BOILING HEAT TRANSFER AND BOILING EQUIPMENT

A Five Day Short Course in Pisa, Italy (October 8-12, 2007)

Course Host: Heat Transfer Research Inc. (HTRI)
150 Venture Drive
College Station, Texas 77845, USA

COURSE DESCRIPTION

Boiling is an essential basic operation in thermal sciences. It is the most effective heat transfer method because of its high performance due to latent heat transport, thus allowing to reduce size, weight and volume of heat exchange devices and improve the thermal performance of components for the process industry and power plants. Therefore, boiling heat transfer plays a very important role for a wide number of applications in many technological and industrial areas, including energy production. As an example, subcooled boiling heat transfer can accommodate very high heat fluxes, and this can be suitably employed in the cooling of some components for fusion reactors, where it is required to remove up to 10-15 MW/m2. Furthermore, very compact heat exchangers can be manufactured thanks to the high heat transfer rate obtained with boiling heat transfer. Steam generators can be better designed if the boiling process is known in details, thus improving the thermal cycle and the plant efficiency.
The objective of this course is to provide the participants with today's detailed knowledge on the boiling heat transport mechanisms based on recent research results and the most updated methods for the prediction of boiling heat transfer, its enhancement, and its applications to technological and industrial areas. Specific attention will be paid to the description and prediction of the critical heat flux, which represents the upper limit of the boiling heat transfer and has to be avoided for safety reasons. Boiling of mixtures, which is of paramount importance for industrial applications such as retrofitting of existing plants will be treated exhaustively. Application to compact heat exchangers will be dealt with special care in view of the industrial interest towards this component, while the very recent application of boiling heat transfer to microscale, including microstructured surfaces, which allow very high heat transfer rates for specific applications, will be treated in great detail.
The course is addressed to scientists, professionals, engineers and graduate students in the several fields of Engineering, Applied and Fundamental Sciences with specific interest in phenomena involving boiling (process industry, refrigeration industry, energy production, heat exchanger manufacturers, etc.) who want to get acquainted with the traditional background and the most recent developments of this discipline.

COURSE LECTURERS

Paolo Di Marco (*Course Coordinator, 7 lectures*) is Professor of Engineering Thermodynamics and Heat Transfer, Department of Energetics, Faculty of Engineering, University of Pisa. He received his PhD in Nuclear Engineering in 1989 at the University of Pisa. His research interests include single-phase and boiling heat transfer, bubble dynamics, heat transfer in microgravity, effect of electric fields on heat transfer, instability in boiling loops, two-phase flow measurements. His main field of activity is the study of the effect of force fields on boiling heat transfer and bubble dynamics, conducted through many experimental campaigns in microgravity conditions, ranging from parabolic to satellite flights. He took part in the organization of several international conferences, giving also invited lectures, and he is member of several international associations.

Lectures content - Generalities on pool boiling: boiling curve, phase equilibria, transport properties and equations; surface tension, equilibrium on a curved interface. Basic mechanisms in nucleate pool boiling: nucleation, bubble growth in the fluid and at the wall, bubble detachment, Marangoni convection. Heat transfer mechanisms in nucleate boiling. Nucleate boiling correlations. Critical heat flux in pool boiling: mechanisms and correlations. Parametric effects in boiling; effect of force fields: gravity and electric field.

Gian Piero Celata *(7 lectures)* is Director of the Institute of Thermal-Fluid Dynamics at the Italian national research center ENEA and is honorary chair of the European Two-Phase Flow Group among his many international appointments. He is the President of the UIT, Italian Union of Thermal-Fluid Dynamics, and of the World Conference on Experimental Heat Transfer, Fluid Mechanics and Thermodynamics, and member of several international associations. He received the JSMF Award in 2003. He is a world expert on measurement and prediction of critical heat fluxes in flow boiling, giving many keynote lectures and seminars, and publishing extensively, and has done in recent years extensive research on single-phase flow and boiling heat transfer in microchannels boiling (he edited a book published by Begell House and gave many lectrues and seminars), flow boiling and quenching at zero gravity. He is also very well known for the numerous international research conferences he has organized and chaired and he has edited numerous books.

Lectures content - Generalities on flow boiling, flow regimes, void fraction, two-phase frictional pressure drop, subcooled and saturated flow boiling in circular tubes, critical heat flux in subcooled flow boiling, critical heat flux in saturated flow boiling, predictions methods for the subcooled flow boiling CHF: correlations and mechanistic models, predictions methods for the saturated flow boiling CHF: correlations and mechanistic models, post-CHF heat transfer, augmentation of CHF and post-CHF heat transfer, boiling of mixtures, flow boiling in microgravity.

R. Stanley Kistler (*2 lectures*) HTRI Vice President, Research and Software Development, obtained his undergraduate and master's degrees as well as his Ph.D. in Chemical Engineering, with an emphasis in boiling, from the University of Missouri – Rolla, Missouri, USA. Although Kistler's career at HTRI has focused on software development, he also conducted experimental research on shellside single-phase flow. Since 1995 he has led HTRI's software development efforts; in 2003 he also assumed responsibility for HTRI's research activities. Kistler has helped develop many HTRI workshops and over the course of his career has taught dozens of courses and workshops around the world. He also serves as a guest lecturer for academic courses and has been involved in various engineering events in academia. Named an AIChE Fellow in 1996, Kistler is past chair of the Heat Transfer and Energy Conversion division. He has chaired numerous sessions at National Heat Transfer Conferences.

Lectures content - Post-CHF regimes: transition boiling and film boiling; fundamentals and parametric effects; dry pacthes; minimal heat flux; correlations and mechanistic models, predictions methods, practical examples.

Peter Stephan (*7 lectures*) is Professor of Technical Thermodynamics and head of the eponymous institute at Darmstadt University of Technology. He was a Marie-Curie Research Fellow at the EC Joint Research Centre in Ispra, Italy, from 1989 to 1992, and received his PhD in 1992 at the University of Stuttgart. From 1992 to 1997 he was working as a senior process engineer and R&D manager in the Daimler-Benz group. Since 1997 he is at Darmstadt University of Technology. His main fields of research are boiling heat transfer, microscale heat and mass transfer, interfacial phenomena, heat pipe technology, drying and freezing processes. Specific interests lie in multiscale approaches and the combination of numerical and experimental studies. He received the IIR Sadi Carnot Prize in 1995 and the SFT Prize for Excellence in Heat Transfer Research in 2002. He is president of the VDI Heat and Mass Transfer Committee and member of several international associations.

Lectures content - Microscale and multiscale modelling approaches to predict pool boiling heat transfer. Description of transport phenomena on different scales (from nano- to macroscale). Experimental studies aiming at the evaluation of microscale phenomena and the validation of micro- and multiscale models. Boiling in microstructured surfaces. Thermocapillary instability of falling evaporative films. The use of microstrucured surfaces to increase the evaporation rate and prevent a local dryout.

John R. Thome (*6 lectures*) is Professor of Heat and Mass Transfer at the Swiss Federal Institute of Technology in Lausanne (EPFL), Switzerland, where his primary interests of research are two-phase flow and heat transfer in microscale and macroscale processes. He received his Ph.D. at Oxford University (1978) and from 1984 to 1998 ran his own international engineering consulting company. He is the author of three books: Enhanced Boiling Heat Transfer (1990), Convective Boiling and Condensation, 3rd Edition (1994), Wolverine Engineering Databook III (2004) and is working on a 4th. He received the ASME Heat Transfer Division's Best Paper Award in 1998 for his work on flow boiling heat transfer. He has published extensively on boiling and two-phase flow in microchannels and gave the keynote lecture on this topic at the 13th Int. Heat Transfer Conference in Sydney.

Lectures content - Flow patterns map in horizontal and vertical tubes, heat transfer models based on flow patterns, pool boiling in liquid mixtures, forced convective boiling in liquid mixtures, critical heat transfer in liquid mixtures, models for heat transfer in pool and flow boiling of mixtures, flow boiling in microchannels, differences between microscale and macroscale in flow boiling in tubes, flow patterns in microchannels, modelling of flow boiling in microchannels.

Vishwas V. Wadekar (*6 lectures*) is Principal Technologist and HTFS Research Manager at Aspen Technology Ltd. In addition to managing HTFS research, he chairs the HTFS Industrial Review Panel on Compact Heat Exchangers. He has lectured internationally at various conferences as an invited speaker and has participated in many international scientific organising committees. He has presented numerous training courses in many countries around the world, related to advances in heat exchanger technology, two-phase heat transfer, heat transfer enhancement technology and compact and other exchanger types. He has been a Visiting Scientist at Lehigh University, USA, Visiting Lecturer at Nottingham University, England, and Visiting Professor at Newcastle University, England and Hamburg University, Germany. He is an active member of AIChE, currently serving on the Executive Board of Transport and Energy Processes Division of AIChE as a Director. He is also serves on the Editorial board of journals dealing with heat exchange engineering.

Lectures content - Passive and active methods, flow boiling in advanced geometries, flow boiling in compact heat exchangers: evaluation of the boiling heat transfer performances of different compact heat exchangers, flow boiling in multichannels, flow boiling instabilities, external flow boiling in tube bundles.

Heat Transfer Research Inc. (*Host*) is a well-known industrial research and development consortium founded in 1962 with over 600 member companies from around the world and extensive experience in training (www.htri.net).

DETAILED PROGRAM

Time	Monday October 8	Tuesday October 9	Wedne Octobe
9.00 – 9.45	Registration Welcome	P. Di Marco	P. Step
9.45 – 10.30	P. Di Marco	P. Di Marco	P. Step
11.00 – 11.45	P. Di Marco	G.P. Celata	R.S. Ki
11.45 – 12.30	P. Di Marco	G.P. Celata	R.S. Ki
14.00 – 14.45	G.P. Celata	G.P. Celata	P. Step
14.45 – 15.30	G.P. Celata	G.P. Celata	P. Step
16.00 – 16.45	G.P. Celata		V.V. Wa
16.45 – 17.30	P. Di Marco		V.V. Wa
17.30 – 18.15	P. Di Marco		

COURSE LOCATION AND TRAVEL INFORMATION
(The location of the lecture room at the University of Pisa will be sent by e-mail before the course)

The course is held at the Faculty of Engineering, University of Pisa, Via Diotisalvi 2, Pisa. The Faculty is located close to Miracles' Square and is at walking distance from most of Hotels in Pisa.

Pisa airport (http://www.pisa-airport.com/) is well connected with major international airports in Europe, including low cost companies (Ryan Air). Transportation to downtown can be either by bus or by taxi (approx. 15 Euro).

Alternatively, the airport of Florence (http://www.aeroporto.firenze.it/IT/index.php) may be used. Pisa is reachable in about one hour by bus or train.

Pisa is a lovely city located not far from Florence (1 hour by train) in the north of Tuscany, one of the most wonderful regions of Italy. The Miracles' Square with the Dome, the Baptister and the world-wide well known Leaning Tower represent the most unique and original complex of the tuscan Romanesque architecture. But many other attractions deserve some attention from the tourists such as the sculptures and the paintings of the local Thirteenth and Fourteenth century stored in the St. Matthew National Museum, the ancient city, and many wonderful churches. Pisa is also a convenient location for exploring Tuscany hills, wineyards, and its beautiful cities, such as Florence, Siena, S. Gimignano, Lucca, Volterra, etc. It offers also the possibility to reach most of the touristic attractions of Italy (Rome, Venice) by train (about 4 hrs.). The climate in early October is normally very pleasant in Pisa.

COURSE INSCRIPTION FEE

Course Inscription Fee: **$1200** U.S. dollars for each participant, except for Ph.D. students there is a discount rate of $**850** U.S. dollars per person. Registration deadline is **September 30**. Cancellations will be charged a **25%** cancellation fee.

REGISTRATION pdf file; doc file

PAYMENT BY CREDIT CARD pdf file; doc file

PAYMENT BY BANK TRANSFER pdf file; doc file

The Deutsche Forschungsgemeinschaft offers scholarships to German students (please contact Dr. Michael Meier, DFG, Kennedyallee 40, 53175 Bonn (+49 (0) 228 885 2281, http://www.dfg.de/)

HOTEL REGISTRATION INFORMATION

Participant must contact a hotel to make his/her own hotel room reservation.

All the Hotels are within 1 km from the course site and are listed as a function of the distance from it (top left-hand side is the closest, bottom right-hand side is the farthest).

Hotel Soggiorno Atena Viale Risorgimento 42 From 55 Euro http://www.pisaonline.it/HotelAthena	Grand Hotel Bonanno Via Carlo Francesco Gabba 17 From 100 Euro http://www.grandhotelbonanno.it	Hotel Cecile Via Roma 54 From 58 Euro tel.: +39 0502
Hotel Ariston Via Cardinale Maffi 42 From 80 Euro http://www.hotelariston.pisa.it	Hotel Francesco Via Santa Maria 129 From 80 Euro http://www.hotelfrancesco.com	Grand Hotel Du Via Santa Mari From 90 Euro http://www.gr
Hotel Leonardo Via Tavoleria 17 From 70 Euro http://www.hotelleonardopisa.it	Hotel Di Stefano Via Sant'Apollonia 35 From 90 Euro http://www.pisaonline.it/HotelDiStefano	Hotel Bologna Via Mazzini 57 From 80 Euro http://www.ho

CONTACT PERSON AND COURSE COORDINATOR

Prof. Paolo Di Marco, Dipartimento di Energetica, Università di Pisa, via Diotisalvi 2, 56122 PISA Italy, tel. +39 050 2217107, FAX +39 050 2217150, e-mail: p.dimarco@ing.unipi.it ; http://docenti.ing.unipi.it/~d6600/