Combining Energy Monitoring and LCA/LCCA analyses to improve the Sustainability of an Extrusion process

Luzi Andrea*, Marilungo Eugenia*, Papetti Alessandra*, Peruzzini Margherita*, Germani Michele*

*Department of Industrial Engineering and Mathematical Sciences, Polytechnical University of Marche, via Breccia Bianche, 60131, Ancona – Italy (a.luzi@univpm.it, e.marilungo@univpm.it, a.papetti@univpm.it, m.peruzzini@univpm.it, m.germani@univpm.it)

Purpose

It is well known that industrial processes require large consumption of energy and other resources during the product manufacturing phase. This exploitation of energy is reflected both in terms of environmental impact and in terms of economic impact, which can be measured through specific tools. The measurement of these environmental and economic impacts is an essential step towards both the control of the energy consumption and energy costs and in sustainability energy assessment. In this paper is presented the extrusion process of plastic materials in a big Italian company. This process is highly energy-consuming and for this reason it is necessary monitoring the energy consumption and controlling the process parameters to increase the energy sustainability and, at the same time, decrease the environmental and social impacts. The aim of this work is presenting a methodology to capture the extrusion process sustainability to have a base line useful to compare the results of any other extrusion process assessment.

Design/methodology/approach

The proposed methodology aims to identify the high energy consuming machineries, components, and devices in the company. To do this, the industrial process must be organised in several functional components which have a specific number of input and output. The first step in this propose is the process evaluation in terms of the definition of the functional modules involved and the identification of the input/output needed in each one. After the collection of these data, the next step is the assessment of the environmental and economic impacts through Life Cycle Assessment analysis (LCA) and Life Cycle Cost Assessment analysis (LCCA). This study is supported by a hardware and software infrastructure among the extrusion process machineries and the SimaPro tool to conduct the LCA and LCCA analyses.

Originality/value

The innovation of this paper is to consider the Life Cycle Assessment of a process through the evaluation of each its components. The resulted impacts are focused on the process sustainability and not on the product sustainability as is instead largely made clear in the literature. The results of this work are related to the definition of a methodology in the field of industrial processes evaluation; in fact, it has been defined a new approach to conduct the Life Cycle Assessment focused on the industrial process and it has been suggested a method to evaluate the Energy Sustainability in a highly energy-consuming process.

Keywords: Sustainable Manufacturing, Energy efficiency, Process monitoring, Process Life Cycle Assessment

1.Introduction

The concept of Sustainability evolved in the last decade and aims to have a green development that does not compromise the natural resources and the human health for the future generations.

This paper is focused on the theme of “Sustainable Manufacturing”; it stems from the growing interest in energy efficiency in industrial processes. In fact, sustainable manufacturing could be considered an effective solution to support the continuous expansion of manufacturing industry, where the environmental, social and economic impacts are the focus in production assessment (Yuan et al.). The current studies propose three dimensions to identify the core of sustainable thinking: environment, economy, and social wellbeing (Adams W.-M.).

The principles of Sustainable Manufacturing, which are an extension of the principles of Sustainable Product, include
zero waste, low environmental and social impact, fewer raw materials, optimization of product and process parameters, and development of an infrastructure to manage the sustainable manufacturing implementation. The main difference between these two principles, one applied on the product and one on the process, is the introduction of energy as an important asset in the sustainability assessment. The inputs in the environmental and economic assessment of a product are the raw materials, the transports, and the processes involved. If the focus changes from products to processes, the sustainability assessment necessarily involves all production inputs such as raw materials, energy, water, manpower and the other resources that contribute to the final product manufacture.

Thus, having a methodology to assess the impacts from various resources that are used during the production process is useful. Moreover, this approach could be the starting point to evaluate the energy efficiency of industrial parameter processes.

This paper focused on the extrusion process, which is a good example of high energy consumption process.

2. State of the art

2.1 Growing Interest in Energy Efficiency

In recent years, the increasing pressure on material availability, energy prices, and emerging environmental legislation is leading manufacturers to adopt solutions to reduce their material and energy consumption as well as their carbon footprint, thereby becoming more sustainable (Pusavec et al.). Major industrial repercussions due to this trend can be observed, especially in high-energy-consuming companies (and consequently large CO₂ emitters), such as petroleum refining, primary metal processing, paper product manufacturing, etc. These companies are characterised by continuous or semi-continuous processes and energy is the major cost voice. The optimization of these processes has received significant attention in both academic and industrial research environments (Dufolu et al., 2012).

Many industrial companies still lack methods and tools that are able to correctly allocate energy consumption along the production chain. In this case, Information and Communication Technologies (ICT) and controlling systems play an important role for improving energy efficiency in manufacturing processes. Several studies have also identified a low status of energy management as a barrier to energy efficiency (SPRU). Indeed, the measurement of energy consuming by industrial processes is the basis for deciding about improvement measures, for tracking changes and improvements in energy efficiency, and for implementing the process control (Bunse et al.).

Energy used in industry can be classified as direct energy and indirect energy. The first is used in production processes, while the second is used in the supporting processes such as ventilation, lighting, heating and cooling. Measuring energy efficiency is the basis to control the energy consumption in the production processes, to decide the improvement measures, and to track the changes and improvements in energy efficiency. The sensor devices are used to measure the energy consumption and the collected data are useful to determine the energy efficiency. Herrmann et al. provided an overview of energy consumption metering procedure and tools and Kara et al. presented an overview of the evolution and the latest developments in power measurement and monitoring systems.

2.2 “Sustainability” measurement

Regarding the environmental impact assessment, the use of the LCA methods to assess the production system footprint requires specific developments in life cycle modelling. Specifically, when the production process is considered during the analysis as a product, the system LCA modelling highlights that to realize a correct and complete analysis are required an amount of data bigger than the number of modules that compose the product itself. Then, the final amount of the information to be collected for the Life Cycle Inventory (LCI) usually becomes prohibitive when it is applied to the whole life cycle of machines and equipment, which compose the production lines (Brondi C. and Carpanzano E.). The Centre for Sustainable Manufacturing and Reuse/Recycling Technologies (SMART) at the University of Loughborough has developed a system enables to model the Embodied Product Energy (EPE), that is required during the manufacturing phase of a product (Dufolu et al., 2011).

To resolve the lack of environmental analysis of the manufacturing processes and the corresponding LCI data, the CO2PE! Initiative (Cooperative Effort on Process Emissions in Manufacturing) was launched. The CO2PE! Initiative has the objective to define and quantify the environmental impact of a wide range of emerging industrial processes and to give the guidelines in order to improve their performances.

Herrmann et al. proposed a framework to visualise the environmental impact of the manufacturing processes using virtual reality. Lofgren B. et al. developed a method that combines discrete-event simulation (DES) with life-cycle assessment (LCA), with the aim to capture the dynamic interrelationships between manufacturing processes in order to analyse systemic responses to configuration changes.

Although the energy consumption from 1999 to 2009 by the industrial sector was decreased by 15%, more improvements are still necessary.

2.3 The extrusion process

Over the last decades, plastic production has increased intensively. European plastic production in 2010 was approximately 57 million tons, which represented 21.5% of the global production. In particular, PVC and PE productions represented 29% and 12% of the total production, respectively. Extruders play a major role in processing polymer materials and the related process is highly complex and variable due to significant interdependencies among material properties, operating conditions, and machine geometry (Abeyskoonna et al.).
There are many studies on discrete-part manufacturing and how it can be improved in terms of energy efficiency, but the study of continuous and semi-continuous processes is limited. Currently, this type of processes are better analyzed with the aim to improve the product quality. For example, “on-line monitoring” is used to analyze the product faults that occur along the production chain and to reduce the waste production. In fact, these processes are widely used in pressure- and temperature-control systems. The field of quality control and the use of specifically related tools are widely described (Rohe et al.).

The extrusion process, that we consider in this paper, consists of the gradual melting of solid polymer using thermal conduction and the viscous shearing between a rotating screw and a barrel (Vera-Sorroche J.). Some interesting studies have focused their attention to the energy used by the extruder (Köster M. and Thommes M), in particular, to the torque measurement and the related electrical energy required. Other studies (Mihelic A. and Stok B.) are referred to the use of finite element method to determine the required minimal energy or the critical point during the extrusion phase, which can significantly affect the product quality. Improvements in extrusion-process monitoring are invaluable for advanced process control and troubleshooting, and they will help to increase the process efficiency, and to seek the optimal conditions.

This paper aimed to present a method that is a joint venture between a monitoring system and a sustainable analysis related to the process.

3. Sustainable manufacturing

3.1 The context

The modern enterprise is characterized by a complex system of relationships among various stakeholders (customers, employees, shareholders, regulators, and society in general) and each of them exercises specific pressures, arising new opportunities and threats. Therefore, it is fundamental to define responsible and forward-looking policies and strategies.

In this context, process monitoring and controlling are the main pillars in modern industrial production to achieve the total quality for the overall control of the production processes and to connect the elements between the environmental impacts and the decision making process.

This paper responds to a general need to have full control on the highly energy-intensive processes, characterized by a high resources exploitation where a small change in the production process can produce a big benefit in terms of process sustainability.

Extrusion process is a good example because it involves a several number of machineries and auxiliary systems (i.e. chiller, shredder, etc.) which consume a lot of energy, water and raw materials each one. Moreover this process is based on rules of thumb and experience of the operators and not on codified knowledge. Extrusion is a continuous process used to realize semi-manufactured products such as pipes, profiles and cable sheaths. Although the design of the mould and some extrusion components are different, each product has the same production method (Van Heur R. and Verheijen M.).

The plastic material, initially in the solid state in the form of small particles (pellets) or powder is conveyed using a screw pump and heated by suitable heating bands at a controlled temperature until it becomes a highly viscous liquid to be extruded through a die, which gives it the desired shape. Subsequently, the product thus obtained is cooled and calibrated. When the product has reached the desired length, it is cut to size. The biggest energy consumers in the extrusion process are the motors and the heating units.

Today the environmental and economic impacts affected by the extrusion process are not known due to the lack of a methodology that investigates each process components and its resources consumption. The method proposed in this paper tries to reply to this issue, using a highly flexible system that can be applied to any company that has a continuous production flow, high energy consumption and problems to keep the process under control. In fact, the method that will explain in the next chapters can be applied to other manufacturing companies in order to monitor their process parameters and save the energy consuming during their exploitation phase. It requires to have high energy consuming that justify an investment for a customized infrastructure to capture and to collect the data needed. The constrain about the continuous production flow is necessary in this analysis in order to monitor and control the extrusion process; if we had a discrete manufacturing process, would be difficult compare data and information during time period different and unrelated.

3.2 The methodology

The proposed methodology aims to identify the high energy consuming machineries, components and devices in the company. This study is supported by a hardware and software infrastructure among the machineries.

The hardware infrastructure consists of a several sensors implemented on the chiller cycle, on the main electrical panel plant, and on the extrusion lines, both inside each component and at the upstream of the production line. The sensor typology varies according to the measurement expected:

- temperature measurement, through temperature probes;
- energy measurement, through a network analyzer;
- chiller pressure, measurement through pressure transducers;
- productivity measurement, in terms of tube meters per minute, through encoders or magnetic sensors.

For the new generation extruder some of these data are collected directly by a PLC on board.

First of all, the software infrastructure allows the user (e.g. department head, production manager, etc.) the monitoring and controlling the production line in term of
energy consumptions. Then, to understand and discover the critical process components and auxiliary systems, the enterprise must have a database of several historical data, so that the process designer or the head of the production can compare the real measured data with the collected historical data. When there is an incongruity between real and hypothetical values, user can read in real time this issue and he can intervenes as soon as possible. Moreover, the data collected by the LCA and LCCA analyses allow the production manager to understand the process criticality, related to the data collected by the process.

In order to identify only the production lines and the auxiliary system which have an high energy consuming it is necessary to apply a step by step methodology that allows the tracking at first of all macro areas high energy consuming in the plant, and then, for each macro area identified, all high energy consuming processes and devices recognised. In the last step, the critical parameters and the critical values for each machine and device identified are studied and monitored.

4. Sustainability of Extrusion Process

The study was conducted with a plastic pipe manufacturer, which had at least three plants where the extrusion process was performed. The plant involved by this new monitoring and controlling process method was affected by the production of polyethylene (PE) pipes. The macro areas identified were:

- raw materials storehouse. This area involves both the plastic powder storehouse and the transporting means through the plant from the raw materials silos to the extruder alimentation zone;
- extrusion lines. This is the production area, which involved seven extrusion lines, many of which are of the latest generation. Thus, they are supported by a PLC on board. Moreover, the extrusion lines work continuously;
- refrigeration unit (chiller and cooling tower). This area allows an effective cooling of the freshly extruded tubes;
- finished product storage. This area involves the devices and sensors that store the finished product.

Figure 1 shows how the two main macro-areas identified in this specific extrusion enterprises (chiller group and extrusion lines) are interconnected. The blue line represents the ICT connection among the macro-areas and the orange lines represent the set of sensors and devices to collect the process parameters by each components in the macro-area.

After the macro areas in the plant were identified, it was necessary to understand their energy-consuming contribution. To solve this problem, a network of sensors, encoders and appropriate devices was developed and implemented in the industry plant (hardware infrastructure defined before).

The purpose was to capture all data that the monitoring and control methodology needs. These data are:

- the productivity of each line; this value involves the production speed (meters/minutes or kg/hours) and the number of pieces produced;
- the temperature detected along the extrusion line, which is the temperature of the cylinder, the extrusion head and the cooling tanks;
- the temperature measured in the refrigerating circuit, which is the temperature in the evaporator inlet and the chiller outlet;
- the flow rate of the refrigerant circuit.

Regarding the extrusion process, the plant areas most affected by energy consumption were the production area (the extrusion lines) and the refrigerator area. The crushing waste area is critical but unlike the previously mentioned areas, it does not work continuously. In the discussion of monitoring and control, we only refer to processes that operate continuously and difficult to keep under control. Otherwise, it becomes difficult to understand the contribution of a batch process with the proper conditions and working hypotheses.

In the production area, the critical components are the extruder (the main motor), the co-extruder, the extrusion head and the vacuum calibration tank. In the refrigerator area, the critical system is the chiller. At this point, the network to collect all necessary data into an enterprise was defined and built.

The next step in this methodology definition was the evaluation of the LCA and LCCA analyses, applied to the production process. In this way, all process parameters and critical values are involved. The measured data during the methodology application were necessary to create also a LCA database, where the environmental impacts related the extrusion process were collected. The use of this tool allows to involve and merge in the methodology all process parameters and critical values affected by a high-energy-consuming.

In fact, the studied method had to present the promising prospect of a hardware and software system to control
and monitor the industrial production processes. This system is promising due to the current needs to increase the productivity and decrease the waste of industrial processes while respecting the environmental sustainability.

In the previous paragraph the hardware system functionalities have been presented in detail; here the software system functionalities will be defined.

The software system is based on a correlation model between the process parameters and the energy consumption, which also considered the related environmental and economic impacts. These values are associated to extrusion process components and devices.

The process parameters and the energy consumption are collected through the network of sensors and devices which compose the hardware infrastructure. The environmental and economic impacts are defined through the LCA and LCCA analyses application on the process. This is an innovative way to identify and control the industrial processes. Figure 2 shows the schematics of the methodology, which was developed in the industrial case of the extrusion process. In the environmental and economic analyses the main concept is to translate the LCA and LCCA analyses from product application to process application; this means that the industrial process must be organised in several functional components which have a specific number of input and output. In the extrusion process considered in this paper, these functional components are the same defined during the hardware system design and implementation. This is the reason why the methodology defined is innovative; in fact, it allows to understand where the high and expensive consuming and the major environmental impacts are located in the industrial plant. So far, we focused on the network developed in the industrial plant to identify the areas affected by high energy consumption and to measure all parameters of the process and the product. Now, it was essential to understand the connection between the concept of sustainable manufacturing and this proposed method of monitoring and control.

“Sustainable Manufacturing is defined as the creation of manufactured products that use processes that minimise negative environmental impacts, conserve energy and natural resources, are safe for employees, communities, and consumers and are economically sound”. In this vision, some reasons to implement the sustainability of the enterprises are:

- rational use of energy and raw materials consumed by the processes through the optimisation of all parameters involved in the production process;
- development of technologies to monitor the processes and the products;
- reduced environmental and economic impacts throughout the whole process life cycle (implementation of LCA and LCCA methodologies).

According to this definition and the related guidelines, the methodology proposed in this paper accurately reflects the character of sustainable manufacturing. In fact, the first steps aims to identify the subject of the analysis: factories areas, and for each area, the affected processes and devices are also identified. The next steps aim to define for each subject its parameters, energy consuming, environmental and economic impacts. In this way, it is possible to create a database of real data collected by the process and the product. The last step is the creation of a database of a set of rules to manage the several data and information come from the industrial process. The process control is implemented through a user interface directly by the user (e.g. the head production).

5. Conclusions

The proposed methodology is a good example to implement the monitoring and controlling in the high-consuming industrial processes. Moreover, it is a great starting point to realize the first example of sustainability manufacturing implementation in the process enterprises.

This paper presented the methodology, its bases and principles, its main modules and its required data. With a thorough understanding of this information, a real case study can be defined and developed.

In order to validate this methodology a case study must be developed. Currently, the hardware infrastructure at the extrusion enterprise has been implemented. Future works will present the process and the product parameter value that were collected by the process. Moreover, process LCA and LCCA analyses will be conducted. These steps are necessary to concretise the value of sustainability manufacturing in an extrusion process. It is important to validate also a mobile or tablet application which allows to user to remote control the process and to send it the data feedback in real time.


