SYNTHESIS, CHARACTERIZATION AND PERFORMANCE OF ADSORBENTS FOR MERCURY VAPOR REMOVAL

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Dedicated to my parents, family and my husband for their love and support

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ABSTRACT

Mercury pollution is a growing concern due to its toxicity, volatility, and bioaccumulation in the environment. The main and most problematic source of mercury emission comes from the coal-fired power plants and gas processing activities. Hence, mercury needs to be removed and adsorption has been proven to be an excellent method due to easiness of operation and efficiency. In this study, coconut husk such as coconut pith and fiber were used as alternative low-cost adsorbents in exchange to the existing conventional elemental mercury (Hg^o) adsorbents. The potential use of coconut based-adsorbents for elemental mercury removal from gas streams has not yet been fully explored due to lack of research in this regard. This research focused on synthesis and modifications of coconut husk such as surface, carbonization and sulfurization treatments in order to enhance elemental mercury adsorption performance. The adsorbents were characterized using proximate analysis, scanning electron microscope (SEM), Fourier transform infrared (FTIR) spectroscopy, nitrogen adsorption/desorption (NAD), carbon-hydrogen-nitrogen-sulfur (CHNS) analysis and X-ray photoelectron spectroscopy (XPS) measurement. The Hg^o adsorption experiments were conducted using a conventional flow type packed-bed reactor system with nitrogen as carrier gas. The results show that the chemical, physical, morphological and spectral properties of the adsorbents were greatly influenced by the modification methods used. Adsorbents obtained through carbonization and sulfurization treatments produced the best Hg^o adsorption capacity. The experimental data exhibited that the increase of thermal carbonization up to 900 ^oC, resulted in high adsorption capacity of 6067.49 µg/g. The sulfurization at lower temperature (i.e. CPS300) resulted in the highest adsorption capacity (26077.69 µg/g). Enhancement in Hg^o adsorption capacity might due to the higher sulfur compounds on the surface which acts as active site towards elemental mercury. The adsorption data revealed that the adsorbent with larger equilibrium adsorption capacity possessed poor adsorption reaction kinetics and diffusion process. This study also revealed that the char adsorbent could sustain Hg^o adsorption capacity over multiple regeneration cycles. However, sulfurized-char is non-regenerative adsorbent, which can be utilized for longer adsorption process. Finally, the present findings indicate that the coconut husk can be potential low-cost elemental mercury adsorbents by applying appropriate modifications such as carbonization and sulfurization treatments. In addition, the utilization of coconut husks can reduce waste disposal problems and thus improving environmental quality and sustainability.

ABSTRAK

Pencemaran raksa semakin mendapat perhatian disebabkan oleh ketoksidan, kemeruapan, bioakumulasinya dalam alam sekitar. Sumber utama dan paling bermasalah adalah pengeluaran raksa berpunca dari loji kuasa arang batu dan aktiviti-aktiviti pemprosesan gas. Oleh itu, raksa perlu disingkirkan dan penjerapan telah terbukti sebagai proses yang unggul kerana mudah dioperasi dan cekap. Dalam kajian ini, sisa kelapa seperti habuk dan serat sabut kelapa digunakan sebagai alternatif penjerap kos rendah kepada penjerap raksa lazim yang sedia ada. Keupayaan kegunaan penjerap berasaskan kelapa untuk penyingkiran unsur raksa dari aliran gas masih belum diterokai sepenuhnya kerana kekurangan penyelidikan dalam hal ini. Kajian ini tertumpu pada sintesis dan pengubahsuaian sabut kelapa seperti proses rawatan permukaan, pengkarbonan dan pensulfuran bagi meningkatkan prestasi penjerapan unsur raksa. Penjerap dicirikan melalui pengukuran analisis hampiran, mikroskop elektron imbasan (SEM), spektrometer Fourier transformasi inframerah (FTIR), penjerapan/penyahjerapan nitrogen (NAD), analisis karbon-hidrogen-nitrogen-sulfur (CHNS) dan spektroskopi fotoelektron sinar-X (XPS). Ujikaji penjerapan Hg^o telah dijalankan dengan menggunakan aliran lazim reaktor sistem jenis lapisan terpadat dengan nitrogen sebagai gas pembawa. Hasil kajian menunjukkan bahawa ciri kimia, fizikal, morfologi dan spektrum penjerap banyak dipengaruhi oleh kaedah pengubahsuaian yang digunakan. Penjerap diperoleh melalui rawatan pengkarbonan dan pensulfuran menunjukkan keupayaan penjerapan Hg^o yang terbaik. Data ujikaji menunjukkan kenaikan terma pengkarbonan sehingga 900 ^oC menghasilkan keupayaan penjerapan yang tinggi iaitu 6067.49 µg/g. Pensulfuran pada suhu lebih rendah, (misalnya CPS300) menghasilkan keupayaan penjerapan yang paling tinggi (26077.69 µg/g). Peningkatan dalam kapasiti penjerapan Hg^o mungkin disebabkan oleh sebatian sulfur yang tinggi dipermukaan yang bertindak sebagai tapak aktif terhadap raksa. Data penjerapan mendedahkan bahawa penjerap dengan keseimbangan keupayaan penjerapan yang besar memiliki proses penjerapan kinetik dan resapan yang lemah. Kajian ini juga mendedahkan penjerap arang boleh mengekalkan keupayaan jerapan Hg^o sepanjang kitaran penjanaan semula berganda. Walau bagaimanapun, penjerap sulfur-arang adalah penjerap tanpa penjanaan semula, yang boleh digunakan untuk proses penjerapan yang panjang. Akhirnya, penemuan ini menunjukkan bahawa sabut kelapa berkeupayaan sebagai penjerap unsur raksa kos rendah dengan menggunakan pengubahsuaian yang sesuai seperti rawatan pengkarbonan dan pensulfuran. Tambahan pula, penggunaan sabut kelapa boleh mengurangkan masalah pembuangan sisa, sehubungan itu memperbaiki kualiti alam sekitar dan kesinambungannya.

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LIST OF SYMBOLS

Hg	-	Mercury
A	-	Mass of air-dry sample (g)
A_c	-	Constant in the Clark model
A_r	-	Arrhenius factor
α	-	Initial adsorption rate in Elovich equation (ng/mg.min)
α_K	-	Khan isotherm model exponent
α_R	-	Redlich-Peterson isotherm constant (1/mg)
α_s	-	Sips isotherm model constant (L/mg)
α_T	-	Toth isotherm constant (L/mg)
B	-	Mass of sample after drying at 105^{o}C (g)
b_k	-	Khan isotherm model constant
b_T	-	Tempkin isotherm constant
C	-	Mass of sample after drying at 950°C (g).
C_e	-	Equilibrium concentration (mg/L)
C_s	-	Saturation concentration of solute (mg/L)
C_o	-	Concentrations ($\mu g/m^3$) at time t = 0 (min)
C_t	-	Concentrations ($\mu g/m^3$) at time t = t (min)
C_{BP}	-	Bypassed concentration ($\mu g/m^3$)
C_{BET}	-	BET adsorption isotherm relating to the energy of surface interaction (L/mg)
D	-	Mass of the residue (g)
D_{eff}	-	Effective diffusivity (cm^2/s)
D_{ep}	-	Effective pore diffusion coefficient
$(D_e)_{Ma}$	-	Effective diffusion coefficient of macropore region
$(D_e)_{Mi}$	-	Effective diffusion coefficient of micropore region

D_s	-	Surface diffusion coefficient
E_a	-	Action energy of adsorption (kJ/mol)
ε	-	Dubinin-Radushkevich isotherm constant
f	-	Volume fraction of the macropore region
g	-	Redlich-Peterson isotherm exponent
k_o	-	Kinetic rate constant of pseudo-zero order adsorption kinetic (min^{-1})
k_1	-	Kinetic rate constant of pseudo-first order adsorption kinetic (min^{-1})
k_2	-	Kinetic rate constant of pseudo-second order adsorption kinetic (g/µg.min)
k_d	-	Kinetic rate constant (m^2/min)
k_{id}	-	Intraparticle rate constant (mg/g.min)
k_{DR}	-	Dubinin-Radushkevich isotherm constant (mol^2/kJ^2)
k_{TH}	-	Thomas rate constant (dm^3/min.mg)
k_{AB}	-	Mass transfer coefficient (L/mg.min)
k_{YN}	-	Yoon-Nelson rate constant (min^{-1})
K_F	-	Freundlich isotherm constant (mg/g) $(dm^3/g)^n$
K_L	-	Langmuir isotherm constant (L/mg)
K_R	-	Redlich-Peterson isotherm constant (L/g)
K_s	-	Sips isotherm model constant (L/g)
K_T	-	Tempkin isotherm equilibrium binding constant (L/g)
K_{TOTH}	-	Toth isotherm constant (mg/g)
m	-	Mass of the adsorbent (g)
m_c	-	Mass of final char produced (g)
m_o	-	Mass of air-dried precursor (g)
n	-	Characteristic constant related to adsorption intensity or degree of favorability of adsorption (Freundlich)
N	-	Number of observations in the experimental
N_o	-	Saturation concentration (mg/L)
p	-	Number of parameters in the regression model
q	-	Adsorption capacity (µg/g)

q_o	-	Maximum solid-phase concentration of the solute (mg/g)
q_{exp}	-	Calculate adsorption capacity (μg/g)
q_{calc}	-	Measured adsorption capacity (μg/g)
Q	-	Quantity of the mercury adsorbed
q_e	-	Equilibrium adsorption capacity (μg/g)
$q_{e,exp}$	-	Experimental equilibrium adsorption capacity (μg/g)
$q_{e,theory}$	-	Theoretical equilibrium adsorption capacity (μg/g)
q_{Ma}	-	Adsorbed concentration of the macropore zone
q_{Mi}	-	Adsorbed concentration of the micropore zone
q_{max}	-	Saturated monolayer adsorption capacity (μg/g)
q_t	-	Adsorption capacity at time t (μg/g)
q_s	-	Theoretical isotherm saturation capacity (mg/g)
ρ	-	Bed density
r	-	Constant in the Clark model (min^{-1})
r	-	Distance to the centre of pellet (general rate model)
r_c	-	Critical radius
R	-	Universal gas constant (8.314 J/mol.K)
R^2	-	Coefficient of determination
R_b		Branched pore kinetic model rate constant
R_p	-	Particle radius (cm)
t	-	Time (minute or hour or day)
T	-	Temperature (^oC or K)
U_o	-	Superficial velocity (cm/min)
v	-	Wavenumber (cm^{-1})
$\dot{V}$	-	Volumetric flow rate (L/min)
(v/v)	-	Volume per volume
wt. %	-	Weight percentage
z	-	Bed height (cm)
β	-	Desorption constant in Elovich equation (mg/ng)
β_s	-	Sips isotherm model exponent
β_w	-	Kinetic coefficient of the external mass transfer (min^{-1})
τ	-	Time required for 50% adsorbate breakthrough

LIST OF ABBREVIATIONS

AB	-	Adsorbent bed
AC	-	Activated carbon
APCD	-	Air pollution control devices
ARE	-	Average relative error
AWs	-	Agricultural wastes
BDDT	-	Brunauer-Deming-Deminng-Teller
BE	-	Binding energy
BET	-	Brunauer-Emmett-Teller
BJH	-	Barret-Joyner-Halenda
BJH	-	Barret–Joyner–Halender
BP	-	Bypass
CAAA	-	The Clean Air Act Amendment
CCA	-	Char, closed, ambient
CCN	-	Char, closed, purging nitrogen
CF	-	Coconut fiber
CFN	-	Char, flow nitrogen
CHNS	-	Carbon, Hydrogen, Nitrogen, Sulfur
CP	-	Coconut pith
D-R	-	Dubinin-Radushkevich
EPA	-	Environmental Protection Agency
ESP	-	Electrostatic precipitators
ETD	-	Everhart-Thornley Detector
FC	-	Fixed carbon
FF	-	Fabric filters

FGD	-	Flue gas desulfurization
FPD	-	Flame photometric detector
FTIR	-	Fourier Transform Infrared Spectroscopy
LFD	-	Large Field Detector
M	-	Moisture
MF	-	Mercury feed
MPSD	-	Marquardt's percent standard deviation
NAD	-	Nitrogen Adsorption/Desorption
NS	-	Nitrogen stream
ppb	-	Parts-per-billion
ppm	-	Parts-per-million
SEM	-	Scanning Electron Microscopy
TCD	-	Thermal conductivity detector
VM	-	Volatile matter
WD	-	Working distance
WHO	-	World Health Organization
XPS	-	X-ray photoelectron spectroscopy

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CHAPTER 1

INTRODUCTION

1.1 Research Background

Mercury is one of the most toxic heavy metals which could contaminate the environment and accumulate in animals and plants (Wang *et al.*, 2009). It is transported in the environment by air and water, as well as by biological organisms through the food-chains. The exposure to high levels of mercury can permanently damage the central nerve system, the brain and kidneys (Merrifield *et al.,* 2004). Mercury may exist in three different forms namely metallic mercury (e.g. Hg^o), inorganic mercury compounds (e.g. $HgCl_2$), and organic mercury compounds (e.g. $MeHg^+$) (Pirrone *et al.*, 2010).

Mercury enters the environment by natural processes (e.g. volcanic eruptions, and geothermic activities) and anthropogenic (e.g. coal-fired power plants, metal mining and refining, cement plant, municipal incinerators and wellhead natural gas processing) sources. It is well known that the coal fired power plants are the largest single source in most countries with high mercury emissions which release more than 50 tons of mercury annually (US EPA, 2014). At high temperature in the combustion zone of the boiler, the elemental mercury was released, and oxidized to Hg^{2+} (Wilcox *et al.*, 2012). The Hg^{2+} was tendency to form particulate bound mercury (Hg_p) which has been reported to be efficiently captured by air pollution control devices (APCD), such as electrostatic precipitators (ESP), fabric filters (FF) and flue gas desulfurization (FGD) (Wang *et al.*, 2010; Wilcox *et al.*, 2012). However, it is still difficult to directly remove Hg^o from flue gas with these APCDs due to its high volatility and insolubility in water (Padak *et al.*, 2006). The downstream of APCD (stack flue gas) contains major mercury species of Hg^o and low concentrations of NOx and SO_2. The removal of mercury is generally performed by using fixed-bed adsorber system under low dust and low temperature process conditions (≈ 50 to 100 ^oC).

Mercury also presents in natural gas which can cause catastrophic failures of aluminium heat exchangers in gas processing plants (Abu El Ela *et al.*, 2008; Abu El Ela *et al.*, 2008a). It was reported that the mercury concentration in natural gas is between 1 and 200 ng/L (Shafawi *et al.*, 1999) which are sufficiently high to cause both safety and health concerns. The natural gas processing typically consists of fixed-bed adsorbents to remove elemental mercury carried out, for instance, at temperature of 16 - 60^oC (El Ela *et al.,* 2008; Eckersley, 2010).

Several techniques have been developed in which adsorption is one of the most effective approaches to remove elemental mercury from gas streams. The solid materials such as activated carbon (Karatza *et al.*, 2013; Ie *et al.*, 2013), silica-based materials (Saman *et al.*, 2015; Johari *et al.*, 2014; Meyer *et al.*, 2007), fly ash (Gao *et al.*, 2013; Xu *et al.*, 2013; Xu *et al.*, 2012) and zeolites (Fan *et al.*, 2012; Chen *et al.*, 2010) have been proved as successful adsorbents for Hg^o removal by many researchers. However, some limitations towards their applications include their complex preparations, high cost and non-renewable sources. Attempts towards the new precursors such as agricultural residues which are cheaper have recently been explored (Sun *et al.*, 2013).

Agricultural wastes (AWs) have been gaining increasing attention during recent years as new precursors for production of low-cost adsorbents (Chowdury *et al.*, 2011; Johari *et al.*, 2013; Johari *et al.*, 2014; Johari *et al.*, 2015; Lim and Aris, 2013; Song *et al.*, 2013). These agricultural wastes are naturally and abundantly available, in which could obtain for free or at a minimal cost. In addition, the AWs would be attractive for conversion to high added-value product such as adsorbents due to their simple and low-cost preparation process. In addition, their proper utilization may improve the environmental quality and sustainability. The common

AWs such as oil palm (*Elaeis guineensis*), rice (*Oryza sativa L.)* and coconut (*Cocos nucifera L.*) residues have been reported to have a high adsorption capacity of heavy metals from water and wastewaters (Bhatnagar *et al.,* 2010; Ahmad *et al.*, 2011; Chowdhury *et al.,* 2011; Johari *et al.*, 2013; Johari *et al.*, 2014; Lim and Aris, 2013; Song *et al.*, 2013).

Coconut (*Cocos nuciferas L.*) is one of the most widely planted tree species in tropical region such as Brazil, India, Philippines, Malaysia and Indonesia. It is known for its great versatility of its parts such as coconut shell, fibers, and pith for commercial and industrial uses. A large amount of coconut processing wastes is also generated and becoming an environmental problems. So far, the coconut wastes have been used for fertilizer, building materials and automotive components (Sulaiman *et al.*, 2010; da Costa Castro *et al.*, 2012; Ucol-Ganiron JR, 2013) or left to decompose on the fields. Thus, the development of high value added product from coconut wastes is essential to solve their disposal problems. Besides, it helps in improving the environment quality and sustainability. In recent years, the use of coconut wastes has been extensively studied in adsorbent preparation for specific applications (Johari *et al.*, 2013; Johari *et al.*, 2014; Anirudhan *et al.*, 2008). For instances, the coconut wastes were reported on the production of carbonaceous adsorbents for the removal of mercury (Johari *et al.*, 2015), dye (Foo and Hameed, 2012; Kavitha and Namasivayam, 2007; Phan *et al.*, 2006), arsenic (Manju *et al.*, 1998), copper (Namasivayam and Kadirvelu, 1997), and chromium (Shen *et al.*, 2012) from water and wastewater. However, there is no research on coconut pith except for coconut shell as elemental mercury adsorbents (Matsumura 1974; Hu *et al.*, 2009).

1.2 Problem Background

Recently, the potential risk of toxic elements emitted from anthropogenic sources has become a public concern. Like other elements, mercury is persistent, cannot be destroyed by combustion or bacterial degradation and eliminated from environment. A great attention has been focused on mercury due to the increasing level of bioaccumulation in the environment and food-chain which can cause potential risk for human health (Jack, 2010). Among the existing mercury removal systems, adsorption process is attractive for coal combustors and hazardous/municipal waste incinerators for treatment of mercury from both gas and liquid streams.

Several adsorbents have been commercialized for heavy metal removal processes (Sag and Kutsal, 2001; Dias *et al.,* 2007; Shareef, 2009; Park *et al.,* 2010). The carbonaceous adsorbents such as activated carbon has proven in their ability as adsorbents in aqueous and gas phase treatments due to their excellent thermal stability and non-specific adsorption characteristics (Dias *et al.,* 2007). The uses of carbonaceous adsorbents are limited by their non-renewable source of coal and high cost (Granite *et al.,* 2007). In addition, the preparation of carbonaceous adsorbents is complex, the cost is high and the specific surface area is small, limiting on their application. Moreover, they are not easily functionalized with mercury functional groups because of their surfaces are non-polar in nature.

Manchester *et al.* (2008) reported that the sulfur impregnated carbons have high adsorption capacities towards elemental mercury. However, it is too costly and the adsorption kinetics was observed too slow for some important applications. The low-cost methods namely oxidation process have been used for modifying carbon surface using reagents that include molecular oxygen, ozone, hydrogen peroxide, nitric acid, and permanganate. Despite of activated carbon prolific use in adsorption process, the biggest barrier of its application in industries is its high cost and difficulties associated with regeneration (Foo and Hameed, 2009). In order to reduce the adsorbent cost and thus the cost of treatment, the use of low-cost adsorbent precursors such as agricultural wastes namely coconut pith, orange peel, sawdust, rice husk, and baggase pith (Sag and Kutsal, 2001; Dias *et al.,* 2007; Shareef, 2009; Park *et al.,* 2010) have gained considerable researches recently. The agriculture wastes have been widely studied for removal of heavy metals from aqueous solutions. In addition, the processing and transformation of these wastes into charcoal or activated carbon would solve their disposal problems.

Since the last two decades, the development of low-cost adsorbents using lignocellulosic agricultural wastes has gained consideration among research communities. The agricultural wastes would be attractive as precursors for development of adsorbents due to their being abundant and cheap, simple and low-cost preparation process, possessing no waste disposal problems, and contributing to the sustainability of the surrounding environment (Johari et al. 2013; Rahman and Khan, 2007). It was previously proven by several literatures on the potential use of coconut wastes (e.g. desiccated, pith, fiber and shell) as potential low-cost adsorbents (Johari et al. 2013; Sharma et al. 2013; Johari et al. 2014b; Tan et al. 2008; Namasivayam and Sangeetha, 2004; Parab and Sudersanan, 2010; Igwe et al. 2008) from aqueous phase. To my knowledge, the use of coconut waste especially coconut husk as adsorbents for the elemental mercury (Hg^o) removal is still limited, even though it is in abundance and low-cost. Furthermore, the facile treatments of the coconut husk (pith and fiber) for elemental mercury adsorbents has not been thoroughly reported. Thus, with proper treatements via mercerization, bleaching, carbonization and sulfurization can be very promising adsorbents for Hg^o removal process from gas streams. This study ultimately demonstrated the potential application of coconut husk (fiber and coconut pith) as precursors for elemental mercury adsorbent synthesis since they are expected to be good and relatively inexpensive adsorbent precursors and thus cheaper than the existing adsorbents.

1.3 Objectives

Based on the research background and the problem statement identified, the objectives of this study are as follows:

i. To synthesize and characterize the coconut husk as an elemental mercury adsorbents

ii. To investigate the elemental mercury adsorption process of coconut-based adsorbents

iii. To study the elemental mercury adsorption performances of selected adsorbent.

1.4 Scopes of the Studies

In this study, the coconut husk such as coconut pith (CP) and coconut fiber (CF) was selected as precursor for elemental mercury (Hg^o) adsorbent. The synthesis was carried out by mercerization, bleaching, carbonization and sulfurization treatments. The carbonization treatment was done in different environment conditions, meanwhile the sulfurization was conducted at various temperatures and sulfur ratios. The pristine and treated coconut husk adsorbents obtained were characterized by proximate analysis (moisture, volatile matter, and ash content), scanning electron microscopy (SEM), nitrogen adsorption/desorption (NAD), X-ray photoelectron spectroscopy (XPS) analysis, Fourier transform infrared (FTIR), and CHNS elemental analysis.

The adsorption capability of the coconut husk adsorbents was measured using fabricated Hg^o adsorption rig at fixed experimental conditions ([Hg^o] = 200±20 $\mu g/m^3$, bed temperature = 50^{o}C, nitrogen flow rate = 50 mL/min, mass of adsorbent = 50mg). The Hg^o adsorption experimental data were analyzed using the existing isotherm (i.e. Langmuir, Freundlich, and Temkin) and kinetic (i.e. pseudo-zero order, pseudo-first order, pseudo-second order, Elovich and Fick's intraparticle diffusion) models. These adsorption model analyses were carried out towards understanding the mechanism of the Hg^o adsorption process.

The adsorbent with highest adsorption capacity was selected for further Hg^o adsorption performances. Several experimental conditions such as initial mercury concentrations (i.e 100 - 500 $\mu g/m^3$) and adsorbent bed temperatures (i.e. 50 – 200^{o}C) were performed. In addition, the adsorption and desorption were also studied via thermal desorption method in order to evaluate the regenerability of the adsorbents and thus the mechanism of desorption process.

1.5 Thesis Outline

Chapter 1 presents the general introduction of the elemental mercury adsorption problems and the utilization of agricultural wastes as high value added products. The problem backgrounds of the study are reviewed in Section 1.2, which contain on the effect of elemental mercury emission to the environment and the limitations of the existing adsorbents. The objective and scopes of this study are presented in Sections 1.3 and 1.4. Chapter 2 deals with critical review of mercury in the environment, development of numerous agricultural wastes as mercury adsorbents and theory of adsorption process. In Sections 2.1 and 2.2, the mercury overviews include the mercury toxicity and the adsorbent development for elemental mercury removal process. The review in Section 2.3 is intended to provide the evident those agricultural wastes (i.e. coconut husk), which is inexpensive and abundantly available, could be the potential adsorbents for the heavy metals removal. A mathematical model is presented in Section 2.5 including adsorption isotherm, kinetic and packed-bed column performances in term of engineering aspects of adsorption process.

Chapter 3 discusses about the research methodology, which comprises of research materials and experimental procedures for synthesis, characterization, and Hg^o adsorption and desorption measurements. The selection of precursors and methods of synthesis are justified. The experiment conducted using lab-scale mercury adsorption rig in order to collect the experimental data. Chapter 4 presents the results and discussions of adsorbent synthesis and characterizations, evaluation of Hg^o adsorption process onto the adsorbents and Hg^o adsorption performances of the selected adsorbents. In Section 4.2, the findings based on the adsorbent preparation using coconut husk as precursor and adsorbent characterizations are discussed. In addition, the experimental data obtained from Hg^o adsorption is used to analyze the validity of adsorption models and the assumptions made describing the mechanism of the adsorbent towards adsorption process. Chapter 5 is a summary of the research findings on the elemental mercury removal by coconut-based adsorbents and recommendations for extending in the future work. This is followed by list of references cited in the thesis.

REFERENCES

Abe, M., Kawashima, K., Kozawa, K., Sakai, H., and Kaneko, K. (2000). Amination of AC and Adsorption Characteristics of Its Aminated Surface. *Langmuir*. 16: 5059–5063.

Abu El Ela, M., Mahgoub, I. S., Nabawi, M. H., and Ahmed, M. A. A. (2008a). Mercury Monitoring and Removal at Gas-Processing Facilities: Case Study of Salam Gas Plant. Society of Petroleum Engineers. DOI:10.2118/106900-PA.

Abu El Ela, M., Nabawi, M. H., and Ahmed, M. A. A. (2008). Behavior of the Mercury Removal Absorbents at Egyptian Gas Plant. Society of Petroleum Engineers, DOI: http://dx.doi.org/10.2118/114521-MS.

ACAP. (2004). Artic Council Action Plan to Eliminate Pollution of the Arctic. Assessment of Mercury Releases from the Russian Federation: Reduction of Atmospheric Mercury Releases from Arctic States. Russian Federal Service for Environmental, Technological and Atomic Supervision Danish Environmental Protection Agency, COWI A/S.

Afrane, G. and Achaw, O.W. (2008). Short communication: Effect of the Concentration Of Inherent Mineral Elements On The Adsorption Capacity Of Coconut Shell-Based Activated Carbon. *Bioresource Technology.* 99: 6678-6682.

Ahmad, M., Lee, S. S., Dou, X., Mohan, D., Sung, J. K., Yang, J. E., and Ok, Y. S. (2012). Effects of Pyrolysis Temperature on Soybean Stover- And Peanut Shell-Derived Biochar Properties and TCE Adsorption in Water. *Bioresource Technology*. 118: 536-544.

Ahmad, T., Rafatullah, M., Ghazali, A., Sulaiman, O., and Hashim, R. (2011). Oil Palm Biomass-Based Adsorbents for the Removal of Water Pollutants: A Review. *Journal Environmental Science Health C Environmental Carcinogenesis & Ecotoxicology Reviews.* 29(3): 177-222.

Amuda, O. S., Giwa, A. A., and Bello, I. A. (2007). Removal of Heavy Metal From Industrial Wastewater Using Modified Activated Coconut Shell Carbon. *Biochemical Engineering Journal*. 36: 174-181.

Anirudhan, T. S., Divya, L., and Ramachandran, M. (2008). Mercury (II) Removal From Aqueous Solutions And Wastewaters Using A Novel Cation Exchanger Derived From Coconut Coir Pith And Its Recovery. *Journal of Hazardous Material.* 157: 620-627.

Anirudhan, T. S., Divya, L., and Suchithra, P. S. (2009). Kinetic and Equilibrium Characterization Of Uranium (VI) Adsorption Onto Carboxylate-Functionalized Poly(Hydroxyethylmethacrylate)-Grafted Lignocellulosics. *Journal of Environmental Management*. 90: 549-560.

Anirudhan, T. S., Rijith, S., and Suchithra, P. (2010), Preparation and Characterization Of Iron (III) Complex Of An Amino-Functionalized Polyacrylamide-Grafted Lignocellulosics And Its Application As Adsorbent For Chromium (VI) Removal From Aqueous Media. *Journal of Applied Polymer Science*. 115(4): 2069–2083.

Asasian, N. and Kaghazchi, T. (2013). Optimization of Activated Carbon Sulfurization to Reach Adsorbent with the Highest Capacity for Mercury Adsorption, *Separation Science and Technology*. 48: 2059-2072.

Asasutjarit, C., Hirunlabh, J., Khedari, J., Charoenvai, S., Zeghmati, B., and Cheul Shin, U. (2007). Development of Coconut Coir-Based Lightweight Cement Board. *Construction and Building Materials*. 21: 177-288.

Assari, M. J., Rezae, A., Jafari, A. J., and Bahrami, A. (2013). Optimization of a Novel Setup For An On-Line Study Of Elemental Mercury Adsorption By Cold-Vapor Atomic Absorption Spectrometry, *Journal of Research in Health Sciences*, 13(1): 37-42.

ASTM International (2007). *ASTM E1762-84.* Standard test method for chemical analysis of wood charcoal. West Conshohocken, PA.

ASTM International (2008). *ASTM E1755-01.* Standard test method for determination of total solids in biomass. West Conshohocken, PA.

ASTM International (2008). *ASTM E1756-08.* Standard test method for ash in biomass[1]. West Conshohocken, PA.

Baek, J. I., Yoon, J. H., Lee, S. H., and Ryu, C. K. (2007). Removal of Vapor-Phase Elemental Mercury by Oil-Fired Fly Ashes. Industrial & Engineering Chemistry Research. 46: 1390-1395.

Bailey, S. E., Olin, T. J., Bricka, R. M., and Adrian, D. D. (1999). A Review of Potentially Low-Cost Sorbents for Heavy Metals, *Water Research*. 33(11): 2469-2479.

Baltrus, J. P., Granite, E. J., Pennline, H. W., Stanko, D., Hamilton, H., Rowsell, L., Poulston, S., Smith, A., and Chu, W. (2010). Surface Characterization Of Palladium-Alumina Sorbents For High Temperature Capture Of Mercury And Arsenic From Fuel Gas. *Fuel*. 89: 1323-1325.

Basha, S., Murthy, Z.V.P., and Jha, B. (2008). Sorption of Hg(II) from Aqueous Solutions Onto *Carica Papaya*: Application Of Isotherms. *Industrial & Engineering Chemistry Research.* 47: 980-986.

Bergan, T. and Rodhe, H. (2001). Oxidation of Elemental Mercury in the Atmosphere; Constraints Imposed By Global Scale Modeling. *Journal of Atmospheric Chemistry.* 40(2): 191-212.

Bhatnagar, A., Vilar, V. J. P., Botelho, C. M. S., and Boaventura, R. A. R. (2010). Coconut-Based Biosorbents for Water Treatment–A Review of the Recent Literature, *Advances in Colloid and Interface Science*. 160 (1-2): 1-15.

Bilba, K., Arsene M. A., and Ouensanga, A. (2007). Study of Banana and Coconut Fibers Botanical Composition, Thermal Degradation and Textural Observations. *Bioresource Technology.* 98: 58-68.

Bismarck, A., Mohanty, A. K., Aranberri-Askargorta, I., Czapla, S., Hinrichsen, G., and Springer, J. (2001). Surface Characterization of Natural Fibers, Surface Properties and the Water Up-Take Behavior of Modified Sisal and Coir Fibers. *Green Chemistry.* 3: 100-107.

Boutsika, L. G., Karapanagioti, H. K., and Manariotis I. D. (2013). Aqueous Mercury Sorption by Biochar from Malt Spent Rootlets. Water, Air, & Soil Pollution. 225: 1805-1815.

Brigida, A. I. S., Calado, V. M. A., Gonçalves, L. R. B., and Coelho, M. A. Z. (2010). Effect of Chemical Treatments on Properties of Green Coconut Fiber. Carbohydrate Polymers. 79(4): 832-838.

Brodeur, G., Yau, E., Badal, K., Collier, J., Ramachandran, K. B., and Ramakrishnan, S. (2011). Chemical and Physicochemical Pretreatment of Lignocellulosic Biomass: A Review. *Enzyme Research*. 2011: 1-17.

Buitrago, P. A., Morrill, M., Lighty, J. S., and Silcox, G. D. (2009). Modelling and Experimental Studies of Mercury Oxidation and Adsorption in a Fixed-Bed Reactor: Topical Report. University of Utah, East Salt Lake City, Utah.

Cagnon, B., Py, X., Guillot, A., Stoeckli, F., and Chambat, G. (2009). Contributions of Hemicellulose, Cellulose and Lignin to the Mass and the Porous Properties of Chars and Steam Activated Carbons from Various Lignocellulosic Precursors. *Bioresource Technology.* 100, 292-298.

Cagnon, B., Py, X., Guillot, A., Stoeckli, F., and Chambat, G. (2003). The Effect of the Carbonization/Activation Procedure on the Microporous Tecture of the Subsequent Chars and Active Carbons. *Microporous Mesoporous Materials.* 57: 273-282.

Cai, J., Shen, B., Li, Z., Chen, J., and He, C. (2014). Removal of Elemental Mercury By Clays Impregnated With KI and KBr. *Chemical Engineering Journal.* 241: 19-27.

Çalışkana, E., Bermúdezc, J. M., Parrac, J. B., Menéndezc, J. A., Mahramanlıoğlud, M., and Ania, C. O. (2012). Low Temperature Regeneration of Activated Carbons Using Microwaves: Revising Conventional Wisdom. *Journal of Environmental Management.* 102: 2012, 134–140.

Cantrell, K. B., Hunt, P. G., Uchimiya, M., Novak, J. M., and Ro, K. S. (2012). Impact of Pyrolysis Temperature and Manure Source on Physicochemical Characteristics of Biochar. *Bioresource Technology*. 107: 419-428.

Cathum, S., Velicogna, D., Obenauf, A., Dumouchel, A., Punt, M., Brown, C.E., and Ridal, J. (2005). Detoxification of Mercury in the Environment. *Analytical and Bioanalytical Chem*istry. 38: 1491-1498.

Cazetta, A. L., Vargas A. M. M., Nogami, E. M., Kunita, M. H., Guilherme, M. R., Martins, A. C., and Silva, T. L. (2011). NaOH-Activated Carbon Of High Surface Area Produced From Coconut Shell: Kinetics And Equilibrium Studies From The Methylene Blue Adsorption. *Chemical Engineering Journal.* 174: 117-125.

Chang, R. and Offen, G. (1995). Mercury Emission Control Technologies: An EPRI Synopsis. *Power Engineering.* 99(11): 51–57.

Chauhan, D. and Sankararamakrishnan, N. (2011). Modeling and Evaluation on Removal of Hexavalent Chromium from Aqueous Systems Using Fixed Bed Column. *Journal of Hazardous Materials.* 185(1): 55-62.

Chen, L., Li, C. T., Gao, Z., Fan, X. P., Peng, D. L., and Cui, H.F. (2010). Experimental Study of Removing Elemental Mercury from Flue Gas by MnOx/HZSM-5, *China Enviromental Science*. 30(8): 1026-1031.

Chen, W. C., Lin, H. Y., Yuan, C. S., and Hung, C. H. (2009). Kinetic Modeling on the Adsorption of Vapor-Phase Mercury Chloride on Activated Carbon by Thermogravimetric Analysis. *Journal of the Air & Waste Management Association*. 59(2): 227-235.

Chen, Y. Q., Yang, H. P., Wang, X. H., Zhang, S. H., and Chen, H. P. (2012). Biomass-Based Pyrolytic Polygeneration System on Cotton Stalk Pyrolysis: Influence of Temperature. *Bioresource Technology*. 107: 411-418.

Chen, Y., Zhou, L. J., Hong, Y. Z., Cao, F., Li, L., and Li, J. B. (2010). Preparation of High-Surface-Area Activated Carbon from Coconut Shell Fibers. *Carbon*. 25(2), 151-155.

Chen, Y., Zhu, Y., Wang, Z., Li, Y., Wang, L., Ding, L., Gao, X., Ma, Y., and Guo, Y. (2011). Application Studies Of Activated Carbon Derived From Rice Husks Produced By Chemical-Thermal Process-A Review. *Advances in Colloid and Interface Science*. 163: 39-52.

Chowdhury, S., Mishra, R., Saha, P., and Kushwaha, P. (2011). Adsorption Thermodynamics, Kinetics and Isoteric Heat of Adsorption of Malachite Green onto Chemically Modified Rice Husk. *Desalination*. 265: 159-168.

Chowdhury, Z. Z., Abd Hamis, S. B., Das, R., Hasan, M. R., Mohd Zain, S., Khalid, K., and Uddin, M. N. (2013). Preparation of Carbonaceous Adsorbents from Lignocellulosic Biomass and Their Usein Removal of Contaminants from Aqueous Solution. *BioResources.* 8(4): 6523-6555.

Chung, S. T., Kima, K. I., and Yunb, Y. R. (2009). Adsorption of Elemental Mercury Vapor by Impregnated Activated Carbon from a Commercial Respirator Cartridge. *Powder Technolology.* 192(1): 47-53.

Coade, R. and Coldham, D. (2006). The Interaction of Mercury and Aluminium in Heat Exchangers in Natural Gas Plants. *International Journal of Pressure Vessels and Piping*. 83: 336–342.

Coolidge, A. S. (1927). The Adsorption of Mercury Vapor by Charcoal. *Contribution from the Chemical Laboratory of Harvard University*. 49: 1949-1952.

Couling, D. J., Nguyen, H. V., and Green, W. H. (2012). Screening of Metal Oxides and Metal Sulfides as Sorbents for Elemental Mercury at Elevated Temperature. *Fuel*. 97: 783-795.

Couper, J. R., Penney, W.R., and Fair, J. R. *Chemical Process Equipment. Selection and Design*. Third Edition. Butterworth Heinemann: IChemE. 2012.

Crini, G. and Badot, P. M. (2008). Application of Chitosan, A Natural Aminopolysaccharide, For Dye Removal From Aqueous Solutions By Adsorption Processes Using Batch Studies: A Review Of Recent Literature. *Progress Polymer Science.* 33: 399-447.

Crittenden, B. and Thomas, W. J. *Adsorption Technology and Design*. London, England. Elsevier Science & Technology Books. 1998.

da Costa Castro, C. D. P. Faria, J. A.F., and Dantas T. B.H. (2012). Testing the Use of Coconut Fiber as a Cushioning Material for Transport Packaging. *Materials Sciences and Applications.* 3(3): 151-156.

Dan, T.K. (1993). Development of Lightweight Building Bricks Using Coconut Pith, *Indian Coconut Journal.* 23(11): 12-19.

Das, S. K., Das, A. R., and Guha, A. K. A. (2007). Study on the Adsorption Mechanism of Mercury on Aspergillus Versicolor Biomass. *Environmental Science & Technology*. 4: 8281–8287.

De Rosa, I. M., Kenny, J. M., Maniruzzaman, M., Moniruzzaman, M., Monti, M., Puglia, D., Santulli, C., and Sarasini, F. (2011). Effect of Chemical Treatments on the Mechanical and Thermal Behaviour of Okra (Abelmoschus Esculentus) fibres. *Composites Science and Technology*. 71: 246-254.

de Sousa, D. A., de Oliveira, E., da Costa Nogueira, M., and Espósito, B. P. (2010). Development of a Heavy Metal Sorption System Through the P=S Functionalization Of Coconut (Cocos Nucifera) Fibers. *Bioresource Technology*. 101: 138–143.

De, M., Azargohar, R., Dalai, A. K., and Shewchuk, S. R. (2013). Mercury Removal By Biochar Based Modified Activated Carbons. *Fuel*. 103: 570-578.

Demirbas, A. (2004). Effects of Temperature and Particle Size on Bio-Char Yield from Pyrolysis of Agricultural Residues. *Journal of Analytical and Applied Pyrolysis.* 72(2): 243-248.

Demirbas, A. (2008). Heavy Metal Adsorption onto Agro-Based Waste Materials: A Review. *Journal of Hazardous Materials*. 157(2-3): 220-229.

Deng, S. Sorbent Technology. In: Lee, S. (Ed.), *Encyclopedia of Chemical Processing*, New York: Taylor & Francis Group. 2825-2845; 2006.

Di Balsi, C. (2009). Combustion and Gasification Rates of Lignocellulosic Chars. *Progress in Energy and Combustion Science*. 35: 121-140.

Dias, J. M., Alvim-Ferraz, M. C. M., Almeida, M. F., Rivera-Utrilla, J., and Sanchez-Polo, M. (2007). Waste Materials For Activated Carbon Preparation And Its Use In Aqueous-Phase Treatment: A review. *Journal of Environmental Management*. 88: 833-846.

Diaz-Somoano, M., Unterberger, S., and Hein, K. R. G. (2007). Mercury Emission Control in Coal-Fired Plants: The Role of Wet Scrubbers. *Fuel Processing Technology.* 88: 259-263.

Ding, F., Zhao, Y., Mi, L., Li, H., Li, Y., and Zhang, J. (2012). Removal of Gas-Phase Elemental Mercury In Flue Gas By Inorganic Chemically Promoted Natural Mineral Sorbents. *Industrial & Engineering Chemistry Research*. 51: 3039-3047.

Dombrowski, K. D., Machalek, T., Richardson, C. F., Chang, R., and Rostam-Abadi, M. Recent Developments in EPRI's novel mercury sorbent development program. combined Power Plant Air Pollutant Control Mega Symposium, Washington, DC, 19–22 May 2003.

Dong, J., Xu, Z., and Kuznicki, S. M. (2009). Mercury Removal From Flue Gases By Novel Regenerable Magnetic Nanocomposite Sorbents. *Environmental Science & Technology*. 43: 3266-3271.

Eckersley, N. (2010). Advanced Mercury Removal Technologies. *Hydrocarbons Technology*. 29–35.

Eswaran, S. and Stenger, H. G. (2007). Gas-Phase Mercury Adsorption Rate Studies, *Energy Fuels*. 21: 852-857.

European Commission, (2010). Requirements for Facilities and Acceptance Criteria for the Disposal of Metallic Mercury. Citing internet sources URL: http://ec.europa.eu/environment/chemicals/mercury/pdf/ bipro_study20100416.pdf.

Ewecharoen, A., Thiravetyan, P., and Nakbanpote, W. (2008). Comparison of Nickel Adsorption From Electroplating Rinse Water By Coir Pith And Modified Coir Pith. *Chemical Engineering Journal.* 137: 181-188.

Fan, X., Dickey, E. C., Pennycook, S. J., and Sunkara, M. K. (1999). Z-Contrast Imaging And Electron Energy-Loss Spectroscopy Analysis Of Chromium-Doped Diamond-Like Carbon Films. *Applied Physics Letters*. 75: 2740-2742.

Fan, X., Li, C., Zeng, G., Zhang, X., Tao, S., Lu, P., Tan, Y., and Luo, D. (2012). Hg^o Removal from Simulated Flue Gas Over CeO_2/HZSM-5. *Energy Fuels*. 26: 2082-2089.

Fang, S. C. (1978). Sorption and Transformation of Mercury Vapor By Dry Soil, *Environmental Science & Technology*. 12(3): 285-288.

Febrianto, J., Kokasih, A. N., Sunarso, J., Ju, Y. H., Indraswati, N., and Ismadji, S. (2009). Equilibrium and Kinetic Studies in Adsorption of Heavy Metals Using Biosorbent: A Summary of Recent Studies. *Journal of Hazardous Materials.* 162: 616-645.

Feng, W., Borguet, E., and Vidic, R. D. (2006). Sulfurization of Carbon Surface for Vapor Phase Mercury Removal – I: Effect of Temperature and Sulfurization Protocol. *Carbon*. 44: 2990-2997.

Feng, W., Borguet, E., and Vidic, R.D. (2006a), Sulfurization of Carbon Surface for Vapor Phase Mercury Removal – II: Sulfur Forms and Mercury Uptake. *Carbon*. 44(14): 2998-3004.

Foo, K. Y. and Hameed, B. H. (2009). Recent Developments in the Preparation and Regeneration of Activated Carbons by Microwaves. *Advances in Colloid and Interface Science.* 149: 19–27.

Foo, K. Y. and Hameed, B. H. (2012). Coconut Husk Derived Activated Carbon via Microwave Induced Activation: Effects of Activation Agents, Preparation Parameters and Adsorption Performance. *Chemical Engineering Journal*. 184(1): 57-65.

Foo, K. Y. and Hammed, B. H. (2010). Insights into the Modeling of Adsorption Isotherm Systems, *Chemical Engineering Journal.* 156: 2–10.

Fuente-Cuesta, A., Diaz-Somoano, M., Lopez-Anton, M. A., Cieplik, M., Fierro, J. L. G., and Martinez-Tarazona, M. R. (2012). Biomass Gasification Chars For Mercury Capture From A Simulated Flue Gas Of Coal Combustion. *Journal of Environmental Management.* 98: 23-28.

Funke, A. and Ziegler, F. (2010). Hydrothermal Carbonization of Biomass: A Summary and Discussion of Chemical Mechanisms for Process Engineering. *Biofuels, Bioproducts and Biorefining*. 4(2): 160–177.

Gao, Y., Zhang, Z., Wu, J., Duan, L., Umar, A., Sun, L., Guo, Z., and Wang, Q. (2013). A critical review on the heterogenous catalytic oxidation of elemental mercury in flue gases. *Environmental Science & Technology*. 47: 10813-10823.

Gaspard, S., Passé-Coutrin, N., Durimel, A., Cesaire T., and Jeanne-Rose V. Chapter 2: Activated carbon from biomass for water treatment. In *Biomass for Sustainable Application: Pollution Remediation and Energy*. Royal Society of Chemistry. 46-105; 2014.

Geethammaa, V. G., Mathew, K. T., Lakshminarayanan, R., and Thomas, S. (1998). Composite of Short Fibres and Natural Rubber: Effect of Chemical Modification, Loading and Orientation of Fibre. *Polymer.* 39(6-7): 1483-1491.

Goel, J., Kadirvelu, K., Rajagopal, C., and Garg, V. K. (2005). Investigation of Adsorption of Lead, Mercury and Nickel from Aqueous Solutions onto Carbon Aerogel. *Journal of Chemical Technology and Biotechnology.* 80: 469–476.

Goel, J., Kadirvelu, K., Rajagopal, C., and Garg, V.K. (2005a). Removal of Lead (II) by Adsorption Using Treated Granular Activated Carbon: Batch And Column Studies. *Journal of Hazardous Materials*. B125: 211-220.

Gonzalez, M. H., Araujo, G. C. L., Pelizaro, C. B., Menezes, E. A., Lemos, S. G., de Sousa, G. B., and Nogueira, A. R. A. (2008). Coconut Coir As Biosorbent For Cr(VI) Removal From Laboratory Wastewater. *Journal of Hazardous Materials.* 159(2-3): 252-256.

Goodarzi, F. and Hower, J. C. (2008). Classification of Carbon in Canadian Fly Ashes and Their Implications in the Capture of Mercury. *Fuel*. 87(10-11): 1949-1957.

Goshadraou, A. and Moheb, A. (2011). Continuous fixed bed adsorption of *C.I. Acid Blue 92* by exfoliated graphite: An experimental and modeling study. *Desalination*. 269: 170-176.

Granite, E. J., Freeman, M. C., Hargis, R. A., O'Dowd, W. J., and Pennline, H. W. (2007). The Thief Process for Mercury Removal from Flue Gas. *Journal of Environmental Management.* 84: 628-634.

Granite, E. J., Pennline, H. W., and Hargis, R. A. (2000). Novel Sorbents For Mercury Removal From Flue Gas. *Industrial & Engineering Chemistry Research.* 39: 1020-1029.

Gritti, F., Piatkowski, W., and Guiochon, G. (2002). Comparison of the Adsorption Equilibrium of A Few Low-Molecular Mass Compounds on a Monolithic and a Packed Column in Reversed-Phase Liquid Chromatography. *Journal Chromatography A*. 978: 81-107.

Gu, H. (2009). Tensile Behaviours of the Coir Fiber and Related Composites after NaOH Treatment. *Materials & Design.* 30(9): 3931-3934.

Guo, J. and Lua, A. C. (1998). Characterization of Chars Pyrolyzed From Oil Palm Stones For The Preparation Of Activated Carbons. *Journal of Analytical and Applied Pyrolysis.* 46: 113-125.

Gupta, V. K., Jain, R., Shrivastava, M., and Nayak, A. (2010). Equilibrium and Thermodynamic Studies on the Adsorption of the Dye Tartrazine onto Waste "Coconut Husks" Carbon and Activated Carbon. *Journal of Chemical & Engineering Data*. 55 (11): 5083–5090.

Hamdaoui, O. (2006). Dynamic Sorption of Methylene Blue by Cedar Sawdust and Crushed Brick in Fixed Bed Columns. *Journal of Hazardous Materials*. 138(2): 293-303.

Hameed, B. H. and Foo, K. Y. (2012). Coconut Husk Derived Activated Carbon via Microwave Induced Activation: Effects of Activation Agents, Preparation Parameters and Adsorption Performance. *Chemical Engineering Journal*. 184: 57-65.

Hameed, B. H. and El-Khaiary, M. I. (2008). Sorption kinetics and isotherm studies of cationic dye using agricultural waste: broad bean peels. *Journal of Hazardous Material.* 154: 639–648.

Hameed, B. H., Tan, I. A. W., and Ahmad, A. L. (2008). Adsorption Isotherm, Kinetic Modeling And Mechanism Of 2,4,6-Trichlorophenol On Coconut Husk-Based Activated Carbon. *Chemical Engineering Journal.* 144, 235-244.

Han, L., Lv, X., Wang, J., and Chang, L. (2012). Palladium-Iron Bimetal Sorbents for Simultaneous Capture of Hydrogen Sulfide and Mercury from Simulated Syngas. *Energy Fuels*. 26: 1638-1644.

Hasany, S. M. and Ahmad, R. (2006). The Potential of Cost-Effective Coconut Husk for the Removal of Toxic Metal Ions for Environmental Protection. *Journal of Environmental Management.* 81: 286-295.

Hassett, D. J. and Eylands, K. E. (1999). Mercury Capture on Coal Combustion Fly Ash. *Fuel*. 78: 243-248.

Hayashi, T., Lee, T. G., Hazelwood, M., Hedrick, E., and Biswas, P. (2000). Characterization of Activated Carbon Fiber Filters for Pressure Drop, Submicrometer Particulate Collection, and Mercury Capture. *Journal of the Air & Waste Management Association.* 5: 922–929.

He, J., Reddy, G. K., Thiel, S. W., Smirniotis, P. G., and Pinto, N. G. (2013). Simultaneous Removal Of Elemental Mercury And NO From Flue Gas Using CeO_2 modified $MnOx/TiO_2$ materials. *Energy Fuels.* 27: 4832-4839.

Ho, Y. S. and McKay, G. (1998). Sorption of Dye from Aqueous Solution by Peat. *Chemical Engineering Journal.* 70: 115-124.

Ho, Y. S. and McKay, G. (1999). Pseudo-Second Order Model for Sorption Processes. *Process Biochemistry.* 34: 451–465.

Ho, Y. S. and Ofomaja, A. E. (2006). Biosorption Thermodynamics of Cadmium On Coconut Copra Meal As Biosorbent. *BioChemical Engineering Journal.* 30: 117-123.

Hsi, H. C., Rood, M. J., Rostam-Abadi, M., Chen, S. G., and Chang, R. (2001). Effects of Sulfur Impregnation Temperature on the Properties and Mercury Adsorption Capacities of Activated Carbon Fibers (ACFs). *Environmental Science & Technology*. 35(13): 2785-2791.

Hsi, H. C., Rood, M. J., Rostam-Abadi, M., Chen, S., and Chang, R. (2002). Mercury Adsorption Properties of Sulfur-Impregnated Adsorbents. *Journal of Environmental Engineering*. 128: 1080-1089.

Hsi, H. C., Tsai, C. Y., Kuo, T. H., and Chiang, C. S. (2011). Development of Low-Concentration Mercury Adsorbents from Biohydrogen-Generation Agricultural Residues Using Sulfur Impregnation. *Bioresource Technology*. 102: 7470-7477.

Hsi, H. C. and Chen, S. (2012). Influences of Acidic/Oxidizing Gases On Elemental Mercury Adsorption Equilibrium And Kinetics Of Sulfur-Impregnated Activated Carbon. *Fuel*. 98: 229–235.

Hsi, H. C., Chen, S., Rostam-Abadi, M., Rood, M. J., Richardson, C. F., Carey, T. R., and Chang, R. (1998). Preparation and Evaluation Of Coal-Derived Activated Carbon For Removal Of Mercury Vapor From Simulated Coal Combustion Flue Gases. *Energy Fuels*. 12: 1061-1070.

Hu, C., Zhou, J., He, S., Luo, Z., and Cen, K. (2009). Effect of Chemical Activation Of An Activated Carbon Using Zinc Chloride On Elemental Mercury Adsorption. *Fuel Processing Technology*. 90: 812-817.

Hua, X. Y., Zhou, J. S., Li, Q., Luo, Z. Y., and Cen, K. F. (2010). Gas-Phase Elemental Mercury Removal by CeO_2 Impregnated Activated Coke. *Energy Fuels*. 24: 5426-5431.

Huang, J. L. and Pramoda, N. Chapter 7: Processing and characterization of alumina/chromium carbide ceramic nanocomposite. In: Dr. Abbass Hashim (Ed.), ISBN: 978-953-307-347-7. *Advances in Nanocomposite Technology*. InTech. DOI: 10.5772/17899; 2011.

Hubbe, M. A., Hasan, S. H., and Ducoste, J. J. (2011). Cellulosic Substrates For Removal Of Pollutants From Aqueous Systems: A Review. 1. Metals. *BioResources*. 6(2): 2161-2914.

Hutchison, A. R. and Atwood, DA. (2003). Mercury Pollution and Remediation: The Chemist's Response to a Global Crisis. *Journal of Chemical Crystallography*. 33: 1074–1542.

Ie, I. R., Hung, C. H., Jen, Y. S., Jen, Y. S., Yuan, C. S., and Chen, W. H. (2013). Adsorption of Vapor-Phase Elemental Mercury (Hg^o) and Mercury Chloride ($HgCl_2$) With Innovative Composite Activated Carbons Impregnated With Na_2S and S^o in Different Sequences. *Chemical Engineering Journal*. 229: 469-476.

Igwe, J. C., Abia, A. A., and Ibeh, C. A. (2008). Adsorption Kinetics and Intraparticulate Diffusivities of Hg, As and Pb ions On Unmodified And Thiolated Coconut Fiber. *International Journal of Environmental Science and Technology*. 5(1): 83-92.

Israel, A. U., Ogali, R. E., Akaranta, O., and Obot, I. B. (2011). Extraction and Characterization of Coconut (*Cocos Nucifera L.*) Coir Dust. *Songklanakarin Journal of Science and Technology*. 33(6): 717-724.

Issaro, N., Abi-Ghanem, C., and Bermond, A. (2009). Fractionation Studies of Mercury in Soil and Sediments: A Review of the Chemical Reagents Used For Mercury Extraction. *Analytica Chimica Acta*. 631: 1-12.

Jack, W. (2010). An NGO Introduction to Mercury Pollution, International POPs Elimination Network. Citing internet sources URL:http://www.ipen.org/ipenweb/documents/ipen_education.html.

Ji, L., Abu-Daabes, M., and Pinto, N. (2009). Thermally Robust Chelating Adsorbents for the Capture of Gaseous Mercury: Fixed-Bed Behavior. *Chemical Engineering Science*. 64: 486-491.

Ji, L., Sreekanth, M., Smirniotis, P. G., Thiel, S., and Pinto, N. G. (2008). Manganese Oxide/Titania Materials for Removal of NOx and Elemental Mercury from Flue Gas. *Energy Fuels*. 22: 2299-2306.

Jia, Y. F. and Thomas, K. M. (2000). Adsorption of Cadmium Ions on Oxygen Surface Sites in Activated Carbon. *Langmuir*. 16(3): 1114–1122.

Johari, K., Saman, N., and Mat, H. (2014). Adsorption Enhancement of Elemental Mercury onto Sulphur-Functionalized Silica Gel Adsorbents. *Environmental Technology*. 35(5): 629-636.

Johari, K., Saman, N., Song, S. T., and Mat, H. (2015). Removal Performance Of Elemental Mercury By Low-Cost Adsorbents Prepared through Facile Methods of Carbonization and Activation of Coconut Husk. *Waste Management & Research*. 33(1): 81-88.

Johari, K., Saman, N., Song, S. T., Heng, J. Y. Y., and Mat, H. (2014a). Study of Hg(II) Removal From Aqueous Solution Using Lignocellulosic Coconut Fiber Biosorbents: Equilibrium and Kinetic Evaluation. *Chemical Engineering Communications*. 201: 1198-1220.

Johari, K., Saman, N., Song, S. T., Mat, H., and Stuckey, D. C. (2013). Utilization of Coconut Milk Processing Waste As A Low-Cost Mercury Sorbent. *Industrial & Engineering Chemistry Research.* 52(44): 15648–15657.

Kadirvelu, K. and Namasivayam, C. (2003). Activated Carbon Form Coconut Coirpith As Metal Adsorbent: Adsorption of Cd(II) from Aquoeus Solution. *Advances in Environmental Research.* 7: 471-478.

Kadirvelu, K., Goel, J., and Rajagopal, C. (2007). Sorption of Lead, Mercury and Cadmium Ions in Multicomponent System Using Carbon Aerogel as Adsorbent. *Journal of Hazardous Materials.* 153(1-2): 502-507.

Karatza, D., Lancia, A., and Musmarra, D. (1998). Fly Ash Capture Of Mercuric Chloride Vapors From Exhaust Combustion Gas. *Environmental Science & Technology*. 32: 3999-4004.

Karatza, D., Lancia, A., Musmarra, D., and Zucchini, C. (2000). Study of Mercury Absorption and Desorption On Sulfur Impregnated Carbon. *Experimental Thermal and Fluid Science*. 21: 150-155.

Karatza, D., Lancia, A., Prisciandaro, M., Musmarra, D., and Mazziotti di Celso, G. (2013). Influence of Oxygen on Adsorption of Elemental Mercury Vapors onto Activated Carbon. *Fuel*. 111: 485-491.

Karatza, D., Prisciandaro, M., Lancia, A., and Musmarra, D. (2011). Silver Impregnated Carbon for Adsorption and Desorption Of Elemental Mercury Vapors. *Journal of Environmental Sciences*. 23(9): 1578-1584.

Katesa, J., Junpiromand, S., and Tangsathitkulchai, C. (2010). Effect of Carbonization Temperature on Properties of Char and Activated Carbon from Coconut Shell. *Suranaree Journal of Science and Technology*. 20(4): 269-278.

Kavitha, D. and Namasivayam, C. (2007). Experimental and Kinetic Studies on Methylene Blue Adsorption by Coir Pith Carbon. *Bioresource Technology*. 98: 14-21.

Kavitha, D. and Namasivayam, C. (2007b). Recycling Coir Pith, an Agricultural Solid Waste, For the Removal of Procion Orange from Wastewater. *Dyes and Pigments*. 74: 237-248.

Kim, K. H., Kim, J. Y., Cho, T. S., and Choi, J. W. (2012). Influence of Pyrolysis Temperature On Physicochemical Properties Of Biochar Obtained From The Fast Pyrolysis of Pitch Pine (*Pinus Rigida*). *Bioresource Technology*. 118: 158-162.

Kiselev, A. V. (1968). Adsorption Properties of Hydrophobic Surfaces. *Journal of Colloid Interface Science*. 28(3–4): 430–442.

Klasson, K. T., Lima, I. M., Boihem Jr., L. L., and Wartelle, L. H. (2010). Feasibility of Mercury Removal From Simulated Flue Gas By Activated Chars Made From Poultry Manures. *Journal of Environmental Management*. 91: 2466-2470.

Kong, F., Qiu, J., Liu, H., Zhao, R., and Ai, Z. (2011a). Catalytic Oxidation of Gas-Phase Elemental Mercury By Nano-Fe_2O_3. *Journal of Environmental Sciences*. 23(4): 699-704.

Kong, H., He, J., Gao, Y., Wu, H., and Zhu, X. (2011). Cosorption of Phenanthrene And Mercury(II) From Aqueous Solution By Soybean Stalk-Based Biochar. *Journal of Agricultural Food Chemistry*. 59: 12116-12123.

Korpiel, J. A. and Vidic, R. D. (1997). Effect of Sulfur Impregnation Method on Activated Carbon Uptake of Gas-Phase Mercury. *Environmental Science & Technology.* 31: 2319-2325.

Krishnan, S. V., Gullet, B. K., and Jozewicz, W. (1994). Sorption of Elemental Mercury by Activated Carbons. *Environmental Science & Technology*. 28: 1506-1512.

Krishnani K. K. and Ayyappan S. (2006). Heavy Metals Remediation Of Water Using Plants And Lignocellulosic Agrowastes, *Reviews of Environmental Contamination and Toxicology*. 188: 59-84.

Kumar. G. and Gaur, J. P. (2011). Chemical Reaction- And Particle Diffusion-Based Kinetic Modeling Of Metal Biosorption by a Phormidium sp.-Dominated Cyanobacterial Mat. *Bioresource Technology*. 102(2): 633-640.

Kumar, P., Barrett, D. M., Delwiche, M. J., and Stroeve, P. (2009). Methods for Pretreatment of Lignocellulosic Biomass for Efficient Hydrolysis and Biofuel Production. *Industrial & Engineering Chemistry Research.* 48(8): 3713–3729.

Kumar, S., Loganathan, V. A., Gupta, R. B., and Barnett, M. O. (2011). An Assessment of U(VI) Removal from Groundwater Using Biochar Produced From Hydrothermal Carbonization. *Journal of Environmental Management.* 92: 2504-2512.

Lata, H., Garg, V. K., and Gupta, R. K. (2008). Adsorptiove Removal of Basic Dye by Chemically Activated Parthenium Biomass: Equilibrium and Kinetic Modeling. *Desalination*. 219: 250-261.

Le Cloirec, P. and Faur, C. Adsorption of Organic Compounds Onto Activated Carbon- Applications In Water And Air Treatments. In: Teresa J. B. *Activated Carbon Surfaces In Environmental Remediation*. New York, USA. 375-419; 2006.

Lee, S. H. and Park, Y. O. (2003). Gas-Phase Mercury Removal by Carbon–Based Sorbents, *Fuel Processing Technology.* 84: 197-206.

Lee, S. H., Rhim, Y. J., Cho, S. P. and Baek, J. I. (2006b). Carbon-Based Novel Sorbent For Removing Gas-Phase Mercury. *Fuel*. 85(2): 219–226.

Lee, S. J., Seo, Y. C., Jurng, J., and Lee, T. G. (2004). Removal of Gas-Phase Elemental Mercury By Iodine And Chlorine-Impregnated Activated Carbon. *Atmospheric Environment.* 38: 4887-4893.

Lee, S. S., Lee, J. Y., and Keener, T. C. (2009). Mercury Oxidation And Adsorption Characteristics Of Chemically Promoted Activated Carbon Sorbents. *Fuel Processing Technology.* 90: 1314-1318.

Lee, S. S., Lee, J. Y., and Keener, T. C. (2009a). Bench-Scale Studies Of In-Duct Mercury Capture Using Cupric Chloride-Impregnated Carbons. *Environmental Science & Technology.* 43: 2957-2962.

Lee, S. S., Lee, J. Y., and Keener, T. C. (2009b). The Effect Of Methods Of Preparation On The Performance Of Cupric Chloride-Impregnated Sorbents For The Removal Of Mercury From Flue Gas. *Fuel*. 88(10): 2053-2056.

Lee, S. and Park, Y. (2003). Gas Phase Mercury Removal by Carbon-Based Sorbents. *Fuel Processing Technology*. 84: 197-206.

Lee, W. and Bae, G. N. (2009). Removal of Elemental Mercury (Hg(0)) by Nanosized V_2O_5/TiO_2 Catalysts. *Environmental Science & Technology.* 43: 1522-1527.

Li, H. Li, Y., Wu, C. Y., and Zhang, J. (2011a). Oxidation and Capture of Elemental Mercury over SiO_2,-TiO_2-V_2O_5 Catalysts in Simulated Low-Rank Coal Combustion Flue Gas, *Chemical Engineering Journal*. 169: 186-193.

Li, H., Wu, C. Y., Li, Y., and Zhang, J. (2011). CeO_2-TiO_2 Catalysts for Catalytic Oxidation of Elemental Mercury in Low-Rank Coal Combustion Flue Gas. *Environmental Science & Technology*. 45: 7394-7400.

Li, J. and Maroto-Valer, M. M. (2012). Computational and Experimental Studies of Mercury Adsorption on Unburned Carbon Present In Fly Ash. *Carbon*. 50: 1913-1924.

Li, P., Feng, X. B., Qiu, G. L., Shang, L. H., and Li, Z. G. (2009). Mercury Pollution in Asia: A Review of Contaminated Sites. *Journal of Hazardous Materials.* 168: 591-601.

Li, Y. H., Lee, C. W., and Gullet, B. K. (2003). Importance of Activated Carbon's Oxygen Surface Functional Groups on Elemental Mercury Adsorption. *Fuel*. 82: 451-457.

Li, Y. H., Lee, C. W., and Gullett, B. K. (2002). The Effect of Activated Carbon Surface Moisture On Low Temperature Mercury Adsorption. *Carbon*. 40: 65-72.

Li, Z., Wu, L., Liu, H., La, H., and Qu, J. (2013). Improvement of Aqueous Mercury Adsorption on Activated Coke by Thiol-Functionalization. *Chemical Engineering Journal*. 228: 925–934.

Liu, B., Zeng, L., and Ren, Q. (2010). Simulation of Levulinic Acid Adsorption In Packed Beds Using Parallel Pore/Surface Diffusion Model. *Chemical Engineering & Technology*. 33(7): 1146-1152.

Libra, J. A., Ro, K. S, Kammann, C., Funke, A., Berge, N. D, Neubauer, Y., Titirici, M. M., Fühner, C., Bens, O., Kern, J., and Emmerich K. H. (2011). Hydrothermal Carbonization of Biomass Residuals: A Comparative Review of the Chemistry, Processes and Applications of Wet and Dry Pyrolysis. *Biofuels*. 2(1): 71-106.

Lillo-Ródenas, M. A., Cazorla-Amorós, D., and Linares-Solano, A. (2003). Understanding Chemical Reactions between Carbons and NaOH and KOH. An Insight into the Chemical Activation Mechanism. *Carbon*. 41: 267-275.

Lim, A. P. and Aris, A. Z. (2014). A Review on Economically Adsorbents on Heavy Metals Removal in Water And Wastewaters. *Reviews in Environmental Science Biotechnology*. 13: 163-181.

Lim, A. P. and Aris, A. Z. (2014a). Continuous Fixed-Bed Column Study And Adsorption Modeling: Removal of Cadmium (II) and Lead (II) Ions in Aqueous Solution by Dead Calcareous Skeletons. *Biochemical Engineering Journal*. 87: 50-61.

Lim, W. C., Srinivasakannan, C., and Balasubramanian, N. (2010). Activation of Palm Shells by Phosphoric Acid Impregnation for High Yielding Activated Carbon. *Journal of Analytical and Applied Pyrolysis.* 88: 181–186.

Lindqvist, O., Jernelow, A., Hohansson, K., and Rodhe, H. (1984). Mercury in the Swedish Environment: Global and Local Sources, National Swedish Protection Board, Solna, Sweden.

Liu, W. and Vidic, R. D. (1998). Optimization of Sulfur Impregnation Protocol For Fixed-Bed Application Of Activated Carbon-Based Sorbents For Gas-Phase Mercury Removal. *Environmental Science & Technology.* 32: 531-538.

Liu, W., Vidic, R. D., and Brown, T. D. (1998). Optimization of Sulfur Impregnation Protocol for Fixed-Bed Application of Activated Carbon-Based Sorbents for Gas-Phase Mercury Removal. *Environmental Science & Technology.* 32: 531–538.

Liu, W., Vidic, R. D., and Brown, T. D. (2000). Impact of Flue Gas Conditions On Mercury Uptake By Sulfur-Impregnated Activated Carbon. *Environmental Science & Technology.* 34: 154–159.

Lopes, C. B., Pereira, E., Lin, Z., Pato, P., Otero, M., Silva, C.M., Rocha, J., and Duarte, A. C. (2011). Fixed-Bed Removal of Hg^{2+} From Contaminated Water by Microporous Titanosilicate ETS-4: Experimental and Theoritical Breakthrough Curves. *Microporous and Mesoporous Materials.* 145: 32-40.

Low, K. S., Lee, C. K. and Lee, P. L. (1997). Chromium(III) Sorption Enhancement Through NTA—Modification Of Biological Materials. *Bulletin of Environmental Contamination Toxicology*. 58(3): 380-386.

Lua, A. C. and Guo, J. (1998). Preparation and Characterization of Chars from Oil Palm Waste. *Carbon*. 36(11): 1663-1670.

Luo, G., Yao, H., Xu, M., Cui, X., Chen, W., Gupta, R., and Xu, Z. (2010). Carbon Nanotube-Silver Composite for Mercury Capture and Analysis. *Energy Fuels*. 24: 419-426.

Luo, J., Hein, A. M., and Hwang, J. Y. (2004). Adsorption of Vapor Phase Mercury on Various Carbons. *Journal of Mineral & Materials Characterization & Engineering.* 3(1): 13-22.

Luox, N. T. (1998). An assessment of Mercury-Species-Dependent Binding with Natural Organic Carbon. *Chemical Speciation & Bioavailability*. 10(4): 127-136.

Madaria, P. R., Mohan, N., Rajagopal, C., and Garg, B. S. (2004). Application of Carbon Aerogel for Electrolytic Removal of Mercury from Aqueous Solutions. *Journal of Scientific & Industrial Research.* 63: 938-943.

Makkuni, A., Bachas, L. G., Varma, R. S., Sikdar, S. K., and Bhattacharyya, D. (2005). Aqueous and Vapor Phase Mercury Sorption by Inorganic Oxide Materials Functionalized With Thiols and Poy-Thiols. *Clean Technologies and Environmental Policy.* 7: 87-96.

Manchester, S., Wang, X., Kulaots, I., Gao, Y., and Hurt, R. H. (2008). High Capacity Mercury Adsorption on Freshly Ozone-Treated Carbon Surfaces. *Carbon*. 46(3): 518-524.

Manju, G. N., Raji, C., and Anirudhan, T. S. (1998). Evaluation of Coconut Husk Carbon For The Removal Of Arsenic From Water. *Water Research*. 32(10): 3062-3070.

Manocha, S. M. (2003). Porous Carbons. *Sadhana*. 28(1&2), 335-348.

Maroto-Valer, M. M., Zhang, Y., Granite, E. J., Tang, Z., and Pennline, H. W. (2005). Effect of Porous Structure and Surface Functionality on the Mercury Capacity of a Fly Ash Carbon and Its Activated Sample. *Fuel*. 84: 105–108.

Mašek, O., Brownsort, P., Cross, A., and Sohi, S. (2013). Influence of Production Conditions on the Yield and Environmental Stability of Biochar. *Fuel*. 103: 151-155.

Matisova, E. and Skrabakova, S. (1995). Review: Carbon Sorbents and Their Utilization for the Preconcentration of Organic Pollutants in Environmental Samples. *Journal of Chromatography A*. 707: 145-179.

Matsumura, Y. (1974). Adsorption of Mercury Vapor on the Surface of Activated Carbons Modified By Oxidation or Iodization. *Atmospheric Environment.*8 (12): 1321–1327.

McBeath, A. V., Smernik, R. J., Schneider, M. P. W., and Schmidt, M. W. I. (2011). Plant EL Determination of the Aromaticity and the Degree of Aromatic Condensation of a Thermosequence of Wood Charcoal Using NMR. *Organic Chemistry*. 42: 1194-1202.

McLarnon, C. R., Granite, E. J., and Pennline, H. W. (2005). The PCO Process for Photochamical Removal of Mercury from Flue Gas. *Fuel Processing Technology.* 87: 85-89.

Meena, A. K., Mishra, G. K., Rai, P. K., Rajagopal, C., and Nagar, P. N. (2005). Removal of Heavy Metal Ions from Aqueous Solutions using Carbon Aerogel as an Adosrbent. *Journal of Hazardous Materials.* B122: 161-170.

Mei, Z., Shen, Z., Wang, W., and Zhang, Y. (2008). Novel Sorbents of Non-Metal-Doped Spinel CO_3O_4 for the Removal of Gas-Phase Elemental Mercury. *Environmental Science & Technology.* 42: 590-595.

Mei, Z., Shen, Z., Zhao, Q., Wang, W., and Zhang, Y. (2008b). Removal and Recovery Of Gas-Phase Element Mercury By Metal Oxide-Loaded Activated Carbon, *Journal of Hazardous Materials.* 152: 721-729.

Mendelsohn, M. H., Grove, D., Huang, H. S., and Darien. (1999), *Method For The Removal Of Elemental Mercury From A Gas Stream*. US Patent number 5900042.

Merrifield, J. D., Davids, W. G., MacRae, J. D., and Amirbahman, A. (2004). Uptake of Mercury by Thiol-Grafted Chitosan Gel Beads. *Water Research.* 38: 3132-3138.

Meyer, D. E., Meeks, N., Sikdar, S., Hutson, N. D., Hua, D., and Bhattacharyya, D. (2008). Copper-Doped Silica Materials Silanized with Bis-(Triethoxy Silyl Propyl)-Tetra Sulfide for Mercury Vapor Capture. *Energy Fuels*. 22: 2290-2298.

Meyer, D. E., Sikdar, S. K., Hutson, N. D., and Bhattacharyya, D. (2007). Examination of Sulfur-Functionalized, Copper-Doped Iron Nanoparticles for Vapor-Phase Mercury Capture In Entrained-Flow and Fixed-Bed Systems. *Energy Fuels*. 21: 2688-2697.

Meyer, S., Glaser, B., and Quicker, P. (2011). Technical, Economical, and Climate-Related Aspects of Biochar Production Technologies: A Literature Review. *Environmental Science & Technology.* 45: 9473-9483.

Mibeck, B. A. F., Olson, E. S., and Miller, S. J. (2009). $HgCl_2$ Sorption on Lignite Activated Carbon: Analysis of Fixed-Bed Results. *Fuel Processing Technology.* 90: 1364–1371.

Miller, S. J., Dunham, G. E., Olson, E. S., and Brown, T. D. (2000). Flue Gas Effects On Carbon-Based Mercury Sorbent. *Fuel Processing Technology.* 65-66: 343-363.

Min, F., Zhang, M., Zhang, Y., Cao, Y., and Pan, W. P. (2011). An Experimental Investigation into Gasification Reactivity and Structure of Agricultural Waste Chars. *Journal Analytical Applied Pyrolysis*. 92: 250-257.

Miranda, R., Sosa, C., Bustos, D., Carrillo, E., and Rodríguez-Cantú, M. Characterization of Pyrolysis Products Obtained During The Preparation Of Bio-Oil And Activated Carbon, Lignocellulosic Precursors Used In The Synthesis Of Activated Carbon - Characterization Techniques And

Applications In The Wastewater Treatment. In: Dr. Virginia Hernández Montoya (Ed.), ISBN: 978-953-51-0197-0. 2012.

Mohan, D. and Jr. Pittman, C. U. (2006). Activated Carbons And Low Cost Adsorbents For Remediation Of Tri-And Hexavalent Chromium From Water. *Journal of Hazardous Materials.* B137: 762-811.

Mohan, D., Gupta, V. K., Srivastava, S. K., and Chander, S. (2001). Kinetics of mercury adsorption from wastewater using activated carbon derived from fertilizer waste. *Colloids and Surfaces A: Physicochemical and Engineering Aspects.* 177: 169-181.

Monser, L. and Adhoum, N. (2002). Modified Activated Carbon For The Removal Of Copper, Zinc, Chromium And Cyanide From Wastewater. *Separation and Purification Technology*. 26: 137–146.

Montenegro, H. M. (1985). Coconut Oil and Its By-Products. *Journal of the American Oil Chemists Society*. 62: 259-261.

Monterroso, R., Fan, M., and Argyle, M. Chapter 9: Mercury removal. In: David A. B., Brian, F. T. and Maohong F. *Coal Gasification and Its Applications*. Elsevier. 247-288. 2011.

Morán, J. I., Alvarez, V. A., Cyras, V. P., and Vázquez, A. (2008). Extraction of Cellulose and Preparation of Nanocellulose from Sisal Fibers. *Cellulose*. 15: 149-159.

Morimoto, T., Wu, S., Uddin, M. A., and Sasaoka, E. (2005). Characteristics of the Mercury Vapor Removal From Coal Combustion Flue Gas By Activated Carbon Using H_2S. *Fuel*. 84: 1968-1974.

Morris, E. A. Kirk, D. W. and Jia, C. Q. (2012). Roles of Sulfuric Acid in Elemental Mercury Removal by Activated Carbon and Sulfur-Impregnated Carbon. *Environmental Science & Technology*. 46: 7905-7912.

Mosier, N., Wyman, C., Dale, B., Elander, R., Lee, Y. Y., Holtzapple, M., and Ladish, M. (2005). Features of Promising Technologies for Pretreatment of Lignocellulosic Biomass, *Bioresource Technology.* 96(6): 673-686.

Namasivayam, C. and Kadirvelu, K. (1997). Activated Carbons Prepared From Coir Pith By Physical And Chemical Activation Methods. *Bioresource Technology.* 62: 123-127.

Namasivayam, C. and Kadirvelu, K. (1997). Agricultural Solid Wastes For The Removal Of Heavy Metals: Adsorption of Cu(II) by Coirpith Carbon. *Chemosphere.* 34(2): 377-399.

Namasivayam, C. and Sangeetha, D. (2004). Equilibrium and Kinetic Studies of Adsorption of Phosphate onto $ZnCl_2$ Activated Coir Pith Carbon. *Journal of Colloid and Interface Science.* 280: 359-365.

Namasivayam, C. and Sangeetha, D. (2005). Kinetic Studies of Adsorption of Thiocyanate onto $ZnCl_2$ Activated Carbon from Coir Pith, an Agricultural Solid Waste. *Chemosphere*. 60: 1616–1623.

Namasivayam, C. and Sangeetha, D. (2008). Application of Coconut Coir Pith for the Removal of Sulfate and Other Anions from Water. *Desalination*. 219: 1–13.

Namasivayam, C. and Senthilkumar, S. (1997). Recycling of Industrial Solid Waste for the Removal of Mercury (II) By Adsorption Process. *Chemosphere*. 34 (20): 357–375.

Namasivayam, C. and Sureshkumar M. V. (2006). Anionic Dye Adsorption Characteristics of Surfactant Modified Coir Pith, a Waste Lignocellulosic Polymer. *Journal of Applied Polymer Science.* 100: 1538–1546.

Newman, J. (2007). Core Facts about Coir. Citing internet sources URL: http://www.GreenBeam.com.

Niksa, S., Helble, J. J., and Fujiwara, N. (2001). Kinetic Modeling Of Homogenous Mercury Oxidation: The Importance of NO and H_2O in Predicting Oxidation In Coal-Derived Systems. *Environmental Science & Technology*. 35: 3701-3706.

Ofomaja, A. E. (2008). Sorptive Removal of Methylene Blue from Aqueous Solution Using Palm Kernel Fibre: Effect of Fibre Dose. *Biochemical Engineering Journal*. 40: 8–18

Okwadha, G. D. O., Li, J., Ramme, B., Kollakowsky, D., and Michaud, D. (2009). Thermal Removal of Mercury in Spent Powdered Activated Carbon from TOXECON Process, *Journal of Environmental Engineering.* 135: 1032-1040.

Olayinka, K. O., Alo, B. I., and Adu, T. (2007). Sorption of Heavy Metals from Electroplating Effluents by Low-Cost Adsorbents II: Use of Waste Tea, Coconut Shell, and Coconut Husk. *Journal of Applied Science*. 7(16): 2307-2313.

Orlando, U. S., Okuda, T., Baes, A. U., Nishijima, W., and Okada, M. (2003). Chemical Properties Of Anion-Exchangers Prepared From Waste Natural Materials. *Reactive and Functional Polymers*. 55: 311–318.

Otani, Y., Emi, H., Kanaoka, C., Uchijima, I., and Nishino, H. (1988). Removal of Mercury Vapor from Air with Sulfur-Impregnated Adsorbents. *Environmental Science & Technology.* 22(6): 708-711.

Ozao, R., Okabe, T., Nishimoto, Y., Cao, Y., Whitely, N., and Pan, W. P. (2005). Gas and Mercury Adsorption Properties Of Woodceramics Made From Chicken Waste. *Energy Fuels*. 19: 1729-1734.

Padak, B., Brunetti, M., Lewis, A., and Wilcox, J. (2006). Mercury Binding On Activated Carbon. *Environmental Progress.* 25(4): 319-326.

Padhye, L. P., Hertzberg, B., Yushin, G., and Huang, C. H. (2011). N-Nitrosamines Formation From Secondary Amines By Nitrogen Fixation On The Surface Of Activated Carbon. *Environmental Science & Technology.* 45: 8368-8376.

Panda, R., Panda, H., Prakash, K., and Panda, A. (2010). Coconut. Science Technology Entrepreneur. Citing internet sources URL: http://www.techno-preneur.net.

Parab, H. and Sudersanan, M. (2010). Engineering a Lignocellulosic Biosorbent–Coir Pith for Removal of Cesium from Aqueous Solutions: Equilibrium and Kinetic Studies. *Water Research.* 40: 854-860.

Parab, H., Joshi, S., Shenoy, N. Lali, A., Sarma, U. S., and Sudersanan, M. (2008). Esterified Coir Pith As An Adsorbent For The Removal Of Co(II) From Aqueous Solution. *Bioresource Technology.* 99: 2083–2086

Parab, H., Joshi, S., Shenoy, N., Verma, R., Lali, A., and Sudersanan, M. (2005). Uranium Removal from Aqueous Solution by Coir Pith: Equilibrium and Kinetic Studies. *Bioresource Technology.* 96: 1241–1248.

Park, D., Yun, Y. S., and Park, J. M. (2010). The Past, Present, and Future Trends Of Biosorption. *Biotechnology and Bioprocess Engineering*. 15: 86-102.

Park, K. S., Seo, Y. C., Lee, S. J., and Lee, J. H. (2008). Emission and Speciation Of Mercury From Various Combustion Sources. *Powder Technology.* 180(1-2): 151-156.

Pavlish, J. H., Holmes, M. J., Benson, S. A., Crocker, C. R., and Galbreath, K. C. (2004). Application of Sorbents for Mercury Control for Utilities Burning Lignite Coal. *Fuel Processing Technology.* 85(6-7): 563-576.

Pavlish, J. H., Sondreal, E. A., Mann, M. D., Olson, E. S., Galbreath, K. C., Laudal, D. L., and Benson, S. A. (2003). Status Review of Mercury Control Options For Coal-Fired Power Plants. *Fuel Processing Technology.* 82: 89-165.

Phan, N. H., Rio, S., Faur, C., Coq, L. L., Cloirec, P. L., and Nguyen, T. H. (2006). Production of Fibrous Activated Carbons from Natural Cellulose (Jute, Coconut) Fibers for Water Treatment Applications. *Carbon*. 44: 2569-2577.

Phannenstiel, L. L., McKinley, C., and Sorensen, J. S. (1976). Mercury in Natural Gas. Paper PAP76-T-12. Presented at American Gas Association, Operation Section Transmission Conference, Las Vegas, Nevada, 3–5 May.

Pietrzak, R. and Bandosz, T. J. (2007). Activated Carbon Modified With Sewage Sludge Derived Phase And Their Application In The Process of NO_2 Removal. *Carbon*. 45: 2537-2546.

Pirrone, N., Cinnirella, S., Feng, X., Finkelman, R. B., Friedli, H. R., Leaner, J., Mason, R., Mukherjee, A. B., Stracher, G. B., Streets, D. G., and Telmer, K. (2010). Global Mercury Emissions to the Atmosphere from Anthropogenic and Natural Sources. *Atmosphere Chemistry and Physics*. 10: 5951-5964.

Pirronea, N., Costaa, P., Pacynab, J. M., and Ferrara, R. (2001). Mercury Emissions to The Atmosphere From Natural And Anthropogenic Sources In The Mediterranean Region. *Atmospheric Environment.* 35: 2997–3006.

Pitoniak, E., Wu, C. Y., Londeree, D., Mazyck, D., Bonzongo, J. C., Powers, K., and Sigmund, W. (2003). Nanostructured Silica-Gel Doped with TiO_2 for Mercury Vapor Control. *Journal Nanoparticle Research*. 5: 281-292

Poulston,S., Granite, E. J., Pennline, H. W., Myers, C. R., Stanko, D. P., Hamilton, H., Rowsell, L., Smith, A. W. J., Iikenhas, T., and Chu, W. (2007). Metal Sorbents for High Temperature Mercury Capture from Flue Gas. *Fuel*. 86: 2201-2203.

Presto, A. A. and Granite, E. J. (2007). Impact of Sulfur Oxides on Mercury Capture by Activated Carbon. *Environmental Science & Technology.* 41: 6579-6584.

Pyrzynska, K. (2007). Application of Carbon Sorbents for the Concentration and Separation of Metal Ions. *Analytical Sciences*. 23: 631-637.

Qiao, S., Chen, J., Li, J., Qu, Z., Liu, P., Yan, N., and Jia, J. (2009). Adsorption and Catalytic Oxidation of Gaseous Elemental Mercury in Flue Gas over MnO_x/Alumina. *Industrial & Engineering Chemistry Research.* 48: 3317-3322.

Qiao, W., Korai Y., Mochida I., Horib Y., and Maedab T. (2002). Preparation of an Activated Carbon Artifact: Oxidative Modification of Coconut Shell-Based Carbon to Improve the Strength. *Carbon*. 40: 351–358.

Qiu, H., Lu, L. V., Pan, B. C., Zhang, Q. J., Zhang, W. M., and Zhang, Q. X. (2009). Critical Review in Adsorption Kinetic Models. *Journal of Zhejiang University SCIENCE A*. 10(5): 716-724.

Qu, Z., Yan, N., Liu, P., Jia, J., and Yang, S. (2010). The Role of Iodine Monochloride for the Oxidation of Elemental Mercury. *Journal of Hazardous Materials.* 183: 132-137.

Quek, S. Y. and Al-Duri, B. (2007). Application of Film-Pore Diffusion Model for the Adsorption of Metal Ions on Coir in a Fixed-Bed Column. *Chemical and Engineering Process.* 46: 477-485.

Rahman, M. M. and Khan, M. A. (2007). Surface Treatment of Coir (*Cocos nucifera*) Fibers and Its Influence on the Fibers' Physico-Mechanical Properties. *Composites Science and Technology*. 67: 2369-2376.

Ramadan, H., Ghanem, A., and El-Rassy, H. (2010). Mercury Removal From Aqueous Solutions Using Silica, Polyacrylamide And Hybrid Silica Polyacrylamide Aerogels. *Chemical Engineering Journal.* 159: 107-115.

Randall, P. and Chattopadhyay, S. (2004). Advances in Encapsulation Technologies for the Management of Mercury-Contaminated Hazardous Wastes. *Journal of Hazardous Materials.* B114: 211-223.

Rangel-Mendez, J. R. and Streat, M. (2002). Mercury and Cadmium Sorption Performance of a Fibrous Ion Exchanger and Granular Activated Carbon. *Process Safety and Environmental Proctection.* 80(3): 150-158.

Raveendran, K. and Ganesh, A. (1998). Adsorption Characteristics and Pore-Development of Biomass-Pyrolysis Char. *Fuel*. 77(7): 769-781.

Reddy, K. S. K., Al Shoaibi, A., and Srinivasakannan, C. (2014). Elemental Mercury Adsorption on Sulfur-Impregnated Porous Carbon – A Review. *Environmental Technology*. 35(1): 18-26.

Ren, J. Zhou, J. Luo, Z., Zhong, Y., and Xu, Z. Fixed bed experimentas and mathematical modeling for adsorption of mercury vapor. *International Conference on Power Engineering*. October 23-27, 2007. Hangzhou, China. 843-849.

Rodriguez-Perez, J., Lopez-Anton, M. A., Diaz-Somano, M., Garcia, R., and Martinez-Tarazona, M. R. (2011). Development of Gold Nanoparticle-Doped Activated Carbon Sorbent For Elemental Mercury. *Energy Fuels*. 25: 2022-2027.

Romero-Anaya, A. J., Lillo-Rodenas, M. A., Salinas-Martinez de Lecea, C., and Linares-Solano, A. (2012). Hydrothermal and Conventional H_3PO_4 Activation of Two Natural Bio-Fibers. *Carbon*. 50(9): 3158-3169.

Rout, J., Tripathy, S. S., Nayak, S. K., Misra, M., and Mohanty, A. K. (2001). Scanning Electron Microscopy Study of Chemically Modified Coir Fibers. *Journal Applied Polymer Science*. 79(7): 1169-1177.

Sag, Y. and Kutsal, T. (2001). Recent Trends in the Biosorption of Heavy Metals: A Review. *Biotechnology and Bioprocess Engineering.* 6: 376-385.

Saman, N., Johari, K., and Mat, H. (2015). Removal of Elemental Mercury From Gas Stream Using Sulfur-Functionalized Silica Microspheres (S-SMs). *Clean Technologies and Environmental Policy*. 17(1): 39-47.

Saman, N., Johari, K., Song, S. T., and Mat, H. (2014). Removal of Hg(II) and Ch3Hg(I) Using Rasped Pith Sago Residue Biosorbent. *Clean – Soil, Air, Water.* 11(1): 1541-1548.

Sarin, V., Singh, T. S., and Pant, K. K. (2006). Thermodynamic and Breakthrough Column Studies For the Selective Sorption of Chromium from Industrial Effluent on Activated Eucalyptus Bark. *Bioresource Technology.* 97: 1986-1993.

Scala, F. (2001). Simulation of Mercury Capture By Activated Carbon Injection In Incinerator Flue Gas. 2. Fabric Filters Removal. *Environmental Science & Technology.* 35: 4373–4378.

Scala, F., Anacleria, A., and Cimino, S. (2013). Characterization of Regenerable Sorbent For High Temperature Elemental Mercury Capture from Flue Gas. *Fuel.* 108: 13-18.

Scala, F., Chirone, R., and Lancia, A. (2011). Elemental Mercury Vapor Capture by Powdered Activated Carbon in a Fluidized Bed Reactor. *Fuel*. 90: 2077-2082.

Schneider, R. M., Cavalin, C. F., Barros, M. A. S. D. and Tavares, C. R. G. (2007). Adsorption of Chromium Ions in Activated Carbon. *Chemical Engineering Journal.* 132: 355–362.

Sekar, M., Sakthi, V., and Rengaraj, S. (2004). Kinetics and Equilibrium Adsorption Study Of Lead (II) Onto Activated Carbon Prepared From Coconut Shell. *Journal of Colloid and Interface Science.* 279(2): 307-313.

Seneviratne, H. R., Charpenteau, C., George, A., Millan, M., Dugwell, D. R., and Kandiyoti, R. (2007). Ranking Low Cost Sorbents for Mercury Capture from Simulated Flue Gases. *Energy Fuels*. 21: 3249-3258.

Serre, S. D. and Silcox, G. D. (2000). Adsorption of Elemental Mercury on the Residual Carbon in Coal Fly Ash. *Industrial & Engineering Chemistry Research.* 39: 1723–1730

Shadbad, M. J., Mohebbi A., and Soltani A. (2011). Mercury(II) Removal From Aqueous Solutions By Adsorption On Multi-Walled Carbon Nanotubes. *Korean Journal of Chemical Engineering*. 28(4): 1029-1034

Shafawi, A., Ebdon, L., Foulkes, M., Stockwell, P., and Corns, W. (1999). Determination of Total Mercury in Hydrocarbons and Natural Gas Condensate by Atomic Fluorescence Spectrometry. *Analyst.* 124: 185-189.

Shafawi, A., Ebdon, L., Foulkes, M., Stockwell, P., and Corns, W. (2000). Preliminary Evaluation of Adsorbent-Based Mercury Removal Systems for Gas Condensate. *Analytica Chimica Acta*. 415: 21-32.

Shah, I. K., Pre, P., and Alappat, B. J. (2013). Steam Regeneration of Adsorbents: An Experimental and Technical Review. *Chemical Science Transactions*. 2(4): 1078-1088.

Shareef, K. M. (2009). Sorbents for Contaminants Uptake from Aqueous Solutions. Part I: Heavy Metals. *World Journal of Agricultural Sciences.* 5(S): 819-831.

Sharma, P. K., Ayub, S., and Tripathi, C. N. (2013). Agro and Horticultural Wastes as Low Cost Adsorbents for Removal of Heavy Metals from Wastewater: A Review. *International Refereed Journal of Engineering and Science.* 2(8): 18-27.

Sharma, Y. C., Uma, and Upadhyay, S. N. (2009). Removal of a Cationic Dye From Wastewaters By Adsorption On Activated Carbon Developed From Coconut Coir. *Energy Fuels*. 23: 2983-2988.

Shen, Y. S., Wang, S. L., Tzou, Y. M., Yan, Y. Y., and Kuan, W. H. (2012). Removal of Hexalent Cr by Coconut Coir and Derived Chars–The Effect of Surface Functionality. *Bioresource Technology.* 104: 165-172.

Shen, Z., Ma, J., Mei, Z., and Zhang, J. (2010). Metal Chlorides Loaded On Activated Carbon to Capture Elemental Mercury. *Journal of Environmental Sciences*. 22(11): 1814-1819.

Shiels, D. O. (1929). The Adsorption of Mercury Vapour by Activated Charcoal. Chemistry Department, University of Melbourne. 1398-1402.

Shu, T., Lu, P., and He, N. (2013). Mercury Adsorption of Modified Mulberry Twig Chars in a Simulated Flue Gas, *Bioresource Technology.* 136: 182-187.

Shukla, S. R., Pai, R. S., and Shendarkar, A. D. (2006). Adsorption of Ni(II), Zn(II), and Fe(II) on Modified Coir Fibers. *Separation and Purification Technology*. 47: 141-147.

Sikkema, J. K., Alleman, J. E., Ong, S. K., and Wheelock, T. D. (2011). Mercury Regulation, Fate, Transport, Transformation, and Abatement within Cement Manufacturing Facilities: Review. *Science of the Total Environment.* 409: 4167-4178.

Silbergeld, E. K. and Devine, P. J. (2000). Mercury–Are We Studying The Right Endpoints And Mechanisms. *Fuel Processing Technology.* 65-66: 35-42.

Singh, K. P., Malik, A., Sinha, S., and Ojha, P. (2008). Liquid-Phase Adsorption Of Phenols Using Activated Carbons Derived From Agricultural Waste Material. *Journal of Hazardous Materials.* 150: 626–641.

Skodras, G., Diamantopolou, Ir., Zabaniotou, A., Stavropoulos, G., and Sakellaropoulos, G. P. (2007). Enhanced mercury adsorption in activated carbons from biomass materials and waste tires. *Fuel Processing Technology*. 88: 749-758.

Skodras, G., Diamantopoulou, I., Pantoleontos, G., and Sakellaropoulos, G. P. (2008). Kinetic Studies of Elemental Mercury Adsorption In Activated Carbon Fixed Bed Reactor, *Journal of Hazardous Materials.* 158: 1-13.

Skodras, G., Diamantopoulou, Ir., and Sakellaropoulos, G. P. (2007). Role of Activated Carbon Structural Properties and Surface Chemistry in Mercury Adsorption. *Desalination*. 210: 281–286.

Sondreal, E. A., Benson, S. A., Pavlish, J. H., and Ralston, N. V. C. (2004). An Overview of Air Quality III: Mercury, Trace Elements, and Particulate Matter. *Fuel Processing Technology.* 85: 425-440.

Song, J., Zou, W., Bian, Y., Su, F., and Han, R. (2011). Adsorption characteristics of methylene blue by peanut husk in batch and column modes. *Desalination*. 265: 119-125.

Song, S. T., Saman, N., Johari, K., and Mat, H. (2013). Removal of Hg(II) from Aqueous Solution By Adsorption Using Raw And Chemically Modified Rice Straw As Novel Adsorbents. *Industrial & Engineering Chemistry Research.* 52(36): 13092–13101.

Song, S. T., Saman, N., Johari, K., and Mat, H. (2013a). Removal of Mercury (II) from Aqueous Solution by Using Rice Residues, *Jurnal Teknologi (Science Engineering).* 63(1): 67-73.

Sousa, F. W., Olivera, A. G., Ribeiro, J. P., Rosa, M. F., Keukeleire, D., and Nascimento, R. F. (2010). Green Coconut Shells Applied As Adsorbent For Removal Of Toxic Metal Ions Using Fixed-Bed Column Technology. *Journal of Environmental Management.* 91: 1634-1640.

Spiric, Z. Innovative Approach to the Mercury Control During Natural Gas Processing. *Proceedings of the ETCE, Engineering Technology Conference*. February 5-7, 2001. Energy, Houston, Texas.

Sreedhar, M. K. and Anirudhan, T. S. (2000). Preparation of an Adsorbent By Graft Polymerization Of Acrylamide Onto Coconut Husk For Mercury (II) Removal From Aqueous Solution And Chloralkali Industry Wastewater. *Journal of Applied Polymer Science*. 75: 1261-1269.

Sreekala, M. S., Kumaran, M. G., and Thomas, S. (1997). Oil Palm Fibers: Morphology, Chemical Composition, Surface Modification, and Mechanical Properties. *Journal of Applied Polymer Science.* 66: 821-835.

Sreenivasan, S., Iyer, P. B., and Iyer, K. R. K. (1996). Influence of Delignification and Alkali Treatment on the Fine Structure of Coir Fibers (*Cocos nucifera*). *Journal of Materials Science.* 31: 721-726.

Srivastava, V. C., Mall, I. D., and Mishra, I. M. (2008). Adsorption of Toxic Metal Ions onto Activated Carbon. Study of Sorption Behaviour through Characterization and Kinetics. *Chemical Engineering and Processing*. 47: 1269-1280.

Steiner, S. A. III., Baumann, T. F., Kong, J., Jr. Satcher, J. H., and Dresselhaus, M. S. (2007). Iron-Doped Carbon Aerogels: Novel Porous Substrates for Direct Growth of Carbon Nanotubes. *Langmuir*. 23: 5161-5166.

Suarez-Ruiz, I. and Parra, J. B. (2007). Relationship Between Textural Properties, Fly Ash Carbons, And Hg Capture In Fly Ashes Derived From The Combustion Of Anthracitic Pulverized Feed Blends. *Energy Fuels*. 21: 1915–1923.

Suksabye, P., Thiravetyan, P., and Nakbanpote, W. (2008). Column Study of Chromium (VI) Adsorption from Electroplating Industry by Coconut Coir Pith. *Journal of Hazardous Materials.* 160: 56-62.

Sumathi, K. M. S., Mahimairaja, S., and Nandu, R. (2005). Use of Low-Cost Biological Wastes and Vermiculite for Removal of Chromium from Tannery Effluent. *Bioresource Technology.* 96(3): 309-316.

Sun, C., Snape, C. E., and Liu, H. (2013). Development of Low-Cost Functional Adsorbents for Control of Mercury (Hg) Emissions from Coal Combustion. *Energy Fuels*. 27: 3875-3882.

Suryavanshi, U. S. and Shukla S. R. (2009). Adsorption of Ga(III) on Oxidized Coir. *Industrial & Engineering Chemistry Research.* 48: 870–876.

Suzuki, M. *Adsorption Engineering*. Japan. Kodansha Ltd. Elsevier Science. 1990.

Tagliabue, M., Farrusseng, D., Valencia, S., Aguado, S., Ravon, U., Rizzo, C., Corma, A., and Mirodatos, C. (2009). Natural Gas Treating By Selective Adsorption: Material Science and Chemical Engineering Interplay. *Chemical Engineering Journal.* 155: 553-566.

Takenami, J., Uddin, M. A., Sasaoka, E., Shioya, Y., and Takase, T. (2009). Removal of Elemental Mercury from Dry Methane Gas with Manganese Oxides. *World Academy of Science, Engineering and Technology.* 56: 26-30.

Tan, I. A. W., Ahmad, A. L., and Hameed, B. H. (2008). Adsorption of Basic Dye On High-Surface-Area Activated Carbon Prepared From Coconut Husk: Equilibrium, Kinetic And Thermodynamic Studies. *Journal of Hazardous Materials.* 154: 337-346.

Tan, I. A. W., Ahmad, A. L., and Hameed, B. H. (2008a). Preparation of Activated Carbon From Coconut Husk: Optimization Study On Removal of 2,4,6-Trichlorophenol Using Response Surface Methodology. *Journal of Hazardous Materials.* 153: 709-717.

Tan, Z., Qiu, J., Zeng, H., Liu, H., and Xiang, J. (2011). Removal of Elemental Mercury By Bamboo Charcoal Impregnated With H_2O_2. *Fuel*. 90: 1471-1475.

Tan, Z., Sun, L., Xiang, J., Zeng, H. Liu, Z., Hu, S., and Qiu, J. (2012). Gas-Phase Elemental Mercury Removal by Novel Carbon-Based Sorbents. *Carbon*. 50: 362-371.

Tawabini, B., Al-Khaldi, S., Atieh, M. and Khaled, M. (2010). Removal of Mercury From Water By Multi-Walled Carbon Nanotubes. *Water Science and Technology*. 61: 591-598.

Tay, J. H., Chen, X. G., Jeyaseelan, S., and Graham, N. (2001). Optimising the Preparation of Activated Carbon from Digested Sewage Sludge and Coconut Husk. *Chemosphere*. 44: 45-51.

Taylor, R. W., Hassan, K., Mehadi, A. A., and Shuford, J. W. (1995). Kinetics of Zinc Sorption by Soils. *Communications in Soil Science and Plant Analysis*. 26(11&12): 1761-1771.

Tian, L., Li, C., Li, Q., Zeng, G., Gao, Z., Li, S., and Fan, X. (2009). Removal of Elemental Mercury By Activated Carbon Impregnated With CeO_2. *Fuel*. 88(9): 1687-1691.

Tomczak, F., Sydenstricker, T. H. D., and Satyanarayana, K. G. (2007). Studies on lignocellulosic fibers of Brazil. Part II: Morphology and Properties of Brazilian Coconut Fibers. *Composites: Part A*. 38: 1710-1721.

Trgo, M., Vukojevic, N., and Peric, J. (2011). Application of Mathematical Empirical Models to Dynamic Removal of Lead on Natural Zeolite Clinoptilolite in a Fixed Bed Column. *Indian Journal of Chemical Technology*. 18: 123-131.

Tupkanjana, P. and Phalakornkule, C. (2007). Development of Activated Carbons From Sunflower Seed Husk For Metal Adsorption. *Journal of Chemical Engineering of Japan.* 40 (3): 222–227.

U.S. E.P.A. (1997). Mercury study report to congress: Volume VI: An ecological assessment for anthropogenic mercury emissions in the United States.

U.S. E.P.A. (2001). Research and Development-Mercury in Petroleum and Natural Gas: Estimation of Emissions from Production, Processing, And Combustion. Report Reviewed by the U.S. Environmental Protection Agency.

U.S. E.P.A. (2005). Control of mercury emissions from coal fired electric utility boilers: An update. Citing internet sources URL: http://www.epa.gov/ttn/atw/utility/ord_whtpaper_hgcontroltech_oar_2002_0056_6141.pdf.

U.S. E.P.A. (2007). Background paper for stakeholder panel to address options for managing U.S. non-federal supplies of commodity-grade mercury. Citing internet sources URL: http://www.epa.gov/mercury/ stocks/backgroundpaper.pdf.

U.S. E.P.A. (2014). Mercury and Air Toxics Standards (MATS), Citing internet sources URL: http://www.epa.gov/mats/powerplants.html.

Ucol-Ganiron Jr, T. (2013). Recycling of Waste Coconut Shells as Substitute for Aggregates in Mix Proportioning of Concrete Hollow Blocks. *WSEAS Transactions on Environment and Development*. 4(9): 290-300.

Uddin, M. A., Yamada, T., Ochiai, R. and Sasaoka, E. (2008). Role of SO_2 for Elemental Mercury Removal from Coal Combustion Flue Gas by Activated Carbon. *Energy Fuels*. 22 (4): 2284–2289.

Unnithan, M. R., Vinod, V. P., and Anirudhan, T. S. (2004). Synthesis, Characterization, and Application as a Chromium (VI) Adsorbent of Amine-Modified Polyacrylamide-Grafted Coconut Coir Pith. *Industrial & Engineering Chemistry Research.* 43: 2247-2255.

Valenzuela-Calahorro, C., Macías-García, A., Bernalte-García, A., and Gómez-Serrano, V. (1990). Study of Sulfur Introduction in AC. *Carbon*. 28: 321–335.

Vidic, R. D. and McLaughlin, J. B. (1996). Uptake of Elemental Mercury Vapors By Activated Carbons. *Journal of the Air & Waste Management Association*. 46: 241-250.

Vidic, R. D. and Siler, D. P. (2001). Vapor-Phase Elemental Mercury Adsorption By Activated Carbon Impregnated With Chloride And Chelating Agents. *Carbon*. 39: 3–14.

Vidic, R. D., Chang, M. T., and Thurnau, R. C. (1998). Kinetics of Vapor-Phase Mercury Uptake By Virgin And Sulfur-Impregnated Activated Carbons. *Journal of the Air & Waste Management Association*. 48: 247-255.

Vitolo, S. and Seggiani, M. (2002). Mercury Removal from Geothermal Exhaust Gas By Sulfur-Impregnated And Virgin Activated Carbons. *Geothermics*. 31: 431–442.

Wan Daud, W. M. A., Wan Ali, A. S., and Sulaiman, M. Z. (2001). Effect of Carbonization Temperature On The Yield And Porosity Of Char Produced From Palm Shell. *Journal Chemistry Technology Biotechnology*. 76(12): 1281–1285.

Wan, W., Duan, L., He, K., and Li, J. (2011). Removal of Gaseous Elemental Mercury Over A CeO_2-WO_3/TiO_2 Nanocomposite In Simulated Coal-Fired Flue Gas. *Chemical Engineering Journal.* 170: 512-517.

Wang, H., Zhou, S., Xiao, L., Wang, Y., Liu, Y., and Wu, Z. (2011). Titania Nanotubes-A Unique Photocatalyst and Adsorbent for Elemental Mercury Removal. *Catalysis Today*. 175: 202-208.

Wang, J. Deng, B. Wang, X., and Zheng, J. (2009). Adsorptions of Aqueous Hg(II) by Sulfur Impregnated Activated Carbon. *Environmental Engineering Science.* 26: 1693–1699.

Wang, J., Yang, J., and Liu, Z. (2010). Gas-Phase Elemental Mercury Capture by a V_2O_5/AC Catalyst. *Fuel Processing Technology.* 91: 676-680.

Wang, Q., Kim, D., Dionysiou, D. D., Sorial, G. A., and Timberlake. (2004). Sources and Remediation for Mercury Contamination in Aquatic Systems-A Literature Review. *Environmental Pollution.* 131: 323-336.

Wen, X., Li, C., Fan, X., Gao, H., Zhang, W., Chen, L., Zeng, G., and Zhao, Y. (2011). Experimental Study of Gaseous Elemental Mercury Removal with CeO_2/γ-Al_2O_3. *Energy Fuels*. 25: 2939-2944.

Wilcox, J., Rupp, E., Ying, S. C., Lim, D. H., Negreira, A. S., Kirchofer, A., Feng, F., Lee, K. (2012). Mercury Adsorption and Oxidation in Coal Combustion and Gasification Processes. *International Journal of Coal Geology*. 90-91: 4-20.

Wilhelm, S. M. and Bloom, N. (2000). Mercury in Petroleum. *Fuel Processing Technology.* 63: 1–27.

Wu, B., Peterson, T. W., Shadman, F., Senior, C. L., Morency, J. R., Huggins, F. E., and Huffman, G. P. (2000). Interactions between Vapor-Phase Mercury Compounds and Coal Char in Synthetic Flue Gas. *Fuel Processing Technology.* 63: 93-107.

Wu, S., Uddin, M. A., and Sasaoka, E. (2006). Characteristics of the Removal of Mercury Vapor in Coal Derived Fuel Gas over Iron Oxide Sorbents. *Fuel*. 85: 213-218.

Xu, W., Wang, H., Zhu, T., Kuang, J., and Jing, P. (2013). Mercury Removal from Coal Combustion Flue Gas by Modified Fly Ash. *Journal of Environmental Sciences*. 25(2): 393-398.

Xu, X., Gao, B., Tan, X., Zhang, X., Yue, Q., Wang, Y., and Li, Q. (2013a). Nitrate adsorption by stratified wheat straw resin in lab-scale columns. *Chemical Engineering Journal*. 226: 1-6.

Xu, Y., Zhong, Q., and Xing, L. (2014).Gas-Phase Elemental Mercury Removal From Flue Gas By Cobalt-Modified Fly Ash at Low Temperatures. *Environmental Technology*. 35(22): 2870-2877.

Xu, Z., Cai, J-G., Pan, B.C. (2013b). Mathematically Modeling Fixed-Bed Adsorption in Aqueous Systems. *Journal of Zhejiang University SCIENCE A*. 14(3): 155-176.

Yaman, S. (2004). Pyrolysis of Biomass to Produce Fuels and Chemical Feedstocks. *Energy Conversion and Management.* 45: 651-671.

Yan, N., Chen, W., Chen, J., Qu, Z., Guo, Y., Yang, S., and Jia, J. (2011). Significance of RuO_2 Modified SCR Catalyst for Elemental Mercury Oxidation in Coal-Fired Flue Gas. *Environmental Science & Technology*. 45: 5725-5730.

Yan, R., Liang, D. T., Tsen, L., Wong, Y. P., and Lee, Y. K. (2004). Bench-Scale Experimental Evaluation of Carbon Performance on Mercury Vapour Adsorption. *Fuel*. 83: 2401-2409.

Yang, S., Guo, Y., Yan, N., Qu, Z., Xie, J., Yang, C., and Jia, J. (2011). Capture of Gaseous Elemental Mercury From Flue Gas Using A Magnetic And Sulfur Poisoning Resistant Sorbent Mn/γ-Fe_2O_3 At Lower Temperatures. *Journal of Hazardous Materials.* 186: 508-515.

Yao, Y., Velpari, V., and Economy, J. (2014). Design of Sulfur Treated Activated Carbon Fibers for Gas Phase Elemental Mercury Removal. *Fuel.* 116: 560-565.

Yardim, M. F., Budinova, T., Ekinci, E., Petrov, N., Razvigorova, M., and Minkova, V. (2003). Removal of Mercury (II) From Aqueous Solution By Activated Carbon Obtained From Furfural. *Chemosphere*. 52: 835–841.

Yi, Z., Yao, J., and Ma, X. Y. (2012). Absorption Behavior and Removal of Gaseous Elemental Mercury by Sodium Chlorite Solutions. *Journal Environmental Engineering*. 138: 620-624.

Yin, C. H., Aroua, M. K., and Daud, W. M. A. W. (2007). Review of Modifications of Activated Carbon for Enhancing Contaminant Uptakes from Aqueous Solutions. *Separation and Purification Technology.* 52: 403–415.

Yu, Y., Addai-Mensah, J., and Losic, D. (2012). Functionalized Diatom Silica Microparticles For Removal Of Mercury Ions. *Science and Technology of Advanced Materials.* 13: 1-11

Yuen, F.K. and Hameed, B.H. (2009). Recent Developments in the Preparation and Regeneration of Activated Carbons by Microwaves. *Advances in Colloid Interface Science*. 149: 19-27.

Yun, C. H., Park, Y. H., and Park, C. R. (2001). Effects of Pre-Carbonization On Porosity Development Of Activated Carbons From Rice Straw. *Carbon*. 39: 559-567.

Zhang, F. S., Nriagu, J. O., and Itoh, H. (2005). Mercury Removal From Water Using Activated Carbons Derived From Organic Sewage Sludge. *Water Research.* 39: 389-395.

Zhang, H., Zhao, J., Fang, Y., Huang, J., and Wang, Y. (2012). Catalytic Oxidation And Stabilized Adsorption Of Elemental Mercury From Coal-Derived Fuel Gas. *Energy Fuels*. 26: 1629-1637.

Zhang, J., Zhang, H., and Zhang, J. (2014). Evaluation of Liquid Ammonia Treatment on Surface Characteristics of Hemp Fiber. *Cellulose*. 21(1): 569-579.

Zhao, P., Guo. X., and Zheng, C. (2010). Removal of Elemental Mercury by Iodine-Modified Rice Husk Ash Sorbents. *Journal of Environmental Sciences*. 2(10): 1629-1636.

Zhu, J., Deng, B., Yang, J., and Gang, D. (2009). Modifying Activated Carbon With Hybrid Ligands For Enhancing Aqueous Mercury Removal. *Carbon*. 47: 2014-2025.

Zuim, D. R., Carpine, D., Distler, G. A. R., Scheer, A. P., Igarashi-Mafra, L., and Mafra, M. R. (2011). Adsorption of Two Coffee Aromas From Synthethic Aqueous Solution Onto Granular Activated Carbon Derived From Coconut Husks. *Journal of Food Engineering.* 104: 284-292.