CHAPTER 2.0 LITERATURE REVIEW

2.1 THE ENVIRONMENTAL CONDITION

The destruction of the pristine environment is occurring very rapidly particularly from human activities. The major pollution contributed by man is from improper utilization of land, which causes siltation, and from the industrial sector. However, the acceleration of the environmental destruction is particularly from the industries. The manufacturing industry differs in one essential aspect from others, with the uniqueness of the chemical transformations. The transformation of raw materials into new products involves various chemical reactions. The amount and characteristic of the resultant products, and the side reactions depend on the energy level of the materials utilized. Most of the time these by-products are undesired. They can rarely be reused or recycled and must be separated from desired product.

In order to improve the yield or quality of a desired product, large variety of additives, catalysts, filter aids, solvents, and adsorbing agents, are frequently added. At the end of the chemical reaction these additives must be separated from the desired product, at which point they also become waste materials. All wastes must be transformed into a form which will give no further adverse impact on the environment during its final elimination. The unique economic growth of supplying the ever increasing demands of the society for goods and services lead not only to the depletion of resources, but also increased the amount of waste generated which accelerated environmental pollution level.

Saigo and Cunningham (1992) gave the definition of pollution as 'to make foul, unclean, dirty: any physical, chemical, or biological change that adversely affects the health, survival, or action of living organisms or that alters the environment in undesirable ways'. Environmental pollutants can be biological, physical or chemical (Environmental Encyclopedia. 1997). Air and surface water pollution are the most conspicuous types of pollution and therefore receive prime attention from the public. In contrast, soil and groundwater pollution are concealed from direct observation and become public issues only after massive ingestion has already taken place.

Sources of pollution, vary according to the particular country and location. Single pollution compounds are generated in gaseous, liquid or solid forms (Saigo and Cunningham, 1992). Many of them are relatively inert to physico-chemical or biological degradation and thus pose no particular threat to the natural environment. However, others are highly reactive and must be treated and disposed of safely to minimize possible environmental impact.

Waste products commonly would end up in landfill which not only caused the loss of energy from being further utilized but also pollute the groundwater as leachate. Such contamination can only be avoided if waste products and potentially toxic compounds are safely contained within the boundaries of the repositories and no further contact occurs with the enclosing geologic environment particularly in handling hazardous waste. A hazardous waste is considered to be any combination of waste that poses a substantial danger, now or in the future, to humans, plants and animal life, and which therefore cannot be handled or disposed of without special precautions (Davis, 1997). For hazardous waste, incineration appears to be the best option of disposal as it reduced waste volume and toxicity to less harmful ashes (Rappaport, 1997). Figure 2.1 shows the five major concerns in world population (Ross, 1995). The major environmental pollution was caused by industrial and population growth.

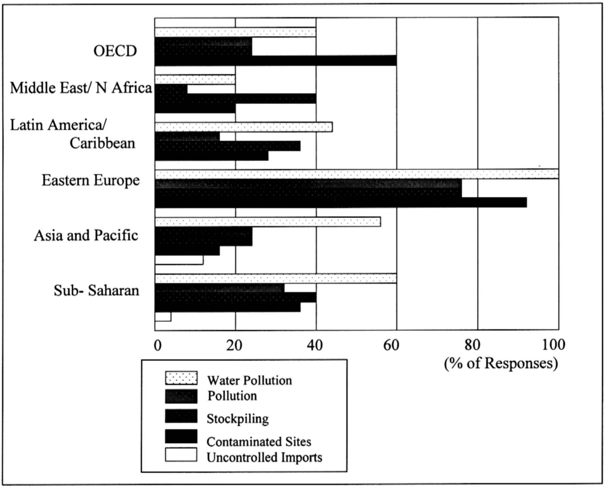
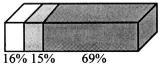
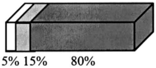
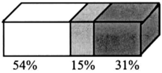


Figure 2.1: Global Waste Inventory 1990/1.

2.2 ENVIRONMENTAL CONDITION IN MALAYSIA

The deterioration of the environmental condition in Malaysia due to the increasing population and expanding industrial sectors required the promulgation of Environmental Quality Act (EQA) in 1974. The Department of Environment (DOE) plays the major role in monitoring the environmental state of Malaysia. Amendments to the EQA 1974 in April 1996 included penalty to polluters with higher fines; requirement of recycling and environmental labeling; prohibition order by DOE; control of scheduled waste; better definition of terms of EQA 1974; request of environmental auditing reports; establishment of environmental quality council; establishment of Environmental Fund from cess collection for research, pollution prevention and conservation measures; compensation for damages; forfeiture and disposal of transportation, and ministerial power to draft new regulations on ambient water quality standards and discharge standards (Sunday Star, April 28, 1996).

From the data presented in the Environmental Quality Report 1998, the number of clean rivers declined slightly to 24 from 42 in 1996 but in 1997, the number of slightly polluted and polluted rivers increased from 61 to 68 and 13 to 25 accordingly. The major sources of pollution which caused high biochemical oxygen demand (BOD) were from agrobased industries, livestock farms, sewage and manufacturing activities as indicated in Figure 2.2.

Source of Pollution (Activity).	River Condition	Pollution Indicator (Parameter)
Agro-based, Domestic Waste Manufacturing Industry, & Livestock farming.	 16% 15% 69%	Biochemical Oxygen Demand (BOD)
Livestock Farming & Domestic Waste	 5% 15% 80%	Ammoniacal Nitrogen (NH_3-N)
Earthworks & Land Clearing	 54% 15% 31%	Suspended Solids (SS)

Indicators:

☐ Clean

▨ Slightly Polluted

■ Polluted

Note:

- Number of River Basins Monitored = 117
- Number of Monitoring Stations = 908
- Length of Rivers Monitored = 7599 km

Figure 2.2: Status of River Water Quality Based on Activity, 1997

Among the manufacturing sector, the metal finishing and electroplating, rubber based, textile, food and beverage, and cement industries continue to be the main water polluters as indicated in Table 2.1.

Table 2.1: Malaysia: Compliance Status of Manufacturing Industries, 1997

% of Compliance with Environmental Quality (Sewage and Industrial Effluents) Regulations, 1978	**Industry Type**	% of Compliance with Environmental Quality (Clean Air) Regulations, 1978
82	Transport Based	99
71	Paper	99
70	Food and Beverage	97
86	Chemical Based	97
96	Electrical & Electronics	97
83	Textile	96
91	Cement	94
97	Metal Fabrication	94
69	Metal Finishing & Electroplating	93
96	Machinery	92
99	Plastic	91
92	Refinery (Edible)	89
89	Leather	88
99	Wood based	86
79	Refinery (Petroleum)	86
85	Others	86
94	Quarry	76
84	Rubber based	64
97	Non Metallic Mineral	56

(Source: The Environmental Quality Report 1998, (DOE, 1999))

2.3 AGRO-BASED INDUSTRY IN MALAYSIA

Due to the fact that the country is very rich with equatorial climate and fertile soil, agricultural sector has become a major option as an economic income to the people. The expansion contributes towards a considerable portion of the country's gross domestic production (GDP). Among the largest industry in the agro-based industry is the palm oil industry.

2.3.1. Palm Oil Industry: The General Overview

Historical records indicated that palm oil has been used for food and medicinal purposes far longer than 500 years back. The importance of palm oil is recognized widely in world that the industry has begun to expand and the trend continues. The Oil World predicted that the demand for palm oil and palm oil products will continue to grow faster than any other oil (Nielsen, 1990). This is due to the quality and composition of the palm oil (The Star, November 22, 2000).

2.3.2 Palm Oil Industry in Malaysia

In Malaysia palm oil industry started as early as 1917 and has been expanding rapidly since the late 1950s (PORIM, 1996). It has contributed a handsome portion of income to the Malaysian economy and by 1960s the total area cultivated with oil palm reached 55,000 hectares with the production of 92,700 tonnes per annum. By the year 1990, the production increased further and made Malaysia the biggest producer of global palm oil, with the contribution of 60 % of world palm oil. In 1996, Malaysia captured 65 % shares of palm oil export market from the world total of 11,100 tonnes (Palm Oil Link, 1997) and in the year 1999, Malaysia produced 8.0 million tonnes of palm oil and 2.5 million tonnes of palm kernel (PORIM, 1999).

In the year 1995, this sector contributed 8% of the GDP with RM 9 billion exports revenue (Utusan Malaysia, March 21, 1996). Due to the popular demand of oil palm products, more and more land have been planted with oil palm, and rubber and cocoa plantations were converted to oil palm estates (Ahmad and Mohamed Jaafar, 1993).

Data showed that in 1996, 2.6 million hectares of planted area were covered with oil palm with 73.6% in Peninsular Malaysia, 21.3 % in Sabah and 5.1 % in Sarawak (Statistics of Malaysia Commodities 1996). This increased to 3.2 million hectares in 1999.

The industry is also the main source of livelihood to over 200,000 rural family in various land schemes (PORIM, 1990). The distribution of oil palm planted areas to the sectors ranges from smallholders to Federal Land Development Authority (FELDA), Federal Land Consolidation and Rehabilitation Authority (FELCRA), Rubber Industry Small Holder Development Authority (RISDA), other government agencies and private estates.

Thus, the palm oil industry in one way or another, contributes to no small measure to the government objective of eradicating rural poverty.

Generally, there are two main products produced by the palm oil industry namely crude palm oil (CPO) and crude palm kernel oil (CPKO). Later, the industry progressed into downstream processing of CPO and CPKO in the line with the government's objective to exploit the country's agro-based resources.

The production of CPO increased 3.89 % from 1995 to 1996 with the total of 8,385,886 tonnes (PORLA, 1997). This is the direct consequence of the expansion of the number of palm oil mills to 290 plants with operation capacity of 52.8 million tonnes of fresh fruit bunch (FFB) per year. The operation capacity of palm oil refineries also increased accordingly with the increment of CPO production up to 11.5 million tonnes in the year 1996. The number is expected to grow further with the establishment of 17 new refineries (PORLA, 1996).

Malaysia as the world's main producer of palm oil, the sector manages to offer job opportunities to more than 300 000 people (Utusan Malaysia, March 21, 1996). The export of palm oil and palm oil products contributed greatly to the total value of Malaysian exports in 1996, is shown in Table 2.2:

Table 2.2: Export of Palm Oil and Palm Oil Products

Items	**Volume** **(1 000 Tonnes)**	**Value** **(RM Million)**
Crude Palm oil	69.0	85.5
RBD Palm oil	2,313.1	2,977.6
RBD Palm Stearin	809.6	852.7
RBD Palm Olein	3,384.7	4,632.9
Palm Acids Oil	46.2	32.1
Palm Fatty Acids Distillate	277.4	241.1
Other Processed Palm Oil	311.9	410.1
Total Palm Oil	*7,211.9*	*9,232.0*
Palm Kernel Oil	465.4	862.5
Palm Kernel Cake	994.2	255.1
Total Export	**8,671.5**	**10,649.6**

(Source: PORIM 1997)

For the first seven months of 1999, palm oil and palm oil based products maintained their spot as the second largest export earner valued at RM. 11.3 billion (Palm Oil Link, August 1999).

The acceleration of world population to 6.3 billion in 2000, and the increased fats consumption expands the oils and fats demand to 115 million tonnes (Palm Oil Link, January 1997). Realizing the need for new markets products, downstream industries have been established in the form of refining plants and oleochemical manufacturing facilities.

2.4 OVERVIEW OF OLEOCHEMICAL INDUSTRIES IN MALAYSIA

The availability of abundant raw materials has turned the palm oil industry towards the production of oleochemical products. The first oleochemical plant was set up in 1982, after less than a decade of the country's advert into palm oil refining (Ahmad and Muhammad Jaafar, 1993). Initially, five major plants were established with the capacity to produce about 165,000 tonnes per year of fatty acids (Zafarizal, 1997).

In recent years, additional plants have been set up and constructed to produce more sophisticated oleochemicals including esters and fatty alcohols. In 1997, there were 16 plants, which produced 968,000 metric tons of basic oleochemicals. This enabled Malaysia to be the world's third largest oleochemicals producers with the contribution of nearly 20% of the 115 million tonnes (Palm Oil Link, August 1996).

Currently, Malaysia produced about 8 million tonnes of palm oil, that is 20 % of the world palm oil production and about 1.2 million tonnes of oleochemical products (PORIM, 1997). The expansion of the oleochemical sector saw the establishment of Advanced Oleochemical Technology Center (AOTC) in September 1994. This center carries out efforts to diversify research in producing high-value and more environmental friendly products (PORIM, 1995). Table 2.3 indicates the global and Malaysia's production of basic oleochemicals in 1995 and the production for the year 2000.

Table 2.3: Production of Basic Oleochemicals in 1995 and 2000 (tonnes)

Country	Basic Oleochemical Products	1995	2000
Malaysia	Fatty Acids	462,500	560, 000
	Fatty Esters	80,000	110,000
	Fatty Alcohols	168,000	350,000
	Fatty Nitrogens	30,000	60,000
	Glycerol	66,450	120,000
	TOTAL	**806,950**	**1,200,000**
World	Fatty Acids	2,383,000	2,593,000
	Fatty Esters	544,000	624,000
	Fatty Alcohols	1,168,000	1,575,000
	Fatty Nitrogens	487,000	526,000
	Glycerol	682,000	780,000
	TOTAL	**5,264,000**	**6,098,000**

2.4.1 Oleochemical Industries: General Overview

Oleochemicals are chemicals derived from natural oils and fats which are analogous to petrochemicals which are chemicals derived from petroleum. Palm kernel oil is considered as the selected raw material in oleochemical industries due to its C12 content (Speed, 1990). The hydrolysis of the oil to the corresponding fatty acids and glycerol formed the basis of the oleochemical industry. Oleochemical products, which involve splitting process, distillation, hydrogenation, fractionation, esterification, and neutralization, are often divided into at least two categories: the basic oleochemicals and their derivatives. Basic oleochemicals are required for the production of detergents, cosmetics, pharmaceuticals and animal feed. Methyl ester together with fatty acids, fatty alcohol, fatty amines and glycerol, are important basic oleochemical raw materials. These are the essential building blocks for the oleochemical industry (Choo and Ma, 1996). Table 2.4 shows the main utilization of oleic/palmitic acids and their derivatives.

Table 2.4: Major Uses of Oleic/Palmitic Acids and Their Derivatives

Fatty Chemicals	**Major Industrial Applications**
Oleic Acid	Soaps, lubricants, ore floatation, paper chemicals, nitrogen derivatives, leather, rubber, nylons, vinyl stabilizers.
Oleyl Alcohol	Cosmetic as emollients, emulsion stabilizer, pigment dispersing material. Also used in lipstick and other stick cosmetics, creams and lotions.
Isopropyl Oleate	An oiliness and film- strength improver for lubricating oils, producing a marked improvement in shear-resistance and film brake down under pressure or at high speed.
Ethyl Oleate	Valuable oil medium for injections, oral administration being frequently preferable to natural oils. Used also as a lubricant in dried fruit processing.
Sorbitan Mono Oleate	An amber liquid monoester product from oleic acid and sorbitol widely used as a rust-inhibitor; in cosmetics and as an ingredient of textile softeners.
Polyoxyethylene 20 (Sorbitan Mono Oleate)	A yellow water-soluble liquid formed by the reaction of sorbitan-mono stearate with 20 molls of ethylene-oxide. As a liquid ice cream emulsifier, for vitamin solubilization, in cosmetics and solubilization of essential oils.
Palmitic Acid	Soaps, cosmetics, detergents, stabilizers, candles, paper chemicals, rubber, inorganic coatings, textile auxiliaries.

(Source: Bhat, 1990)

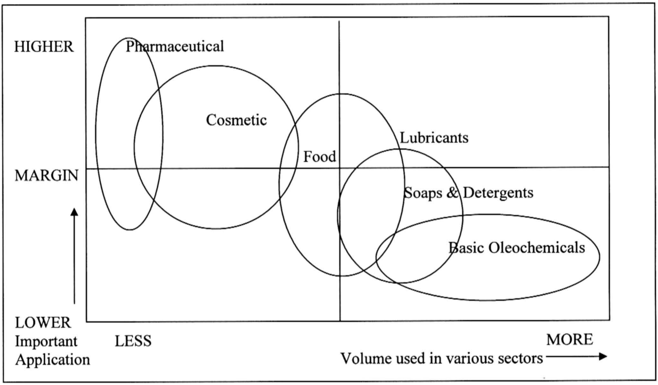
The manufacture of oleochemicals uses a wide range of raw materials from edible to inedible oils and fats. Studies show that palm oil and palm stearin can replace tallow to a large extent while palm kernel oil and coconut oil are interchangeable materials in oleochemical manufacturing (Ong *et al.*, 1986).

2.4.2 Oleochemical products and utilization

The five basic oleochemicals are fatty acids, fatty esters, fatty alcohols, fatty nitrogens and glycerol. The basic oleochemicals produced depend mostly on the palm kernel products (Ong *et al.*, 1986). A forecast has been made that Malaysia will account for nearly one fifth of the world's total production of these basic oleochemical in the 21st century (Agamuthu and Sastry, 1997). One of the largest users of oleochemicals is the rubber industry, besides the detergent and soap industries, where stearin functions as a processing aid. Various types of derivatives can be produced from these basic oleochemicals through various chemical modifications.

In the plastics industry, stearates and oleates of heavy metals such as cadmium, zinc and lead etc., are used in many ways, for example in the form of metal soaps, as stabilizers in PVC formulations, and in the form of amides as slip and antiblock agents. In the lubricants industry, simple and complex esters are used to replace traditional oils and fats.

Fatty acids and their derivatives are used in cosmetics, pharmaceuticals and food industries. Esters like glycerol monostearate and sorbitant monoleates are being utilized as emulsifiers in food industries, meanwhile, isopropyl palmitate and isopropyl myristate are applied as emollients in cosmetic industry (Speed, 1990). The simplified applications of oleochemical products are indicated in Figure 2.3 below:



(Source: Speed, 1990)

Figure 2.3: Range of Applications of Oleochemical Products

2.4.3 The processes of oleochemicals production

Basically, the production of oleochemicals involved splitting of fats at high temperature into fatty acids and glycerol. The process includes fat splitting, transesterification and enzyme catalyzed esterification, to produce alkyl esters, which are less corrosive and more easily transported. Figure 2.4 illustrates the production of oleochemicals.

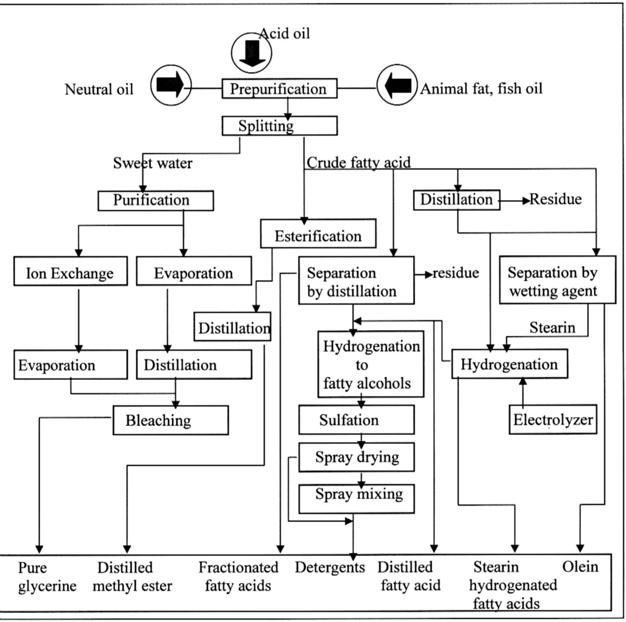


Figure 2.4: Production Technology for Oleochemicals

The manufacturing operation for the main oleochemicals can be described using the Lurgi process, which operates at specific temperature and pressure (Ong *et al.*, 1986). The fundamental of Lurgi process involved a hydrolytical splitting of triglycerides in oils and fats into free fatty acids and glycerin at the temperature of 250^0 C - 260^0 C and pressure of 48 - 55 bar. The most common method for the production of fatty acids adopted by the oleochemical industries is high temperature (250 ^{0}C) and medium pressure (50-60 bar) fat splitting. The fatty acids produced are purified or fractionated into broad cuts or pure fatty acids through a simple fractional distillations. Without further chemical modifications, fatty acids can be used for the production of candles, cosmetics products and rubber or plastic processing.

Derivatives of fatty acids include sodium salt or soap which is produced through the neutralization process between sodium hydroxide and fatty acids. It also includes metallic soap which is commercially prepared through precipitation and non-aqueous fusion methods (Zafarizal, 1997). Production of fatty esters can be done through the following routes:

1. Esterification of fatty acids with alcohols using an acid catalyst.
2. Alcoholysis of triglycerides with basic catalyst, a process also known as interesterification.
3. Acidolysis of triglycerides with an acid catalyst.
4. Interchange of two different esters with a basic catalyst.
5. Reaction of acid anhydride with alcohol, with acid as the catalyst or the reaction of acid chloride with alcohol.

Lurgi process engages a single-stage counter-current splitting process which is operated continuously to ensure sufficient level of water dissolves in the fat. The vacant section of the tower acts as the reaction compartment where crude fat passes in coherent phase to the top. Heavy splitting water flows downwards through fat and fatty acid mixture, counter-currently and the splitting process can extent up to 99 %.

The fatty acids are distilled under pressure at low temperature to retrieve high grade purity of fatty acids. Crude fatty acid is then dried in drier and degasser under vacuum of about 40 mbar and drawn into the distillation tank with vacuum of approximately 12 mbar. The vapour of fatty acid is condensed in surface condensers where low volatile components are removed. The removal of low volatile component is carried out by recycling the distillate directly to hot stripping tray in the still and heating up near to the temperature of fatty acid vapours. The heavy ends can be extracted separately or directly and redistilled as indicated in Figure 2.5 below.

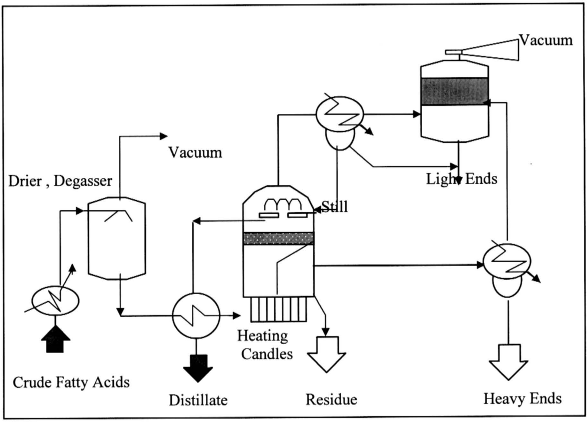


Figure 2.5 : Fatty Acid Distillation

Methyl ester of fatty acids can be produced by esterification of fatty acids or the transesterification of triglicerides. The esterification can be carried out batch by batch at

200-250 °C at which the reaction water must be removed constantly to obtain higher ester production. Common method used is the counter-current reaction of continuous esterification.

The common process for the production of methyl esters is transesterification of fats and oil with methanol. At low temperature of 50-70 ° C and 1 atm, ester interchanges occur with the presence of alkaline catalyst. After the process of alcohol component, glycerin being replaced by methanol, the mixture was left to settle. The glycerin layer in the lower part, is removed while the methyl ester is further processed. This process required pre-neutralization of fat with alkali refining and steam distillation of preesterification of free fatty acids. The following simplified diagram (Figure 2.6) clarifies the manufacturing of methyl ester from fatty acid.

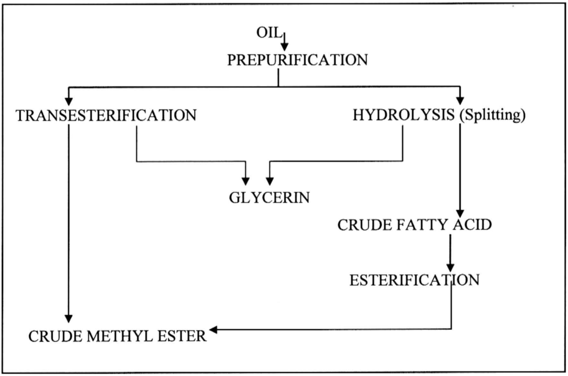


Figure 2.6 : A Simplified Flow Diagram of The Manufacturing of Methyl Ester

Esterification and alcoholysis are the most common methods used for the synthesis of esters. For oils with more than 5% free fatty acids, a combination of esterification and alcoholysis is also practiced. The Table 2.5 indicates the commonly used catalysts for alcoholysis or interesterification.

Table 2.5: Catalysts for Interesterification Process

Catalysts	% Used	Temperature (°C)	Time
Metal Salts :			
Acetates, carbonates, chlorides, nitrates, oxides of Sn, Zn, Fe, Co and Pb	0.1 - 2	120 - 260	0.5 - 6 hr under vacuum
Alkali Hydroxides:			
NaOH, KOH, LiOH	0.5 - 2	250	1.5 hr under vacuum
Alkali hydroxide and Glycerol	0.05 - 0.1 0.1 - 0.2	60 - 160	30-35 min. under vacuum
Metal Soap:			
Sodium stearate	0.5 - 1	250	1 hour under vacuum
LiAl stearate/ NaTi stearate	0.2	250	
Alkali Metals:			
Na, K, Na/K alloy	0.1 - 1	25 - 270	3 - 120 min.
Metal Alkoxides:			
Sodium methoxide, ethoxide, butoxide.	0.2 - 2	50 - 120	50 - 120 min.
Metal Hydrides:			
Sodium hydride	0.2 - 2	170	3 - 120 min.
Metal Amide:			
Sodium amide	0.1 - 1.2	80 - 120	10 - 60 min.

(Source: Hamilton, 1990)

Figure 2.7 indicates a detail process flow of fatty acid methyl ester manufacturing through an esterification route. Fatty acids are used in various industries including textile, cosmetics, pharmaceuticals, plastic, lubricants, diesel substitute and other applications.

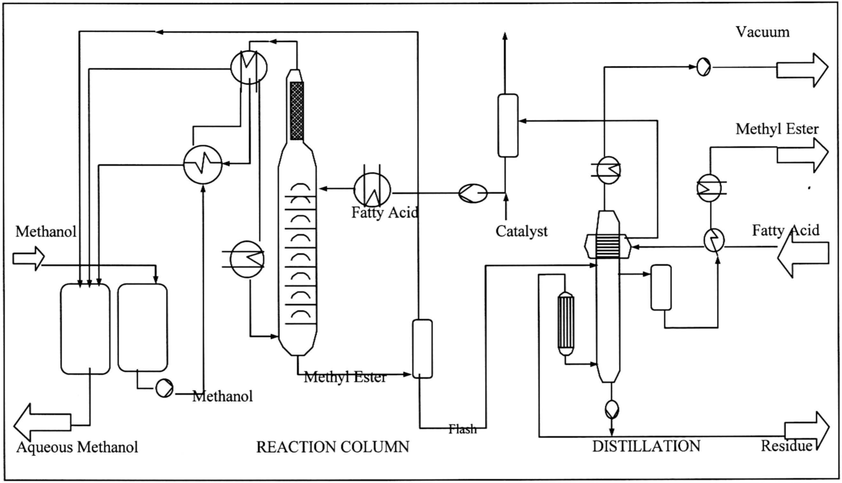


Figure 2.7: The manufacture of fatty acid methyl esters by esterification

The derivatives of fatty esters include soaps and alpha-sulphonated methyl esters (SME) (Salmiah, 1993).

Glycerol is produced as a mixture of 10 % - 30 % glycerol and water, that is the sweet waters during the production of fatty acids through the fat splitting or fatty esters through alcoholysis (Zafarizal, 1997). The manufacturing process involved four major steps i.e. purification, evaporation, distillation and bleaching. The sweet water is purified through the distillation process or ion-exchange methods to obtain the glycerol in an improved quality as shown in Figure 2.8. In this step, fatty matters and protein in the crude sweet water are removed by mineral acid addition.

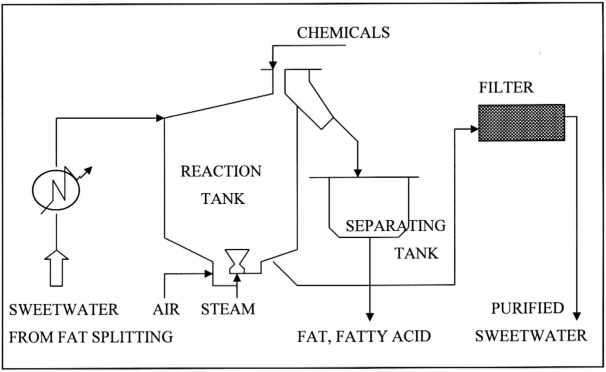


Figure 2.8: Sweetwater Purification

The crude glycerine obtained is then treated with alkaline salts or aluminium before it undergoes neutralization. The precipitates are abstracted in filter presses, which contain 88% of crude glycerine. The process is indicated in Figure 2.9.

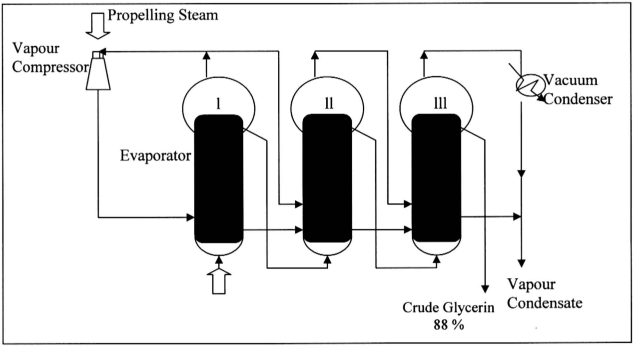


Figure 2.9: Sweetwater Evaporation (Triple Effect with Vapour Condenser)

Crude glycerine is then distilled to extract glycerine in a vacuum distillation tank at 160 – 170 °C while agitating by direct steam injection.The major part of the glycerine vapour is condensed in the 'hot condenser' whereas in the 'cold condenser' residual glycerine vapour condensed with the low volatile components. The odourous and coloured low volatile components of about 5 - 8% are extracted with activated carbon adsorption for the production of higher quality glycerine. The process of distillation and bleaching are shown in Figure 2.10.

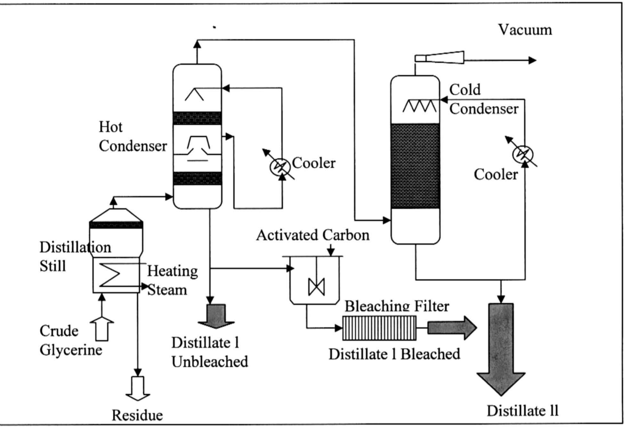


Figure 2.10: Glycerine distillation and bleaching steps

Glycerol is used as solvent or drugs carrier in pharmaceutical products, as humectants in cosmetics and tobacco, as anti-freeze or heat transfer agents, as hydraulic fluids and as plastics stabilizer for less polar polymers (Salmiah, 1993). Glycerol is commonly used as an ingredient for the production of nitroglycerine which is used in explosives; polyesters which can be used in grease or lubricants; polyols for the production of polyurethanes and mono and diglycerides which are useful for food emulsifier (Salmiah, 1993).

The production of fatty alcohols is carried out using the three common technologies that include, high temperature and pressure hydrogenation of oils, high temperature and pressure hydrogenation of fatty acid methyl esters, and high temperature and pressure hydrogenation of fatty acids.

The three basic commercial scale methods of fatty alcohols production commonly applied are the Ziegler process, the Oxo synthesis and high pressure hydrogenation of natural fatty acids and esters. The high pressure hydrogenation can be used with triglycerides, fatty acids or fatty acid esters, as feedstock.

These can be carried out by esterification of fatty acids or by transesterification of triglycerides. High pressure hydrogenation of methyl esters to fatty alcohol with catalyst, have various process options characterized by the application of the catalyst in either a fixed bed or suspended feed.

The high pressure hydrogenation process converted fatty acids or the derivatives into fatty alcohols catalyzed by heterogeneous catalysts. Normally, it can be utilized with either the suspension or a fixed bed process. However, the suspension process has a higher catalyst consumption of 0.4 - 0.7 % than of the fixed bed process.

Nevertheless, the advantage of utilizing a fixed bed process (indicated by Figure 2.11) is the quantitative conversion of the ester into fatty acid with low formation of hydrocarbon compared to the suspension process (Figure 2.12). Therefore, crude fatty alcohols produced with the fixed bed process is of a higher quality due to the lower content of hydrocarbon, whereas, in order to produce a better quality of fatty alcohols from a suspension process, additional purification stage is necessary.

Lurgi process involved the hydrogenation of fatty acids as the feedstock without previous esterification in separation unit. The process is done by recirculating fatty alcohol in the initial step as the 'in situ' esterification take place and convert fatty acids into wax esters. This is followed by the hydrogenation of wax ester in the same way a hydrogenolysis of esters occurred. These fatty alcohols have limited uses. Stearyl alcohols is used as suppressors of water evaporation in dry areas. Unsaturated alcohols are used as emulsifiers and textile auxiliaries. More than 90 % of fatty alcohols produced worldwide are used for the production of derivatives, fatty sulphates, fatty alcohols ethoxylates and fatty alcohols ether sulphates (Salmiah, 1993). These derivatives are extensively used in the production of washing and cleaning products.

The most common fatty nitrogens are fatty amines, nitriles and amines. Fatty acids or esters reacted with ammonia at 200°C under mild pressure to produce fatty amines. If the reactions were to be carried out in the presence of aluminium oxide then the fatty nitriles would be formed. Fatty amides are used in lubricants, as water repellent agents, foam stabilizers and additives in rubber compounding. Fatty nitriles are used in synthetic fibers, textiles auxiliaries and the production of fatty amines.

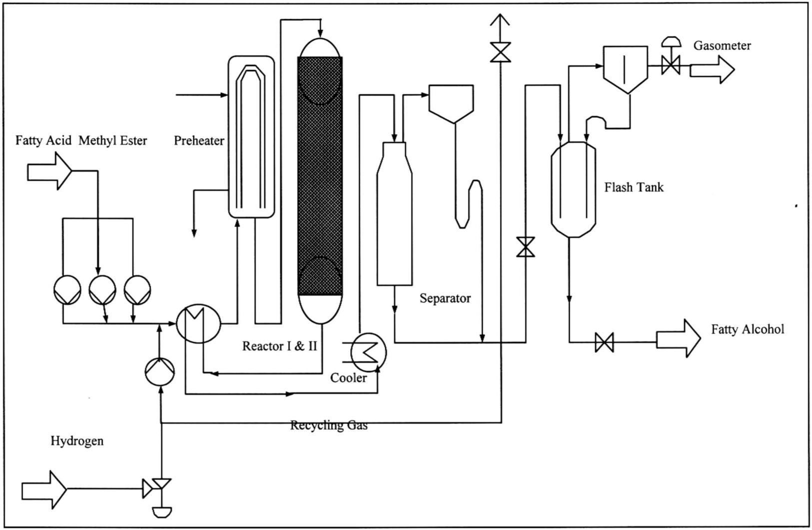


Figure 2.11 : High pressure hydrogenation of fatty acid methyl esters- Fixed bed process

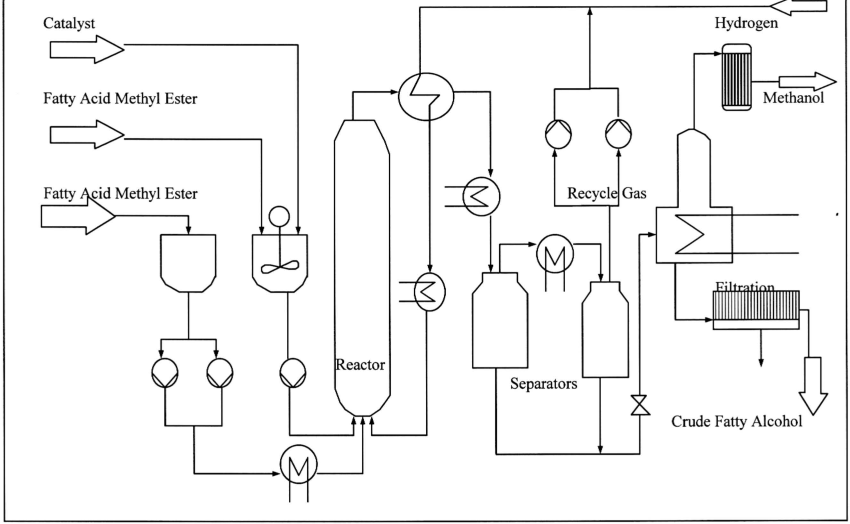


Figure 2.12: High pressure hydrogenation of fatty acid methyl esters - Suspension process

Fatty nitriles are used as lubricating additives, corrosion inhibitors, fuel and gasoline additives, floatation agent, collectors of mica, silica and feldspar and as agent reclaiming natural and synthetic rubber. The derivatives of fatty nitrogen are used as cationic surfactants in fabric softeners, conditioners, antimicrobial disinfectants, textiles and paper softeners, anti static and oil drilling auxiliaries (Salmiah, 1993)

Due to the availability of raw materials, technology, capital and market demand, the nonfood applications of palm oil based oleochemicals are expected to have a bright future. With the current awareness on the environmental issues and preference for the environmentally friendly products, the utilization of the palm oil and palm oil products through the oleochemical route is also expected to increase.

2.5 INDUSTRIAL WASTE

2.5.1 Definition of Industrial Waste

Industrial waste has been defined as '"material or energy which, in the eye of the producer, arises at a rate and in a form such that it has no value" (Smith, 1997). The definitions of industrial waste by the United Kingdom Environmental Protection Agency also have been widely accepted i.e. :

i) any substance which constitutes of a scrap material or an effluent, or other unwanted surplus substance arising from the application of a process; and

ii) any substance or article which requires to be disposed of as being broken, worn out or contaminated or otherwise spoiled. Industrial wastes vary according to the raw materials being used and the chemical introduced during the process of manufacturing.

The waste deposited in whatever environment is applicable and can be a mixture of organic and inorganic materials, solids, liquids, sludge, or a combination of any or all of these. Waste can be defined as the material purchased that is not consumed by customers, and it is used for activities that do not add value to the service rendered to the customers (Goodrich, 1994). The definition of solid waste by the UNEP is " all domestic refuse and non-hazardous wastes such as commercial and institutional wastes, street sweepings and construction debris". Waste can be categorized into hazardous or non-hazardous. Hazardous waste covers a range of industrial and other wastes, the disposal of which calls for special procedures, either because of their hazardous nature or their physical characteristics. The problems associated with hazardous wastes arise principally from the lack of definition and therefore resulting in imprecise method of control and reason of its hazardous nature (Piggott and Barron, 1990).

Data gathered by the United Nation Environmental Programme (UNEP) at Rio Conference in 1992, indicated that from the total global waste generation, 95 % of it are produced by developed countries due to over-consumption of finished industrial goods. The global production of industrial waste in 1990 reached up to 2100 million tonnes of solid waste together with additional 338 million tonnes of hazardous wastes (Goh, 1990).

2.5.2 Hazardous Waste

Hazardous waste is defined as 'waste other than radioactive wastes which by reason of their chemical reactivity or toxic, explosive, corrosive, or other characteristic causes danger or are likely to cause danger to health or the environment' (Batstone, 1989). According to the Encyclopedia of Environmental Science (1999), the term hazardous waste refers to 'any material which a) is intended to be discarded or is of no further use and, b)exhibits characteristic or qualities which make it dangerous to humans or the environment'. It gives serious risk of health to workers as well as to the public during the handling, storage, transportation, and disposal of the waste either through inhalation, ingestion or skin contact with acute or chronic biological effects (Lim, 1990).

Health effects of hazardous waste normally is recorded by making assessments on blood lead levels, organochlorine fat levels, urinary phenol level, mercury hair levels, blood enzyme levels, DNA adducts and protein adducts (Kamrin, 1997). The generation of hazardous waste among the Asian countries are shown in Table 2.6. The bulk of it is disposed into landfills.

Table 2.6: Hazardous Waste Generation in Asian Countries

Country	Hazardous Waste Generation (tonnes)
China	35 000 000 - 75 000 000
Hong Kong	105 000
Indonesia	4 224 000 (Jakarta area)
	90 000 (Surabaya area)
Korea	8 637 000
Malaysia	380 000
Philippines	100 000 - 290 000 (Metro Manila)
Singapore	42 000
Taiwan	620 000
Thailand	1 200 000

(Source: Piggott and Barron, 1990)

2.5.3 The Scheduled Wastes Scenario in Malaysia

In Malaysia, the Environmental Quality (Scheduled Wastes) Regulations enacted under the Environmental Quality Act, listed out that 28 waste categories under nonspecific sources, 30 under specific sources and 107 waste streams as scheduled wastes with special requirement in the handling, transportation and disposal (Cirillo, *et al.,* 1994). The quantity of scheduled wastes generated decreased from 632,521.31 metric tonnes in 1996 (Environmental Quality Report 1997) to 279,510.9 tonnes in 1997 (Environmental Quality Report 1998). The total hazardous waste generation grows about 35 % in 2000 to 377,339.7 tonnes (Idris and Jaafar, 1993; Singh and Idris, 1993). The quantity of waste generated according to industry is indicated in Table 2.7

Table 2.7: Percentage of Scheduled Waste Generated According to Industry, 1997

Industry	Percentage of Waste Generated
Chemical	31.6
Others	29.1
Textile	13.8
Metal	10.8
Electronic	4.6
Rubber & Plastic	2.9
Industrial Gas	2.4
Printing and Packaging	2.02
Workshop	1.3
Petroleum	0.7
Pharmaceutical	0.3
Oleochemical	0.2
Resin & Adhesive	0.1
Asbestos	0.07
Total Quality of Waste Generated:	279, 510.9 metric tonnes (100%)

(Source: Environmental Quality Report 1998, (DOE, 1999))

The characteristics which identify industrial waste as hazardous waste include ignitability, corrosivity, reactivity, and toxicity of the waste (Davis, 1997). Department of Environment's (DOE) definition of hazardous waste as stated in EQA 1996 is 'any natural or artificial substances including raw material, whether in a solid, semi solid or liquid form, or in the form of gas or vapor or in a mixture of at least two of these substances, or any living organism intended for any environmental protection conservation and control activity which can cause pollution'.

The amended EQA (1996) provides the regulation that makes it mandatory for industries to make inventories of the waste movement and source of toxic waste of the industry and report to the DOE (New Straits Times, May 7, 1996). The hazardous wastes generated by the industries are required to be disposed of at The Hazardous Waste Treatment Centre, a central hazardous waste treatment plant constructed in Bukit Nanas, Negeri Sembilan (Idris and Jaafar, 1993).

The hazardous waste land disposal facility is designed and operated to avoid human health exposure and to minimize migration of contaminants from the site particularly to reduce the possibility of contaminating surface or ground water and others. Federal and state legislations require proper handling and management of hazardous waste in order to prevent environmental degradation. It is widely accepted that to remain competitive in the industry, waste reduction is essential to companies as regulatory measures are taken by the government, making landfill disposal more costly and more difficult (New Straits Times, June 7, 1998; Sunday Star, November 24, 1996; Chen, 1990). The subject of toxic and hazardous waste disposal has been studied in Malaysia since the early 80's and although the Environmental Quality Act (EQA) of 1974 came in force in 1975, until March 1989 there were no incentives for hazardous waste producers to reduce the quantity of wastes generated (Goh, 1990). To reduce the possibility of environmental contamination, the DOE has drafted several Orders and Regulations in 1989 as guidelines in handling and disposal of hazardous wastes (Abd. Rahman, 1990) which includes:

1) Environmental Quality (Prescribed Premises) (Scheduled Waste Treatment and Disposal) Order 1989.

2) Environmental Quality (Prescribed Premises) (Scheduled Waste Treatment and Disposal) Regulations 1989.

3) Environmental Quality (Scheduled Waste) Regulations 1989.

Environmental Quality (Prescribed Premises) (Scheduled Waste Treatment and Disposal) Order 1989 came into force on May 1st, 1989, and this order stipulates that disposal of scheduled wastes are required to be carried out in the off-side storage facilities, off-side treatment facilities, off-side recovery facilities, scheduled waste incinerators, land treatment facilities or secure landfills.

Environmental Quality (Prescribed Premises) (Scheduled Waste Treatment and Disposal) Regulations 1989 states that inventory of scheduled wastes is compulsory with accurate and up-to-date information on types and quantities of scheduled wastes received, stored, treated, recovered, destroyed, disposed of or handled at a premise. The neglection to comply is considered as an offence and may be compounded under section 45 of the Act (Environmental Quality Act, 1974).

The Occupational Safety and Health Act 1994 provides guidelines on management, usage and control in handling of hazardous chemicals (INTIB, 1994). It also states that safety measures are to be taken when supplying chemical product to users; underlining the responsibilities of hazardous chemical supplier; and stress the need for close supervision in the classification, packaging and labeling of hazardous chemicals (New Straits Times, April 17, 1997).

2.5.4 Hazardous Waste Management

Hazardous waste management includes prevention with waste minimization, recycling, clean technology, waste treatment (physical, chemical or biological) and waste disposal. The objectives of the treatment and disposal technologies are to render waste less hazardous and to dispose them in such a manner that any negative impact on the environment is reduced to the lowest possible level.

In order to control waste, particularly, in handling hazardous waste, the involvement and participation of various agencies are essential as indicated in Figure 2.13

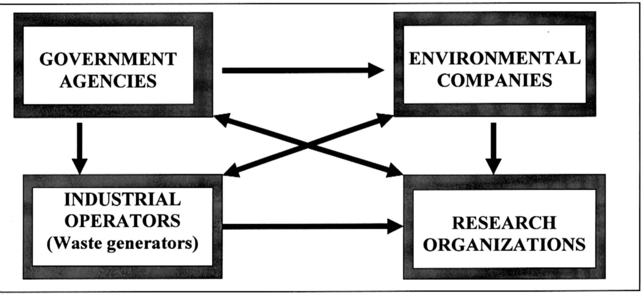


Figure 2.13: Major participants in waste control

Pollution prevention is 'the use of materials, processes, or practices that reduce or eliminate the creation of pollutants or wastes at the source which includes practices that reduce the use of hazardous material, energy, water, or other resources and practices that protect natural resources through conservation or more efficient use' (US EPA, 1990).

2.5.5 Oleochemical Wastes

Besides the requirement to comply the standards and regulations set by the DOE as indicated in the Environmental Quality (Sewage and Industrial Effluents) Regulation 1978, the oleochemical industries are also obligated to be within the regulations and standards for scheduled waste due to the production of hazardous waste (Ma, 1992). As indicated in Table 2.7, oleochemical industries contributed up to 0.2 % of the total quantity of 279, 510.9 metric tonnes of scheduled waste generated in 1997, which comes from its various pathways of the oleochemical processes. Water and solid waste are the two main components of oleochemical output. The wastewater generated by different units of production, differs in flow and composition and requires different treatments. Wastewater generated in this industry includes waste from:

i) Barometric condenser,

ii) Glycerine evaporator,

iii) Glycerine distillation unit i.e. glycerine pitch and vacuum barometric condenser,

iv) Sweet water treatment filter press equipment, and

v) Equipment and floor washing.

The total volume of wastewater generated was 0.2 to 0.3 m^3 per hour for a feed of 5 MT/hr with the water consumption of 25 m^3 per hour (Ma *et al.*, 1996). Oleochemical waste consists of fatty acids, highly biodegradable glycerine, methanol, sodium soaps, oil and grease, ester and detergents, with a BOD and COD of 2 000 - 3 500 mg/l and 4 000 - 7 000 mg/l respectively. The major production of solid waste in this industry is from the filtration of sweetwater treatment, distillation of crude fatty acid and the final bleaching process of glycerine production. The effluent discharged from this industry falls under Environmental Quality (Sewage and Industrial Effluents) Regulations, 1979. Table 2.8 shows the parameter limits of effluent Standard A and B.

Table 2.8: Parameter Limits of Effluent Standard A and B

Parameter	**Unit**	**Standard**	
		A	**B**
Temperature	°C	40	40
pH Value	-	6.0-9.0	5.5-9.0
BOD_5 at 20 °C	mg/l	20	50
COD	mg/l	50	100
Suspended Solids	mg/l	50	100
Mercury	mg/l	0.005	0.05
Cadmium	mg/l	0.01	0.02
Chromium, Hexavalent	mg/l	0.05	0.05
Arsenic	mg/l	0.05	0.10
Cyanide	mg/l	0.05	0.10
Lead	mg/l	0.10	0.5
Chromium, Trivalent	mg/l	0.20	1.0
Copper	mg/l	0.20	1.0
Manganese	mg/l	0.20	1.0
Nickel	mg/l	0.20	1.0
Tin	mg/l	0.20	1.0
Zinc	mg/l	1.0	1.0
Boron	mg/l	1.0	4.0
Iron (Fe)	mg/l	1.0	5.0
Phenol	mg/l	0.001	1.0
Free Chlorine	mg/l	1.0	2.0
Sulphide	mg/l	0.50	0.50
Oil and Grease	mg/l	not detectable	10.0

(Source: Ong and Choo, 1990)

2.6 WASTE MINIMIZATION PROGRAM

2.6.1 Definition and Implementation of Waste Minimization Program

The best possible solution of hazardous waste is by minimizing hazardous waste at their sources. According to the hierarchy of waste management practices of USEPA and European Environmental Agencies, "waste reduction" is situated at the top followed by "waste recycling" and "reuse" and lastly "treatment and disposal" at the bottom. Figure 2.14 indicates the hierarchy of waste minimization program being adopted by Standard and Industrial Research Institute of Malaysia (SIRIM):

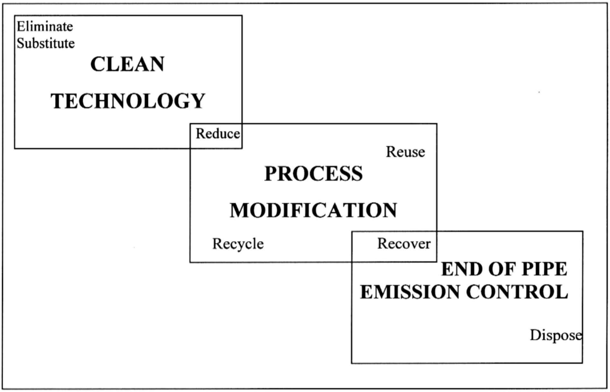


Figure 2.14: Hierarchy of Waste Minimization Program

Among the most widely adopted option of cleaner technology is waste minimization program. In a waste minimization program, the hierarchy involves clean technology to eliminate or substitute waste production; process modification to reduce; reuse, recycle and recover waste; and the end-of-pipe emission control of the technology of waste disposal. Waste reduction program should be incorporated and act as a key part of an environmental management system (Hunt and Newman, 1997).

Material exchange program may helps to reduce the volume of waste for disposal and encourages waste minimization (Czek, 1997). However, such institutional arrangement for this particular purpose is not available in Malaysia that the possibility of material exchange especially hazardous chemicals is very low. Waste minimization program suggested by Ciambrone (1995) requires five major steps:

1. Reducing the amount of chemicals used,
2. Changing to more environmental friendly chemicals or processes whenever possible,
3. Reducing solid waste,
4. Recycling/reducing as much as possible, and
5. Working with design engineering to reduce the requirements for environmental friendly materials and processes.

2.6.2 Benefits of Waste Minimization

Waste minimization is not a new concept as it has been applied as long as man has been manufacturing products. The following diagram (Figure 2.15) simplifies the benefits gained by an industry with the implementation of waste minimization.

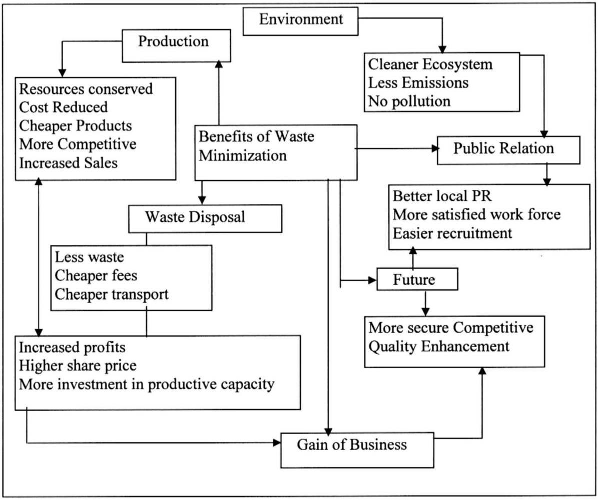


Figure 2.15:Various Benefits Accrued from Implementation of Waste Minimization Program (Clark, 1995)

2.6.3 Cleaner Technology .

In the fifties and sixties, environmental law only stressed on the dilution of pollutants. The seventies focused more on laws and regulations that required the end-of-pipe treatment of waste. The result does not solve the worsening condition of the environment. However, in the eighties, a new approach of recovery and recycling of waste was implemented with a more promising result. Finally, 'cleaner production' technology was introduced that really moves towards the preservation and betterment of the environment. With the introduction of ISO 14000, industries are encouraged to continuously improve their environmental performance in meeting regulatory requirements (The New Straits Times, October 10, 1998).

The Global Environmental Outlook (GEO-1) Report indicates a significant progress by the industrial and developing countries towards the betterment of the environment where legal frameworks, economic instruments, environmentally sound technologies, and cleaner production processes have been improved and implemented. This is so as the number of governments, non-governmental organization (NGOs), private sectors, civil society, and scientific and research community has increased to accept the challenges in preserving and improving the environment in their daily activities. In Malaysia, ISO 14000 is not compulsory in order to allow industries to establish a self-regulatory mechanisms. However, this resulted in a slow response from the industries (The New Straits Times, May 28, 1997). DOE has set targets to encourage industries to have a vision and consistently improve their processes with separate sets of standard for each sector for effective enforcement under the Eight Malaysian Plan (The New Straits Times, October 27, 1998).

Cleaner technology is generally a technology, which avoids generating pollutants in the production process. Unlike 'clean-up' technology that focuses on waste handling and disposal and usually reduces environmental damage but increases production costs, cleaner technology frequently cuts cost and reduces occupational risks, reduces wastage of raw materials and energy, and reduces toxic emission of waste (The Star, September 1, 1998). Cleaner technology applies to the production of goods and services with least environmental impacts practicable under the technological and economic constrains (Goh, 1993). This allows the industrial growth to continue and maintain the environmental sustainability.

Definition of cleaner technology adopted by UNEP is "the continuous application of an integrated preventive environmental strategy to processes and products so as to reduce the risks to human and the environment". The cleaner production technology emphasizes mainly on prevention of waste applicable to each stage of an industrial process flow. It also includes *in situ* reduction of emissions and wastes in the production processes while for products, it concentrates on lessening the impacts through the whole life-cycle of the manufacturing goods.

In order to implement the cleaner technology program, an industry must first recognize the manufacturing routes that generate waste and require the utilization of energy. It can be carried out by implementing various methods including project environmental screening, environmental impact and risk assessments, environmental auditing and many more. At the management level the method helps the verification on product evaluations, technology assessments, hazards identifications, energy, waste and safety audits, pollution monitoring, waste minimizations, residue management and energy efficiency. At the technical level, the cleaner technology program can be implemented with the improvement of the general housekeeping, changes in the processes, substituting materials, redesigning products and investment in new improved technologies. The implementation of cleaner technology not only contributes towards the betterment of the environmental condition but also profits the industries through less investment of clean up costs and waste disposal costs.

The targets of the UNEP Cleaner Production Programme are to increase global awareness of the preventative environmental protection strategy incorporated in the cleaner production concept, and to abet industries and governments to establish actual cleaner production programmes and activities that result in the adoption of cleaner technology know-how, technology and approaches. Environmental auditing enables the determination of the degree of compliance of an industry's environmental management system and the overall environmental risk of the premises. Industries are encouraged to focus on clean technology and improve design by involving efficient resource utilization, waste minimization, energy conservation, recycling, reuse, reclaim, elimination and reduction of waste (SIRIM, 1992). Pollution control forms an inherent part required to safeguard the environment, while at the same time permitting the advancement of industrial and social development. The key factors to improve the environmental condition are the action of every party to use the alternative and renewable energy resources, global cleaner and cleaner production systems, harmonious world-wide action for protection and conservation of the exhaustible resources.

Besides the preservation of the environment, factors that also contribute towards the requirement and the necessity of implementing cleaner technology in industries are :

- intensifying legal requirements and regulation,
- increasing environmental responsibility for process and products,
- pressure from public,
- improvement of general efficiency and quality,
- competitions from rival companies,
- to create environmentally friendly image for positive public image,
- to reduce cost and liabilities particularly concerning waste treatment and disposal,
- to create new market etc.

Therefore, cleaner technology emphasized on the possibility to reduce waste quantity in every possible process which can be detected by carrying out a waste auditing process.

2.6.4 Waste Audit

The process of manufacturing goods in an industry requires various elements as indicated in Figure 2.16 by which the generation of waste hold no commercial values to the industry. Besides the contribution to no positive income, the treatment, transportation and disposal of these wastes actually required considerable management costs particularly to industries that generate hazardous waste. In order to minimize the waste generation, waste auditing needs to be carried out to avoid unnecessary cost for the waste management.

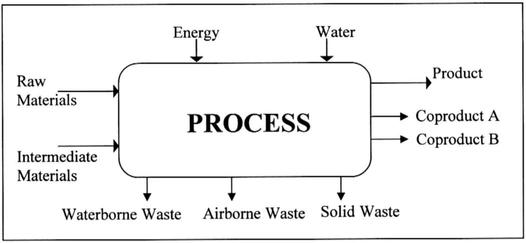


Figure 2.16: Life Cycle Inventory Template (Ciambrone, 1997)

The most significant steps in achieving waste minimization goals require the auditing of waste generated by an industry (Sastry, 1995; Shen, 1995; EPA, 1990). It involves the investigation of each operation that produces waste to resolve the process of the waste being generated, the distinctive characters, the management and the costs involved.

This auditing steps contribute information in the evaluation towards waste minimization goals and recognize the options of minimizing it. In addition to it, the auditing steps also allow identifications of waste stream that requires the most attention based on the composition, quantity, disposal costs, degree of risk, minimization possibility, recyclable and status of compliance (Haas, 1995). There are various forms of conducting waste reduction audit and one simplified version has been suggested which consists of 4 major steps:

Stage 1: Common Sense Waste Minimization.

Stage 2: Information-Driven Waste Reduction.

Stage 3: Audit Dependent Waste Reduction.

Stage 4: Research and Development Based Waste Reduction.

The common procedures involved in conducting a waste audit are (Resch, 1989):

1. Identify the quantity and classes of hazardous substances in the process wastes and emission (including both the regulated and unregulated),
2. Identify the waste distinct production sources,
3. Determine priorities for possible waste minimization action with the reference to the costs, environmental consideration, health and safety of workers, liabilities, and production obligations,
4. Analyze and choose the most feasible minimization programs,
5. Compare alternative options of waste minimization in the economic aspect with current and future waste management or pollution control options,
6. Evaluate the progress and success of the selected waste minimization techniques.

In order to carry out a good waste audit, the following phases should be included in the auditing process:

1. Formation of audit team, and pre-audit phase to prepare for auditing processes,
2. Collection of data period to obtain a material balance, and
3. Synthesis phase to analyze and apply possible waste reduction plan according to data on material balance.

The UNEP and UNIDO dictated 20 steps to be taken in three main phases in carrying out a waste audit as indicated in Figure 2.17.

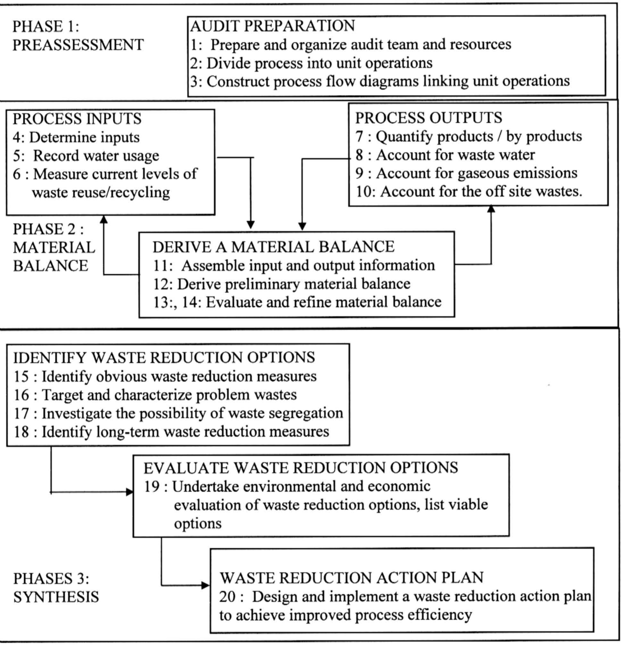


Figure 2.17: Methodology of Waste Audit

2.7 WASTE TREATMENT PROCESS

Before final disposal to landfills, waste undergoes treatment to avoid groundwater contamination. Among the most common waste treatment options include physical, chemical and biological treatments that involve the usage of physical mechanisms, various chemical additives and degradation of organic waste accordingly.

Biodegradation methods are being investigated to develop, identify and test microorganisms capable of degrading highly toxic and refractory organohalide pollutants. Aerobic and anaerobic biological processes are suitable for treatment of a few types of industrial waste that contain organic constituents by including these factors (Bordacs and Young, 1997):

1. solid retention time,
2. organic loading rate and influent waste characteristics,
3. effluent and biomass recycle,
4. media type, specific surface area, and placement for fixed film processes,
5. equalization,
6. influent waste distribution and waste sludge withdrawal,
7. operating temperature, and
8. desired final end products.

Toxic constituents can inhibit microbial growth to the point where it is difficult to maintain active population of microbes to metabolize wastes at reasonably rapid rates of conversion. The treatment processes include activated sludge, composting, trickling filters and aerobic and anaerobic waste stabilization lagoons that are generally referred to as land treatment (Agamuthu, 1995). Research has not yet identified an organism capable of treating all types of pollutants. However, a white rot fungus (*Phaenerochaete chrysosporium*) appears to be very promising with a unique secretion of hydrogen peroxide-dependent oxidant that has the capability of degrading lignin and other organohalides.

2.7.1 Composting

Compost has been used for centuries in soil and crop management. As agriculture moves more and more towards sustainable farming practices, greater emphasis is placed on the utilization of compost in agriculture. Composting has been increasingly popular as an alternative to dispose waste in these recent years and as a beneficial option of recycling wastes (Agamuthu *et al.,* 1999; Agamuthu, 1997). It has emerged as a possible organic waste recovery, which is not only abating the environmental pollution but is also promoting sustainable development (Warmer Bulletin, 1998; Grehan *et. al.,* 1996; Gujer, 1991).

The application of composts to agricultural soils is now recognized as an effective method to improve productivity in agroecosystems. A survey carried out by the Roper Organization, New York, USA (1995) presented data that 96% of solid waste professionals predicted that composting will expand in the coming years as the best method of handling solid waste.

The composting involves biological decomposition of waste containing organic substances of plants or animal origin, under controlled conditions, to a state sufficiently stable for nuisance free storage and utilization. Composting can provide a sustainable solution to recover valuable organic products with the production of fertilizers and soil amendments (Pratt and Deol, 1992).

2.7.2 Definition of Composting

Compost is defined as the end product i.e. innocuous humus, remaining after the composting process is completed (Spellman, 1997). In terms of the chemical property, compost is a heterogeneous mixture of substances that includes a variety of compounds synthesized by the microbial populations through the microbial decomposition, to a state that the materials could not be degraded further.

Properly composted material has the acceptable characteristics of humus. As humus, compost is not biochemically static and under appropriate condition, it will be decomposed further by microbes and to some extent by higher forms of life until eventually oxidized to mineral salts, carbon dioxide and water.

The term 'humus' was defined by Waksman (1938) as being complex aggregates of amorphous substances resulting from the microbiological activity that takes place in the breakdown of plants and animal residues. The composting process depends on the activity of the decomposers such as bacteria, fungi, actinomycetes and various protozoa.

2.7.3 Composting Techniques

The composting process can occur under aerobic condition, which will produce a pathogen-free yield. Under anaerobic condition a longer decomposition time is required with odor disturbance and pathogenic risks (Obeng and Wright, 1987). Because of its high humus content, compost has an ample capacity for base exchange. The quality of the compost depends on various parameters, including moisture content, temperature, particle size, oxygen supply, nutrient content, pH and others.

Moisture content of a composting mixture should stay within 40 to 70 %. This is to ensure that sufficient amount of moisture is available for the decomposers. As decomposition continues, moisture content of the composting materials decreases due to evaporation during thermophilic phase. When composting material has a moisture content exceeding 80 %, dewatering and the addition of bulking agents are required. It directly affects the composting process and the quality of the final product (Metcalf and Eddy, 1991). Too high in moisture content may cause the process to undergo anaerobic degradation and may require bulking agents. Bulking agents are materials added to prevent compaction of the composting mixture and to sustain sufficient airflow through the process of composting (Diaz *et al.*, 1993). The ideal bulking agent has low bulk weight, is readily degradable, and is dry as possible (Haug, 1980) and with appropriate particle size, moisture content and absorbency (Corbitt, 1990). Commonly, woodchips, straw, hay (dried grass), rice hulls, shredded tires, sawdust, rocks, peanut shells and garbage are used as bulking agent to amend the compatibility of composting materials (Diaz *et al.*, 1993 and Obeng and Wright, 1987).

Groups of the active organisms in the compost process are the bacteria and fungi that characterized by the successive appearance of mesophilic and thermophylic forms of bacteria, fungi and actonomycetes, and some protozoa. The microorganisms normally originated from the composting material or seeded from the atmosphere. In cases that involve the composting of hazardous materials, inoculum of appropriate microorganisms are required to be introduced into the composting system (Rochkind *et al.*, 1986). Introduction of inoculum into hazardous waste requires additional nutrients to enhance the microbial growth (Savage *et al.*, 1997). Different groups of microbes are involved since the composting process is a dynamic succession of microbial interact with substrate in the wastes. Figure 2.18 shows the organisms involved in the composting process.

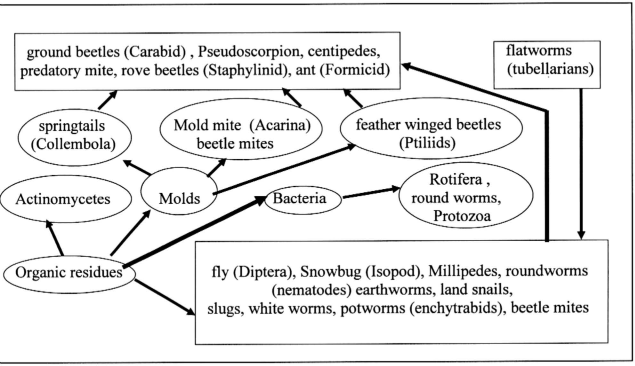


Figure 2.18: Food Web of The Compost Pile and Stages of Organisms Involved in Composting. (Source: Diaz *et al.*, 1993)

A typical temperature pattern of composting process is indicated in Figure 2.19. An increment of temperature to 45 ^{0}C takes place during the mesophilic phase. The temperature continues to rise that the mesophilic activity starts to subside while thermophilic activity increases up to a stage when thermophilic microorganism increased in population. Subsequently, the temperature drop allows the mesophilics to be activated again. As the process verge upon completion, nutrient level declines that it become a limiting factor for the survival of decomposers. The reduction of metabolic rate in the compost causes it to eventually come to ambient temperature indicating the completion of composting process.

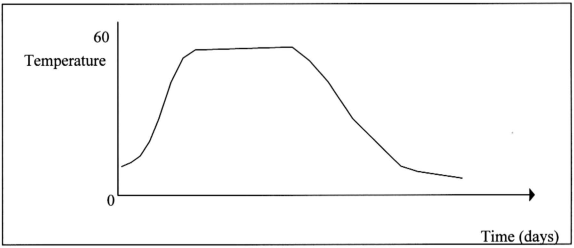


Figure 2.19: Typical Temperature Pattern of Composting System.

Temperature changes during decomposition of organic matter can be used as an indication of suitable functioning of composting as it directly affects pathogen control for production of high quality compost. The maximum temperature attained differs according to raw material used, the operations and design factors.

Particle size plays an important role in composting process as it provides different surface area contact and rate of oxygen diffusion. Typical particle size of material used for composting range from 10 to 50 mm. Oxygen supply should be within 5 to 15 % to optimize growth of mesophilic organisms. The quality of compost produced relies on duration required for the completion of composting process. High composting temperature with the optimum temperature of 50-55°C must be maintained for a sufficient length of time or at least two days to destroy pathogenic microorganism (Obeng and Wright, 1987). The curing and maturation periods of the compost vary from system to system according to the combination of materials used.

Composting material takes on an earthly odour towards the end of the composting phase where fungi and actinomycetes usually become visible. The earthly odor mingled with slightly musty overturns, continues to be characteristics of the product long after the processing phase has been completed. Finally the appearance of the finished product strongly depends upon the physical waste that was composted. Moisture content of the compost will be less than 15 % and approaches the consistency of fine dust and has been satisfactorily stabilized. The Figure 2.20 indicates the input and output analysis of the composting process.

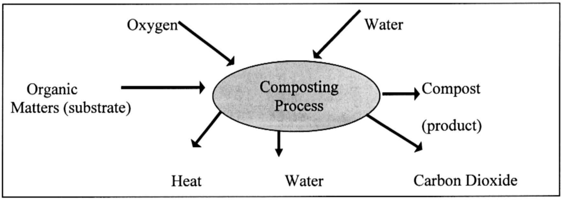


Figure 2.20: Input and Output of The Composting Process

The substrate is one of the most.important factors. With respect to the nutritional needs of the decomposing microbes, the carbon to nitrogen ratio (C:N) of the waste to be composted is the most important factor that requires attention. C:N represents the quantity of carbon in relation to the quantity of nitrogen in soil or organic material that determines the composting potential of a material and serves to indicate product quality. Departures from the ratio of 20 to 25:1 lead to a slowing of decomposition and hence of composting. Nitrogen in excess will be converted by the organisms into ammonia and the combination of high pH level and elevated temperature to volatilization of the ammonia (Agamuthu, 1994). The nitrogen content of waste varies greatly with the type and source of waste as is indicated in Table 2.9.

Table 2.9: Nitrogen Content and C:N of Various Wastes and Residues

Waste	**Nitrogen**	**C:N**
Activated sludge	5	6
Animal tankage	-	4.1
Blood	10-14	3.0
Cow manure	1.7	18
Digested sewage sludge	2-4	-
Grass clipping	3-6	12-15
Horse manure	2.3	25
Mixed grasses	214	19
Night soil	5.5-6.5	6-10
Nonlegume vegetables waste	2.5-4	11-12
pig manure	3.8	-
potato tops	1.5	25
Poultry manure	6.3	15
Raw sewage sludge	4-7	11
Sawdust	0.1	200-500
Sheep manure	3.8	-
Urine	15-18	0.8

(Source: Diaz, 1993.)

2.7.4 Benefits of Composting

As composting is a biological process, it has many advantages and limitations. The advantages include a generally lower equipment and operating outlay and fewer unfavorable impacts upon the quality of the environment, whereas the disadvantages are the slow rate of processing and unpredictability.

Other advantages of composting include the generation of a product that can be commercially profitable and reduction of treatment and disposing cost for waste treatment and disposal. Also, it is perhaps the most cost effective technology in which a waste material can be converted into a valuable agricultural resource by providing an inexpensive and environmentally sound method.

Compost may also be used as a substitute for peat in preserving wetland areas particularly in countries that have limited fertilized soil. Compost applied to plantation can act as soil amendment in improving the health of agricultural crops.

The process of composting not only reduces the bulk volume of solid waste but also have the ability to destroy human and plant pathogen in the compost itself as well as providing a recycling option of valuable plant nutrient in organic solid wastes. The following Table 2.10 shows the innovative utilization of compost as suggested by the US EPA.

Table 2.10: Innovative Utilization of Compost

Innovative uses of compost	**Application**
Bioremediation and pollution prevention	• Agricultural effluents, industrial residues, industrial accidents contaminate surface waters, soils, air, streams and reservoirs. • Contaminated soils, manage stormwater, control odour, degrade volatile organic compounds.
Disease control for plants and animals	• Sustainable farming systems • Agricultural plantations • Poultry industry
Erosion control, turf remediation and landscaping	• Soil amendment to alleviate soil compaction
Composting of soils contaminated by explosive	• Munitions sites particularly on explosive contaminated sites
Sites restorations	• Reforestation, wetlands restoration and habitat revitalization

(Source: US EPA, 1998)