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Energy Consumption and Efficiency in Industrial Processes

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Abstract: *The paper presents an overview of the energy intensive industries, analyzes some of the most frequently used energy efficiency indicators and considers opportunities to increase energy efficiency of industrial processes by means of automated process control and energy management systems.*

Keywords: *Energy intensive industries, energy efficiency indicators, automation, process control.*

1. Introduction

Energy is one of the main resources of production in industrial manufacturing processes and accordingly, it is an important factor for economic growth. Industrial sectors of developed and high-income countries are employing energy efficient technologies and alternative renewable resources, but nevertheless, the demand for energy is increasing due to the increased volume of production. The energy consumption by the industries of developing countries and economies in transition is generally characterized by a less efficient energy use [13].

It is evident that energy resources are limited and, on the other hand, it is also well recognized that the increased energy consumption is one of the reasons for environmental problems such as carbon emissions, ecology pollutions and climate change [4, 8]. This is the reason why the energy efficiency in industry is a subject of intensive studies and, at present, it is considered to be the main tool for reducing the energy consumption of the production processes and to overcome the environmental problems. From an economical point of view, increasing energy

efficiency clearly reduces the cost of production and increases the competitiveness of companies.

There are various energy efficiency indicators which may depend on the particular production process and the type of the energy used. One of the most widely used indicators in industry is the specific energy consumption of a given process. It is simply the ratio between the energy used and the number or volume of the products produced. In order to measure the energy efficiency of national economies, ratios between the energy and the gross domestic product are most frequently used. In literature there also exist different levels of energy efficiency analysis including models from a micro to a macro level [9, 10]. The union of all levels of analysis leads to a pyramidal organization of energy efficiency indicators including both the most detailed and the most aggregate indicators.

In this paper we offer an overview of the energy intensive industries, analyze some of the most frequently used energy efficiency indicators and consider opportunities to increase energy efficiency of industrial processes by means of automated process control and energy management systems.

2. Energy-intensive industries

According to the US Department of Energy [1], the large energy consumers are distributed in the main sectors of economy which include industrial, commercial, transportation and residential sectors. The energy consumption by sectors in US for 2010 is shown in Fig.1 together with the basic energy sources for each sector [5]. The energy consumption by economic sectors of the 27 countries in the European Union (EU) through the period 1990-2006 is shown in Fig. 2 [2].

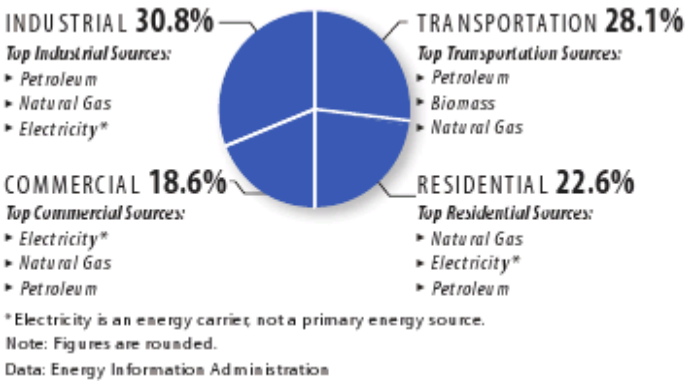

Fig. 1. US Energy consumption by sectors, 2010

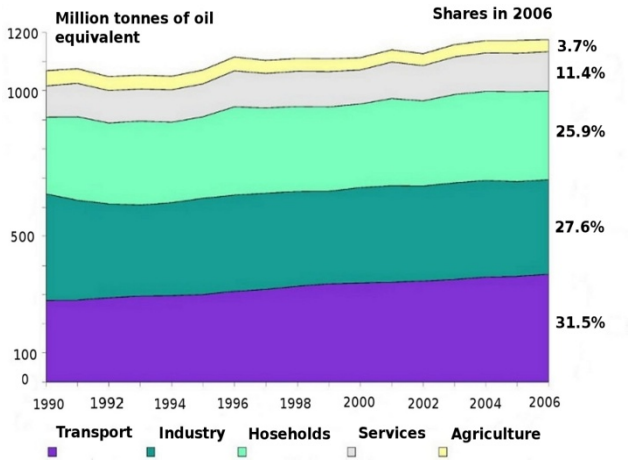

Fig. 2. Energy consumption by sectors in EU-27

From Fig. 1 it is seen that the highly automated industry of US consumes more than 30 % from the total nation's energy. Fig. 2 shows that the industrial sector of EU uses slightly less energy (27.6 %) and this value remains almost constant during the period 1990-2006. China's industrial energy consumption is about half of the country's total energy consumption and the percent of energy used for industrial purposes in developing countries is even more.

Within the industrial sector of each economy there are several energy intensive industries which consume most of the industrial energy. Typically these are iron and steel industry, petroleum industry, cement industry, chemical industry and paper industry. The common characteristics of all these industries are as follows:

- the energy intensive industries make a significant contribution to the economy in terms of the national Gross Domestic Product (GDP);
- these industries are of crucial importance to meeting the national and international emissions regulations and targets;
- from a technological point of view, the energy intensive industries provide a basis for innovation, development and application of new perspective technologies;
- these industries make significant investments in the research and development activities, the employment and training of highly qualified staff which is vital to increasing the national competitiveness.

Some specific characteristics of the energy intensive industries are as follows.

2.1. Iron and steel industry

Steel is produced from iron ore and scrap material (recycled steel). The cost of energy in steel manufacturing amounts to 15 % of the total cost of producing the steel. The sources of this energy are coal and natural gas or electricity generated from them. The most significant energy consumer in the steel making process is the production of steel from iron ore. The use of recycled steel consumes 75 % less energy as compared to the production of steel from ore. The amount of recycled

steel in 2006 is reported to be equal to about 37 % of the crude steel produced in this year and in 2004 the same number is 42.7 % [14]. The recycled steel is utilized by melting it in an electric arc furnace process or it can also be used in converters of the basic oxygen furnace process [7, 14].

Another high energy consuming process in this sector is aluminum production. Aluminum is obtained from bauxite or aluminum ore and the process consumes large amounts of electrical energy. As in the case of steel manufacturing, the usage of recycled aluminum in the production process allows significant reduction of energy consumption. According to [5], in 2010 about one-third of the supply for aluminum production came from recycled materials.

2.2. Petroleum industry

The petroleum refining industry produces a wide range of products by converting crude oil into gasoline, diesel fuel, heating oil, chemicals, asphalt and other products. A refinery can consist of many different units such as a distillation towers, catalytic crackers, cokers, vacuum devices, etc., and it consumes a great deal of energy. According to [12], more than 30 % of the global industrial energy is used by the chemical and petrochemical sector. Due to the significant improvement of technologies and application of automated process control systems and best practice technologies, the energy consumption in modern refineries is significantly reduced in comparison with the seventy years of the last century.

2.3. Cement industry

This sector includes cement, lime and plaster manufacturing. Cement production includes processing of raw material in crushing and grinding mills, clinker production, and cement finishing processes. Two types of energy are used. Electricity is consumed in all the three processes and a lot of thermal energy is consumed in the clinker production process as it requires extremely high temperatures, about 1200 degrees Celsius [8]. As in the other energy intensive industries, cement plants are reducing their energy consumption by using innovative energy saving programs. The main environmental concern of cement manufacturers are dust emissions. The European cement industry reports a reduction of these emissions by 90% over the last 30 years.

2.4. Chemical industry

In this sector a large number of products are manufactured and consumed by the society including products in medicine, cleaning products, fertilizers, polymer products etc. For example, the total polymer consumption in 2006 is reported as 245 Mt excluding 55 Mt consumption of non-plastics, i.e. polymers used as coatings, adhesives and other applications [12]. In general, the chemical industry uses energy to power the production processes and also it uses petroleum, propane, and natural gas as raw materials for the production of chemicals. According to [5] the application of new technologies has increased energy efficiency in the chemical industry by more than 50 percent in the last 35 years. Another opportunity which is

not fully employed in this sector for saving energy is the usage of recycled materials and the management of the large volume of plastic waste.

2.5. Paper industry

In paper manufacturing energy is used to grind the wood into pulp and then to dry and roll the pulp into paper. The use of recycled material in this industry is not very effective from an economic perspective because it is necessary to collect, sort, and process the waste paper. Recycling, however, is beneficial from an environmental point of view. The application of innovative technologies and usage of wood waste appear to be the main perspectives in this industry.

The above review suggests the following observations.

- The most energy-intensive sectors are industries, in which bulk materials are manufactured: metals from ore and scrap, pulp and paper, industrial chemicals, refined petroleum products, cement and paper. The process of grinding in rod and ball mills in mineral industry is another example of energy intensive manufacturing.
- Many industries have lowered energy use by using recycled materials. Typically, these are steel and aluminum manufacturing and paper industry. It should be noted however, that the demand for steel and aluminum is continuously increasing and the metal products usually have a long life cycle because of which the recycled metal is insufficient to meet the demand.
- The technological advancement, process automation and applications of energy management systems contain the main potential for saving energy by improving energy efficiency in energy intensive industries.

3. Energy efficiency measurement

The measurement of energy efficiency of a process is important because it is the first step in the control of the energy consumption and energy costs in this process. Intuitively, energy efficiency is defined by the simple ratio:

$$\text{Energy efficiency} = \frac{\text{Useful output of the process}}{\text{Energy input of the process}}.$$

This ratio does not give a strong quantitative definition and it is necessary to develop and use energy efficiency indicators. Essentially, these are classified in the following groups [6,10,16].

- **Thermodynamic indicators** measure the energy efficiency as the ratio between the input and output work of a given energy converting process. These indicators have a limited application as they do not account for the quality of energy and the final effect of its usage.
- **Physical-thermodynamic** indicators to some extent overcome the above problem by measuring the amount of energy necessary to perform a given task. Such measures however, may not be appropriate in all circumstances.
- **Economic-thermodynamic** indicators measure the energy efficiency as energy per dollar of profit and thus, these indicators allow to measure and compare

efficiencies of different processes. For example, the energy consumption per dollar of GDP is a measure for energy efficiency of a nation's economy.

- **Economic indicators** use only monetary units to measure the values of input energy and output product. These metrics however, are sensitive to changes in energy prices.

It should be noted that within each of the above categories there is a wide range of indicators and the choice of an appropriate metric usually depends on the particular energy converting process. For many industrial processes a widely used energy efficiency indicator is the specific energy consumption, representing the ratio of energy input to the product output measured in physical units [3].

Another analytical tool to estimate the energy efficiency is the construction of bbenchmark curves which are used to compare the efficiency of a particular plant or process with the most energy efficient units in a given industrial sector. A typical benchmark curve used in [11,13] is shown in Fig.3 where the energy use of individual plants is plotted as a function of their cumulative production. In the figure the left end of the curve indicates the most efficient plants while the right end shows the last efficient plants. The curve also indicates the plants using the Best Practice Technologies (BPT) and the Best Available Technologies (BAT). Except for the performance assessment of individual plants in a given sector, benchmark data can be used to collect and aggregate information about the energy efficiency of a nation's economy.

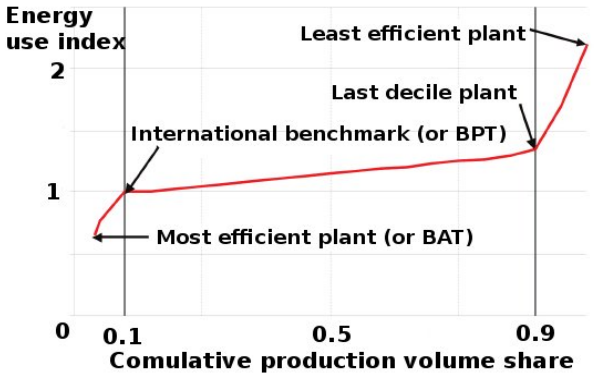

Fig. 3. Illustrative benchmark curve

4. Energy efficiency improvement

According to [11, 12] the implementation of BPT and BAT offers potentials in a short- and medium-term for energy efficiency improvement. In [11] the energy use of the worldwide manufacturing industry is studied and the energy efficiency improvement is forecasted in a period up to 2030. The results are as follows. Impact of BPT: if all plants are operating at the current levels of BPT by 2030, the result will be equivalent to an energy efficiency improvement of 1.2 % per year in the period from 2007 upto 2030. Impact of BAT: if all plants are operating at the

current levels of BAT by 2030, the result will be equivalent to an energy efficiency improvement of 1.7% a year in the period 2007 to 2030. These results show that both BPT and BAT contain a potential for energy efficiency improvement but they also require additional investments in manufacturing industry for implementation of these technologies.

Energy management and optimization in industrial processes is one of the main factors for improving energy efficiency. Modern Energy Management Systems are treating energy as an economic variable which should meet both the energy efficiency criteria and production requirements. At the level of a manufacturing plant or process, such a system includes monitoring and control devices placed at power distribution points and large energy consumers. This enables to monitor and manage energy distribution and consumption and to prevent peak demand charges. Schematically, the structure of an energy management system is shown in Fig. 4, [15].

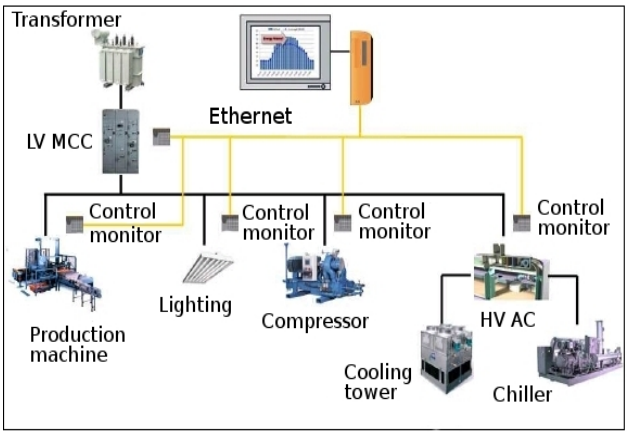

Fig. 4. Energy management system

At the level of technological control of an individual production process, automation plays a crucial role in saving energy and improving energy efficiency. In traditional practice, industrial controllers are implemented in feedback systems with P, PI or PID control. Such controllers use high-gain feedback to stabilize the process dynamics and usually do not account for the excessive use of control energy.

On the other hand, the advanced process control systems and the new industrial controllers are designed on the basis of intelligent control concepts and energy saving requirements. The main advantages of these systems with respect to the energy efficiency are as follows.

- The system performs real-time optimization of process setpoints and operating parameters which optimizes energy consumption.
- The system is equipped with variable-speed drives providing precise and energy efficient control of motor-driven equipment. Control signals are amplitude-limited which prevents excessive loads and saturation of system actuators.

- Intelligent control and advanced control techniques such as adaptive, model predictive and failure tolerant control allow to compensate various process uncertainties and to achieve less energy consumption for equal performance.
- Modern process control systems are incorporated in complex energy management systems which make it possible to develop policies and procedures addressing all aspects of energy consumption and efficiency.

5. Conclusion

The problems related to energy use, saving and efficiency are of global importance and affect both highly industrialized countries and developing economies. In this work we have summarized data concerning the most energy intensive sectors of industry and the energy efficiency indicators commonly accepted in practice. Energy intensive industrial processes use large amounts of energy but they also provide substantial opportunities for improving energy efficiency. In the industrial sector of economy, the development and implementation of energy management systems and highly automated process control systems can contribute to a great extent in increasing the efficiency of energy use.

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Энергетическая консуммация и эффективность индустриальных процессов

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(Р е з ю м е)

В работе представлен обзор энергоемких индустрий и анализ наиболее часто используемых индикаторов для оценки энергийной эффективности. Обсуждаются возможности увеличения энергийной эффективности путем автоматизации процесса управления и применения энергоуправляющих систем.