IAPWS Canadian National Committee

Annual Report 2014

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CNC Executive: *William Cook (Chair); David Guzonas (IAPWS Vice President); Derek Lister; Peter Tremaine; Melonie Myszczyszyn; Steve McGee (CANDU Owners Group Representative, Treasurer)*

1. Canadian National Committee: Dues for the Canadian National Committee (CNC) of IAPWS are supported by the National Research Council of Canada. This arrangement requires support and participation by a national organization representing industry. In 2004 the CANDU Owners Group took on this role on a trial basis, and in 2007 the CANDU Owners Group accepted this role for a five-year term, including travel support for the academic members of the CNC. In December 2012, COG agreed to another five-year term as the CNC's industrial sponsor (2013-2017).

Dr. Dave Guzonas has been the IAPWS vice-president since 2013. He will transition to IAPWS president for 2015-2016.

2. NSERC/NRCan/AECL Generation IV Energy Technologies Program

A major university-based program to study water chemistry in support of the development of the Canadian Supercritical Water-cooled Reactor concept (NSERC/NRCan/AECL Generation IV Energy Technologies Program) is currently in Phase II and includes seven water chemistry projects that cover two main themes: a) corrosion product transport and deposition, and b) water radiolysis. The goal is to develop chemistry control strategies for the SCWR as well as recommend realistic chemistry conditions for corrosion testing for materials selection. The program also funds eight projects examining materials degradation phenomena (e.g., corrosion, stress corrosion cracking, creep, ageing) at temperatures up to 850 ºC. The yearly workshop for the program members will be held in Vancouver in August 2014 in conjunction with the Pacific Basin Nuclear Conference.

Research on high-temperature water chemistry being funded by this program includes:

P. Tremaine (U. of Guelph): Aqueous chemistry of metals and fission product under SCWR conditions.

C. Pye (St. Mary's University): Ab initio calculations on ionic hydration and complexation.

W. Cook (U. of New Brunswick): Corrosion product transport and deposition under SCWR conditions.

I. Svishchev (Trent University): Water chemistry, pH control and particle formation process in an SCWR.

A. Anderson (St. Francis Xavier University): Time-resolved investigations of metal oxide-water systems under conditions of extreme temperature, pressure and radiation.

P. Percival (Simon Fraser University), K. Ghandi (Mount Allison University): Reaction kinetics in SCW probed using muonium.

J.-P. Jay-Gerin (U. of Sherbrooke): Computational modelling of water radiolysis in high temperature water (including SCW).

C. Wren (U. of Western Ontario): Water radiolysis effects on materials degradation in high temperature water (including SCW).

The chemistry program is co-ordinated by D. Guzonas (AECL).

3. Activities at the University of New Brunswick

D. Lister

Heat exchanger fouling; examining the effects of surfactants on magnetite deposition during boiling heat transfer (collaboration with AECL). Preliminary studies developed an accurate way of measuring local deposit thicknesses ex-situ and measured the effects of surfactants and film-forming amines on deposition.

Flow-accelerated corrosion (FAC); predicting the characteristics of scallops (the sculpting of surfaces undergoing FAC). Correlating the pattern of FAC recorded in many laboratory experiments and field measurements at different conditions of flow, pH, etc. lead to greater understanding of the FAC phenomenon in general.

Modelling reactor primary circuit contamination. Inserting FAC mechanisms and in-core effects into models for material transport lead to predictions of radiation fields.

Sampling high-temperature water systems; modelling hold-up of corrosion products in coolers and introducing precipitation kinetics provide information relevant to the IAPWS technical guidance document.

Characterising the effects of film-forming amines on FAC in two-phase flow. Scoping studies in single-phase flow are complete and similar experiments under two-phase flow at 200^{o}C are almost complete.

Developing a robust probe for measuring FAC in-situ in operating plant. A probe has been designed and an agreement negotiated with a power utility to install it in a coal-fired station.
Verifying the effects of dissolved iron on FAC. Experiments injecting iron into a coolant stream by promoting FAC upstream of an in-situ FAC probe are almost complete. The measured effects are being modelled for incorporation into a commercial code.

W. Cook

W. Cook has been asked by the University of New Brunswick to become the Director of the Centre for Nuclear Energy Research (CNER), a research institute on UNB's campus. CNER has over two-decades of research / collaboration with the nuclear industry and has developed and patented online sensors for monitoring corrosion of plant piping in-situ. Efforts will be undertaken to facilitate more field trials to show the utility of the sensors for nuclear power plants. Additional research programs in power cycle chemistry and corrosion will be launched from the CNER Institute over the next year.

Active involvement in the Generation IV Technologies Program for development of the SCWR. The major focus is corrosion-product transport and deposition in the core of a SCWR where both experimental techniques and modeling are employed to elucidate material corrosion and the deposition kinetics of the "fall-out" from solution that occurs upon traversing the critical point.

Hydrogen control in CANDU cooling systems is a new project being undertaken in conjunction with industrial collaborators. Current CANDUs have conducted successful trials injecting hydrazine into the shield cooling system, which acts to suppress the water radiolysis reactions to keep the coolant in a reducing condition. Alternate chemical additives are being examined to duplicate the effect, eliminating the need for hydrazine use in this system.

Electrowinning of metals from solutions is an additional industrial project of note. Modelling and experimental work was undertaken on zinc, indium and manganese production. A series of electrowinning tests for manganese production, using ion-exchange membranes as the compartment separator, was undertaken to validate and improve upon process efficiency. Optimization of the winning process and associated modelling of the system involves use of the PCAS thermodynamic models.

4. Activities at the University of Guelph (Prof. Peter Tremaine)

Research Themes

1. Ions and Organic Solutes in Very High Temperature Water
   1.
2. Origins of Life: Pre-Biotic Chemistry under Deep Ocean Hydrothermal Vent Conditions
   2.
3. CANDU Nuclear Reactor Chemistry: the Next Generation
   3.
4. Thermal Power Generation, Carbon Capture, and Hydrogen Co-Generation

Current and Recent Funders

The following companies and granting agencies contributed to our research during the past five years: NSERC, Atomic Energy of Canada Ltd., Ontario Power Generation Ltd., The Electric Power Research Institute (EPRI), Inco, IAPWS, UNENE, Natural Resources Canada.

Specific Projects

Solvation and Equilibria of Ions and Organic Solutes in Water up to Near-Critical Conditions

Origins of Life: Pre-Biotic Chemistry under Deep Ocean Hydrothermal Vent Conditions

CANDU Nuclear Reactor Chemistry: D_2O Isotope Effects on Acid-base Ionization and Metal Hydrolysis (UNENE/NSREC CRD Grant)

Generation IV Nuclear Reactor Chemistry: Ion Pairs and Complexes in Sub-critical and Supercritical Water (NRCan/AECL/ NSERC CRD Grants):

Carbon Capture and Sequestration by Novel Phase-Separating Solvents (NSERC International Strategic Grant with University Blaise Pascal, France)

5. Activities Planned to next ICPWS (2017/18)

The CNC activities over the next few years will continue the work that is currently ongoing, as described above. The supercritical water-cooled reactor project is a focus for much of the current research activities of the CNC. This university-government-industry program focused on fundamental research will conclude Phase II in 2016 but it is currently planned to have more focused research beginning in Phase III.

The possibility of organizing an "IAPWS" session at a national conference such as those organized by the Chemical Institute of Canada or by the processed water industry surrounding the Alberta oil sands development was discussed. The goal would be to raise the profile of the Canadian National Committee and IAPWS activities with researchers in Canada doing complementary research.

Each of the CNC members and IAPWS-involved researchers in Canada are involved in industry-sponsored research with organizations such as EPRI and the CANDU Owners Group pertinent to topics of interest to IAPWS.

The CNC identified that the reformulation of the properties of heavy water is of great interest to Canada and provided contacts with the CANDU community to support the work.

6. Select List of Publications

1. D.A. Guzonas, R. Novotny, "Supercritical Water-cooled Reactor Materials – Summary of Research and Open Issues", Progress in Nuclear Energy (2014), http://dx.doi.org/10.1016/j.pnucene.2014.02.008.

2. L. M. Alrehaily, J. M. Joseph, A. Y. Musa, D. Guzonas, J. C. Wren, "Gamma-radiation Induced Formation of Chromium Oxide Nanoparticles from Dissolved Dichromate", Phys. Chem. Chem. Phys., **15** (2013) 98.

3. X. Huang, D. Guzonas "Characterization of Ni–20Cr–5Al Model Alloy in Supercritical Water", Journal of Nuclear Materials 445 (2014) 298–307.

4. F. Barrett, X. Huang, D. Guzonas, "Characterization of TiO2 Doped Yttria Stabilized Zirconia (YSZ) for Supercritical Water-Cooled Reactor Insulator Application", Journal of Thermal Spray, Journal of Thermal Spray Technology, 22 (2013) 734-743.

5. Z. Dong, W. Chen, W. Zheng, D. Guzonas, "Effect of Yttria Addition on the Stability of Porous Chromium Oxide Ceramics in Supercritical Water", Journal of Nuclear Materials 432 (2013) 466–474.

6. I. M. Svishchev, R.A.Carvajal-Ortiz, K.I.Choudhry, D.A.Guzonas "Corrosion Behavior of Stainless Steel 316 in Sub- and Supercritical Aqueous Environments: Effect of LiOH Additions", Corrosion Science 72 (2013) 20–25.

7. D. Guzonas "Extreme Water Chemistry – How GEN IV Water Chemistry Reseacrh Improves GEN III Water-cooled Reactors, 19th Pacific Basin Nuclear Conference (PBNC 2014), Vancouver, Canada, 2014 August 24-28.

8. S. Sanguanmith, J. Meesungnoen, D.A. Guzonas C.R. Stuart and J.-P. Jay-Gerin "Low-LET Radiation Chemistry of Supercritical Water at 400 °C: A Re-analysis of the Water Density Dependence of the Spur Lifetime and the "Escape" e-aq Yield", Recent Res. Devel. Physical Chem. 11 (2013) 1-14.

9. D.Guzonas "The Physical Chemistry of Corrosion in a Supercritical Water-cooled Reactor", Proceedings of the 16th Int. Conf on the Properties of Water and Steam, 1-5 September 2013, University of Greenwich, London, UK.

10. L. Qiu, D.A. Guzonas, J. Qian "Dissolution of Silicon Nitride in High Temperature Alkaline Solutions", Proceedings of the 16th Int. Conf on the Properties of Water and Steam, 1-5 September 2013, University of Greenwich, London, UK.

11. L.M.S.G.A. Applegarth, C.R. Corbeil, D.J.W. Mercer, C.C. Pye and P. R. Tremaine, A Raman and Ab Initio Investigation of Aqueous Cu(I) Chloride Complexes from 25 to 80^{o}C. J. Phys. Chem. B 118, 204-214 (2014).

12. L. Applegarth and P. Tremaine, Boiling Points and Speciation of Aqueous Electrolyte Solutions Under "Hideout" Conditions in Supercritical Water-cooled Reactor Coolant by Raman Spectroscopy, Proc. 19th Pacific Basin Nuclear Conf. (Vancouver, Aug. 24-28, 2014) (Submitted).

13. C. Pye, Liwei Cheng, and P.R. Tremaine, Metal Speciation under Supercritical Water-Cooled Reactor Coolant Conditions by Ab Initio Calculations, Spectroscopy and Conductivity Measurements, Proc. 19th Pacific Basin Nuclear Conf. (Vancouver, Aug. 24-28, 2014) (Submitted).

14. Non-Complexing Anions for Physico-Chemical Studies by Raman Spectroscopy under Hydrothermal Conditions L.M.S.G.A. Applegarth, C. Alcorn, K. Bissonnette, J. Noel and P.R. Tremaine, Proc. 16th Int. Conf. Properties of Water and Steam (IAPWS & Inst. Mech. Eng.; Greenwich, U.K., Sept. 1 - 5, 2013)

15. Ion Pair Formation Constants and Transport Properties for Aqueous Strontium Complexes up to 350°C at 20 MPa by Flow AC Conductance, H. Arcis, G.H. Zimmerman‡ and P.R. Tremaine†,*Proc. 16th Int. Conf. Properties of Water and Steam (IAPWS & Inst. Mech. Eng.; Greenwich, U.K., Sept. 1 - 5, 2013).

16. Uchida, S., Naitoh, M., Okada, H., Suzuki, H., Koshizuka, H. and Lister, D.H. (2013). "Contribution of Probabilistic Risk Evaluation of Flow-Accelerated Corrosion to System Safety Analysis of Aging NPPs". Proc.16th Intern. Conf. Props. Water and Steam, Greenwich, London, UK. Sept. 1st-6th.

17. Addison, D., Lister, D. and Thomsen, K. (2013). "Monitoring and Analysing Total Iron and Copper in Fossil and Combined Cycle Plants – Technical Guidance Document". Proc.16th Intern. Conf. Props. Water and Steam, Greenwich, London, UK. Sept. 1st-6th.

18. Srisukvatananan, P., Lertsurasakda, C., Lister, D. and Mathews, J. (2013). "Sampling Amines from Flowing Steam-Water Mixtures". Proc.16th Intern. Conf. Props. Water and Steam, Greenwich, London, UK. Sept. 1st-6th.

19. Lister, D., Srisukvatananan, P. and Uchida, S. (2013). "Sampling Nuclear Reactor Coolant Systems". Proc.16th Intern. Conf. Props. Water and Steam, Greenwich, London, UK. Sept. 1st-6th.

20. Lister, D.H. and Khumsa-Ang, K. (2013). "Oxide Particle Deposition under Low-Temperature Cooling Water Conditions: Experiments under Subcooled Boiling at High pH". Heat Trans. Eng., 34, Issues 8-9 (April-May).

21. Lertsurasakda, C., Srisukvatananan, P., Liu, L., Lister, D. and Mathews, J. (2013). "The Effects of Amines on Flow-Accelerated Corrosion in Steam-Water Systems". Power Plant Chem., 15 (3), 181-189.

22. Suzuki, H., Uchida, S., Naitoh, M., Okada, H., Koikara, S., Hasegawa, K., Kojima, F., Koshizuka, S. and Lister, D.H. (2013). "Risk Evaluation of Flow-Accelerated Corrosion Based on One-Dimensional FAC Code". Nuclear Technology, 183, 194-209.

23. Suzuki, H., Uchida, S., Naitoh, M., Okada, H., Koikara, S., Nagaya, Y., Nakamura, A., Koshizuka, S. and Lister, D.H. (2013). "Verification and Validation of One-Dimensional Flow Accelerated Corrosion Evaluation Code". Nuclear Technology, 183, 62-74.

24. Lister, D.H. and Uchida, S. (2014). "Determining Water Chemistry Conditions in Nuclear Reactor Coolants". J. Nucl. Sci. Techn. Invited Review for 50th Anniversary Edition, in press (April 10).

25. Uchida, S., Koshizuka, S. and Lister, D.H. (2014). "Evaluation of the Effects of pH and Oxygen on Mitigation of Wall Thinning of Carbon Steel due to Flow-Accelerated Corrosion." Proc. EUROCORR 2014, Pisa, Italy. September 8-12.

26. Cook, W.G., Stuart, C.R. and Gardner, E., *Secondary System Return to Service Following the Refurbishment Outage at the Point Lepreau Generating Station*, Oral presentation accepted to NPC 2014 - Nuclear Plant Chemistry 2014, Sapporo, Japan, October 2014.

27. Stuart, C.R, Cook, W.G. and Gardner, E., *Primary Heat Transport System Return to Service Following the Refurbishment Outage at the Point Lepreau Generating Station*, Oral presentation accepted to NPC 2014 - Nuclear Plant Chemistry 2014, Sapporo, Japan, October 2014.

28. Cook, W. and Olive, R., *Corrosion Product Transport and Deposition in a Supercritical Water-Cooled Reactor,* ICPSW16, Greenwich, UK, September 2013.

29. Cook, W. and Olive, R., *Predicting Corrosion Product Solubility in Supercritical Water using Revisited HKF-model Parameters and Thermodynamic Modelling,* ICPSW16, Greenwich, UK, September 2013.