CHEMICAL ENGINEERING TRANSACTIONS
VOL. 57, 2017

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.aidic.it/cet

Guest Editors: Sauro Pierucci, Jiří Jaromír Klemeš, Laura Piazza, Serafim Bakalis

ISBN 978-88-95608- 48-8; **ISSN** 2283-9216

DOI: 10.3303/CET1757119

Energy Saving in Industrial Process Based on the Equivalent Production Method to Calculate Energy Performance Indicators

Guillermo E. Valencia[b], Yulineth Cardenas[a]*, Erni S. Ramos[b], Alexis Morales[c], Juan C. Campos[b]

[a]Industiral Engineering Program, Universidad del Atlantico, Puerto Colombia – Atlantico, 081001
[b]Mechanical Engineering Program, Universidad del Atlantico, Puerto Colombia – Atlantico, 081001
[c]Process Engineering Division, Monomeros S.A., Via 40, Barranquilla - Atlantico
ydcardenas@mail.uniatlantico.edu.co

This paper presents the estimation and analysis of energy performance indicators based on the equivalent production method to improve the decisions and operational actions to reduce the energy consumption of a fertilizer company in Colombia, where the global consumption of natural gas in the plant is 4800 kcf per day for an equivalent production of 1,029 MT of NPK fertilizer 15-15-15, where the 63.4% of the energy is consumed by the complex fertilizers line, the 29.2% by equipment of the energy supply plant, and finally the 7.4% is consumed by the fertigation SoluNKP plant. Based on the standard ISO 50001 and the operational data for 2015, some energy performance indicators such as the baseline and goal line of consumption, the actual consumption rate compared to the theoretical consumption index, the efficiency Index Base 100 and finally the consumption trend accumulated (CUSUM) were calculated, allowing to identify energy saving potentials of 16.1% through good operational practices without technological changes, besides 25.6% for production planning. Finally, the natural gas potential savings identified have been achieved by the organization through the implementation of an Integrated Energy Management System.

1. Introduction

Nowadays, a worldwide environmental crisis is latent with serious consequences in the way that people feed and generate power. Thus, encouraging the use of renewable energies and the improvement of energy efficiency in industrial processes through the implementation of Energy Management Systems, which allows to reduce the energy consumption in 37% of the current worldwide industrial energy consumption (Abdelaziz et al., 2011). Moreover, researches conducted by the International Energy Agency (IEA) show evidences that approximately the 40% of CO_2 emissions, including combustion processes and heat and power generation, are related to industrial processes (Sucic et al., 2015). According to the previously stated, the implementation of Energy Management Systems turns out into an orientation for industrial companies to assemble efficient productive structures, thus a better way to the use of energy resources, which allows to increase the industrial competitiveness so that to use it as a way to encourage the innovation, at the same time these systems blend with facts such as environmental sustainability and industrial eco efficiency (May et al., 2016).
The performance of the equipments, is one of the main factors which encourage industrial competitiveness, considering this as one of the main actives in the production chain. The measurement and quantification of energy efficiency in equipment, processes and factories is the first step to energy management in any company. Energy management requires information related to the energy consumption and production through the time in order to calculate energy performance indicators that evidence the actual energetic and productive state of industrial processes (Campos et al., 2007; Campos and Lora, 2009; Campos and Prias, 2013).
Energy efficiency is one of the most promising tools in the race to reduce the energy consumption, thus the energy costs (Schulze et al., 2016), therefore companies with high energy consumption such as paper,

Please cite this article as: Valencia-Ochoa G., Cardenas Y., Ramos E., Morales A., Campo J., 2017, Energy saving in industrial process based on the equivalent production method to calculate energy performance indicators, Chemical Engineering Transactions, 57, 709-714
DOI: 10.3303/CET1757119

petrochemical, metallurgy and so forth and so on, have achieved continuous and successful progress with respect to energy efficiency management within the last three decades (Indicators, n.d.) (ENERGY, 2007). Nowadays, energy efficiency is measured with some evaluation methods such as e-KPI method implemented in industrial processes, which presents as a way of evaluation seven steps that conduct to the calculation of performance indicators related to the energy consumption and productivity (May et al., 2015), which allows to translate the cause – effect relations, thus supporting operative decisions in the company. Other energy performance evaluation methods are implemented in non-residential buildings where the methodology gathers five relevant categories: engineering calculation, simulation, statistical methods, automatic learning and other methods, based on an exhaustive analysis so that to classify and evaluate the energy performance in non-residential buildings (Borgstein et al., 2016).
This paper aims the application or equivalent production in order to obtain energy performance indicators for a petrochemical plant located in Colombia, with the purpose to reduce the energy consumption following stages of strategic decisions and energetic characterization, which represent fundamental for the proper implementation of and Energy Management System. This work presents results of an energy diagnosis through the evaluation of energy indicators based on historical information of energy consumption and productivity, thus identifying opportunities of organizational, energetic and technological upgrades for the company so that to address the managing department of the company in the creation of an organizational structure and adoption of undertaken commitments to conduct to the effective implementation of an Energy Management System.

2. Methodology

This work shows a description of the power generation system of the plant and each stage of the fertilizer production chain, furthermore, it is described the scope of an energy management system developed in the industrial complex so that to identify the energy saving potentials. Finally, the equivalent production method is presented through the use of fundamentals of mathematics, applied to the energetic and productive characterization of the fertilizer plant, the main source of energy is natural gas, which is directly related to the production of fertilizers. The equivalent production method allowed to estimate the energy performance indicators of the plant, in addition to identify energy and economic saving potentials, in order to look for saving potentials project without technological changes.

2.1 Industrial Process and Power Generation System

The agronomic complex produces a wide variety of fertilizers with different components and different blending processes using as raw material: phosphate rock, ammonia, nitric acid, potassium sulphate or potassium chloride, ammonia phosphate, and ammonia sulphate as a product. The fertilizer production complex is divided in humid and dry zone. The humid zone is integrated by the stages of dissolution, where phosphate rock enters in reaction with the nitric acid, thus obtaining a solution rich in phosphoric acid and calcium nitrate, followed by a deposition stage, where the product reacts with an ammonia sulphate solution, ammonia nitrate and ammonia phosphate formation and a deposition of calcium sulphate, afterwards, during the filtration, the calcium sulphate solution is separated in order to stabilize the pH and nitrogen/phosphor ratio, subsequently the product goes through a boiling process until obtaining concentrated salts with 5 – 10% of humidity.
In the other hand, the dry zone is integrated by granulation stage where the salts make contact with a solid phase composed by phosphate salts and potassium, so that to obtain fertilizer grains, subsequently the product is dried with hot air until the moisture is reduced to 1.0%, afterward it goes through a sifting process which allows to get three different streams of the same product: a thick grain stream, a fine grain stream and the stream with the proper size of grain, it means the size of grain required by the customer. After that, the stream of thick grain goes through a breaking process so that to reduce its size and together with the fine grain stream is recycle for the granulation stage. Finally, the final stream is sent to the cooling stage until obtain a fertilizer with the proper handling temperature.
The required power of the complex to carry out the previously described processes is generated by two gas turbines with a net capacity of 6.9 MW, the power generation process starts with the air compression from atmospheric pressure to 186 psig and temperature of 385 ºC followed by the blending with natural gas and start the combustion in the combustion chamber of the turbine, the heat gases flow are expanded in the turbine which rotates at 14000 rpm, this rotational energy is transferred through central shaft to a speed reductor until 1800 rpm and finally transmitted to a power generator of 6600 V at a frequency of 60 Hz. At the exit of the gas turbines, the heat waste products have a temperature of 550 – 560 ºC which are seized in the boiling recovery attached to the gas turbines, these devices generate saturated vapor at 18kg/cm^2 which is transported to the fertilizers plant and other facilities of the complex. The exhaust gases are sent to the environment at a temperature of 237ºC.

2.2 Energy Management Systems

The model for an energy management system is integrated by three fundamental stages that allows to improve the energy consumption of the company and reduce energy consumption without the levels of production. The first stage is the strategic decision where is necessary a high level commitment of the senior management of the company in order to assign the resources available for the Energy Management System, the starting point is the energetic characterization of the plant, followed by a socialization of the results with the senior management, subsequently the whole structure of the company is aligned toward the rational use of energy, and finally the structure is upgraded and validated according to the current processes.
The second stage is the calculation and set up of energy performance indicators and the identification of significant controlled variables within the main areas of the company, afterward to identify corrective plan, control of events, operative procedures, in addition to inner projects with energy saving potentials. A monitoring system is established in the system, accompanied of an energy diagnosis, improvement opportunities identification, and so forth and so on.
Finally, in the operative stage, it is necessary to constantly track and socialize energy performance indicators, moreover the evaluation of proper manufacturing practices, maintenance, production, and coordination obtained through the implementation of projects encouraged to the energy efficiency management.

2.3 Equivalent Production Method

This method is based on the calculation of an energy base line with the linear form as in Eq(1).

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

Obtained from the linear regression of historical data of energy consumption and production. As a case study for a petrochemical company located in Colombia dedicated to the production and commercialization of fertilizers in which is highlighted the series NPK 15-15-15. This linear regression identifies two variables that represent the energetic behavior of the company in one hand there is the energy intensity represented with the letter “m” and is given by the slope the linear regression, this variable indicates the energy consumption directly related to the level of production, on the other hand it is found the variable “Eo” which represents the energy consumption non related to the production, therefore it is presented a model to identify the variables which directly affects the energy consumption (Velázquez et al., 2013). In order to calculate an equivalent production, it is necessary to determine a value for the energy consumption as the sum of every level of production times its corresponding energy intensity for every different product, as in Eq(2).

$$CE = \beta_0 + \beta_1 P_1 + \beta_2 P_2 + \cdots + \beta_j P_j \tag{2}$$

The variable “Pj” represents the amount of units produced for every different product considering the model of production, the coefficients “βj” correspond to the energy intensity for every kind of product, and “βo” defines the energy consumption non related to the production. Therefore, the energy intensity is calculated as in Eq.(3).

$$\beta_j = \frac{Energy\ Consumption}{Unid\ of\ Product\ j} \tag{3}$$

Once calculated the coefficients for energy intensity, the intensive products related to the energy consumption are identified, as equal as the production levels, thus indicating the process with higher rates of energy consumption as shown in Eq(4).

$$\alpha_i = \frac{\beta_i}{\beta_{Base}} = \frac{Unids\ of\ products\ j}{Unid\ of\ base\ product} \tag{4}$$

The energy relationship of the products αj, corresponds to the number of units of product base that can be elaborated with the energy used to produce a unit of product (j). With this information, a production according to energy equivalencies αj is set, besides the levels of production for product j as shown in Eq(5).

$$P_{eq} = P_{Base} + \alpha_1 P_1 + \alpha_2 P_2 + \cdots + \alpha_j P_j \tag{5}$$

3. Results

The analysis tools used for the energy characterization of the plant were the production and energy consumption analysis through the time. In addition, some energy performance indicators such as the base line and goal line and actual index of consumption compared with the theoretical index of consumption in order to identify energy saving potentials by good practices of production and good planning of the production

respectively. Within the energy performance indicators, it is included a control indicator known as the base 100 index of efficiency. Prior to the analysis of indicators of performance is makes necessary the application of limits of control for data of consumption of gas and production so that to exclude data considered atypical for the set of data of shows in the characterization.
According to the data supplied by the team of energy managers, and after applying the first filter in the charts of boundary control, shown in Figure 2, it is obtained three different base lines, as shown in Figure 1, for each fertilizer, with a correlation coefficient of 0,49618, 0,82515 and 0,64084 for the references 15-15- 15, 13-26-6, and 17-6-18-2 respectively.

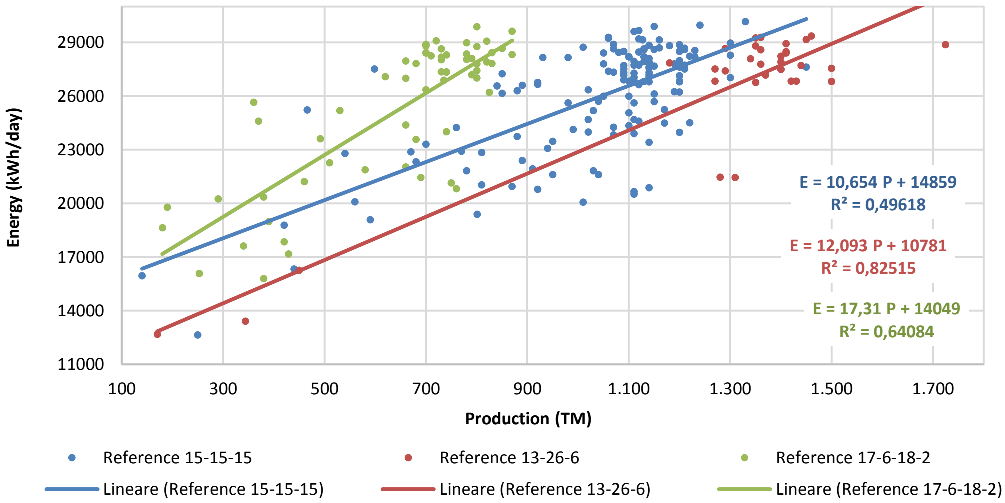

Figure 1. Base lines for energy consumption for three different produced fertilizers.

The Figure 2 shows the graphics of boundary control, which set an upper limit and a lower limit separated with three times the standard deviation of the average Value, where is observes that four (4) data of production are below the limit lower of production, while a (1) data is above the limit of consumption top which means that these data considered as outliers will not be considered for the productive plant energy analysis, while for energy consumption, there are five (5) data that are considered outliers.

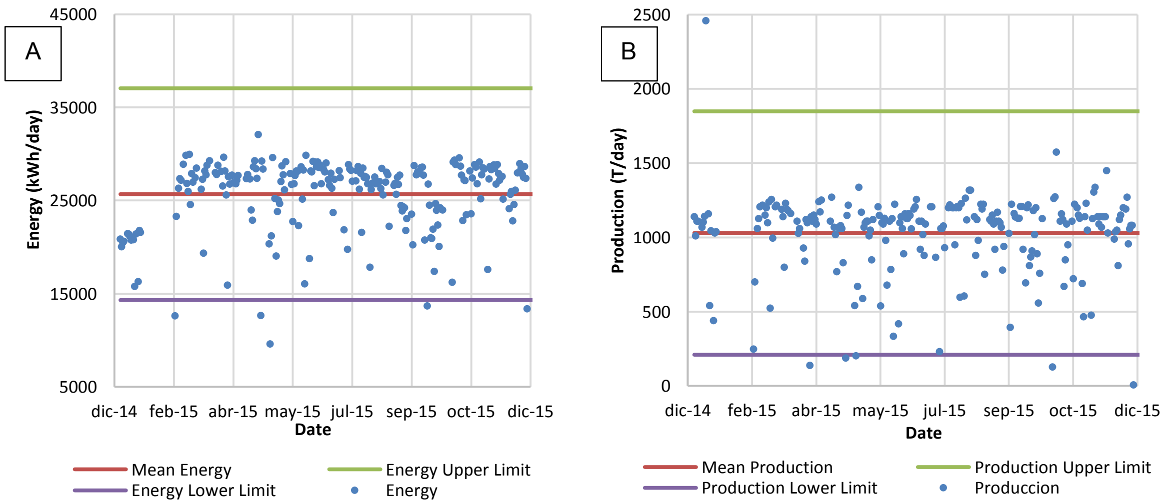

Figure 2. Boundary control charts a) Energy Consumption, b) Equivalent production of fertilizers.

The index of efficiency base 100 relates the actual and theoretical consumption, this indicator generates alerts about positive or negative variations in the energy efficiency of the process, thus facilitating the analysis and proposed plans of action on the basis of energy improvements, allowing the analytical interaction between production and energy consumption, pointing to a better energy performance of the fertilizer plant processes. As is seen in the Figure 5a, to express two intervals of results B100 < 100% and B100 ≥ 100%. For the case when the index is greater than 100% translates into a good energy performance, since the real power consumption was less than the theoretical power consumption, therefore in Figure 5a points above the limit of 100% are considered good energy performance data located in the area of energy efficiency of the plant. On the other hand, when the index of efficiency is lower to 100%, is indicates that the data belong to a zone of inefficiency energy of the plant. However, for the analysis of the fertilizer plant, in the area of efficiency energy, several peaks of high efficiency with a random behavior are evidences, by what it indicates that these peaks located in the area of efficiency energy not are result of improvements in the energy management system of the company.

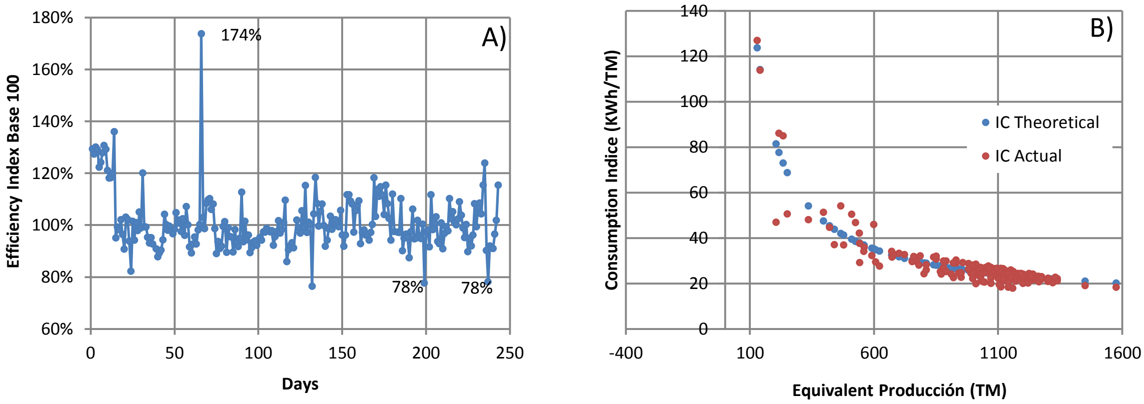

Figure 3. Energy Performance Indicators for the fertilizer plant. a) Index of base 100 efficiency, b) Index of energy consumption.

Comparison of actual and theoretical consumption index is observed in Figure 5b, where data in blue represent the rate of theoretical consumption, while the red points represents the actual consumption. It evidenced that the rate of actual consumption varies in 120 and 20 kWh/Mt of fertilizer, indicating that the company has production levels above the critical equivalent production directly related to the technology of the plant, which is calculated as 1020 TM according to the theoretical consumption index, clearly the company has much higher production levels, that indicate a better performance energy given the low rates of consumption. Starting from this, it reflects that the company has a very good planning with regard to their daily production represented in the historical data supplied for 2015.

4. Conclusions

Taking into account the successful results of energy diagnosis in the plant, it was considered the implementation of an energy management system according to the ISO standard 50.001 in the petrochemical company in Colombia attacking to significant uses of energy in the plant, it is necessary to provide continuity to the stage of implementation of the system, in which occurs the monitoring and control of energy indicators, the accompaniment in the verification of the functioning of the operational control system and the implementation of technological improvements of void, or low investment.

In order to guarantee the improvement of the use of energy and the sustainability of the reduction of energy for the company with low investment measures, it is necessary to develop a Software for tracking, measurement, and analysis of the energy performance for each significant use of energy installed and set in operation, so that to calculate the equivalent production of the different types of produced fertilizers in the plant.

Finally, it is necessary a third stage of monitoring and adjustment in which is performed a measurement of results, to identify the technological improvements of medium and high investment, to evaluate the energy savings potentials obtained with the implementation of the system, to document the energy management system, and to incorporates to the management system of the company, furthermore to perform the exercise of audit external for purposes of ISO 50001 standard certification.

References

Abdelaziz, E.A., Saidur, R., Mekhilef, S., 2011. A review on energy saving strategies in industrial sector. Renewable and Sustainable Energy Reviews 15, 150–168. doi:10.1016/j.rser.2010.09.003

Borgstein, E.H., Lamberts, R., Hensen, J.L.M., 2016. Evaluating energy performance in non-domestic buildings : A review. Energy & Buildings 128, 734–755. doi:10.1016/j.enbuild.2016.07.018

Campos, J.C., Lora, E.D., 2009. Manual de mantenimiento centrado en la eficiencia energética para sistemas industriales. Universidad del Atlantico, Barranquilla.

Campos, J.C., Meriño, L., Tovar, I.R., Prias, O., Quispe, E.C., Vidal, J.R., Ulianov, Y., Castrillon, R., Lora, E.D., 2007. Sistema de Gestion Integral de la Energia. Universidad del Atlantico, Barranquilla.

Campos, J.C., Prias, O., 2013. Implementación de un Sistema de Gestión de la Energía; Guía con base en la norma ISO 50001. Universidad Nacional de Colombia, Bogota, Colombia.

Indicators, E., n.d. Tracking Industrial Energy Efficiency and CO 2 Emissions ENERGY.

May, G., Barletta, I., Stahl, B., Taisch, M., 2015. Energy management in production : A novel method to develop key performance indicators for improving energy efficiency 149, 46–61. doi:10.1016/j.apenergy.2015.03.065

May, G., Stahl, B., Taisch, M., 2016. Energy management in manufacturing: Toward eco-factories of the future - A focus group study. Applied Energy 164, 628–638. doi:10.1016/j.apenergy.2015.11.044

Schulze, M., Nehler, H., Ottosson, M., Thollander, P., 2016. Energy management in industry e a systematic review of previous fi ndings and an integrative conceptual framework. Journal of Cleaner Production 112, 3692–3708. doi:10.1016/j.jclepro.2015.06.060

Sucic, B., Al-Mansour, F., Pusnik, M., Vuk, T., 2015. Context sensitive production planning and energy management approach in energy intensive industries. Energy 108, 1–11. doi:10.1016/j.energy.2015.10.129

Velázquez, D., González-Falcón, R., Pérez-Lombard, L., Marina Gallego, L., Monedero, I., Biscarri, F., 2013. Development of an energy management system for a naphtha reforming plant: A data mining approach. Energy Conversion and Management 67, 217–225. doi:10.1016/j.enconman.2012.11.016