Attachment 6

MINUTES OF INDUSTRIAL REQUIREMENT AND SOLUTIONS WORKING GROUP

VEJLE, DENMARK – AUGUST 25 - 30, 2003

Note: Most meetings were held in joint session with TPWS. TPWS agenda items 7 through 11 are documented within these minutes. All others will be found in Minutes of TPWS Working Group.

Agenda Item 1 – Opening Remarks; Adoption of Agenda

After chairman Dr. Friend had conducted the initial TPWS business, IRS chairman Mr. Kiyoshi Miyagawa conducted opening business for the Industrial Requirement and Solutions working group. He expressed appreciation to Mr. Ingo Weber for acting as chairman for the working group last year held in Buenos Aires. The agenda was modified to add items 4 and 5; otherwise it was the same as originally distributed prior to meeting. It is provided as IRS Attachment A.

Agenda Item 2 – Appointment of Clerk

Dr. Bill Parry was appointed clerk of the minutes.

Agenda Item 3 – Approval of Minutes

Minutes from the 2002 annual meeting held in Buenos Aires were approved without objection.

Agenda Item 4 (TPWS Agenda Item 5) – Discussion of future of IAPWS as related to Working Groups.

See TPWS minutes for this item.

Agenda Item 5 (TPWS Agenda Item 6) – 14th ICPWS to be held next year in Kyoto, Japan

See TPWS minutes for this item.

Agenda Item 6 (TPWS Item 7) – Supplementary Release on Backward Equations for the functions T(p,h), v(p,h), and T(p,s), and v(p,s) for the Critical and Supercritical Regions to IAPWS-IF97.

At the September 2002, Buenos Aires Meeting, a draft of the supplementary release was proposed and an evaluation task group was established. In March 2003, the evaluation report and revised draft were sent to IRS and TPWS members. In May, technical discussion closed and the revised draft was sent to IRS and TPWS Working Group members. Tests were performed by Evaluation Task Group, including reproducibility and accuracy requirements of IAPWS-97 and consistency

at boundary between sub regions. The computing speed was verified by independently derived software.
It was the recommendation of the task group to have the draft be accepted by IAPWS as a supplementary release. The Task Group further recommends that the proposed code be treated as part of the IAPWS-IF97 authorized code. Dr. Friend made a motion to present the supplementary release of these equations to the executive committee for adoption as recommended by the task group. Dr. Allan Harvey seconded this motion. The motion was accepted without dissention.

Agenda Item 7 (TPWS Item 8) – Progress Report on Development of IAPWS-IF97 Backward Equations in Region 3

Prof. Hans-Joachim Kretzschmar gave an overview on the progress for development of supplementary backward equations. Ms. K. Knobloch then gave a detailed talk describing the work in developing backward functions in region 3 of IAPWS-IF97 for the functions $p_3(h,s)$, $T_3(h,s)$, and $v_3(h,s)$. The resultant backward equations reduce the need for time consuming two-dimensional iterations. They meet the accuracy requirements of IAPWS-IF97, and result in 11 times faster result than the iteration process. Backward equations for determining the region boundaries as a function of h,s were presented which showed a 14 times resultant speed advantage over IAPWS-IF97. Finally, a backward calculation for $T_{sat}(h,s)$ was presented. This routine was 11 times faster than IAPWS-IF97. Several questions were asked including reference to a survey which indicated that 2/3 of those questioned did not see a need for a backwards set of equations in region 3. It was pointed out that there was currently renewed interest in supercritical and ultracritical cycles which will require more calculations in region 3 for both turbine and boiler manufacturers.
Mr. Miyagawa started discussion for Proposal for new Region 3 Supplementary Release. Ingo Weber suggested an establishment of Evaluation Task Group. Mr. Miyagawa proposed using same task group, Miyagawa (chairman), Okita, Gallagher, and Weber who were members of the prior task group. Testing task group will develop their own testing software, and independently access the accuracy of the proposed group. Based on his past experience, Mr. Miyagawa proposed the evaluation report to WG by January 2004, Draft Release to WG and Editorial Committee by February 2004, and Final Release to executive secretary for distribution to the National Committees by April, 2004.

Agenda Item 8 (TPWS Item 9) – Progress Report of the Guideline on Tabular Taylor Series Expansion (TTSE)

Chairman Miyagawa reported that the guideline had been approved by Editorial Committee, the approved draft had been sent to the executive secretary, and the guideline had been distributed to National Representatives for Postal Ballot. The EC has approved the Guideline in its current form, and the guideline referenced downloadable software is now available from the Japanese National Committee website. A demonstration by Dr. Kenji Yasuoka in real time showed how the method can be accessed from the Japanese National Website. The Website can be accessed at "http://www.iapws.jp."
As a result of the software availability and normal acceptance procedures being complete, the joint IRS and TPWS will recommend to the EC that this guideline be approved.

Agenda Item 9 (TPWS Item 10) – Topics on the TTSE method, expansion of TTSE *p-h* version for transport properties

Mr. Kiyoshi Miyagawa made a presentation on the TTSE Method for Transport Properties. He pointed out the calculation of μ (dynamic viscosity) is a time consuming process with either IAPWS-95 or IAPWS-IF97 due to the contained exponential function. Similarly, λ (thermal conductivity) can be calculated with either IAPWS-95 or IAPWS-IF97 (with some loss in accuracy near critical region), but this is even a more time consuming process due to three contained exponential functions, an exponentiation by a non-integer value, and two call of derivatives of thermodynamic properties. He then showed that TTSE can be used for μ in the *p-h* plane where the behavior is smooth. The resulting calculations with TTSE have less than a 0.1% deviation from the original IAPWS-95 except at high pressure and very low enthalpy where the IAPWS equation is not applicable. Unfortunately, the behavior of λ on the *p-h* plane is not as well defined, and shows a steep peek at the critical point. The TTSE results show deviations of less than 0.1% except near the critical point. It is recommended to use the original formulation near the critical region to obtain accurate results. Isobaric specific heat (c_p) is similar to thermal conductivity in that deviations occur near the critical point; therefore, the same approach is used as with thermal conductivity. The Prandtl Number (Pr) = $c_p \, \mu/\lambda$ was evaluated by the two methods; as expected, the TTSE method is significantly faster.

Dr. Dan Friend urged continuation of TTSE method but felt that a release of this methodology should be delayed until the expected release of the new Transport Properties which should take place within two years. He also pointed out that the current recommendation of transport properties is to use either IAPWS-95 or IF97; the resulting difference between the two is less than the expected deviation in actual transport properties. Dr. Dan Friend asked whether computational speed is as important for transport properties. Mr. Ingo Weber, Dr. Bill Parry, and Mr. Jeff Cooper responded that speed was important, especially in CFD work.

Agenda Item 10 (TPWS item 11) – Uncertainties in the enthalpies of IAPWS-95 and IAPWS-IF97; status of skeleton tables

Prof. Wolfgang Wagner presented a method to determine the uncertainties in enthalpy in IAPWS-95. Prof. Wagner showed uncertainty results for enthalpy for the prior IAPS-84; this was in the form of Pressure plotted on the ordinate versus Temperature on the abscissa showing the percentage uncertainty for different regions. These were calculated based on differences between experimental c_p data and c_p derived from IAPS-84. However, there is no experimental data of enthalpies related to the zero point. Therefore, Prof. Wagner decided to consider primarily the differences in enthalpy among the best equations of state represented by IAPWS-95, Hill (1990), and Saul and Wagner (1989). Additionally, he considered the older formulations IAPS-84, Pollak (1974), and International Skeleton Tables IST-85. He created a plot of Pressure versus temperature with regions of uncertainty in enthalpy expressed in kJ/kg. These range from +/- 0.1 kJ/kg up to a small area of +/- 15 kJ/kg at very high pressure and temperature. He then considered uncertainties in percent change in enthalpy based on an isobaric change in temperature; a plot of Pressure versus Temperature shows the vast majority of results with +/- 0.2% or less. Near the critical point, there is a small area of +/- 2%. He also considered two different types of adiabatic paths, adiabatic reversible (constant entropy), and adiabatic irreversible (simulating normal turbine expansions). The resulting uncertainty regions on a *P* vs. *T* plot show that the most of the region are +/- 0.4% or below, with the small areas near the critical point being +/- 5%. There was no substantial difference in the results whether reversible or irreversible.

He also compared IAPWS-IF97 to IAPWS-95. The plot of *P* vs. *T* shows that most of the regions are with +/- 1 kJ/kg. Near the critical point the uncertainty is +/- 15 kJ/kg. He also investigated the uncertainty of IAPWS-IF97 versus IAPWS-95 using the isobaric methodology. The *P* vs. *T* plot has most of its area at or below +/- 0.3%, with a small area near the critical point being +/- 2%.
A series of questions followed the presentation. Prof. Wagner was asked to publish the method and results in a technical paper which he said he would consider.
Dr. Friend then started discussion on acceptance of Advisory Note No. 1 which details the results of the enthalpy uncertainty. Mr. Jeff Cooper felt that a procedure for acceptance had not yet been established. Consensus was reached to recommend to EC that this Advisory Note be approved. The need for a skeleton table is no longer necessary with the adoption of the Advisory Note, and therefore, consensus was reached to recommend to the EC that the skeleton document be withdrawn. Much discussion ensued about whether to list or not list the skeleton table. There was strong opinion that a section be created on the IAPWS website listing outdated IAPWS releases (IST85, IFC67, etc.). Dr. Friend asked Dr. Harvey to draft such a document for inclusion on the website for outdated documents.

Agenda Item 11 (TPWS Agenda Item 12) – Progress on document concerning differences among IAPWS products for calculating water properties

See TPWS Minutes for this item.

Agenda Item 12 – Membership

There are no changes to current membership. However, the chairman will write to each National Committee for those IRS members who have not attended the last three IAPWS meeting so ascertain whether that member is still interested in serving on the committee.

Agenda Item 13 – Other Business

There was no Other Business.

Agenda Item 14 – Preparation of Report to Executive Committee

This item will be undertaken by the Chairman and Clerk of the Minutes.

Agenda Item 15 – Adjournment

The chairman thanked all participants for their attention and involvement and adjourned the meeting.

IRS Attachment A

Agenda of Industrial Requirement and Solutions Working Group

Vejle, Denmark August 24 through 30, 2003

1. Opening Remarks, Adoption of Agenda
2. Appointment of Clerk of Minutes
3. Approval of Minutes of Buenos Aires Meeting, July 2002
4. Discussion of future of IAPWS as related to Working Group
5. Discussion of ICPWS-14
6. Supplementary Release on Backward Equations for the Functions *T(p,h), v(p,h)* and *T(p,s), v(p,s)* for the Critical and Supercritical Regions of IAPWS-IF97
   4a) Report of the Evaluation Task Group
   4b) Acceptance of the Supplementary Release
7. Progress Report of the Task Group for the Development of IAPWS-IF97 Backward Equations in Region 3
   (proposal: supplementary release on *p(h,s)* equations)
8. Progress of the Guideline on Tabular Taylor Series Expansion (TTSE) Method
9. Topics on the TTSE method, expansion of TTSE *p-h* version for transport properties
10. Uncertainties in the enthalpies of IAPWS-95 and IAPWS-IF97; status of skeleton tables
11. Progress on document concerning differences among IAPWS products for calculating water properties
12. Membership
13. Other Business
14. Preparation of Report to Executive Committee
15. Adjournment