APPLICATION OF GOOD PRACTICES IN INDUSTRIAL PROCESSES WITH A FOCUS ON ENERGY EFFICIENCY.

Fabiana N. de Andrade[a] , Luan C. F. Gonzaga[a], Rafaela R. Rodrigues[a] ,Yan V. S. Rodrigues[a], Tatyana B. T. Sampaio[a], Daniel A. de Lira[a], Fernanda M. T. Paiva, Turan D. Oliveira[a].

[a], SENAI CIMATEC, Brazil.

Abstract: Brazilian industries consume around 35% of the electricity produced in the country. As such, there is a growing need to optimize energy consumption to reduce operating costs. Actions aimed at energy efficiency generate results with fewer natural resources and the same energy, so there is increasing investment and study in this area. The aim of this article is to look at good practices related to energy efficiency that can be applied to various segments of the industrial production sector. The cases presented here used engineering tools such as AspenPlus© to optimize combustion, the ValorAR program to estimate savings in a compressed air system and the Water Source Diagram (WFD) to evaluate water reuse.

Keywords: Energy Efficiency; Combustion Optimization; Compressed air; WSD.

APLICAÇÃO DE BOAS PRÁTICAS EM INDUSTRIAIS COM FOCO EM EFICIÊNCIA ENERGÉTICA.

Resumo: As indústrias brasileiras consomem cerca de 35% da energia elétrica produzida no país. Sendo assim, há uma necessidade crescente de otimizar o consumo de energia a fim de reduzir custos operacionais. Ações voltadas para eficiência energética geram resultados com menos recursos naturais e a mesma energia, assim, cada vez mais o investimento e estudos nesta área. Esse artigo tem o objetivo de abordar boas práticas relacionadas à eficiência energética que podem ser aplicadas a diversos segmentos do setor produtivo industrial. Os casos aqui apresentados, utilizou ferramentas de engenharia como AspenPlus© para otimização da combustão, o programa ValorAR para estimar economia em sistema de ar comprimido e o Diagrama de Fonte de Águas (DFA) para avaliação de reuso de água.

Palavras-chave: Eficiência Energética; Otimização da combustão; Ar comprimido; DFA.

1. INTRODUCTION

Brazilian industries consume more than 35% of the electrical energy produced in the country, and more than half of this energy is used only by motor systems and not by processes themselves. This is only the energy that can be accounted for by the usual methods [1].

Every day, a diverse range of industrial processes consume energy and resources that can generate opportunities when seeking efficiency in their processes. Many of these consumptions can lead to unnecessary expenditure on inefficient utilities, lost market opportunities in waste or effluent treatment, and even energy due to lost and unrecovered heat.

For the International Energy Agency (IEA, 2007), the concept of energy efficiency is focused on obtaining energy services such as generation, transportation, and heat, per unit of energy used, such as natural gas, coal, or electricity. In essence, energy efficiency is an activity that seeks to improve the use of energy sources, it means generating the same amount of energy with fewer natural resources or obtaining the same service with less energy. The importance of energy efficiency becomes clear when one considers that industry today is responsible for 26% of global CO_2 emissions and that energy efficiency has the technical potential to reduce industrial energy use by about 20% [2-3].

In this sense, the market demand for energy efficiency has made companies organize themselves to develop improvements in their production processes. Benefits are generated through the conscious use of energy, such as cost reduction, increased efficiency of production processes, reduction of greenhouse gas emissions, and waste generation. In this context, the energy used in industrial processes can be used more efficiently. This article aims to exemplify applications of tools, techniques, and technologies that make it possible to optimize production processes involving energy efficiency [1].

2. METHODOLOGY

Several tools can be used to optimize industrial processes for energy efficiency, such as process simulators, CFD (Computational fluid dynamics) tools, Python programs, Excel spreadsheets, and various techniques such as the Water Source Diagram (WFD) and the Pinch method for heat recovery. This article presents examples of energy efficiency that can be applied in multiple industrial segments. The following tools were used to conduct these analyses: AspenPlus©, the ValorAR program, and the Water Source Diagram (WFD).

The AspenPlus© software was used to develop two examples related to combustion and heat recovery. We used the models available in the software, the ESTOIC reactor, and HEAT, to represent the effects of the air/gas ratio in complete and incomplete reactions, as well as fuel savings through preheating using a heat exchanger.

ValorAr is a program that estimates savings in compressed air systems. This program was developed using VBA in Microsoft Excel© and is an adaptation of PROCEL's E3AC open-source software. A simulation was carried out to estimate the annual savings from implementing optimizations in the compressed air system, such as reducing the air intake temperature, reducing the system pressure, and reducing leaks.

The DFA was used as an evolutionary heuristic approach for synthesizing networks of water-using equipment. This technique was optimized based on previous references [4] and aims to optimize mass transfer in concentration intervals, minimizing the consumption of cleaner external water and reducing the effluent generated [5].

3. RESULTS AND DISCUSSION

Implementing new equipment and developing processes requires industries to plan and experiment, making them use bench prototypes to pilot plants. However, these study forms have a high cost without necessarily a return guarantee. An alternative is process simulation, which can help reduce costs and obtain answers without the need for major investments, as it works using engineering calculations to represent reality, generating solutions, and aiding decision-making.

Process simulation uses various software such as AspenPlus©, Prosim©, SuperProDesigner©, DWSIM©, EMSO©, and COCOSimulator©. These simulators can be used in different applications, for example in modeling combustion reactions. Still, in these situations, there are other options, such as using a programming language to simulate and solve problems. For example, Python can be used for the phenomenological modeling of heat diffusion.

There are also other actions aimed at improving industrial processes such as using SPC (Statistical Process Control), and technologies based on process intensification. Other possibilities are the modeling of problems via CFD (Computational Fluid Dynamics) or FEA (Finite Element Analysis) [6,7].

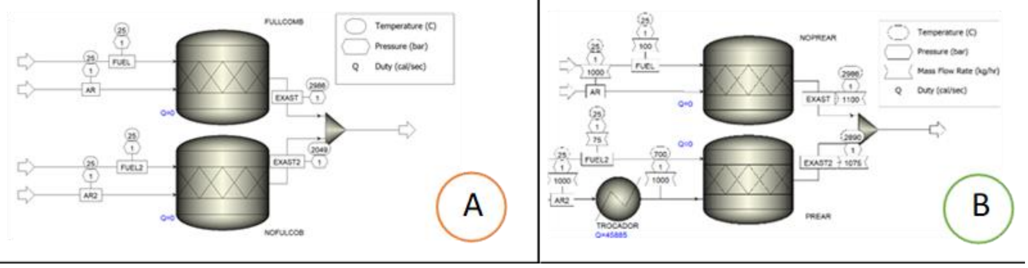
AspenPlus© has modules capable of simulating complete (pure O_2) and incomplete (atmospheric air) combustion, optimizing the process, and generating scenarios that can reduce fuel consumption and optimize heat generation. By approaching complete combustion, it is possible to reduce fuel consumption and increase heat generation in the reaction. However, the use of pure O_2 makes its use in industrial processes unfeasible, which makes atmospheric air indispensable as a source of O_2, but due to the presence of N_2 in atmospheric air, pollutants such as NO_x are generated.

The simulation of incomplete combustion considers stoichiometric ratios of air and fuel in furnaces, boilers, and burners. The relevance of adjusting the stoichiometric ratio of air and fuel to find the optimum point of combustion contributes to better efficiency and energy utilization in the simulated process and fewer pollutants emitted to the atmosphere. In Figure 1A, it is possible to evaluate this association in natural gas combustion equations and the enthalpies and temperatures obtained via AspenPlus© simulation [8].

Another widely used application is the recovery of heat from hot streams to preheat cold streams. An instance of this is when a stream of combustion air is heated beforehand using an outlet stream emanating from a furnace or reactor. In Figure 1B, via simulation, a heat exchanger is used to preheat the combustion air and reduce fuel consumption by 25%, it is also observed how close temperatures can be reached without preheating.

Figure 1 - Cases of Air/Gas ratio (A) and Air preheating (B).

Combustion Reactions		Total ΔH (kJ/mol)	Temperature (°C)	Case	Fuel flow (Kg/h)	Temperature (°C)
Complete	$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$	11,58	2986	No Preheating	100	2986
	$C_2H_6 + 7/2\,O_2 \rightarrow 2\,CO_2 + 3\,H_2O$					
	$C_3H_8 + 5O_2 \rightarrow 3CO_2 + 4H_2O$					
Incomplete	$CH_4 + 1{,}5O_2 \rightarrow CO + 2H_2O$	10,73	2049	With Preheating	75	2890
	$2C_2H_6 + 5O_2 \rightarrow 4CO + 6H_2O$					
	$C_3H_8 + 3{,}5O_2 \rightarrow 3CO + 4H_2O$					



Graphical energy integrations, using the Pinch technique or by algorithms such as the "Total Site" approach, are methodologies employed in heat recovery in industrial processes. These methods allow studies to be carried out on the heat recovery of multiple streams in a network of equipment, to obtain an optimal heat exchange network with the implementation of heat exchangers at multiple points, making it possible to achieve cost reductions with little investment in the plant infrastructure [9,10].

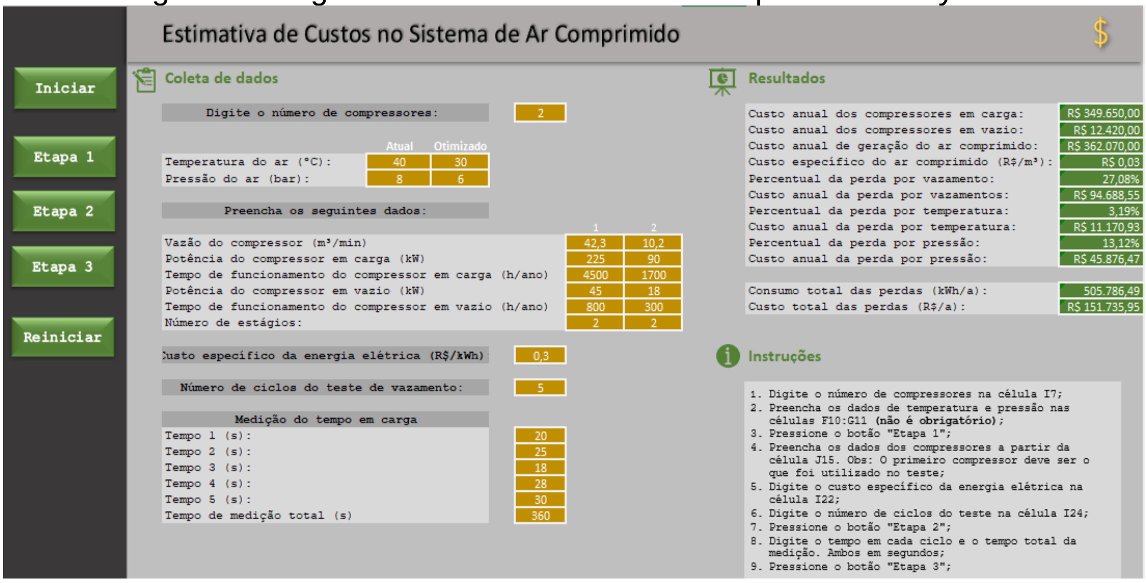
One crucial aspect of the industry involves supporting industrial production such as electricity, steam (at various pressure levels), hot/cold or industrial water, or compressed air. These utilities have a fundamental role in the production line of processes, for example, compressed air has a wide application in industrial installations, and can be applied in pneumatic tools, drives, equipment controls, and material transportation, among others [11,12,13]. The study on compressed air is segregated into three parts, namely: (1) Generation, which refers to the capture, treatment, and storage of compressed air; (2) Distribution, which represents the transportation of air to the points of consumption and (3) Consumption, which are the end uses of compressed air. The compressed air generation stage is regarded as a process with a high associated cost for companies.

Even though there are no raw material costs (since it is captured from the atmosphere), the air compression process involves electric motors and dryers. The electricity consumed to generate compressed air varies between 10 and 30 %. Optimizing compressed air systems is necessary to lower costs [13,14]

By examining the mass and energy balance of a compressed air system, it is possible to identify any losses that decrease its efficiency. This can lead to opportunities for improving energy efficiency in the process. Some optimizations can be adopted to reduce the cost of the compressed air system, such as: capturing air with the lowest possible temperature, installing a secondary network with lower pressure when economically feasible, and eliminating leaks as soon as they are detected [13].

As an example, to estimate the losses in the compressed air system and the annual savings from implementing the optimizations described in the process, a simulation was carried out in the ValorAR program (Figure 2). The machine's room temperature was set at 40ºC, reduced to 30ºC; compressed air pressure from 8 to 6 bar, operating with two compressors and carrying out a test procedure with 5 cycles and a total duration of 6 min to detect leaks. The "Results" section of Figure 2 shows the estimated costs for each optimization. This shows a loss of 3%, 13%, and 27% for temperature, pressure, and leakage, respectively, generating a total annual cost of losses of R$192 thousand.

Figure 2: Program for cost estimation in compressed air system



Finally, in industrial plants, solid and liquid waste is generated at the end of the process or some intermediate stage, or even during effluent treatment. Solid waste can serve as a source of heat generation or as raw material in other sectors, depending on its composition. To become more environmentally conscious, one can implement sustainable waste treatment solutions for both liquid and solid waste. These can be reused within the production process or sold for commercial use.

Usually, liquid waste is treated and sent to a receiving body if it follows the legislation in force for this purpose. A commonly used alternative for liquid waste is water reuse, which can be broken down into three modes: reuse of effluent in another operation without prior treatment; regeneration with reuse, treatment for partial removal of contaminants and regeneration with recycling, partial removal of contaminants to be reused in the same process or operation that generated it.

An "evolutionary heuristic procedure for the synthesis of water-using equipment networks" was optimized by [15]. Called the Water Source Diagram (WSD), it aims to meet the mass transfer in the concentration intervals, using the lowest flow rate of the cleanest external water source, reducing the flow rate of consumption and the effluent generated [16].

To minimize liquid effluents containing one or more contaminants, even if there are limitations in the process, such as systems with flow restriction; systems with multiple water sources; systems with losses related to the process. In addition, there are the options of regeneration with reuse and/or with recycling and maximum reuse. Considering that liquid effluents in industrial processes with only one contaminant are less usual, a greater focus on a method for multiple contaminants is necessary [15].

In the application of the DFA, it is necessary to identify the operations that use water and to inform the limit flows for the streams (f_k), as well as the maximum concentrations at the inlet and outlet ($C_{ik,max}$ and $C_{fk,max}$), as well as the contaminant loads (Δm_k). Table 1 shows the values for an example application of the method.

Table 1: Flow rate, concentration, and contaminant load values of a process

Operation (k)	f_k (t/h)	$C_{ik,max}$ (ppm)	$C_{fk,max}$ (ppm)	Δm_k (kg/h)
1	20	0	100	2
2	100	50	100	5
3	40	50	800	30
4	10	400	800	4

Applying the DFA method, it is possible to draw a representative diagram of water consumption and effluent regeneration according to Figure 3. From the figure, it is possible to see the results obtained through the procedure, where the used flow rate of primary water (0ppm) was reduced to 51 t/h when compared to the value of 130.5 t/h, from the source. And the flow rate of regenerated water is equal to 62.7 t/h [15].

To ease the application of the method, a computer program (MINEA) was developed, on the Microsoft Excel® platform, as shown in Figure 4. However, the program does not generate the contaminant balance directly in the flowsheet [4,5,15,16].

Through the proposed procedure of the source diagram method, it is possible to apply it in several other fields such as energy generation and storage, hydrogen network flowchart synthesis, and reduction of carbon emission in electrical systems [17]. It is worth mentioning the work presented by [18], defined as Hybrid System Sources Diagram (HSSD), where it is possible to use the grid energy to provide load when renewable sources.

Figure 3: Diagram representation considering regeneration and reuse.

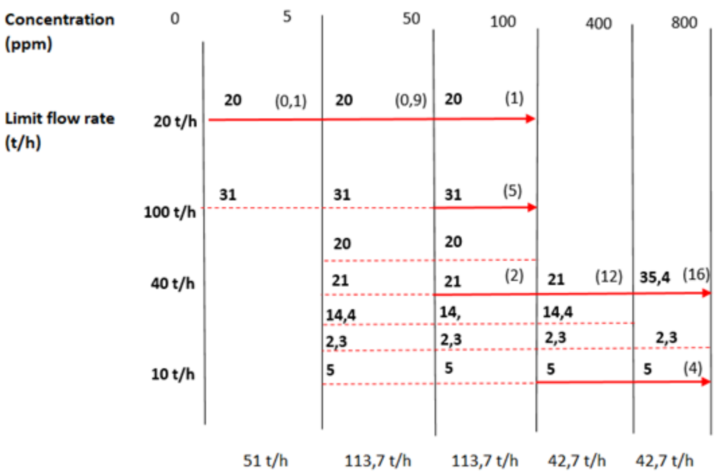
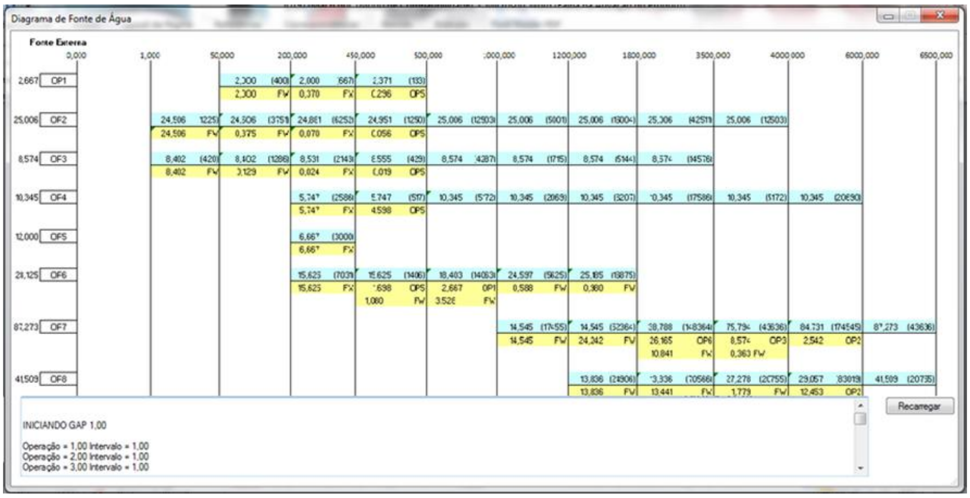


Figure 4: Example of diagram generation using MINEA.



4. CONCLUSION

In this article, it was possible to verify the importance of energy efficiency in several examples of good practices applicable to industrial plants. Thus, it is clear that, due to the need for better use of natural resources and conscious use of energy, energy efficiency is characterized as one of the tools that can be applied to reduce costs, increase productivity and generate competitiveness in national industries, aiming at sustainable and productive development.

Acknowledgments

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5. REFERENCES

[1]. COSTA, A. L. et al. Resultados PROCEL 2020. [s.l.] Eletrobras, 2019.

[2]. ACORONI, J. C. et al. EFICIÊNCIA ENERGÉTICA: Melhores Práticas em economia de energia em um setor industrial. 2013.

[3]. INNOVATION, D. F. S., TECHNOLOGY AND; STEEL COMMITTEE. AN INTRODUCTION TO ENERGY MANAGEMENT SYSTEMS: ENERGY SAVINGS AND INCREASED INDUSTRIAL PRODUCTIVITY FOR THE IRON AND STEEL SECTOR. [s.l.] Organisation for Economic Co-operation and Development, 17 fev. 2015. Disponível em: <https://www.oecd.org/sti/ind/DSTI-SU-SC(2014)14-FINAL-ENG.pdf>.

[4]. GOMES, Juliana Freitas Santos. Procedimento para Minimização de Efluentes Aquosos. 2002. Tese (Mestre em Ciências) - Universidade Federal do Rio de Janeiro, 2002.

[5]. MIRRE, Reinaldo Coelho; YOKOYAMA, Lídia; PESSOA, Fernando Luiz Pellegrini; CALIXTO, Ewerton Emmanuel da Silva. REÚSO DE ÁGUA EM PROCESSOS QUÍMICOS: MODELO INTEGRADO PARA GERENCIAMENTO SUSTENTÁVEL. 2. ed. Curitiba: Appris, 2021. 293 p.

[6]. HESSEL, V. Process intensification–engineering for efficiency, sustainability and flexibility. Green Processing and Synthesis, v. 1, n. 1, 1 jan. 2012.

[7]. LOUZADA. Controle Estatístico de Processos-Uma Abordagem Prática para Cursos de Engenharia e Administração. 1. ed. [s.l.] LTC, 2013.

[8]. THERMAL ENERGY EFFICIENCY IMPROVEMENT HANDBOOK . 1. ed. [s.l.] Department of Industrial Promotion, Ministry of Industry of Thailand And The Energy Conservation Center of Japan, 2007.

[9]. LEE, P. Y. et al. Total Site Heat and Power Integration for Locally Integrated Energy Sectors. Energy, v. 204, p. 117959, ago. 2020.

[10]. INCROPERA, F.P.; DEWITT, D.P. Fundamentos de Transferência de. Calor e de Massa,8a edição, LTC - Livros Técnicos e Científicos Editora. S. A., R. J. 2008.

[11]. BORGES, Giovanni Caixeta et al. Implementação do sistema de trabalho integrado no setor de utilidades industriais. 2018.

[12]. AGHA, M. H. et al. Integrated production and utility system approach for optimizing industrial unit operations. Energy, v. 35, n. 2, p. 611–627, fev. 2010.

[13]. HAHN, A. Compressores Guia Avançado: Eficiência Energética Industrial. Rio de Janeiro: PROCEL INDÚSTRIA, dez 2004.

[14]. Energy Tips – Compressed Air.: Energy Efficiency and Renewable Energy. [s.l.] U.S Department of Energy,[s.d.]. Disponível em: <https://www.nrel.gov/docs/fy01osti/28006.pdf>.

[15]. GOMES, Juliana F.S.; QUEIROZ, Eduardo M.; PESSOA, Fernando L.P. Design procedure for water/wastewater minimization: single contaminant. Journal of Cleaner Production, p. 474-485, 10 jul. 2023.

[16]. MIRRE, Reinaldo Coelho; FRANCISCO, Flávio; CALIXTO, Ewerton Emmanuel da Silva; PESSOA, Fernando Luiz Pellegrini; QUEIROZ, Eduardo. MINEA, Software para a Minimização do Consumo de Água em Processos Químicos com Base no Diagrama de Fontes de Água (DFA). CAIP, Lima, p. 1-10, 24 out. 2013.

[17]. QUARESMA, Ana Carolina de Lira et al. Source diagram: A new approach for hybrid power systems design. Elsevier, n. 47, p. 1-19, 2021.

[18]. QUARESMA, Ana Carolina de Lira et al. Hybrid System Sources Diagram for Designing Off-grid Distributed Energy Systems. Process Integration and Optimization for Sustainability, p. 1-12, 22 jun. 2023.