Process Systems Engineering

Edited by Efstratios N. Pistikopoulos,
Michael C. Georgiadis, and Vivek Dua

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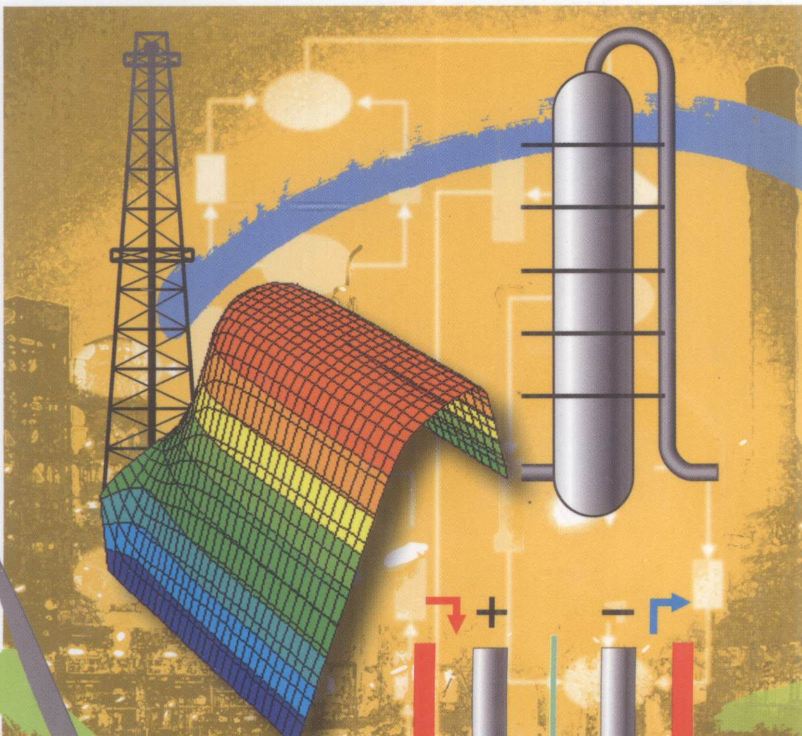
Energy Systems Engineering



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Centre for
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Volume 5: Energy Systems Engineering

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Preface

Energy is one of the most critical international issues at the moment and most likely to be so for the years to come. As part of the energy debate, it is becoming gradually accepted that current energy systems, networks encompassing everything from primary energy sources to final energy services, are becoming unsustainable. Driven primarily by concerns over urban air quality, global warming caused by greenhouse gas emissions, and dependence on depleting fossil fuel reserves, a transition to alternative energy systems is receiving serious attention. Such a tradition will certainly involve meeting the growing energy demand of the future with greater efficiency as well as using more renewable energy sources (such as wind, solar, biomass, etc.). While many technical options exist for developing a future sustainable and less environmentally damaging energy supply, they are often treated separately driven by their own technical communities and political groups (Pistikopoulos [1]).

Energy systems engineering provides a methodological scientific framework to arrive at realistic integrated solutions to the complex energy problems by adopting a holistic systems-based approach. This book demonstrates the potential of an energy-systems engineering-based approach to systematically quantify different options at different levels of complexity (technology, plant, energy supply chain, megasystem) through a number of real-life applications.

In Chapter 1, Pistikopoulos and coworkers present a polygeneration energy systems approach, which combines power generation and chemical fuel synthesis in a single plant, thus providing a promising alternative pathway toward achieving sustainable and flexible economic development. A mixed-integer programming formulation is proposed in constructing long-term decision models which are suitable for investment planning and design of polygeneration infrastructure systems. More specifically, two models are presented: one for investment planning of a polygeneration plant, and the other for the configuration design – both models are then applied to a case study involving a polygeneration plant producing methanol and electricity.

The group of Marechal and coworkers in Chapter 2 proposes a systematic methodology for designing urban energy conversion systems. The methodology allows the integration of polygeneration energy conversion technologies as well as the design of heat and cold distribution networks. It leads to the optimal selection

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and combination of energy conversion technologies, their geographical implementation, the optimal supply and return temperatures of the distribution networks, the connection of buildings, and the use of local renewable resources that can be used for heat pumping. The methodology integrates thermodynamic considerations, mathematical programming techniques, conceptual design principles, and various alternative technologies, geographical locations and buildings.

Kikkinides in Chapter 3 presents a comprehensive review of important issues and challenges associated with hydrogen storage for the case of stationary and mobile applications. Different methods of storage have been analyzed in terms of process performance and heat management. The results of this analysis demonstrate that each method has its own advantages and disadvantages and the final selection depends on a variety of characteristics such as type of storage application, hydrogen supply requirements, etc. In the near term, compressed hydrogen will compete with liquefied hydrogen as the dominant storage method for fuel-cell vehicles at the demonstration level. Metal or chemical hydrides are expected to offer significant advantages when the current research and development efforts succeed in commercializing the required technology. It is illustrated that in metal hydride storage tanks enhanced heat transfer allows for faster tank filling while at the same time it prevents the formation of large temperature gradients in the storage tank. Finally, it is concluded that for this reason innovative design strategies for both heat transfer configurations and/or material microstructure should be developed to improve process performance.

The group of Li and coworkers, in collaboration with Liu and Pistikopoulos, presents in Chapter 4 a generic model for the optimal long-range planning and design of future hydrogen supply chains for fuel cell vehicles. The model relies on mixed-integer optimization techniques to provide optimal integrated investment strategies across a variety of supply chain decision-making stages. Key high-level decisions addressed by the model are the optimal selection of the primary energy feedstocks, allocation of conversion technologies to either central or distributed production sites, design of the distribution technology network, and selection of refueling technologies. At the strategic planning level, capacity expansions as well as technology shutdowns are captured to explicitly address the dynamics of the infrastructure and the timing of the investment. Low-level operational decisions addressed include the estimation of primary energy feedstock requirements and production, distribution, and refueling rates. Realizing that both financial and ecological concerns are driving the interest in hydrogen, formal multiobjective optimization techniques are used to establish the optimal tradeoff between the Net Present value of the investment and green house emissions. The applicability of the proposed models is illustrated by using a large-scale case study from China. It is shown how the model can identify optimal supply chain designs, capacity expansion policies, and investment strategies for a given geographical region.

Georgiadis and Pistikopoulos in Chapter 5 present a formulation for the optimization of oil and gas production operations. The formulation simultaneously optimizes well rates and gas lift allocation, is able to handle flow interactions among wells and can be applied to difficult situations where some wells are too weak to flow to the manifold or require a certain amount of gas lift to flow. The accuracy, efficiency, and robustness of the formulation have been established by comparisons with an exact optimization formulation that was solved using an SQP method in a number of examples. The algorithm is applicable both to tree-like structure pipeline networks and to pipeline networks with loops. Due to the ability of the algorithm to account for flow interactions it always leads to superior operating policies compared to the heuristic rules typically applied in practice. The proposed optimization method can be used for real-time production control since all the variables required for the construction of a well model can be measured and the discrete data can be directly incorporated in the formulation.

In Chapter 6, Kouramas and Pistikopoulos present a model-based approach for power control of wind turbines including the design of a novel explicit multi-parametric model predictive controller. A wind turbine with its detailed nonlinear, approximating nonlinear and approximating ARX model is proposed. Simulation analysis is used to discuss the wind turbine's performance in the presence of wind speed variations as well as blade pitch angle variations. The latter was shown that can be manipulated to provide power regulation in the presence of wind speed disturbances. Finally, the steps for the design of an explicit model predictive controller are illustrated and the resulting controller is evaluated against the actual nonlinear model of the system.

The work of Kuhn, Parpas, and Rustem in Chapter 7 is motivated by the need to develop systematic methods for taking optimal decisions on whether to invest in new power system infrastructure. In this context, the timely expansion of generation and transmit ion capacities is crucial for the reliability of a power system and its ability to provide uninterrupted service under changing market conditions. Assuming a probabilistic model for future electricity demand, fuel prices, equipment failures, and electricity spot prices, a capacity expansion problem is formulated that minimizes the sum of the costs for upgrading the local power system and the costs for operating the upgraded system over an extended planning horizon. The arising optimization problem represents a two-stage stochastic program with binary first-stage decisions. Solution of this problem relies on a specialized algorithm, which constitutes a symbiosis of a regulated decomposition method and a branch-and-bound scheme.

Adjiman and coworkers in Chapter 8 present a process for the capture of CO_2 from natural gas streams through physical absorption into n-alkane solvent. A methodology for the optimization of the solvent blend and operating conditions is also introduced in the context of three different process flowsheets. The model indicates that this process is commercially viable, since profit through gas sales far outweighs capital and operating costs. Overall CO_2 inlet concentrations was studied. The process can be extended to investigate nonequilibrium strategies, or to the screening of solvents outside the n-alkane family. The work clearly demonstrates the benefits of employing a complex equation of state within a process modeling and optimization framework.

Klemes and coworkers in Chapter 9 present initially a critical overview of the energy-efficiency problem. Energy-saving techniques that are currently available, relatively simple but effective screening and scoping approaches are reviewed, including energy auditing, benchmarking, and good housekeeping. Energy-saving techniques, such as balancing and flowsheeting simulation, and a heat integration approach are also discussed in details. Then the increasingly significant issue of emissions and carbon footprint assessment and minimization is introduced. It is shown that even renewable energy sources make some contribution to the overall carbon footprint, which is frequently not accounted for in assessment studies. Various renewable technologies applicable in the domestic sector are assessed in a view of reducing the release of CO_2. A number of industrial applications are also presented including an energy-efficiency retrofit study from a large energy consuming petrochemicals industry, followed by a pulp and paper plant energy minimizations study and several examples from the food industry. Case studies related to the domestic energy sector are demonstrated as well. These cover a hospital and a total site comprising a sugar plant and a nearby town.

In the final chapter, Markowski and Urbaniec present a systematic methodology for the design of energy-efficient gas separation systems comprising a sequence of conventional distillation columns and a refrigeration subsystem. Tools and concepts derived from the well-known Pinch Technology are employed to address this problem. Assuming an ideal column and its profile, thermal integration of the underlying conventional systems is first considered. Extensions to flowsheets including heat-integrated columns are also presented. The efficiency of the proposed methodology is illustrated to flowsheets involving separation of complex hydrocarbon mixtures. The energy-saving potential of including heat-integrated distillation columns is revealed. Furthermore, extension to systems comprising also a heat-exchanger network and a refrigeration subsystem are illustrated, leading to significant reductions in the compressor shaftwork required for the gas separation process.

This collection represents a set of stand-alone works that capture recent research trends in energy systems engineering – the development and application of techniques, methodologies, algorithms, and tools for optimizing various energy systems. We hope that by the end of the book, the reader will have developed a commanding comprehension of the main aspects of integrated energy systems and energy supply chains, the ability to critically access the key characteristics and elements related to the design and operation of energy systems and the capacity to implement the new technology in practice.

We are extremely grateful to the authors for their outstanding contributions and for their patience, which have led to a final product that exceeded our expectations.

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