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Equipment suppliers integration to the redesign for emissions reuse in industrial processes



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ABSTRACT

It is a fact that industrial equipment is the main consumer of natural resources, impacting considerably on companies' sustainability. In this context, the sustainable redesign of production processes is one of the main companies' challenges seeking to gain competitive advantage in an increasing sustainable environment. This research paper proposes a methodology for industrial application for the redesign of production processes in collaboration with equipment suppliers through resource efficiency based on Circular Economy (CE) closing loops. The redesign for emissions reuse (R4ER) methodology is a practical guidance on how manufacturing companies could address the challenges posed by the large amount of resources consumed during the operational stage of equipment's life cycle involved in production processes. The main results of this implementation are based on a real case study in a Catalan manufacturing company showing a reduction of 38% of water and 26% of electricity during the operational stage of a sterilization process in a year.

1. Introduction

For manufacturing companies involved in an increasingly sustainable environment, the reduction of the resource consumption of their production processes is essential to maintain the competitiveness but it is also crucial for the survival of the company. This is only possible when the industrial equipment use resources in a more efficient way reducing waste emissions or even reuse it as a new primary material resources (TU Delft, 2015). This is by no means a trivial task, it requires the integration of equipment suppliers to the redesign practice and the redesign of many production processes as well as the equipment involved in them. Thus, it is essential that the process redesign considers simultaneously all of the equipment that operate in a production process involved in it as part of a whole system where a modification or improvement in the equipment with the aim to reuse emissions, result directly in a reduction of resource consumption in the production process (Pisano, 1997).

The sustainable redesign for production processes require a fundamental readjustment of manufacturing companies with the aim of achieving a circular flow model (Swisher, 2006). The moving towards CE require a change in the way of the redesign of processes including the closed loop concept in the process redesign (Ferdousi and Qiang, 2016). For this, companies have to adapt their current production

processes and this adaptation must be supported by appropriate analysis and evaluation tools (Alves et al., 2016). The earlier works on process redesign have not especially focused on the reuse of resource emissions between equipment that operate in the same production process. The use of the function modeling method IDEF0 allows a holistic view of the process to be redesigned and the involved equipment. Likewise, a transversal vision of the life cycle assessment (LCA) and the analysis of the relations of coexistence (ARC) for the equipment (Llorens, 2015) in conjunction with the material flow cost accounting (MFCA) is essential to achieve a CE closed loop.

This research paper proposes a methodology for industrial application for redesigning production processes in conjunction with equipment suppliers with the aim to reuse the emissions between the equipment involved in the process. The main results of the methodology implementation indicate the potential of sustainable innovation showing a decrease in the resource consumption in an operational stage of the sterilization process.

2. Frame of reference

2.1. The redesign of processes

The redesign of processes refers to a major effort to improve an

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Nomenclature			
ΔQ	Heat variation (kcal)	T_i	Initial temperature ($^{\circ}\text{C}$)
m	Mass (kg)	S	Sterilizer
c	Specific heat constant $\frac{\text{kcal}}{\text{kg}\cdot^{\circ}\text{C}}$	Wm	Wash machine
T_f	Final temperature ($^{\circ}\text{C}$)	ΔS	Stored water volume change (l)
		Q_i	Total volume of input (l)
		Q_o	Total measure volume of outputs (l)

existing process (Harmon, 2014). It consists in the modification or reduction of steps in processes to remove non value activities and improve those that add value to the customers (Spring Singapore, 2013). Including the delivery of production process with the capacity to respond efficiently to customer demands in a zero-waste way (Alves et al., 2015). The redesign of processes is an activity of industrial engineering and it is not new. The basis for the redesign of processes was established in *Principles of Scientific Management* from Frederick W. Taylor in 1911 (Serrano and Ortiz, 2012), by the creation of assembly lines divided into operations with different employees by Henry Ford in 1913 (Dooley and O'Sullivan, 2000), by the *Structure Approach* of Henry Fayol and in the *Time and Motion Studies* of the Gilbreth spouses in 1917 (Niebel and Freivalds, 2004). In addition, a very important contribution was the *Systems Approach* presented by Boulding in 1950 where it was mentioned that the organization is more than the combination of unique elements and that their interaction is more important than the elements themselves (Dooley and O'Sullivan, 2000).

During the 1980s, different methodologies with a focus on quality were presented in order to emphasize the importance of meeting the customer's quality needs. Among the most important are the Statistical Process Control (SPC), Factory Focus, the Quality Circles, the Total Quality Management (TQM), Just in Time (JIT), ISO 9000 and the Benchmarking among others. Since 1990, a variety of authors has appeared with methodologies of process improvement that have made valuable contributions in the redesign of processes. Among the most remarkable are the contributions of Davenport and Short who proposed the *Business Process Redesign (BPR)* methodology in 1990. They focused on the concept of processes description and on the definition and analysis of critical processes to reduce cycle time, to strengthen the value chain and to improve competitiveness (Davenport and Short, 1990). *Business Process Management (BPM)* is a structured and systematic way for the analysis, improvement, control and management of processes, with the aim of improving the quality of products and services (Serrano and Ortiz, 2012). As part of the methodology Toyota Production System, *The Value Stream Mapping (VSM)* was presented in 1997. It is a lean manufacturing method for mapping and analyzing the production process which supports the redesign of processes and services (Serrano, 2007). Harmon in 2004 proposed a *Business Process Change (BPC)* methodology. This methodology is based on the improvement through process redesign due to the changes that can be experienced by the interactions of the staff, the management, IT systems, the technology and the structure of the organization (Serrano and Ortiz, 2012).

2.2. Process-equipment design relationship

The first record to understand the design relationship between existing industrial equipment and the production process in which they interact was introduced by Hubka and Eder (1988) presenting the *Theory of Technical Systems (TTS)*. They classified and categorized the knowledge of the technical equipment in a nature, structure, origin, development and empirical observations. The principal contribution of Hubka is that the analysis of the equipment must be based on the production process that reflects the activity where they operate (Riba et al., 2005).

Later, in the course of the GAMMA project (Riba et al., 2003) the necessity of a new design perspective is perceived that includes the

equipment to be designed and the production process to which it contributes. Contrasting with the end-user products that are used in situations where the relationship between the user and product is direct, the equipment for production processes operates in complex situations where different operators collaborate and many environmental factors contribute as resources availability, cultural and climatic conditions (Riba and Molina, 2006). Under this new perspective, the authors defined a new frame for the design and development of the equipment involved in the production processes named *Process-Equipment* (Riba et al., 2005). While the previous design philosophies only accentuate the manufacture and the minimization of cost in the equipment, the *Process-Equipment* philosophy is pronounced the usability and the effectiveness of the complete production process system (Riba et al., 2005). With the purpose of the implementation of this philosophy, the concepts of *Process Equipment Architecture and Portfolio Equipment Architecture* were defined (Riba and Molina, 2006).

For the purpose of complementing the terminology proposed during the GAMMA project, Llorens (2015) structured a design methodology for the establishment of the architecture of gamma of equipment re-defining some concepts like a process family, architecture of process families, product family, product catalogue, gamma of equipment and the gamma architecture of equipment goods. The methodology to perform the design model contains five steps; 1.- Identify, analyze and represent the operational process; 2.- Identify, analyze and represent the existing contexts; 3.- Get the scheme of the family of operational processes (based on existing context); 4.- Analyze and represent the architecture of existing product gamma; 5.- Redefine operational processes and architecture product gamma. It is performed considering an operational process in which there is a complete gamma of equipment that coexist and interact in the same production process. Llorens established a new framework for analysis and definition of the architecture of gamma of equipment through transversal visions of the life cycle assessment (*diachronic dimension*) and the analysis of the relations of coexistence (*synchronic dimension*) for the equipment in the production process.

Taking in consideration the increase of environmental requirements in the design of process equipment, in 2010, the CDEI-UPC promoted a design methodology called *Design in blue*, which takes its name from the concept of the Blue Economy of Gunter Pauli. In contrast to the green economy, it advocated a simple change of unsustainable technologies for sustainable technologies accepting an increase in costs. The blue economy proposes a paradigm shift that eliminates the unsustainable production and consumption so that the good and innovative become competitive. It suggests that business models improve the quality of life of all evolving in harmony with ecosystems, using available resources and ensuring that process residues become resources for another process (Pauli, 2010). Based on this, Riba (2012) identified three lines of work in the methodology Design in blue that set the paradigm shift in the design and development of equipment; 1.- The consideration of the operational process as the basis for analysis; 2.- Assessment of energy consumption and environmental impact; 3.- The consideration of social, cultural, natural environment and technological context. The consideration of the operational process as the basis of the analysis point of view should be extended from the equipment to the operating process including technical and human operators and all flows of materials, energy and information.

The different approaches and methodologies presented in the

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