removal and kinetic study of Mn, Fe, Ni and Cu ions from waste water onto activated carbon from coconut shells", Received: 26 August 2010 , Accepted: 9 December 2010 , Published online: 21 December 2010 ©Springer Science+ Business Media, LLC 2010-Adsorption (2011) 17: 505–514 DOI 10.1007/s10450-010-9311-5.

[78] Juan Rafael García1 & Ulises Sedran & Muhammad Abbas Ahmad Zaini & Zainul Akmar Zakaria, "Preparation,characterization,and dye removal study of activated carbon prepared from palm kernel shell", Environ Sci Pollut Res DOI 10.1007/s11356-017-8975-8 Crossmark_tools, techniques and technologies for pollution prevention, control and resource recovery_Received: 5 January 2017/Accepted: 31 March 2017 # Springer-Verlag Berlin Heidelberg 2017.

[79] Aseel M. Aljeboree, Abbas N. Alshirifi, Ayad F. Alkaim, "Kinetics and equilibrium study for the adsorption of textile dyes on coconut shell activated carbon", King Saud University Arabian Journal of Chemistry Received 29 June 2013; accepted 28 January 2014 Available online 4 February 2014.

[80] Umar Isah A., Giwa Abdulraheem, Salisu Bala, Sallahudeen Muhammad, Mustapha Abdullahi, "Kinetics, equilibrium and thermodynamics studies of C.I. Reactive Blue 19 dye adsorption on coconut shell based activated carbon", Received 15 January 2015 Received in revised form 4 April 2015 Accepted 4 April 2015 Available online xxx

[81] Diana C.S. Azevedo, J. Ca ´ssia S. Arau ´jo, Moise ´s Bastos-Neto, A. Eurico B. Torres, Emerson F. Jaguaribe, Ce ´lio L. Cavalcante, "Microporous activated carbon prepared from coconut shells using chemical activation with zinc chloride".

[82] Osei-Wusu Achaw, George Afrane, "The evolution of the pore structure of coconut shells during the preparation of coconut shell-based activated carbons", Microporous and Mesoporous Materials 112 (2008) 284–290 Received 19 March 2007; received in revised form 16 July 2007; accepted 2 October 2007, Available online 9 October 2007.

[83] Donni Adinata, Wan Mohd Ashri Wan Daud, Mohd Kheireddine Aroua, "Preparation and characterization of activated carbon from palm shell by chemical activation with K2CO3", Bioresource Technology 98 (2007) 145–149 Received 28 June 2005; received in revised form 30 October 2005; accepted 5 November 2005 Available online 27 December 2005.

[84] R.R. Bansode, J.N. Losso, W.E. Marshall, R.M. Rao, R.J. Portier, "Adsorption of volatile organic compounds by pecan shelland almond shell-based granular activated carbons", Bioresource Technology 90 (2003) 175–184 Received 18 October 2002; received in revised form 24 March 2003; accepted 25 March 2003.

[85] R. Azargohar and A. K. Dalai, "Biochar As a Precursor of Activated Carbon", Applied Biochemistry and Biotechnology Vol. 129-132, 2006.

[86] Ramasamy Boopathy & Sekar Karthikeyan & Asit Baran Mandal & Ganesan Sekaran, "Adsorption of ammonium ion by coconut shell-activated carbon from aqueous solution: kinetic, isotherm, and thermodynamic studies", Environ Sci Pollut Res (2013) 20:533–542 DOI 10.1007/s11356-012-0911-3 Received: 21 February 2012 / Accepted: 2 April 2012 / Published online: 5 May 2012 Springer-Verlag 2012

[87] Matteo Caccin, Francesca Giacobbo, Mirko Da Ros, Luigi Besozzi, Mario Mariani, "Adsorption of uranium, cesium and strontium onto coconut shell activated carbon", J Radioanal Nucl Chem (2013) 297:9–18 DOI 10.1007/s10967-012-2305-x Received: 11 October 2012 , Published online: 5 November 2012 Akade´miai Kiado´, Budapest, Hungary 2012.

[88] André L. Cazettaa, Alexandro M.M. Vargasa, Eurica M. Nogamia, Marcos H. Kunitaa, Marcos R. Guilhermea, Alessandro C. Martinsa, Tais L. Silva b, Juliana C.G. Moraesa, Vitor C. Almeidaa, "NaOH-activated carbon of high surface area produced from coconut shell:Kinetics and equilibrium studies from the methylene blue adsorption", Chemical Engineering Journal 174 (2011) 117– 125 Received 5 July 2011 Received in revised form 20 August 2011 Accepted 22 August 2011.

[89] André L. Cazettaa, Osvaldo P. Juniora, Alexandro M.M. Vargasa, Aline P. da Silva b, Xiaoxin Zouc, Tewodros Asefac, Vitor C. Almeidaa, "Thermal regeneration study of high surface area activated carbon obtained from coconut shell: Characterization and application of response surface methodology", Journal of Analytical and Applied Pyrolysis 101 (2013) 53–60 Received 7 December 2012 Received in revised form 23 February 2013 Accepted 23 February 2013 Available online 4 March 2013.

[90] Thio Christine Chandra, Magdalena Maria Mirna, Jaka Sunarso, Yohanes Sudaryanto, Suryadi Ismadji, "Activated carbon from durian shell: Preparation and characterization", Journal of the Taiwan Institute of Chemical Engineers 40 (2009) 457–462 Received 11 August 2008 Received in revised form 13 October 2008 Accepted 13 October 2008.

[91] Yu-Chun Chianga, Pen-Chi Chiangb, Chin-Pao Huangc, "Effects of pore structure and temperature on VOC adsorption on activated carbon", Carbon 39 (2001) 523–534 Received 19 February 2000; accepted 9 June 2000.

[92] B. V,eena Devi, A.A. Jahagirdar, M.N. Zulfiqar Ahmed, “Adsorption of Chromium on Activated Carbon Prepared from Coconut Shell”, International Journal of Engineering Research and Applications (IJERA) ISSN: 2248-9622 www.ijera.com Vol. 2, Issue 5, September- October 2012, pp.364-370.

[93] Norhusna Mohamad Nor, Lau Lee Chung, Lee Keat Teong, Abdul Rahman Mohamed, “Synthesis of activated carbon from lignocellulosic biomass and its applications in air pollution control—a review”, Journal of Environmental Chemical Engineering 1 (2013) 658–666