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Editorial

Energy systems engineering

ABSTRACT

This Special issue deals with the Energy Systems Engineering as a part Computer Aided Process Engineering. In this editorial introduction, the editors are highlighting the individual articles presented and discussed in this issue. Main areas of this issue can be summarised as follows: Process Integration including Total Sites, exergy, distributed energy production and consumption, energy production and generation control and energy related environmental impact.

1. Introduction

Issues related to energy saving - pollution reduction and energy systems engineering are closely related. Their importance has increased in recent years and presents considerable academic and industrial challenges. They generally represent complex tasks of a considerable scale and comprehensive interactions.

The European Symposium on Computer Aided Process Engineering (ESCAPE) series presents the latest innovations and achievements of leading professionals from the industrial and academic communities. The ESCAPE series serves as a forum for engineers, scientists, researchers, managers and students to present and discuss progress being made in the area of Computer Aided Process Engineering (CAPE).

CAPE-WP [1] is a working party of the European Federation of Chemical Engineers on the topic "Computer Aided Process Engineering". The Working Party was originally established in 1966, under the chairmanship of Professor H. Brusset and with the title "Programmes de Calculs de Routines et Emploi des Ordinateurs Electroniques". Since 1996 international symposiums every year on CAPE related topics, computers are now routinely applied throughout the entire spectrum of process and product engineering activities covering chemical, petrochemical, bio-chemical, pharmaceutical industries and thereby, reflecting the success of the energy and success of the Working Party's activities. CAPE-WP organizes from 1992 yearly European Symposium of Computer Aided Process Engineering (first ESCAPE-1 was in Helsingør, Denmark) traditionally attended by more than 400 delegates and where the latest developments within CAPE and CAPE-related fields are presented. The CAPE-WP also promotes smaller meetings: CAPE-Forum and workshops such as those organised through EURECHA (The European Committee for Computers in Chemical Engineering Education).

European industries large and small are bringing innovations into our lives, whether in the form of new technologies to address environmental problems, new products to make our homes more comfortable and energy efficient or new therapies to improve the health and well-being of European citizens. Moreover, the European Industry needs to undertake research and technological initiatives in response to humanity's "Grand Challenges", described in the declaration of Lund [2], namely, Global Warming, Tightening Supplies of Energy, Water and Food, Ageing Societies, Public Health, Pandemics and Security.

21st European Symposium on Computer Aided Process Engineering [3] was organised in a beautiful part of Greece - Porto Carras Grand Resort near Thessaloniki. ESCAPE 21 had a topical session ESE (Energy System Engineering). For this Special issue 20 manuscripts have been selected and after thorough review process 14 papers of them have been selected for the publication in ENERGY.

2. Special issue content overview

2.1. Process Integration

Pinch Analysis is a well-established methodology of Process Integration for designing optimal networks for recovery and conservation of resources such as heat, mass, water, carbon, gas, properties and solid materials for more than four decades. However its application to power systems analysis still needs development. The paper presented by Wan Alwi et al. [4] extends the Pinch Analysis concept used in Process Integration to determine the minimum electricity targets for systems comprising hybrid renewable energy sources. PoPA (Power Pinch Analysis) tools described in this paper include graphical techniques to determine the minimum target for outsourced electricity and the amount of excess electricity for storage during start up and normal operations. The PoPA tools can be used by energy managers, electrical and power engineers and decision makers involved in the design of hybrid power systems.

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A large amount of low grade energy is still often wasted without heat recovery in the process industry. Kapil et al. [5] studied over-the-fence Heat Integration for district heating (DH). The waste heat can be utilised and consequently alleviate the carbon footprint of the integrated energy system. They stated that the economic performance of over-the-fence Process Integration depends on the cost of fuel, electricity and distance for the transfer of waste heat to DH network. Their new design methodology systematically evaluates the economic benefit of integration of low grade heat with local district heating networks. A Total Site analysis tool using Site Composite Curve profiles [6] is incorporated in order to identify the quality and quantity of low grade heat available. The optimisation framework identifies economically acceptable distance for the over-the-fence heat recovery from the industrial site to local community. The study considered in this work can be extended to consider renewable energy sources [7] and interactions with the existing grid, as these design aspects strongly influences the design and performance of localised and distributed energy systems [8].

Another extension of Total Site Integration to Locally Integrated Energy Sectors [6] producing more realistic utility and heat recovery targets. Varbanov et al. [9] started from the observation that it is still an open question how to solve the Total Site targeting problem when different values for the minimum allowed temperature differences (ΔT_{min}) are specified for each process on the site. A single uniform ΔT_{min} for all processes integrated in a Total Site as mostly practiced cannot be generally optimal. It can lead to inadequate results due to imprecise estimation of the overall Total Site heat recovery targets. The modified Total Site targeting procedure, proposed in this paper, allows obtaining more realistic heat recovery targets for Total Sites. It is illustrated with a case study for Locally Integrated Energy Sectors, also providing a comparison with the traditional targeting procedure and the advantages offered by the modified one. The magnitude of the discrepancies between the targets in that case was from about 30% up to about 200% and proven to the significance of using the proper ΔT_{min} specifications.

Another problem related to the exploitation renewable energy sources, such as wind and solar radiation, is their fluctuating availability. Nemet at al [10] used the Heat Integration methodology for batch processes based on Time Slices [11] and [12]. They extended it to cover the integration of solar thermal energy, thus allowing for dealing with such variations. A procedure for identifying the number and durations of Time Slices for a problem featuring variable renewable energy supply has been formulated, and developed for solar energy utilisation. The main procedural steps involve partitioning of the measured/forecasted heat availability profile using a large number of candidate time boundaries, and then approximating it by a piecewise-constant profile using high-precision. The approximation profile is obtained by subjecting the candidate superset of time-boundaries to MILP optimisation, thus minimising integral inaccuracy compared to the forecasted availability profile. The Time Slice definitions are completed by approximating the heat loads within the Time Slices. The integration of solar thermal energy can be performed for the specified Time Slice, after the optimal number of Time Slices with approximated constant load has been selected. Using heat storage, the heat can be transferred between Time Slices.

2.2. Exergy

Ghannadzadeh et al. [13] presented a general methodology for exergy balance in chemical and thermal processes integrated in ProSimPlus®. After exergy balance, the essential elements such as source of irreversibility for exergy analysis are presented to help the user for modifications on either process or utility system. The applicability of the proposed methodology in ProSimPlus® is shown through a simple scheme of Natural Gas Liquids (NGL) recovery process and its steam utility system. The methodology offers the exergy based criteria to pinpoint the source of exergy losses and also finds the way to reduce them. They report that the comparison of solving the similar problem by the other process simulators, e.g. [14] is favourable for their approach.

Oxy-combustion is a promising technology to mitigate CO_2 emissions, particularly from coal based power plants, see e.g. [15]. When a double-column distillation cycle is applied to produce O_2 with a purity of 95 mol%, the oxygen production process is causing the largest power penalty (6.6% points) related to CO_2 capture. The actual power consumption is around 4.7 times the theoretical minimum. Fu and Gundersen [16] performed a comprehensive exergy analysis of an air separation unit for producing O_2 with low purity (95 mol%) and low pressure (120 kPa). The air compression process and the distillation system cause the two largest exergy losses: 38.4% and 28.2%. They found that the power consumption in the air compressor can be reduced by 19% if the isentropic efficiency increases from 0.74 to 0.9. The total power consumption is reduced by 10% when dual reboilers are applied in the lower pressure column. The exergy losses in the condenser/reboiler exchanger is responsible for only 6.3% of the total losses and the power saving potential by developing new heat exchangers with smaller temperature differences is limited. The authors concluded that the plant performance in air separation units deserves the flowsheets to be improved. Their reasons are twofold: the compression heat should be integrated with the steam cycle or other units and it is an additional N_2 available after the requirement of reflux, which can be satisfied with a low purity (around 95 mol%) O_2 production process. Efficient utilisation of the available N_2 can generate some advanced cycles.

Generation of Boil-off gas (BOG) in liquefied natural gas (LNG) receiving terminals considerably affects operating costs and the safety of the facility. A proper BOG handling process is a major determinant in the design of an LNG receiving terminal. Park et al. [17] come with the concept of a retrofit design using a fundamental analysis. A base design was determined for a minimum send-out case in which the BOG handling becomes the most difficult. The cryogenic energy of the LNG stream is used to cool other streams inside the process. It leads to a reduction in the operating cost of the compressors in the handling process. Design variables of the retrofit design are optimised with non-linear programming to maximise profitability. Optimisation results compared with the base design provides 22.7% energy saving ratio and 0.176 y payback period.

2.3. Distributed energy production and consumption

Pérez-Fortes et al. [18] work is focused on a mathematical programming approach applied to bio-based supply chains that use locally available biomass to produce electricity or other bioproduct. These supply chains have been subject to intensive studies dealing with the logistics [18, 19], uncertainties [20] and carbon and nitrogen footprints [21]. The problem is formulated as an MO-MILP (multi-objective mixed-integer linear programing) considering economic, environmental and social criteria. The model supports decision-making about location and capacity of technologies, connectivity between the supply entities, biomass storage periods, matter transportation and biomass utilisation. The advantages are highlighted by solving a case study of a specific district in Ghana. The aim is to determine the most suitable biomass and electricity network among the different communities. The technology considered to transform the biomass into electricity is gasification combined with a gas engine. The energy block is can be easily adapted to other microgeneration sources, such as wind, hydro or solar, or even to investigate the use of more than one renewable source in hybrid systems.

Mehleri et al. [22] present a mixed-integer linear programming (MILP) super-structure model for the optimal design of distributed energy generation systems for the heating and power demand for small neighbourhood region. They looked for an optimal selection of several candidate technologies (micro combined heat and power units, photovoltaic arrays, boilers, central power grid), including the optimal design of a heating pipeline network. The objective function to be minimised contains the annualised overall investment cost and the annual operating cost of the system. They shown that special constraints derived from graph theory are needed to ensure a correct design or to add special configurations as it is the use of a single centralised μCHP unit. The usefulness of the model for energy optimisation is illustrated on applications of two different in size problems and comparison with conventional design not involving heating pipeline networks.

2.4. Energy production and generation control

Controlling the production and also the consumption of electricity in an efficient, flexible and proactive manner is challenging task. This problem received a considerable attention, see e.g. [23]. Hovgaard et al. [24] describe a novel economic-optimising Model Predictive Control (MPC) scheme reducing the operating cost by thermal storage capabilities. They suggested for simulations with validated scenarios to use a non-linear optimisation tool to handle a non-convex cost function. They address advantages from daily variations in outdoor temperature and electricity prices and formulate a new cost function enabling the refrigeration system to contribute with ancillary services. This can be economically beneficial and crucial services can be delivered to a future flexible and intelligent power grid (Smart Grid). Using a non-linear MPC solver they illustrated that significant savings of up to 9–32% can be achieved by utilising thermal storage capacities together with predictions of varying loads and energy prices. Their proposed future work includes the addition of uncertainty in the more realistic scenarios by reformulating or separating the non-convex cost function.

Much current research addresses the efficiency of a wide range of energy systems in scheduling [25] control [26], and design [27]. Macek and Mařík [28] aim article is an introduction of a methodology to quantitatively compare two or more solutions for a system that is operated under varying conditions. They focus on scheduling and control solutions, although the solutions could also be applicable to system design. Newly developed solutions are assumed to demonstrate improvement over previous solutions especially in cost savings. The authors focused on the area of HVAC systems (heating, cooling and air conditioning). Their methodology for quantitative comparison of control solutions with respect to operational cost claims achieved quality of control and external conditions that could also play important roles.

Renewable energy systems make up averagely 7–8% of the entire energy supply in Europe [29], however only 2.2% in South Korea [30]. Kim et al. [31] concluded that the relatively high cost of renewable energy systems and the uncertain outlook of their rate of diffusion in the market make it difficult to fully rely on them. The uncertain in the production cost are especially challenging. The concept of the learning rate is adopted to handle uncertainties to compute the cost of energy systems in the future and Monte Carlo simulation is performed. The aim of this work is to optimise plans of conventional and renewable energy systems with respect to production cost. The energy situation in South Korea is used for the case study. The proposed methodology could provide useful insights economically and strategies of sustainable energy management for ambiguous environments. Korea relies on imports for 97% of the energy sources and above 30% of the total electricity generation depends on the nuclear power. The solar energy can play a role in the future by virtue of its high learning rate and low CO_2 emission. The proportion of renewable energy in 2011 was just 0.9% in the total supply. As the amount of energy demand increases, renewable energy systems can be a solution to satisfy the abatement of CO_2 emission. This satisfies one of the goals of the Korean National Energy Plan to make renewable energy sources providing at least 11% of the total energy supply by the year 2030 [32].

2.5. Energy related environmental impact

Currently a lot of research is being performed on the topics of alternative power/fuel generation [33]. However, even renewable sources of energy, as e.g. biomass, have some impact to the environment. Besides green house emissions, several other negative impacts may result from biomass production and use for bioenergy generation – water pollution and shortage, nitrogen footprint, as well as food and land scarcity, to name a few. Čuček at al [34] made an attempt to explore those impacts. They present a multi-criteria optimisation (MCO) of regional biomass supply chains for the conversion of biomass to energy through the simultaneous maximisation of economic performance and minimisation of the environmental and social footprints. The energy supply chain model contains agricultural, pre-processing, processing, and distribution layers. An integrated model for regional biomass energy network optimisation [35] is used as a basis, and now extended for simultaneous assessment of the supply chain performance based on Life cycle assessment (LCA). Several total footprints are introduced for "cradle" to "grave" evaluation, which, comprises also indirect effects caused by products' substitutions. In the MCO approach, the annual profit is maximised against each footprint (FP) generating different sets of Pareto optimal solutions, one for each FP. With this approach the aggregation of different environmental and/or social pressures is can be avoided. The results indicate that total footprints enable the obtaining of more realistic solutions, than in those cases when only direct footprints are considered. More profitable and less environmentally harmful solutions can be gained with significant reduction in total carbon and total energy footprints. In the future the number of environmental footprints should be reduced to a minimum of –independent FPs through those correlations among FPs that show similar behaviour. The correlations from other FPs should also be investigated, as assessed in this contribution, such as nitrogen and phosphorus footprints, and the issue of biodiversity measured by biodiversity footprint.

The current progress in the area of waste-to-energy (WTE) and incineration systems in general is again a very fast developing filed [36]. More and more sweeping environmental legislation can be in fact considered as a driving force leading to developing novel types of technologies and equipment. It is necessary to reach a balance between economically, technically and environmentally appropriate ways of waste processing provided the emissions limits are respected. Technologies for incineration went through a rapid development from simple waste disposal to current complex WTE units. The final contribution of this Special issue [37] provides an overview of thermal treatment methods for WTE processes technologies in terms of their performance and environmental impact. It presents the possibilities of waste treatments and related legislation by the European Communities. As an example - in the Czech Republic they are 19 industrial waste incinerators in wide range of process capacities from 15 kt/y to 0.3 kt/y, and three municipal waste incinerators 300, 250 and 9 kt/y. The pathways of energy production and the treatment of undesirable outputs are considered. There are analysed issues related to the WTE, technologies for thermal treatment of waste, heat recovery systems, flue gas issues and measures for flue gas cleaning. Different WTE performance techniques are included to provide a basis for comparison of different technologies. Software tool for the simulation WTE processes is overviewed as well. The work has been concluded with some promising future trends and approaches.

3. Conclusions and acknowledgements

This Special issue devoted to a topical session Energy Systems Engineering of 21th European Symposium on Computer Aided Process Engineering – ESCAPE 21 provided an overview of several topics cover by the venue. The Guest editors believe that the selected papers would be of the interest of readers of ENERGY journal and that the similar collaboration is going to be continued in the future again.

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