WASTE TO VALUABLE BY PRODUCT: UTILIZATION OF CARBONISED DECANTER CAKE FROM PALM OIL MILLING PLANT AS AN EFFECTIVE ADSORBENT FOR HEAVY METAL IONS IN AQUEOUS SOLUTION

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ABSTRACT

Palm oil milling plant generates large amount of waste that was proven to cause environmental problems. About 40 kg decanter cake was generated from each ton of fresh fruit bunch processed. Previous studies suggested agricultural waste could be employed as heavy metal ion adsorbent. Due to the similarity of decanter cake with other agricultural waste we proposed to explore the use of decanter cake as an adsorbent for heavy metal ion removal.

Utilization of decanter cake as an effective adsorbent for Cd^{2+}, Cu^{2+} and Pb^{2+} ion removal from aqueous solution has been studied. The decanter cake was first dried at 105 °C and then carbonized at various temperatures. The resulting carbonized decanter cake were tested for removing Cd^{2+}, Cu^{2+} and Pb^{2+} ions. Proximate analysis using thermogravimetry analysis of decanter cake carbonized at 500 °C indicated that the adsorbent contained 4% moisture, 21% volatile,23% fixed carbon, and 52% ash. Adsorption test were normally carried out by mixing 1.0 g of the decanter cake in 100 mL aqueous solution of the various ions. The concentration of metal ions in the solutions used is in the range of 100 – 1000 mg/L.

The results of adsorption studies indicated that the removal of metal ions was highest in the case of Pb^{2+} when the carbonization temperature was 500 °C and 600 °C in the case of Cd^{2+} and Cu^{2+}. Maximum removal of the Cd^{2+}, Cu^{2+} and Pb^{2+}were also observed to take place when the pH of the solution is in the range of 4 – 5. Langmuir and Freundlich isotherm models were used to fit the isotherm experimental data. The maximum uptakes of Cd^{2+}, Cu^{2+} and Pb^{2+} onto the carbonized decanter cake in this study were estimated to be 24, 23, and 97 mg/g respectively. Adsorbed metal ions can be desorbed from adsorbent using dilute HCl solution. The adsorption kinetics was found to follow the pseudo-second-order kinetic model. Thermodynamic parameters such as standard enthalpy (ΔH°), standard entropy (ΔS°) and Gibbs free energy (ΔG°) were determined. Adsorption process was endothermic and had negative value of Gibbs free energy changes. The competitive adsorption characteristics of binary and ternary heavy metal ions Cd^{2+}, Cu^{2+} and Pb^{2+} on PDC500 were investigated in batch systems. Equilibrium adsorption data showed that PDC500 displays a high selectivity toward one metal in two-component or a three-component system with an affinity order of Pb^{2+} > Cu^{2+} > Cd^{2+}Chemical activation of decanter cake using $ZnCl_2$ increased the maximum adsorption capacity for Cd^{2+}, Cu^{2+} and Pb^{2+} significantly to 52, 44, and 159 mg/g respectively. Kinetic and thermodynamic properties of adsorption were affected by chemical activation.

Scale up of the batch process into industrial scale was explored using the Langmuir parameter from experimental data. A three-stage continuous counter current adsorption unit gave the best adsorption performance for Pb^{2+} ion removal in term of minimum adsorbent consumption.

ABSTRAK

Kilang kelapa sawit menghasilkan sejumlah besar bahan buangan di mana ia menjadi punca terhadap pencemaran alam sekitar. Setiap satu tan tandan buah segar kelapa sawit yang diproses menghasilkan 40 kg *decanter cake*. Kajian terdahulu mencadangkan bahawa bahan buangan pertanian dapat digunakan sebagai penjerap ion logam berat. Memandangkan *decanter cake* mempunyai persamaan dengan bahan buangan pertanian yang lain, ia dicadangkan sebagai bahan penjerap untuk menyingkirkan ion logam berat.

Penyingkiran ion-ion Cd^{2+}, Cu^{2+} dan Pb^{2+} daripada *decanter cake* minyak kelapa sawit telah dikaji. *Decanter cake* dikeringkan terlebih dahulu pada 105 °C dan pada pelbagai suhu. Hasil pirolisis mendakan itu diuji untuk menyingkir ion-ion Cd^{2+}, Cu^{2+} dan Pb^{2+}. Analisa pirolisis mendakan pada 500 °C dengan menggunakan 'thermogravimetry' mendapati bahawa penjerab mengandungi 4% kelembapan, 21% bahan ruap, 23% karbon mampat dan 52 % abu. Ujian penjerapan dijalankan dengan mencampurkan 1.0 g mendakan ke dalam 100 mL larutan pelbagai ion. Kepekatan ion-ion logam yang digunakan di dalam larutan adalah dalam lingkungan 100-1000 mg/L.

Hasil ujikaji penjerapan menunjukan penyingkiran ion-ion Pb^{2+} adalah tinggi pada suhu 500 °C dan 600 °C bagi ion Cd^{2+} dan Cu^{2+}. Penyingkiran ion-ion Cd^{2+}, Cu^{2+} and Pb^{2+} adalah maksima juga diperhatikan apabila pH larutan di dalam lingkungan 4 – 5. Model isoterma Langmuir dan Freundlich telah digunakan untuk mengukuhkan lagi data eksperiment. Maksimum ion- ion Cd^{2+}, Cu^{2+} dan Pb^{2+} terhadap pirolisis mendakan adalah dianggarkan 24, 23 dan 97 mg/g masing-masing. Ion-ion logam yang terjerap boleh dinyahkan dari penyerap dengan menggunakan larutan HCL cair. Kinetik penjerapan didapati mengikut model kinetik order kedua *pseudo*. Parameter termodinamik seperti enthalpy piawai ($\Delta H°$), entropi piawai ($\Delta S°$) dan tenaga bebas piawai ($\Delta G°$) telah ditentukan. Pengaktifan kimia bagi hasil mendakan dengan menggunakan $ZnCl_2$ meningkatkan keupayaan penjerapan maksimum bagi Cd^{2+}, Cu^{2+} dan Pb^{2+} sehingga 52, 44 dan 159 mg/g. Ciri-ciri kinetic dan termadinamik penjerapan telah dipengaruhi oleh pengaktifan secara kimia. Ciri-ciri perbezaan penjerapan binari dan ketiga bagi ion-ion logam berat Cd^{2+}, Cu^{2+} dan Pb^{2+} terhadap PDC500 telah dikaji dalam sistem kelompok. Data keseimbangan penjerapan menunjukan bahawa PDC500 memberikan kupayaan memilih yang tinggi terhadap logam dalam system dua komponen atau tiga komponen dengan turutan $Pb^{2+} > Cu^{2+} > Cd^{2+}$.

Berdasarkan data-data yang diperolehi, sistem berskala makmal dinaikskala kepada skala industri menggunakan parameter Langmuir. Didapati, proses penyingkiran optimum ion Pb^{2+} berdasarkan penggunaan minimum bahan penjerap diperolehi apabila proses penjerapan tiga peringkat arus melawan berterusan digunakan.

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LIST OF SYMBOLS

C_e	equilibrium concentration of metal ions in solution
c_i	concentration of adsorbate in solution (linear isotherm)
F	fluid flow rate
k_1	first order rate constant
k_2	second order rate constant
K_d	equilibrium constant
K_F	Freundlich constant
K_i	adsorption constant (linear isotherm)
K_L	affinity constant of Langmuir isotherm
n	intensity of adsorption constant (Freundlich isotherm)
n_i	concentration of adsorbate in adsorbent (linear isotherm)
q	amount of metal ion adsorbed per unit weight adsorbent
q_e	amount of metal ion adsorbed per unit weight adsorbent at equilibrium
q_m	maximum adsorption capacity of the adsorbent
R	ideal gas constant
R^2	correlation coefficient
S	selectivity
T	temperature
t	adsorption time
V	fluid volume
W	adsorbent weight/flow rate
ΔG	Gibbs free energy change
ΔH	enthalpy change
ΔS	entropy change

LIST OF ABBREVIATIONS

AAS	Atomic Absorption Spectrometry
BET	Brunauer-Emmer-Teller
BOD	Biological oxygen demand;
CFC	Chlorofluorocarbon
CPO	Crude palm oil
CST	Continuous settling tank
DOE	Department of Environment
EDX	Energy dispersive X-ray fluorescence
EEA	European Environmental Agency
EFB	Empty fruit bunch
EPA	Environmental Protection Agency
ESCAP	Economic and Social Commission for Asia and the Pacific
FAAS	Flame Atomic Absorption Spectrometry
FELDA	Federal Land Development Authority
FFB	Fresh fruit bunch
GFAAS	Graphite Furnace Atomic Absorption Spectrometry
ICP-MS	Inductively Coupled Plasma-Mass Spectrometry
ICP-OES	Inductively Coupled Plasma-Optical Emission Spectrometry
MSW	Municipal solid waste
NOS	Non oil solid
NRC	National Research Council
SEM	Scanning electron microscope
TGA	Thermogravimetry analysis
TKN	Total Kjeldahl Nitrogen
VOC	Volatile organic compound
WHO	World Health Organization
WW	Wastewater

CHAPTER 1

INTRODUCTION

1.1 WASTE

Waste is an unavoidable by-product of most human activity. Economic development and rising living standards have led to increases in the quantity and complexity of generated waste; whilst industrial diversification and the provision of higher quality of processed agricultural products have added substantial quantities of industrial and agricultural waste into the waste stream with potentially severe environmental and human health consequences. The rising of waste generation as the consequences of economic development become serious challenge to develop robust and cost effective waste management strategies. It is important to have a clear appreciation of the quantities and characteristic of the waste being generated to do that.

There are three major waste sources: municipal waste, industrial waste and agricultural waste. Municipal waste is generated from households, offices, hotels, shops, schools and other institutions. The major components are food waste, paper, plastic, rags, metal and glass, although demolition and construction debris is often included in collected waste, such as electric light bulbs, batteries, automotive parts and discarded medicines and chemicals. The composition of municipal solid waste varies significantly across the region. As an example, Kuala Lumpur has generated waste containing approximately 60 per cent organic waste, while Bangkok has generated it by 50 per cent of organic waste, according to Economic and Social Commission for Asia and the Pacific (ESCAP, 2000).

Industrial solid waste encompasses a wide range of materials of varying environmental toxicity. Typically this range would include paper, packaging materials, waste from food processing, oils, solvents, resins, paints and sludge, glass, ceramics, stones, metals, plastics, rubber, leather, wood, cloth, straw, abrasives, etc. Based on an average ratio of the region, the industrial solid waste generation in Asia Pacific region is equivalent to 1,900 million tones per annum. This amount is expected to increase substantially and at the current growth rates, it is estimated that it will double in less than 20 years (ESCAP, 2000). As the existing industrial solid waste collection, processing and disposal systems of many countries are grossly inadequate; such incremental growth will pose very serious challenges to the environment.

Expanding agricultural production has naturally resulted in increased quantities of livestock waste, agricultural crop residues and agro-industrial by-products. The approximate annual production of agricultural waste and residues in Malaysia is 42 million tones (ESCAP, 2000). From this 54.5 per cent was generated from oil palm industries, while other portions of it were mainly generated from rubber, coconut, rice and wood industries.

For two last decades, palm oil significantly showed increase of world's consumption and became important edible oil among the other, e.g. soybean oil, sunflower oil, rapeseed oil and others. This amazing increase of consumption is enabled by the spectacular growth of production sector of palm oil in the last decade. Many new plantations and palm oil milling plants are installed in South East Asia to meet demands of world's consumption. In Malaysia and Indonesia, palm oil becomes a major commodity to lead the economic growth in the area. Malaysia became the most important palm oil producer with 44% share equals by 14.962 million metric tons, leading from Indonesia (42% share) in 2005 (Basiron 2007).

The commercial variety of oil palm planted in Malaysia is *Elaeis guineensis* which originates from Africa. The species was first introduced into Malaya as ornamental plant in 1875, and started to be commercialized commodities in 1917. Since 1960, planted area for oil palm in Malaysia has been increasing rapidly, covering 4.05

million hectares in 2005 with annual growth of 10.06% (Basiron, 2007). With these areas, oil palm became largest agricultural commodities in Malaysia leaving rubber in second.

Palm oil industries contribute enormous waste and effluent to the environment. More than 70% of fresh fruit bunches processed are released as effluent and waste during the milling process. There are three major types of waste and effluent generated by palm oil milling plant. Air emission of palm oil plant consist vapor, steam blow down and particulate matters. Waste water effluent covers oil contaminated and high organic contaminated waste water. Solid waste was generated by palm oil industries in the forms of empty fruit bunch, fiber, shell, decanter cake and ashes.

The major solid wastes that result from the milling operations are empty fruit bunches, palm fiber, and palm kernel shell. The wastes that are mentioned above usually are not considered as waste, but refer as by-product since they could be used for economic purposes. Traditionally, the biomass can be treated easily as fuel source after drying under the sun. The fuel can be used for boiler to produce steam for oil palm extraction process or to move steam turbine and generate electricity (Yusoff, 2006). Empty fruit bunches or palm fiber can also be sent back to plantation as fertilizer. Pyrolysis of palm oil biomass converts it into a volatile fraction consisting of gases, vapors and tar components and a carbon rich solid residue (char) fraction. The volatile fraction can be used as a fuel or as a chemical feedstock. For the remaining solid fraction, it can be used in several applications, for example, in the production of activated carbon or used directly as a solid fuel (Luangkiattikhun et al., 2008). Palm kernel shell can be used as granular filter for water treatment, as a suitable aggregate in plain, light and dense concretes and as a road building material road (Olanipekun et al., 2006). Tangchirapat et al. (2006) utilized the palm oil fuel ash as constituents in concrete.

Decanter cake is a solid waste produced from the three phase separation step of crude palm oil process. The production rate of decanter cake amount to about 4 – 5 weight % of fresh fruit bunch processed. Fresh decanter cake contains about 70 weight

% moisture, while the dry matter contains oils, fiber and inorganic components. The most common utilization of decanter cake is as fertilizer and animal nutrition sources due to the presence of C, N, P, K and Mg (Chavalparit et al., 2006).

1.2 WASTE REDUCTION

Many methods have been developed to reduce the solid waste generation and its impact to environment. The concept of waste management include the options of prevention of waste generation, minimizing waste source, reuse, recycle, energy recovery of waste, and waste disposal. Transforming the waste into a valuable by product can be another option to reduce it and give more benefits rather than other options.

Recent studies have indicated the potential utilization of agricultural waste and solid waste as effective adsorbent. Pulp and paper mill has been investigated as a prospective adsorbent. Khalili et al. (2002) reported that conversion of paper mill sludge to useful activated carbons and biocatalysts was a significant process since it reduced environmental problems associated with disposal of waste sludge, enhanced wastewater treatment using carbons produced from industrial waste itself, and promoted conservation of the naturally available primary resources currently used to make activated carbons. Paper mill sludge was also reported capable for increasing the capability of soil to retain heavy metal, particularly cadmium and lead (Battaglia et al., 2003). Dried paper mill sludge has been successfully employed to remove lead, copper, silver and cadmium ion from aqueous solution in acid condition (Calace et al., 2003). Jha et al. (2006) also reported that pulp and paper mill sludge has been investigated to absorp nickel.

A number of studies on adsorption by sewage sludge have been reported. Sewage sludge could be transformed into activated carbon adsorbent by heat treatment (Fan and Zhang, 2008), chemical activation (Rozada et al., 2002; Martin et al., 2003; Zhang et al., 2005), or steam activation (Rio et al., 2006). Other materials like discarded tyres (Rozada et al., 2005), coconut husks (Tay et al., 2001) and rice straw

(Shuang-quan, 2009) were mixed with sewage sludge to obtain higher adsorption properties. Applications of sewage sludge, modified sewage sludge and its derivates have been investigated for dyes adsorption (Rozada et al. 2003; Martin et al., 2003), mercury removal (Zhang et al., 2005), alkaline black adsorption (Fan and Zhang, 2008), lead and chromium (III) ion removal (Rozada et al., 2008). Dried sewage sludge demonstrated ability for use as a low-cost biosorbent for phenol from wastewater (Thaworchaisit and Pakulanon, 2001). Seredych and Bandosz (2006) also reported that sewage sludge can be employed as an adsorbent to remove copper from aqueous solution.

Agricultural waste or by-products in their original form and in some cases appropriately modified have been established to have high capacity for heavy metal adsorption (Demirbas, 2008a). Agricultural by-products usually are composed of lignin and cellulose as major constituents and may also include other polar functional groups of lignin, which includes alcohols, aldehydes, ketones, carboxylic, phenolic and ether groups. These groups have the ability to some extent to bind heavy metals by donation of an electron pair from these groups to form complexes with the metal ions in solution (Pagnanelli et al., 2003). Activated carbon was developed from agricultural waste or by-products were also used for the removal of dyes from wastewater successfully (Demirbas, 2008b). Since agricultural solid wastes are freely, abundantly and locally available, its use for adsorption is expected to be economically viable for wastewater treatment.

Some of agricultural by-products that has been investigated as adsorbent for metal ion; are brown rot fungus *Lentinus edodes* (Chen et al., 2008), olive pomace (Martin-Lara et al., 2008), palm shell (Issabayeva et al., 2008), sugar cane bagasse (Gurgel et al., 2008), sugar beet pulp (Reddad et al., 2002; Pehlivan et al., 2008) , pinus bark (Vazquez et al., 2002), kenaf bark (Othman et al., 2008), peanut hull (Johnson et al., 2002), sawdust (Ajmal et al., 1998), peanut shell (Tao and Xiaoqin, 2008), hazelnut shell (Cimino et al., 2000), hazelnut husk (Imamoglu and Tekir, 2008), corncobs (Vaughan et al., 2001), and rice hull (Low et al., 1999).

With rapid development in agriculture, industry, commerce, hospital and health-care facilities, many activities are consuming significant quantities of toxic chemicals and generating a large amount of hazardous waste. Currently, there are about 110 000 types of toxic chemicals commercially available. Each year, another 1 000 new chemicals are added to the market for industrial and other uses. One of the most hazardous pollutants in environment is heavy metals. Heavy metals generally refers to the elements such as Cd (cadmium), Cr (chromium), Cu (copper), Hg (mercury), Ni (nickel), Pb (lead), and Zn (zinc) which are commonly associated with pollution and toxicity problems. Heavy metals occur naturally in rock formation and ore minerals and so a range of normal background concentration is associated with each of these elements in soils, sediments, waters and living organisms. Industrial uses of metals and other domestic processes have introduced substantial amounts of potentially toxic heavy metals into the atmosphere and into the aquatic and terrestrial environments.

In small quantities, certain heavy metals are nutritionally essential for healthy life. Some of these are referred to as the trace elements (e.g., iron, copper, manganese, and zinc). These elements, or some form of them, are commonly found naturally in foodstuffs, in fruits and vegetables, and in commercially available multivitamin products. Heavy metals are also common in industrial applications such as in the manufacture of pesticides, batteries, alloys, electroplated metal parts, textile dyes, steel, and so forth). Many of these products are in our homes and actually add to our quality of life when properly used. However, high concentrations of heavy metals are known to produce a range of toxic effect. Lead can cause encephalopathy, cognitive impairment, behavioral disturbances, kidney damage, anemia, and toxicity to the reproductive system (Pagliuca and Mufti, 1990). At high exposure level, cadmium can cause nephrotoxic effect, while after long term exposure it can cause bone damage (Friberg, 1985). Other study reported that copper can cause weakness, lethargy, anorexia, and gastrointestinal tract (Theopanides and Anastassopoulou, 2002).

Concerning the health hazard, heavy metals are among the most detrimental pollutants in source and treated water, and are becoming a severe health problem. Since the damaging effects of heavy metals in environment are known, many methods have been developed for removal of heavy metals from waste discharges. Various chemical treatment methods have been developed for the removal and recovery of heavy metals from wastewater. There are four major classes of chemical separation technologies: chemical precipitation, electrolytic recovery, adsorption/ion exchange, and solvent extraction/liquid membrane separation (Lewinsky, 2007). These major classes involves various methods including chemical treatment with lime, caustic oxidation and reduction, ion exchange, adsorption, reverse osmosis, solvent extraction, membrane filtration, electrochemical treatment and evaporative recovery. Some of chemical methods are often not economically viable especially when the effluents contain a large concentration of heavy metals. Most metal rich wastewater is treated by precipitation process. In this process, soluble metal ions are removed as insoluble hydroxide precipitates. But this process has several disadvantages. The major disadvantage with this treatment technique is the production of sludge. As a result, an aquatic problem is changed into solid waste problem. Electrolytic recovery technique uses lesser chemical consumption and recover pure metal as an added economic value, but requires high capital cost and less efficient at dilute concentrations. Solvent extraction and membrane separation provide selective heavy metal removal. Major disadvantage of these methods is high capital cost. For low concentration of heavy metal, adsorption is highly effective method to be applied. Usage of low cost adsorbent will reduce the operating cost of the process (Lewinsky, 2007).

1.3 ADSORPTION PROCESS

In general, adsorption can be defined as accumulation or depletion of solute molecules at an interface. Adsorption process can be a physical adsorption which involve only relatively weak intermolecular forces, and chemisorptions which involve the formation of a chemical bond between the sorbate molecule and the surface of the adsorbent. Chemical adsorption results in the formation of a monomolecular layer of the adsorbate on the surface through forces of residual valence of the surface molecules. Physical adsorption results from molecular condensation in the capillaries of the solid. Adsorption of heavy metals onto adsorbent is a pH dependent phenomenon. In general, the cationic species removal will increase with increasing solution pH, while in the case of inorganic ion present as anionic species; removal generally increases with decreasing pH (Lewinsky, 2007).

Heavy metal ion adsorption onto adsorbent can be characterized by some parameters. Adsorption capacity and heavy metal affinity by adsorbent can be illustrated by Langmuir and Freundlich adsorption isotherm model. Some other adsorption models can be used to explain the adsorption mechanism for specific case like Temkin isotherm, Dubinin-Radushkevich equation, Flory-Huggins isotherm, Halsey isotherm, Brunauer-Emmer-Teller (BET) model, Sips isotherm, Toth equation and Redlich-Paterson isotherm (Febrianto et al., 2008). Other important parameters of adsorption process are kinetic and thermodynamic properties. Selectivity of particular metal ion is becoming important parameter due to the complexity of wastewater composition.

1.4 PROBLEM STATEMENT

Palm oil milling plant generate large amount of decanter cake that can cause serious environmental impact. Currently, the decanter cake from palm oil milling plant are discharge as landfill, or is utilized in small quantities as fertilizer or ruminant feed ingredient. There are no further developments to transform decanter cake into more valuable by-product. In the other hand, heavy metal pollution especially in aquatic environment becomes the most detrimental pollution since heavy metal ion exposure to human can cause adverse health effects are well known. This research is aiming to solve the two of problems in one simultaneous process by utilize decanter cake from palm oil milling plant as an effective adsorbent to remove heavy metal ion from aqueous solution.

1.5 OBJECTIVES

Objectives of this research are to:

1. Investigate the nature of heavy metal adsorption onto carbonized decanter cake include equilibrium time, effect of pH, adsorption isotherm and desorption.

2. Evaluate the kinetic and thermodynamic properties of heavy metal adsorption onto carbonized decanter cake.
3. Investigate the effect of chemical activation of decanter cake on adsorption parameters.
4. Evaluate industrial application of adsorption unit base on batch experimental data in laboratory scale.

1.6 SCOPE OF WORK

This research is limited to the following scope of work:

1. The study use decanter cake from LKPP Corporation Sdn. Bhd. palm oil mill in Lepar, Pahang as sample.
2. Cadmium (II), copper (II) and lead (II) ion are employed in investigation of metal ion adsorption parameter like equilibrium time, pH effect, adsorption isotherm, kinetic and thermodynamic properties.
3. Batch experiments in laboratory scale are carried out to obtain all data in this study.

1.7 THESIS STRUCTURE

Chapter one of this thesis provides the general information and background of the research, while chapter two provides the detail information about the current status of palm oil industries, the heavy metals adsorption and their mechanisms. This chapter also presents the adsorption equilibria, kinetic and thermodynamics of adsorption.

Chapter three discusses experimental techniques used in this work. This chapter gives detail information on how decanter cake of palm oil milling plant was prepared for the experiments, and how the whole experiments are carried out. This chapter also provides the information about chemical, reagents used and characterization procedures.

In chapter four, results of the present work are presented and discussed. It also discussed the effect of parameters and various factors towards the adsorption process.

Effects of adsorbent carbonization temperature, equilibrium time, pH, initial concentration of metal ions, were varied systematically to ascertain their effects towards the adsorption process.

Conclusions of present work and recommendations for future work are discussed in chapter five.

CHAPTER 2

LITERATURE REVIEW

2.1 DECANTER CAKE OF PALM OIL MILLING PLANT

Almost in every step of palm oil extraction produce waste. The waste can be divided into two groups: liquid effluent and solid waste. In a well run palm oil mill, it is expected that each 100 tons of FFB processed yields 20 to 24 tons of crude palm oil and about 4 tons of palm kernels. Thus 72 to 76 wt percent of the FFB comes out at various stages of the process as waste (Poku, 2002). Wastes from palm oil milling plant are generated in the form of air emission, wastewater and solid waste. Solid wastes are released as empty fruit bunch, fiber, shell, decanter cake and ash. Figure 2.1 shows per ton FFB generate 530 kg of solid waste, 0.64 m^3 of wastewater flow and 12.7 m^3 gas emissions. The natural resources consumption per ton of FFB processed is 1.26 m^3 of water, 0.12 L of fuel, 14.5 kWh of electricity (Chavalparit et al., 2006).

Palm oil decanter cake is a by-product from palm oil milling decantation process. In the last stage of clarification process of crude palm oil, extracted palm oil is introduced to decanter unit. Extracted palm oil is separated into three phases in the decanter: oil phase, aqueous phase, and solid phase. Oil phase in the top of decanter cake are collected as product and sent to refined-bleached-deodorized palm oil plant. Aqueous phase is discharged as palm oil milling effluent. Fine solid particles which are suspended in extracted palm oil will be completely decanted after certain residence time. A screw conveyor in the bottom of the decanter discharges the decanter cake from