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Five Steps for Process Development under the Energy Sustainability Criteria

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Considering that sustainability criteria play a fundamental role in the control and efficient operation of production processes, this article presents five fundamental steps based on the benefits of an Integrated Energy Management System. The five steps formulated for the development of processes under a sustainable development approach are based on measures for the rational use of energy that seek both environmental and economic benefits, if these savings measures are applied in the respective production process. The results obtained from the application of the five steps to a company of the product sector in Colombia, resulted in an additional benefit such as increased energy control of the production process. The article shows in detail how to establish the Baseline, evaluate the consumption trend, quantify emission reductions, economically quantify savings, and evaluate the energy control of the production process with a view to the sustainable operation of industrial processes. The main contribution of this article is the development of a systematic tool based on performance indicators and historical operational information of the process to achieve a sustainable and environmentally friendly operation of any company that implements it.
Keywords: process development, sustainability, energy management system, performance indicator.

1. Introduction

The UN Convention on Climate Change of 2015 established that global warming should be kept below 2°C and that efforts should be redoubled to keep it below 1.5°C (Adoption of the Paris Agreement, 2015). According to the Intergovernmental Panel on Climate Change (IPCC), warming of more than two degrees would be catastrophic for humans and nature (Intergovernmental Panel on Climate Change, 2007). Bearing in mind that industries are the largest contributors of greenhouse gases with nearly 40% of CO_2 emitted into the environment (IEA, 2009), the need to optimize industrial processes for an efficient and environmentally friendly energy consumption arises. This is achieved through the development of a set of activities, techniques, procedures and tools that lead to the establishment, implementation and continuous improvement of energy consumption management systems, in order to guide companies to focus on the continuous development of energy use, energy security, energy use and consumption (Schulze *et al*., 2016). In addition, the identification of equipment and areas with the most significant use of energy and the planning of strategies to improve the performance of these equipment. These changes in industries are not generated overnight, but are the result of a series of analyses, strategies and evaluations that determine the viability of the project, therefore, it is necessary to identify the prerequisites for including energy management programs in the strategic agenda of energy-intensive process industries (Rudberg *et al*., 2013). The need to improve processes has led to the development of strategies to implement processes that help companies to effectively manage energy in production (May *et al*., 2015).

The efficiency of the equipment is one of the main factors promoting industrial competitiveness, considering it as one of the main assets in the production chain. Measuring and quantifying energy efficiency in equipment, processes and factories is the first step towards energy management in any company (Valencia *et al*., 2017a), which is nothing more than establishing the company's baseline. To improve energy management, measurements and data acquisition at all levels play a key role, from the different machines to the sub-processes and production lines (Campos and Prias, 2013), (O'Driscoll et al., 2013). With all the data obtained, it is possible to evaluate the performance of the equipment and the consumption in general of the whole company and obtain a characteristic trend in order to proceed to implement measures that favour the reduction of consumption (Valencia *et al*., 2017a), in this way quantifying the emission reductions and the economic savings. The final stage is the operational part where the performance indicators must be constantly monitored and socialised, a plan for technological improvements of zero or low investment must be developed, and projects aimed at energy efficiency management must be implemented. The implementation of these steps has proven to achieve significant savings in companies where they have been developed, in addition to evidencing great potential savings.

The main contribution of this article is the development of a systematic tool based on the evaluation of performance indicators and historical operational information of the process, which allows the identification of opportunities for organizational, energy and technological improvements, to achieve a sustainable and environmentally friendly operation of any company that implements it within the framework of an integrated energy management system that leads to the identification of competitive improvement actions (Valencia *et al*., 2017b).

2. Methodology

This paper describes the scope of an integrated energy management system developed to identify the potential for energy savings and reduction of pollutant emissions from the environment, resulting in greater energy control of the production process, in which the data were collected from a fertilizer company. Finally, energy sustainability criteria are presented using mathematical foundations. The energy sustainability criteria allow us to estimate the energy performance indicators of a plant, as well as to identify the energy and economic saving potentials, to develop potential savings projects without technological changes that contribute to the reduction of emissions, following the steps presented in Figure 1.

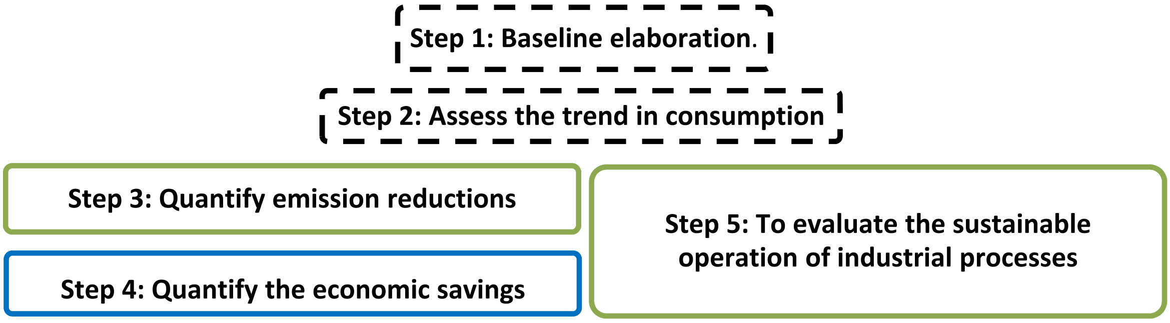

Figure 1: Schematic diagram of an energy sustainability criteria applied to an industrial process

3. Results and discussion

In this item is presented the description of the five steps for the development of processes seeking energy sustainability, where it is highlighted that the main differences in the practical order between the current traditional model available in the litter and the new energy management model to be implemented is that the traditional approach is focused on the improvement of larger consumer equipment, while the present proposal is focused on the efficiency of the entire system, in addition to the fact that there is currently a strong trend towards technological change while the current objective is to emphasize the standardization of good practices in the maintenance and operation of the final use of energy.

Step 1: Baseline elaboration. It is used to determine the equivalent production of products or related processes of the company, comparing the products or processes that are determined necessary for a correct characterization of the system. The baseline is described by the form:

$$y = mx + b \tag{1}$$

Where y represents energy consumption, which in turn is also represented as E_t in the typical baseline equation, where m is the energy consumption per unit tonne produced, P is production and $ENAP$ is the energy not associated with production.

$$E_t = m \times P + ENAP \tag{2}$$

The equivalent production is calculated taking as a reference the same value of energy consumption, which makes it possible to equate the equations considered in the characterisation of the system, to determine the equivalent productions of the products or processes with respect to which it was taken as a reference. In a graph of equivalent production vs. energy consumption, the baseline of the plant operation can be directly appreciated, as shown in Figure 2 for three different products of the same company, and the equations of each product can also be appreciated according to their respective order.

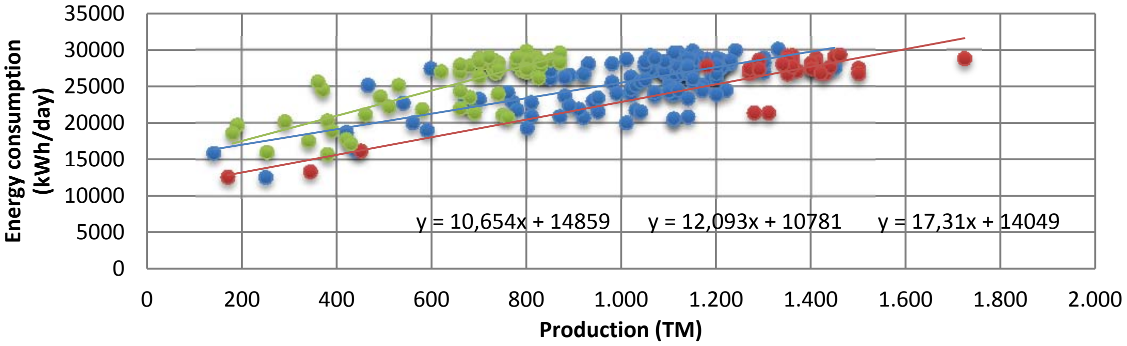

Figure 2: Baseline of three products from a fertilizer company

Considering that the equivalent baseline represents a nominal energy consumption for the operation of the plant, from the historical records of production and energy consumption, it is defined that the data above the baseline represent points of low energy performance, while the data below the baseline represent good energy performance.

From the good energy performance data, a Goal Line is constructed, as shown in Figure 3. The Goal Line will establish a potential for energy consumption savings associated with good manufacturing practices, without the need for technological changes in the plant infrastructure, this potential for energy consumption savings being determined by the difference between the ENAPs of the baseline and the target line, expressed as a percentage.

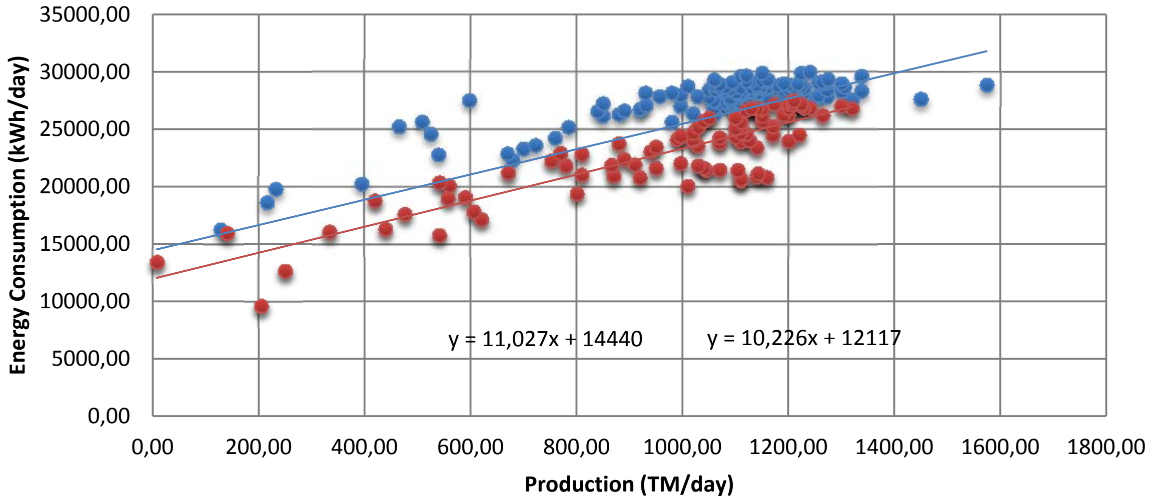

Figure 3: Equivalent baseline and goal line

Step 2: Assess the trend in consumption. To evaluate the consumption trend, the energy consumption index is used, which is defined as the relationship between the energy consumed and the value of the production obtained through this energy consumed. It is an indicator of energy performance that is analyzed by means of a graphical comparison of the real consumption index with the theoretical consumption index, both of which are plotted against the plant's production. The actual consumption index is constructed using the energy consumption and actual production data as shown in Eq (3).

$$IC_{Real} = \frac{E_{Real}}{P} \tag{3}$$

While the theoretical consumption index is constructed using Eq (4).

$$IC_{theorist} = \frac{E_{theorist}}{P} \tag{4}$$

The theoretical energy consumption used in Eq (4) is calculated using the adjusted baseline Eq (2), so replacing Eq (2) in (4) gives equation (5) to calculate the theoretical consumption index.

$$IC_{theorist} = m + \frac{ENAP}{P} \tag{5}$$

Once the graph of consumption vs. production rates is made, both indices are compared to analyze the system, high values indicate poor management of the energy resource, the graph can identify the average production, the average energy consumption and can identify the daily production rate, at which the plant should operate, so that the consumption rate does not present significant variations, this production rate is known as critical production rate and for this example is given as 1400 TM/day, or 58.33 TM/h.
From Figure 4 it can be concluded that there are high levels of consumption and therefore inefficiency for productions below 400 MT, apart from the fact that the real consumption index of the plant varies on average between 18 and 35 kWh/TM and an average production of 1034 MT/day.

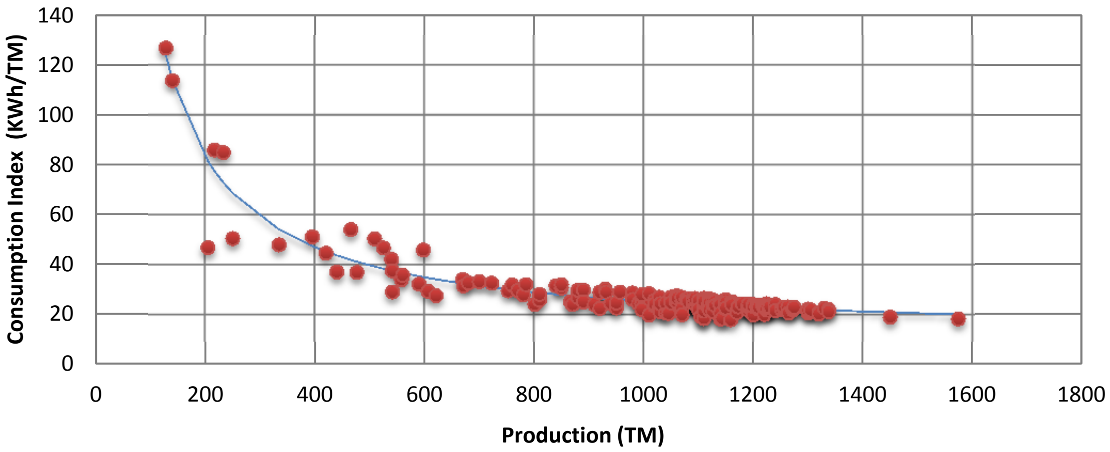

Figure 4: Theoretical Consumption Index vs. Real Consumption Index, the points indicate real consumption

The consumption trend can also be graphically evaluated by means of the CUSUM accumulated trend graph, which allows for monitoring the trend in energy consumption for the company, with respect to a base period, in order to monitor the consumption trend in the same year, identifying possible time periods where good energy performance is present in the company, or if it is the case, identifying time periods where poor energy performance is found in order to establish opportunities for improvement.

Step 3: Quantify emission reductions. For the calculation of emissions there is a wide range of possibilities, being able to generalize in three big fields: by type of consumption, by type of installations and by types of equipment. By type of consumption, the emissions from both electricity and fuel consumption are calculated separately to obtain a total for the plant. The calculation of emissions by electricity consumption is carried out by multiplying the electricity consumption by the emission factor, which varies according to the policies of each country. The following equation can be obtained by generalizing

$$FE\_electricity\_consumption = x\frac{tCO_2}{MWh} \tag{6}$$

Where x is the value assigned to the factor by each country, region or association. You can also have expressions per year. Another generalization is obtained for the calculation of emissions by fuel consumption.

$$FE\_diesel\_oil = x\frac{tCO_2}{TJ} \tag{7}$$

Eq (7) is used for calculations from thermal energy, while Eq (8) is used for calculations from fuel volume.

$$FE\_diesel\_oil = x\frac{tCO_2}{tdiesel\_oil} \tag{8}$$

A similar procedure applies for all other types of emissions calculations. Once the total emissions are obtained, the data are tabulated and compared with previous data, determining the trends and reductions achieved.

Step 4: Quantify the economic savings. This section identifies the savings potentials for energy consumption associated with and not associated with production. The savings potentials will be identified for the indicators of energy performance of electrical energy. The savings potential not associated with the production of electricity consumption is identified; from Eq (2), the consumption not associated with production (ENAP) is taken from the baseline and the target line, so the savings potential is calculated according to equation (6).

$$Savings\_potential = \frac{\left(ENAP_{Base} - ENAP_{Goal}\right)}{ENAP_{Base}} \times 100 \tag{9}$$

The resulting savings potential would be the consumption not associated with production that can be reduced. In addition, it is possible to determine a potential energy saving potential associated with production, which is established from the ratio of the theoretical and the actual IC. For the consumption of electrical energy there is a critical production (P_{Crit}) and an average production (P_{Prom}) of the plant of 1034 MT/day, the savings potential is given by the equation (7).

$$Savings\_potential = P_{Average}\left(IC_{Average} - IC_{Crit}\right) \tag{10}$$

From Eq (7) IC_{Prom} is the Average Consumption Index of the real consumption indices, calculated with the real consumption and production data, while IC_{Crit} is the Theoretical Consumption Index calculated for PC_{rit}.

Step 5: To evaluate the energy control of the production process with a view to the sustainable operation of industrial processes. Based on steps 4 and 3, the base efficiency index 100 is an energy management tool that allows the performance of the energy consumption results measured during a period of plant operation to be evaluated with respect to the theoretical energy consumption values calculated using the base line. The efficiency index base 100 is calculated using the following equation:

$$Base100 = \frac{E_{theorist}}{E_{Real}} \times 100\% \tag{11}$$

This indicator generates alerts regarding positive or negative variations in the energy efficiency of the process, thus facilitating the analysis and proposal of action plans based on energy improvements, allowing analytical interaction between energy production and consumption, aiming at a better energy performance of the plant processes.

The base efficiency index 100 can express two result ranges B100 < 100 % and B100 ≥ 100%. For the case when the index is greater than 100%, it translates into good energy performance, otherwise, when the efficiency index is less than 100%, it is indicated that the data belongs to a zone of energy inefficiency of the plant. In Figure 5, the points above the horizontal boundary line are good energy performance data located in the plant's energy efficiency zone.

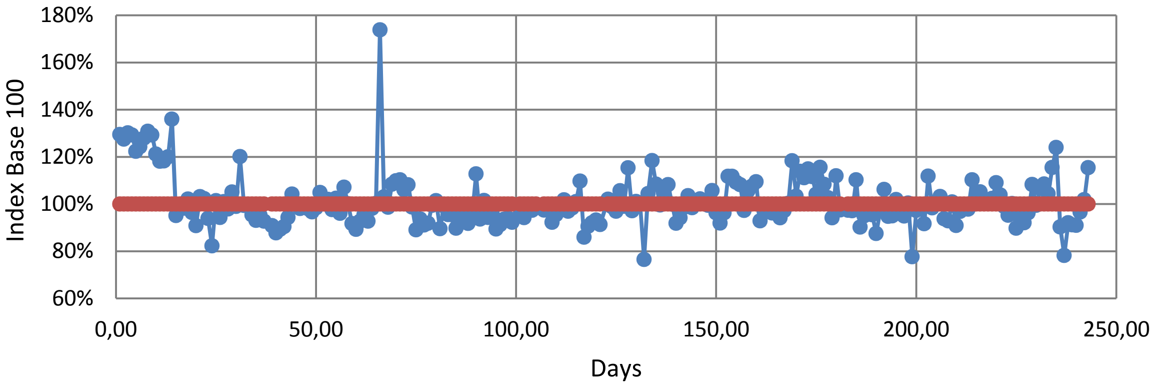

Figure 5: Efficiency Index Base 100 for Electric Power

4. Conclusions

According to the results of the energy diagnosis in the plant, the implementation of an energy management system according to the ISO 50001 standard can be considered, focusing on the significant uses of energy in the plant. It is necessary to give continuity to the implementation stage of the system, in which the monitoring and control of the energy indicators is produced, the accompaniment in the verification of the operation of the operational control system and the implementation of technological improvements of vacuum, or low investment.

To guarantee the improvement of energy use and the sustainability of energy reduction, for the company with low investment measures, it is necessary to develop an energy efficiency monitoring, measurement, and analysis software for each significant use of the energy installed and put into operation, so that the equivalent production of the different processes of the plant is calculated.

Finally, a third stage of monitoring and adjustment in which a measurement of results is carried out, to identify the technological improvements of medium and high investment, evaluating the energy saving potentials obtained with the implementation of the system, documenting the energy management system, and incorporating it into the company's management system, in addition to carrying out external audit exercises for the purposes of ISO 50001 certification.

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