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POTENTIAL USE OF PALM OIL FUEL ASH AS A CONSTRUCTION MATERIAL

PUI YUN FATT

A project report submitted in partial fulfillment of the
requirements for the award of the degree of
Master of Science (Construction Management)

Faculty of Civil Engineering
Universiti Teknologi Malaysia

MAY 2011

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To my beloved parents, siblings, and friends

Thanks for your never ending love and support

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ABSTRACT

Malaysia is one of the world's largest producer and exporter of palm oil and Besides that, palm oil industry shows their concern regarding to the palm oil renewable energy. One of the renewable energy implementing method is reuse or recycles the waste and effluent from palm oil mill in order to reduce the environment pollution. The solid waste such as empty fruit shell (EFS), empty fruit fiber (EFF) and empty fruit bunches (EFB) can be used as bio-fuel in biomass boiler to generate recovery energy for the palm oil mill process and other industry use. However, biomass boiler produce by-product known as boiler ash or palm oil fuel ash (POFA) is considered as hazardous materials without any commercial return would disposes directly to the environment. Thus, this study is important to discover the potential use of POFA as construction materials such as cement replacement material in order to reduce harmful effect to the environment. The investigations were carried out to further understand the local palm oil mills waste management practice by the interview and questionnaire survey method. The potential barriers and suggestions were also identified from the local palm oil and construction industry through this research. In conclusion, the POFA disposal is considered as a costly practice and very few of the local palm oil mills are aware of the utilization of the POFA in other applications. In addition, there are several important influence factors and feedbacks that need to taken into consideration especially the attitude or acceptance of construction industry toward the new materials, continuously exploration, increase of production rate and the role of government in promoting POFA. The research also showed that more effort is necessary to boost this project towards creating a sustainable environment.

ABSTRAK

Malaysia merupakan salah satu pengeluar dan pengeksport minyak sawit yang terbesar di dunia. Selain itu, industri minyak sawit menunjukkan minat dalam bidang tenaga boleh diperbaharui. Penggunaan atau mengitar sisa pepejal dan cair daripada kilang kelapa sawit merupakan antara kaedah-kaedah pelaksanaan tenaga boleh diperbaharui yang sedang dilaksankan oleh pihak kilang minayk sawit tempatan bertujuan mengurangkan akibat pencemaran alam sekitar. Sisa pepejal seperti tempurung kelapa sawit (EFB), sabut kelapa sawit (EFF) dan tandan kelapa sawit (EFB) boleh digunakan sebagai bahan api bio oleh dandang loji janakuasa untuk menghasilkan tenaga bagi kegunaan proses dalaman kilang kelapa sawit atau industri-industri yang lain. Namun, bahan hasil sampingan dandang loji janakuasa yang dikenali sebagai *boiler ash* atau abu kelapa sawit (POFA) dianggap sebagai bahan pencemaran tidak mempunyai pulangan komersial yang akan dibuang terus ke alam sekitar. Oleh demikian, kajian ini amat penting untuk memcari potensi penggunaan POFA sebagai bahan pembinaan seperti sebagai bahan pengganti simen yang boleh mengurangkan kesan pencermaran kepada alam sekitar. Selain daripada itu, kaedah-kaedah seperti soal selidik dan temuduga telah dijalankan agar lebih memahami amalan pengurusan sisa buangan kilang kelapa sawit tempatan. Pendapat and faktor-fator yang berpotensi yang dapat menpengaruhi penggunaan POFA telah dikenalpasti daripada industri minyak sawit tempatan dan pembinaan. Kesimpulannya, pembuangan POFA adalah sesuatu yang memerlukan perbelanjaan yang besar dan hanya sebilangan kecil kilang kelapa sawit tempatan yang sedar akan penggunaan POFA dalam aplikasi lain. Tambahan itu, terdapat beberapa faktor pengaruh dan suapbalik yang perlu dipertimbangkan terutamanya sikap dan penerimaan indusri pembinaan terhadap bahan pembinaan baru, penerokaan berterusan, peningkatan kadar penghasilan and peranan kerajaan dalam

mempromosikan POFA. Kajian ini juga menunjukkan bahawa lebih banyak usaha diperlukan untuk menyokong projek ini demi mencipta persekitaran yang berlestari.

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LIST OF ABBREVIATIONS

ton	-	Tonne
%	-	Percentage
^oC		Celsius
m^2/kg	-	Meter Square per Kilogram
μm	-	Micrometer
mm^2/g	-	Millimeter Square per Gram
Mpa	-	Mega pascal
RM	-	Ringgit Malaysia
POFA	-	Palm Oil Fuel Ash
CPO	-	Crude Palm Oil
FFP	-	Fresh Fruit Palm
FFB		Fresh Fruit Bunches
EFB	-	Empty Fruit Bunches
EFF	-	Empty Fruit Fiber
EFS	-	Empty Fruit Shell
POME	-	Palm Oil Mill Effluent
CRM	-	Cement Replacement Material
OP	-	Ordinary Portland Cement
MP	-	Medium Size POFA Replacement Cement
SP	-	Small Size POFA Replacement Cement
GGBS	-	Ground Granulated Blast Furnace Slag
FELDA	-	Federal Land Development Authority
FELCRA	-	Federal Land Consolidation and Rehabilitation Authority
RISDA	-	Rubber Industry Smallholders Development Authority
GLC	-	Government - Linked Company

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CHAPTER 1

INTRODUCTION

1.1 Introduction

Malaysia is one of the world's largest palm oil producer and exporter. The total export of palm oil products is 22,427,049 tons with includes crude palm oil (2,537,433 tons), processed palm oil (13,343,311tons), crude palm oil kernel oil (184,296 tons), processed palm kernel oil (933,182 tons), palm kernel oil (1,117,478 tons) and palm kernel cake (2,381,571 tons) in year of 2009. The total value of palm oil products is RM 49,659.00 million with total palm oil RM 36,947.6 million and total palm kernel oil RM 3,021.2 million. There are 30 major palm oil exporting countries in year 2009 such as China (4,027,229 tons), European Union (1,892,099 tons), Pakistan (1,257,396 tons) and India (1,354,429 tons). (Malaysia Palm Oil Board, 2010)

Palm oil plantation requires less area compare to the other oilseed plantation. Malaysian palm oil plantation area makes up about 1.85% of the total world oilseed area. The total palm oil planted area is about 4,304,913 hectares which is divided to Peninsula Malaysia about 2,362,057 hectares and Borneo Malaysia about 1,942,856 hectares in year 2007. The total oil palm planted area increased to 4,487,957 hectares with Peninsula Malaysia making up about 2,410,019 hectares and Borneo about 2,077,938 hectares. (Malaysia Palm Oil Board, 2010)

The palm oil industry has shown interest toward renewable energy development. There are many significant products or implementations in palm oil industry such as bio-diesel, bio-mass, bio-gas, bio-plastic, bio-compost, ply-wood, activated carbon and animal feedstock. Besides that, the palm oil waste such as EFB and POME can be used as bio-fuel and bio-gas to generate electricity at power plants. The palm oil industry shows large potential in the future sustainable development. (Sumathi et. al, 2008)

1.2 Background of study

The processing of fresh fruit palm (FFP) starts when it is received at the mill and ends when it is becomes crude palm oil. Then, the crude palm oil stored in the mill storage tank. In the process, large amount of high organic waste are product such as palm oil mill effluent (POME), empty fruit shell (EFS), empty fruit fiber (EFF) and empty fruit bunches (EFB) are produced. The discharge of this high organic waste will cause negative impact to the environment. Thus, local palm oil mills will reuse or recycle the palm oil waste in order to reduce the harmful effect to the environment. Firstly, the POME, EFS and EFF can be used in generating recovery energy. On the other hand, the EFB can produce fertilizer for agricultural purposes. (Sumathi et. al, 2008)

The EFS and EFF are used as bio-fuel in palm oil mill boiler to produce steam for electricity generation and palm oil extraction process. However, palm oil mill boiler produces another by-product which is boiler ash or palm oil fuel ash (POFA). The weight of POFA is about 5% weight of the original EFS and EFF. In addition, the physical properties and chemical analysis indicated that POFA is a pozzolanic material that grouped in between Class C and Class F as specified in ASTMC618-08a.

Besides that, POFA is highly reactive and posses pozzolanic properties that is suitable for use in construction industry as a cement replacement material (CRM). Additionally, POFA showed good improvement in the properties of concrete in terms of compressive strength, drying shrinkage, water permeability, resistance to alkali-silica reaction, carbonation, chloride and sulfate. (Altwair and Kabir, 2010) (Weerachart et al., 2007) and (Mohamed et. al., 2010)

Local palm oil mill will dispose the POFA directly to the environment. As a result, the minerals and traces metals of POFA such as Al, Mg, Cr and Fe are emitted to soil when in contact with the ground. The impact of POFA is category under eco-toxicity. (Subramaniam et. al, 2008) In additional, the toxicity characteristic leaching procedure (TCLP) method indicated that POFA should not be classified as toxic wastes in terms of heavy metal leach ability. (Yin el. al, 2008)

1.3 Problem statement

The utilization of palm oil waste as the fuel resource is considered as another alternative renewable energy resource to solve energy shortage problems. However, increasing the usage of palm oil waste required in order to generate energy also increases the production of its by-produce (POFA). This is a serious issue as POFA cannot be reused or recycled and will be disposed directly into the environment. The increase of the POFA amount will harm the environment as if it is under eco-toxicity.

Thus, the studies have shown that the palm oil wastes have great potential to be commercialized as the sustainable construction materials besides generating energy. In addition, there are many studies about the reuse and recycle of the POFA as the cement replacement material. However, the construction material market still lacks awareness towards the great potential use of the POFA.

,

1.4 Research aim and objectives

The aim of this study is to discover the potential use of the palm oil fuel ash as the construction materials. To achieve this aim, the following objectives of this study have been identified as below:

1. To find out the current POFA disposal practice in local palm oil mills.

2. To identify the factors that influences the use of POFA as the construction materials.

3. Strategize the alternative ways to promote POFA as the construction material.

1.5 Research scopes and limitations

The scope of study is limited to the local palm oil waste management system especially solid waste management in Peninsula Malaysia and Borneo Malaysia. Besides that, the scope also focuses on local construction industry in order to understand the current cement replacement materials demand. The study will be limited to investigate the current local palm oil mill scenario and the critical factors that influence the POFA as the future sustainable construction material.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

This chapter discusses comprehensively about the palm oil industry real scenario and sustainable development. Besides that, this chapter also discusses about the properties and performance of POFA in concrete.

2.2 Palm oil fuel ash

POFA or boiler ash consists of clinkers and ash due to burning of the EFF and EFS with equal volume in order to produce steam for electricity generation and palm oil extraction process. The POFA that produced is about 5% weight of the original solid materials. However, POFA is considered as worthless hazardous materials or without any commercial return and is usually directly disposed to environment.

The physical properties of it and chemical analysis indicate that POFA is categories as pozzolanic material. POFA is grouped in between Class C and Class F as specified in ASTMC618-92a. In additional, the POFA optimum particle size is 10 μm that enables it to highly react as a unique cement replacement for building construction materials. Many researches have proven that POFA is able improve the properties of concrete in terms of compressive strength, drying shrinkage, water permeability, alkali-silica reaction, carbonation resistance, resistance to chloride penetration and sulfate resistance. (Altwair and Kabir, 2010)

2.2.1 Chemical content

According to Rukzon and Chindaprasirt (2008), the main chemical components of POFA are 63.6% of silicon dioxide (SiO_2), 7.6% of calcium oxide (CaO) and 6.9% of potassium oxide (K_2O). The sum of SiO_2, aluminium oxide, (Al_2O_3) and iron oxide (Fe_2O_3) is 66.6% which is slightly less than 70% as required for natural pozzolan according to ASTM C618-08a. However, the chemical composition can vary depending on the different palm oil mill. Table 2.1 showed the POFA chemical composition from 8 different palm oil mills in Johor, Malaysia can be various. Pekan palm oil mill and Trong palm oil mill contain the highest percentage of silica, SiO_2 about 71.20% respectively. While, the lowest SiO_2 content of POFA is from Kluang mill about 49.20%. On the other hand, Masai palm oil mill and Kluang contain the highest sulphur trioxide (SO_3) which about 1.76% and 1.73% respectively. (Galau, 2010)

Table 2.1: Chemical composition from 8 different mills from Johor State (Galau, 2010)

Mill	Chemical Composition (%)						
	SiO_2	Fe_2O_3	CaO	MgO	SO_3	K_2O	CO_2
Kota Tinggi	52.50	5.73	11.30	3.55	0.82	10.20	0.10
Masai	52.30	6.78	10.80	5.43	1.76	11.40	0.10
Alaff	59.60	8.77	8.06	3.90	0.57	7.64	0.10
Kluang	49.20	5.73	17.50	3.53	1.73	9.49	0.10
Trong	71.20	7.12	4.37	1.95	0.89	5.59	0.10
Rantau	56.70	11.40	6.81	3.31	0.87	7.83	0.10
Pekan	71.20	10.10	5.68	1.31	-	5.68	0.10
Carey	58.30	9.77	6.72	3.69	0.96	8.40	0.10

2.2.2 POFA concrete durability performance

2.2.2.1 Compressive strength

According to Weerachart et al (2007) study, POFA concrete compressive strength is very much influenced by the level of replacement and fineness of the POFA. The Ordinary Portland concrete with 10%, 20% 30% and 40% of POFA replacement showed a decreasing compressive strength with the increased of the replacement level compared to the Portland cement type I (CT1) and Portland cement type V (CT5). CT 1 and CT 5 is the Portland cement that contains tricalcium aluminate (C_3A) about 6.84% and 0% respectively. (American Society for Testing and Materials, 2008). The result of this study is shown in Figure 2.1, 2.2, and 2.3.

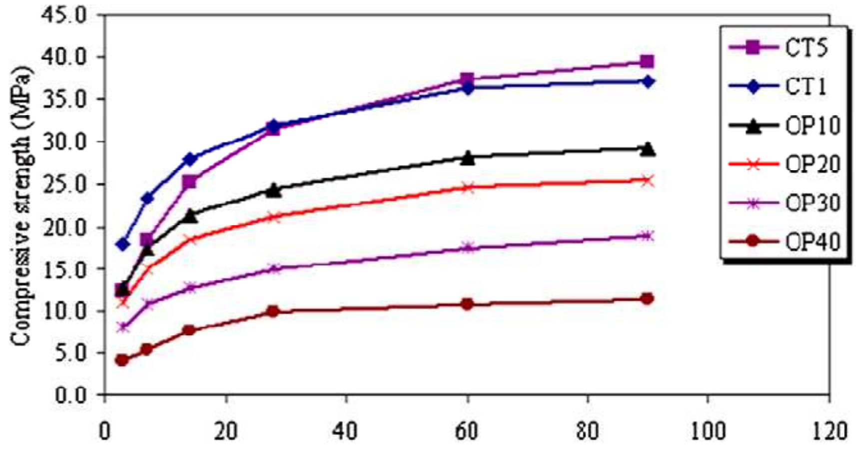


Figure 2.1: Age of concrete (days) OP Concretes

(Weerachart et al., 2007)

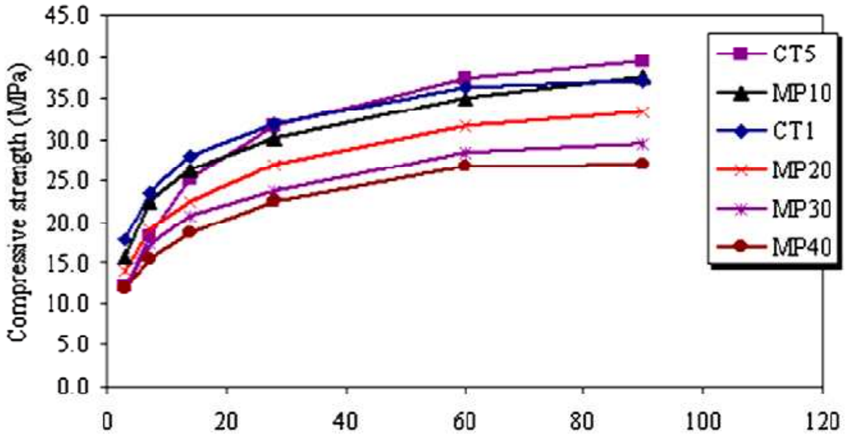


Figure2.2: Age of concrete (days) MP Concretes

(Weerachart et al., 2007)

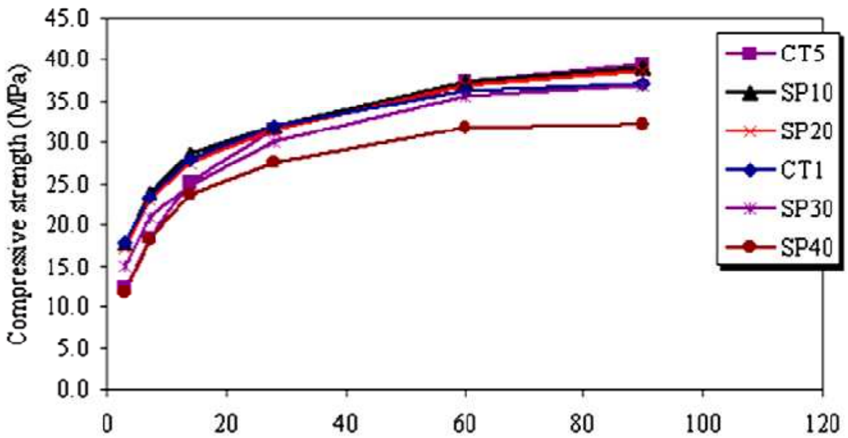


Figure 2.3: Age of concrete (days) SP Concretes

(Weerachart et al., 2007)

2.2.2.2 Chemical attack

The study has shown that the concretes bars of CT1, CT5, original size of POFA(OP), medium size of POFA (MP) and small size of POFA (SP) showed the different performance toward sulfate attract in 5% magnesium sulfate solution (Expansion Test). The control concretes bars of CT1 and CT5 showed 0.047% and 0.038% expansion respectively at 364 days. However, the concrete bars of OP had shown the higher expansion compared with CT5 concretes bars at all replacement levels. In addition, OP concrete bars expansion value is higher than the CT1 concrete bar with 10% and 20% replacement levels at 364 days. The physical properties of the sample materials are shown in Table 2.4.

Table 2.2: Physical properties of materials (Weerachart et. al., 2007)

Sample	Specific gravity	Retained on 45 μm sieve (No. 325), %	Medium particle size (d_{50}), μm
Portland cement type I	3.14	N/A	14.7
Portland cement type V	3.17	N/A	7.5
OP	1.89	94.4	183.0
MP	2.36	`19.5	15.9
SP	2.43	1.0	7.4

Note: N/A, not applicable.

The concrete bars of OP with 30% replacement level showed improvement in the expansion performance with 0.046%. The expansion of OP is close to the CT1 concrete bars at 0.047% expansion. OP with 40% of replacement level caused the highest expansion of concrete bar that is about 0.065%. In addition, OP with 40% replacement levels caused a higher water-to-binder ratio and causes the decrease in sulfate resistance of OP concrete bars. However, the OP with 30% of replacement level of the compressive strength of concretes was too low compared to the CT1 concrete. Thus, the OP is not suitable to be used as a pozzolanic material in concrete. (Weerachart et. al., 2007)

However, Prasad et. al. (2006) research results have shown that both of the C_3A and tricalcium silicate (C_3S) content in the cement are very important in influencing the acid attract performance. However, the C_3A is not the sole parameters that cause the expansion of the concrete bars. The sole parameter of the expansion in this study is C_3S content according to the research of the Gonzalez and Irassar (1997) investigation regarding to the sulfate attack mechanism on four cements with low C_3A content (0–1%) and a C_3S content that varied from 40% to 74%. Thus, the results showed that the increased of the C_3S content caused greater expansion of the concretes bars in CT1 and CT5.

2.2.3 Factors that influence the POFA concrete performance

2.2.3.1 Fineness

The Figure 2.1, 2.2, and 2.3 showed that POFA concrete performance is better that the ordinary portland with medium size (MP) and small size (SP) replacement of POFA. This indicated that the MP and SP increased the contributed to the increase of the concrete compressive strength by pozzolanic reaction. The compressive strength of the MP with 10% and 20% of POFA replacement level are about 94% and 84% compressive strength at 28 days then increased to 101% and 90% compressive strength at 90 days respectively compared to CT1.

While, the SP with 10%, 20% of POFA replacement showed higher compressive strength performance at 28 days and about 100% and 99%, 105% and 104% respectively at 90 days compared to CT1. In additional, the SP with 30% POFA replacement level showed the compressive strength about 99% of the CT1. Thus, the POFA replacement has shown great improvement towards concretes compressive strength as the fineness of the POFA increased. (Weerachart et. al, 2007)

2.2.3.2 Proportion

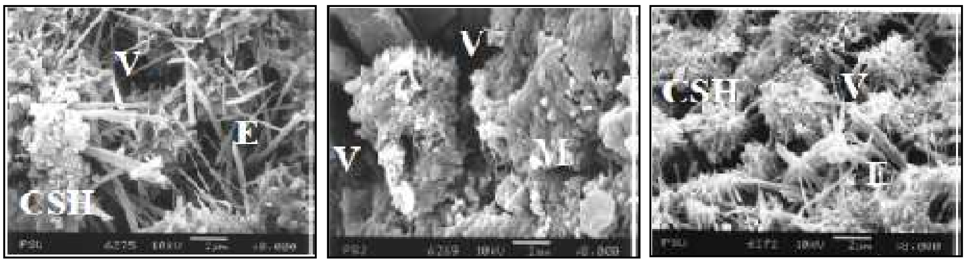
The different proportion of the POFA replacement is the other main factor that influences the characteristic of the POFA concretes. The study of the Weerachart et al. (2007) showed the decreased of the ordinary Portland concretes compressive strength as the replacement levels of the POFA in the concretes increased (10%, 20%, 30% and 40%). However, the MP concrete with 10% and 20% of the replacement levels at 28 and 90 days were about 94% and 84% or 101% and 90% of compressive strength compared to CT1. In addition, the SP concretes with 10% and 20% replacement levels of POFA improved at 28 and 90 days and about the 100% and 99% or 105% and 104% compressive strength compared to CT1. While, the SP concretes with 30% replacement levels showed compressive strength close to 99% compared to the CT1.

On the other hand, the proportional factor greatly influences the expansion of the POFA concretes in term of compressive strength. The study showed that the OP concrete bars with 10% and 20% mixture had higher expansion than the CT1 concrete bars. In addition, the concrete bars with 30% of replacement levels had the lowest expansion (0.046%) and was close to the expansion of the CT1 (0.047%). The MP concrete bars with 10%, 20%, 30% and 40% replacement levels had the lower expansion values compared to OP concretes bars values about 0.053%, 0.049%, 0.045% and 0.043% at 364 days. The result showed that increase of MP replacement levels will cause the reduction of the concrete bars expansion values.

Thus, the replacement levels about 30%-40% showed the expansion values which were less than CT1 concrete bars. The SP concrete bars with 10%, 20%, 30% and 40% replacement level showed the lowest expansion values compare to MP: 0.046%, 0.042%, 0.040% and 0.036% (346 days). The SP replacement levels at 40% even showed lower values than CT5.

2.2.4 Scanning electron micrographs

The scanning electron micrographs (SEM) analysis of concretes confirmed that there is evidence of pozzolan reaction between the POFA and cement matrix. This will certainly have a reinforcement effect on the compressive strength of concrete made with normal aggregate and might also affect the hardening on concrete. The result of SEM analysis showed in Figure 2.4. (Tonnayapas, 2006)



(a) **(b)** **(c)**

Figure 2.4: SEM micrograph of concrete at age of 28 days with magnification of 8,000 (a) control, (b) containing 15%POFA and (c) containing 25% POFA. (Tonnayapas, 2006)

2.2.5 Other cement replacement material

2.2.5.1 Ground granulated blast furnace slag

Slag is generated during the production of iron and steel. Granulated foamed or dense blast furnace slag can be produced depending on the rate and manner of cooling of the molten slag. Blast furnace slag increases cement chemical attack resistances due to it high slag content up to 60% that enables it to reduce the heat evolution rate. As a result, the low rate of heat evolution causes the blast furnace cement early strength and is less affected by the hot weather. Thus, blast furnace slag cements are suitable to be used in hot weather, mass concrete and high chemical resistance marine structure. (Gambhir, 2004)

While, the high calcium fly ash and granulated blast furnace slag both have similarities in term of mineralogical character and reactivity. These two materials are essentially noncrystalline, and highly calcium glass reactive in both cases appears to be similar. Additionally, high calcium fly ash and granulated blast furnace slag contribute significant strength as early as 7 days after hydration. Although particle size characteristics, composition of glass, and the glass content are primary factors determining the reactivity of slag, it may also be noted that the glass itself varies with the thermal history of the material.

Slag particles less than 10 μm contribute to early strength of concrete up to 28 days and particles of 10 to 45 μm contribute to later strength, while particles coarser that 45 μm are difficult to hydrate. Generally, slag obtained after granulation is very coarse and humid. Thus, the slag after granulation needs to be dried and pulverized to particles mostly fewer than 45 μm and corresponding to approximately 400 to 500 m^2/kg Blaine surface area. (Mehta and Monteiro, 2006)

2.2.5.2 Fly ash

Fly ash or pulverized fuel ash is by product of the combustion of powered coal in modern thermal power plants which is the fine dust carried upward by combustion gases and collected in cyclones or wet scrubbers, and electronic precipitators. The bulk ash which is grayish in color becomes darker with increasing proportions of unburnt carbon.

The use of fly ash in concrete contribute to the direct water reduction, increase in the effective volume of paste in the mix and high resistance toward sulphate attack due to low rate of heat evolution. However, fly ash reduces the rate of development of strength and increase drying shrinkage and creep strains. The early strength of fly ash concrete is also less than that of portland, its proportion is generally limited to 30% in the same situation where early strength is important. (Gambhir, 2004)

Typically, the fly ash can be divided into low calcium and high calcium fly ash. The spherical particles in low calcium fly ash look cleaner than those in high calcium fly ash. The studies show that the particles in a typical fly ash vary from ≤ 1 μm to nearly 100 μm in diameter, with more than 50% by mass less than 20 μm. The particle size distribution, morphology, and surface characteristics of the fly ash selected for use as a mineral admixture exercise are considerable influences on the water requirement and workability of fresh concrete and rate of strength development in hardened concrete. (Mehta and Monteiro, 2006)

2.2.4.3 Silica fume

Silica-fume is known as volatilized silica, microsilica, or condensed silica fume. Silica-fume is the by-product of the silicon metal and ferrosilicon alloy industries in the reduction process of high purity quartz with coal in electric arc furnaces during the production of ferro-silicon metal. Silica-fume is able to react efficiently with the hydration products of portland cement in concrete due to its extreme fineness (about 20,000,000 mm^2/g) and high glass content.

Silica-fume is generally more efficient in concretes having high water-cement ratios. In addition, mixture of silica-fume make it possible to produce ultra high strength concrete (of the order of 70 to 120 Mpa) with improve in modulus of electricity, low creep and drying shrinkage, excellent freeze-thaw resistance, low permeability and increase chemical resistance. (Gambhir, 2004)

Silica fume shows particle size distributions that are two orders of magnitude finer compared to ordinary portland cement and typical fly ashes. However, it is hard to handle even posse high pozzolanic reaction because it increases the water requirement in concrete appreciably unless high range water-reducing admixtures are used. The by-products from the silicon metal and the ferrosilicon alloy industry, producing alloys with 75% or higher silicon content, contain 85 to 95% noncrystalline silica. Thus, the by-product from the production of content is unsuitable for use as a pozzolanic material. (Mehta and Monteiro, 2006)

Silica-fume in concrete can be used for the following purposes:

1. To conserve cement
2. To produce ultra high strength concrete
3. To control alkali-silica reaction
4. To reduce chloride associated corrosion and sulphate attack
5. To increase early age strength of fly ash/slag concrete

2.2.4.4 Rice husk ash

Rice husks, also called rice hulls, are the shells produced during the dehusking operation of paddy rice in rice mill. Because of its very low density, rice husk requires large space for storage and hauling. For example in India it is disposed by burning in order to reduce the bulky waste to manageable volumes of ash of less than 50% of its initial volume. However, this method of disposal presents a huge environmental problem to the nation. Each tonne of paddy produce about 200 kg of husk and on combustion yield approximately 40kg ash. (Gambhir, 2004)

The uncontrolled combustion in furnaces produces a large proportion of less crystalline reactive silica minerals (cristobalite and tridymite) and these must be ground to a very fine particle size in order to develop some pozzolanic activity. A highly pozzolanic ash can be produced by controlled combustion when silica is retained in a noncrystalline form and in a cellular microstructure. This type of rice husk ash produced sample about 50 to 60 m^2/g surface area by nitrogen adsorption. (Mehta and Monteiro, 2006)

Generally, natural organic waste materials often contain substances (cement poisons) which retard the hydration and hardening of cement. However, rice husks contain only very small quantities of waste-soluble cement poisons as compared to saw dust. Rice-husk ash is make up of amorphous SiO_2 (80 to 90%), KO_2 (1 to 2%) and the rest being unburnt carbon. Thus, the ground reactive rice-husk ash is able to blend with ordinary portland cement to produce satisfactory hydraulic acid resistant cements.

The pozzolanas usually contribute to the concrete strength in the later stage. However, the rice-husk ash contribute concrete strength in the early stage because the hydration produces calcium hydroxide ($Ca(OH)_2$) which quickly combines with highly reactive silica of rice-husk ash to form additional calcium silicates. The ordinary portland will deterioration in acidic environment due to 60 to 65% of calcium oxide (CaO) will be released upon hydration as free Ca $(OH)_2$. The rice husk ash concrete is more resistant to acid environment due to it containing less CaO (about 20%). Thus, none of the product of the hydration of free limes would be present as Ca $(OH)_2$, the products of hydration being mainly calcium silicate hydrates and silica gel. (Gambhir, 2004)

2.3 Palm oil industry

2.3.1 Palm oil mills in Malaysia

According to Table 2.2 and 2.3, Malaysia is one of the world largest palm oil producer and exporter till year 2008. While, the Table 2.4 shown the total palm oil product export is 21,763,929 tons with value of RM 65,215.2 million in 2008. Then, the total palm oil products increased to 22,427,049 tons with value of RM 49,659.0 million in 2009. Thus, these show the great potential contribution of palm oil industry toward the nation economy. There are 30 major palm oil export countries in year 2009 such as China (4,027,229 tons), European Union (1,892,099 tons) and India (1,354,429 tons) shown in Table 2.5. (Malaysia Palm Oil Board, 2010)

Table 2.3: World major producers of palm oil year 1999-2008 (Malaysia Palm Oil Board, 2010)

Country	Volume ('000 tons)									
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Indonesia	6,250	7,050	8,080	9,370	10,600	12,380	14,100	16,050	17,270	19,330
Malaysia	10,554	10,842	11,804	11,909	13,355	13,976	14,962	15,881	15,824	17,734
Thailand	560	525	625	600	690	735	700	860	1,020	1,170
Nigeria	720	740	770	775	785	790	800	815	835	860
Colombia	500	524	548	528	527	632	661	713	732	800
Ecuador	263	218	228	238	262	279	319	352	396	415
P. N. Guinea	264	336	329	316	326	345	310	365	384	400
C. d'Ivoire	264	278	205	265	240	270	320	330	320	330
Hondurans	90	101	130	126	158	170	180	195	220	268
Brazil	92	108	110	118	129	142	160	170	190	220
Costa Rica	122	137	150	128	155	180	210	198	200	202
Guatemala	53	65	70	86	85	87	92	125	130	139
Vanezuela	60	70	52	55	41	61	63	65	70	56
Others	833	873	883	895	906	940	969	1,023	1,083	1,194
Total	**20,625**	**21,867**	**23,984**	**25,409**	**28,259**	**30,987**	**33,846**	**37,142**	**38,674**	**43,118**

Table 2.4: World major exporters of palm oil year 1999-2008 (Malaysia Palm Oil Board, 2010)

Country	Volume ('000 tons)									
	1999	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**
Indonesia	8,912	9,081	10,625	10,886	12,266	12,575	13,445	14,423	13,747	15,413
Malaysia	3,319	4,139	4,940	6,490	7,370	8,996	10,436	12,540	12,650	14,470
P. N. Guinea	254	336	327	324	327	339	295	362	368	395
Colombia	90	97	90	85	115	214	224	214	316	328
Singapore *	292	240	224	220	250	237	205	207	186	205
C. d'Ivoire	101	72	74	65	78	109	122	109	106	116
Hong Kong *	94	158	192	318	185	127	39	20	20	28
Others	788	896	1,099	1,027	1,320	1,647	1,736	2,121	2,474	2,665
TOTAL	**13,850**	**15,019**	**17,571**	**19,415**	**21,911**	**24,244**	**26,502**	**29,996**	**29,867**	**33,620**

Table 2.5: Export volume and value of palm oil products of year 2008 and 2009 (Malaysia Palm Oil Board, 2010)

Palm Oil Production	**Volume (tons)**		**Value (RM million)**	
	2008	**2009**	**2008**	**2009**
Crude palm oil	2,336,577	2,537,433	6,379.4	5,739.5
Processed palm oil	13,075,935	13,343,311	41,546.6	31,208.1
Total palm oil	15,412,512	15,880,744	47,925.9	36,947.6
Crude palm kernel oil	149,182	184,296	521.0	408.2
Processed palm kernel oil	898,236	933,182	3,638.8	2,613.0
Total palm oil kernel oil	1,047,418	1,117,478	4,159.8	3,021.2
Palm kernel cake	2,261,268	2,381,571	990.9	496.1
Oleochemicals	2,075,897	2,174,667	8706.4	6,582.9
Biodiesel	182,108	227,457	610.7	605.8
Finished Production	670,612	580,233	2,656.6	1,913.2
Other	114,114	64,898	164.8	92.2
Total palm oil product	**21,763,929**	**22,427,049**	**65,215.2**	**49,659.0**

Table 2.6: Export of palm oil to major destinations year 2008 and 2009 (Malaysia Palm Oil Board, 2010)

Country	Volume (tons)	
	2008	2009
China, P. R.	3,794,494	4,027,229
European Union	2,052,771	1,892,099
Pakistan	1,257,396	1,769,321
India	970,734	1,354,429
U. S. A.	1,047,668	859,401
Egypt	347,558	609,210
Ukraine	486,451	544,143
Japan	547,468	538,878
Singapore	355,216	353,477
Benin	343,359	353,275
Iran	259,511	342,273
South Korea	196,470	293,233
Vietnam	202,354	241,340
Russia	122,530	210,603
UAE	357,949	186,878
Myanmar	130,916	181,331
Taiwan	132,150	150,767
Djibouti	104,121	136,239
Australia	119,271	126,152
Philippines	161,453	119,255
South Africa	156,950	114,661
Bangladesh	271,265	109,771
Sri Lanka	61,576	102,904
Oman	92,942	98,601
Togo	106,242	95,707
Mauritania	64,994	81,966
Yemen	63,119	76,793
Ghana	114,162	74,949
Other	1,491,422	835,860
Total	**15,412,512**	**15,880,744**

2.3.1.1 Palm oil plantation area

According to Table 2.6, palm oil planted areas are categorized to the private, government schemes, state schemes and smallholders. This statistic clearly show the growing of Malaysia palm oil planted area from year 2007 until 2009. The majority of palm oil planted area is owned by private estates about 2,598,859 hectares (60.37%), 2,706,876 hectares (60.31%) and 2,807,210 hectares (59.84%) in year of 2007, 2008 and 2009 respectively.

The second largest palm oil planted area is owned by government schemes. The government schemes palm oil planted areas are divided under few important agencies such as FELDA, FELCRA and RISDA. The statistic shows that FELDA owned palm oil planted area were about 676,977 hectares (15.73%) in year 2007, 675,167 hectares (15.04%) in year 2008 and 705,607 hectares (15.04%) in year 2009. Mean while, FELCRA owned palm oil planted area consisted about 163,891 hectares (3.81%) in year 2007, 163,511 hectares (3.65%) in year 2008 and 160,832 hectares (3.43%) in year 2009. RISDA owned palm oil planted area were about 81,386 hectares (1.89%) in 2007. 81,486 hectares (1.89%) in year 2007, 80,262 hectares (1.79%) in year 2008 and 78,932 hectares (1.68%) in year 2009. The other state schemes and smallholders also own certain amount of palm oil planted area.

On the other hand, the Malaysia owned palm oil planted area can be divided into different states. The total Malaysia palm oil planted area in year 2007 is about 4,304,913 hectares (Peninsula Malaysia about 2,362,057 hectares and Borneo Malaysia about 1,942,856 hectares) as shown in Table 2.6. Malaysia total palm oil planted area increased from 4,487,957 hectares in year 2008 (Peninsula Malaysia about 2,410,019 hectares and 2,077,938 hectares) to 4,691,160 hectares in year 2009 (Peninsula Malaysia about 2,489,814 hectares and 2,201,346 hectares) as shown in Table 2.7, 2.8 and 2.9.

Table 2.7: Distribution of palm oil planted area by category year 2007, 2008 and 2009 (Malaysia Palm Oil Board, 2010)

Category	2007		2008		2009	
	Hectares	**Percentage**	**Hectares**	**Percentage**	**Hectares**	**Percentage**
Private Estates	2,598,859	60.37%	2,706,876	60.31%	2,807,210	59.84%
Govt. Schemes:						
FELDA	676,977	15.73%	675,167	15.04%	705,607	15.04%
FELCRA	163,891	3.81%	163,511	3.65%	160,832	3.43%
RISDA	81,486	1.89%	80,262	1.79%	78,932	1.68%
State Schemes	313,545	7.28%	321,947	7.17%	329,543	7.03%
Smallholders	470,155	10.92%	540,194	12.04%	609,036	12.98%
Total	**4,304,913**	**100.00%**	**4,487,957**	**100.00%**	**4,691,160**	**100.00%**

Table 2.8: Distribution of oil palm planted area by states year 2007 (Malaysia Palm Oil Board, 2010)

State	Plantation Area (Hectares)						Total
	S/Holders (Licensed)	**FELDA**	**FELCRA**	**RISDA**	**State Schemes/ Govt. Agencies**	**Private Estates**	
Johor	151,025	119,740	22,070	5,134	43,921	328,751	670,641
Kedah	15,484	510	1,124	1,252	1,916	54,810	75,096
Kelantan	1,873	38,230	5,314	767	8,878	44,701	99,763
Melaka	6,419	2,848	2,411	1,966	-	35,469	49,113
N. Sembilan	15,229	46,125	7,644	10,523	3,003	88,319	170,843
Pahang	29,213	284,228	31,283	22,112	55,956	218,660	641,452
P. Pinang	7,054	-	511	56	-	5,683	13,304
Perak	72,292	20,252	31,548	19,779	12,717	193,395	350,983
Perlis	61	-	199	-	-	-	260
Selangor	30,685	4,989	4,297	342	1,126	87,876	129,315
Terengganu	5,435	38,500	19,862	19,555	12,732	65,103	161,287
P. Malaysia	**334,770**	**555,422**	**126,363**	**81,486**	**141,249**	**1,122,767**	**2,361,057**
Sabah	106,186	113,874	14,690	-	94.087	949,407	1,278,244
Sarawak	29,199	7,681	22,838	-	78,209	526,685	664,612
Sabah/Sarawak	**135,385**	**121,555**	**37,528**	**-**	**172,296**	**1,476,092**	**1,942,856**
Malaysia	**470,155**	**676,977**	**163,891**	**81,486**	**313,545**	**2,598,859**	**4,304,913**

Table 2.9: Distribution of oil palm planted area by states year 2008 (Malaysia Palm Oil Board, 2010)

State	Plantation Area (Hectares)						Total
	S/Holders (Licensed)	FELDA	FELCRA	RISDA	State Schemes/ Govt. Agencies	Private Estates	
Johor	170,549	118,543	22,088	5,063	43,824	327,839	687,906
Kedah	17,073	685	1,124	1,207	2,265	54,726	77,080
Kelantan	2,086	36,069	4,188	767	13,492	47,034	103,636
Melaka	7,559	2,848	2,396	1,892	-	33,713	48,408
N. Sembilan	18,162	48,655	7,564	9,979	2,888	84,399	171,647
Pahang	31,177	279,163	31,505	22,619	58,708	224,707	647,879
P. Pinang	7,076	-	511	56	-	5,358	13,001
Perak	80,970	23,052	31,616	19,241	16,214	191,929	363,022
Perlis	80	-	171	-	-	-	251
Selangor	35,675	5,434	4,035	343	2,486	87,556	135,529
Terengganu	6,284	39,631	20,048	19,095	12,524	64,078	161,660
P. Malaysia	**376,691**	**554,080**	**125,246**	**80,262**	**152,401**	**1,121,339**	**2,410,019**
Sabah	129,176	113,407	15,756	-	91,950	983,277	1,333,566
Sarawak	34,327	7,680	22,509	-	77,596	602,260	744,372
Sabah/Sarawak	**163,503**	**121,087**	**38,265**	**-**	**169,546**	**1,585,537**	**2,077,938**
Malaysia	**540,194**	**675,167**	**163,511**	**80,262**	**321,947**	**2,706,876**	**4,487,957**

Table 2.10: Distribution of oil palm planted area by states year 2009 (Malaysia Palm Oil Board, 2010)

State	Plantation Area (Hectares)						Total
	S/Holders (Licensed)	FELDA	FELCRA	RISDA	State Schemes/ Govt. Agencies	Private Estates	
Johor	187,957	127,661	22,106	4,932	45,099	324,693	712,448
Kedah	18,614	717	1,124	1,044	2,220	54,665	78,384
Kelantan	2,429	36,216	3,460	767	13,325	56,988	113,185
Melaka	8,366	2,848	2,324	1,734	0	35,921	51,193
N. Sembilan	20,070	47,489	7,377	9,986	2,807	78,772	166,501
Pahang	33,922	297,418	31,276	21,708	65,704	225,639	675,667
P. Pinang	7,845	0	511	56	0	5,176	13,588
Perak	90,668	22,760	31,653	19,014	17,061	192,698	373,854
Perlis	79	0	155	0	0	0	234
Selangor	38,059	5,771	3,920	343	1,618	89,833	139,544
Terengganu	7,403	41,615	19,927	19,348	13,049	63,874	165,216
P. Malaysia	**415,412**	**582,495**	**123,833**	**78,932**	**160,883**	**1,128,259**	**2,489,814**
Sabah	149,840	115,492	15,205	0	90,844	990,217	1,361,598
Sarawak	43,784	7,620	21,794	0	77,816	688,734	839,748
Sabah/Sarawak	**193,624**	**123,112**	**36,999**	**0**	**168,660**	**1,678,951**	**2,201,346**
Malaysia	**609,036**	**705,607**	**160,832**	**78,932**	**329,543**	**2,807,210**	**4,691,160**

2.3.1.2 Distribution

According to the Malaysia Palm Oil Board (2010), the statistic of Table 2.10, 2.11 and 2.12 shows the number of mills and capacities in year of 2007 until 2008. The statistic showed that the palm mills are mostly distributed in Sabah, Pahang, Johor, Perak and Sarawak. In addition, the statistic also showed that palm oil mills were distributed to almost every state in Malaysia except Perlis state and three federal territories. The overall number of palm oil mills in Malaysia slightly increased during the period of 2007 until 2009.

Sabah owned the highest number of palm oil mills with about 120 mills followed by Pahang with about 68 mills in year 2009. The total number of palm oil mills in peninsula Malaysia was about 249 mills. Meanwhile, the number of oil palm mills in Borneo Malaysia (Sabah and Sarawak) is about 167 mills. Lastly, Sabah and Sarawak show great potential in palm oil plantation development due to the availability of abundant plantation area for continued development.

Table 2.11: Number of mills and capacities year 2007 (Malaysia Palm Oil Board, 2010)

State	Mills Approved		Total Mills Approved As At End Of 2007 (tons FFB/year)							
			Existing Mills				Mills Under Planning And Construction		Total	
			In Operation		Not In Operation					
	No	Capacity	No	Capacity	No	Capacity	No	Capacity	No	Capacity
Johor			66	16,028,600			1	180,000	67	16,208,600
Kedah			6	1,040,000			1	96,000	7	1,136,000
Kelantan			10	1,715,200					10	1,715,200
Melaka			3	552,000					3	552,000
N. Sembilan			15	3,163,400					15	3,163,400
Pahang	1	270,000	68	14,311,400	1	259,200	2	390,000	71	14,960,600
Perak			45	9,108,400			1	144,000	46	9,252,400
P. Pinang			3	438,000					3	438,000
Selangor			21	3,429,600	2	288,000			23	3,717,600
Terengganu	1		12	2,795,600			2	300,000	14	3,095,600
P. Malaysia	**2**	**180,000**	**249**	**52,582,200**	**3**	**547,200**	**7**	**1,110,000**	**259**	**54,239,400**
Sabah	7	1,150,000	115	27,760,200			12	1,870,000	127	29,630,200
Sarawak	4	744,000	42	8,940,400			6	834,000	48	9,774,400
Sabah/Sarawak	11	1,894,000	157	36,700,600			18	2,704,000	175	39,404,600
Malaysia	**13**	**2,344,000**	**406**	**89,282,800**	**3**	**547,200**	**25**	**3,814,000**	**434**	**93,644,000**

Table 2.12: Number of mills and capacities year 2008 (Malaysia Palm Oil Board, 2010)

State	Total Mills Approved As At End Of 2008 (tons FFB/year)							
	Existing Mills				Mills Under Planning And Construction		Total	
	In Operation		Not In Operation					
	No	Capacity	No	Capacity	No	Capacity	No	Capacity
Johor	66	16,160,400	1	259,200	1	180,000	68	16,599,600
Kedah	6	1,184,000	1	96,000	1		7	1,280,000
Kelantan	10	1,715,200					10	1,715,200
Melaka	3	552,000					3	552,000
N. Sembilan	14	3,019,400			2	216,000	16	3,235,400
Pahang	70	14,799,400	1				70	14,799,400
Perak	45	9,576,400			2	294,000	47	9,870,400
P. Pinang	3	438,000					3	438,000
Selangor	22	3,621,600					22	3,621,600
Terengganu	13	3,051,600			1	180,000	14	3,231,600
P. Malaysia	**252**	**54,118,000**	**2**	**355,200**	**6**	**870,000**	**260**	**55,343,200**
Sabah	117	29,333,200			11	1,630,000	128	30,963,200
Sarawak	41	9,048,000	1	120,000	8	1,074,000	50	10,242,000
Sabah/Sarawak	158	38,381,200	1	120,000	19	2,704,000	178	41,205,200
Malaysia	**410**	**92,499,200**	**3**	**475,200**	**25**	**3,574,000**	**438**	**96,548,400**

Table 2.13: Number of mills and capacities year 2009 (Malaysia Palm Oil Board, 2010)

State	**Total Mills Approved As At End Of 2009 (tons FFB/year)**							
	Existing Mills				**Mills Under Planning And Construction**		**Total**	
	In Operation		**Not In Operation**					
	No	**Capacity**	**No**	**Capacity**	**No**	**Capacity**	**No**	**Capacity**
Johor	64	16,384,400	2	355,200	1	180,000	67	16,919,600
Kedah	6	1,324,000	1	96,000	0	0	7	1,420,000
Kelantan	10	1,715,200	0	0	0	0	10	1,715,200
Melaka	3	606,000	0	0	0	0	3	606,000
N. Sembilan	14	3,149,400	0	0	3	576,000	17	3,725,400
Pahang	70	14,889,400	0	0	1	270,000	71	15,159,400
Perak	45	9,699,800	0	0	2	294,000	47	9,993,800
P. Pinang	2	294,000	0	0	0	0	2	294,000
Selangor	22	3,781,600	0	0	0	0	22	3,781,600
Terengganu	13	3,137,600	0	0	1	180,000	14	3,317,600
P. Malaysia	**249**	**54,981,400**	**3**	**451,200**	**8**	**1,500,000**	**260**	**56,932,600**
Sabah	120	29,893,200	1	120,000	9	1,630,000	130	31,643,200
Sarawak	47	10,664,000	0	0	7	990,000	54	11,654,000
Sabah/Sarawak	167	40,557,200	1	120,000	16	2,620,000	184	43,297,200
Malaysia	**416**	**95,538,600**	**4**	**571,200**	**24**	**4,120,000**	**444**	**100,229,800**

2.3.1.3 The milling capacity utilization

The statistics in Table 2.13 showed a stable increase of the monthly milling capacity utilization in year from 2007 until 2009. (Malaysia Palm Oil Board, 2010) Thus, the statistic clearly showed that Malaysia palm oil mills able to ensure a stable POFA supply. The milling capacity utilization of palm oil mills will continue to grow due to the high market demand of crude palm oil.

Table 2.14: Malaysia milling capacity utilization rate from year 2008 to 2010 (Malaysia Palm Oil Board, 2010)

Region	State	Volume (tons/month)											
		Jan			Feb			Mar			Apr		
		2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Northern	Kedah	109.89	109.15	101.84	112.68	114.89	96.44	123.82	117.37	116.43	112.16	115.53	107.17
	Perak	100.12	86.98	82.56	95.89	88.43	72.82	104.93	95.59	90.20	100.18	96.09	81.89
	Pulau Pinang	71.28	94.39	118.04	98.77	115.98	129.71	66.97	117.38	124.62	55.51	114.02	145.58
	Total	**281.29**	**290.52**	**302.44**	**307.34**	**319.3**	**298.97**	**295.72**	**330.34**	**331.25**	**267.85**	**325.64**	**334.64**
Central	N. Sembilan	94.70	92.40	75.69	88.16	91.39	66.17	100.94	92.92	85.05	93.54	93.22	80.00
	Selangor	84.65	84.18	71.07	89.20	82.89	65.91	95.43	92.62	81.80	93.01	89.43	78.92
	Total	**179.35**	**176.58**	**146.76**	**177.36**	**174.28**	**132.08**	**196.37**	**185.54**	**166.85**	**186.55**	**182.65**	**158.92**
Southern	Johor	93.65	83.21	77.70	82.84	76.57	71.84	91.97	78.51	89.02	82.08	80.26	84.31
	Melaka	101.90	101.65	80.08	96.17	96.87	82.30	98.97	102.18	91.53	83.92	73.31	94.40
	Total	**195.55**	**184.86**	**157.78**	**179.01**	**173.44**	**154.14**	**190.94**	**180.69**	**180.55**	**166.00**	**153.57**	**178.71**
East Coast	Kelantan	74.79	61.63	61.56	62.65	52.79	60.22	74.49	65.73	73.78	83.92	73.31	67.65
	Pahang	91.64	79.71	72.69	78.55	73.28	66.17	93.52	83.31	85.05	91.10	80.38	80.00
	Terengganu	78.14	65.41	65.41	65.34	57.09	56.92	74.16	66.68	70.50	73.13	63.97	63.35
	Total	**244.57**	**206.75**	**199.66**	**206.54**	**183.16**	**183.31**	**242.17**	**215.72**	**229.33**	**248.15**	**217.66**	**211.00**
East Malaysia	Sabah	102.00	89.82	91.05	79.47	69.72	73.67	81.45	75.78	82.85	88.41	72.47	80.14
	Sarawak	92.82	87.93	83.29	74.21	76.07	61.66	76.44	81.74	79.21	82.77	80.98	80.19
	Total	**194.82**	**177.75**	**174.34**	**153.68**	**145.79**	**135.33**	**157.89**	**157.52**	**162.06**	**171.18**	**153.45**	**160.33**
Overall		**1095.58**	**1036.46**	**980.98**	**1023.93**	**995.97**	**903.83**	**1083.09**	**1069.81**	**1070.04**	**1039.73**	**1032.97**	**1043.6**

Region	State	Volume (tons/month)											
		May			Jun			Jul			Aug		
		2008	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**	**2008**	**2009**	**2010**
Northern	Kedah	128.35	105.22	109.28	144.93	125.81	124.23	155.07	154.72	124.26	166.23	135.20	116.79
	Perak	114.20	107.70	94.13	109.22	115.16	109.07	119.10	126.87	115.53	116.75	111.00	105.65
	Pulau Pinang	85.16	125.71	145.58	75.72	126.08	167.35	69.41	150.26	167.60	71.06	140.13	171.97
	Total	**327.71**	**338.63**	**348.99**	**329.87**	**367.05**	**400.65**	**343.58**	**431.85**	**407.39**	**354.04**	**386.33**	**394.41**
Central	N. Sembilan	91.13	94.68	83.18	96.13	99.07	90.78	103.29	102.82	94.38	103.11	95.29	90.53
	Selangor	101.72	90.44	85.42	102.67	98.68	98.68	113.41	101.00	103.39	102.38	86.68	95.34
	Total	**192.85**	**185.12**	**168.60**	**198.80**	**197.75**	**189.46**	**216.70**	**203.82**	**197.77**	**205.49**	**181.97**	**185.87**
Southern	Johor	89.47	90.51	93.57	93.35	97.00	98.41	103.18	105.60	102.58	101.92	93.61	97.09
	Melaka	99.77	108.68	100.09	107.47	114.85	109.32	121.12	106.82	127.78	121.67	96.76	113.57
	Total	**189.24**	**199.19**	**193.66**	**200.82**	**211.85**	**207.73**	**224.30**	**212.42**	**230.36**	**223.59**	**190.37**	**210.66**
East Coast	Kelantan	82.49	67.19	66.30	79.60	65.60	66.76	93.19	71.74	72.50	81.33	75.97	69.57
	Pahang	95.76	88.70	83.00	98.06	89.52	84.51	109.06	99.33	94.73	104.03	99.37	100.19
	Terengganu	79.27	67.55	63.10	104.34	64.57	75.33	106.90	83.46	91.43	98.20	82.17	90.91
	Total	**257.52**	**223.44**	**212.40**	**282.00**	**219.69**	**226.60**	**309.15**	**254.53**	**258.66**	**283.56**	**257.51**	**260.67**
East Malaysia	Sabah	98.40	76.03	82.10	98.99	77.77	76.37	99.87	75.40	80.84	98.89	80.39	88.72
	Sarawak	86.14	89.19	87.59	91.10	85.36	88.85	105.35	83.55	106.14	111.70	94.90	117.90
	Total	**184.54**	**165.22**	**169.69**	**190.09**	**163.13**	**165.22**	**205.22**	**158.95**	**186.98**	**210.59**	**175.29**	**206.62**
Overall		**1151.86**	**1111.6**	**1093.34**	**1201.58**	**1159.47**	**1189.66**	**1298.95**	**1261.57**	**1281.16**	**1277.27**	**1191.47**	**1258.23**

Region	State	Volume (tons/month)											
		Sep			Oct			Nov			Dec		
		2008	2009	2010	2008	2009	2010	2008	2009	2010	2008	2009	2010
Northern	Kedah	156.21	139.04	96.18	145.33	146.84	93.21	143.54	108.95	72.80	127.54	103.45	73.54
	Perak	105.86	103.80	99.72	99.91	124.90	93.11	107.71	100.57	94.15	97.14	100.02	82.51
	Pulau Pinang	69.14	125.14	143.50	73.83	161.52	144.77	77.07	129.59	127.03	101.64	134.96	125.07
	Total	**331.21**	**367.98**	**339.4**	**319.07**	**433.26**	**331.09**	**328.32**	**339.11**	**293.98**	**326.32**	**338.43**	**281.12**
Central	N. Sembilan	100.29	98.25	92.54	104.74	112.25	95.16	105.85	82.30	84.03	92.77	78.97	66.71
	Selangor	95.79	86.37	91.02	91.85	100.96	84.37	98.51	85.40	80.09	86.39	81.53	71.08
	Total	**196.08**	**184.62**	**183.56**	**196.59**	**213.21**	**179.53**	**204.36**	**167.7**	**164.12**	**179.16**	**160.5**	**137.79**
Southern	Johor	96.19	92.35	91.85	103.64	121.75	99.30	106.86	95.76	86.67	95.44	88.93	70.19
	Melaka	114.25	104.26	118.24	116.81	126.63	111.93	119.19	87.31	97.94	112.12	94.47	81.42
	Total	**210.44**	**196.61**	**210.09**	**220.45**	**248.38**	**211.23**	**226.05**	**183.07**	**184.61**	**207.56**	**183.4**	**151.61**
East Coast	Kelantan	78.63	76.05	65.02	90.31	107.01	65.86	85.81	70.72	72.80	72.00	71.34	50.74
	Pahang	97.83	99.17	99.37	102.62	124.87	99.76	101.64	96.41	89.38	93.99	84.97	65.57
	Terengganu	98.66	86.95	86.21	103.77	119.86	95.01	105.12	86.76	86.76	87.02	81.97	71.56
	Total	**275.12**	**262.17**	**250.6**	**296.7**	**351.74**	**260.63**	**292.57**	**253.89**	**248.94**	**253.01**	**238.28**	**187.87**
East Malaysia	Sabah	103.50	93.16	86.57	108.19	119.35	93.12	104.09	105.93	83.45	92.63	104.83	74.66
	Sarawak	115.56	103.33	117.47	121.58	126.19	121.92	117.65	104.29	106.53	104.29	97.37	97.47
	Total	**219.06**	**196.49**	**204.04**	**229.77**	**245.54**	**215.04**	**221.74**	**210.22**	**189.98**	**196.92**	**202.2**	**172.13**
Overall		**1231.91**	**1207.87**	**1187.69**	**1262.58**	**1492.13**	**1197.52**	**1273.04**	**1153.99**	**1081.63**	**1162.97**	**1122.81**	**930.52**

2.3.1.4 Solid waste materials and by-products

There are various forms of solid and liquid wastes that are produced product from palm oil mills. These include solid waste materials and by product such as EFB, EFS, EFF and POME that have been identified.

a. Empty fruit bunches (EFB)

EFB is the major component of the palm oil wastes that are produced from sterilization in palm oil extraction process. Thus, EFB have very high moisture content about 60% that make it unsuitable to be use as bio-fuel. EFB contain C (42%), N (0.8%), P (0.06%), K (2.4%) and Mg (0.2%). Normally, EFB can be use as raw materials for mushroom cultivation. Then, the residue that is obtained from the mushroom cultivation with or without compositing is easier for transportation and fertilization compared with the original EFB.

Besides that, the EFB also can apply be utilized in fruit orchards to retain moisture and return organic matter to the soil. EFB fiber can be use as cushion filling material by adding a binding agent such as rubber latex. The EFB in the form of medium density fiber (MDF) board has great potential in producing the products like coir fiber board, cement board, roofing tile and card paper. (Prasertsan and Prasertsan, 1996)

However, the EFB faces difficulty in discharging from the palm oil mill. The landfill disposal method is very costly compared to other methods in order to discharge EFB. The other methods are direct application and incinerated in furnace that will bring harmful impact to our environment. The incineration of EFB will emit particulates and gases (SO_2, CO_2, and NO_x) that cause air pollution. The incineration of EFB will produce about 4 kg by-product (ash) for every 1 ton of EFB. (Prasertsan and Prasertsan, 1996)

b. Empty fruit fiber (EFF)

EFF is a good combustible material to produce steam and electric power for mills especially for certain process utilization. This is because EFF retained oil in its cells wall making it suitable to become bio-fuel. However, only 30% of EFF will be uses when the mills do not generate electric power. Thus, other 70% of EFF needs to be discharged to the environment. EFF ash that is produce from combustion contains P (1.7 to 6.6 %), K (17 to 25 %), and Ca (7%). On the other hand, EFF is not suitable to become animal feed due to it high content of fiber and lignin that not easy to be digested by animals. However, it is suitable as substrate for mushroom cultivation, pulp and paper industry. (Prasertsan and Prasertsan, 1996)

c. Empty fruit shell (EFS)

EFS size is uniform and difficult to decompose. While, EFS is consider as unusable in the mill or disposed by the landfill method. EFS is an energy intensive substance that can be used in steam process and there are boiler designs for fuel oil. Additionally, the EFS has a great potential in power generation can solve the problem of the industry that is over reliant on fossil fuel. The EFS can be use in activated carbon production or charcoal because it contains 20.3% of fixed carbon. The active carbon can be applied for the decolorization of the unacceptably dark – colored effluent of the palm oil mills. (Prasertsan and Prasertsan, 1996)

2.3.2 Crude palm oil (CPO) production process

According to Malaysia Department of Environment (1999), the fresh fruit bunches (FFB) are produced as end products which are crude palm oil (CPO) and palm kernel after being received from the oil palm plantations. Normally, a few palm oil mills in Malaysia include kernel crushing facilities in order to crush the palm oil kernel into palm kernel oil. However, by-product is produced throughout the crude palm oil and palm kernel production process. Thus, this study discusses the extraction process and the sources of pollution of Malaysia palm oil mills. Figure 2.9 shows the process flow diagram for the extraction of crude palm oil.

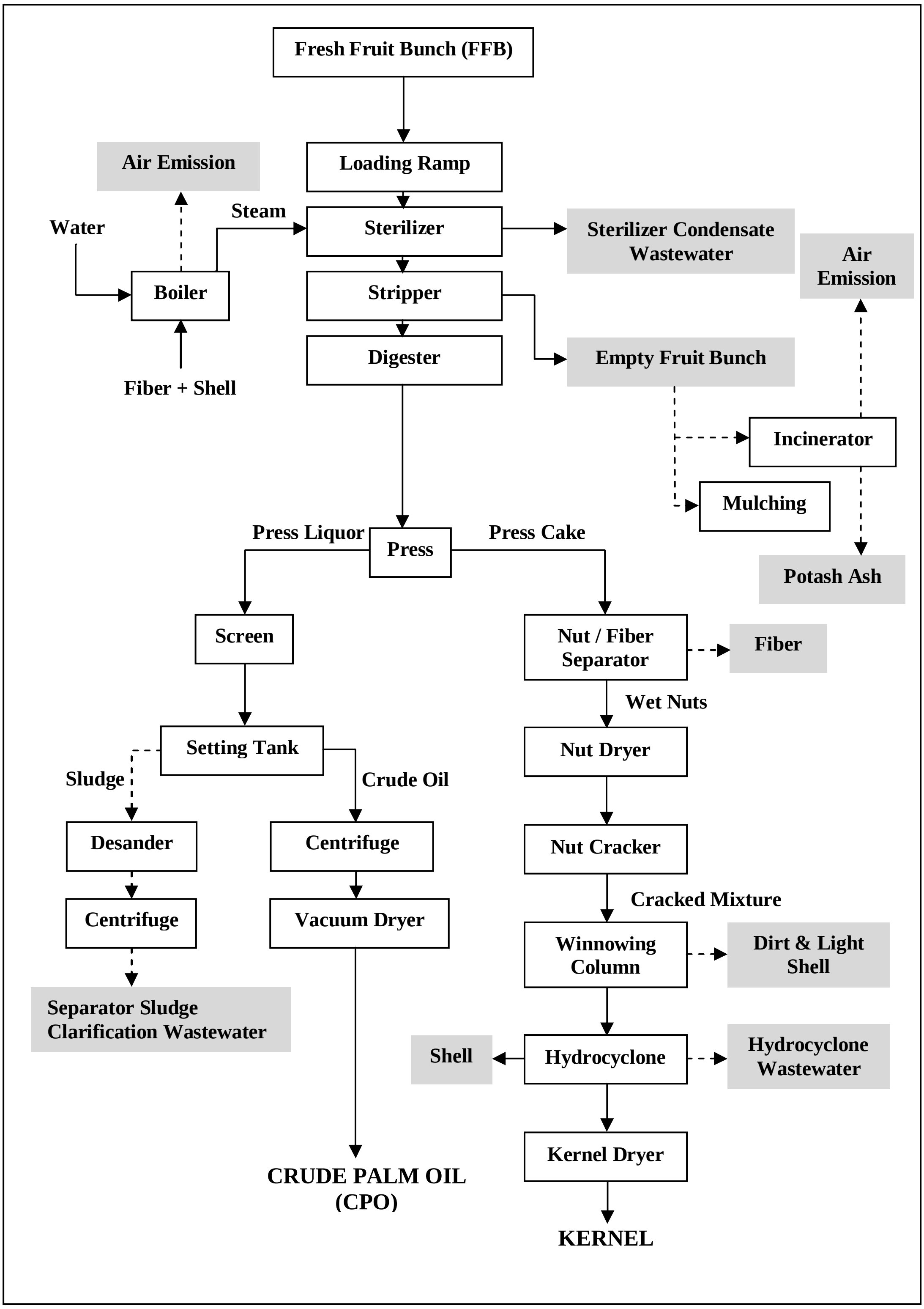


Figure 2.5: Conventional palm oil extraction process and source of waste generation (Department of Environment, 1999)

2.3.2.1 Reception, transfer and storage

During this process, a very good care must be taken in harvesting, handling and transportation of FFB so that the FFB is not damaged. The damaged palm fruits will give rise to poor quality crude palm oil (CPO) due to increased free fatty acid (FFA) content. The ripe FFB must be transported to palm oil mills for immediate process in order to ensure the quality of crude palm oil.

2.3.2.2 Sterilization

After the FFB is loaded into the sterilizer cages, the FFB is subjected to steam-heat treatment in horizontal sterilizers for 75 to 90 minutes at a pressure of 3 kg/cm^2 and a temperature of 140^{o}C. The sterilization is important to prevent further formation of free fatty acids due to enzyme action in order to maintain the quality of crude palm oil and facilitate stripping of the fruits from the spikelet.

Besides that, it also prepares the fruit mesocarp for subsequent processing by coagulating the mucilaginous material which facilitates the breaking of the oil cells and pre-conditioning of the nuts to minimize kernel breakage during pressing and nut cracking. However, different mills in Malaysia have sterilization cycles of various time and pattern. The three-peak sterilization pattern is normally used due to the FFB that was brought about by the weevil pollination introduced in the early 1980s. Then, the steam condensate is discharged as wastewater and referred to as sterilizer condensate.

2.3.2.3 Stripping

After sterilisation, the FFB is sent to rotary drum-stripper to separate the fruits from the spikelets or bunch stalks. As the drum-stripper rotates, the bunches are lifted up and then dropped again repeatedly as the bunches travel along the stripper. The fruits are knocked off the bunch as the drum-stripper rotates and the detached fruits pass through the bar screen of the stripper. Then, all the screened fruits will be collected below by a bucket conveyor before being discharged into the digester. The waste that is produced is EFB which will pass out at the end of the stripping process.

2.3.2.4 Digestion

The separated fruits from the stripping process are discharged into vertical steam jacketed drum in order to mash it under steam heated conditions. Besides that, the mashing process can also be heated directly with live steam injection. The fruits mash under heat will have the oil-bearing cells of the mesocarp broken by the rotating arms. Then, some of palm oil is released and is collected in the crude oil tank together with the pressed oil described below. It is important to maintain the digester full all the time at about $90^{o}C$ in order to have good digestion of the fruits.

2.3.2.5 Crude palm oil extraction

Palm oil will be pressed out from digested mash under high pressure by using twin screw presses. The hot water is added to enhance the flow of the oils. However, some of the local palm oil mills practice the double pressing operation to reduce the undesirable high nut breakage. Thus, this can separate the nut and fiber effectively and avoid the contamination of palm oil by the kernel oil. Then, fiber and nut (press cake) are conveyed to a depericarper for separation. The crude palm oil slurry is fed to a clarification system for oil separation and purification

2.3.2.6 Clarification and purification of the crude palm oil

The crude palm oil slurry from the presses consists of a mixture of palm oil (35% to 45%), water (45% to 55%) and fibrous materials in varying proportions will be pumped to a horizontal or vertical clarification tank for oil separation. The temperature of the clarification tank content is maintained at about 90^{o}C to enhance oil separation.

The clarified oil that skimmed-off from top of the clarification tank has moisture and dirt content of below 0.1% and 0.01% respectively. Then, it passed through a high speed centrifuge and a vacuum dryer before it is sent to the storage tanks. The underflow sludge from the clarification tank will by pass through a sludge separator and then returned to the clarification tank. This process is necessary to reduce the oil loss in this stage. Then, other stream consisting of water and fibrous debris is discharged as wastewater, which is generally referred to as separator sludge or clarification wastewater.

2.3.2.7 Depericarping and nut fiber separation

In this stage, the press cake from the screw press that consists of moisture, oily fiber and nuts (including broken nuts and kernels) are conveyed by fitted conveyor to a depericarper for nut and fiber separation. The suction fan is used to separate the fiber and nuts. Then, nut is sent to nut cracker. But the remaining fiber need to be removed by rotating drum before sent to nut cracker. After that, all fiber is sent to the boiler house and is used as boiler fuel

2.3.2.8 Nut cracking

The nuts from separator are cooled in order to increase the effectiveness of nuts cracking process. The conventional centrifugal type nut-cracker is used in the splitting of the nuts and any kernels sticking to the broken shell.

2.3.2.9 Separation of kernels and shells

Typically, most of palm oil mills use hydrocyclone in kernels and shells separation. The hydrocyclone is popular because of is easier to operate and maintain compared to other methods. The discharge from this process constitutes the last source of wastewater stream which is called hydrocyclone wastewater. However, the usage of this method using is very much depends on the availability, costs and maintenance of the materials and equipment.

The method choice to separate the kernels and shells also very much depend on the difference in specific gravity (SG) between the kernels and the shells. The un-dried kernels and shells have a SG of about 1.07 and 1.15 to 1.25, respectively. Thus, a separation medium consisting of clay suspension or salt solution with a SG of 1.12 will effectively separate the kernels and the shells.

2.3.3 Sources of waste generation

The sources of waste that are generated from palm oil mills can be categorized onto liquid effluent, gaseous emission and solid waste.

2.3.3.1 Sources of liquid effluent

A large amount of water is used during the extraction of crude palm oil from the fresh fruit bunch. About 50% of the water results in POME and the rest being lost as steam such as through sterilizer exhaust and piping leakages of wash waters. The POME comprises a combination of the wastewaters which are principally generated and discharged from the major processing operations as shown in Table 2.14.

Table 2.15: Major process of palm oil extraction contribute to the POME

Process	Percentage of total POME
Sterilization	36%
Clarification	60%
Hydrocyclone	4%

2.3.3.2 Sources of gaseous emission

There are two principal sources of air pollution in palm oil mills which are boilers and incinerators. Boilers are used to burn the empty fruit fiber and shell materials to generate recovery energy, while incinerators are uses burn the EFB for recovery of potash ash. However, the smoke and dust emissions are the main concerns due to incomplete combustion of the solid waste materials.

2.3.3.3 Sources of solid waste materials and by-products

Table 2.16: Solid waste materials and by-products that generate from palm oil mill

Solid waste materials and by-products	Percentage of total FFB
Empty fruit bunches	23%
Empty fruit fiber	13.5%
Empty fruit shell	5.5%
Palm kernel	6%
Potash ash	0.5%

The solid waste materials and by-products generated in the palm oil extraction process are shown in Table 2.15. Typically, the EFB may be incinerated to produce potash which is applied in the plantations as fertilizer or used for superior process of mulching. The other by-product such as EFB and FFS materials is used as boiler fuel to generate recovery energy for palm oil mill. Then, the palm kernel is sold to palm kernel oil producers who extract the palm kernel oil from the kernels.

However, the Department of Environment (DOE) Malaysia has discouraged the use of incineration to disposal of the EFB in order to reduce air pollution. The EFB are laid in between the rows of oil palms and allowed to mulch and progressively release their nutrient elements to the soil. This method is, not only environmentally-friendly, but also advantageous in that it permits controlled release of the nutrients to the soil without significant loss due to rainfall and washout.

2.4 Sustainable development

2.4.1 Sustainable development

“Sustainable development is a development that meets the needs of the present without compromising the ability of future generations to meet their own needs (The Brundtland Report, 1987).”

“According the Commission for Sustainable Development, the achievement of sustainable development is not only dependent upon the sustainability of the environment and its natural resources, but also on the level of economic and social conditions reached by the people using the environment and its natural resources (Commission for Sustainable Development, 1992).”

“From this continent, the cradle of humanity, we declare, through the Plan of Implementation of the World Summit on Sustainable Development and the present Declaration, our responsibility to one another, to the greater community of life and to our children (Johannesburg Declaration, 2002).”

“The Organization for Economic Co-operation & Development (OECD) recognizes today that ‘global co-operation is required to achieve sustainable economic, environmental and social conditions worldwide (Organization for Economic Co-operation & Development, 2006).”

“Far from being a burden, sustainable development is an exceptional opportunity - economically, to build markets and create jobs; socially, to bring people in from the margins; and politically, to give every man and woman a voice, and a choice, in deciding their own future (UN Secretary-General Kofi Annan, 2010).”

"At the Center, We view solutions to environmental and social problems as business opportunities, not a cost of doing business (Center for Sustainable Global Enterprise, 2010)."

As a conclusion, there are many version of definition or concept of sustainable development which try to balance three pillars (economic, social and environmental) in ways that meets the needs of present without compromising the ability of future generation to meet their own needs. Figure 2.6 shows the holistic approach in Malaysia perspective on sustainable.

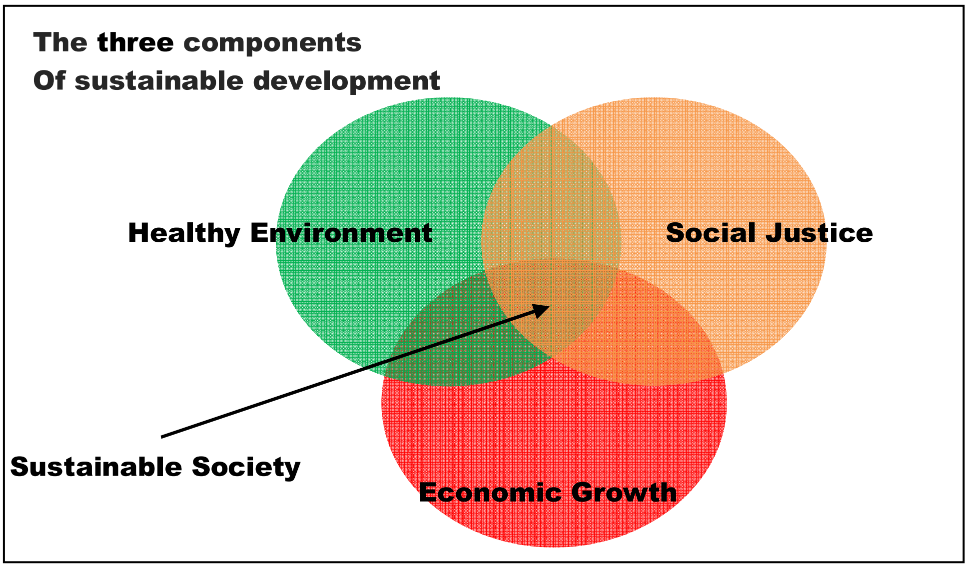


Figure 2.6: A holistic approach in Malaysia perspective on sustainable

(College Student Education International, 2010)