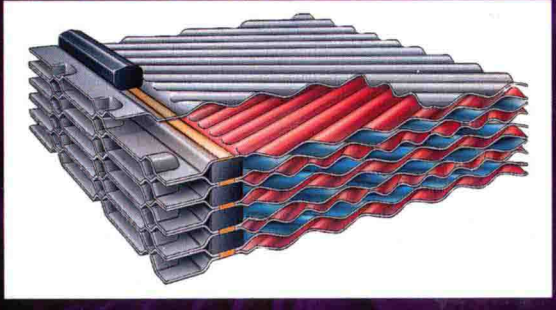
COMPACT HEAT EXCHANGERS FOR ENERGY TRANSFER INTENSIFICATION

Low Grade Heat and Fouling Mitigation



Jiří Jaromír Klemeš · Olga Arsenyeva
Petro Kapustenko · Leonid Tovazhnyanskyy

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COMPACT HEAT EXCHANGERS FOR ENERGY TRANSFER INTENSIFICATION

Foreword

Compact heat exchangers, while accounting for perhaps 10% of the worldwide market for heat exchangers, have in recent years, as it has been suggested, seen their sales increase by about 10% per annum, compared to 1% for all heat exchangers. The majority of automotive heat exchangers are 'compacts', and compact heat exchangers of all types are being used increasingly where fluid inventory is an important factor, such as in refrigeration and heat pumping equipment using flammable working fluids and in chemical processes where the 'process intensification' approach leads to increased safety. Aerospace and electronics are also major uses, where small size and low weight are important. The chemical process industries were relatively slow to adopt these units because of concerns about fouling, except in areas such as cryogenics, where the aluminium plate–fin heat exchanger is difficult to improve for flexibility. Where the demands on space and efficiency are great – such as off-shore platforms for oil and gas processing – there are hundreds of compact examples such as printed circuit heat exchangers abound, as well as in other uses where fouling can be avoided or controlled. The mitigation of fouling in all heat exchanger systems, but particularly in compact units and those with enhanced features on the surface to encourage better heat transfer, remains key to their wider application. The importance attached to this topic is evident in this book.

Often the theoretical attractiveness of cycles – refrigeration/heat pumping and power generation – is countered by the practical realisation that the cycle efficiency depends upon heat exchanger approach temperatures as well as expander or compressor efficiencies. One sees a continuing trend towards the use of 'compacts' in cycles dealing with low-grade heat – vapour compression and absorption/adsorption cycles and Rankine-based organic power generation cycles. Many commercial packages in refrigeration and heat pump duties use plate heat exchangers, for example – where liquids are the heat sources or sinks. In examples where air is a source or sink, the need for air-side extended surfaces, because of modest heat transfer coefficients, provides greater challenges in the desire for compact units. This has led to much research on modifications to fins – the plate–fin characteristics detailed by Kays and London decades ago remain topical and authors such as Ralph Webb and John Hesselgreaves have tackled enhanced surfaces in single-phase and, increasingly important, in two-phase heat transfer.

While much has been written about the many types of compact heat exchangers and their design and optimisation, much less is available outside specialist organisations such as HTRI and HTFS on how such heat exchangers can be integrated into low-grade heat recovery duties (and other applications in the process sectors), and the use of process integration methodologies to implement this is one of the great strengths of the authors of this book.

I am particularly pleased to see a chapter on the integration of intensified compact heat exchangers into heat exchanger networks. Some years ago, I collaborated with Jiří Klemeš when he was at UMIST (now the University of Manchester) on a European project in this topic. Our aim was to integrate intensified unit operations

(not just compact heat exchangers) into Process Integration methodologies. It is fair to say that a lack of methodologies, or the potential users' awareness about them, has been a significant hindrance to the wider take-up of intensified plant, including 'compacts', and not just in the chemical process industries. Implicit in the chapter and section headings is the extension of the methodology outside the process industries to areas such as building heating systems, where the experience of the co-authors in areas such as district heating will be brought to the fore.

Not neglected are the fundamentals, so the heat exchanger designer should have access to up-to-date correlations and data to allow the design of several types of compact heat exchangers for operation in the single phase, as well as boiling and condensing duties. The backing up of the analyses with case studies will be of inestimable value to those who are less familiar with the analytical approaches and desire to see verification of design procedures in practice.

This text encompasses all the important features associated with the successful design and implementation of many types of compact heat exchangers in a wide variety of potentially demanding and valuable applications – the emphasis on fouling mitigation, uses in heat pumping and power cycles and Process Integration gives the book a unique flavour that will ensure its value across a wide readership.

Professor David Reay
David Reay and Associates
Lancashire, United Kingdom

Preface

The book has been based on the long-term collaboration amongst the authors, which started with the British Council Know-How–funded LINK project in 1993. To exploit a synergy between the Centre of Excellence in Process Integration at the University of Manchester Institute of Science and Technology – UMIST with previously closed (secret) leading university of the former Soviet Union just opening to the world in a newly independent Ukraine proven to be very beneficial. It had been even boosted when one of the leading academics in Kharkiv started to use the accumulated know-how for a high–tech, small to medium enterprise 'Spivdruzhnist-T' closely collaborating with UMIST and a world-leading plate heat exchanger manufacturer Alfa Laval. This brought a strong industrial experience into the joint research and collaboration.

The joint research was initiated in 1993 by The British Know-How–funded REAP project 'Training educational courses on energy saving integrated processes in Ukraine' with Ukraine. Technology transfer and collaborative preparation of degree courses for Ukrainian Universities.

Another very beneficial factor boosting the research and know-how have been several successful project supported by the European Community. They should be listed and highly praised as they provided the ground for the continuous collaboration amongst the authors of this book as well some other leading partners in the field of advanced and compact heat exchangers.

They started in 1997–1999 by INTAS-96-2017, 'Integration of alternative energy sources and energy saving processes into regional energy systems', with partners from France, Ukraine and the United Kingdom and continued in 1999–2001 by the EU Programme INCO-COPERNICUS 'Sustainable Development by Retrofit and Debottlenecking for Energy Based System (REDBAS)'. Research & Technology Development Project 'PL 5046' with partners Romania, the Czech Republic, Ukraine, Belgium and the United Kingdom.

The following EU programme SYNERGY project was 'Analysis of possibilities of energy saving and application of non-traditional sources of energy, with prognostication of corresponding reduction in green-house gasses emissions in the North-East Ukraine', 2000–2001. Partners were Ukraine, Germany and the United Kingdom. In 2001–2004 followed the EU INCO-COPERNICUS project ICFP5-1999-A2PRO1 (INCO-COPERNICUS-2), 'DEMACSYS – Development and Application of Decision-making Computerised System for Environmental Impact Assessment and Pollution Reduction Management in Chemical Industrial Areas' with partners from Italy, Greece, Russian Federation, and Ukraine, and also the EO FP6 Horizontal Research Activities Including SMEs – Collaborative Research project 'SHERPA – Sustainable Heat and Energy Research for Heat Pump Applications' with partners France, Sweden, Ireland, Bulgaria, Czech Republic, Poland, Spain, the Netherlands, Austria, Italy, Ukraine, Poland and Germany.

In 2001–2004 came the TACIS/TEMPUS CD JEP-21242-20000/UKR 'Education development in environmentally safe energetics' with partners from Spain, France and Ukraine, and in 2006–2008 the EU FP6 Co-operative Research Project 'CONNECT Advanced Controllers for Economic, Robust and Safe Manufacturing Performance' with partners from Austria, Greece, Norway, Slovenia, Ukraine and the United Kingdom.

Very important for the creation of this book was the EC FP7 project 'Intensified Heat Transfer Technologies for Enhanced Heat Recovery' – INTHEAT, Grant Agreement №. 262205, in 2010–2012. Its contributing partners were Process Integration Ltd (UK), Cal Gavin (UK), Akstionerne Tovarystvo 'Spivdruzhnist-T' (Ukraine), Makatec Apparate GmbH (Germany), Oikos, svetovanjezarazvoj, d.o.o. (Slovenia), The University of Manchester (UK), the University of Bath (UK), Paderborn University (Germany), the University of Pannonia (Hungary) and EMBaffle (The Netherlands). The academic partners perform targeted research for the benefit of the involved SMEs for improving their competitiveness and active contribution to the EU's sustainability objectives.

In 2012–2015 another EC FP7 FP7-PEOPLE-2011-IRSES, MARIE CURIE ACTIONS, International Research Staff Exchange Scheme, brought opportunities for long time secondments, which were crucial for writing this book. The project 'Distributed Knowledge-Based Energy Saving Networks' – DISKNET, Grant Agreement No: PIRSES-GA-2011-294933, enabled the coordination among the following partners: the University of Pannonia (Hungary), the Centre for Research and Technology Hellas – CERTH (Greece), the University of Zagreb – Faculty of Mechanical Engineering and Naval Architecture – UNIZAG-FSB (Croatia), Aristotle University of Thessaloniki – AUTH (Greece), National Technical University 'Kharkiv Polytechnic Institute' – NTU KhPI (Ukraine), The Hashemite University (Jordan) and the University Mohammed I (Morocco).

In 2012–2015, another major contribution brought an EC project FP7-ENERGY-2011-2, 296003 'EFENIS Efficient Energy Integrated Solutions for Manufacturing Industries' with partners The University of Manchester (UK), Bayer Technology Services Gmbh (Germany), MOL plc (Hungary), VestasAircoil AS (Denmark), IPLOM, SpA (Italy), ENN Group (China), Teknologian Tutkimuskeskus VTT (Finland), AO Spivdruzhnist-T Limited Liability Company (Ukraine), ESTIA Consulting & Engineering S.A. (Greece), PannonEgyetem – University of Pannonia (Hungary), Universitaet Paderborn (Germany), Aristotelio Panepistimio Thessalonikis – Aristotle University (Greece), Università degli Studi di Genova (Italy), Univerza v Mariboru – University of Maribor (Slovenia), Hanyang University (Korea) and Alexandra Instituttet A/S (Denmark).

Also the NATO Scientific and Environmental Division Priority Area in High Technology Programme HTECH.LG 941 Creative Energy Saving Technologies Research Based on Thermodynamic Optimum Synthesis on Graphs, with Ukraine academia and industry in 1994–1998 and in 1995–1998 NATO Scientific Affairs Division Priority Area on Computer Networking programme CN.SUPPL 951064 with Ukraine academia and industry should be praised.

This book is a strong example of how researchers from different parts of Europe can closely and effectively collaborate in research and technology development and how their joint effort can be mutually beneficial, as well as benefit the wider scientific community.

The authors appreciate all these projects and collaborations that have been a major source of information for this book. They believe that the results and experience presented in this book will be of wide interest to the community and initiate even more collaboration and applicable research results in the future.

Authors

Professor Habil Jiří Jaromír Klemeš, DSc, is a Pólya professor and a head of the Centre for Process Integration and Intensification – CPI^2 at the University of Pannonia, Veszprém in Hungary. Previously, he worked for nearly 20 years in the Department of Process Integration at UMIST and after the merge at The University of Manchester, United Kingdom, as a senior project officer and honorary reader. He holds a DSc from the Hungarian Academy of Sciences, an H DSc (doctor honoris causa) from National Polytechnic University Kharkiv, Ukraine; the University of Maribor, Slovenia; and Politehnica University of Bucharest, Romania. He has many years of research and industrial experience, including research in process and heat integration, sustainable technologies and renewable energy, which has resulted in many successful industrial case studies and applications. He has extensive experience in managing major European and UK know-how projects and consulted widely on energy saving and pollution reduction. Previously, Professor Klemeš ran research in mathematical modelling and neural network applications at the Chemical Engineering Department, University of Edinburgh, Scotland. He has been a distinguished visiting professor at University Technologi Malaysia, Universiti Technologi Petronas in Malaysia, South China University of Technology Guangzhou, Tianjin University, Jiaotong Xi'an University in China, University of Maribor, Slovenia, and Brno University of Technology, the Czech Republic. He has unique success record in managing and coordinating research projects funded by the European Community FP2 to FP7, UK Know How Fund, NATO High Technology, European Training Foundation, and others. He is an editor-in-chief of *Chemical Engineering Transactions*; subject editor of *Journal of Cleaner Production* and *Energy*; executive editor of *Applied Thermal Engineering* and *Cleaner Technologies and Environmental Policies*; editor of *Resources, Conservation and Recycling*, *Integrated Technologies and Energy Saving*, and *Theoretical Foundations of Chemical Engineering*; guest editor of *Applied Energy* and several others. In 1998, he founded and has been since the president of the International Conference *Process Integration, Mathematical Modelling and Optimisation for Energy Saving and Pollution Reduction—PRES* (www.conferencepres.com). He is chair of the CAPE Working Party of the European Federation of Chemical Engineering. Among his books are *Sustainability in the Process Industry: Integration and Optimization* (McGraw-Hill), edited books *Process Integration Handbook* and *Handbook of Water and Energy Management in Food Processing* (Woodhead Cambridge/Elsevier) and *Assessing and Measuring Sustainability in Engineering* (Elsevier).

Professor Olga P. Arsenyeva, DSc, is associate professor in the Department of Integrated Technologies, Processes and Apparatuses at the National Technical University, Kharkiv Polytechnic Institute (NTU KhPI), Kharkiv, Ukraine. She graduated from the Kharkiv State Polytechnic University (Kharkiv, Ukraine), worked for the Centre for Energy Saving Process Integration (CESPI) at NTU KhPI, which was founded following the program for British Council Training and Academic Link, where she did her PhD under the supervision of Professor Leonid Tovazhnyianskyy.

In 2005, she joined Professor Petro Kapustenko in AO 'Spivdruzhnist-T' Engineering Company (Kharkiv, Ukraine). Both CESPI and AO 'Spivdruzhnist-T' had close relations with the Department of Process Integration UMIST and Centre for Process Integration – CPI^2 of Pannonia University. In 2014, she was awarded the DSc at NTU KhPI. The objects of her research are plate heat exchangers design and application and Process Integration.

Professor Petro O. Kapustenko, PhD, is professor and the deputy head, since 1994, of the Centre for Energy Saving Process Integration at National Technical University Kharkiv Polytechnic Institute (NTU KhPI), Kharkiv, Ukraine, founded with the support of DPI UMIST under British Council Know How Link project. He graduated in 1972 from the same university. In 1980, he earned his PhD at DI Mendeleev Russian Chemical Technology University in Moscow. In 2000, he became professor at NTU KhPI. In 1991, he cofounded Sodrugestvo-T engineering company and become its chief executive officer. The company has been involved in a number of projects funded by the EC and the World Bank aimed at the renovation of district heating networks and industry using Process Integration methods. They implemented advanced energy saving equipment like CHP units, compact heat exchangers, heat pumps, modern district heating substations and others, mostly in Ukraine and the Russian Federation. Professor Petro Kapustenko is also member of the Ukrainian Building Construction Academy.

Professor Leonid L. Tovazhnyanskyy, DSc, professor and head of the Department of Integrated Technologies, Processes and Apparatuses (ITPA) at the National Technical University Kharkiv Polytechnic Institute, Kharkiv (NTU KhPI), Ukraine. He graduated in 1959 from the Kharkiv V.I. Lenin Polytechnic Institute in the former Soviet Union and in 1966 was awarded a PhD. In 1988, he received his DSc at DI Mendeleev Russian Chemical Technology University in Moscow. Since 1995, he has been the director of the Centre for Energy Saving Integrated Processes and in 2000 he became the rector of the NTU KhPI and served several terms as the rector. After that he became an Honorary Rector of NTU KhPI. His research interests include heat and mass transfer processes in channels of complicated geometry, including various types of channels with corrugated walls, for industrial plate heat exchangers, optimisation of heat exchanger networks and Process Integration. Leonid L. Tovazhnyanskyy is corresponding member of the National Academy of Sciences of Ukraine.

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