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Editorial

Advances in process integration, energy saving and emissions reduction

1. Introduction

The efficient use of energy is a very important issue for the processing industry, businesses and services, residential sector and agriculture. There are not just monetary incentives but also a growing challenge for a cleaner environment. The impact of energy generation, transport and consumption systems on environmental pollution have both local and global effects. Over the years there have been various powerful methodologies developed to cope with those problems. Heat integration based on pinch technology [1–3] extended into the total site [4] and integration of the renewable energy sources [5] has been one of them. The performance of the heat exchanger network in a system is an important aspect of energy conservation. Its efficiency, flexibility, reliability and maintenance are very important issues. The ways to deal with pollution and emissions including CO_2 have received growing attention. Because of the increasing urgency to successfully deal with these and related problems, various conferences are being held to encourage closer collaboration among people of many nations.

The series of conferences on *"Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction"* (PRES) is one such opportunity for cross-fertilisation, running now into its second decade. It has been established originally to address issues relevant to process energy integration in connection with efficient heat transfer issues. The organisers of the PRES conferences are proud to continuously attract delegates from numerous countries world-wide providing a friendly and highly collaborative platform for fast and efficient spreading of novel ideas, processes, procedures and energy saving policies. PRES conferences have a comprehensive publication strategy. This Special Issue is already the tenth of *Applied Thermal Engineering* dedicated to selected contributions from PRES conferences The collaboration started in 2000 with PRES'99 [6] and successfully continued with PRES 2000 [7], PRES'01 [8], PRES 2002 [9], PRES'03 [10], PRES 2004 [11], PRES'05 [12], PRES 2006 [13] and PRES'07 [14]. Beside *Applied Thermal Engineering* some other well-known journals have been collaborating with PRES conferences – *Heat Transfer Engineering* [15], *Journal of Cleaner Production* [16], *Cleaner Technologies and Environmental Policy* [17], *Resources, Conservation and Recycling* [18] and *Energy* [19] supported by related workshops publications [20]. However, the collaboration with *Applied Thermal Engineering* has the longest tradition and has been mutually greatly appreciated.

Societal challenges to develop and implement energy efficient, clean and sustainable technologies are taken up by academia and industry. They have been increasingly responding to the economic, environmental and sustainability challenges. The economic crisis is widely regarded as a barrier for implementation of advanced and clean technological solutions. However, should the recent political initiatives towards energy efficiency be translated into legislative, regulatory and economic incentives there is a good chance for a wide range of advanced and sustainable technologies to take off. One of the most established and world renowned conferences in this field is PRES.

The 11th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction – PRES 2008 – which was held in Prague in August 2008, provided an excellent opportunity for researchers and industry for dissemination of novel ideas, processes, procedures and energy saving policies. PRES 2008 was held, following tradition, every second year in collaboration with the 18th International Congress CHISA 2008 in the heart of Europe – in Prague, the capital of the Czech Republic. This Central European capital, known as a city of thousand spires and a golden city, welcomed so far a record number of PRES delegates from more than 55 countries. 987 authors submitted 345 contributions. They represented, beside traditional European countries, Asia, Africa, Australia and North and South America.

2. Selected contributions – main thematic groups

For this Special Issue of the *Applied Thermal Engineering*, nine manuscripts were selected dealing with various aspects of total site integration, case studies implementing the integration and reliability, heat-integrated heat pumping, availability and maintainability of HENs, and finally CO_2 emissions issues and biological hydrogen production. The authors came from eight countries in Asia and Europe – from India, Finland, Czech Republic, UK, Slovenia, Hungary, France and Austria.

2.1. Total site and heat integration options

Three papers dealing with this topic have been selected. The first paper comes from the Department of Energy Science and Engineering, Indian Institute of Technology Bombay, Powai, Mumbai, in India and the authors are Santanu Bandyopadhyay, James Varghese, Vikas Bansal entitled *Targeting for Cogeneration Potential through Total Site Integration* [21]. They further studied and extended the Total site integration methodology of Dhole and Linnhoff [22] and Klemeš et al. [4]. This methodology offers an approach for evaluating the energy conservation opportunities across different individual processes including the central utility system. To achieve the maximum possible indirect integration between processes via assisted heat transfer, they further studied heat transfer options outside the region between the process pinch points and confirmed the previous observation that it plays a significant role. Their concept is to generate a Site Level Grand Composite Curve (SGCC). They noted that their procedure for

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generating SGCC becomes identical to that proposed by Dhole and Linnhoff [22] for constructing the Total Site Profiles if the GCCs pockets would be removed. The approach has been used by UMIST and The University of Manchester in their lecture courses for the last 15 years as well [23]. The proposed SGCC targets the maximum possible indirect integration as it incorporates assisted heat transfer. Their main contribution is a development of a methodology for estimating the cogeneration potential at the total site level, utilising the concept of multiple utility targeting on the SGCC. They claim that the proposed methodology is simple and linear as well as utilising the rigorous energy balance at each steam header. It targets the cogeneration potential of the total site prior to the detailed design of the utility system. After a detailed analysis they noted that in many practical cases, which the authors term as assisted (i.e. additional) heat transfer, may not lead to significant energy conservation and these may not lead to reduction of the overall cost considering extra capital investment related to additional heat exchangers. In their paper only the targeting methodology has been presented. After setting targets, heat recovery network along with the steam distribution network should be designed and evolved according to the well established pinch principles. They suggested that a rigorous economic model, similar to one proposed by Kaikko et al. [24] may be developed for techno-economic evaluation of the proposed scheme. Economic optimisation and a detailed cost benefit analysis of the entire system should be performed before selecting any particular configuration.

The second paper was authored by Jarmo Söderman and Pekka Ahtila from the Heat Engineering Laboratory, Åbo Akademi University, and Industrial Energy Engineering and Economics, Helsinki University of Technology, both in Finland. The title is *Optimisation model for integration of cooling and heating systems in large industrial plants* [25]. The authors developed an optimisation model for integration of cooling and heating systems to tackle the problem. The work is complementary to the process integration and is based on their previous work – the heat exchange part of the model [26] and the approach based on temperature intervals [27]. The integration of power generation and heating systems with cooling systems was included in their model and an illustrative example was presented. The authors selected ten process streams with cooling demands and ten streams with heating demands, all situated at different locations on the plant site. The optimal matches between the streams were identified together with the sizes of the heat exchangers and the demands for hot and cold utilities. The costs for piping and pumping were also accounted for. The model can be used in the grassroots design as well as for retrofit investments. The authors claim that the procedure is a versatile what-if analysis of the plant design or operation. The approach should provide the industry support for improving the efficiency of the cooling systems, reduce the energy costs by effective integration of the energy systems and reduce the environmental impact caused by the processing plants.

2.2. Energy efficiency related case studies

This part offers a variety of case studies – four papers dealing with process integrated heat pumping of biomass, steam cracker, brewery, oil refinery and heat exchanger network. The first paper in this part was a result of a wide international collaboration under the umbrella of the European Community-supported project SHERHPA – Sustainable Heat and Energy Research for Heat Pump Applications – FP6 Horizontal Research Activities Involving SMEs Collective Research Project 500229-2. The authors come from four institutions in the Czech Republic and the UK, combining the academia and the industry: Martin Pavlas and Petr Stehlík from Brno University of Technology, Institute of Process and Environmental Engineering, UPEI VUT Brno; Jaroslav Oral from EVECO Brno Ltd., Czech Republic; Jiří Klemeš and Jin-Kuk Kim from the Centre for Process Integration, CEAS, The University of Manchester; and Barry Firth from Firth Executive Ltd., Porthdafarch, Holyhead, Wales, UK. The title is *Heat-Integrated Heat Pumping for Biomass Gasification Processing* [28]. The main part of this paper is an industrial case study. It deals with an application of a heat pump in energy systems for biomass gasification in a wood processing plant. Process Integration methodology [1–3] and its extensions [23,29,30] are applied to deal with the complex design interactions as many streams requiring heating and cooling are involved in the energy recovery. A refrigeration cycle maintains low temperature in the scrubber where the production gas (syngas) is cooled down and undesirable contaminants are removed before the syngas is introduced into the engine. In addition to electricity generation, a large amount of waste heat is available in the biomass gasification system studied in the paper, and its appropriate heat integration with utility systems within a plant allows the available heat to be efficiently utilised on the site. The conceptual understanding gained from the case study provides systematic design guidelines for further process development and industrial implementation in practice. The authors demonstrated that significant energy savings can be achieved through the strategic use of a heat pump applied in the biomass gasification unit. The refrigeration cycle provides conditions for extensive syngas cleaning before it is introduced into the combustion engine. The power output of the engine is 454 kW. The power generation efficiency exceeds 20%. Most of the waste heat is utilised for covering plant demand on drying air heating by using a heat pump. The Grand Composite Curve provides beneficial information for sizing the heat pump cycle (heat removed is 92.4 kW) and determining the most appropriate levels of heat rejection/removal from the heat pump. The authors paid attention to the heat-integrated heat pump to ensure the cost-effectiveness of its applications since the shaft power can vary significantly – from 28 to 77 kW – for different operation conditions. They observed that in some cases – boiler feed water preheating – the potential for energy savings is very low and a practically unacceptable temperature lift of the heat pump is observed and large compression work would be unavoidable.

The second paper of this part comes from Finland. Mari Tuomaala, Markku Hurme, Anna-Maija Leino from Department of Energy Technology and Department of Biotechnology and Chemical Technology at Helsinki University of Technology supported by Borealis Polymers Oy Porvoo presented the paper *Evaluating the efficiency of integrated systems in the process industry – case: steam cracker* [31]. They claim two objectives of their paper – to study: (i) How the efficiency of an olefin production process could be improved by adjusting operational parameters and (ii) How comprehensive are the results obtained by conventional engineering approaches, mainly simulations and test runs. Their case study deals with the efficiency improvement in an olefin plant in the chemical industry. The plant represents a large process site with three main processes: olefin production, aromatics production and polyolefin production. The processes are highly integrated with each other: the aromatics and polyolefin production processes obtain their feedstock directly from the olefin plant. All of the processes are served by the same energy production unit – a Combine Heat and Power process. The case study covered the first section of the olefin manufacturing process, mainly steam cracking. The purpose was to study how much additional efficiency could be gained by adjusting the operating parameters. A target was to improve plant efficiency by adjusting operational parameters. The analysis was supported using a conceptual framework that has been developed to analyse the efficiency of integrated systems. They carried out test runs and simulations to verify whether increasing a hydrocarbon feed rate would result in improved efficiency. The results showed that the ethylene and High Value Chemical yield remained about the same or decreased slightly. However, the coking rate increased and the run length shortened. Despite this, the annual ethylene production increased. Changing operating parameters was considered desirable.

The third paper was written by Hella Tokos, Zorka Novak Pintarič and Peter Glavič from the Faculty of Chemistry and Chemical Engineering, University of Maribor in Slovenia. The title is *Energy saving opportunities in heat integrated beverage plant retrofit* [32]. Their paper presents an application of mathematical programming for energy integration in a large brewery. The annual heat consumption was 127.2 MJ and the annual electricity consumption 13.58 GW h. The brewery generates steam for its own needs using a conventional boiler, while electricity is purchased from the vendors. The wort preparation process was the largest consumer of heat, while the highest need for cooling energy was during fermentation and maturation operations. They analysed the opportunities for heat integration between batch operations by a mixed integer linear programming (MILP) model, which they slightly modified by considering specific industrial circumstances. They also studied the feasibility of combined electricity, heating and cooling production was studied using a simplified MILP model, developed for the selection of an optimal polygeneration system. Their superstructure includes cogeneration systems with different prime movers (steam turbine and gas turbine), and a trigeneration system with a back-pressure steam turbine. A pressure level of 42.4 bar had the highest net present value. Heat production would be increased during the heating season by 50%. Electricity production would cover 42.5% of the current consumption of the brewery. The net present value is positive and they reached payback period is 3.2 year. This does not seem very competitive; however, it might be in the future shortened by increasing electricity price. The disadvantage of this solution is that the plant would become dependent on external consumers of surplus heat energy.

The fourth and the last contribution in this group was *Reliability, availability and maintenance optimisation of heat exchanger networks* [33]. The authors were Laszlo Sikos and Jiří Klemeš, Centre for Process Integration and Intensification – CPI[2], Research Institute of Chemical and Process Engineering, Faculty of Information Technology, University of Pannonia, Veszprém in Hungary. The paper has been prepared in close collaboration and with extensive support from staff of the MOL (Magyar Olaj- és Gázipari Nyrt.) plant located in Százhalombatta refinery. The authors proposed a methodology to use comprehensive up-to-date commercial software tools for Heat Exchanger Network (HEN) reliability modelling and optimisation. The right combination of specific HEN optimisation and reliability software packages proven to have several advantages. There are many related issues – the robustness, the type of welding, the increment of maximum mechanical resistance, the impact on manufacturing costs, reduction of lost opportunity costs caused by exchanger outages, troubleshooting of heat exchanger problems by operators etc. Fouling should be analysed as it has a significant impact on maintenance issues. Up to 30% decrease of maintenance costs can be achieved annually by applying advanced reliability results and determining heat exchanger failure causes. These analyses include the investigation of failure causes, prediction of future probabilities of failures, cleaning planning and scheduling and the calculation of reliability and maintainability. The authors studied a HEN of a petroleum refinery plant. The refinery has a conventional Crude Preheat Train which consists of a set of shell and tube heat exchangers. Fouling of this unit reduces heat input. Energy consumption is 10–20% higher due to fouling. The analysed subsystem contains 36 heat exchangers and 2 desalters. The calculations were based on the failure data of the last 2 years. The measured failure data were inserted into the spreadsheets of Relex Reliability Studio. The software tools proved that the examined subsystem of the plant runs in a nearly optimal way. Inherent availability was 99.54% in 2007 and 98.53% in 2008. Small corrections could still improve RAM issues. Some recommendations still can be added. In the worst cases fouling reduced the diameter of tubes by one third. A threshold should be applied to prevent very high fouling levels. The most sensitive parts in the system from the point of maintainability are the frequency of cleaning to avoid the effects of fouling, the failed heat exchangers and the efficiency of repairs (e.g. the repair of tube furnace burn control).

2.3. CO_2 emissions, biological hydrogen production

This part has three manuscripts. The first one came from Department of Energy and Environment, Chalmers University of Technology, Göteborg in Sweden. Elin Svensson and Thore Berntsson presented their work entitled *Economy and CO_2 emissions trade-off: a systematic approach for optimising investments in process integration measures under uncertainty* [34]. The authors presented a systematic approach trading off CO_2 emissions reductions against investments in process integration measures in industry when optimising those investments under economic uncertainty. Many of the uncertainties affecting investment decisions are related to future CO_2 emissions targets and policies. The optimisation should not only consider economic criteria, but greenhouse gas reductions as well. They applied a model for optimisation of decisions on energy efficiency investments under uncertainty. The decision problem becomes a multiobjective programming problem. The method is applied to a case of energy efficiency investments at a chemical pulp mill. The proposed method provides a good framework for decision-making about energy efficiency measures when considerations regarding greenhouse gas reductions influence the decisions. The multiobjective approach enabled the use of Pareto graphs for illustrating the trade-off between the economic and the CO_2 objective. The target graph shows that the CO_2 emission reductions corresponding to an economically optimal solution for reasonable probability distributions is quite close to what is maximally achievable.

The second CO_2 emissions related paper is *Pre-combustion, post-combustion and oxy-combustion in thermal power plant for CO_2 capture* [35]. Authors Mohamed Kanniche, René Gros-Bonnivard, Philippe Jaud, Jose Valle-Marcos, Jean-Marc Amann, and Chakib Bouallou are from Fluid Mechanics Energies and Environment Department, Research and Development Division EDF and Chatou and Centre Énergétique et Procédés (CEP), Mines ParisTech, both in France. Their paper extends the previously presented studies e.g. [36,37] and presents a comprehensive summary of technical–economic studies. It evaluates the production cost of electricity derived from coal and gas power plants with the capture of CO_2, and the cost per tonne of CO_2 avoided. Three systems were studied: an Integrated Gasification Combined Cycle (IGCC), a conventional combustion of Pulverized Coal (PC) and a Natural Gas Combined Cycle (NGCC). Three main methods were envisaged for the capture of CO_2: pre-combustion, post-combustion and oxy-combustion. For the IGCC, two gasification types have been studied: a current technology based on gasification of dry coal at 27 bars (Shell or GE/Texaco radiant type) integrated into a classical combined cycle providing 320 MWe, and a future technology based on gasification of a coal–water mixture (slurry) that can be compressed to 64 bars (GE/Texaco slurry type) integrated into an advanced combined cycle (type H with steam cooling of the combustion turbine blades) producing a gross power output of 1200 MWe. The authors concluded that constraints related to resources such as fuel and water may also influence the choice. Consequently it is difficult to make a once-and-for-all decision about the "best CO_2 capture process. The results of the studies suggest that pre-combustion capture by physical absorption (methanol) should be used for IGCC. Oxy-combustion should be used for PC and post-combustion capture (amines) should be used for NGCC. The authors again warn that these recommendations are based on a number of assumptions that may whose reliability depends on the particular process. They also correctly reminded us that the evaluation studies carried out are no more than a first phase and the thorough work has to be continued with other more detailed pre-feasibility studies to enable a more accurate evaluation of the industrial feasibility of the different processes for capturing CO_2.

The third paper was prepared by Ala Modarresi, Walter Wukovits, and Anton Friedl from Vienna University of Technology, Vienna in Austria. The title is *Application of exergy balances for evaluation of process configurations for biological hydrogen production* [38]. The authors applied exergy analysis to a novel process for biological production of hydrogen from biomass employing thermophilic and photo-heterotrophic bacteria. The exergy content of the process streams is calculated using a MS-Excel spreadsheet. The studied process incurs an exergy loss of 7–9% of the total exergy input. The efficiency based on chemical exergy of biomass feed and produced pure hydrogen refers to 36–45% depending on the configuration of the overall process. A parameter study underlines the strong dependence of obtained exergy efficiency from definition of obtained products and shows options for process improvement and optimisation. Based on the results the authors recommended that one avoids hydrogen losses or uses the chemical exergy of hydrogen in the tail gas to produce heat and power for the process. The most important contribution to the increase of the exergy efficiency comes from (re-) use of produced cell mass and non-fermentables as well as effluent from process as feedstock or nutrient, for heat and power generation or fertilizer, respectively. From the exergy point of view, the contribution of heat integration to the increase of exergy efficiency is negligible for the investigated low temperature process. The calculated improvement of exergy efficiencies only represents a theoretical maximum. The impact on exergy balance and efficiency has to be investigated in more detail considering also additional process steps necessary to implement the suggested process improvements.

3. Conclusions

We believe that the papers in this Special Issue of *Applied Thermal Engineering* will be of interest and relevance to a broad range of the scientific and industrial community and will bring to their attention the PRES Conference series as well. The special thanks belong to all reviewers, mostly members of the PRES International Scientific Committee [39]. Their dedicated effort made this Special Issues possible and to be published in a comparatively short term after the conference.

The next PRES'09 Conference was held in May 2009 in Italy, in the historical city of Rome. Another Special Issue should be presented in the foreseeable future. For the year 2010 PRES joined forces with CHISA again. PRES 2010 and CHISA 2010 will be organised as a part of the 7th European Congress of Chemical Engineering ECCE-7.

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