

ICDL 2023

22nd IEEE International Conference on Dielectric Liquids

JUNE 25-28, 2023

Worcester Polytechnic Institute
Worcester, Massachusetts, U.S.A.



ICDL Program Changes

Not included

Session 5: #168 Yang, Zijian

“Effect of molecular structure on the oxidation stability of trimethylolpropane ester insulating oil”

Chongqing University, Chongqing, China

New Addition

Session 5: #160 Paramanandam, Thomas

“Effect of Mg(OH)₂ on the AC Breakdown voltage and Ageing Characteristics of Synthetic Ester”

Central Power Research Institute, Bangalore, India

Recorded Presentations

Session 4: #170 Wedin, Pär

“Dissolved Gas Analysis on uninhibited and inhibited mineral oils and a natural ester under a simulated thermal fault using the Tube Heating Method”

NYNAS AB, Stockholm, Sweden

Session 2: #161 Zhou, Jian

“Effect of Thermal Field on Moisture Distribution Characteristics of Ester Oil-paper Insulation Interface: Insights From Molecular Dynamics”

Chongqing University, Chongqing, China

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ICDL Chair

The 22nd International Conference on Dielectric Liquids (ICDL) will be held in person at the Worcester Polytechnic Institute main campus, located in Worcester, Massachusetts, U.S.A. This will be the first time the ICDL is held in the U.S.A.

ICDL is the lead international conference on dielectric liquids. It covers fundamental and applied topics as well as industrial applications. The 22nd ICDL will aim to provide the most advanced and comprehensive global forum for disseminating results and data in research, development, and applications in dielectric liquids. The conference will also aim to bring together world-renowned engineers and scientists from both academia and industry in this university environment.

Conference topics:

- Basic properties and fundamental studies
- Electrohydrodynamics
- Electrical discharges and breakdowns
- High Voltage Equipment
- Other relevant topics on dielectric liquids

I would like to take this opportunity to utterly thank all the authors, presenters, and participants in advance for making the 22nd ICDL a success. I am personally looking forward to welcoming you to the 22nd ICDL in June 2023.

Jamal S. Yagoobi

22nd ICDL Chair

George F. Fuller Professor

Mechanical and Materials Engineering Department

Worcester Polytechnic Institute

Worcester, Massachusetts, U.S.A.

Committees

International Advisory Committee

Per-Olof Astrand
Maks Babuder
Abderrahmane Beroual
Nelly Bonifaci
Francesco Borghesani
Davide Fabiani
Issouf Fofana
Tim Gradnik
Naoki Hayakawa
Olivier Lesaint
Qiang Liu
Christophe Louste
Lars Lundgaard
Massimo Pompili
Pawel Rozga
Igor Timoshkin
Pedro Á. Vázquez
Zhongdong Wang
Jamal Yagoobi

Local Organizing Committee

Conference Chair:

Jamal Yagoobi

Conference Organizers:

Pat Howe
Edward Burnham
Nathaniel O'Connor
Alexander Castaneda

2023 ICDL Program at a Glance

SUNDAY, JUNE 25TH

14:00-20:00 – REGISTRATION (Innovation Studio, 1st Floor)

18:00-20:00 – RECEPTION (Higgins House Garden)

MONDAY, JUNE 26TH

7:00-17:00 – REGISTRATION (Innovation Studio, 1st Floor)

8:30-9:00 – CONFERENCE OPENING CEREMONY (Innovation Studio, 203/205)

9:00-9:30 Hans Tropper Lecture (Innovation Studio, 203/205)

9:30-12:15 – TECHNICAL ORAL SESSION 1 (Innovation Studio, 203/205)
Basic Properties and Fundamental Studies

10:45-11:00 – COFFEE BREAK (Innovation Studio, 2nd Floor)

12:15-13:15 – LUNCH (Higgins House Garden)

12:15-13:15 LUNCH for International Advisory Committee Members (Higgins House Library)

13:15-16:30 – TECHNICAL ORAL SESSION 2 (Innovation Studio, 203/205)
Electrohydrodynamics

14:35-15:00 COFFEE BREAK (Innovation Studio, 2nd Floor)

16:45-21:00 – BOSTON HARBOR CRUISE (bus departs at 16:45 from Quad)

TUESDAY, JUNE 27TH

7:00-17:00 – REGISTRATION (Innovation Studio, 1st Floor)

8:30-12:10 – TECHNICAL ORAL SESSION 3 (Innovation Studio, 203/205)
Basic Properties and Fundamental Studies and Electrical Discharges and Breakdowns

10:10-10:30 COFFEE BREAK (Innovation Studio, 2nd Floor)

12:10-12:30 – GROUP PHOTO (Quad)

12:30-13:30 – LUNCH (Higgins House Garden)

12:30-13:30 LUNCH for International Advisory Committee Members (Higgins House Library)

13:30-16:50 – TECHNICAL ORAL SESSION 4 (Innovation Studio, 203/205)
Electrohydrodynamics and Other Relevant Topics on Dielectric Liquids

15:10-15:30 – COFFEE BREAK (Innovation Studio, 2nd Floor)

17:00-18:30 – Multi-Scale Heat Transfer Laboratory and Center for
Advanced Research in Drying tours (gather at Quad)

19:00-21:30 – BANQUET (Worcester Art Museum)

WEDNESDAY, JUNE 28TH

7:00-12:00 – REGISTRATION (Innovation Studio, 1st Floor)

9:00 -12:00 – TECHNICAL ORAL SESSION 5 (Innovation Studio, 203/205)
High Voltage Equipment and Other Relevant Topics on Dielectric Liquids

10:20 -10:40 – COFFEE BREAK (Innovation Studio, 2nd Floor)

12:30 – 13:00 – AWARDS AND CONFERENCE CLOSING CEREMONY (Innovation Studio, 203/205)

12:15-13:30 – LUNCH BOXES (Innovation Studio, 203/205)



Sunday, June 25th

- 14:00-20:00** | **REGISTRATION**
(Innovation Studio, 1st Floor)
- 18:00-20:00** | **RECEPTION**
(Higgins House Garden)



Monday, June 26th

- 7:00-17:00** | **REGISTRATION**
(Innovation Studio, 1st Floor)
- 8:30-9:00** | **CONFERENCE OPENING CEREMONY**
(Innovation Studio, 203/205)
- 9:00-9:30** | **HANS TROPPER LECTURE**
(Innovation Studio, 203/205)
Abderrahmane Beroual
"Models for Predicting the Streamers Propagation Velocity in Liquid Dielectrics"
Ecole Centrale de Lyon, Lyon, France
- 9:30-12:15** | **TECHNICAL ORAL SESSION 1**
(Innovation Studio, 203/205)
Basic Properties and Fundamental Studies
Chair: Francesco Borghesani, Università degli Studi di Padova, Italy
- 9:30-10:45** | **#185 Stuchala, Filip; Rozga, Pawel**
"Breakdown and Acceleration Voltage of Selected GTL based Dielectric Liquids under Negative Lightning Impulse", Lodz University of Technology, Poland
- #188 Nassar, Michelle (1) ; Daaboul, Michel (2); Michel, Anny (3); Louste, Christophe (3)**
"Electro-optical Kerr effect in HFE-7100", 1: Schneider Electric, Rueil-Malmaison, France; 2: University of Balamand, Balamand, Lebanon; 3: University of Poitiers, Poitiers, France
- #197 Pöbniker, Christian (1); Matharage, Shanika (1); Wang, Zhongdong (1); Walker, David (2); Hilker, Andree (3); Gyore, Attila (4)**
"Bubble Formation from Non-thermally Upgraded Kraft Paper in Alternative Insulating Liquids", 1: University of Exeter, United Kingdom; 2: Scottish Power, Glasgow, United Kingdom; 3: Shell Global Solutions (Deutschland) GmbH, Hamburg, Germany; 4: M&I Materials Ltd., Manchester, United Kingdom
- #178 Greaves, Brad (1); Prevost, Thomas (1); Casserly, Edward (2); Burk, Griffin(2); Niroula, Ashmita (2)**
"Water Solubility of Aged Mineral Oil and Natural Ester Liquids", 1: Weidmann Electrical Technology Inc, United States of America 2: Ergon Refining, Inc., Newell, West Virginia, United States of America

10:45-11:00

COFFEE BREAK

(Innovation Studio, 2nd Floor)

11:00-12:15

#173 Leivo, Senja; Aronniemi, Mikko; Leppänen, Jukka

“Effect of Moisture on the Dielectric Strength of Insulation Liquids”, Vaisala Oyj, Vantaa, Finland

#177 Thota, Jaya Sree (1); Rozga, Pawel (2); Fofana, Issouf (1);

Ungarala, Mohan Rao (1,2); Brettschneider, Stephan (1);

Picher, Patrick (3); Celis, E. M. Rodriguez (3)

“Streamer Inception and Breakdown Voltage of a Low Pour Point Synthetic Ester under Lightning Impulse”, 1: University of Quebec, Canada; 2: Lodz University of Technology, Lodz, Poland; 3: Institut de Recherche d’Hydro-Québec, Canada

#186 Rozga, Pawel (1); Stuchala, Filip (1); Wolmarans, Carl (2);

Milone, Marco (3)

“Inception and Breakdown Voltage of the Oil-Wedge Type Electrode Model Insulated with Bio-based Hydrocarbon and Mineral Oil”, 1: Lodz University of Technology, Lodz, Poland; 2: Nynas AB, Stockholm, Sweden; 3: SGB-SMIT

#167 Casserly, Edward; Burk, Griffin

“Short-Chain Carboxylic Acids Generated During Oxidation of Natural Ester Insulating Liquids”, Ergon Refining, Inc., Newell, United States of America

12:15-13:15

LUNCH

(Higgins House Garden)

12:15-13:15

LUNCH for International Advisory Committee Members

(Higgins House Library)

13:15-16:30

TECHNICAL ORAL SESSION 2

(Innovation Studio, 203/205)

Electrohydrodynamics

Chair: Pedro Á. Vázquez, Universidad de Sevilla, Spain

13:15-14:35

#181 Dorji, Chenchu (1); Lesaint, Olivier (1); Hanna, Rachelle (1); Khazaka, Rabih (1,2)

“Assessment of Contribution of EHD to the Cooling of Power Semiconductor Devices Immersed in Dielectric Liquids”, 1: University Grenoble Alpes, CNRS, Grenoble, France; 2: Safran Tech, Châteaufort, France

#199 Mondal, Subhadeep (1); Traoré, Philippe (2); Bhattacharya, Anandaroop (1); Pérez, Alberto (3); Vázquez, Pedro (3); Yan, Zelu (4)

“Effect of Electric Permittivity and Ionic Mobility on Electro-Solutio-Convection Within Two Stacked Layers of Miscible Dielectric Liquids Induced by Unipolar Injection”, 1: Indian Institute of Technology Kharagpur, India; 2: Prime Institute, Futurescope, France; 3: Universidad de Sevilla, Sevilla, Spain; 4: Shanghai Maritime University, Shanghai, China

#194 Nishikawara, Masahito; Ueda, Tomoya; Yokoyama, Hiroshi; Yanada, Hideki

“Scaling Effect on Micro Electrohydrodynamic Conduction Pump with Flush Electrode”, Toyohashi University of Technology, Aichi, Japan

#189 Daaboul, Michel (1); Matar, Ihsan (2); Nassar, Michelle (3); Louste, Christophe (2)

“Testing Different Tracer Types in Particle Image Velocimetry Measurements in Electrohydrodynamics”, 1: University of Balamand, Balamand, Lebanon; 2: University of Poitiers, Poitiers, France; 3: Schneider Electric, Rueil-Malmaison, France

14:35-15:00

COFFEE BREAK

(Innovation Studio, 2nd Floor)

15:00-16:30

#192 Gonzalez, Léna (1); Roux, Jean-Maxime (1); Davoust, Laurent (2)

“MicroPIV study of vortex produced by electrothermal flows inside microfluidic chamber”, 1: CEA/LETI, Grenoble, France; 2: GRENOBLE-INP/Grenoble Alpes University/CNRS, Grenoble, France

#193 Yang, Pengfei (1,2); Shi, Wen (1); Sun, Zhihao (1); Liu, Qiang (1); Wu, Jian (1)

“Experimental study on electrospray characteristics of viscoelastic dielectric liquids”, 1: Harbin Institute of Technology, Harbin, China; 2: FAW-Volkswagen Automotive Co., Changchun, China

#195 Wang, Junxiu; Huang, Junyu; Peng, Yuxing; Liu, Fengwei; Wu, Jian

“Electrohydrodynamic convection of dielectric liquids in a square enclosure with a circular cylinder”, Harbin Institute of Technology, Harbin, China

#161 Zhou, Jian; Wang, Feipeng; Wang, Qiang

“Effect of Thermal Field on Moisture Distribution Characteristics of Ester Oil-paper Insulation Interface: Insights From Molecular Dynamics”, State Key Laboratory of Power Transmission Equipment & System Security and New Technology, Chongqing University, Chongqing, China

16:45-21:00

BOSTON HARBOR CRUISE
(bus departs at 16:45 from Quad)



Tuesday, June 27th

7:00-17:00

REGISTRATION

(Innovation Studio, 1st Floor)

8:30-12:10

TECHNICAL ORAL SESSION 3

(Innovation Studio, 203/205)

Basic Properties and Fundamental Studies and Electrical Discharges and Breakdowns

Chair: Nelly Bonifaci, Université Grenoble Alpes and CNRS, France

8:30-10:10

#191 Okamoto, Takahiro (1); Okumura, Daigo (1); Hamasuna, Kyouhei (1); Kozako, Masahiro Kozako (1); Hikita, Masayuki (1); Tsuchie, Motoo (1); Maharana, Mrutyunjay (2); Olmo, Cristian (3)

“Effect of Moisture Content on Temperature Characteristics of Dielectric Breakdown Strength of Biodegradable Ester Oils”, 1: Kyushu Institute of Technology, Kitakyushu, Japan; 2: Xi’an Jiaotong University, Xi’an, China; 3: Engineering University of Cantabria, Santander, Spain

#196 Alshehawy, Abdelrahman M. (1,2); Matharage, Shanika (1); Wang, Zhongdong (1); Tsuchie, Motoo (3); Kozako, Masahiro (3); Hikita, Masayuki (3)

“Impact of Thermal Aging on The Conductivity of Kraft Paper Impregnated with Mineral Oil and Synthetic Ester”, 1: University of Exeter, Exeter, United Kingdom; 2: Tanta University, Tanta, Egypt; 3: Kyushu Institute of Technology, Kitakyushu, Japan

#182 Yu, Haichuan (1); Liu, Qiang (1); Wang, Zhongdong (1,2); Mark Wilkinson (3); Attila Gyore (4); Luke Van der Zel (5)

“A New Method for Calculation of Lightning Impulse Breakdown Voltages of a Synthetic Ester at Different Gaps”, 1: The University of Manchester, Manchester, United Kingdom; 2: Department of Engineering, University of Exeter, Exeter, United Kingdom; 3: SGB-SMIT Group, Nijmegen, Netherlands; 4: M & I Materials, Ltd., Manchester, United Kingdom; 5: EPRI, California, United States of America.

#159 Takamura, Norimitsu; Araoka, Nobutaka; Fujimura, Masahiro; Hanai, Masahiro

“Analysis of Dissolved Nitrogen and Oxygen Gases in Palm Fatty Acid Ester Added with Nitrogen Fine Bubbles”, Fukuoka University, Fukuoka, Japan

10:10-10:30 #183 Amizhtan, S K (1); Sarathi, R (1); Vinu, R (1); Edin, Hans (2); Taylor, Nathaniel (2)
"Investigation on Carbon particle formation with Electro-Thermal ageing of Transformer oil" 1: Indian Institute of Technology Madras, Chennai, India; 2: KTH Royal Institute of Technology, Stockholm, Sweden

10:30-12:10 **COFFEE BREAK**
(Innovation Studio, 2nd Floor)

#205 Galbato Muscio, Gabriele; Calcara, Luigi; Pompili, Massimo; De Bellis, Giovanni
"Effect of strong DC Electric Fields on the flow properties of insulating liquids at different temperatures", University of Roma La Sapienza, Rome, Italy

#166 Borghesani, Armando Francesco (1); Bonifaci, Nelly (2); Atrazhev, Vladimir (3); Khrapak, Aleksey (3)
"Threshold density for electron self-localization in gaseous Helium", 1: Università degli Studi di Padova, Padua, Italy; 2: Université Grenoble Alpes and CNRS, Grenoble, France; 3: Joint Institute for High Temperatures, Moscow, Russia

#180 Dorji, Chenchu (1); Lesaint, Olivier (1); Hanna, Rachelle (1); Khazaka, Rabih (1, 2)
"Partial Discharges and Electroluminescence Measurements on Power Electronic Substrates Embedded in Liquids", 1: Université Grenoble Alpes, CNRS, Grenoble, France; 2: Safran Tech, Châteaufort, France

#172 Hayakawa, Naoki (1); Kamada, Hirotaka (1); Kojima, Hiroki (1); Aruga, Nobu (2); Utatsu, Kiyoshi (2); Shunya, Watanabe (2)
"Applicability of Lubricating Oil Insulation in Higher Power Density Motors for Electric Powered Aircraft", 1: Nagoya University, Nagoya, Japan; 2: Sinfonia Technology Co., Tokyo, Japan

#175 Khelifa, Hocine; Vagnon, Eric; Beroual, Abderrahmane
"AC Dielectric Strength and Partial Discharge Activity in Naturel Ester and Naturel Ester-Based Fullerene Nanofluids" University of Lyon, Ecole Centrale de Lyon, Lyon, France

12:10-12:30 **GROUP PHOTO**
(Quad)

12:30-13:30 **LUNCH**
(Higgins House Garden)

12:30-13:30 **LUNCH for International Advisory Committee Members**
(Higgins House Library)

13:30-16:50

TECHNICAL ORAL SESSION 4
(Innovation Studio, 203/205)

Electrohydrodynamics and Other Relevant Topics on Dielectric Liquids
Chair: Zhongdong Wang, University of Exeter, United Kingdom

13:30-15:10

#163 Du, Zhonglin (1); A. Vázquez, Pedro (2); Wu, Jian (1)
"Electro-thermo-convection in a planar layer of dielectric liquid subjected to electrohydrodynamic conduction and thermal gradient", 1: Harbin Institute of Technology, Harbin, China; 2: Universidad de Sevilla, Sevilla, Spain

#169 Yan, Zelu (1,3); Louste, Christophe (2); Traoré, Philippe (2); Fang, Jian'an (3)
"Reconstruction of reduced-order EHD flow fields using the proper orthogonal decomposition", 1: Shanghai Maritime University, Shanghai, China; 2: CNRS, Université de Poitiers, Futuroscope Chasseneuil, France; 3, Donghua University, Shanghai, China

#201 Matar, Ihssan (1); Louste, Christophe (1); Daaboul, Michel (2)
"Numerical Estimation of the Electric Force Induced by a Cylinder-to-Cylinder EHD Device", 1: University of Poitiers, Poitiers, France; 2: University of Balamand, Balamand, Lebanon

#203 O'Connor, Nathaniel; Yagoobi, Jamal
"The Effect of Pulsating Dielectrophoresis on Liquid Film Flow Boiling", Worcester Polytechnic Institute, Worcester, United States of America

#184 Berry, Valentin (1); Lin, Zheng (2); Leblanc, Paul (1); Hole, Stéphane (2); Paillat, Thierry (1)
"Numerical study of the electric charge measurement by PWP method: application to the electrical double layer" 1: CNRS, University of Poitiers, Poitiers, France; 2: CNRS – Sorbonne University – ESPCI, Paris, France

15:10-15:30

COFFEE BREAK
(Innovation Studio, 2nd Floor)

15:30-16:50

#204 Castaneda, Alexander Javier; Yagoobi, Jamal
"Experimental and Numerical Study of an Oscillating Electrohydrodynamic Conduction Pump", Worcester Polytechnic Institute, Worcester, United States of America

#165 Zhao, Yaohong (1); Qian, Yihua (1); Wang, Ruifeng (2); Pan, Siwei (1); Peng, Lei (1); Gong, Jun (3)

"Simultaneous quantitative determination of nine antioxidants in natural ester insulating liquid by HPLC", 1: Electric Power Research Institute of Guangdong Power Grid Corporation, Guangzhou, China; 2: North China Electric Power University, Baoding, China; 3: Guangdong JOOYN New Material Technology Co., Guangdong, China

#170 Wedin, Pär; Minchak, Elena; Wolmarans, Carl; Singh, Jessica; Feyzabi, Kaveh; Norrby, Thomas

"Dissolved Gas Analysis on uninhibited and inhibited mineral oils and a natural ester under a simulated thermal fault using the Tube Heating Method", NYNAS AB, Stockholm, Sweden

#176 Khelifa, Hocine (1); Beroual, Abderrahmane (2); Vagnon, Eric (3)

"Effect of Fullerene Nanoparticles on the Electrostatic Charging Tendency of Natural Ester FR3", 1: University of Lyon, Lyon, France, 2: Ecole Centrale de Lyon, Ecully, France, 3: Ampère CNRS, Lyon, France

17:00-18:30

Multi-Scale Heat Transfer Laboratory & Center for Advanced Research in Drying Tours
(gather at Quad)

19:00-21:30

BANQUET
(Worcester Art Museum)



Wednesday, June 28th

7:00-12:00

REGISTRATION

(Innovation Studio, 1st Floor)

9:00-12:00

TECHNICAL ORAL SESSION 5

(Innovation Studio, 203/205)

High Voltage Equipment and Other Relevant Topics on Dielectric Liquids
Chair: Naoki Hayakawa, Nagoya University, Japan

9:00-10:20

#164 Wang, Ruifeng (1,4); Huang, Zhiqiang (2); Rapp, Kevin J (3); Liu, Yunpeng (1)

"Essential Evaluations on Developing Natural Ester Immersed 750kV Power Transformer", 1: North China Electric Power University, Beijing, China; 2: Chint Electric Group, Zhejiang, China; 3: Rapp Consulting Intl., Oak Creek, United States of America; 4: Cargill Bioindustrial, Gouda Netherlands.

#171 Scatiggio, Fabio (1); Campi, Giorgio (1); Actis, Riccardo (2); Tumiatti, Vander (2)

"A validated procedure for transformer retrofilling", 1: A&A Fratelli Parodi, Campomorone, Italy; 2: Sea Marconi Technologies, Collegno, Italy

#187 Gautam, Leena (1); Sarathi, R. (1); Fofana, I. (2); Rao, U. Mohan (2)

"Investigation on Different Partial Discharge pattern in Transformers by Detection Adopting UHF and Fluorescent Fiber Techniques", 1: Indian Institute of Technology, Madras, India; 2: University of Quebec at Chicoutimi, Saguenay, Canada

#162 Qian, Yihua (1); Zhou, Jian (2); Zhao, Yaohong (1); Wang, Qing (1); Wang, Feipeng (2)

"Infrared Spectroscopy for Ageing Assessing of Insulating Oils via Interfacial Tension", 1: Electric Power Research Institute of Guangdong Power Grid Co., China 2: Chongqing University, Chongqing, China

10:20-10:40

COFFEE BREAK

(Innovation Studio, 2nd Floor)

10:40-12:00

#190 Zupan, Tomislav (1); Novko, Ivan (1); Ziger, Igor (2)

"Influence of Insulating Liquid on Lightning Impulse Withstand Voltage Level for Instrument Transformers", 1: KONCAR - Electrical Engineering Institute, Zagreb, Croatia; 2: KONCAR - Instrument Transformers Inc., Zagreb, Croatia

#174 Da Silva, Roberto Ignacio (1); Vasconcellos, Vagner (2)

"High-Temperature Insulation Systems for More Compact Mobile Power Transformers", 1: Cargill, Sao Paulo, Brazil; 2: CPFL Energia, Sao Paulo, Brazil

#198 Malde, Jinesh Ratilal (1); Breazeal, Robert (2); Greaves, Brad (3)

"Investigating Performance of Mineral Insulating Liquid and Less Flammable Ester Liquid Filled Distribution Transformers in Overload Conditions", 1: M&I Materials Inc, Manchester, United Kingdom; 2: Southern California Edison, Rosemead, United States of America; 3: Weidmann Electrical Technology Inc, Zurich, Switzerland

#160 Paramanandam, Thomas

"Effect of Mg(OH)₂ on the AC Breakdown voltage and Ageing Characteristics of Synthetic Ester", Central Power Research Institute, Bangalore, India

12:30-13:00

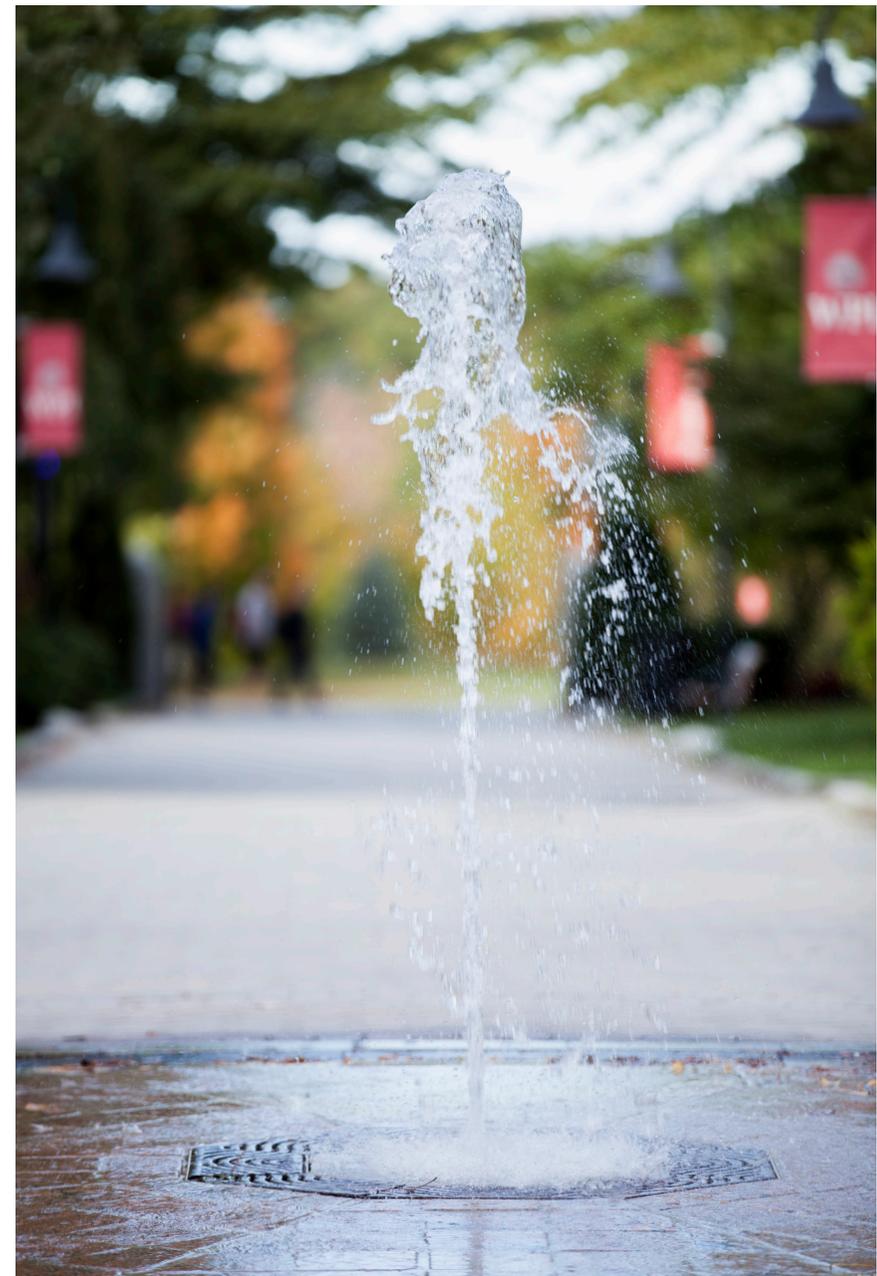
AWARDS AND CONFERENCE CLOSING CEREMONY

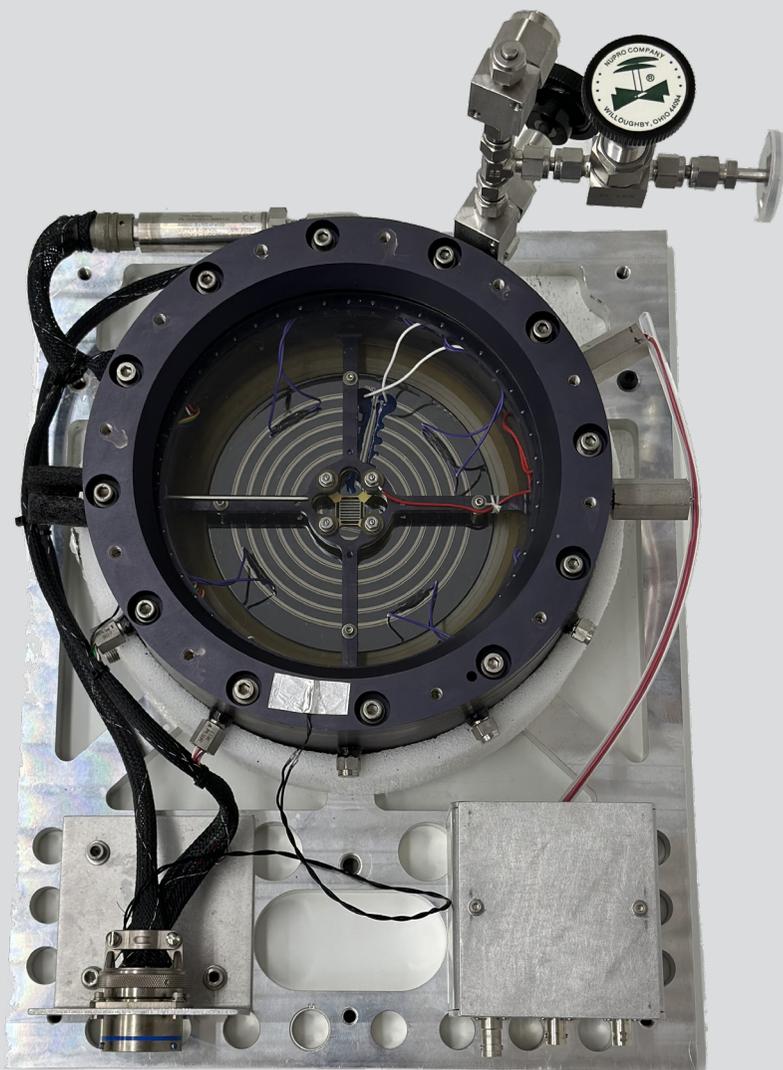
(Innovation Studio, 203/205)

12:15-13:30

LUNCH BOXES

(Innovation Studio, 2nd Floor)





Multi-Scale Heat Transfer Laboratory at WPI

test chamber for EHD conduction driven liquid film flow boiling in the presence of dielectrophoretic force, flown in micro-gravity flights
project supported by the National Aeronautics and Space Administration (NASA)

