

# **1st IIR International Conference on the Cold Chain and Sustainability 2010**

**Refrigeration Science and Technology Proceedings 2010-1**

**29-31 March 2010  
Cambridge, United Kingdom**

**ISBN: 978-1-61738-230-7**

**Printed from e-media with permission by:**

Curran Associates, Inc.  
57 Morehouse Lane  
Red Hook, NY 12571



**Some format issues inherent in the e-media version may also appear in this print version.**

Copyright© (2032) by the International Institute of Refrigeration  
All rights reserved.

Printed by Curran Associates, Inc. (2010)

For permission requests, please contact the International Institute of Refrigeration  
at the address below.

International Institute of Refrigeration  
177 Boulevard Malesherbes  
F 75017 Paris France

Phone: 33 1 422 73 235

Fax: 33 1 422 31 798

[iifiir@iifiir.org](mailto:iifiir@iifiir.org)

**Additional copies of this publication are available from:**

Curran Associates, Inc.  
57 Morehouse Lane  
Red Hook, NY 12571 USA  
Phone: 845-758-0400  
Fax: 845-758-2634  
Email: [curran@proceedings.com](mailto:curran@proceedings.com)  
Web: [www.proceedings.com](http://www.proceedings.com)

# TABLE OF CONTENTS

## **PLENARY SESSION**

*Chairman: Robert Heap*

<b>Introduction: Sustainability in Refrigeration and Air Conditioning</b> .....	1
<i>R. Heap</i>	
<b>Welcome: The International Institute of Refrigeration (IIR)</b> .....	4
<i>X. Meignien</i>	
<b>Recent Research and Progress in Measuring and Improving the Performance of the Cold Chain</b> .....	5
<i>J. Guilpart</i>	

## **REFRIGERANTS & REFRIGERATION IN THE FUTURE**

*Chairman: Andy Pearson*

<b>Reducing the Environmental Impact of Refrigeration: An Ineos Fluor Perspective</b> .....	18
<i>R. Low</i>	
<b>Sustainable Refrigerant Selection in Binary Blends of the R1234yf – Hydrofluoroethers</b> .....	27
<i>S. Artemenko, D. Nikitin, S. Haddad, V. Mazur</i>	
<b>F Gas Containment – Two UK Led Projects on Reducing Refrigerant Emissions and Leakage</b> .....	36
<i>D. Cowan, I. Chaer, G. Maidment</i>	

## **FOOD QUALITY, SAFETY AND MICROBIOLOGY**

*Chairman: Jacques Guilpart*

<b>Growth Potential of <i>Listeria Monocytogenes</i> in Salted Diced Bacon</b> .....	44
<i>A. Beaufort, H. Bergis, P. Garry</i>	
<b>Chilling Individual Retail Pots of Hot-Filled Soups and Sauces Using Air to Meet Cook-Chill Guidelines</b> .....	51
<i>C. James, C. Bobst, H. Fleury, S. Palpacelli, S. James</i>	
<b>Possible Use of Negative Ions and Ozone As Anti Bacterial Mixture</b> .....	59
<i>G. Panozzo, L. Fedele, M. Franceschi, S. Rossi, D. Spolaor</i>	

## **MODELLING & PREDICTIVE TOOLS**

*Chairman: Monica Axell*

<b>Theoretical Analysis of the Coupling of Heat and Mass Transfer of Fruits and Vegetables in Precooling</b> .....	67
<i>L. Bin, C. Jinghui, H. Yanhong, Y. Xingying</i>	
<b>Thermal Modelling of Catering Meals Under Blast-Cooling</b> .....	74
<i>J. Rabi, J. Guilpart, E. Derens, A. Duquenoy</i>	

## **REFRIGERANTS & REFRIGERATION IN THE FUTURE**

*Chairman: Andy Pearson*

<b>‘Lubricating the Future of Refrigeration – CO<sub>2</sub>’: Effective Lubrication of Carbon Dioxide Refrigeration Systems</b> .....	82
<i>R. Rogers</i>	
<b>Using Natural Refrigerants in the Cold Chain</b> .....	89
<i>A. Pachai, M. Jones</i>	
<b>Ammonia a Safe Refrigerant?</b> .....	97
<i>L. Rolfsman</i>	
<b>Use of Carbon Dioxide for Air Conditioning and General Refrigeration</b> .....	102
<i>S. Pearson</i>	
<b>Sensitivity of Tewi Estimate – Leakage and Energy for CO<sub>2</sub> As Refrigerant in Commercial Refrigeration</b> .....	110
<i>R. Islam</i>	

## **INNOVATION IN STORAGE & TRANSPORTATION**

*Chairman: Robert Heap*

<b>Usefulness and Subtlety of the Overall Coefficient of Heat Transfer in Cooling Containers</b> .....	118
<i>G. Labranque, A. Kacimi</i>	
<b>Cryogenic Refrigerated Transport Equipment Tests: Methodology and Results</b> .....	127
<i>G. Cavalier, P. Nol, B. Valentin, S. Amara</i>	
<b>Dynamic Simulation of the Refrigerated Compartment of a Truck Coupled with Its Refrigeration System</b> .....	135
<i>A. Rachek, V. Sartre, J. Bonjour</i>	
<b>Energy Consumption Reduction in Marine Refrigerated Containers</b> .....	143
<i>A. Lawton, T. Mynott, N. Marshall</i>	
<b>Influence of Mass-Flow Injection Ratio on an Economised Indirect Multi-Temperature Transport Refrigeration System</b> .....	154
<i>S. Smyth, D. Finn, B. Brophy</i>	
<b>Evaluation of Secondary Coolants in Multi-Temperature Indirect Refrigeration Systems for Transport Applications</b> .....	162
<i>S. Smyth, D. Finn, B. Brophy</i>	

## **ENERGY EFFICIENCY IN FOOD & PHARMACEUTICALS**

*Chairman: Don Cleland*

<b>Reducing Energy Consumption in Cold Storage Rooms</b> .....	170
<i>J. Evans, A. Gigiel</i>	
<b>Energy Use Across Supermarket Refrigeration</b> .....	179
<i>J. Lawrence, D. Gibson</i>	
<b>Bread Freezing and Storage: Impact of Process Condition on Energy Demand</b> .....	191
<i>A. Le-Bail, T. Dessev, V. Jury, T. Park, R. Zuniga</i>	
<b>Improving the Energy Efficiency of Food Refrigeration Operations Throughout the Cold Chain</b> .....	198
<i>S. James</i>	
<b>The Energy Saving Potential of Ambient Cooling Systems</b> .....	206
<i>S. James, Y. Senso, C. James</i>	
<b>Distribution of Superchilled Meat</b> .....	214
<i>T. Nordtvedt, E. Indergard, A. Stevik, A. Hemmingsen</i>	

## **INNOVATION IN PROCESS & EQUIPMENT DESIGN**

*Chairman: Graeme Maidment*

<b>Improved Efficiency and Real Time Temperature Monitoring in the Food Supply Chain</b> .....	222
<i>G. Olafsdottir, S. Bogason, C. Colmer, M. Eden, T. Haflioason, M Kuck</i>	
<b>Packaged Ammonia Chillers in the Cold Chain</b> .....	230
<i>R. Lamb, A. Pearson</i>	
<b>Possible Interest of Electric Field During Food Freezing: A Review on Electrofreezing</b> .....	241
<i>A. Le-Bail, M. Orłowska, M. Havet</i>	
<b>Air Cycle Combined Heating and Cooling for the Food Industry</b> .....	248
<i>A. Foster, T. Brown, A. Gigiel, J. Evans</i>	
<b>The Use of NH<sub>3</sub> and CO<sub>2</sub> Heat Pumps in Food Processing Plants with Cold Storage Facilities</b> .....	256
<i>K. Visser</i>	
<b>Feasibility of Using Vascular Perfusion Chilling for Red Meat Carcasses</b> .....	264
<i>T. Brown, J. Evans</i>	

## **ADVANCES IN COMMERCIAL REFRIGERATION**

*Chairman: Guy Hundy*

<b>Ecodesign of Refrigeration Products</b> .....	272
<i>S. Mudgal, J. Bain, M. Liput</i>	
<b>Theoretical Evaluation of Integrated Systems for Refrigeration and Air Conditioning in Supermarkets</b> .....	283
<i>L. Cecchinato, M. Corradi, E. Fornasieri, S. Minetto</i>	

<b>Integration of CO<sub>2</sub> Refrigeration and Trigeration Systems for Supermarket Applications .....</b>	<b>295</b>
<i>I. Suamir, S. Tassou, A. Hadawey, D. Marriott</i>	
<b>A R744 Transcritical System with Heat Recovery for a Supermarket – A Case Study .....</b>	<b>303</b>
<i>I. Colombo, L. Jordan, G. Maidment, J. Missenden, I. Chaer</i>	
<b>Performance Optimization of a Secondary Refrigerant Display Cabinet Using Tests and CFD Modelling.....</b>	<b>311</b>
<i>A. Hadawey, S. Tassou, I. Suamir, H. Jouhara</i>	
<b>Reducing the Wastage of Fresh Fruit and Vegetables by Consumers.....</b>	<b>319</b>
<i>N. Hipps, D. Johnson, S. Hails, J. Evans</i>	

## **FOOD QUALITY, SAFETY AND MICROBIOLOGY**

*Chairman: Silvia Estrada Flores*

<b>Superchilling, Ice Fraction and Quality.....</b>	<b>327</b>
<i>A. Stevik, A. Hemmingsen, A. Duun, H. Walnum, T. Nordvedt</i>	
<b>Experimental Study on Vacuum Freeze-Drying of <i>Hylocereus Undatus</i>.....</b>	<b>333</b>
<i>T. Zou, S. Ma, B. Liu, X. Yi</i>	
<b>The Effect of Freezing and End Cooking Temperature on the Eating Quality of Beef Steaks .....</b>	<b>338</b>
<i>C. James, D. Briggs, S. James</i>	
<b>Time Temperature Integrators (TTI) for Shelf Life Monitoring and Optimization and Risk Reduction in the Food Chill Chain: Application on Map Minced Beef.....</b>	<b>346</b>
<i>P. Taoukis, T. Tsironi, M. Giannoglou, I. Metaxa, E. Gogou</i>	
<b>Guaranteeing Food Quality in the Food Chain for Imported Meat Products .....</b>	<b>354</b>
<i>F. Bowater</i>	
<b>Regression Equations for Heat Load and Weight Loss During Beef Chilling .....</b>	<b>362</b>
<i>Q. Pham, F. Trujillo, L. Davey, N. McPhail</i>	

## **INNOVATION IN STORAGE & TRANSPORTATION**

*Chairman: Savvas Tassou*

<b>Developments in Active and Passive Refrigerated Transportation for the Pharmaceutical Industry .....</b>	<b>370</b>
<i>M. Miller, A. Mistry, A. Lawton, T. Mynott</i>	
<b>The Potential for Super-Cooled Storage of Vegetables and Fruits.....</b>	<b>381</b>
<i>C. James, V. Seignemartin, N. Salaun, S. Costa, B. Nanthieras, S. James</i>	
<b>Air Leakage and Heat Leakage in Insulated Road Transport Equipment .....</b>	<b>389</b>
<i>L. Lukasse, M. Staal</i>	
<b>Experimental Evaluation of Optical Absorption Coefficient of Insulated Vehicle Sandwich Panel at the Sun Radiation .....</b>	<b>396</b>
<i>G. Panozzo, A. Dragano, S. Rossi, M. Franceschi, P. Bison</i>	
<b>Modeling and Experimental Investigation of A Transportation Refrigeration System.....</b>	<b>404</b>
<i>J. Mun, K. Choi, M. Rifaldi, J. Oh</i>	

## **MODELLING & PREDICTIVE TOOLS**

*Chairman: Alan Foster*

<b>A Model to Evaluate Refrigerated Cabinet Designs for Energy Efficiency .....</b>	<b>410</b>
<i>R. Love, D. Cleland</i>	
<b>Annex 31: Advanced Modeling and Tools for Analysis of Energy Use in Supermarket Systems .....</b>	<b>418</b>
<i>J. Arias, P. Lundqvist, S. Sawalha, M. Axell</i>	
<b>An Interactive Refrigeration System Simulator Software.....</b>	<b>426</b>
<i>I. Eames, T. Brown, G. Maidment, J. Missenden, J. Evans, M. Swain, S. James</i>	
<b>Performance Evaluation and Design Optimization of Refrigerated Display Cabinets Through Fluid Dynamic Analysis .....</b>	<b>434</b>
<i>G. Artico, S. Mousset, D. Fortini</i>	

## **INNOVATIVE TECHNOLOGIES FOR PROCESS EQUIPMENT DESIGN**

*Chairman: Judith Evans*

<b>Generic Data for the Performance of Alternative Insulation Systems Measured Over the Temperature Range -160 to +20°C</b> .....	442
<i>B. Crunkhorn, P. McDonald</i>	
<b>Optimal Configuration and Energy Conservation of Condensers Based on Part-Load</b> .....	450
<i>J. Zhang, y. Xu</i>	
<b>Development of Solar Thermal Heating and Cooling Systems Using the Jet Pump Cycle</b> .....	456
<i>R. Fenton, S. Knowles, I. Eames, G. Maidment</i>	
<b>A Review of “Pumpless” Absorption Refrigeration Cycles</b> .....	466
<i>A. Paurine, G. Maidment, I. Eames, J. Missenden</i>	
<b>Waste Heat Driven MAC</b> .....	479
<i>Z. Tamainot-Telto, S. Metcalf, R. Critoph</i>	

## **SHORT COURSES**

*Chairpersons: Bart Nicolai, Silvia Estrada-Flores, Graeme Maidment*

<b>Mathematical Modelling</b> .....	492
<i>B. Nicolai, K. Leuven</i>	
<b>Achieving Temperature Control and Energy Efficiency in the Cold Chain</b> .....	514
<i>S. Estrada-Flores</i>	
<b>Retail Display</b> .....	527
<i>J. Evans</i>	
<b>The Performance and Use of Domestic Refrigerators</b> .....	539
<i>S. James, C. James</i>	
<b>Sustainable Innovation – A Technology Review</b> .....	549
<i>G. Maidment</i>	

## **PLENARY SESSION**

*Chairman: Graeme Maidment*

<b>Towards a Sustainable Cold Chain</b> .....	556
<i>D. Cleland</i>	
<b>Introduction to the Co-Operative Research Programme, Biological Resource Management for Sustainable Agricultural Systems</b> .....	568
<i>J. Schofield</i>	

## **SUSTAINABLE RETAIL REFRIGERATION**

*Chairman: Radim Cermak*

<b>Evaluation of Energy Savings by Heat Recovery from Refrigeration Plants in Supermarkets</b> .....	570
<i>G. Cortella, O. Saro</i>	
<b>Concurrent Refrigeration Passive Defrost (CRPD) to Control Meat Surface Temperature in an Open Refrigerated Display Cabinet</b> .....	578
<i>R. Islam</i>	
<b>Performance of Retail and Commercial Refrigeration Systems</b> .....	586
<i>J. Evans, M. Swain</i>	
<b>Controlling Noise of Refrigeration Equipment in Neighbourhood Retail</b> .....	594
<i>S. Lamy, P. Poysat</i>	
<b>Vertical Display Cabinets Without and with Doors – A Comparison of Measurements in a Laboratory and in a Supermarket</b> .....	602
<i>U. Lindberg, M. Axell, P. Fahlen</i>	

## **MODELLING & PREDICTIVE TOOLS**

*Chairman: Tuan Phan*

<b>Prediction of Thermal Conductivity for Frozen Foods with Air Voids</b> .....	610
<i>J. Wang, J. Carson, J. Willix, M. North, D. Cleland</i>	

<b>Temperature Prediction in Domestic Refrigerator: Determinist and Stochastic Approaches</b> .....	618
<i>O. Laguerre, D. Flick</i>	
<b>Investigation of Heat Pump Seasonal Efficiency Using a Computation Model</b> .....	626
<i>E. Winandy, G. Hundy</i>	
<b>Novel Design and Performance of Domestic Refrigerators</b> .....	632
<i>C. Marques, J. Evans, G. Davies, G. Maidment, I. Wood</i>	
<b>Optimization of Chicory Root Cold Store Humidification System Using Computational Fluid Dynamics</b> .....	641
<i>M. Delele, A. Schenk, B. Nicolai, P. Verboven</i>	

## **INNOVATIVE TECHNOLOGIES FOR PROCESS & EQUIPMENT DESIGN**

*Chairman: Andrew Gigiel*

<b>Development of a Micro Cooling Probe for Brain Mapping</b> .....	649
<i>S. Mahmoud, R. AL-Dadah, D. Aspinwall, S. Soo</i>	
<b>Groundwater System with Heat Pumps Saves 70% of Energy</b> .....	657
<i>H. Winther, M. Klootwijk</i>	
<b>District Heating, District Cooling and Desalination Using Ammonia Heat Pumps</b> .....	665
<i>D. Pearson, S. Appleton</i>	
<b>Alternative Geothermal Heating Sources, Heat Pumps and Their Application</b> .....	673
<i>J. Thompson, G. Maidment</i>	
<b>Numerical Analysis of a Plate Fin and Tube Evaporator Using the Natural Refrigerant CO<sub>2</sub></b> .....	681
<i>J. Shilliday, S. Tassou</i>	

## **SUSTAINABLE RETAIL REFRIGERATION**

*Chairman: Issa Chaer*

<b>Energy-Efficient Laminar Flow Heat Exchangers in Indirectly Cooled Display Cabinets - Reduced Use of Energy and Improved Temperature Quality of the Provisions</b> .....	689
<i>C. Stignor, M. Axell</i>	
<b>Performance Evaluation and Control Optimization of a CO<sub>2</sub> Booster Refrigeration System in Supermarket</b> .....	697
<i>Y. Ge, S. Tassou</i>	
<b>Development of a Design Tool for Recirculated Air Curtains Used on Retail Display Cabinets</b> .....	705
<i>E. Hammond, J. Evans, A. Foster</i>	

## **DEVELOPMENTS IN PACKAGING**

*Chairman: Robert Heap*

<b>Proposal for determining the thermal rating of insulated packages intended for the transport of perishables</b> .....	711
<i>A. Sharp, E. Orszulok</i>	
<b>The Rate of Moisture Sorption by Packaging in the Cold Chain</b> .....	719
<i>J. Bronlund, D. Cleland, S. MacKay, T. Elsten</i>	
<b>Low Emissivity Food Packaging for More Efficient Refrigeration and Carbon Saving</b> .....	727
<i>G. Davies, G. Maidment, D. Man, D. Andrews, N. Jia, M. Hutchins</i>	

## **CARBON FOOT PRINTING & ASSESSMENT METHODOLOGIES**

*Chairman: Graeme Maidment*

<b>Carbon Footprint of Ready-Made Chilled Meals</b> .....	735
<i>N. Espinoza-Orias, H. Stichmothe, A. Azapagic</i>	
<b>Estimation of CO<sub>2</sub> Emission from the Transportation Process of Mackerel in Japan</b> .....	742
<i>M. Watanabe, A. Suzuki, H. Komaki, K. Osako, T. Suzuki</i>	
<b>Measurement and Simulation of Energy Consumption of Transport Refrigeration Equipments</b> .....	749
<i>G. Cavalier, A. Stumpf</i>	

**CLOSING SESSION**

*Chairman: Andy Pearson*

**Innovation and Sustainability Lessons from the Life of Thomas Midgley, Jr.**..... 760  
*A. Pearson*

**ADDITIONAL INFORMATION**

**The Institute of Refrigeration Membership Information**..... 766

**Refrigeration and Food Security, A Message from the IIR**..... 768

**SIRAC – An introduction**..... 770

**SIRAC – Newsletter, January 2010**..... 793

**International Journal of Refrigeration – Information**..... 800

**OECD Co-operative Research Programme, Biological Resource Management for Sustainable  
Agricultural Systems** ..... 826

**Author Index**