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Comparison of methods assessing environmental friendliness of petrochemical process design

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ABSTRACT

Traditionally chemical process design has been built on the primary basis of economic viability. However with the growing concern on sustainability, the design of petrochemical plant can no longer be focused only on the techno-economic criteria. As for the environmental performance of a petrochemical process, to date the approach for environmental solutions for process facilities are mostly revolved around the concept of end-of-pipe pollution control techniques, aiming to attain waste treatment, toxicity diminution and industrial discharge volume reduction. This however is not a cost-effectiveness and sustainable approach since hazards do still present in the process, making the process inherently less environmental friendlier in the first place. This paper compared eighteen existing methods for assessing environmental friendliness of a process early starting from the design stage. The comparison of the environmental assessment methods as presented here shows that the diversity of the methods has a good balance between simplicity and complexity, depending on the aim of the particular method itself. It is found that achieving a comprehensive yet simple method is actually possible, by developing such method exclusively for specific stage of the design phase and not claiming to be applicable throughout the whole design phase, as what most of the previous works did. The review conducted in this work suggests that a deeper study associated with an assessment of petrochemical processes' environmental impact in specific stages of process design is highly needed.

1. Introduction

Nowadays, a chemical industry is an essential key to a nation's economic health and modern standing. Chemical processes offer a collection point for various important products and materials, ranging from health care to transportation and food processing. However, it is also a main source of pollution since it generates vast amounts of waste and emissions to the environment (Pereira, 1999).

During recent decades, on the other hand, the chemical process industry (CPI) increased its efforts to decrease the environmental impact of chemical manufacturing through the implementation of energy efficient processes and green technologies early in the design phase. The application of those strategies by chemical industries consequently maximizes environmental efficiency and reduces production costs.

According to the Brundtland report (WCED, 1987) development is sustainable if there exists no negative external effects. Yet sustainability has a multi-dimensional nature and can be divided into economic, environmental, and social aspects. Despite industries' major concern of profitability, there has been growing awareness on the importance of considering the environmentally conscious design of new processes. The effort of incorporating pollution prevention techniques into process design is not something new, as it dates back to the 1970s. The occurrence of a number of major environmentally related accidents has imposed stricter regulations that require process industries worldwide to start taking into account other criteria related to sustainability besides economic factors when developing a new process.

To date, the most widely adopted strategy by process industries for environmental protection is the "end of pipe pollution" control techniques, which revolve around waste treatment, toxicity diminution, and the reduction of industrial discharge volume. By using these add-on systems, hazards however still remain in the process and the associated risks to the receptors can only be reduced through add-on counter measures (Hassim and Hurme, 2010). Such a strategy is costly as industries need to try different new technologies to cope with these regulations (especially on discharge and emissions), which are continuously growing stricter and stricter. Besides, as mentioned earlier, the strategy does not erase

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the problems at the root through hazards related to reduction but focuses instead on minimizing the impact and probability of unwanted events. More recently, new pollution prevention techniques known as “clean technology” have been introduced to increase the environmental friendliness of processes through the prevention or elimination of the intrinsic hazards arising from a process. Therefore, technical and scientific efforts have been gradually moved from downstream pollution control to more aggressive practices of trying to prevent pollution.

Plenty of major decisions on processing, including those related to raw materials, technologies, and operations, are made during the process development and conceptual design phases. Based on the concept of inherent safety (IS), the best approach toward designing an environmentally benign process is to consider early-on the environmental aspect when developing a new process or retrofitting an existing one (Kletz, 1991). In fact, sustainable waste reduction can be achieved through a comprehensive understanding of the fundamental (i.e. reaction chemistry), techno-economic aspects of a process. Such a concept may offer more profitable and sustainable solutions compared to “end of pipe” control methods.

A variety of quantitative methods for the design of friendlier environmental chemical processes are widely available. The majority of them were developed based on scoring, benchmarking, and ranking approaches and the employment of the Inherent Safer Design (ISD) concept; namely the Inherent Environmental Toxicity Hazard Index (IETH) (Gunasekera and Edwards, 2006), Integrated Environmental Index (IEI) (Jia et al., 2004), Green Degree (GD) (Zhang et al., 2008), Environmental Fate and Risk Assessment Tool (EFRAT) (Shonnard and Hiew, 2000), Environmental Performance Evaluation (EPE) (Shokravi et al., 2012), and the Environmental, Health, and Safety tool (EHS-tool) (Koller et al., 2000a,b).

Inherently friendlier environmental processes are those that have reduced or have even avoided hazards as well as those with low levels of operational impact (Gunasekera and Edwards, 2006). In a stepwise manner, early hazard assessment poses a lot of advantages and, most importantly, appropriate counter measures can be taken earlier and at lower cost when the process begins as inherently friendly to the environment even before entering the construction phase. However, due to lack of information at the early design phase, especially during the research and development stage (R&D), proactive measures for the elimination or reduction of hazards has received far less interest from the industries rather than retrospective approaches.

Realizing the importance of early hazard assessment and, despite the complications encountered because of lack of data, the abundance of qualitative and quantitative methods and techniques have been introduced to assess environmental friendliness at different stages of process design. The methods, however, differ from each other—notably in case of the considered aspects, evaluated parameters, assessment approaches and the presentation of results, which heavily depend on the stage and ultimate aims of the evaluation. Even though quite a few works on environmental impact assessment methods have been developed, there is still a variety of room for improvement and the topic remains a hotspot for both environmental and chemical engineers.

A number of attempts have been made to classify and summarize the variety of methods for the environmental assessment of chemical processes, including their substances and processes. Methods were compared from the process design and optimization standpoints (Cano-Ruiz and MacRae, 1998), the Life Cycle Assessment (LCA) (Hertwich et al., 1998), and substance ranking (Swanson et al., 1997). On the other hand, a number of methods are categorized according to their degree of complexity in estimating human health in relationship to assessments on environmental impact. For example, a work by Peninngton and Yue (2000) utilizes a hierarchal framework of five methods to compare regional exposure, associated with toxicological parameters, or comparisons of different methods for SHE hazard assessment in early design (Koller et al., 2000a,b). Adu et al. (2008) present a comprehensive quantitative and qualitative comparison of various safety, health, and environment (SHE) assessment methods developed for the early stage of design. The authors concluded that there was no specific priority among the compared methods and the appropriateness of a single method depends on the unique kind of application as well as the design stage of the process. Although they have extensively compared environmental, health and safety (EHS) methods, the selected environmental methods mostly belonged to the last decade and therefore, an updated comparison based on newly developed environmental methods is necessary.

A comparison of three different environmental assessment methodologies and their application was conducted in 2004 by Hellweng et al. The study selected life-cycle assessment (LCA), environmental, health, and safety hazards (EHS) and highlighted persistence and spatial range (PSR) methods, followed by qualitative comparison. Afterward, the method was applied to a case study of organic solvents for quantitative comparison. Even though they conducted the quantitative and qualitative comparison simultaneously, the limited number of methods considered affected the comprehensiveness of the review.

Diwekar and Shastri (2011), on the other hand, presented a qualitative comparison on environmental assessment methods to analyze their suitability on different stages of design. Even though they reviewed multiple environmental objectives and their social impacts in variety of published efforts, their work has only revealed a qualitative comparison of different environmental assessment methods. Besides, they have concluded that, in terms of the success of process design, a lack of understanding regarding the environmental impact of different chemicals, products, pollutants, and unpredicted human interference makes design efforts for environmental improvement a very challenging mission.

A comprehensive qualitative review of footprint analysis tools have been conducted by Cucek et al. (2012). They considered the commonly defined footprints indicators such as carbon footprint, energy footprint, water footprint, social footprints and economic footprints, for measuring sustainability. The study includes the entire environmental, economic and social footprints to overcome the ill-defined footprints terminology, sustainability and sustainable development measurements. Based on the broad overview of Cucek et al. (2012) the environmental, economic and social footprints and measurements are still not systematically standardized and therefore, extended work is required. Besides, except environmental footprints techniques, the rest are seldom considered by the industries. The methods for the footprints calculation are also reported as lacking of consistency. This led to the conclusion by the authors that extensive efforts are needed for appropriate integration of environmental, economic, and social aspects in decision making process (Cucek et al., 2012). Despite the comprehensiveness of the review presented, the compared methods are selected from the LCA assessment point of view and not considering the environmental safety of petrochemical processes, which is the aim of the current study.

In contrast to process safety, detailed studies on comparison of methods for assessing environmental friendliness of chemical process design are still very much lacking. The reviews mostly describe a large number of analytical methods or proposed a new systematic approach for classification, but none of them demonstrates a comprehensive comparison of the existing methods for the above mentioned scope.

The current study presented in this paper reviews eighteen environmental assessment methods available for chemical process