SCHOOL OF MATERIAL AND MINERAL RESOURCES ENGINEERING

UNIVERSITI SAINS MALAYSIA

LIFE CYCLE ANALYSIS OF FISH PRODUCTS

EMPHASIS ON FISH WASTES AS RAW MATERIAL FOR BIOPLASTICS

By

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Dissertation submitted in partial fulfillment

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(Polymer Engineering)

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DECLARATION

I hereby declare that I have conducted, completed the research work and written the dissertation entitled: “Life Cycle Analysis of Fish Products Emphasis on Fish Wastes as Raw Material for Bioplastics”. I also declare that it has not been previously submitted for the award of any degree or diploma or other similar title of this for any other examining body or university.

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LIST OF ABBREVIATIONS

LCA	Life Cycle Analysis
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
IETS	Industrial Effluent Treatment System
BOD	Biological Oxygen Demand
COD	Chemical Oxygen Demand
TSS	Total Suspended Solids
FOG	Fat, Oil and Grease
ISO	International Organization for Standardization
MFC	Microbial Fuel Cell
OLR	Organic Loading Rate
HACCP	Hazard Analysis and Critical Control Point
FDA	Food and Drug Administration
USDA	United States' Department of Agriculture

LIST OF SYMBOLS

%N	Percentage of nitrogen in the sample
V_s	Volume of hydrochloric acid used to neutralize the sample
V_b	Volume of hydrochloric acid used for blank titration
N_{HCl}	Normality of the hydrochloric acid
M_N	Molar mass of nitrogen (14 $gmol^{-1}$)
W_S	Weight of the sample

ANALISIS KITAR HAYAT PRODUK IKAN MENEKANKAN SISA IKAN SEBAGAI BAHAN MENTAH UNTUK BIOPLASTIK

ABSTRAK

Objektif kajian ini adalah untuk mengklasifikasikan sisa bahan yang dihasilkan semasa proses pembuatan produk ikan dan menilai impak alam sekitar daripada sisa ikan melalui sistem kitaran hayat (LCA) dan juga ciri-ciri penggunaan potensi sisa ikan sebagai termoplastik berasaskan protein. Dalam tesis ini, kitaran hayat sistem pembuatan produk ikan dalam tin di Protigam Food Industries Sdn. Bhd. telah disiasat dengan mengikuti empat langkah LCA; (1) definisi matlamat dan skop, (2) analisis kitaran hayat inventori (LCI), (3) penilaian kesan kitaran hayat (LCIA) dan (4) tafsiran keputusan. Matlamat kerja ini adalah kitaran hidup 'buaian ke kubur' produk ikan dalam tin manakala skop kerja ini adalah unit berfungsi yang ditetapkan, iaitu setiap 1 tan ikan mentah yang memasuki kilang. Analisis LCI telah dijalankan dengan mendapatkan data inventori aliran keseluruhan proses dan input dan output bagi setiap subsistem dalam proses pembuatan. Selepas analisis LCI, LCIA dilakukan dengan mengenal pasti kategori impak yang berkaitan bagi produk ikan dalam tin dan diikuti dengan pengiraan nilai-nilai kategori impak yang berkaitan. Selepas itu, nilai-nilai tersebut dinormalkan dengan unit berfungsi. Hasil LCIA menunjukkan bahawa bagi setiap 1 tan ikan mentah yang memasuki kilang, terdapat 0.22 tan sisa pepejal perbandaran (sisa ikan pepejal) dihasilkan, penambhan 1.27 kg eq PO_4 dalam potensi eutrophikasi dan penggunaan tenaga sebanyak 1383.6 kWh. Hasil analisis sumbangan menunjukkan bahawa sumbangan proses memotong, letak ais dan retort adalah penyumbang terbesar bagi kategori sisa pepejal perbandaran, potensi eutrofikasi dan penggunaan tenaga masing-masing. Di samping itu, analisis Kjeldahl menunjukkan bahawa kandungan protein sisa ikan adalah kira-kira 16% yang masih mencukupi untuk ditransformasikan menjadi termoplastik berasaskan protein.

LIFE CYCLE ANALYSIS OF FISH PRODUCTS EMPHASIS ON FISH WASTE AS RAW MATERIAL FOR BIOPLASTICS

ABSTRACT

The objectives of this research were to classify the wastes generated during the manufacturing processes of fish products and evaluate the environmental impacts of the fish wastes through life cycle analysis (LCA) as well as to characterize the potential utilization of fish wastes as protein-based thermoplastics. Production of canned fish products from Protigam Food Industries Sdn. Bhd. was investigated by following four steps in LCA; (1) goal and scope definition, (2) life cycle inventory (LCI) analysis, (3) life cycle impact assessment (LCIA) and (4) interpretation of result. The goal of this work is ‘cradle-to-grave’ life cycle of canned fish products whereas the scope is the functional unit of every 1 tonne of raw fish entering the factory. The LCI analysis was carried out by obtaining the inventory data of the whole process flow as well as the inputs and outputs of each subsystem in the manufacturing process. Then, LCIA was performed by identifying the related impact categories for the canned fish products, followed by calculation of the values for those related impact categories. The values were then normalized with the functional unit. It was shown that for every 1 tonne of raw fish entering the factory, about 0.22 tonnes of municipal solid waste was produced, an increase of 1.27 kg eq PO_4 in eutrophication potential and 1383.6 kWh of electricity was consumed. Lastly, the results were interpreted through contribution analysis where the process of butchering, icing and retorting were identified as the biggest contributor for impact categories of municipal solid wastes, eutrophication potential and energy consumption respectively. On the other hand, the result of Kjeldahl analysis showed that fish waste powder has about 16% protein content, making it a suitable candidate for protein based thermoplastics.

CHAPTER 1

INTRODUCTION

1.1 Research Background

The production of fish products is increasing from year to year due to the high demand of global fish market. FAO (2016) reported that the growth of global fish supply is increasing at an annual rate of 3.2% from 1950 to 2014. In Malaysia, fish are generally processed into different forms such as frozen, cured and dried fish to meet the market demand (Huda, 2012). For example, the biggest percentage of fish products manufactured in Penang and Perak is processed fish products, including fish balls, fish crackers and fish cakes. However, the fish processing industry also contributes to the high consumption of electricity and generation of huge amount of wastes such as heads, guts and skins as well as wastes effluents (Henriksson, 2011). Hence, there is a need to evaluate the environmental impacts of fish processing industry in order to find solutions to improve the environmental performances of the industry.

In this work, Life Cycle Analysis (LCA) was chosen to be the environmental assessment tool. LCA is a quantitative method to assess the environmental performance throughout the entire life cycle of a product, process or activity in order to identify the best environmental option of waste treatment (Angelo et al., 2017). The LCA should include the entire product life cycle, material and energy acquisition, input material and energy during manufacturing, product outputs, generation of wastes, use of end products and waste management.

Wastes from fish processing industry are becoming the sources of pollution to the receiving environment where these wastes are discharged. According to Islam et al. (2004), the improper discharge of fish processing wastes had contributed to the huge increase in biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS) and fat-oil-grease (FOG). The increase in these environmental parameters will lead to the low oxygen level in the water and contamination of water with foreign particles that can pose great threat to the aquatic animals and the people who use the polluted water.

There are several different waste management techniques used in different countries such as incineration, composting and pyrolysis. According to Ishak (2002), the waste management technique in Malaysia is end-of-pipe treatment. The end-of-pipe treatment is a traditional waste management approach which is applied after the processes to prevent the release of waste and by-products into the environment. There are a few disadvantages of this technique such as high cost of waste treatment as well as increases the environment burdens. Hence, there is a need for waste management technique applied in Malaysia to be updated so the new waste management technique can reduce the environment loads and lower the waste treatment cost.

One of the solutions for disposal of fish processing wastes is by utilizing the fish wastes in the productions of value-added products. Ghaly et al. (2013) reported the utilization of fish wastes in the production of fish silage, fish meal and fish sauces. The fish silage is produced from the liquefaction of fish tissues while fish meal is prepared in powder form from fish filleting wastes. Besides, the fish sauce is produced from the salt fermentation of small pelagic fish by-products. Therefore, more research works on the utilizations of fish processing wastes should be carried out in order to identify more opportunities of income for the industry as well as to reduce the pollution.

The highlight of this project is to increase awareness and knowledge on the environmental impacts of fish wastes while the potential utilizations of fish wastes could aid in creating new industry sector which can leads to increase in job opportunities and new income for the nation.

1.2 Problem Statement

Currently, fish processing industry generates huge amount of wastes that contributes to the increasing environmental pollutions. However, there are limited studies on the waste identification, management and impact assessment on the wastes from fish processing industry in Malaysia. This limitation has restricted the measurement of cleaner production technologies which are seen as directly reducing environmentally harmful impacts during the production process. The end-of-pipe treatment technique which is normally implemented as a last stage of a process before the stream of air, water, waste, and product are disposed or delivered is seen as ineffective method if the demand in the fish products continue to rise in the future as the high cost of end-of-pipe treatment has encouraged the activities of illegal discarding of wastes.

1.3 Research Objectives

i. To evaluate the ‘cradle-to-grave’ life cycle of fish products through LCA.
ii. To classify the wastes produced during manufacturing processes of fish product.
iii. To evaluate the environmental impacts of fish processing wastes.
iv. To evaluate the protein content in fish waste to be used as a raw material for protein based thermoplastics.

1.4 Thesis Outline

This thesis basically consists of five chapters.

Chapter 1 provides the overview of the research and a brief literature survey of the previous and relevant work. The problem statement and the research objectives have also been stated and described in this chapter.

Chapter 2 highlights the detailed literature review of previous and relevant works about global fish consumption, production of fish products, fish processing industries in Penang and Perak, energy usage and processing wastes of fish processing industry, industrial waste, environmental impacts of fish wastes, life cycle analysis (LCA), current and potential utilizations of fish wastes as well as fish protein.

Chapter 3 presents the raw materials, methods and equipment used in the present work, which are Life Cycle Analysis (LCA) and Kjedahl Analysis. The procedures, characterization method and data collection techniques as well as data analysis methods have also been described in details.

Chapter 4 gives the interpretation and discussion of the experimental results of the research work. The results of LCA, including goal and scope definition, life cycle inventory (LCI), life cycle impact assessment (LCIA) and interpretation of result, waste treatment approach for fish product manufacturing as well as the characterization of protein content of fish wastes have been discussed intensively in this chapter.

Chapter 5 presents the significance of the results and the summary of the research study. The recommendations for the future studies in the related research are included in this chapter.

CHAPTER 2

LITERATURE REVIEW

2.1 Global Fish Consumption and Production of Fish Products

Over the last 50 years, the production of seafood and fish products clearly reflected the global market demand. FAO (2016) reported that the growth in the global supply of fish products for human consumption has outpaced population growth by increasing at an average annual rate of 3.2 percent as shown in Figure 2.1. The statistic implies that the world seafood and fish products production will continue to rise in the future due to increasing demand of the global market.

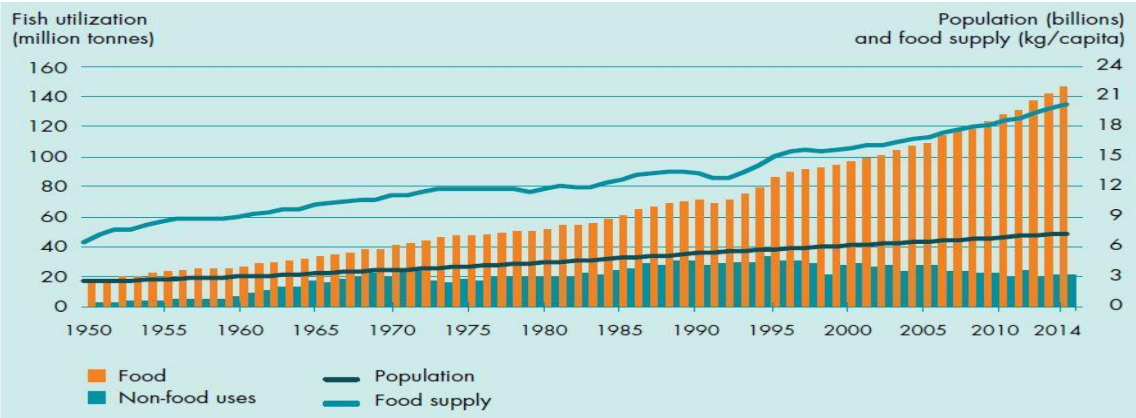

Figure 2.1: The plot of world fish utilization and supply (FAO, 2016).

FAOSTAT (2015) ranked Malaysia as the top seafood eating country in South East Asia with an average of annual per-capita consumption of 59 kg between 2000 and 2011. This indicates that for each Malaysian, the average annual fish consumption is 59 kg which is much higher as compared to that of world fish consumption per capita (21.4 kg). The statistics coincides with the increase in average monthly Malaysian household expenditures between 1993/94 (RM53.00) and 2009/2010 (RM98.00) (Tan et al. 2015). The data indicates that the rate of fish consumption in Malaysia increases with increase in income, the phenomenon will contributes to the increase in fish consumption rate per capita as the income of Malaysian is expected to increase in the future. Hence, the production of fish wastes is predicted to increase with increase in rate of fish consumption.

The huge market demand for fish products indirectly boost the growth of fish processing industry. According to the report of FAO (2016), only 67 million tonnes or 46% of fish for direct human consumption was in the form of live and fresh fish. The remaining 54% was processed in different forms such as cured fish (17 million tonnes), prepared and preserved fish (19 million tonnes) and frozen fish (44 million tonnes).

The trend in the world production of fish products is also reflected in the production of fish products in Malaysia. Huda (2012) reported that around 1,064,422 tons of marine fish that was landed in Peninsular Malaysia in the year of 2009, 63% of the landed marine fish are utilized for direct human consumption in the form of fresh fish while the rest are processed into different forms, which are fish meal (20%), cured (11%), frozen (1%) and disposal (5%). There are a few categories for cured fish, including salted, dried or smoked products (28%), fermented products (28%) and boiled or steamed products (5%) as well as other products like fish balls and fish crackers (39%).

The extensive growth in fish processing industry in Malaysia is observed in recent years. In 2014, there are huge amount of processed fish products was exported to other countries as well as imported into Malaysia (DOF, 2014). Figure 2.2 and Figure 2.3 illustrate the percentages of different exported and imported processed fisheries commodities in 2014 respectively. From Figure 2.2 and Figure 2.3, the fish products which are dried, salted or in brine but not smoked were identified as the most significant contributor of both exported and imported processed fisheries commodities with portions of 42% and 88% respectively. The phenomenon is probably due to the significant usage of these products in the daily meals of Malaysians.

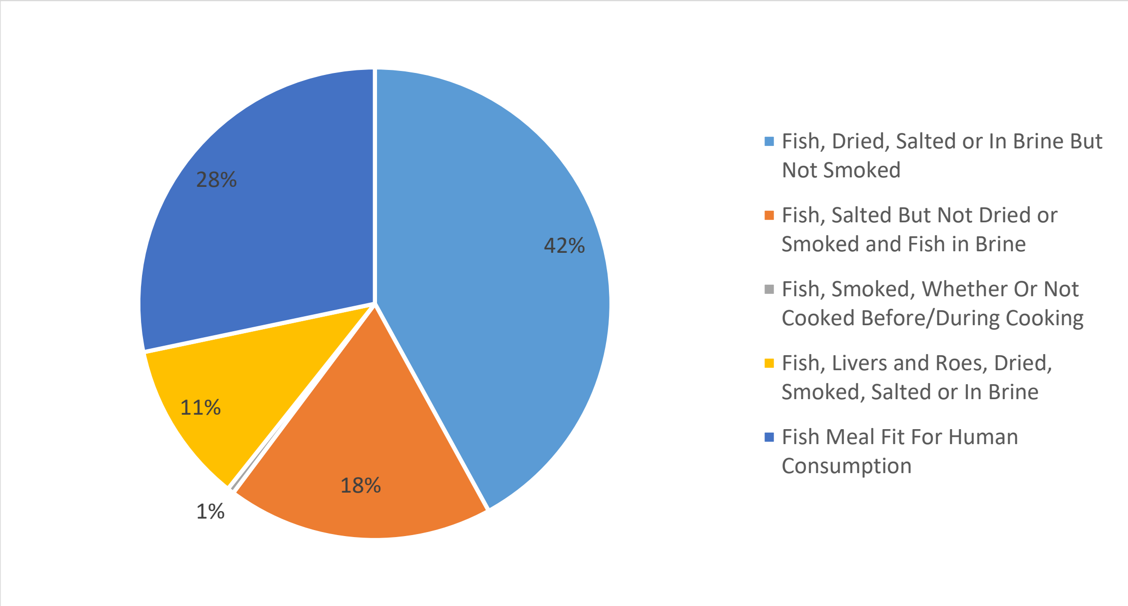

Figure 2.2: Percentages of different exported processed fisheries commodities in 2014 (DOF, 2014)

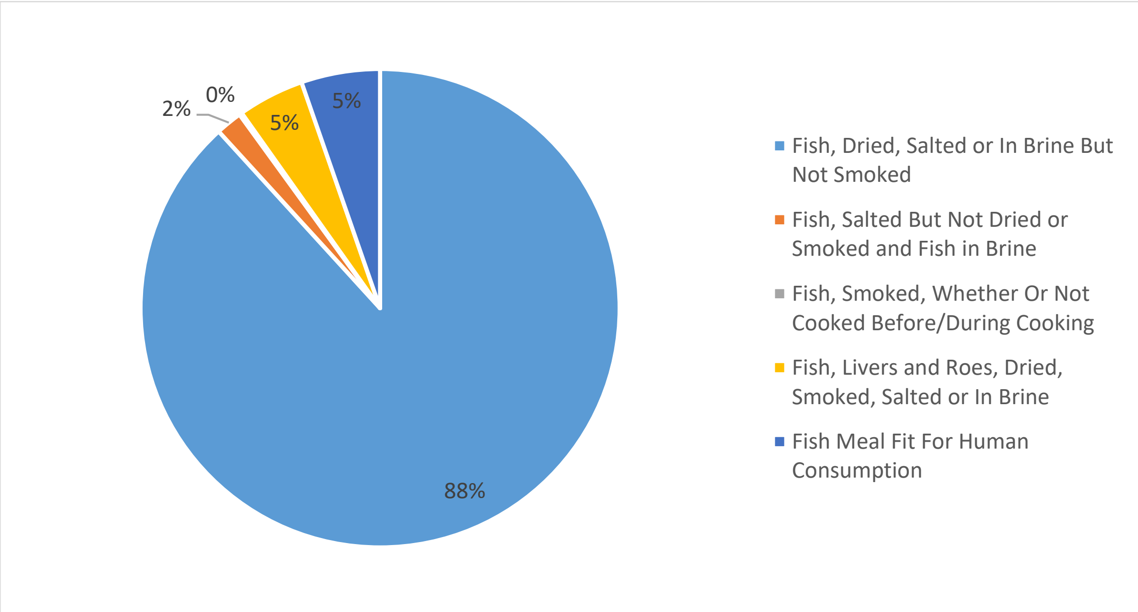

Figure 2.3: Percentages of different imported processed fisheries commodities in 2014 (DOF, 2014).

2.2 Fish Composition

Fish consists of different components such as fins, backbone, fillet, head, skin, roe, gut and liver as shown in Figure 2.4. Usually, fillet is the major fish part consumed in human diet as fillet contains high nutritional values of protein content and omega 3 and 6 series lipids as well as few percent of saturated fat and cholesterol (Nova et al., 2005; River et al., 2016). Table 2.1 listed the average composition of fish.

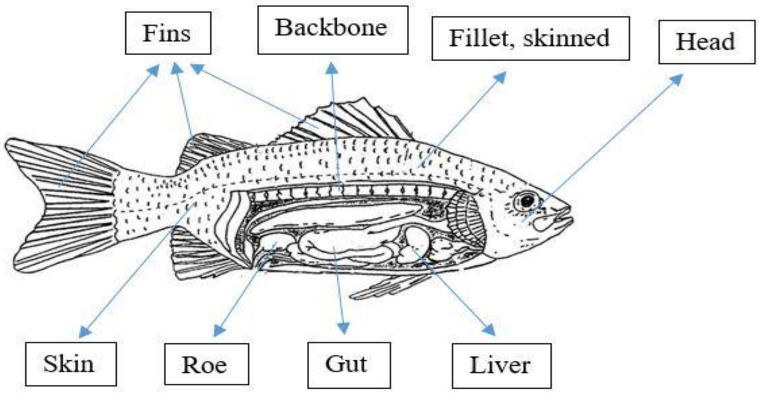

Figure 2.4: Various components of fish.

Table 2.1: Average composition of fish (Waterman, 2001).

Component	Average Weight (%)
Head	21
Gut	7
Liver	5
Roe	4
Backbone	14
Fins and lungs	10
Skin	3
Fillet, skinned	36

From Table 2.1, it was shown that the skinned fillet is the most significant contributor for the weight of a fish. However, different fish species shows different properties. Bud et al. (2008) presented the composition of fish fillet for various fish species in Table 2.2. The main element of the composition of fish fillet is the water content as water content contributes more than 70% of the composition of fish fillet.

Table 2.2: Composition of fish fillet for various fish species (Bud et al. 2008).

Species	Water (%)	Dry matter (%)	Protein (%)	Fat (%)	Gross energy (MJ/kg)	Minerals (%)
Carp	73.22±4.32	26.78±3.45	16.6±3.11	8.97±3.73	6.99±1.00	1.20±0.3
Pike perch	77.56±3.93	22.44±2.68	18.78±1.96	2.56±1.25	5.40±0.34	1.10±0.2
Pike	78.62±4.15	21.38±1.52	17.96±1.34	2.34±0.89	4.93±0.28	1.08±0.1
Sheatfish	71.70±3.74	28.30±1.36	16.80±1.15	10.25±1.82	8.12±0.76	1.25±0.2
Bream	78.41±2.85	21.50±1.68	16.48±1.25	2.96±0.77	5.25±1.15	2.15±0.2
Catfish	72.17±3.46	27.83±1.68	17.20±1.07	8.56±1.14	7.98±2.33	2.07±0.1
Tench	80.40±2.85	19.60±4.36	15.95±1.23	1.80±0.36	3.76±1.12	1.85±0.2
Trout	77.03±3.22	22.97±2.15	18.88±1.63	2.94±0.34	3.67±0.19	1.15±0.1
Mackerel	77.46±2.52	22.54±2.1	17.84±1.09	3.25±0.94	4.93±1.07	1.45±0.1
Squirrel hake	76.38±2.67	23.62±2.18	18.25±1.34	4.07±1.15	5.25±1.25	1.30±0.2

Other than fish fillet, all other non-edible fish parts are categorized as fish wastes. Esteban et al. (2007) listed the composition of fish waste as shown in Table 2.3. The crude protein is identified as the main component of fish waste as crude protein make up about 60% of the composition of fish waste.

Table 2.3: The composition of fish waste (Esteban et al., 2007)

Nutrient	Fish waste
Crude protein (%)	57.92 ± 5.26
Fat (%)	19.10 ± 6.06
Crude fiber (%)	1.19 ± 1.21
Ash (%)	21.79 ± 3.52
Calcium (%)	5.80 ± 1.35
Phosphorous (%)	2.04 ± 0.64
Potassium (%)	0.68 ± 0.11
Sodium (%)	0.61 ± 0.08
Magnesium (%)	0.17 ± 0.04
Iron (ppm)	100.00 ± 42.00
Zinc (ppm)	62.00 ± 12.00
Manganese (ppm)	6.00 ± 7.00
Copper (ppm)	1.00 ± 1.00

Values in % or mg/kg (ppm) on a dry matter basis.

However, the above composition of fish waste cannot be employed for all kinds of fish as each type of fish has its own specific chemical composition that produces wastes.

2.3 Fish Processing Industries in Penang and Perak

To narrow down the scope of research area focusing the nearby industry, fish processing industries in Penang and Perak were considered. In Penang and Perak, the fish are processed into different forms to maintain the quality of fish when the end products are delivered to the customers. The categories of fish products produced includes salted product, dried product, cooked product, frozen product, processed product and the other products. The percentages of fish processing industry manufacturers in Penang and Perak are illustrated in Figure 2.5 and Figure 2.6 respectively.

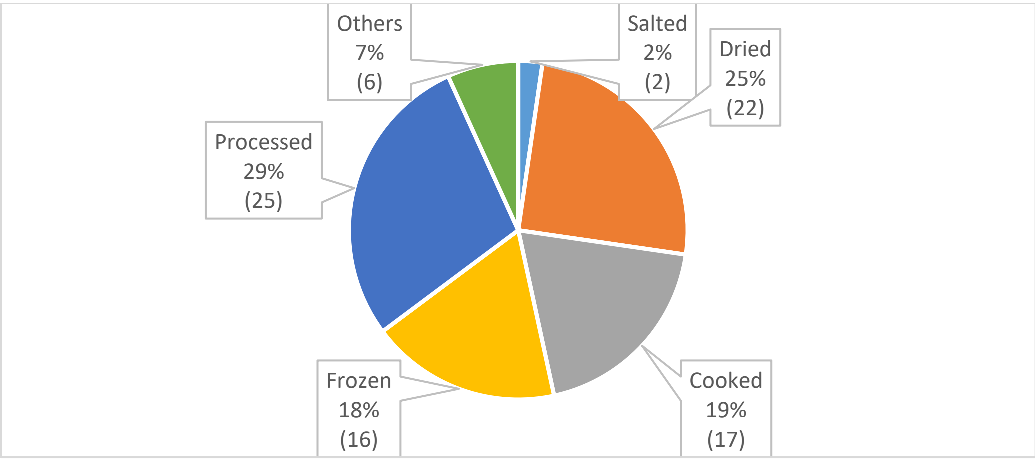

Figure 2.5: Percentages of fish processing industry manufacturers for different fish products in Penang, Malaysia (DOF, 2016).

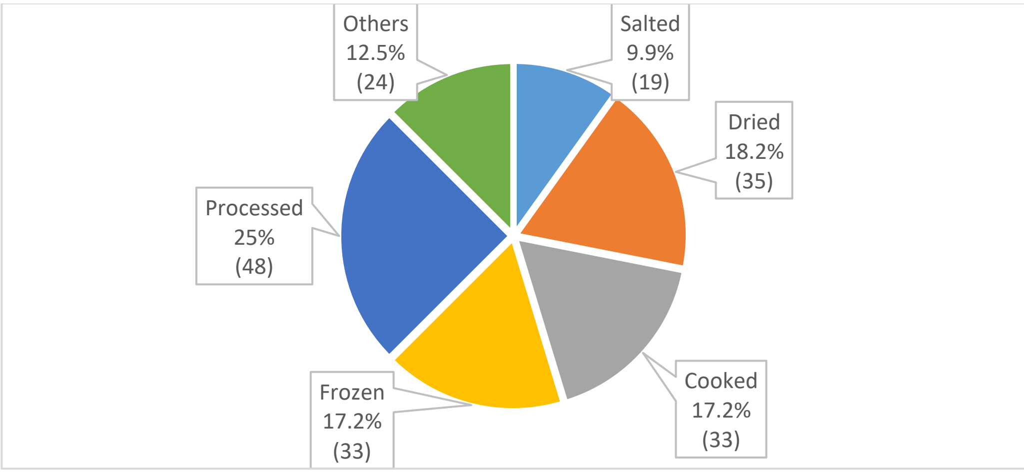

Figure 2.6: Percentages of fish processing industry manufacturers for different fish products in Perak, Malaysia (DOF, 2016).

Figure 2.5 and Figure 2.6 show that the biggest percentages of fish products manufacturers are processed fish products. The processed fish products are generally composed of fish ball, fish cake, fish crackers and other processed food from fish which the end products are no longer in the form of fish. Other than processed fish products, dried fish products, cooked fish products and frozen fish products also contribute to the fish processing industries. The examples of cooked fish products are boiled fish and 'Belacan'. This indicates that the multivariate of sectors of fish processing industry in Malaysia. So far, there is limited data on the waste produced from fish processing industries. However, by looking at the demand, it is not hard to imagine the great amount of fish wastes generated from the various sectors of fish processing industry in Penang and Perak.

2.4 Energy Usage and Wastes Generated from Fish Processing Industry

The fish processing industry contributes to the part of the energy consumption in fish industry. Figure 2.7 illustrates the basic production processes in the fish industry. Fishing phase is the phase which the activities of catching fish are carried out. From Figure 2.7, the fishing phase contributes to the largest part of energy consumption as it involves high consumption of fuel as fishing activities require the use of fishing boats and gears (Henriksson, 2011). Besides, about 25% of energy consumption in the fish industry is due to the transportation of fish products for marketing. Vans, lorries and other transportation vehicles are needed to transport the fish products to the markets such as wet markets, supermarkets and night markets and hence high rate of fuel consumption is involved. The processing of fish products only contributes about 10% of the total energy consumption in fish industry. The processing of fish products requires the use of machineries and motors where high electrical power is used. Although the energy consumption for the production of fish products is not significant compared to fishing phase and marketing phase, the portion is expected to be bigger in the future as the future processing will involve a very high production rate of fish products which will then involve higher consumption of electricity.

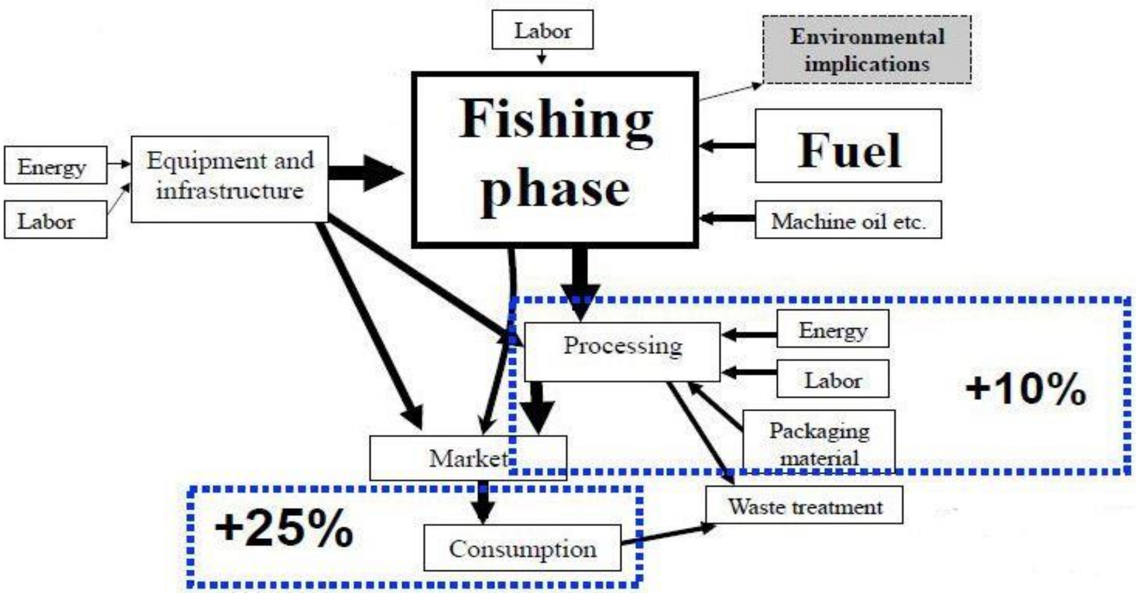

Figure 2.7: Flow chart of the production processes in fisheries with the energy consuming steps identified (Henriksson, 2011).

Ghaly et al. (2013) explained the steps of fish processing in the industry which involves stunning, grading, slime removal, deheading, washing, scaling, gutting, cutting of fins, meat bone separation and steaks as well as filleting. Processing of fish usually begins with the step of stunning. Stunning can provide sufficient movements to rupture the bones and blood vessel. The next step is grading where fish is sorted by species and size, followed by slime removal through continuous washing. The following step is scaling step which removes the scales from the fish to keep the fish fresh. After that, the fish will be washed to clean and remove the accumulated bacteria on the fish. Then, the inedible fish head and internal organs as well as fins will be removed during the consecutive deheading, gutting and fins cutting steps. Finally, filleting step will be carried out to get trimmed fillet and the meat will be removed from skin, scales and bones during process of meat bone separation. Figure 2.8 shows the typical sequence of fish processing steps in the fish processing industry.

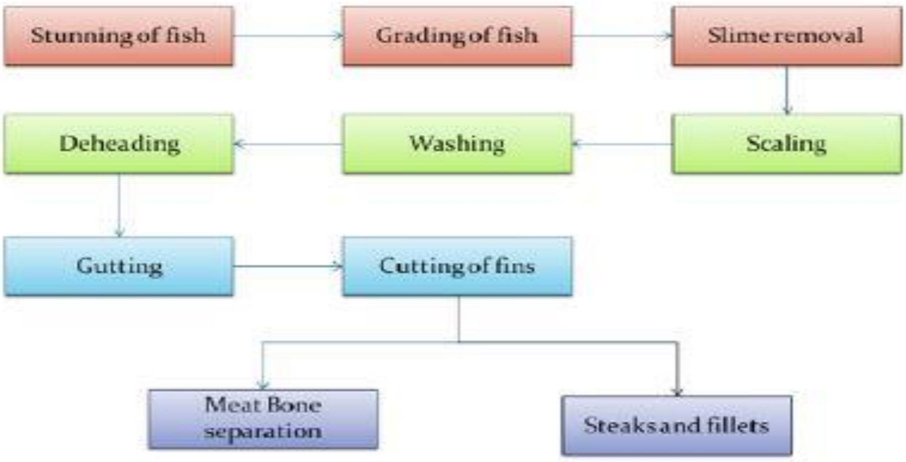

Figure 2.8: Fish processing steps (Ghaly et al., 2013).

During these steps, significant amount of wastes (20% - 80%) was generated depending upon the level of processing and type of fish. Ghaly et al. (2013) explained that there was an important amount of waste streams occurs mainly in the operations of scaling, deheading, gutting and fins cutting as well as meat bone separation. In these operations, solid fish wastes such as head, tails, skin, gut, fins and frames as well as the waste effluents (mainly water and oils) were generated. Okereke & Onunkwo (2014) described the processing steps of fish crackers in the fish processing industry. The deheading, gutting and deboning as well as washing process in the production of fish crackers were identified to be the main processes which generated wastes such as bones, guts and fins as well as huge volume of waste effluents. However, at present, research in energy consumption and processing wastes of fish products is still limited. Further research study is necessary in order to recognize the main contributor of high energy consumption and generation of huge amount of fish processing wastes in the industry.

2.5 Industrial Waste

The wastes generated in the industries such as fish processing industries are generally categorised as industrial wastes. The specific meaning of industrial waste is that it is the unusable or rejected products or by-products of industrial processes. In Malaysia, the Department of Environment (DOE) has specified the definition of industrial waste. DOE characterized industrial waste as water from factories, processing effluents, slurry and sawdust (Ishak, 2002). Mohamed (2009) categorized the industrial wastes in Malaysia into two types which are solid wastes and hazardous wastes. In terms of industrial wastes, solid wastes include the solid, liquid, semi-solid or containerized gaseous wastes generated by industrial processes, activities or by-products which do not cause adverse effects to the human health and environment whereas hazardous wastes incorporate any substance endorsed to be scheduled wastes, or any matter either in solid, semi-solid, liquid, gas or vapour form which is released or emitted to the environment in such amount, volume or manner that can cause environmental pollution.

2.5.1 Current Industrial Waste Management Approach in Malaysia

Ishak (2002) reported that Malaysia is the one of the nations in South East Asia which has applied end-of-pipe treatment as main industrial waste management approach for a long time. The end-of-pipe technology is the traditional approach for industrial waste management, which is usually implemented as a last stage of a process to prevent the delivery and disposal of stream of wastes and by-products into the environment. Mohamed (2009) claimed that this end-of-pipe approach had generating numerous environmental issues such as illegal discarding of waste. The uncontrolled dumping of industrial wastes pose great threat to human health and environment. Table 2.4 listed the important incidents of illegal dumping of industrial waste in Malaysia.

Table 2.4: Reported Incidents of Hazardous Wastes Illegal Disposals in Malaysia (Mohamed, 2009).

Year	Location	Amount and Type of Wastes	Company
1989	Pantai Remis, Perak	1,500 tonnes of toxic wastes	Unknown
1993	Bukit Merah, Perak	Radioactive wastes	Asian Rare Earth Plant, Mitsubishi Kasei.
1995	Pangkor Island, Perak	Forty-one drums of highly toxic potassium cyanide	Unknown
1995	Penang Island	28 drums of trichiorofluoromethane	Unknown
2001	Ulu Tiram, Johor	1,000 tonnes of metal ashes	Foreign-based smelting company
2003	Ijok, Selangor	500 drums of paint sludge and glue	Unknown

For fish processing industries, the main source of wastes is fish waste. Typically, fish waste may be disposed of in three ways depending on the local circumstances:

i. Landfill – the waste may be buried underground in pits at least two metres deep and covered with a minimum of 200 mm of earth to prevent infestation with flies and other pests and to accelerate the rotting process. However, this method is not suitable when groundwater tables are close to the surface.

ii. Return to sea – dumps it a long distance offshore. Disposal of fish wastes can be done in the offshore ecosystems from which the fish are caught. The fish waste disposed in the offshore ecosystems should not cause any water quality problems in open waters.

iii. Utilized as by-products – as value-added products in various fields. Currently, the solid fish wastes can be utilized in the production of fish meal, fish sauce and fish silage. Besides, there are potential utilizations of fish wastes in other applications such as hydroxyapatite product and protein-based thermoplastics.

Among the three disposal methods, landfill is the most widely used waste management method in Malaysia due to the practice of end-of-pipe treatment (Lim et al., 2016). However, instead of solving the waste disposal problems, end-of-pipe treatment transfers the problem elsewhere. There are some other problems arise with the application of end-of-pipe treatment, including the elevated cost of waste treatment, management and disposal, on-site waste control and monitoring. The cost incurred for end-of-pipe treatment is a significant financial burden for the company. Furthermore, the practice of landfilling in end-of-pipe treatment requires some on-site spaces for the storage of the wastes, which involves exorbitant cost and which rather be utilized for profitable operation (Ishak, 2002). The development and enforcement of end-of-pipe control has proven to be very costly, and yet achieving the expected outcome is not guaranteed. Hence, the implementation of end-of-pipe treatment is accompanying with high non-production capital costs and on-going operational costs. The high cost incurred for end-of-pipe treatment has encouraged the illegal discarding of industrial wastes, resulting in various kinds of environmental pollutions such as land pollution and water pollution.

Nevertheless, the research work for investigating the waste management approach applied in various industries of Malaysia is still considered very limited. Therefore, it is essential to carry out research work on waste management approach in fish processing industry of Malaysia which do not gain much attention of researchers in previous works.

2.6 Environmental Impact of Fish Wastes

Due to the fact that end-of-pipe treatment approach has contributing to the activities of illegal discarding of wastes, the fish waste and processing effluents are becoming the hazards to the environment, especially on the receiving coastal and marine environments where these waste effluents are discharged illegally. Islam et al. (2004) studied on waste loading and discharging of shrimp and fish processing effluents. He discovered that fish processing plant produced heavy loads of wastes with complex mixture of various substances such as fish scales, shells, muscles, soluble protein and fats, chemical and organic substances. The increasing production of these inedible fish wastes and by-products poses a great threat to the environment because most of these wastes were discharged into the nearby coastal waters through discharging channel. The report also suggested that fish waste and shrimp processing effluents are very high in biological oxygen demand (BOD), chemical oxygen demand (COD), total suspended solids (TSS), fat-oil-grease (FOG), pathogenic and other micro-flora, organic matters and nutrients.

BOD is an indicator for the amount of oxygen consumed by microorganisms for the processes of oxidation and decomposition of organic matters in one litre of water under aerobic conditions at a specified temperature (Delzer & Mckenzie, 1999). When the organic matters such as fish wastes present in the waste effluent, the bacteria will start to break down the organic wastes. This process requires huge amount of oxygen and hence the oxygen concentration in the water will be reduced, causing the aquatic animals to lack of oxygen for living. COD is the measurement of amount of oxygen required for oxidation of organic compounds and inorganic matters in one litre of water (Yang et al., 2009).

High COD level indicates that there are great amount of oxidizable organic matters in the solution and hence will consume great amount of dissolved oxygen for oxidation process, leading to anaerobic conditions which is endangering all the aquatic life forms. Other than that, TSS are the solid organic materials and minerals that remain trapped in the water sample filtered through 1.2 μm filter (U.S. EPA, 1998). Elevated level of TSS can cause reduction of water clarity, clogging of fish gills and decrease of photosynthesis in the water, resulting in lowering the water quality. In addition, FOG represents the concentration of the fatty and oily substances in the water. The FOG in the water may not appear harmful for human and environment but these substance may solidify and harden in the pipe when these substance mix with sanitary wastes. This condition can cause blockage of the pipe, making the accumulation of debris in the pipeline system and eventually resulting in the flooding of the areas. Therefore, the environmental parameters of the processing effluent should be lowered in order to protect the receiving environment where the effluent is discharged.

Figure 2.9 shows the characteristics of effluents of three Japanese fish products which are fish meal, surimi and kamaboko (Islam et al.. 2004). From Figure 2.9, it shows that fish meal processing effluent has the highest concentration of BOD, COD, TSS, and FOG among the other Japanese fish products. This indicates that fish meal processing effluent has the highest potential to cause water pollution and should be treated properly to avoid the environmental impacts. Although Islam et al. (2004) elaborated the characteristics of effluents of Japanese fish processing plants as illustrated in Figure 2.9, the research work has not comprehensively considered the waste effluents generated in fish processing industry of other countries such as Malaysia. Therefore, a substantial study on the fish processing wastes in Malaysia is essential in order to realize the relative importance of waste management in fish processing industry of Malaysia.

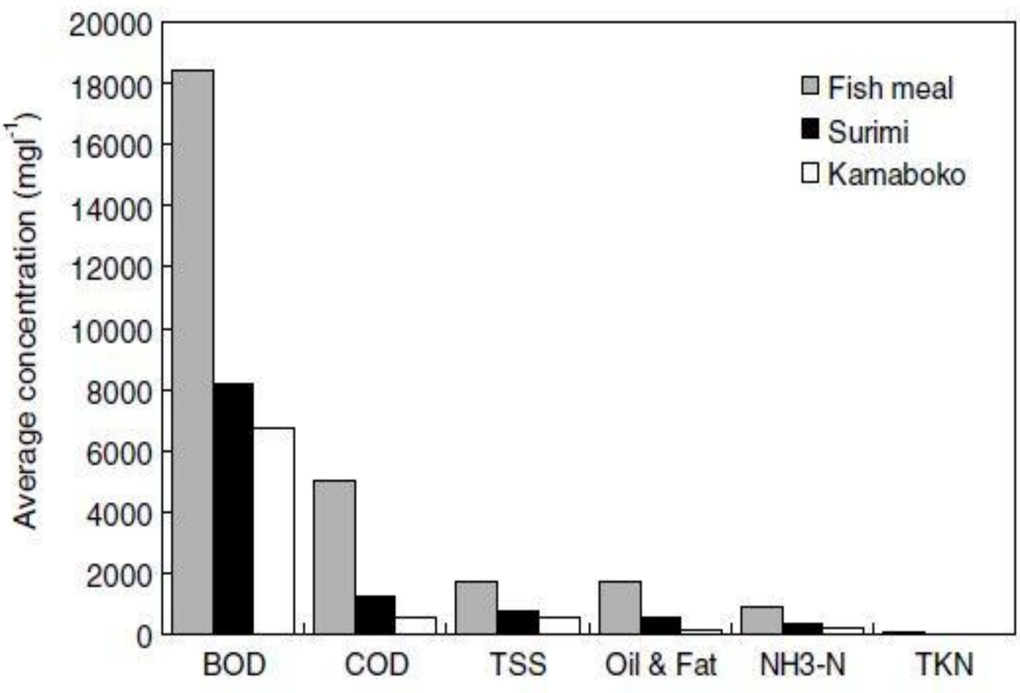

Figure 2.9: Characteristics of effluents resulting from production of three major Japanese fish products (Islam et al., 2004).

2.7 Life Cycle Analysis (LCA)

Due to the increasing concerns on the environmental impacts of fish processing industry, there are some assessment tools and techniques implemented to evaluate the environmental effects of the industry such as ecosystem services evaluation, sustainability impact assessment and life cycle analysis (LCA). Among the multi-impact evaluation methods used in evaluating environmental impacts of industry, LCA is the most commonly and widely used technique.

Avadi & Fréon (2013) explained that LCA is an extensive framework for assessment of environmental performance of food systems, including fishery industries. The International Organisation for Standardisation (ISO) standard benefits LCA with the ISO 14040 series standards and a great number of academic and practical researches. ISO

(2006) described LCA as one of the methodologies developed to address the growing attention concerning environmental impacts innate in the delivery of products and services, and the importance of realizing and reducing these impacts. LCA enables inclusive assessments to be made on the environmental impacts related to associate with products over their entire life cycle, incorporating the facilities, energy supply, raw materials acquisition, processing (cradle-to-gate), transportation, use and final disposal (cradle-to-grave).

2.7.1 Stages of LCA

The increase in the level of complexity of the overall life cycle model had accelerated the development of contemporary LCA standards since 1990s (SETAC, 1991). The modern LCA include four components which are goal and scope definition, life cycle inventory (LCI) analysis, life cycle impact assessment (LCIA) and interpretation of result. Figure 2.10 shows the graphical visualization of the four stages of LCA.

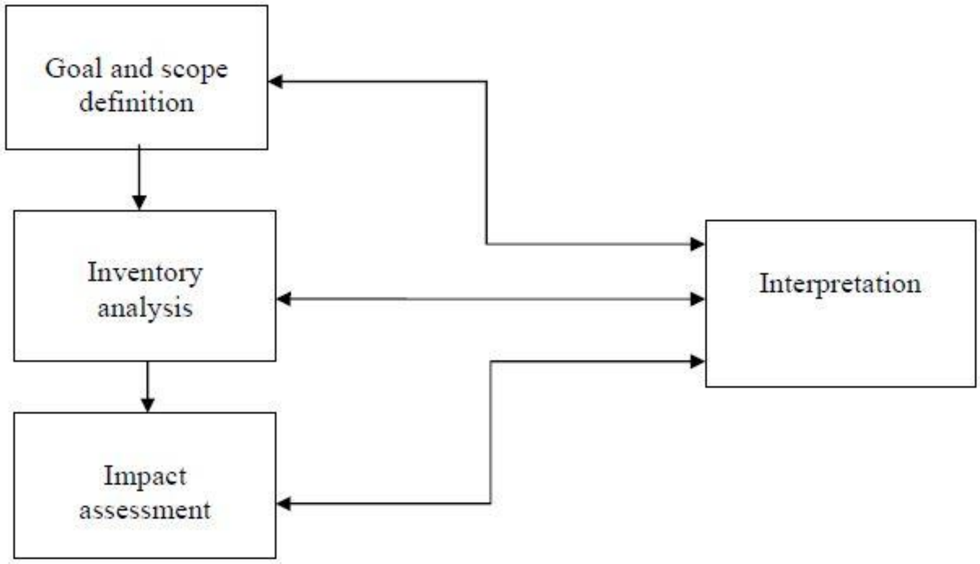

Figure 2.10: Outline of generic life cycle assessment process (Horne et al. 2009).

Goal and scope definition is the first stage of LCA. In this stage, the purposes of the assessment and assumptions for the consecutive analysis are specified. Koo (2006) explained that the goal of LCA is to identify opportunities for minimizing the drawbacks of an existing system or process to the environment and to carry out relative studies with the aim of identifying an optimal process of product from the available options. The scope definition of LCA involves defining boundaries of system, functional unit, presumptions, and parameters of inventory data as well as impact categories that will be applied in the LCA (Koo, 2006). Dias et al. (2007) studied on the sustainability of the printing and writing paper production activity. Hence, they set the LCA goal of their work as to assess the potential environmental impacts associated with the entire life cycle of the printing and writing paper and they fixed their scope of study by only evaluating the printing and writing paper produced in Portugal from *Eucalyptus globulus* pulp and consumed in Germany. By defining their goal and scope of study, Dias et al. (2007) found that the paper production stage played significant role for high energy consumption and emissions of non-renewable gases such as CO_2, NO_x and SO_2 which consequently contributing for the impact categories such as global warming and acidification in the German market scenario. The findings of Dias et al. (2007) shows the importance of goal and scope definition in allowing the researchers to obtain specific results within their desired system boundaries.

The second stage of LCA is LCI analysis. This stage involves the quantification of data for the input material and energy flows of a system which are related to the environment. Koo (2006) stated that inventory analysis is usually done through data collection of a diversity of sources, including direct measurements, hypothetical material flow and energy balances, and statistics from databases and journals. Williams (2009) elaborated on the concepts of inventory analysis. He stressed that the inputs like energy and raw materials and the outputs such as products and wastes are necessary to be taken into account in the inventory analysis. The outputs usually include the desired products and by-products as well as any emission of matter to the environment, such as solid wastes, effluents and waste gas. Accorsi et al. (2015) applied LCA to determine the environmental impact categories associated with the bottled extra-virgin olive oil (EVOO) life cycle. To obtain the LCI data, Accorsi et al. (2015) quantified the flow of material and energy associated with the life cycle phases of bottled EVOO, including the processes of consolidation, fabrication, bottling and packaging, storage and transportation. All the inputs of resources, materials and energy involved in life cycle of bottled EVOO were extrapolated from a renowned LCA database to provide all the essential primary data and information about the inputs and output flows along the entire supply chain, especially on the processing lines. Through such quantification of inventory data, Accorsi et al. (2015) discovered that the life cycle phases of bottled EVOO contributed to a few environmental impact categories such as global warming potential (GWP), acidification potential (AP), ozone layer depletion (OLD) and eutrophication potential (EP). This shows that LCI is also an effective methodology to establish the connection between the environmental effects and life cycle phases involved.

The next stage of LCA is LCIA which functions to analyse the environmental issues related to the material and energy flows determined in the inventory phase. Typical approach of impact assessment is to categorise the inventory data into specific impact classifications such as eutrophication potential and energy consumption. Evaluation and normalization of the impacts are also included in this stage. Basically, the selection of impact categories, grouping, and characterization are usually carried out in LCIA (William, 2009). To characterize the result of LCIA, the entire environmental effects for each material and process needed to be computed. In order to calculate the environmental impacts, the characterization factors for the materials and processes have to be determined. The calculation for the impact indicator is

$$\textit{Inventory Data} \times \textit{Characterization Factor} = \textit{Impact Indicator} \qquad (1)$$

An example for characterization of LCIA result is described in Koo (2006). Koo (2006) examined the life cycle of plastics through LCA. To study the environmental impacts of plastics, Koo (2006) found the equivalency factors of 100 years Global Warming Potential for both carbon dioxide (CO_2) and methane (CH_4) and multiplied with the amount of carbon dioxide and methane produced in Process X in order to gain the total contribution of Process X to global warming. The result of Koo (2006) showed that the total contribution of Process X to global warming is 3.33 g CO_2-Eq which is significant due to incineration and landfilling of plastic materials. Hence, based on the result of LCIA, Koo (2006) suggested that recycling of plastics is better than incineration and landfilling of plastics in order to reduce the emission of greenhouse gases such as carbon dioxide and methane. The finding of Koo (2006) proves the importance of LCIA in assessing the environmental impacts of certain processes and subsequently influencing the corresponding actions for handling the environmental impacts.

Interpretation of result is the final stage of LCA. In this stage, the results of the earlier stages are employed to meet the specified purposes. Usually, decisions or plan of actions will be made in this phase. For analytical LCAs, the data is used to identify significant part of a product life cycle which contribute inordinately to the environmental loads of the entire system. These issues or problems can then be removed or minimized through system improvements. The example of analytical LCA is shown by Hospido et al. (2006) which focused on evaluating the environmental impacts of canned tuna products manufacturing processes. Through the contribution analysis, the tinplate production and transportation was identified to be main contributor for 60.85% of the total Global Warming Potential and 54.76% of the total Acidification Potential associated to processing. Based on the result, it was proposed that process improvement such as recycling of tinplate packaging materials should be done.

LCA can brings a lot of benefits, especially for industries and manufacturers. According to Koo (2006), LCA is a comprehensive tool. The LCI phase enable all essential inputs and outputs in many phases of the life cycle to be studied within the system borderlines. Hence, by incorporating the life cycle concept in overall management and transforming the product and process development in a more sustainable way, the industries and manufacturers can yield the benefits of ecological, work-related health and welfare, hazard and quality management, as well as improving and employing better options of cleaner process and product. Besides, LCA offers the possibility of mapping the flows of energy and material streams and also the wastes and emissions of the total production system. By contrasting such maps of system for various options, the regions where environmental performance can be improved are identified.

Indeed, at present, LCA is the best model of environmental assessment tool that can benefit both researchers and manufacturers. Therefore, it is sensible to apply LCA method on fish processing wastes in order to improve environmental performance of fish processing industry in Malaysia.

2.7.2 LCA Studies for Fish Industry

Presently, LCA has been widely applied in various industries such as chemical industries, energy industries and environmental engineering industries. For fish industry, there is limited work reported regarding LCA studies of fish processing industries and waste management. Thane (2004) studied on the environmental impacts of Danish fish products using LCA. Thane (2004) summarized that the fishing stage is the overall most