# **VDI Heat Atlas**

Verein Deutscher Ingenieure VDI-Gesellschaft Verfahrenstechnik und Chemieingenieurwesen (GVC) Editor

# **VDI Heat Atlas**

# **Second Edition**

With 1011 Figures and 539 Tables



Editor
VDI e. V.
VDI-Gesellschaft Verfahrenstechnik und Chemieingenieurwesen
(VDI-GVC)
VDI-Platz 1
40468 Düsseldorf
Germany

1st edition published in 1993 by VDI-Verlag GmbH, Düsseldorf.

ISBN 978-3-540-77876-9 e-ISBN 978-3-540-77877-6 Print and electronic bundle ISBN 978-3-540-79999-3 DOI 10.1007/978-3-540-77877-6 Springer Heidelberg Dordrecht London New York

Library of Congress Control Number: 2010924812

## © Springer-Verlag Berlin Heidelberg 2010

This work is subject to copyright. All rights are reserved, whether the whole or part of the material is concerned, specifically the rights of translation, reprinting, reuse of illustrations, recitation, broadcasting, reproduction on microfilm or in any other way, and storage in data banks. Duplication of this publication or parts thereof is permitted only under the provisions of the German Copyright Law of September 9, 1965, in its current version, and permission for use must always be obtained from Springer. Violations are liable to prosecution under the German Copyright Law.

The use of general descriptive names, registered names, trademarks, etc. in this publication does not imply, even in the absence of a specific statement, that such names are exempt from the relevant protective laws and regulations and therefore free for general use.

Printed on acid-free paper

Springer is part of Springer Science+Business Media (www.springer.com)

# **Preface to the Second English Edition**

The VDI-Wärmeatlas or VDI Heat Atlas has a long-lasting history and it can be considered as a standard book for heat exchanger and process engineering equipment design. It is not conceived as a textbook presenting an overall view of the theoretical or experimental findings in heat transfer sciences. The aim was and is to present and explain the state of the art of engineering methods to solve industrially relevant heat transfer problems for apparatus design and process modeling. The first German edition was published in 1963. The sixth German edition was translated into English to meet the demands of the more and more internationally acting industry. This first English edition was published in 1992. Since then, the German edition was regularly updated until the tenth edition published in 2006.

In view of today's globally acting industry, the editorial board felt the necessity to revise the English edition in order to account for the most recent state of our knowledge. Instead of only translating the latest German edition, we preferred restructuring it at the same time because this also enabled us to include new subjects and to update methods according to the recent state of the art. This new structure will also serve as a basis for the forthcoming German edition.

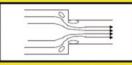
On behalf of the editorial board, I express my sincere thanks to the authors of the various sections for their contributions and kind cooperation. The editorial work was coordinated and assisted by Mrs. Sigrid Cuneus from Springer-Verlag, Berlin. We are indebted to her for the efficient work and pleasant collaboration. We are also grateful to Mrs. Tina Shelton from the Reference and Database Publishing group, Springer Reference Editorial, India, who handled the editorial workflow.

Professor Dr.-Ing. Peter Stephan, Editor-in-Chief Darmstadt, May 2010

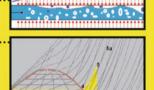
# **WE SUPPORT YOU**

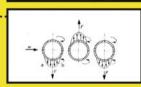
- → Heat Exchanger / Heat Transfer
- → Pressure Drop
- → Combustion
- → 2 Phase Flow
- → Properties of Gases and Fluids
- → Tube Bundle Vibration
- → Steam Generators for Chemical Plants / Power Plants

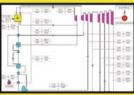












## Contact us

KED GmbH
Talstr. 3
63517 Rodenbach
Germany

christian.voneichhain@ked.de www.ked.de/heatatlas

# **Editorial Board to the Second English Edition**

## Prof. Dr.-Ing. Peter Stephan

Technische Universität Darmstadt Fachbereich Maschinenbau Institut für Technische Thermodynamik Petersenstraße 30 64287 Darmstadt Germany pstephan@ttd.tu-darmstadt.de

## Prof. Dr.-Ing. Stephan Kabelac

Helmut-Schmidt Universität
Universität der Bundeswehr Hamburg
Institut für Thermodynamik
Holstenhofweg 85
22043 Hamburg
Germany
Kabelac@hsu-hh.de

## Prof. Dr.-Ing. Matthias Kind

Karlsruher Institut für Technologie (KIT) Institut für Thermische Verfahrenstechnik Kaiserstraße 12 76131 Karlsruhe Germany matthias.kind@kit.edu

#### Prof. Dr.-Ing. Holger Martin

Karlsruher Institut für Technologie (KIT) Institut für Thermische Verfahrenstechnik Kaiserstraße 12 76131 Karlsruhe Germany holger.martin@kit.edu

# Prof. Dr.-Ing. Dr. h. c. Dieter Mewes

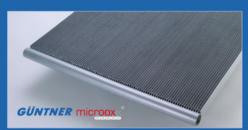
Leibniz Universität Hannover Institut für Mehrphasenprozesse IMP Callinstraße 36 30167 Hannover Germany mewes@imp.uni-hannover.de

#### Prof. Dr.-Ing. Karlheinz Schaber

Karlsruher Institut für Technologie (KIT) Institut für Technische Thermodynamik und Kältetechnik ITTK Engler-Bunte-Ring 21 76131 Karlsruhe Germany Karlheinz.schaber@kit.edu



# The new condenser with microox® technology.



# Leading with smart systems.

- High efficiency EC fans and Güntner Motor Management (GMM) reduce operating costs
- Modern design for perfect integration into application
- Modular extendable construction

For further information, visit: www.guentner.de

Güntner AG & Co. KG Hans-Güntner-Straße 2 - 6 82256 Fürstenfeldbruck Tel.: +49 8141 242-0



# **Table of Contents**

List	List of Contributorsxvii			
Α	Symbols, Units and Dimensionless Numbers			
<b>A1</b>	Symbols and Units			
<b>A2</b>	Dimensionless Numbers			
В	Fundamentals of Heat Transfer			
B1	Fundamentals of Heat Transfer			
C	Fundamentals of Heat Exchanger Design			
C1	Thermal Design of Heat Exchangers			
C2	Overall Heat Transfer       67         Wilfried Roetzel · Bernhard Spang			
C3	<b>Typical Values of Overall Heat Transfer Coefficients</b>			
C4	Fouling of Heat Exchanger Surfaces			
<b>C</b> 5	Heat Exchanger Networks			
C6	Costs and Economy of Heat Exchangers			
D	Thermophysical Properties			
D1	Calculation Methods for Thermophysical Properties			
D2	Properties of Selected Important Pure Substances			
	D2.2 Properties of Dry Air			

	D2.3 Properties of Nitrogen
	<b>D2.4 Properties of Carbon Dioxide</b>
	D2.5 Properties of Oxygen
	<b>D2.6 Properties of Ammonia</b>
	<b>D2.7 Properties of R134a (1,1,1,2-tetrafluoromethane)</b>
D3	Properties of Pure Fluid Substances
	D3.2 Properties at Saturation
D4	Properties of Industrial Heat Transfer Media
	D4.2 Cryostatic Bath Fluids, Aqueous Solutions, and Glycols
	<b>D4.3 Oil-based and Synthetic Heat Transfer Media</b>
D5	Properties of Multicomponent Fluid Mixtures
	<b>D5.2 Polymer Solutions: Vapor–Liquid Equilibrium and Diffusion Coefficients</b>
	D5.3 Vapor Pressures of Aqueous Salt Solutions
D6	Properties of Solids and Solid Materials
	<b>D6.2 Polymers</b>
	D6.3 Thermal Conductivity of Packed Beds
	D6.4 Industrial Refractories
	D6.5 Insulations Materials

	<b>D6.6 Thermal Conductivity of Insulation Materials Depending on Moisture Content and Temperature 595</b> <i>Fabian Ochs · Hans Müller-Steinhagen</i>
	<b>D6.7 Thermal Conductivity of Building Materials</b>
E	Heat Conduction
E1	Steady-State Heat Conduction
<b>E2</b>	Transient Conduction in Stagnant Media
F	Free Convection
F1	Heat Transfer by Free Convection: Fundamentals
F2	<b>Heat Transfer by Free Convection: External Flows</b>
F3	Heat Transfer by Free Convection: Internal Flows
F4	<b>Heat Transfer by Free Convection: Special Cases</b> Werner Kast · Herbert Klan · (Revised by André Thess)
F5	Thermal Output of Heating Appliances Operating with Hot Water
G	Forced Convection
G1	Heat Transfer in Pipe Flow
G2	Heat Transfer in Concentric Annular and Parallel Plate Ducts
G3	Heat Transfer in Helically Coiled Tubes
G4	Heat Transfer in Flow Past a Plane Wall
G5	Heat Transfer to Single Cylinders, Wires, and Fibers in Longitudinal Flow
G6	Heat Transfer in Cross-flow Around Single Tubes, Wires, and Profiled Cylinders
G7	Heat Transfer in Cross-flow Around Single Rows of Tubes and Through Tube Bundles
G8	Shell-Side Heat Transfer in Baffled Shell-and-Tube Heat Exchangers

G9	Fluid-Particle Heat Transfer in Flow Through Packed Beds of Solids
<b>G10</b>	Impinging Jet Flow Heat Transfer
Н	Boiling
H1	Fundamentals of Bubble Formation
H2	Pool Boiling
НЗ	Flow Boiling – An Introduction
	<b>H3.1 Flow Patterns in Evaporator Tubes</b>
	<b>H3.2</b> Pressure Drop in Evaporator Tubes
	H3.3 Subcooled Boiling
	H3.4 Saturated Flow Boiling
	H3.5 Critical Boiling States in Flowing Liquids
	H3.6 Postdryout Heat Transfer in Flow Boiling
	H3.7 Flow Boiling of Mixtures
	H3.8 Special Symbols and References Used and Cited in Subchaps. H3.1–H3.7
J	Condensation
J1	Filmwise Condensation of Pure Vapors
J2	Film Condensation of Binary Mixtures with and without Inert Gas
J3	Dropwise Condensation
J4	Mixing and Spray Condensation

K	Radiation
<b>K</b> 1	Radiation of Surfaces
K2	View Factors
К3	Gas Radiation: Radiation from Gas Mixtures
K4	Thermal Radiation of Gas-Solids-Dispersions
K5	<b>Heat Radiation in Furnaces</b>
К6	Superinsulations
L	Fluid Dynamics and Pressure Drop
L1	Pressure Drop in Single Phase Flow
	L1.2 Pressure Drop in Flow Through Pipes
	L1.3 Pressure Drop in Flow Through Pipes of Changing Cross-section
	L1.4 Pressure Drop of Tube Bundles in Cross Flow
	L1.5 Pressure Drop in the Outer Shell of Heat Exchangers
	L1.6 Pressure Drop in Fixed Beds
	L1.7 Pressure Drop in Orifices and Column Trays
L2	Two-Phase Gas-Liquid Flow
	L2.2 Pressure Drop in Tubes, Valves, and Fittings
	L2.3 Sizing of Safety Devices for Heat Exchangers

	L2.4 Calculating Critical Mass Flux
	L2.5 Flooding and Pressure Drop of Counter Current Gas-Liquid Flow in Vertical Pipes
	L2.6 Pressure Drop and Flooding in Packed Towers
	L2.7 Pressure Drop and Operating Limits of Trays
L3	Two-Phase Gas-Solid Flow
	L3.2 Flow Patterns and Pressure Drop in Fluidized Beds
	L3.3 Pressure Drop in Pneumatic Conveying Systems
	L3.4 Cyclones for the Precipitation of Solid Particles
L4	Bubble and Drops in Technical Equipment
	L4.2 Production and Mechanical Destruction of Foams
	L4.3 Droplet Separation
М	Specific Heat Transfer Problems
M1	Heat Transfer to Finned Tubes
M2	Heat Transfer to Walls with Welded Coils
М3	Heat Transfer to Falling Films at Vertical Surfaces
M4	Heat Transfer to Non-Newtonian Fluids
M5	Heat Transfer in Fluidized Beds
M6	Heat Transfer from a Wall to Stagnant and Mechanically Agitated Beds
M7	Heat and Mass Transfer in Packed Beds with Fluid Flow

M8	Humidifying and Drying of Air
M9	Convective Heat Transfer at High Velocities
M10	Heat Transfer and Momentum Flux in Rarefied Gases
M11	Spontaneous Condensation and Cavitation
N	Specific Heat Transfer Devices
N1	Heat Transfer in Regenerators
N2	Combined Heat and Mass Transfer in Rotating Regenerators
N3	Heat Transfer and Power Consumption in Stirred Vessels
N4	Cooling Towers
N5	Heat Pipes
N6	Pressure Drop and Heat Transfer in Plate Heat Exchangers
0	Construction of Heat Exchangers
01	Hints on the Construction of Heat Exchangers
02	<b>Vibration of Tube Bundles in Heat Exchangers</b>

# **Contributors**

## Klaus Anders, Dr.-Ing.†

Stuttgart Germany

#### Hein Auracher, Prof. Dr.-Ing.

Stuttgart Germany heinaur@gmx.de

#### Wolfgang Bender, Dipl.-Ing.

VDEh-Betriebsforschungsinstitut GmbH Düsseldorf Germany

## Thomas Bodmer, Dipl.-Ing.

Marl Germany thomas.bodmer@eon-energie.com

### Hans-Gerd Brummel, Dr.-Ing.

Siemens Power Generation Berlin Germany hans-gerd.brummel@siemens.com

## Ulrich Busweiler, Prof. Dr.-Ing.

Sachverständigenbüro
Darmstadt
Germany
ulrich.busweiler@mmew.fh-giessen.de

#### Jogindar Mohan Chawla, Prof. Dr.-Ing.†

Ettlingen Germany

#### Hans Detlef Dahl, Dr.-Ing.

Marl Germany h-dahl@versanet.de

#### Paul J. Erens, Dr.

Private Consulting Engineer Stellenbosch Republic of South Africa paulerens@snowisp.com

## Axel Eschner, Dr.

Osterode (Harz) Germany Axel.Eschner@t-online.de

## Felix Flohr, Dipl.-Ing.

Solvay Fluor GmbH Hannover Germany Felix.Flohr@solvay.com

#### Arnold Frohn, Prof. Dr.

Universität Stuttgart Stuttgart Germany arnold.frohn@t-online.de

#### Edward S. Gaddis, Dr.-Ing.

Technische Universität Clausthal Clausthal-Zellerfeld Germany Edward.Gaddis@t-online.de

### Gerd Gaiser, Dr.-Ing.

Reutlingen Germany Gerd.Gaiser@eberspaecher.com

#### Bernhard Gampert, Prof. Dr.-Ing. habil.

Universität Duisburg-Essen Essen Germany bfjg2008@gmx.de

### Horst Gelbe, Prof. Dr.-Ing.

Technische Universität Berlin Berlin Germany

h.gelbe@gmx.de

#### Andreas Glück, Dr.

HTT Vertriebsbüro Süd GmbH Ebersbach Germany a.glueck@htt.de

## Volker Gnielinski, Prof. Dr.-Ing.

Karlsruher Institut für Technologie (KIT) Karlsruhe Germany volker.gnielinski@tvt.uka.de

## Dieter Gorenflo, Prof. Dr.-Ing.

Universität Paderborn Paderborn Germany digo@thet.uni-paderborn.de

<sup>†</sup>Deceased

#### Klaus Görner, Prof. Dr.-Ing.

Universität Duisburg-Essen

Essen

Germany

luat@uni-due.de

#### Erich Hahne, Prof. Dr.-Ing.

Universität Stuttgart

Stuttgart

Germany

hahne@itw.uni-stuttgart.de

### Helmuth Hausen, Dr.-Ing.†

Hannover

Germany

#### Wolfgang Heidemann, Dr.-Ing.

Universität Stuttgart

Stuttgart

Germany

heidemann@itw.uni-stuttgart.de

#### Oliver Herbst, Dr.

AREVA NP GmbH

Erlangen

Germany

Oliver.Herbst@areva.com

#### Ulrich Hochberg, Prof. Dr.-Ing.

Hochschule Offenburg

**University of Applied Sciences** 

Offenburg

Germany

Ulrich.Hochberg@FH-Offenburg.de

#### Christof Hübner, Dr.-Ing.

Fraunhofer-Institut für Chemische Technologie (ICT)

Pfinztal

Germany

christof.huebner@ict.fraunhofer.de

## Dietmar Hunold, Dr.-Ing.

HTT Energy Systems GmbH

Herford

Germany

d.hunold@htt.de

# Ralph Joh, Dr. rer. nat.

Siemens AG

Frankfurt

Germany

ralph.joh@siemens.com

#### Stephan Kabelac, Prof. Dr.-Ing.

Helmut-Schmidt-Universität

Universität der Bundeswehr Hamburg

Hamburg

Germany

Kabelac@hsu-hh.de

#### Günther Kasparek, Dr.-Ing.

Munich

Germany

guenther.kasparek@t-online.de

#### Werner Kast, Prof. Dr.-Ing.

Technische Universität Darmstadt

Darmstadt

Germany

#### Anastassios Katsaounis, Prof. Dipl.-Ing.

Beuth Hochschule für Technik Berlin

Berlin

Germany

akatsaounis@arcor.de

## Paul Bernd Kempa, Dr.

Fraunhofer-Institut für Chemische Technologie (ICT)

Pfinztal

Germany

paul-bernd.kempa@ict.fraunhofer.de

#### David Kenning, Prof. Dr.

**Brunel and Oxford Universities** 

ПK

David.Kenning@brunel.ac.uk

#### Matthias Kind, Prof. Dr.-Ing.

Karlsruher Institut für Technologie (KIT)

Karlsruhe

Germany

matthias.kind@kit.edu

## Günther Kirchner, Dipl.-Ing.

BASF SE, Ludwigshafen

Germany

guenther.kirchner@basf.com

#### Herbert Klan, Dr.-Ing.

Technische Universität Darmstadt

Darmstadt

Germany

#### Michael Kleiber, Dr.-Ing.

Uhde GmbH

**Bad Soden** 

Germany

michael.kleiber@thyssenkrupp.com

#### **Gernot Krakat**

FRAGOL Schmierstoffe GmbH & Co.

Mülheim (Ruhr), Germany

g.krakat@fragol.de

# Rolf Krauss, Dipl.-Ing.

Universität Stuttgart

Stuttgart

Germany

krauss@itt.uni-stuttgart.de

#### Hans-Joachim Kretzschmar, Prof. Dr.-Ing. habil.

Hochschule Zittau/Görlitz University of Applied Sciences

Zittau Germany

HJ.Kretzschmar@hs-zigr.de

#### Alfred Leipertz, Prof. Dr.-Ing.

Friedrich-Alexander-Universität Erlangen-Nürnberg

Erlangen Germany

sek@ltt.uni-erlangen.de

## Xing Luo, Prof. Dr.-Ing.

Helmut-Schmidt-Universität

Universität der Bundeswehr Hamburg

Hamburg Germany

luoxing1122@hotmail.com

## Holger Martin, Prof. Dr.-Ing.

Karlsruher Institut für Technologie (KIT)

Karlsruhe Germany

holger.martin@kit.edu

#### Alfons Mersmann, Prof. Dr.-Ing.

Technische Universität München

Munich Germany

alfons.mersmann@online.de

#### Dieter Mewes, Prof. Dr.-Ing. Dr. h. c.

Leibniz Universität Hannover

Hannover Germany

mewes@imp.uni-hannover.de

## Nimai-Kumar Mitra, Prof. Dr.-Ing<sup>†</sup>

Bochum Germany

#### Jürgen Müller, Dr.-Ing.

BASF AG Ludwigshafen

Germany

juergen.mueller@basf-ag.de

#### Hans Müller-Steinhagen, Prof. D. Eng. Dr.-Ing.

Universität Stuttgart

Stuttgart Germany

Hans. Mueller-Steinhagen@dlr.de

#### Sebastian Muschelknautz, Dr.-Ing.

Linde AG, Pullach

Germany

sebastian.muschelknautz@linde-le.com

#### Ulrich Muschelknautz, Prof. Dr.-Ing.

MK Engineering Innsbruck Austria

um@mkengineering.de

#### Matthias Neubronner, Dr.-Ing.

EON Energie Munich Germany

matthias.neubronner@eon-energie.com

#### Hermann Nirschl, Prof. Dr.-Ing. habil.

Karlsruher Institut für Technologie (KIT)

Karlsruhe Germany

hermann.nirschl@kit.edu

#### Reiner Numrich, Prof. Dr.-Ing.

Paderborn Germany

r.numrich@numrich-gev.de

#### Fabian Ochs, Dipl.-Ing.

Universität Stuttgart

Stuttgart Germany

fabian.ochs@gmx.net

#### Andreas Pfennig, Prof. Dr.-Ing.

RWTH Aachen Aachen Germany

andreas.pfennig@avt.rwth-aachen.de

#### Ewald Preisegger, Dipl.-Ing.

Solvay Fluor GmbH

Hannover Germany

familie.preisegger@gmx.de

#### Norbert Räbiger, Prof. Dr.-Ing.

Universität Bremen

Bremen Germany

nraebiger@iuv.de

### Harald Reiss, Prof. Dr. rer. nat.

Julius-Maximilians-Universität Würzburg

Würzburg Germany

## Wolfgang Richter, Dr.-Ing.†

Essen Germany

#### Wilfried Roetzel, Prof. Dr.-Ing.

Helmut-Schmidt-Universität

Universität der Bundeswehr Hamburg

Hamburg Germany

Wilfried.Roetzel@hsu-hh.de

#### Norbert Roth, Dr.-Ing.

Universität Stuttgart

Stuttgart Germany

norbert.roth@itlr.uni-stuttgart.de

#### Yasushi Saito, Dr. Eng.

**Kyoto University** 

Osaka

Japan

ysaito@rri.kyoto-u.ac.jp

# Wilhelm Schabel, Prof. Dr.-Ing.

Karlsruher Institut für Technologie (KIT)

Karlsruhe

Germany

wilhelm.schabel@kit.edu

#### Karlheinz Schaber, Prof. Dr.-Ing.

Karlsruher Institut für Technologie (KIT)

Karlsruhe

Germany

Karlheinz.Schaber@KIT.edu

#### Ernst-Ulrich Schlünder, Prof. Dr.-Ing. Dr. h. c.

Karlsruher Institut für Technologie (KIT)

Karlsruhe

Germany

#### Michael Schlüter, Prof. Dr.-Ing.

Technische Universität Hamburg-Harburg

Hamburg

Germany

michael.schlueter@tu-harburg.de

#### Florian Schmidt, Dr.-Ing.

Bayer Technology Services GmbH

Krefeld

Germany

florian.schmidt@bayertechnology.com

## Holger Schmidt, Dr.-Ing.

Areva NP GmbH

Erlangen

Germany

Holger.Schmidt@areva.com

## Jürgen Schmidt, Prof. Dr.-Ing.

BASF SE

Ludwigshafen

Germany

juergen.schmidt@onlinehome.de

### Klaus Gerhard Schmidt, Prof. Dr.-Ing.

Institut für Energie- und Umwelttechnik (IUTA) e.V.

Duisburg

Germany

k.schmidt@iuta.de

# Günter Schnabel, Dr.-Ing.

**BIDECO GmbH** 

Biberach (Riss)

Germany

guenter.schnabel@bideco.de

#### Günter H. Schnerr, Prof. Dr.-Ing. habil.

Technische Universität München

Garching

Germany

Schnerr@flm.mw.tu - muenchen.de

#### Jens-Jürgen Schröder, Dr.-Ing.†

Hannover

Germany

## Martin Sommerfeld, Prof. Dr.-Ing. habil.

Martin-Luther-Universität Halle-Wittenberg

Halle (Saale)

Germany

martin.sommerfeld@iw.uni-halle.de

## Roland Span, Prof. Dr.-Ing.

Ruhr-Universität Bochum

**Bochum** 

Germany

roland.span@thermo.rub.de

## Bernhard Spang, Dr.-Ing.

BUCO Wärmeaustauscher International GmbH

Geesthacht

Germany

bernhard@spang-hh.de

#### Martin H. Spitzner, Dr.-Ing.

FIW München

Gräfelfing

Germany

#### Dieter Steiner, Prof. Dr.-Ing.

Karlsruhe

Germany

## Karl Stephan, Prof. Dr.-Ing.

Universität Stuttgart

Stuttgart

Germany

stephan.karl1@gmx.de

#### Peter Stephan, Prof. Dr.-Ing.

Technische Universität Darmstadt

Darmstadt

Germany

pstephan@ttd.tu-darmstadt.de

## Johann Stichlmair, Prof. Dr.-Ing.

Technische Universität München

Garching

Germany

Johann.Stichlmair@apt.mw.tum.de

#### André Thess, Prof. Dr.-Ing.

Technische Universität Ilmenau

Ilmenau

Germany

tthess@tu-ilmenau.de

#### Evangelos Tsotsas, Prof. Dr.-Ing.

Otto-von-Guericke-Universität Magdeburg

Magdeburg

Germany

evangelos.tsotsas@vst.uni-magdeburg.de

#### Dieter Vortmeyer, Prof. Dr.

Munich Germany

#### Manfred H. Wagner, Prof. Dr.-Ing.

Technische Universität Berlin

Berlin

Germany

manfred.wagner@tu-berlin.de

#### Wolfgang Wagner, Prof. Dr.-Ing.

Ruhr-Universität Bochum

Bochum

Germany

wagner@thermo.rub.de

## Bernhard Weigand, Prof. Dr.-Ing.

Universität Stuttgart

Stuttgart

Germany

itlr@itlr.uni-stuttgart.de

## Anton Wellenhofer, Dipl.-Ing.

Linde AG, Pullach

Germany

anton.wellenhofer@linde-le.com

## Hans Werner, Prof. Dr.-Ing.

Hochschule für Angewandte Wissenschaften (FH)

München

Germany

dr.hans.werner@t-online.de

### Karl-Ernst Wirth, Prof. Dr.-Ing.

Friedrich-Alexander-Universität Erlangen-Nürnberg

Erlangen

Germany

k.e.wirth@lfg.uni-erlangen.de

## Hartwig Wolf, Dr.-Ing.

Alstom Switzerland Ltd.

Baden

Switzerland

hartwig.wolf@power.alstom.com

# Manfred Zeller, Prof. Dr.-Ing.

**RWTH Aachen** 

Aachen

Germany

manfred.zeller@rwth-aachen.de

#### Samir Ziada, Prof. Dr.-Ing.

McMaster University

Hamilton, ON

Canada

ziadas@mcmaster.ca