

CHAPTER III

EXPERIMENTAL SECTION

3.1 Material and Equipment

Equipment:

1. A Desktop Computer

Hardware Pentium 4.0/ 2.60 GHz. / RAM 512 MB

Window XP

Microsoft Office XP

2. SimaPro 5.1 Software

3.2 Experimental

1. Goal and Scope Definition

1.1 Objective and purpose of the research work

1.1.1 This research collects data and create data base of polystyrene (general purpose polystyrene (GPPS) and high impact polystyrene (HIPS)) and polyurethane

1.1.2 The environmental effect of polystyrene and polyurethane life cycle is evaluated using SimaPro 5.1 Software with Eco-indicator 95 and Eco-indicator 99.

1.1.3 Hot spot(s) are identified in the production of the model plastics in terms of energy consumption, resources utilization, and environmental problems.

1.2 Functional Unit

In this research, the functional unit is 1 kg of each type of polystyrene and 1 kg of polyurethane.

1.3 Scope and System boundary

This research studies life cycle of polystyrene and polyurethane associated with material acquisition through production, use and disposal, and compare between each step to determine the process which has the highest

environmental effect. The Boundaries of polystyrene and polyurethane are shown in figures 3.1 and 3.2.

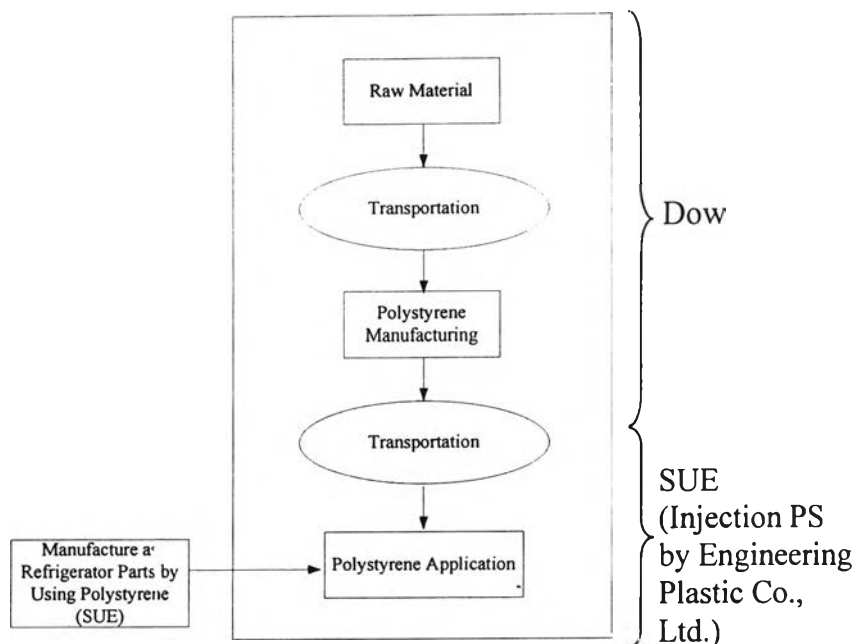


Figure 3.1 Polystyrene boundary.

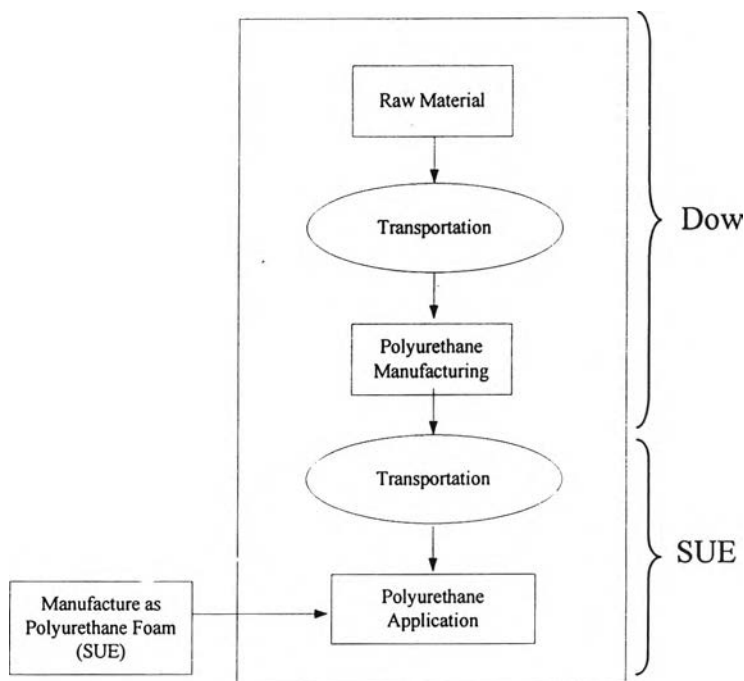


Figure 3.2 Polyurethane boundary.

1.3 Limitation and Assumption

1.3.1 Electricity consumption is those relative to the Thai energy system.

1.3.2 Polystyrene and polyurethane, studied in this research, are similar grade to that used in refrigerator production.

1.3.3 Polystyrene and polyurethane manufacturing data are derived from DOW Chemical.

1.3.4 Injection process data of chemical to get polyurethane foam is derived from SANYO Universal Electric Public Company Limited (SUE).

1.3.5 Injection process data of polystyrene is derived from Engineering Plastics Co., Ltd which produces parts of refrigerator assembly.

1.3.6 Injection machines in this research are JSW J450EII from Solefull Enterprise Limited Company and NISSEI PS40G5ASE from NISSEI Plastic Industrial Co., Ltd.

1.3.7 Clear shelf and side air duct are part of refrigerator in this study.

1.3.8 Some chemicals e.g. styrene monomer, polyether-polyol, etc. data is derived from SimaPro 5.1 database.

1.3.9 Isocyanate used in producing polyurethane foam is diphenylmethane diisocyanate (MDI).

1.3.10 Chemicals used to produce PU foam and PU foam scrap are disposed by landfill.

1.3.11 Packaging of PU foam chemicals (steel drums) is disposed by 20% recycle, 20% incineration, and 60% landfill.

1.3.12 PS waste is disposed by 50% recycle and 50% landfill.

1.3.13 1 kg polystyrene packaging (polyethylene) is disposed by 50% recycle and 50% landfill.

1.3.14 Packaging of GPPS injection product (clear shelf) is polypropylene which is disposed by 50% recycle and 50% landfill.

1.3.15 Disposal of HIPS injection product (side air duct) packaging are negligible because it is produced from polyethylene tray and can be reused many times.

2. Life Cycle Inventory

In this section, the principles of life cycle inventory analysis (LCI) will be applied to any activities that involve the direct or indirect use of energy or materials. The inventory analysis and the tasks to be fulfilled can be supported by a flow sheet for the considered product. It consists of data collection, refining system boundaries, calculation, validation of data, relating data to the specific system, and allocation.

2.1 Data Collection

The inventory analysis includes collection and treatment of data to be used in preparation of a material consumption, energy, waste, and emission profile for all the phases in the boundary of this study. The data acquisition is derived from 3 sections – 1. collecting from company, 2. collecting from literatures, and 3. collecting from government organization which can describe as:

2.1.1 Raw materials: Types and quantities in producing polystyrene and chemicals for making polyurethane foam are collected from Dow Chemical Company

2.1.2 Energy: There are 2 types of energy consumption in producing of this study which are electricity and fuel oil. Their details of them are collected from Dow Chemical Company and Department of Industrial Works.

2.1.3 Transportation: It consists of truck (6 wheels-truck and 10 wheels-truck) in domestic transportation and oceanic ship in international transportation. The data is collected from Dow Chemical Company, SUE, and Engineering Plastics Co., Ltd. The international transportation distance is calculated from Admiralty Distance Table, Harbour Department of Government Pilot Service in the Port of Bangkok.

2.1.4 Packaging: In this study, there are 3 types of packaging for raw materials and products, which are steel drums for PU foam raw materials, low density polyethylene (LDPE) film for polystyrene products (pellet), and low density polypropylene (LDPP) for injection products (refrigerator assembly). Data is obtained from Dow Chemical Company, SUE, and Engineering Plastics Co., Ltd.

2.1.5 Wastes: They consist of emission to air, emission to water, and solid waste in producing polystyrene and polyurethane foam. The data obtaining is from Dow Chemical Company, SUE, Engineering Plastics Co., Ltd, Office of The Natural Resources and Environmental Policy and Planning and. For emission to air

of injection unit in SUE, it is collected by United Analyst and Engineering Consultant Co., Ltd.

2.2 Refining System Boundaries

The system boundaries are defined as a part of the scope definition procedure. After the initial data collection, the system boundaries can be refined e.g. as a result of decisions of exclusion life stages or sub-systems, exclusion of material flows or inclusion of new unit processes shown to be significant. In this study, the exclusion materials are some additives which are not used much in the production and they are not revealed by the company, refrigerator assembly from injection polystyrene is focus on clear shelf (GPPS) and side air duct (HIPS) because they are the biggest assembly which are injected by Engineering Plastics Co., Ltd.

2.3 Calculations

From raw data collected, the amount of quantity of all input-output data has to be converted to functional unit which is 1 kg polystyrene and 1 kg polyurethane. The input-output calculations can be categorized into 5 types which are:

2.3.1. Energy consumption: Data received from the company is in term of power consumed for each equipment, power consumed for each process and cycle time. The energy unit used in this study for SimaPro 5.1 software is in kWh, therefore, the received data has to be initially converted to kW. After that, the calculated kW was converted to kWh by using cycle time and capacity of production as:

$$\frac{\text{Power (kW)} \times \text{Cycle time (hrs/day)} \times 1 \text{ kg}}{\text{Production capacity (kg/day)}} = \text{Power (kWh)}$$

Example of energy calculations in polystyrene and polyurethane production is shown in APPENDIX A.

2.3.2 Emission to water: In this study emission to water calculation occurred only in the mixing unit which produces formulated polyol for making PU foam. However, all waste water which occurs in polystyrene process is all converted to steam. Therefore, data which received from Dow Chemical Company and Office of the Natural Resources and Environmental Policy and Planning would involved only in polyurethane foam production. The example of waste water calculation and

the interesting parameters are shown in APPENDIX B. This emission unit in this study is in mg. The calculation of emission can be obtained from:

$$\frac{\text{Wastewater parameter (mg/l)} \times \text{water flow rate (l/day)}}{\text{Formulated polyol capacity (kg/day)}} = \text{Parameter (mg/kg)}$$

$$\text{Parameter (mg/kg)} \times \text{Formulated polyol for 1 kg PU foam (kg)} = \text{Parameter (mg)}$$

2.3.3 Emission to air: This emission unit in this study is in mg. The calculation of emission to air is shown in APPENDIX C and emission to air can be calculated to:

$$\frac{\text{Emission to air parameter (mg/m}^3\text{)} \times \text{Gas flow rate (m}^3\text{/day)} \times \text{1 kg of functional unit}}{\text{Production Capacity (kg/day)}} = \text{Emission to air parameter (mg)}$$

2.3.4 Input (raw materials) and output (products and wastes): The calculation applied the concept of mass balance which is:

$$\text{Input} = \text{Output}$$

For Input - all raw materials

Output - all products and all wastes (include emission to air and emission to water)

The example of this mass balance is in APPENDIX D.

2.3.5 Packaging: Data received from Dow Chemical Company is in weight (kg) of all packaging material used to contain raw materials or products for delivering to customers. The calculation of packaging converts this total weight to weight of packaging material per functional unit as:

$$\frac{\text{Packaging weight (kg)} \times \text{Weight of each chemical in producing (kg)}}{\text{Net containing weight (kg)}}$$

$$= \text{Packaging weight (kg) corresponding to functional unit}$$

The calculation of packaging is shown in APPENDIX E.

2.3.6 Transportation: Data obtained from Dow Chemical Company is types of transportation vehicles and the distances (km) of transportation for each raw material from suppliers to the company, delivery distances of each product to customers. Transportation calculation in this study converts distance in km to kgkm. And it can be calculated as follow:

Distance of transportation × weight of substance corresponding to functional unit
 = Transportation in kgkm

The typical calculation of transportation and transportation data collected are shown in APPENDIX F.

2.4 Relating Data to the Specific System

The fundamental input and output data are often received from industry in arbitrary units e.g. raw materials and packaging as kg, energy consumption as kWh, emissions to air and emission to water as mg, solid waste as kg, transportation as kgkm.

2.5 Allocation

When performing a life cycle assessment of a complex system, it may not be possible to handle all the impacts and outputs inside the system boundaries. This problem can be solved either by:

1. Expanding the system boundaries to include all the inputs and outputs, or by
2. Allocating the relevant environmental impacts to the studied system.

In this study, the allocation is as followed:

2.6.1 Energy of recovery of styrene monomer unit is calculated by mass balance.

2.6.2 No water consumption data exists in polystyrene process because water will be converted to steam and released to the atmosphere

2.6.3 Cycle time of each polystyrene processes is 4.8E-5 and 1.71E-5 hrs for GPPS and HIPS respectively

3. Life Cycle Impact Assessment

The Impact Assessment of this study uses SimaPro 5.1 with Eco-indicator 95 and Eco-indicator 99 methods. Both methods can calculate numbers that express the environmental load of products or processes. Eco-indicator 99 is developed from Eco-indicator 95 and types of impact categories are relatively similar. The important differences between these 2 programs are:

- Eco-indicator 99 can identify and show damage categories as graph and quantity which are derived from impact categories in characterization. (Damage categories relate to human health, ecosystem quality, and resources)

- Characterization unit of Eco-indicator 95 is kg equivalent but Eco-indicator 99 is in DALYs (Disability Adjusted Life Years).

- Eco-indicator 99 is more concern in resource depletion effect than Eco-indicator 95. So, the processes which require oil or gas or certain minerals will obtain a higher value in resource depletion impact.

- Land-use is included in Eco-indicator 99. Agricultural production processes will have a higher indicator than Eco-indicator 95. Also in the landfill of products with a large volume this is noticeable.

- The dispersion and degradation of substances is included in Eco-indicator 99, substances with a short lifetime will contribute much less to the Eco-indicator 95.

In this research, Eco-indicator 99 is used for identify damage categories and it is also used for considering the resource depletion effect. For Eco-indicator 95, it is focus on characterization which gives the result of impact categories in kg Equivalent unit. Kg Equivalent unit is widely use in many countries. So, the result in this research can easily be compared with other countries results which carry out LCA on the same products or processes.

3.1 Structure of methods in SimaPro

SimaPro software has many different methods for environmental impact calculation such as CML method, EDIP method, etc. However, the basic structure of impact assessment methods in SimaPro is:

1. Characterization
2. Damage assessment
3. Normalization
4. Weighting

The last three steps of the impact assessment method mentioned above are optional according to ISO standards. This means that they are not always available in all methods (Pre' Consultants, 2004)

3.1.1 Characterization

Classification is the step which computed from

$$\text{Characterization} = \text{Substances that contribute to an impact categories} \times \text{Characterization factor}$$

For example, the characterization factor for CO₂ in impact category climate change can be equal to 1, while the characterization factor of methane can be 21. This means that the release of 1 kg methane causes the same amount of climate change as 21 kg CO₂. The total result is expressed as impact category indicators (formerly characterization result)

3.1.2 Damage assessment

Damage assessment is a relatively new additional step in impact assessment. It is added to make use of the end point method as in Eco-indicator 99. The purpose of damage assessment is to combine a number of impact category indicators into a damage category. Damage of impact categories result is expressed in three types of damages:

- Damage to Human Health, expressed as number of year life lost and the number of years lived disabled. These are combined as Disability Adjusted Life Years (DALYs), an index that is also used by the World Bank and the World Health Organization (WHO).

- Damage to Ecosystem Quality, express as the loss of species over a certain area, during a certain time.

- Damage to Resources, expressed as the surplus energy needed for future extractions of minerals and fossil fuel.

3.1.3 Normalization

Many methods allow the impact category indicator results to be compared by reference (or Normal) value. This means

$$\text{Normalization} = \text{Impact category} / \text{Reference value}$$

And,

Reference Value = The average yearly environment load in a country or continent

/ The number of inhabitants

3.1.4 Weighting

Some methods allow weighting across impact categories. This means

$$\text{Weighting} = \text{Impact (or Damage) category indicator results} \times \text{Weighting factor}$$

Weighting value can be added to create a total or single score.

Weighting can be applied on normalized or non normalized scores, as some method

like EPS do not have normalization step. In SimaPro, there are often alternative weighting sets available, always in combination with normalization set.

3.2 Factors used in Eco-Indicator 95 and Eco-indicator99 analysis

3.2.1 Eco-Indicator 95

The structure of this method consists of characterization, normalization, and weighting. All factors in this method are obtained from data of SimaPro 5.1 software shown in APPENDIX G. For damage category, it can be referred to each impact category as also shown in APPENDIX G.

3.2.2 Eco-Indicator 99

Eco-indicator 99 is the successor of Eco-indicator 95. Both methods use the damage-oriented approach. The development of the Eco-indicator 99 methodology started with design of the weighting procedure. Characterization, normalization, weighting, and damage factor are shown in APPENDIX H.