Zittau/Goerlitz University of Applied Sciences
Department of Technical Thermodynamics
http://thermodynamics.hs-zigr.de

Kretzschmar, H.-J., Weidner, M., Stöcker, I.

EU Project AA-CAES

Work Package 4: Thermophysical Properties

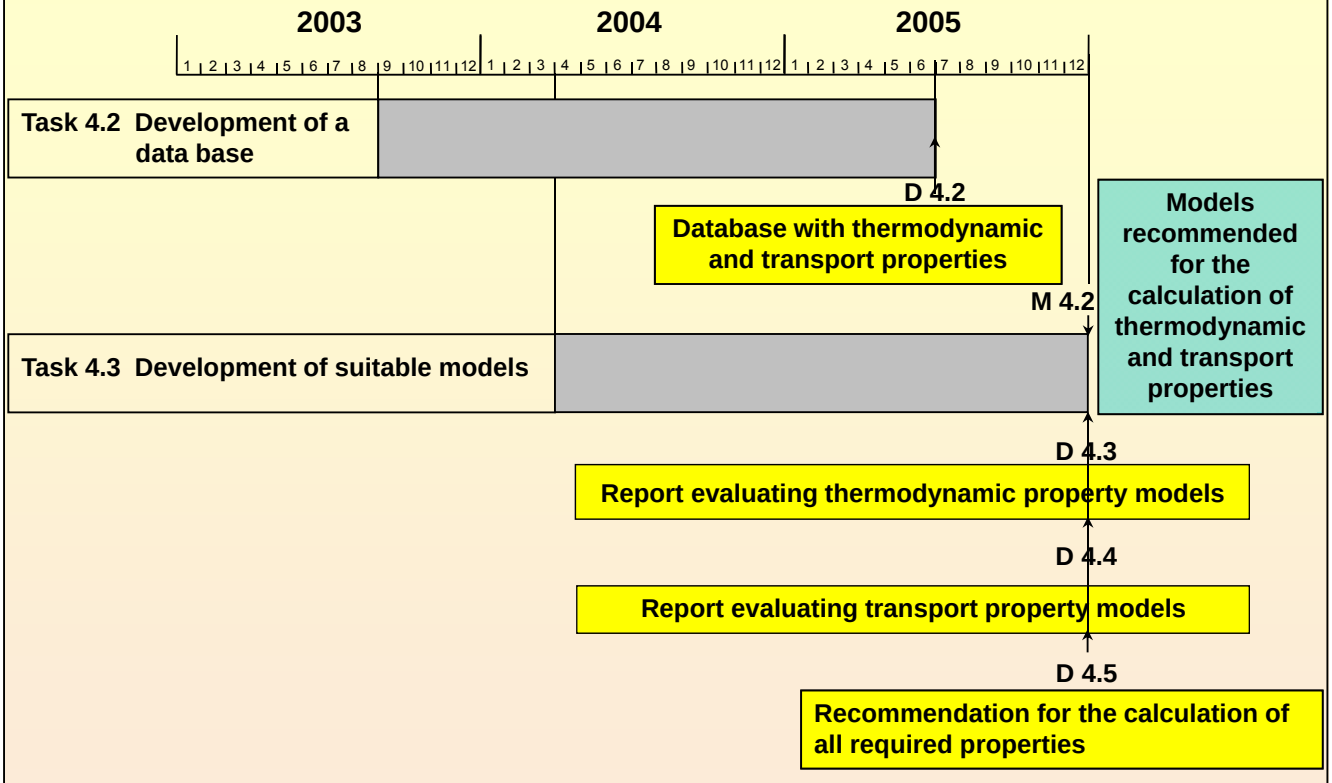
Contributions to:

Task 4.2: Development of a data base

Task 4.3: Identification / development of suitable models, exploitation of the results

Berlin, October 17, 2005

Time schedule of the tasks 4.2 and 4.3



Task 4.2: Development of a Data Base

- The data base comprises 193 articles from the literature
- 7 articles contain experimental data for humid air

- $\Psi_{H2O,s}$	Hyland 1973, 1975
- $f_{H2O,s}$	Wylie 1996
- *p-ρ-T*	Japas 1985
- *B*	Wylie 1996
- *C*	Wylie 1996
- *η*	Kestin 1964, Hochrainer 1966
- *λ*	Gruess 1928

Collection of Data from the AA-CAES Experimental Groups

- **Dry Air**
  - *p-ρ-T* data from PTB, ICSTM and RUB
  - Speed of sound data from ICSTM
  - Viscosity data from RUB
- **Humid Air**
  - $\psi_{H_2O,s}$ data from ICSTM
  - *p-ρ-T* data from ICSTM and PTB
  - Preliminary data for density from RUB
  - Preliminary data for viscosity from RUB

Property Data Base – Final Tasks

- **Collecting new experimental data from the AA-CAES groups**
- **Update of the report D 4.2 “Database with thermodynamic and transport properties” at the end of the year 2005**

Task 4.3: Identification/Development of Suitable Models, Exploitation of the Results

Thermodynamic Properties

⇩

Comparing existing property models with data from literature and new experimental data

⇩

Evaluating different property models

⇩

Recommendation of suitable models for the calculation of thermodynamic properties

⇩

Assumption for the development of a new standard for calculating thermodynamic properties of humid air

Comparisons with Experimental Data – Current State

Library LibHuAir

- Model of ideal mixture of the real fluids
  dry air from Lemmon et al. (2000)
  steam from IAPWS-IF97
- Poynting correction for saturation pressure of steam
- Dissociation from VDI-4670

Library LibHuGas

- Model of ideal mixture of the real fluids
  N_2 from Span et al. (2000)
  O_2 from Schmidt and Wagner (1987)
  Ar from Tegeler et al. (1999)
  Steam from IAPWS-95
- Poynting correction for saturation pressure of steam
- Dissociation from VDI-4670

Algorithm of Hyland and Wexler (1983)

- Virial equation for the mixture
- Using enhancement factor for saturation pressure of steam

Program MoistAirTab

- Model of Hyland and Wexler (1983)

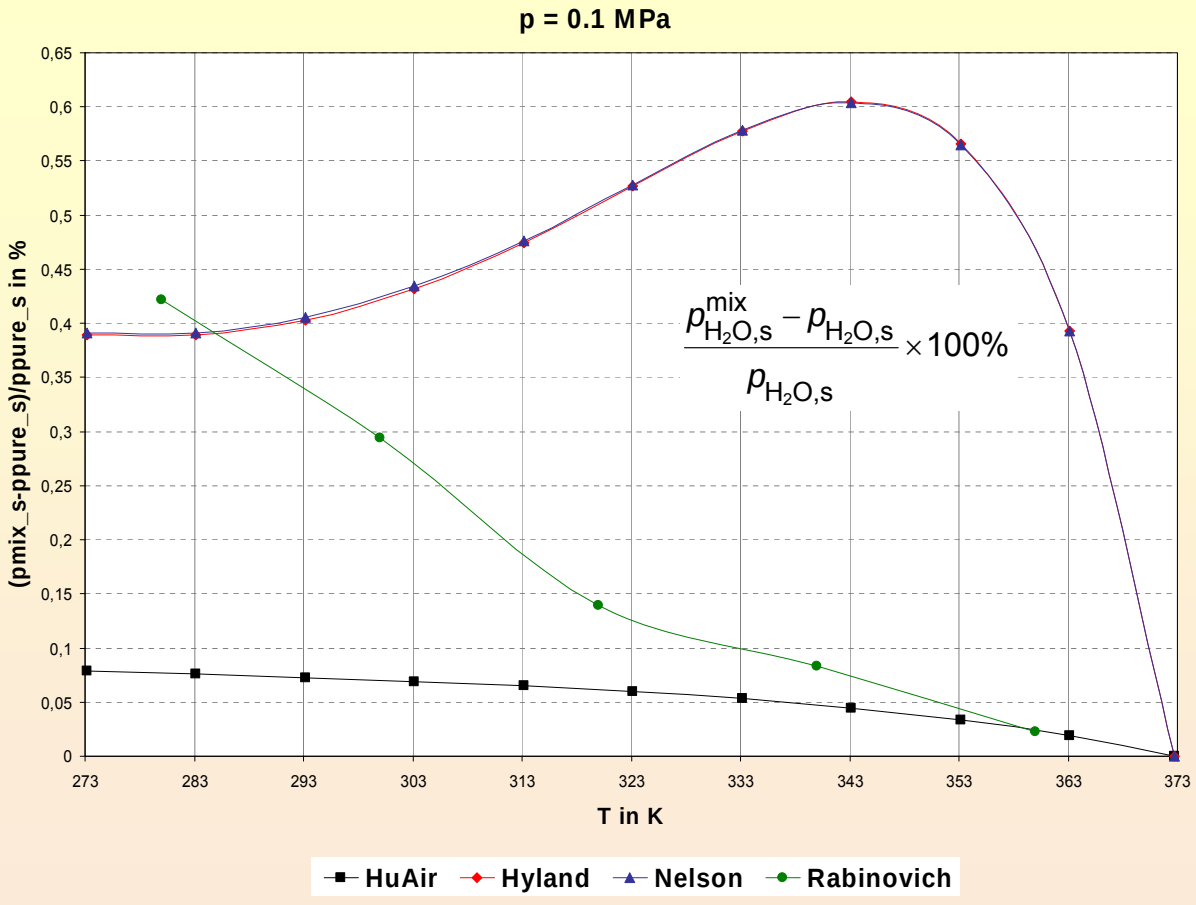
Algorithm of Nelson (2001)

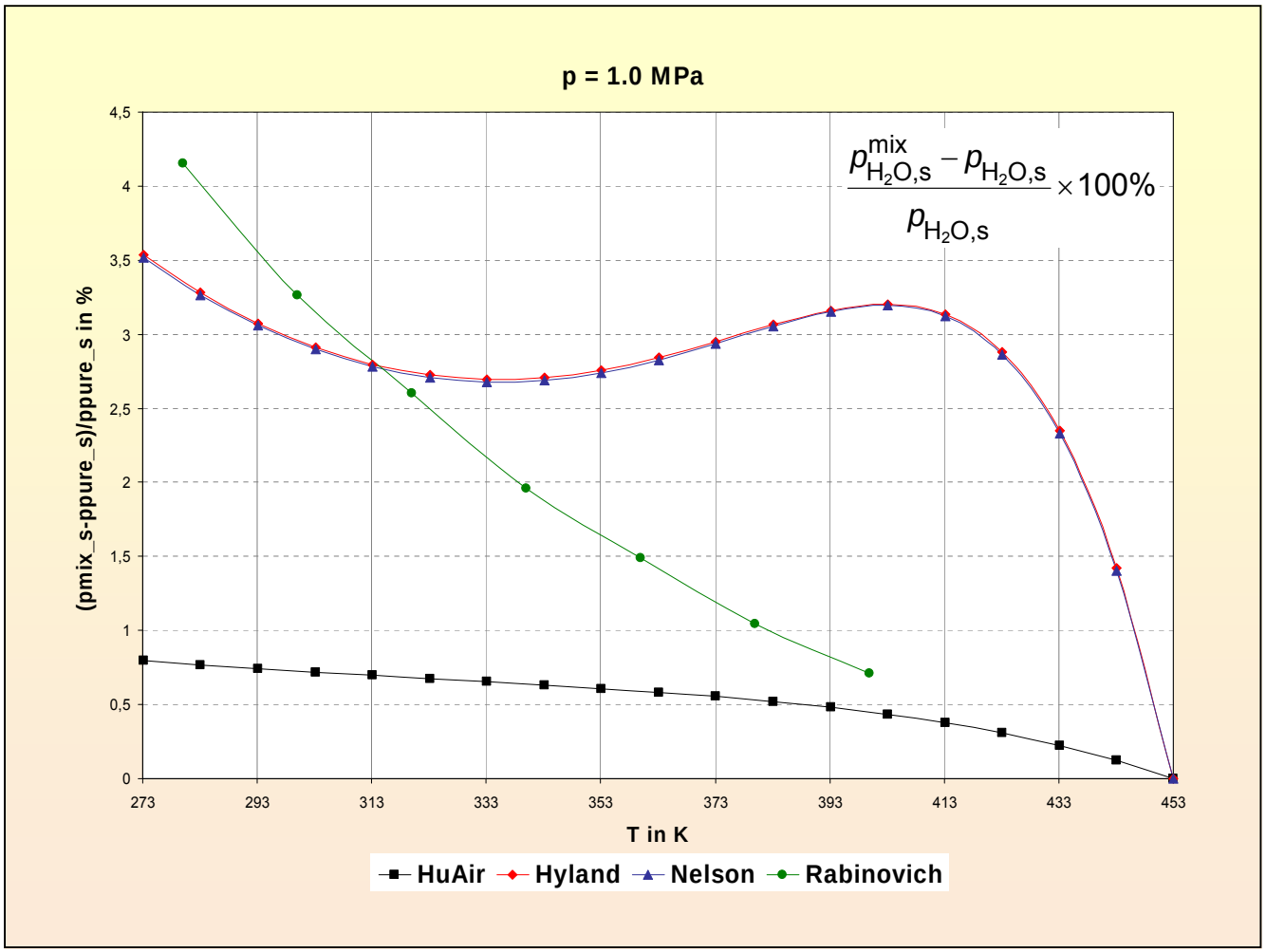
- Modification and extension of the model of Hyland and Wexler (1983)

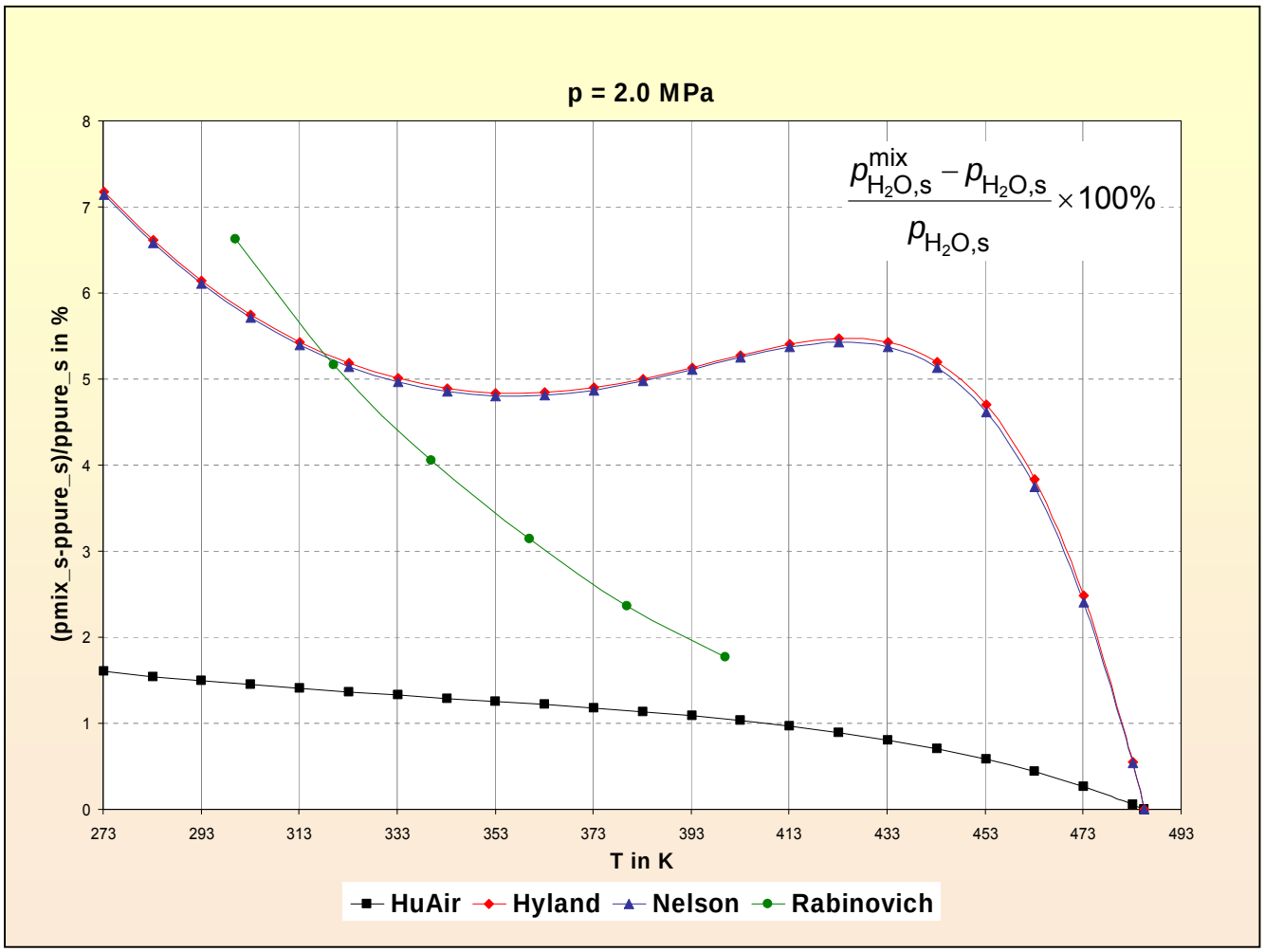
Program Refprop 7.0 (for dry air)

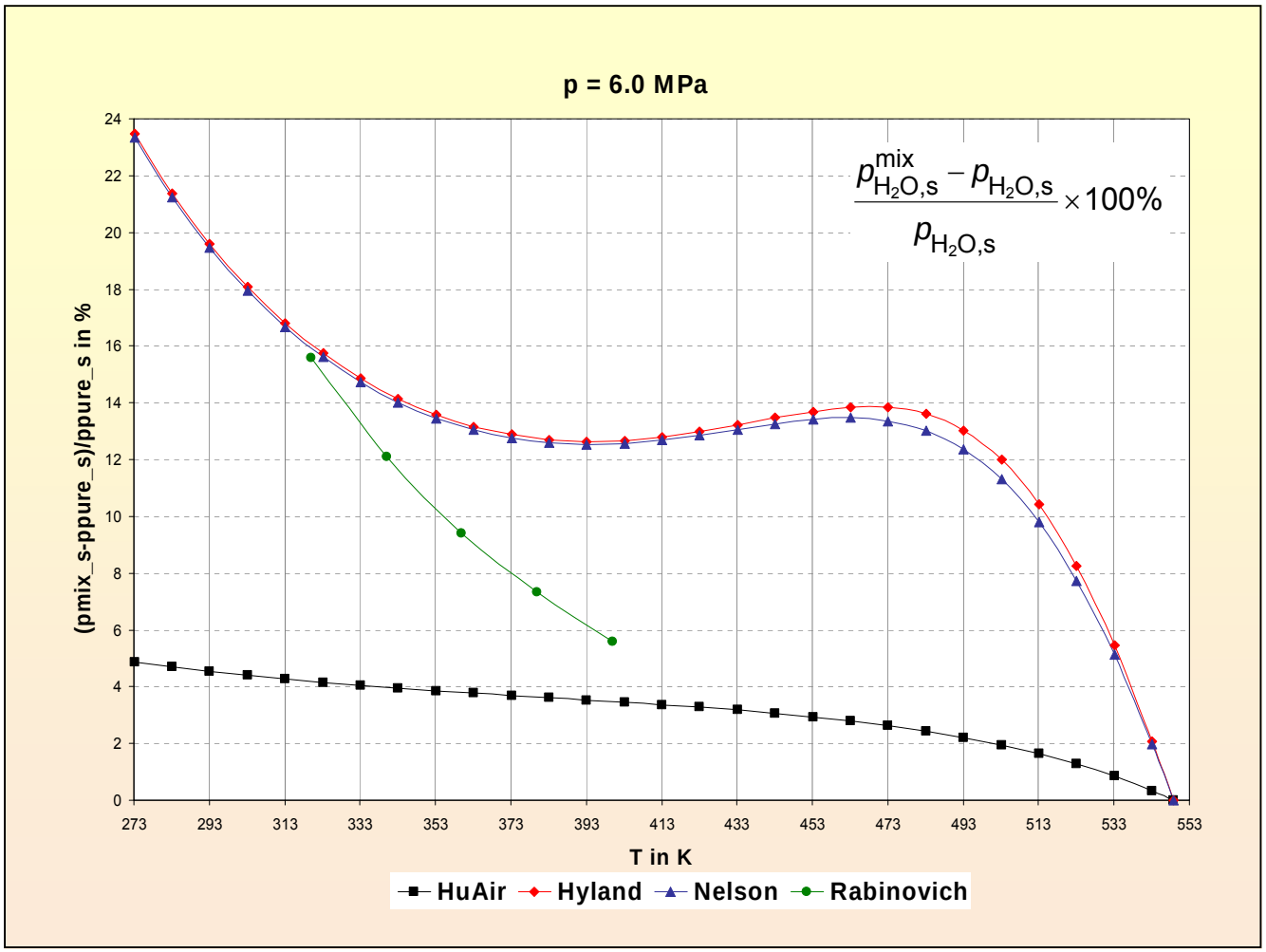
- Fundamental equation for the mixture dry air of Lemmon et al. (2000)
  → Refprop_pure
- Multifluid mixing model of the components N_2, O_2, and Ar of Lemmon et al. (2000)
  → Refprop_mix

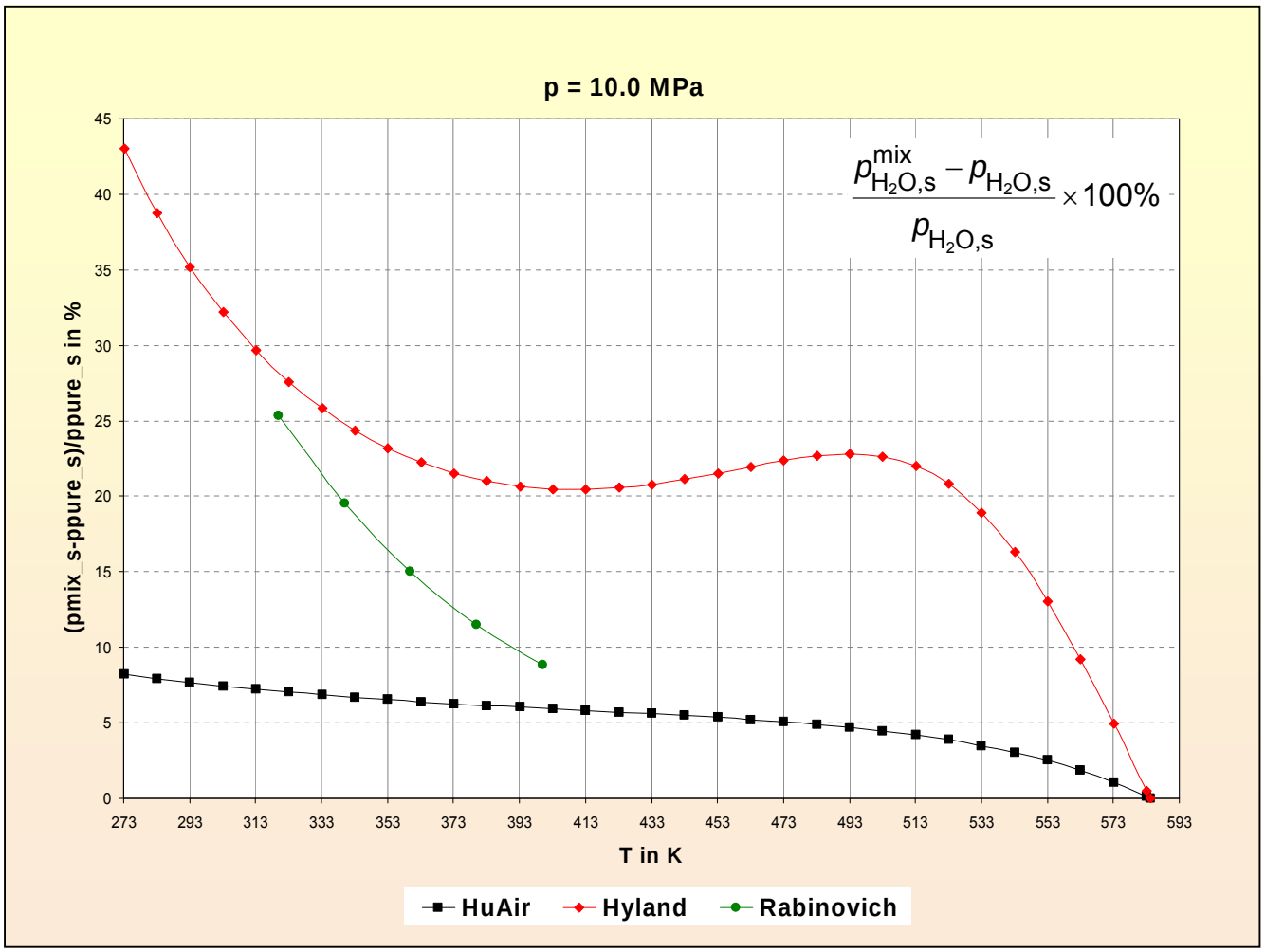
Comparison Calculations for the Saturation Pressure of Steam in Humid Air

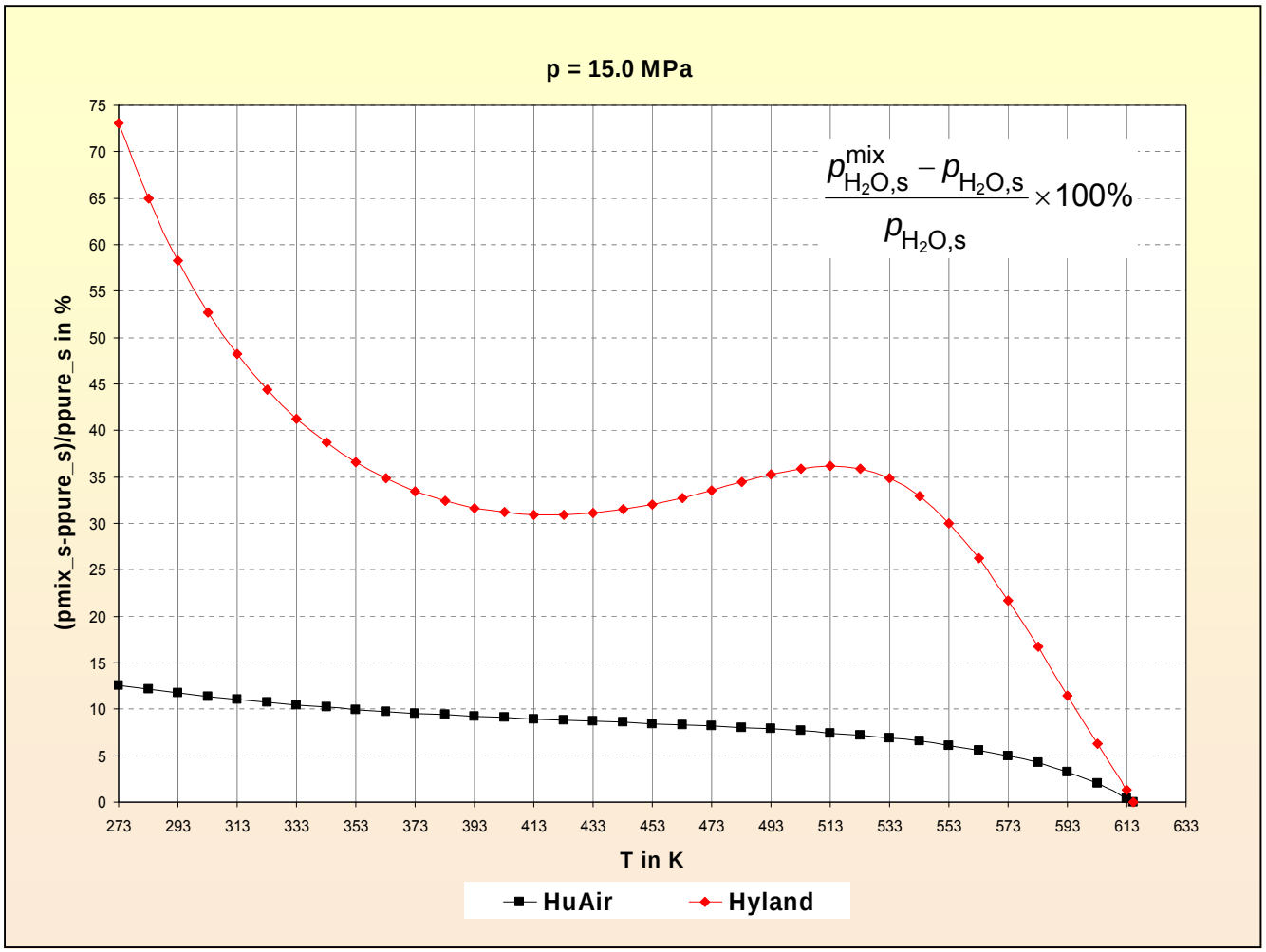


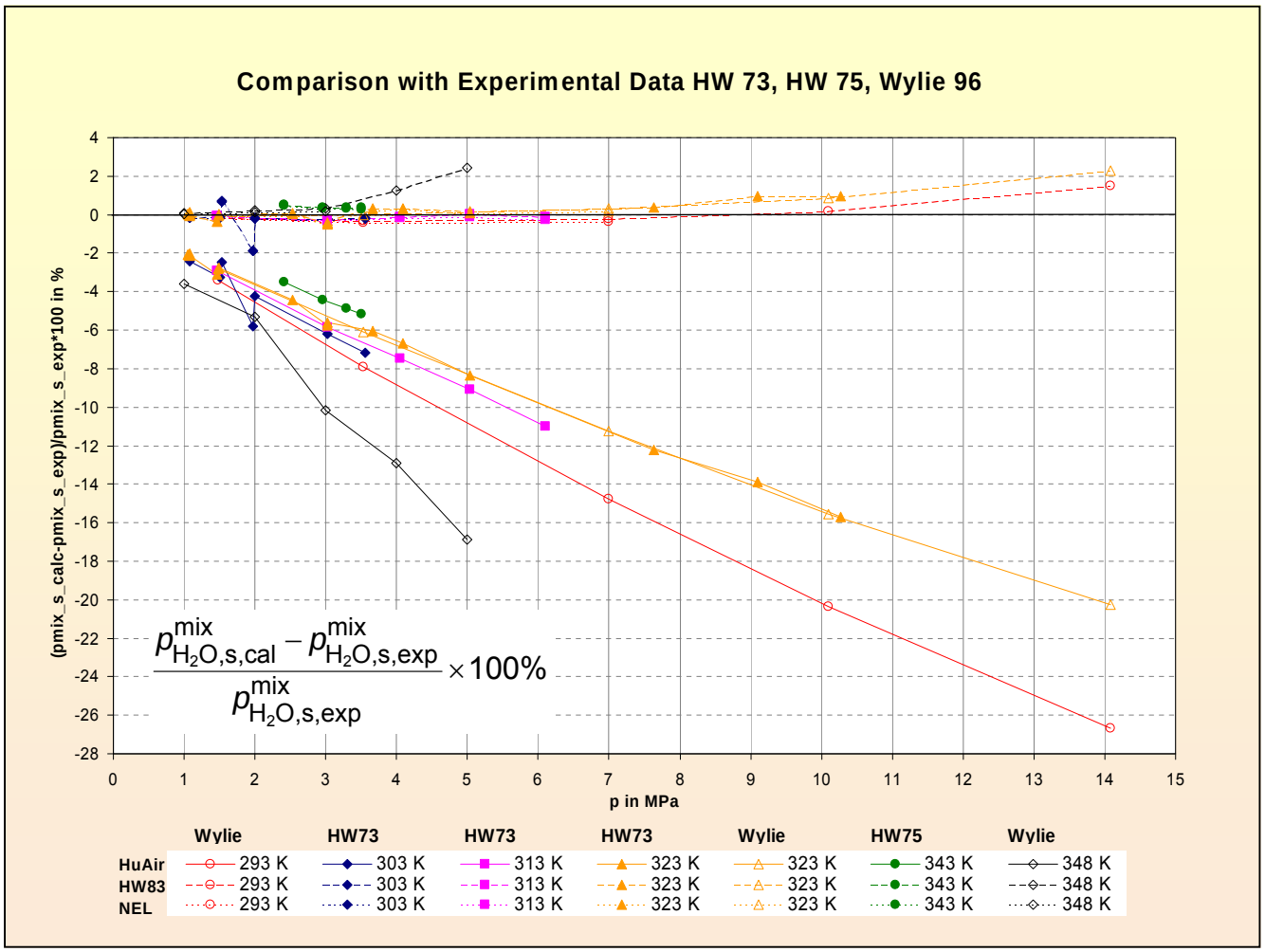

p = 1.0 MPa
$\frac{p^{mix}_{H_2O,s} - p_{H_2O,s}}{p_{H_2O,s}} \times 100\%$
(pmix_s-ppure_s)/ppure_s in %
4,5
4
3,5
3
2,5
2
1,5
1
0,5
0
273
293
313
333
353
373
393
413
433
453
T in K
HuAir
Hyland
Nelson
Rabinovich

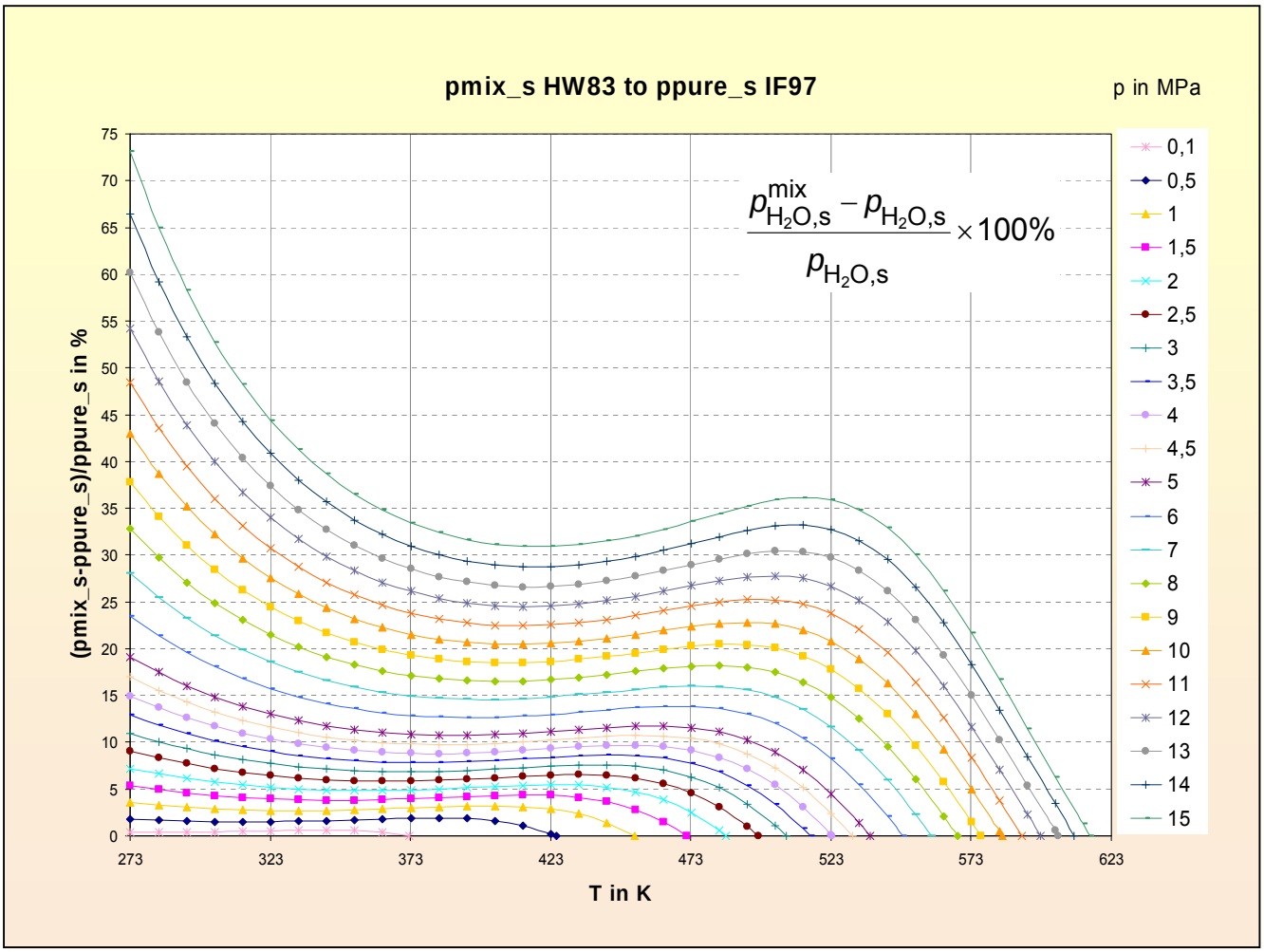

p = 2.0 MPa
$\frac{p^{mix}_{H_2O,s} - p_{H_2O,s}}{p_{H_2O,s}} \times 100\%$
(pmix_s-ppure_s)/ppure_s in %
8
7
6
5
4
3
2
1
0
273
293
313
333
353
373
393
413
433
453
473
493
T in K
HuAir
Hyland
Nelson
Rabinovich


p = 6.0 MPa
$\frac{p^{mix}_{H_2O,s} - p_{H_2O,s}}{p_{H_2O,s}} \times 100\%$
(pmix_s-ppure_s)/ppure_s in %
T in K
HuAir
Hyland
Nelson
Rabinovich


p = 10.0 MPa
$\frac{p^{mix}_{H_2O,s} - p_{H_2O,s}}{p_{H_2O,s}} \times 100\%$
(pmix_s-ppure_s)/ppure_s in %
T in K
HuAir
Hyland
Rabinovich


p = 15.0 MPa
$\frac{p^{mix}_{H_2O,s} - p_{H_2O,s}}{p_{H_2O,s}} \times 100\%$
(pmix_s-ppure_s)/ppure_s in %
T in K
HuAir
Hyland


Comparison with Experimental Data HW 73, HW 75, Wylie 96
$\frac{p^{mix}_{H_2O,s,cal} - p^{mix}_{H_2O,s,exp}}{p^{mix}_{H_2O,s,exp}} \times 100\%$
(pmix_s_calc-pmix_s_exp)/pmix_s_exp*100 in %
p in MPa
Wylie
HW73
HW73
HW73
Wylie
HW75
Wylie
HuAir
HW83
NEL
293 K
303 K
313 K
323 K
323 K
343 K
348 K



Mareike or Hans-Joachim

Perhaps Fred has some info. Mine is limited to the following from the 2nd edition appendix V which I previously sent.
Your curves are similar in shape to those I have plotted up to 5 MPa. Note that if you extend the plots to 173 K you will have higher peaks but this is probably well below your temperature of interest.

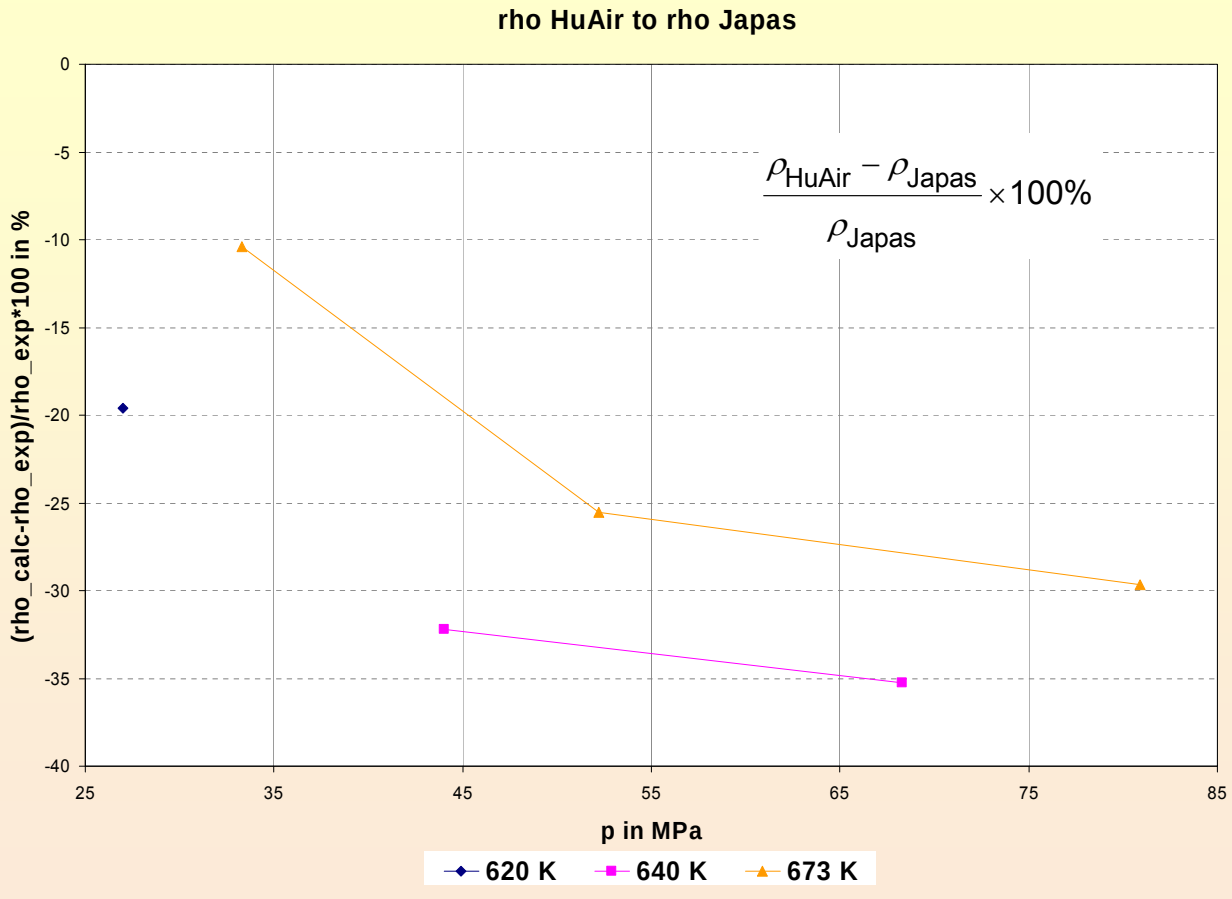
****

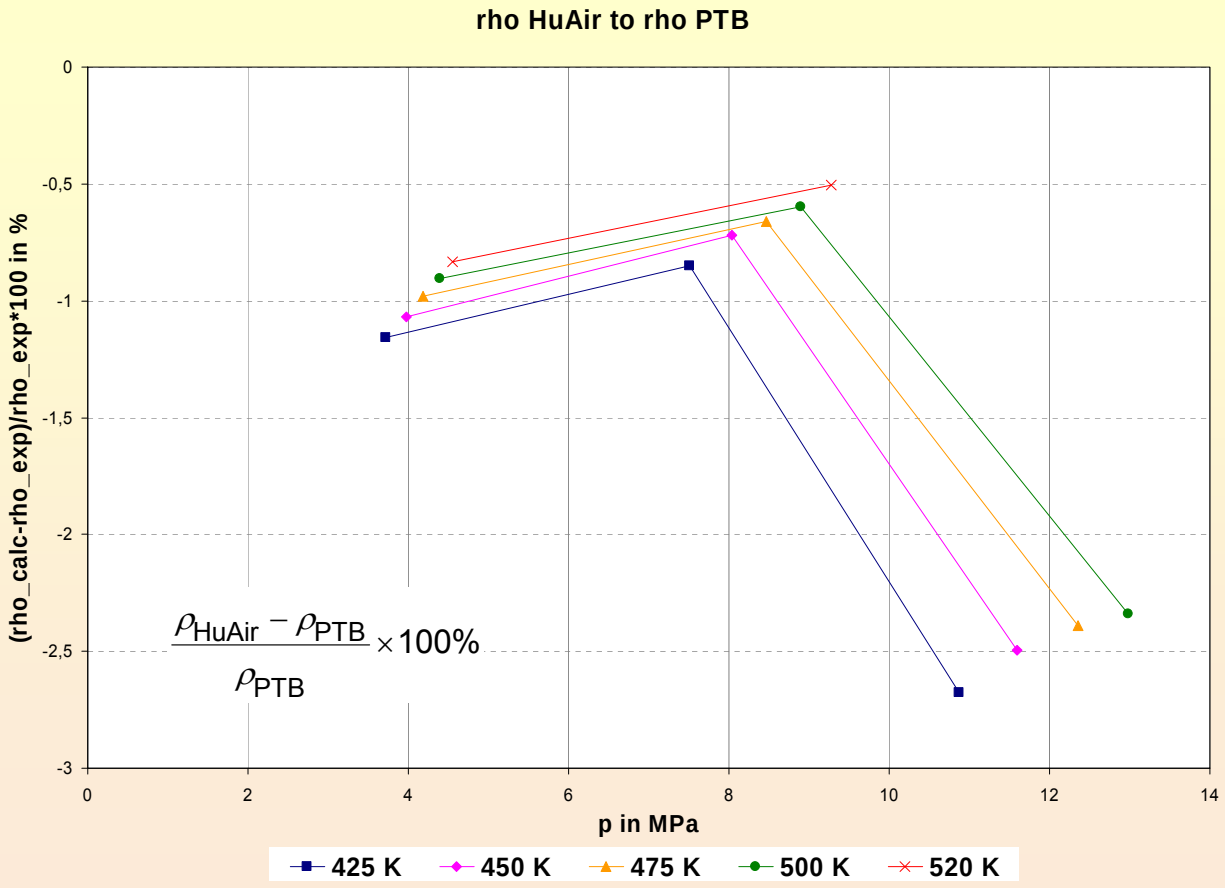
The following quotes J.A. Goff from page 340 of Smithsonian Meteorological Tables, 6th revised edition (1958).
"Within the temperature range -100°C to 60°C and 5000 Pa to 110,000 Pa the enhancement factor lies between 1.0000 and 1.0089. These departures from unity may be ascribed to three separate though not unrelated effects:
(a) the effect of dissolved gases on the properties of the condensed (liquid or solid H2O) phase,
(b) the effect of pressure on the properties of the condensed phase, and
(c) the effect of intermolecular force (gas imperfections) on the properties of the moist air itself. While it is true that these departures are small enough to be disregarded in rough calculations, it should be kept in mind that the error thus committed may well exceed the probable error of the saturation pressure data themselves."
I have not seen the original Goff and Gratch research reports of the 1940s. My recollection of the Hyland Wexler reports regarding the enhancement factor is that they used the Goff methodology and used updated data.

****

Don Gatley

Comparison Calculations for p-ρ-T Data of Humid Air





Conclusions

- Poynting correction for saturation pressure of steam is too weak

→ The Model of Nelson will be taken

- Further Investigations of the different models for humid air can be performed after receiving new experimental data

Thermodynamic Property Models – Final Tasks

- Calculation for steam and water from the scientific formulation IAPWS-95
- Inclusion of speed of sound and isentropic exponent in the library LibHuAir
- Combination of the model: ideal mixture of real fluids with the model of Nelson (2001) for calculating the saturation pressure of steam
- Continuing comparison calculations for humid air after receiving new experimental data
- Comparison with the Multi Fluid Model of Wagner
- Preparation of a property library for humid air including the most accurate algorithms for thermodynamic and transport properties