Journal of Cleaner Production 32 (2012) 101–113

Contents lists available at SciVerse ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Toward an eco-innovative method based on a better use of resources: application to chemical process preliminary design

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ARTICLE INFO

Article history:
Received 22 July 2011
Received in revised form
21 March 2012
Accepted 24 March 2012
Available online 2 April 2012

Keywords:
Eco inventive design
Eco design
TRIZ
Process system engineering

ABSTRACT

Chemical industries have the potential to become a driving force to introduce efficient production practices for reducing the negative impact on the environment. In order to meet these environmental challenges, innovation is a key factor in turning the concept of green growth into a reality through the development of eco-friendly technologies and sustainable production. Therefore, to accelerate and improve the design of eco-inventive solutions, new approaches must be created and adapted to integrate the constraints of eco-invention in the preliminary design. The purpose of this paper is to present the first elements of a computer aided eco-innovation system to support the engineers in preliminary design. This research paper proposes a method based on a synergy between the Theory of Inventive Problem Solving (TRIZ) and the Case Based Reasoning. However, the typical level of abstraction of the TRIZ tools is modified. Indeed, TRIZ only gives way or guidelines to explore in order to find an inventive solution, which are often too abstract and hard to traduce into an inventive concept. To reduce this level of abstraction, this work proposes to apply the physical, chemical, biological, geometrical effects or phenomenon as solutions as they are more concrete. This is done thanks to a resources oriented search in order to better exploit the resources encompassed in the system. A case study on a new production process in chemical engineering illustrates the effectiveness of the proposed approach.

1. Introduction

1.1. Context

Manufacturing and chemical industries have the potential to become a driving force to introduce efficient production practices in order to reduce the negative impact on the environment. Their efforts to decrease this environmental impact have been moving from "end of pipe" technological solutions to limit or control pollution, to the integration of the environmental preoccupation in early stage of product or process design (preliminary design). To generate more integrated, efficient, and sustainable solutions the manufacturing and process industry implements solutions to minimize the material and energy streams by increasing the recycling; output as raw materials for another product or production process. This evolution has been detailed in the Organisation for Economic Co-operation Development (OECD, 2009) report, and summed up in Fig. 1.

To meet these environmental challenges, innovation is a key factor in turning the concept of green growth into reality through the development of eco-friendly technologies and sustainable production. In its reports OECD (2009) defines eco-innovation as "innovation that results in a reduction of environmental impact, no matter whether or not that effect is intended". In their paper (Santolaria et al., 2011) gave some explanations on how eco-design, and broad extent sustainability is connected to innovation driven companies.

In their strategies for sustainable practices, firms try to improve their production processes, their products but they are also more and more interested in the management of their products end of life and their waste. Indeed raw material and more generally all the resources will not be eternally exploited with an open loop approach, based on the input/output capacities of the environment. For instance in chemical engineering, the gradual depletion of hydrocarbon reserves, the scarcity of some resources will imply a decrease of the raw materials consumption and the transition to a circular economy. On this point, the waste management transitions from an environmental approach to an economical one: the waste is not only a constraint to minimize but also a resource to optimize leading to a circular economy. The chemical engineering has,

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doi:10.1016/j.jclepro.2012.03.023

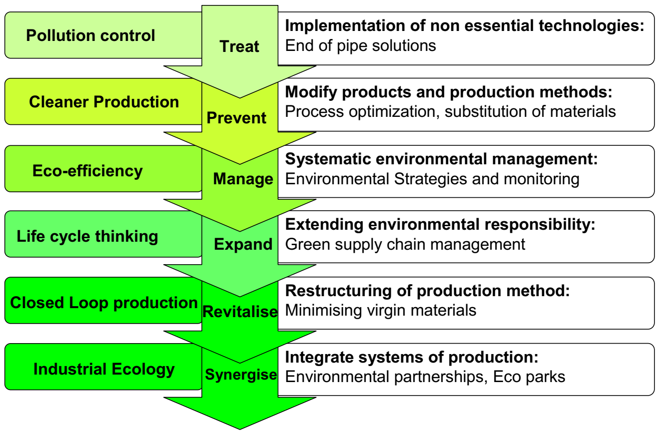

Fig. 1. Evolution of sustainable manufacturing practices, OECD (2009).

obviously an important role to play in so far as it uses resources, it produces waste. Consequently, chemical industry must innovate to find more eco-friendly products, processes but also to create processes for waste valorisation. In the same time, the process industries undergo, new trends imposed by the world market evolution: reduced time to market, decreased product life cycle. However in these industries, the development time for a new product or process is very long and still measured in years. Therefore chemical engineering needs design methods which able to accelerate innovation and to improve and optimize the use of resources in order to reduce the environmental impact of products and processes along their whole life cycle (from design to valorisation).

1.2. Knowledge based design methods

To accelerate its design process a company may use its knowledge capitalized in the past designs. Case Based Reasoning (CBR) is one of the most powerful artificial intelligence methods for formalizing, storing and reusing firms' knowledge. CBR is the process of solving new problems based on the solutions of similar past problems. It has been argued that case based reasoning is not only a powerful method for computer reasoning, but also a pervasive behaviour in everyday human problem solving; or, more radically, that all reasoning is based on past cases personally experienced. But to capitalize design knowledge it must have some repetition in the design activity. This recurrence in the design of systems requires little changes but is less obvious when dealing with innovation. Consequently, CBR deals with eco-design and not with eco-inventive design because it has a weak ability to innovate but can reach solution with a low level of inventiveness corresponding to incremental innovation. In their work (Wu et al., 2008) improved the CBR methods to propose a higher ratio of valuable product ideas but the level of inventiveness is still low. Gupta and Veerakamolmal (2000) and Veerakamolmal and Gupta (2002) applied CBR to eco-design for building a disassembly strategy. Shih et al. (2006) used the CBR to define a recycling strategy for products.

Consequently to propose innovation with a higher level of inventiveness, designers must apply specific methods dealing with creativity enhancement. Current computer aided innovation methods and tools are partially inspired by them as underlined by Leon (2009). Srinivasan and Kraslawski (2006) classified these methods into two main categories: analytical or intuitive methods. The latter searches solutions using randomized process because they do not have a formalized logical structure and among them; brainstorming, lateral thinking, mind mapping are most common. They lead to many iterations to generate a solution, thus a waste of time, money and human resources. In these methods the creativity process is composed of two successive logics of actions: first divergence which is followed by convergence. During the divergent part, engineers generate randomly as many ideas as possible along many directions. Because it is not conceivable to consider all these ideas for further design, the convergent part tries to manage them by merging some of them or by eliminating the less promising solutions using a multi criteria decision but with a high risk to loose very promising concepts. Jones et al. (2001) developed a product idea tree diagram for eco-innovation to structure outputs from chaotic idea generating sessions. Bocken et al. (2011) proposed a tool to facilitate the generation of radical product or process ideas for reductions of greenhouse gas emissions.

In contrast, the analytical methods partially withdraw the previous issue by proposing well-structured methods like morphological analysis or the Theory of Inventive Problem Solving (TRIZ is the Russian acronym). In (TRIZ) the creativity process is converging only because it postulates that no matter the number of concepts generated quality prevails, i.e. viability of the concepts. TRIZ is different from other inventive methods because it operates through generic models and not through the spontaneous creativity of individuals that is why it is widely used by industries and research community. It encompasses methods and tools to propose inventive solutions for not typical problems, and helps corporations and individuals to reach their peak potential.

To conclude, on the one side there are artificial intelligence methods that help to accelerate design thanks to knowledge capitalization through a case base but at the loss of the inventive aspect. On the other side, there are inventive problem solving methods which require a long time to reach a solution because each new design starts from scratch. However there is a lack of information and research on production process oriented approach.

1.3. Eco-inventive design methods

There is a broad diversity of eco-innovation approaches, Carillo-Hermosilla et al. (2010) presented an analytical framework to explore the diversity of eco-innovations according to several key dimensions. This research work focuses only on the design dimension. To support and improve eco-inventive design, several new approaches appear in the research literature. In these approaches, environmental aspects are integrated at the same level as the classical design factors. Most of these approaches and tools are product oriented for the development of functional solutions like in (Li and Huang, 2009), or environmentally or conscious product design by integrating product recovery (disassembly, recycling…) as the research conducted by Ilgin and Gupta (2010). However, there is no production process oriented approach.

In their approach (Cascini et al., 2011) aimed to bridge systematic invention practice with product life cycle management systems by integrating (TRIZ) principles within a computer aided design system. Concerning eco-invention, Fresner et al. (2010) applied (TRIZ) in cleaner production to have a more rational use of materials and energy to reduce waste and emissions in industrial activities. Chang and Chen (2004) conceived an approach based on the technical contradiction of (TRIZ) theory associated with eco-efficiency axes, proposed by Desimone and Popoff (1997), by defining a relationship between both. Their 5 steps process covers a part of the eco-inventive design process; from the problem formulation to the choice of the first design parameters. The main advantage of this method is in the first step with the choice of the eco-efficiency axes with respect to the design problem faced. However, the weaknesses are: the choice of the engineering parameter to improve (among the 39 of (TRIZ), detailed in part 2) is arbitrary, and, is still fuzzy around the technical contradictions. The