Determination of Parameters for Sustainability Assessment of Hollow Fiber Membrane Module Life Cycle

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Abstract. Sustainability assessment has received increasing attention in academic, industry and government over the past decades. There are varieties of sustainability assessment has been developed in difference methodology and it is application. In this paper, sustainability assessment using indicators has been introduced for hollow fiber membrane module life cycle. In addition, this paper discussing the determination of proper parameters involved in developing methodology for assessing its sustainability. In order to balancing the sustainability, 3D of sustainability aspect will be considered; environmental, economical and social.

Introduction

It is generally acknowledge that sustainability results from a balance among the economy, environment and social aspects of sustainable development. Brundtland Commission defined sustainability as meeting the needs of the present generation without compromising the need for future generation [1]. There are many definition and description of sustainability according to variable case study. Sustainability is emphasized as measurement the degree of consistency of present and future needs in an economy, which is a dynamic process [2]. By using sustainability advertisement, organization especially manufacturing operation improved process efficiency, reduce waste minimization and applying 6R concept to satisfy the environmental perspective; reduce, remanufacture, reuse, recover, recycle and redesign. The planning for sustainable development assessment usually refers to long term development. The sustainability of wide areas are more preferable, however it is involve many and diverse dimensions that make problem increase and difficult to implement [3]. In sustainability field, researchers always questioned on how to assess and maintaining the sustainable economy that will allow the society for enjoying high standard of living without destroying its natural and biological support? Sustainability is a subjective, sustainable for an environmentalist does not mean sustainable for economist and socialist.

The perceptions of sustainable development and of planning for sustainable development need to be scrutinized and redefined. The concept of sustainability is understood intuitively, but it remains difficult to express it in operational terms [3]. Basic principles and requirement for sustainability has been proposed in order to cover ecological, economical and social sustainability. Nowadays, sustainable consumption target consumers while manufacturing operation targeting sustainable product development. Sustainability assessments become a rapidly developing area that showing tools developed is increasing for assessing sustainability. In addition, many of the tools have developed provide application guidelines, data and case study experiences. Specifically, the purpose of sustainability assessment will be developed is to indicate the sustainability level of hollow fiber membrane module life cycle. A set of parameters need to be prepared for every sustainability aspects. In addition, sustainability assessment will identify the weakness area for further improvement at every life cycle stages from cradle to grave.

Previously, there are several studies develop a set of parameters for assessing sustainability, however the research focusing on general chemical process design [4,5,6,7]. Furthermore, researchers focusing on manufacturing stages only without considering overall life cycle stage that could have higher sustainability impact. Some of indicators developed were general and less clear.
about relation between the sustainability aspects; environmental, economical and social. In addition, this paper discusses the development of sustainability indicators involved for assessing the sustainability for hollow fiber membrane module.

**Sustainability Assessment Using Indicators**

An indicator has been defined as *variable, parameter, measure, statistical measure, a proxy for a measure* and *a sub-index* [8]. Sustainable development indicators is emphasized as used to assess and evaluate the performance, monitoring on improvement for each dimension of sustainability and provide information to decision makers to formulate strategies and communication [9]. In order to assessing sustainability, the relevant aspect or criteria should be reviewed. Generally, indicators provide the information about the system such as material flow and energy used at every life cycle stage. The trend of sustainable indicator need to be systematically monitored, measured, quantified and interpreted in order to achieve progress in sustainability [10]. There is strong relation between determination of sustainability parameters with the sustainability indicator will be developed. Set of parameters will be used in order to indicate the sustainability level of hollow fiber membrane module during it is life cycle.

Specifically, assessment of sustainability is depending on *quantitative* and *qualitative* evaluation. In *quantitative* evaluation, parameters will be the main feature as important indicator for life cycle performance. Evaluator can be assess by using variable method and select the best sustainability alternatives. While for *qualitative* indices, it is heavily depends on knowledge and experience of the fields’ expertise. Therefore, parameters involved are frequently indicated as subjective perspective and interpretation. However, this method can be scaled numerically by using proper ranking and scaling technique [4]. The qualitative evaluation concept may differ with another assessment since it is involve on human interpretation, experience and knowledge.

Determination of parameters is influenced by varies factors. One of factor stated is determination of what is to be sustained. Previously, there are several methods determining a set of parameters based on what people feel about sustainability issues or problem occurred rather than understanding about system to be sustained. However, there are previous researcher disagreed and stated that sciences have their role in order to describe a system to be sustained and provide the technical foundation for determination of parameters [7]. The sustainability parameters determination is depending on both technical and normative decision such as goals, world views, models and variables [10]. Poorly chosen parameters of indicator can reduce the opportunity of organization to move society towards sustainability. There are three important functions of indicators; indicators are used to describe baseline and current condition such as performance of a system, indicators will measure the effectiveness of actions and policies in order to improve a system, indicators might be selected to forecast the change for future.

Current framework developed should be reviewed based on (i) set of measurable indicators for general framework, (ii) aspect of sustainability elements will be considered; whether 1D, 2D, 3D or more, and (iii) focus wide of framework will be developed; national, community or company level [11]. Optimal decisions can only be made when the environmental, economical and social elements are taken into consideration [12]. Figure 1 illustrates schematic depiction of the dimensions of sustainability assessment concept.

**Case Study: Hollow Fiber Membrane Module.** Hollow fiber membrane module has received the most attention for industry application compared to another module of geometries [13]. Hollow fiber membrane is widely used for application with a high fouling tendency since ease of membrane cleaning and it is process control [14]. The proposed for development of sustainability indicators for hollow fiber membrane module is to assess its life cycle sustainability. Varieties of materials, chemicals, water, process and energy take place in hollow fiber membrane module life cycle from materials until end of life phase. It is necessary to develop a set of parameters considering all sustainability aspect to improve sustainability level and increase the performance. By assessing the sustainability using parameters determined, the weakness area of life cycle product can be identified for further improvement.
Parameters for Sustainability Assessment

The system boundary consists of five sub-systems that represent every life cycle stages. The input and output flow crossing the system boundary will be used as parameters to develop sustainability indicators for hollow fiber membrane module. Figure 2 shows the steps for identifying the sustainability indicator. System boundary need to be selected either cradle to gate, cradle to grave, gate to grave or gate to gate approach. Then, the input and output flow need to be identified such as type of material, energy, chemical involve, cost, emission solid waste, chemical waste, and others. Next, parameters involve will be classified and grouped before assign it to the respective categories; environmental, economical, and social.

**System Boundary.** The selection of system boundary analysis depending on objective, goal and scope of the analysis illustrated. In this paper, the system boundary selected for hollow fiber membrane is cradle to grave consists of five phases; material, manufacturing, transportation, usage and end of life. *Cradle to grave* system boundary will cover widely areas the entire life cycle of membrane module compared to another approach mentioned. By using Life Cycle Assessment (LCA) approach, most important life cycle stages and their impacts for further action taken can be monitored. Product specification and life cycle data are required for LCA such as type of material, bill of material (BOM), process involved, cost and others. The support from life cycle database is also required to determine the input value parameter involved [15].

**Input and Output Crossing System Boundary.** Specifically, this paper will study the hollow fiber membrane module for filtration process in textile industry. Input flow such as raw material, chemicals substances, energy, fuel, and others will be used for producing the products. While the output flow such as solid and liquid waste, toxic, emission and hazardous material produced from the system boundary. Figure 3 provides the elementary input and output flow crossing the system boundary for overall life cycle stages of hollow fiber membrane module.

**Classification of Sustainability Parameters.**

The input and output flow from the system boundary will be classified into their respective categories; environmental, economical and social. **Environmental.** Material flow, energy consumed and emission through air, water, soil and solid waste will be considered in environmental aspect. Environmental aspect should sustain human ways of life by considering the functions of the environment [17]. The Life Cycle Assessment (LCA) approach will be applied that provide a full picture and information of the hollow fiber membrane...
module starting from material will be used, fabrication process, transportation, usage and end of life. Potential environment impact will be calculated such as toxicity, solid waste, global warming potential (GWP) consist of emission of carbon dioxide (CO$_2$), carbon monoxide (CO) and methane (CH$_4$). While acidification potential (AP) considering the emission of sulphur dioxide (SO$_2$), nitrogen oxide that containing nitrogen and oxygen in various amount (NO$_x$) and eutrophication potential (EP) referring to emission of Biological Oxygen Demand (BOD), Chemical Oxygen Demand (COD), phosphate (PO$_4$) and ammonia (NH$_3$). Furthermore, the negative environmental impact such as ozone layer depletion potential (OLDP) and solid waste may be occurred.

**Fig. 3.** Input and output flow crossing the system boundary.

**Economical.** Economical sustainability aspect will focus on direct-cost flow through cost such as cost of materials and chemicals, production, transportation, usage and maintenance, and end of life. In addition energy consumption will be considered for renewable energy and nonrenewable energy. Cost optimization is important in order to reduce necessities for every life cycle phase. Economical element should associate with social and environmental values (e.g. in environmental economics). While ref [5] applied value added to product that adding more skills and expertise applied to the product. However, most analyses only including financial cost and benefits in real practice. Less energy and material consumption indicates a higher level of sustainability level of membrane life cycle.

**Social.** As for social sustainability aspect, it is classified into four elements that are human health, risk, heavy metal and carcinogen. Emission of CO, non-methane volatile compound (NMVOC) and ammonia (NH$_4$) can affect human health. Wastewater from textile industry need to be filtrate that contain heavy metal such as lead, Chromium (Cr) and Cuprum (Cu) used as metal complex in dyes. An indicator developed by previous authors was improved by including awareness and participation, cultural acceptance and institutional requirements [17]. Involvement and acceptance of community is intended to show the level of partnership between developers and community [5].
Assigning Parameters Toward Respective Categories

Since there are three main elements (3D) involved in this methodology for sustainability indicators, the parameter selected will be assigned according to their potential impact. Figure 4 illustrates the determination of parameters was assigned to their respective categories in order to develop the sustainability indicator for hollow fiber membrane module life cycle.

![Diagram of parameter assignment to categories]

**Fig. 4. Parameters determination assigned to respective categories.**

**Conclusions**

The framework proposes a set of parameters for developing an indicator for assessing the sustainability for hollow fiber membrane module life cycle. The determination of parameters considered the three pillars of sustainability (3D); environmental, economical and social aspects. LCA approach was applied in this paper to determine the elementary input and output flow for hollow fiber membrane module from cradle to grave. There are some future work improvements to aggregate all sustainability elements involved quantitatively and qualitatively in developing this methodology for assessing sustainability.

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