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Minimising emissions and energy wastage by improved industrial processes and integration of renewable energy

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ABSTRACT

This article provides an introduction to this Special Issue of Journal of Cleaner Production (JCLP), which contains thirteen, carefully selected articles from the 12th Conference, "**Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction**" – PRES'09. This issue builds upon the multi-year co-operation between the PRES conference planners and the JCLP. The articles cover important subjects of increased efficiency in energy generation and usage and in improvements in industrial process optimisation. The first group of five papers focuses upon recent advances in emissions reduction and the resulting energy penalties. The second group of four papers deals with improving the efficiency and reliability in the utilisation of renewable energy, where hydrogen and biodiesel are the key energy carriers. The final group of three papers focus on process integration challenges of sustainable energy systems and upon the challenges of industrial/societal integration of sustainable energy systems into regional sustainable development planning.

1. Introduction

Enhancing energy saving, decreasing global warming and reducing greenhouse gas emissions have become major technological, societal, and political imperatives. Being closely related to the total energy supply and usage, they are of strategic importance in all countries. Various conferences have been held to provide international avenues for closer co-operation among researchers. The series of conferences "**Pr**ocess Integration, Modelling and Optimisation for **E**nergy **S**aving and Pollution Reduction" (PRES) has been designed to play an increasingly important role in contributing to the solution of numerous, energy supply and demand challenges, through initiating co-operation among participants that often result in international projects, which are presented and discussed within the conferences. This is one of the most prestigious conference series in the field of improvements in energy and materials efficiency. The PRES conference series was first organised under the CHISA umbrella in 1998 in Prague. The 12th conference PRES'09 was held from 10 to 13 May, 2009 in Rome – Italy. The city has often been called "*Caput Mundi*" – Latin for "Capital of the World" and/or "*The Eternal City*" (Microsoft, Capitolium.org., 2010). Rome is widely regarded as one of the most beautiful ancient cities. Its history as a city spans over two and a half thousand years, as one of the founding and most powerful cities of Western Civilisation. It was the centre of the Roman Empire and the most powerful city in Europe. It dominated Europe, North Africa and the Middle East for over four hundred years from the 1st Century BC until the 4th Century AD, and during the Ancient Roman era (Omnibusol.com, 2010). Rome is still the centre of Italy and the place of many business, industries and is the regular host venue for numerous research and scientific meetings. During May 13–15, 2009 the PRES conference attracted a record number of delegates from 53 countries and 513 authors submitted 207 contributions. The participants were from most European countries as well as from Asia, Africa, Australia and North and South America.

The PRES conferences provide opportunities for cross-fertilisation of research and engineering, and are now in its second decade. They have been established to address issues relevant to process energy integration and minimising effluent emissions. Besides the extensive networking and exchange of ideas at the venues, PRES conferences have a comprehensive publication strategy. This Special Issue (SI) is already the fifth SI in the JCLP, dedicated to

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selected contributions from PRES conferences – PRES 2004 (Klemeš and Huisingh, 2008), PRES'03 (Klemeš and Huisingh, 2005a), PRES 2002 (Klemeš and Huisingh, 2005b), PRES'01 (Klemeš and Huisingh, 2004). The JCLP also devoted a SI to the PRES-related Workshop "Energy for Sustainable Future" (Dovì et al., 2009) and the EMINENT project (Klemeš et al., 2009). In addition to the JCLP, other well-known journals such as: *Cleaner Technologies and Environmental Policy* (Bulatov and Klemeš, 2009), *Applied Thermal Engineering* (Klemeš and Friedler, 2010), *Heat Transfer Engineering* (Klemeš and Stehlík, 2010), *Energy* (Klemeš and Lam, 2009), *Resources, Conservation and Recycling* (Klemeš et al., 2010) have been collaborating with PRES conference coordinators. The growing collaboration with the JCLP and the other publications is mutually greatly appreciated.

2. The main topics of this Special Issue

Twelve articles are included in this SI of the JCLP. They deal with three major topics: (i) Recent developments in emissions reduction; (ii) Improving efficiency and reliability in the generation of renewable energy; (iii) Responses to the challenges of integration of sustainable energy systems into industry and society. The authors come from the following 13 countries: Australia, Czech Republic, Finland, France, Israel, Malaysia, New Zealand, Philippines, Qatar, Slovak Republic, Sweden, the United Kingdom and the United States.

2.1. Recent developments in emissions reduction

This was one of the most important topics of the PRES'09 conference. The five best papers in this topical area were selected for inclusion in this SI.

The first paper, titled, "A graphical representation of carbon footprint reduction for chemical processes" (Tjan et al., 2010), was authored by Wendy Tjan, Raymond R. Tan, and Dominic C.Y. Foo, based upon joint research between the Department of Chemical and Environmental Engineering, University of Nottingham Malaysia and the Chemical Engineering Department, De La Salle University, Philippines. They emphasised that because climate change is becoming a major focus for industry and governmental agencies, many researchers are working on developing ways to make improvements. The authors developed and presented a new application of a graphical technique based on pinch concepts for company-level visualization, analysis and improvement of their carbon footprint. Their improved technique is based on the decomposition of total carbon footprint into material- and energy-based components, and also into internal and external components. The use of graphical display on the carbon footprint composite curves facilitates the analysis of potential process improvements and supports the screening and evaluation of cleaner production options. Two industrial case studies on the production of phyto-chemical extracts and bulk chemicals are used to illustrate the benefits of this new development.

The second article, titled, "Reducing the Energy Penalty of CO_2 Capture and Compression Using Pinch Analysis," was written by Trent Harkin, Andrew Hoadley and Barry Hooper from the University of Melbourne and Monash University in Australia (Harkin et al., 2010). The authors focus upon integration of CO_2 capture and storage (CCS) into coal fired power stations. They document that it is a way for significantly reducing the carbon emissions from stationary sources. A large part of the estimated CCS cost is due to the additional energy required for capturing, compressing, transporting and storing the CO_2, which reduces the energy efficiency of the power plant. The authors used pinch analysis and heat integration to reduce the overall energy penalty and therefore, the cost of implementing CCS for power plants whereby, the additional heat and power required for the CCS plant are provided by the existing power plant. Two existing, pulverised brown coal, power plants with new CCS plants based on solvent absorption were used as illustrative case studies to document how the energy penalty can be reduced by up to 50% through appropriate heat integration, using power plant designs with conventional CCS technology (IPCC, 2005) as a benchmark. They also showed that the energy penalty could be reduced further by pre-drying the coal. The results indicate that with heat integration and coal pre-drying, a CCS retrofit may not incur the large energy penalties quoted in the literature.

The third paper in this group titled, "The influence of operational flexibility on the exploitation of CO_2 reduction potential in industrial energy production" (Siitonen and Ahtila, 2010) was authored by Sari Siitonen and Pekka Ahtila from the Department of Energy Technology, School of Science and Technology, Aalto University in Finland. They documented that the emission reduction potential of an energy conservation investment depends on many factors, – including energy prices, the system efficiency, and the operation schedules. The '*EU emissions trading scheme*' has made the investment analysis more complicated and has increased the economic value of operational flexibility under fluctuating carbon prices. According to the authors, increasing operational flexibility enables economic optimisation, which may also result in improvements in CO_2 reductions. The case study is based on analyses of the effects of an energy conservation investment in the pulp and paper industry, where the deviation from the expected emission reduction, was around 30% during 2000–2007. Uncertainties in the energy markets, such as fluctuating energy prices, increasing dependence on imported fuels and changing climate policy, increased the interest of industrial actors to invest in higher operational flexibility of energy production. From the policy-making perspective, it is important to understand that increasing operational flexibility has the potential to improve sustainability but that the flexibility can also be used to improve short-term profitability, which may, unfortunately, result in less than optimum CO_2 reduction.

The fourth paper, titled, "Comparison of Ammonia, Mono-EthanolAmine, DiEthanolAmine and MethylDiEthanolAmine Solvents to Reduce CO_2 Greenhouse Gas Emissions" (Rivera-Tinoco and Bouallou, 2010) was authored by Rodrigo Rivera-Tinoco and Chakib Bouallou, from Centre Energétique et Procédés, Ecole des Mines de Paris – France. Their paper reports on an experimental study comparing the efficiency of several solvents for CO_2 absorption from flue gases. They found that the solvent with the highest absorption capacity contains 5% ammonia, based upon tests done at 278 K and 303 K. CO_2 absorption by ammonia is faster than and superior to that with MethylDiEthanolAmine (MDEA). Those observations can be beneficially used for improving the efficiency of CO_2 capture.

The fifth article is titled, "New approach to common removal of dioxins and NO_x as a contribution to environmental protection" (Dvořák et al., 2010). It was authored by Radek Dvořák, Petr Chlápek, David Jecha, Radim Puchýř and Petr Stehlík, from Brno University of Technology, Institute of Process and Environmental Engineering VUT UPEI, and from EVECO Brno Ltd, in the Czech Republic. According to the authors meeting air emissions' limits is the most important issue in the field of solid waste processing. Their research was directed mainly to prevent the generation of hazardous emissions. In some cases this was not feasible and secondary treatment methods had to be applied. The authors developed a potentially important contribution to the portfolio deNO_x methods in the form of a novel approach. The REMEDIA® filtration material designed to capture particulates as well as

Polychlorinated dibenzo-*p*-dioxins and furans (also known as dioxins), was tested for selective catalytic reduction of NO_x. The average deNO_x reduction by this filtration material was 33.2% under standard conditions with a dosage of 25% ammonia solution in a molar ratio of $NH_3/NO = 1.1$ mol/mol. The authors documented that this method should be combined with selective non-catalytic reduction of NO_x. This combination should be applied for NO_x concentrations ranging from 450 to 650 mg/Nm^3, as this allows achieving NO_x concentrations lower than the 200 mg/Nm^3 limit set by EU regulations.

2.2. Generation and impact of renewable fuels

The second thematic group of papers consists of four papers dealing with production of hydrogen and diesel from renewable sources. Again the authors came from diverse countries, which demonstrates the geographical breadth of research in this field.

The first paper in this group, titled, "Modelling and optimisation for design of hydrogen networks for multi-period operation" (Ahmad et al., 2010), was authored by Muhammad Imran Ahmad, Nan Zhang, and Megan Jobson, from the Centre for Process Integration, in the School of Chemical Engineering and Analytical Science, of The University of Manchester, UK. Hydrogen management is a problem of increasing importance. Hydrogen consumption of refineries is rising sharply with the construction and operation of additional capacities of hydrocracking and hydrotreating units in order to comply with cleaner fuel specifications. The authors of this paper developed a novel approach for the design of flexible hydrogen networks that can remain optimally operable under multiple periods of operation, reflecting the changing operating conditions of refinery processes. The new methodology works effectively with operational variables such as: pressure differences, maximum capacity of existing equipment, and optimal placement of new equipment such as compressors. The resulting hydrogen networks can operate under multiple periods of operation with lower cost compared to hydrogen networks developed for using single-period design approaches.

The second paper, titled "Cleaner Pathways of Hydrogen, Carbon Nano-Materials and Metals Production via Solar Thermal Processing" (Ozalp et al., 2010) was authored by Nesrin Ozalp, Michael Epstein, and Abraham Kogan from – the Mechanical Engineering Dept. at Texas A&M University at Qatar and from the Weizmann Institute of Science, Solar Research Facilities, Rehovot, Israel. The authors described several solar thermo chemical processes for the production of hydrogen, using carbon nano-particles, industrial grade carbon black, and metals with substantially reduced CO_2 emission footprint. Finally, the paper provides an example solar windowed reactor for clean production of hydrogen.

The third paper, titled, "Economic Impact of the Integration of Alternative Vehicle Technologies into the New Zealand Vehicle Fleet" (Leaver and Gillingham, 2010) was authored by Jonathan Leaver from Sustainable Energy Research Group, Unitec NZ, in Auckland, New Zealand and Kenneth Gillingham from Precourt Energy Efficiency Centre at Stanford University in California, USA. They developed a multi-regional integrated energy systems model to assess the economic impact of the hydrogen fuel cell, hydrogen internal combustion, and battery electric technologies on the economy of New Zealand. Their results documented that a hydrogen fuel dominant vehicle fleet offers economic savings over a conventional fleet but requires extensive carbon dioxide sequestration capacity because 75% of hydrogen fuel production is currently derived from fossil fuel. If the oil price would be increased from US$ 120 to US$ 240 per barrel by 2030, and the carbon tax increased from US$ 30 to US $90/t CO_2 equivalent, the savings would increase from −65% to +25%. In summary, their study suggests that the expected improvements in the various technologies are such that the lowest average cumulative cost of achieving mobility could occur in a Hydrogen Fuel Cell vehicle only scenario. Limiting future alternative vehicle technologies to Battery Electric Vehicles results in the lowest greenhouse gas emission and therefore, is the preferred option if the highest priority is to minimize greenhouse gas emissions. These conflicting results suggest that New Zealand policymakers have to carefully consider their objectives in choosing policies leading the way for any one particular energy future.

The last paper in this group, titled "Second generation diesel fuel from renewable sources" (Mikulec et al., 2010), was authored by Jozef Mikulec, Ján Cvengroš, Ľudmila Joríková, Marek Banič, and Andrea Kleinová from the Slovnaft VÚRUP in Bratislava and the Faculty of Chemical and Food Technology at the Slovak University of Technology in Slovakia. The paper is devoted to the issue of direct transformation of triacylglycerols (TAG) into diesel fuel additives by applying commercially available hydrorefining catalysts. The authors demonstrated that during hydrodesulphurisation, a hydrodeoxygenation also takes place, and TAG can be converted to the fuel biocomponent by adding 6.5% vol. of TAG to atmospheric gas oil. In this way, after hydroprocessing at mild conditions, gas oil containing 5–5.5% of biocomponent was produced that fulfils the standard performance and emission requirements.

2.3. Process integration challenges of sustainable energy systems

The last topic contains three papers, which deal with industrial case studies and conceptual designs in the following sectors: milk powder production, pulp and paper production, and heating of a mining site.

The first article, titled, "The challenge of integrating non-continuous processes – milk powder plant case study" (Atkins et al., 2010) was authored by Martin J. Atkins, Michael R.W. Walmsley, and James R. Neale, from Hamilton – Energy Research Group, School of Science & Engineering at University of Waikato, New Zealand. The authors investigated integration of non-continuous processes within an industrial setting. The integration of non-continuous processes, such as a milk powder plant, presents a challenge for existing process integration techniques, because milk production varies considerably with time. They investigated the heat integration potential by using a heat recovery loop and stratified tank at a typical New Zealand dairy factory. They developed a procedure for maximising the heat recovery by varying the temperature of the hot fluid in the recirculation loop.

The second contribution titled, "Influence of Short-term Variations on Energy-Saving Opportunities in a Pulp Mill" (Persson and Berntsson, 2010) was authored by Jörgen Persson and Thore Berntsson, from Chalmers University of Technology, Department of Energy and Environment, Sweden. They documented significant opportunities for energy savings in the energy system of a Kraft pulp mill – up to 18% of the mill's previous steam use. Short-term variations in the process were studied in order to identify and quantify their influence on the energy-saving opportunities. The findings indicate that the energy-saving reductions due to short-term process variations are not significant. They were approximately 10%, while almost 90% of the steady-state energy-saving opportunities remained. The influence of variations was detected largely when using monthly averages. Compared with using ten-minute averages, 65% of the influences on the total energy-saving opportunities were identified when using monthly averages. They found that an enlarged heat transfer area provided additional energy savings in some situations, although it is doubtful whether the relatively small savings would justify the extra investment costs.

The last article in this theme is from Swerea MEFOS AB and Luleå University of Technology in Sweden. It is titled "Conceptual design of

an integrated heating system at LKAB Malmberget with consideration of social-environmental damage costs" (Wang et al., 2010) and was authored by Chuan Wang, Samuel Nordgren, Bo Lindblom, Stefan Savonen, Theresa Hedpalm, Mikael Larsson, and Robert Hansson. LKAB Malmberget is a Swedish mining site located at Malmberget, Sweden. Seven boiler centres are located in the north part of Malmberget, forming a decentralized heating system for heating buildings and the mine ventilation air. Most of the system infrastructure is due for replacement. The paper deals with the optimal design and operation of the heating system. An optimisation model based on the mixed integer linear programming was developed. The modelling results document that a lower cost could be achieved when a waste heat recovery boiler is installed at the older pelletisation plant to recover sensible heat from flue gas. An environmentally friendly heating system could be developed, step-wise. It was recommended to build a centralized heating system first, followed by expansion steps for further improving the fuel utilisation rate.

3. Conclusions

The PRES conferences evolved over the years from the original focus introduced in 1998, which was, 'process integration for energy saving and pollution reduction,' to a wider coverage that is very closely related to cleaner production. It evolved, in parallel with the broader development of priorities in the industrial production and related research commitments on environmental, social and economic challenges. This development can be traced by the new, 'specialised sessions' that were introduced. In sequence the following themes were added: a. Combined heat and power and combined cycles, b. Heat exchangers as equipment and integrated items, and c. Energy efficient drying technologies. The second phase evolved to focus upon specific industrial sectors such as: a. pulp and paper, b. sustainable food and drink production as well as upon specific production modes such as: a. batch processes, b. dynamic, flexible and sustainable plant operation, c. Industrial and experimental studies and d. Industrial application and optimal design. The third steps extended the scope of process integration by including process integration for sustainable development and the Kyoto Protocol, CO_2 sequestration, and waste minimisation. The fourth phase included introduction of sessions focussed upon: a. low emissions, cleaner technologies, b. sustainable processing and production, c. integrated and multifunctional operations, d. waste minimisation/waste prevention, e. thermal treatment of waste, especially via CHP waste to energy systems. The most recent phase was driven by integration of renewable energy into industrial production systems. This led to focus upon issues such as: a. integration of renewables including biomass and energy conversion technologies, b. operational research and supply chain management and advanced biofuel production from renewable resource. As a complement to these developments, various supporting approaches have been incorporated such as: e-learning, e-teaching and e-knowledge, which are related not only academia, but also FPD (Further Professional Development), CFD (Computational fluid Dynamics) and numerical heat transfer.

Each newly introduced topical focus was in response to the research and industrial needs and has been continued, only as long as it was supported by the sufficient demand and the interest expressed by the number of good quality contributions. This natural development keeps the PRES conferences, unlike some traditionally structured conferences, responding dynamically to the developing needs of the modern world, whose citizens have been, step-by-step realizing the necessity of the essentiality of integrating cleaner production and sustainable development.

We are confident that the papers in this SI of *Journal of Cleaner Production* will be of interest and relevance to a broad range of the scientific community and hope it will also bring to their attention the PRES Conference series. The PRES conference for 2010 will be a joint conference with CHISA 2010; it will be held in Prague from August to September 2010 as part of the 7th European Congress of Chemical Engineering ECCE-7. PRES 2010 received nearly 450 abstracts (PRES Conference, 2010).

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