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IECP — an approach for integrated environmental and cost evaluation of process design alternatives and its application to evaluate different NOx prevention technologies in a 125 MW thermal power plant

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ABSTRACT

This paper proposes a methodology, IECP (integrated environmental and cost potential), for the integrated environmental and cost evaluation of a process design option. It is designed for a quick quantitative evaluation of a design option at different levels of process synthesis or retrofit applications. A hazard based approach, Pro-hazard, has been developed for the quantitative evaluation of environmental potential of design options by using a cradle-to-gate life cycle assessment. This assigns an environmental potential index to a design option by comparing its environmental performance with respect to the base option. To quickly evaluate the cost of the resulting option a simple approach, Eco-index, has been developed. It gives a cost potential index to a specific design option by comparing its unit operating and fixed cost with respect to that of the base option. In the IECP framework, both the environmental potential and cost potential indices for a design option are combined by assigning an appropriate weighting factor to each index, which gives an integrated index, IECP, for the design option.

In this paper, the IECP methodology has been combined with a process simulator, Aspen HYSYS, to obtain the necessary data to quickly and accurately determine the IECP index. The applicability of the proposed IECP approach has been demonstrated through a case study for the selection of potential NOx prevention options in a 125 MW combined cycle power plant from a large number of options related to flue gas recirculation, steam and water injection to the furnace.

Introduction

The pollution from industries could be better handled at the design stages when designers can consider a range of alternative design options at each stage of process design to choose more environmentally friendly options. A significant amount of work has been dedicated to incorporate environmental issues during the early stages of process design (Azapagic et al., 2006; Dantus and High, 1996; Ciric and Jia, 1994; Crabtree and El-Halwagi, 1995; Gupta, and Manousiouthakis, 1994; Dunn et al., 1995; Richburg and El-Halwagi, 1995; and Douglas, 1992). As a design objective most identify cost, and consider environment as a design constraint (Cano-Ruiz and McRae, 1998). Even in recent process design books there are no clear guidelines as to how to incorporate environmental issues as a design objective (Turton et al., 2003; Beigler et al., 1997; and Cano-Ruiz and McRae, 1998).

In a few cases, the environmental performance is only evaluated when a complete flow sheet is developed (Azapagic et al., 2006; Young and Cabezas, 1999; Cabezas et al., 1999; Stefanis et al., 1995; and Pistikopoulos et al., 1995). This cannot insure that the design is optimum from an environmental viewpoint.

Some studies have used a more robust approach to incorporating environmental issues during the preliminary stages of a process design. The environment is identified as one of the design objective functions at each and every level of a process flow sheet synthesis (Douglas, 1992; Lewin et al., 2000; and Alexander et al., 2000). The cost is evaluated quantitatively at each level of synthesis, while usually the environmental performance of any options is evaluated based on qualitative judgment. As a result, the selection of the most environmentally benign options cannot be guaranteed. Quantitative evaluation of economics has been well studied and methodologies are present in the literature, however, a simple approach for quantitative environmental evaluation of design options at different stages of process synthesis is not available in the literature.

For multi-objective environmental impact evaluation, use of a single overall indicator is a popular method (Hossain et al., 2007; Goedkoop et al., 1995; Goedkoop and Spriensma, 2001; and Young and Cabezas, 1999). Khan et al. (2004) developed an integrated single index by considering three process design objectives, i.e., environment, safety and cost, and applied to a case study for selecting the best fuel option in a power generation system. The method is qualitative and designed for the detailed analysis of a developed flow sheet.

There is a lack of an adequate approach to determine an integrated index considering cost and environment, for the quick evaluation of process alternatives generated at different steps of process synthesis.

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In this context, the present paper has proposed a quantitative tool, IECP, for estimating the integrated environmental and cost index of a design option. It has the following attributes:

i) It could be set up in a process simulator for performing quick screening, evaluation, and optimization of design alternatives at every level of process synthesis.
ii) Through a two step screening process, it insures the selection of the potential design options for further design considerations.
iii) For environmental impact evaluation of design alternatives, the cradle-to-gate life cycle system boundary is split into two domains – raw materials production and supply domain and gate-to-gate domain – which would help with assessing the impacts of each domain separately. Gate-to-gate domain includes all the processes between input and output gates of an industry.
iv) For developing both the cost and environmental indices, normalization is done by adopting a simple ranking method, which provides a strong basis to obtain a single, integrated overall index. Normalization results in a set of indices, which have the same unit or no dimension, so the indices become comparable among each other.

In the present paper, the applicability of the proposed IECP approach has been demonstrated through a case study for selecting the NOx prevention alternatives with most potential in a 125 MW combined cycle power plant.

Description of the IECP approach

The architecture of the IECP approach is shown in Fig. 1. The application of the IECP approach generates the potential options for design consideration and selects the best option among them from the environmental and economic viewpoints. The description of different major steps of the IECP approach is given below.

Select a P2/design option

Prior to the application of the IECP approach, the designers must first generate design options at a particular stage of process synthesis. This is typically done through "experience" or a process design methodology such as SusDesign, Douglas hierarchy, etc. (Hossain et al., 2010; Douglas, 1992).

Collect/predict the emission data

At this step, designers need to collect data on different emissions associated with the options. Data could be collected through literature search, pilot scale experiments or from existing plants. In case of lack of raw data, the designers may model the process using a process simulator and predict the emissions.

Screening the options

In this step, the emission data on each component for a design option is compared with the corresponding regulatory limit. In case of the lack of regulatory data, the designer may set a limit based on experience or specific situation. The options that fail to comply with the regulatory limit will be screened out and those that do comply will proceed further for environmental and cost potential evaluation. This initial screening insures that the selected options are environmentally sound.

Estimation of P2 potential index

This step is concerned with the evaluation of environmental performance of design options by using the proposed hazard based approach, Pro-hazard. It can quickly evaluate the environmental performance of different design options by determining a numerical

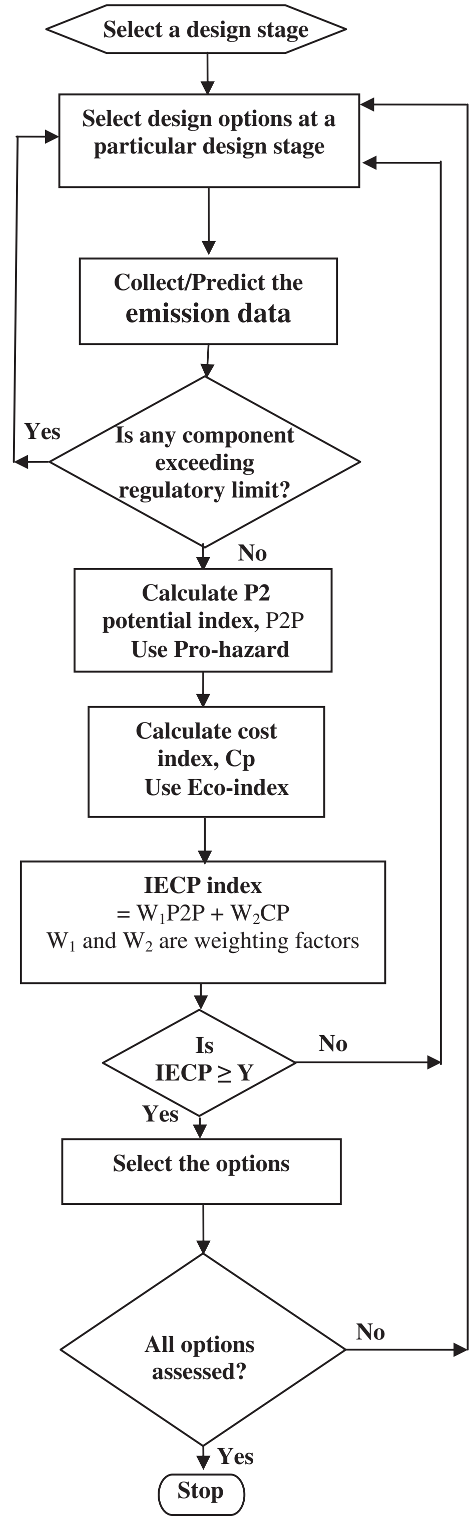

Fig. 1. Architecture of the integrated environmental and cost potential index quantification approach.

index, P2P (pollution prevention potential), for each option which will be discussed later in this paper. Numerical index is used for relative ranking of different options.

Estimation of the cost index

In this step, the economic performance of the potential design options is determined by assigning a numerical index, CP, to each