Minutes
IAPWS Thermophysical Properties of Water and Steam WG
IAPWS Industrial Requirements and Solutions WG
Doorwerth, Netherlands, September 7-10, 2009

NOTE: Because the working groups met jointly, these Minutes combine the activities of Working Groups TPWS and IRS, and also some of the work of the Subcommittee on Seawater. Items are listed according to their order on the TPWS agenda, which is attached as Attachment A. **Bold print** denotes significant actions.

1-2. The meeting was opened on Monday, September 7 at 10:15 by the TPWS Chair, Hans-Joachim Kretzschmar, who was also chairing the IRS portion of the meeting in the absence of the IRS Chair and Vice-Chair. The agenda (Attachment A) was adopted. Allan Harvey was appointed Clerk of Minutes to take combined Minutes for TPWS and IRS. The Chair noted that, in accordance with our new procedure, the 2008 Minutes had been circulated and approved shortly after the 2008 meeting.

3. H.-J. Kretzschmar and M. Kunick demonstrated access to a password-protected website for documents and presentations of the TPWS and IRS Working Groups and the SCSW. The site is accessible from the Working Groups page on www.iapws.org.

4. J. Hruby discussed a proposed international collaboration "Thermophysical Properties of Supercooled Water," which would send Jana Kalova to the University of Maryland for 6 months at the beginning of 2010. The Working Groups endorsed the proposal.

5. (IAPWS-95) W. Wagner reported about the revision to the IAPWS-95 release to better match the triple-point datum states, and to make some minor editorial corrections. In the absence of Mr. Miyagawa, Prof. Kretzschmar reported the favorable evaluation report. There was some discussion about clarifying the language about molar properties, and slightly revised wording was worked out. **The WGs approved the Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use.**

6. (IAPWS-IF97) W. Wagner reported about proposed minor editorial changes to the IAPWS-IF97 release. In the absence of Mr. Miyagawa, Prof. Kretzschmar reported the favorable evaluation report. There was some discussion about how to inform readers on the title page that editorial changes had been made. **The WGs approved the editorial changes to the Revised Release on the Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam, and authorized the Editorial Committee to consider the cover page issue and make a change there if they decided appropriate.** The Chair was requested to write a note of appreciation to Drs. Harvey and Stöcker for their work on this document.

7. (IAPWS-IF97-S04) H.-J. Kretzschmar reported about proposed minor editorial changes to the IAPWS-IF97-S04 Supplementary Release. In the absence of Mr. Miyagawa, Prof. Kretzschmar reported the favorable evaluation report. It was agreed to change "density" to "mass density" in the Nomenclature to be consistent with IAPWS-IF97. **The WGs approved the editorial changes to the Supplementary Release on Backward Equations *p*(*h*,*s*) for**

Region 3, Equations as a Function of *h* and *s* for Region boundaries, and an Equation $T_{sat}(h,s)$ for Region 4 of the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam (IAPWS-IF97-S04), and authorized the Editorial Committee to deal with the same cover page issue mentioned in item 6.

8. R. Feistel presented the proposed Supplementary Release on a computationally efficient Gibbs energy formulation for liquid water, intended to be used in place of IAPWS-95 with the release on thermodynamic properties of seawater in order to speed up oceanographic calculations. J. Hruby presented the favorable evaluation report. **The WGs approved the Supplementary Release on a Computationally Efficient Thermodynamic Formulation for Liquid Water for Oceanographic Use**.

9. (thermal conductivity) E. Vogel presented work from his group on calculation at the molecular level of the low-density thermal conductivity of water vapor. There is some systematic disagreement with existing experimental data (and the current IAPWS release) at high temperatures.

J. Sengers gave a status report on the development of a new thermal conductivity formulation. The critical enhancement is known well from theory and agrees well with data with only one adjustable parameter; it is also consistent with the new viscosity formulation. The remainder of the work awaits a decision on how to proceed with the low-density part.

A. Harvey presented a proposed ICRN (#24) on Thermal Conductivity of H_2O at Low Pressures and High Temperatures. This ICRN encourages theoretical work and new experimental work to help resolve the discrepancy mentioned above. **The WGs approved the ICRN on Thermal Conductivity of H_2O at Low Pressures and High Temperatures and requests that the EC authorize the normal distribution and approval process after the Editorial Committee makes some minor editorial revisions.**

After some discussion of how to proceed on the low-density thermal conductivity, **the following recommendations were adopted**:

1. The Task Group will re-analyze the zero-density extrapolation of thermal conductivity data, using the same methods as for the viscosity.
2. It is thought that the "best" theoretical estimates for the thermal conductivity might be about 1% higher than the current calculations.
3. Uncertainties assigned to experimental data will be expanded if needed to include theoretical values plus 1%, and these larger uncertainties will be used in the weighting of the fitting and in uncertainty evaluation of the final correlation.
4. The low-density thermal conductivity at low temperatures will be reexamined in light of the theoretical calculations.
5. E. Vogel will be added to the Task Group on thermal conductivity.
6. The Task Group will proceed in completing the thermal conductivity correlation on this basis without waiting for possible resolution of the apparent discrepancy between theory and experiment.

The remaining item for the thermal conductivity was to **appoint an Evaluation Task Group. The members will be R. Mareš (Chair), J. Hruby, K. Miyagawa and V. Ochkov.**

10. A. Novy presented some work on spline modeling for backward calculations of the sublimation and melting curves. It was decided to include Mr. Novy as an outside expert on the Task Group appointed in 2008 for fast property calculations.

11. (ice) R. Feistel presented the proposed revision of the 2006 release for thermodynamic properties of ice, to improve consistency with the triple-point datum for energy and entropy. A. Harvey presented the favorable evaluation report on behalf of the Evaluation Committee. One additional minor editorial change was discussed and agreed to in order to make clear the uncertainty of the experimental triple-point pressure. **The WGs approved the Revised Release on the Equation of State 2006 of H_2O Ice Ih**.

12. J. Cooper presented some results of investigation of the possibility of using IAPWS-95 and corresponding-states principles to predict heavy water thermodynamic properties. The method was unable to reproduce densities within the tolerances given in the existing heavy water release.

13.1. T. McDougall reported that the IOC (Intergovernmental Oceanographic Commission) had adopted the IAPWS formulations for seawater and ice as part of their standard known as TEOS-10. This is being adopted widely within marine science communities, and produces many improvements (such as accuracy, additional important properties, and thermodynamic consistency) over the old equations. D. Wright discussed the source code library being developed to put these standards into four computer languages. T. McDougall reported on the work primarily performed by D. Jackett on optimizing the IAPWS-95 Fortran code which produced speed improvements by approximately a factor of 8.

13.2 There was discussion about industrial calculation of seawater properties (for seawater cooling in power applications and for desalination). There was agreement that IAPWS-IF97 should be suitable for the pure-water part for this purpose (even though it was not accurate enough for oceanography). The current seawater release does not extend to high enough temperature for some areas of interest. **It was decided to appoint a Task Group on industrial calculations for seawater with the following mandate: (1) Prepare an Advisory Note describing the use of IAPWS-IF97 in this context, explaining the current limits of the seawater formulation. This Advisory Note should be prepared in time for approval at the 2010 IAPWS meeting. (2) Discern the range of conditions required to satisfy significant industrial needs for seawater thermodynamic properties and recommend where the current formulation might need to be extended (perhaps in an ICRN). The members of the Task Group are Cooper (Chair), Feistel, and Hiegemann, with authorization for one more industrial member to be added later by agreement of the existing members. An Evaluation Task Group was appointed consisting of Hruby (Chair), Mareš, and Miyagawa. The Clerk of Minutes was requested to make a schedule for tasks reflecting completion of a draft by the end of 2009 and circulation for approval at the 2010 IAPWS meeting. That schedule will be:**

Dec. 31, 2009	**Advisory Note drafted & sent to Evaluation TG**
Feb. 28, 2010	**Completion of evaluation by Evaluation TG**
March 15, 2010	**Distribution of Advisory Note and evaluation report to WG**
April 15, 2010	**Deadline for input from WG members**
May 15, 2010	**Finalized draft to Editorial Committee**
June 15, 2010	**Approval by Editorial Committee**

July 1, 2010 Distribution by Executive Secretary to National Delegates

13.3. G. Marion presented a summary of different conventions for defining pH and their effects for seawater and other aqueous electrolyte solutions. Further action was deferred until the meeting of the Subcommittee on Seawater.

13.4. R. Feistel presented a summary of two new experimental data sets for density of seawater (some of which are outside the range of validity of the seawater release) and of a set of data for freezing of seawater brines. Agreement with the freezing data was good. Some empirical correction models were described that could achieve better agreement with the density data. T. McDougall discussed the composition anomalies of the world's oceans, where practical salinity does not definitively determine density and the difference can largely be correlated with silicate composition. On behalf of P. Spitzer, R. Feistel presented some information on SI traceability and uncertainty for seawater measurements, where the main current concern is getting an SI-traceable measurement for salinity. One idea is to use the density as a surrogate variable for the salinity. A Task Group for this will be appointed (see item 6 in the Minutes of the Subcommittee on Seawater).

13.5. (joint with PCAS) A. Anderko presented his work with P. Wang on modeling the viscosity and thermal conductivity of seawater. The results look promising so far. The Task Group on Transport Properties appointed in item 6 of the SCSW minutes was encouraged to continue toward developing final formulations.

14. R. Feistel presented the formulation for humid air properties prepared for the TEOS-10 library which has been adopted by UNESCO. The formulation combines IAPWS-95 with a reference-quality EOS for dry air, and best available values for the 2nd and 3rd cross virial coefficients. It was discussed whether IAPWS should work toward recommendations for properties of humid air or more generally humid gases (such as combustion gases). A Task Group for this already exists from our 2008 meeting consisting of Span (Chair), Harvey, Hruby, Kretzschmar, and Wendland. **It was decided to add R. Feistel to this Task Group.** The mandate of this Task Group is to consider updating the current ICRN on humid gases (ICRN-14) and to consider more generally the existing methods for computing thermodynamics of humid air and humid gases (for example, in the context of metrology and in the energy industries) and consider needs and prospects for IAPWS products in these areas.

In further discussion, it was decided that the formulation used in TEOS-10 should be incorporated into an IAPWS Guideline for thermodynamics of air in contact with seawater. **A Task Group was appointed for drafting this Guideline consisting of Feistel (Chair), Harvey, Kretzschmar, and Wright. An Evaluation Task Group was appointed of Miyagawa (Chair), Hruby, and Ochkov. The Clerk of Minutes was requested to make a schedule for tasks reflecting completion of a draft by the end of 2009 and circulation for approval at the 2010 IAPWS meeting. That schedule will be:**

Dec. 31, 2009	**Guideline drafted & sent to Evaluation TG**
Feb. 28, 2010	**Completion of evaluation by Evaluation TG**
March 15, 2010	**Distribution of Guideline and evaluation report to WG**
April 15, 2010	**Deadline for input from WG members**
May 15, 2010	**Finalized draft to Editorial Committee**
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15. (joint with PCAS) D. Fuentevilla presented her work with colleagues at the University of Maryland on the vapor-liquid critical locus of aqueous electrolyte systems (especially aqueous NaCl) at high temperature. The WGs encouraged the plan of looking at additional systems and working toward a Guideline on this behavior in a number of systems, which would replace the existing Guideline for the H_2O/NaCl critical locus adopted in 2000.

M. Nakahara presented his work on the use of formic acid as a hydrogen carrier in energy technology, with the formation reaction in H_2O or in an ionic liquid.

16. (Advisory Note 4) A. Harvey presented the history of the joint recommendations between IAPWS and the CCM on roles of the different standards for the density of water. The Advisory Note states the recommendations adopted by IAPWS in 2008 (see EC Minute 7.4 from 2008). **The WGs approved the Advisory Note on Roles of IAPWS and CIPM Standards for the Density of Water.**

17.1. J. Kalova presented on an investigation of the density of liquid water from the standpoint of data and correlations, first for temperatures between 0 °C and 40 °C, and then for supercooled water below 0 °C.

17.2. J. Hruby reported on the nucleation of water from supercooled steam, and on efforts (unsuccessful so far) to organize a database effort (and eventual correlation) for water nucleation data. There was discussion of how to advance this important project. **It was decided to have a Task Group with Hruby as Chair. We request the EC to ask National Committees to forward names of other candidates to the Executive Secretary for this Task Group by Dec. 31.**

17.3. ICRN-15 on metastable steam has expired, but from the previous item the area is still clearly important. **We request that ICRN-15 be extended to expire in 2011. An additional mandate of the Task Group mentioned in 17.2 is to work on revising this ICRN by 2011.**

17.4. ICRN-14 on humid gases has expired, but from item 14 the area is still clearly important. **We request that ICRN-14 be extended to expire in 2011. An additional mandate of the Task Group mentioned in item 14 above is to work on revising this ICRN by 2011.**

17.5. A. Harvey reported that there was no need to update the Fundamental Constants Guideline this year.

17.6. Advisory Note 2 is being updated primarily to incorporate the new and revised documents adopted this year (such as that mentioned in Minute 8 above). **Cooper and Harvey were authorized to make the appropriate updates in the document, along with any needed editorial changes.**

17.7. V. Ochkov presented his work on interactive online calculations of properties from IAPWS formulations.

17.8. H.-J. Kretzschmar presented the educational Steam Tables for Excel now linked to from the IAPWS website. He also mentioned that the steam tables for pocket calculators had been a successful project with over 500 downloads since the last IAPWS meeting.

17.9. J. Cooper stated that there was nothing new to report regarding liaison with the IEC.

18. **It was voted to accept E. Vogel (Rostock, Germany) as a new member of TPWS, and M. Kunick (Zittau) as a new member of both IRS and TPWS.**

19. Regarding collaborative projects, see item 4.

20. The Chair and Clerk of Minutes were appointed to prepare the formal motion of the TPWS/IRS WGs to the EC.

21. The meeting was adjourned at 12:15 on Thursday, September 10.

Agenda for the Working Groups

Thermophysical Properties of Water and Steam (TPWS) and Industrial Requirements and Solution (IRS) Doorwerth, The Netherlands. 6-10 September 2009

1. Opening Remarks; Adoption of Agenda
2. Appointment of Clerk of Minutes
3. Web Space for Working Material for WGs TPWS, IRS, and SCSW, joint with WG IRS and SCSW
4. Potential International Collaborative Projects
5. Revised Release on the IAPWS Formulation 1995 for the Thermodynamic Properties of Ordinary Water Substance for General and Scientific Use (IAPWS-95), joint with SCSW and WG IRS
   - Report (W. Wagner)
   - Test Report (K. Miyagawa)
   - Formal consideration of the Revised Release
6. Editorial Changes on the Revised Release on the Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam (IAPWS-IF97), joint with WG IRS
   - Report (W. Wagner)
   - Test Report (K. Miyagawa)
   - Formal consideration of the Editorial Changes
7. Editorial Changes on the Supplementary Release on Backward Equations $p(h,s)$ for Region 3, Equations as a Function of h and s for the Region Boundaries, and an Equation $T_{sat}(h,s)$ for Region 4 of the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam (IAPWS-IF97-S04), joint with WG IRS
   - Report (H.-J. Kretzschmar)
   - Test Report (K. Miyagawa)
   - Formal consideration of the Editorial Changes
8. Supplementary Release on a Computationally Efficient Thermodynamic Formulation for Liquid Water for Oceanographic Use, joint with SCSW
   - Report of the Evaluation Task Group (J. Hruby, K. Miyagawa)
   - Formal consideration of the Revised Release
9. Transport Properties of Water and Steam, joint with WG IRS and SCSW
   - 9.1 Zero-Density Thermal Conductivity of Water Vapor: Comparison of the IAPWS Formulation with Theoretically Calculated Values and Possible Reasons for Their Differences (E. Vogel, E. Bich, R. Hellmann, A.S. Dickinson, V. Vesovic)
   - 9.2 Progress Report on the Thermal Conductivity of H2O (J.V. Sengers, R.A. Perkins, M.L. Huber, D.G. Friend, M.J. Assael, I.N. Metaxa)

9.3 Proposal for ICRN 24 on the Thermal Conductivity of H2O at Low Pressures and High Temperatures (A.H. Harvey, J.V. Sengers, E. Vogel)

10. Industrial Requirements and Solutions for Steam Property Calculations, joint with WG IRS
    - Backward function for sublimation and melting curves based on spline technique (I. Kodl, A. Novy)
    - Fast Steam Property Calculations for CFD (W.T. Parry, H.-J. Kretzschmar)

11. Revised Release on the Equation of State 2006 of H_2O Ice Ih, joint with SCSW and WG IRS
    - Report (R. Feistel)
    - Test Report (J. Hruby)
    - Formal consideration of the Revised Release

12. Properties of Heavy Water D_2O, joint with WG IRS
    - Report (J.R. Cooper)

13. Properties of Seawater (R. Feistel)

    13.1 Oceanographic Seawater Standard TEOS-10
    - Adoption by the international bodies IOC/Unesco (T.J. McDougall)
    - Review of papers published (T.J. McDougall)
    - Review of library code developed (D.G. Wright)
    - Fast ocean-model code versions (T.J. McDougall)

    13.2 Development of an IAPWS Standard on Seawater Properties for Industrial Use
    - Discussion about preparing an IAPWS Standard and appointing a Task Group (M. Hiegemann, H.-J. Kretzschmar, R. Feistel)

    13.3 pH Scales for Aqueous Solutions and Seawater (G.M. Marion)
    - Define and compare scales
    - Experimental measurements vs. modeling
    - Preferences - pros and cons
    - Future directions

    13.4 Seawater Density Measurements
    - New measurements compared to the IAPWS Release 2008 (R. Feistel)
    - Measuring and modeling composition anomalies (T.J. McDougall, F.J. Millero, D.R. Jackett, R. Feistel)
    - SI traceability and uncertainty on climatic time scales (P. Spitzer, S. Seitz)

    13.5 Proposed Models for Calculating Thermal Conductivity and Viscosity of Seawater, joint with WGs PCAS and IRS, and SCSW (A. Anderko)

14. Properties of Humid Air and Humid Combustion Gases, joint with WGs IRS and PCAS, and SCSW
    - Humid-Air Implementation in the TEOS-10 Library (R. Feistel, D.G. Wright)

15. Properties of Aqueous Solutions, joint with WG PCAS and SCSW
    - Vapor-liquid critical locus of aqueous solutions of NaCl revisited (D.A. Fuentevilla, J.V. Sengers, and M.A. Anisimov)
    - A new scheme of hydrogen technology based on hydrothermal chemistry of formic acid (M. Nakahara)
16. Advisory Note No. 4: Roles of IAPWS and CIPM Standards for the Density of Water
    - Report of the Task Group (A.H. Harvey, R. Span)
    - Formal consideration of the Advisory Note
17. Reports on Other TPWS Activities
    - 17.1 Data and Calculations for Density of Liquid Water (J. Kalova)
    - 17.2 Report on Assessment and Correlation of Nucleation of Water Droplets from Supersaturated Steam and Collaboration with Committee for Nucleation and Atmospheric Aerosols (J. Hruby)
    - 17.3 ICRN # 15 Thermodynamic Properties of Metastable Steam (J. Hruby), joint with WG IRS
    - 17.4 ICRN # 14 Thermophysical Properties of Humid Air and Combustion-Gas Mixtures (R. Span, M. Wendland, A.H. Harvey, H.-J. Kretzschmar), joint with WG IRS and SCSW
    - 17.5 Guideline on Fundamental Constants (A.H. Harvey), joint with WG IRS
    - 17.6 Update of Advisory Note # 2: Roles of Various IAPWS Documents (J.R. Cooper, A.H. Harvey), joint with WG IRS
    - 17.7 Modern Notations and "Network Interactive Open IAPWS Formulations" (V.F. Ochkov, J.V. Chudova), joint with WG IRS
    - 17.8 Steam Tables for Excel® for Education on the IAPWS Website (H.-J. Kretzschmar), joint with WG IRS
    - 17.9 Liaison with IEC (J.R. Cooper), joint with WG IRS
18. Membership
19. Other Business
    - Report on International Collaborative Projects
20. Preparation of the Formal Motion to the EC
21. Adjournment