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Georg Kleiser

Energy Efficiency in Manufacturing

Fundamentals – Methodologies – Technologies

Steinbeis-Edition

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Introduction

It was the invention of new energy conversion technologies, based on fossil fuels, that originally triggered the process of industrialization some centuries ago. The availability of cheap and constant energy, without being dependent on special weather or geographic conditions, has been and still is a basic requirement of wealth in our modern, globalized world.

The myriad of amenities, we all are used to, shall not disguise, however, the negative side effects of energy consumption: the exploitation of dwindling energy resources and the emission of greenhouse gases. A thorough and well-considered approach is demanded in all sectors of our society to maintain our wealth and standard of living without sacrificing our livelihood and that of our succeeding generations.

Striving for better energy efficiencies always has been a topic in the industrial sector. Originally, the primary target hereby was reducing costs. Rising energy prices, increasingly stringent legal requirements and voluntary commitments of the industry itself to reduce carbon emissions will promote further efforts to reduce the energy consumption in the industry.

This will require energy managers and experts, who coordinate and control the different measures to improve the energy efficiency. Apart from these experts, any engineer and economist shall have a profound understanding of the energetic impact of certain processes and products.

The aim of this book is to submit the fundamental knowledge in this field. The industrial sector shows in one respect a totally opposite characteristic to most other areas of energy consumption, such as private household or the traffic sector. In other areas, many new solutions to improve energy efficiency can be directly transferred to various similar applications. Technical solutions inside the industry, however, are often very singular. A deep knowledge of the individual process and its boundary conditions is required to be able to successfully implement energy saving measures into the specific systems.

Objective of the book

The focus of this book cannot be discussing entirely the complete variety of all individual processes and procedures, which one can find inside the industry. There are, however, despite the versatility of industrial processes, certain key technologies that one will encounter very frequently. These are typical core activities, like running electric drives, pumping of fluids, transportation of piece goods, heating and cooling. In addition, the energy conversion technologies in typical industrial energy networks is something engineers and economists shall be aware of. Another important aspect are methods for assessing the energy efficiency of industrial sites.

All these elements of industrial energy utilization are explained in six chapters. Starting with a short introduction into the basic definitions of energy, chapter 1 describes the relevance of the industrial energy consumption in the overall context and the special demands of the industry regarding energy conversions.

Chapter 2 lays out the foundation to understand the physical laws behind the energy transfers, the basic definitions of energy efficiency, the methodologies to gather and visualize energy data, and finally to optimize the systems. This includes a description of the prevailing laws and standards.

The production of the most significant, energy-intensive mass products is described in chapter 3. It also contains some examples about the current technologies that are used to improve their energy efficiency.

Chapter 4 is dealing with the technical details of important energy conversions inside the production processes. The energy turnover of drives, transport equipment, cooling and refrigeration systems are explained comprehensively.

The focus of chapter 5 is on energy services that are inextricably connected with the production processes. It is dealing with the heating and lighting of the facilities and premises.

Chapter 6 is finally covering the particularities of industrial energy networks. It introduces the basic concepts of all types of networks providing either heat or work, their energy balances and the most important technical solutions to improve their energy efficiency.

The book is supposed to serve undergraduate students in advanced semesters as well as professionals to acquire or refresh the fundamentals, methods and technologies of industrial energy transfers. Even though the relevant scientific background is explained and repeated shortly, the reader is expected to have a certain background in physics, especially in the area of thermodynamics and electricity, as it is commonly educated in the first two semesters of undergraduate academic education.

In case of statistics, laws and standards, the book is representing the European - or sometimes more specifically the German - perspective. It deliberately intends to disclose the German situation, as a country in the transition of the energy system, and shall, as one objective, facilitate the knowledge transfer in international companies, which have to optimize the energy performance at different locations.

Some general information on utilizing the book

Apart from the theoretic background, the book offers in each chapter also the required calculation formula to assess and design the energy systems presented. As the book covers several fields of physics simultaneously, it is not always possible to assign to each physical parameter its own letter as variable. The denotations, commonly used in the specific subject areas, have been preferred in the choice on cost of some doubling. In case of doubts, the reader is recommended to consult the nomenclature in the appendix.

To stay consistent in the book, some non-conformances to certain standards have been accepted. Apart from lighting, all flows have been assigned to be the same letter as the corresponding physical size in combination with a dot. Thus, a heat flow is denoted by $\dot{Q}$ even though some standards also use Φ and a volume flow always is denoted by $\dot{V}$.

Generally, the variable for the temperature is T, regardless whether the required temperature has to be entered into the formula in degrees Celsius or Kelvin. It is expected that the user is aware of the fact, that single temperatures in thermodynamic formulas require a temperature in Kelvin, whereas differences of temperatures are equal in both unit systems.

As the readers are usually more used to handle temperatures in degrees Celsius, this unit was preferred in tables and diagrams. Pressure is always understood to be the absolute pressure. If in exceptional cases information on basis of gauge pressure is given, the index g for gauge pressure will follow the pressure unit (e.g., $\mathrm{bar_g}$).

Specific enthalpy changes of substances undergoing a chemical reaction, which also embrace combustion reactions, are always denoted by $\Delta \mathrm{h}$, as we are talking here about a change of the energy content of products compared to that of 1 kg of one specific educt. As the inferior and superior calorific value represent nothing else than a specific enthalpy change of fuel as a result of a reaction, the nomenclature $\Delta \mathrm{h_{inf,\ cal}}$ and $\Delta \mathrm{h_{sup,\ cal}}$, respectively, was used instead of $\mathrm{H_i}$ and $\mathrm{H_s}$, which is also common in standards.

In many cases, the application of the formulas is shown at the end of the specific section with an example to facilitate its correct application.

Contents

1. Energy Consumption in the Industrial Context

1.1. Energy types and energy sources

Energy in a purely physical sense is the ability of a certain thermodynamic system to provide work. Energy is something we know from our daily life, for example from kinetic energy of vehicles and equipment in motion, or from potential energy, stored in any body that is located above the ground level. Energy is also known in the form of electrical energy or internal energy, which might be stored as chemical energy in fuel or as thermal energy in hot water. We will deal later in more detail with these different forms of energy and their importance for energy efficiency.

First, however, we turn the view to a more economical orientated specification of energy types. For a distinction of energy forms in an economic or technical perspective, a further classification has been proven useful. In this classification, energy is distinguished by its "processing" state. That form of energy that is directly provided by nature is called *primary energy*. This includes crude oil, natural gas, solid fuels, such as coal or lignite, and renewable forms of energy, like wind and water energy, geothermal energy, solar radiation, and renewable fuels (wood, straw, etc.). In general, this kind of energy cannot be used directly, but requires further processing.

Usually, several steps of transportation and chemical conversion have to be performed, until the energy can be finally used by the end consumer for its purposes. That kind of energy that is finally sold to the end user is called *final energy*. This might be heating oil, diesel fuel, but also electricity and hot water from district heating. Final energy is the form of energy that is traded directly before its utilization by the end user. Its consumption can be easily evaluated for statistical purposes. The final energy is then converted to *useful energy,* inside the appliances of the end user: The useful energy is the energy that finally fulfills the end user's desires. This might be heating, hot water for showering, lighting and others. Some examples for different energy sources are shown in Fig. 1.1.