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Department of Technical Thermodynamics

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EU Project AA-CAES

Work Package 4: Thermophysical Properties

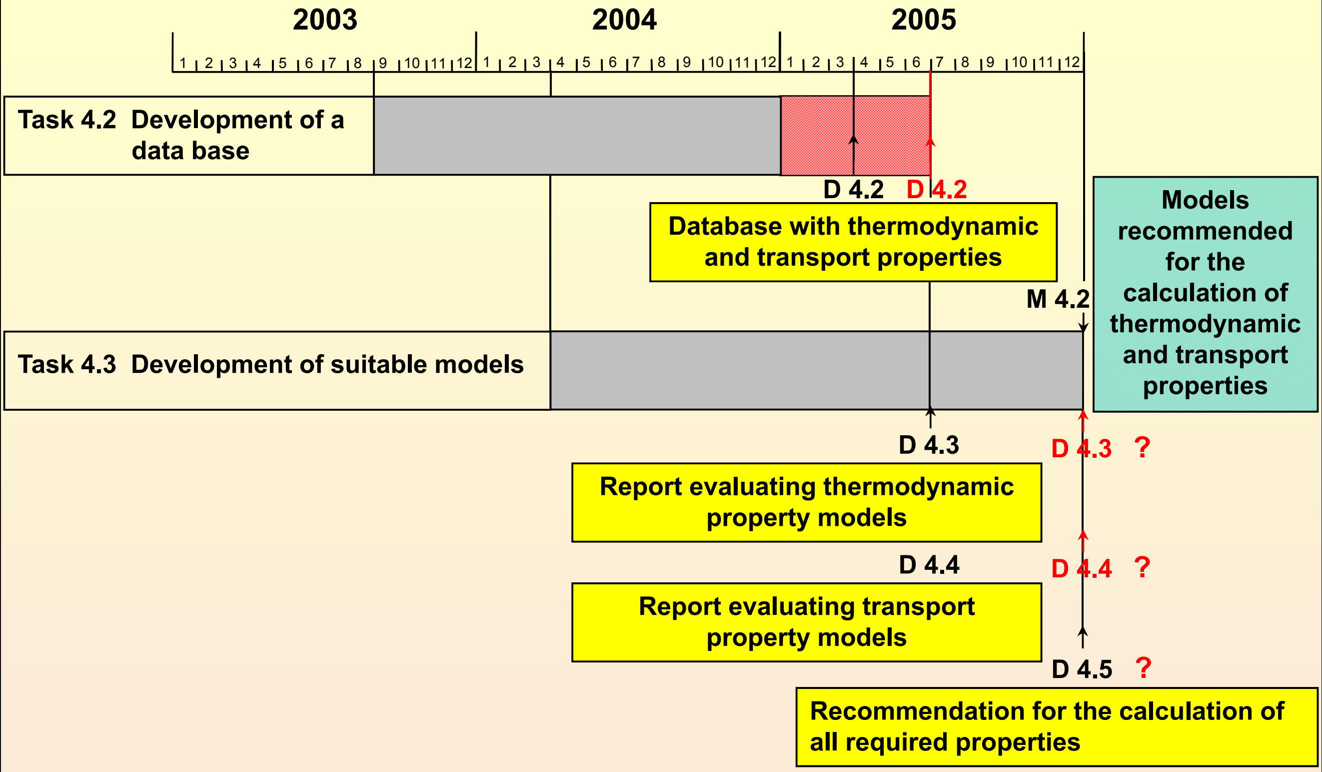
Contributions to:

Task 4.2: Development of a data base

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

Lisbon, April 29, 2005

Time schedule of the tasks 4.2 and 4.3



Task 4.2: Development of a data base

1 Purchase of the server in March, 2003

2 Installation of the Secure FTP-system in April, 2003

3 Installation of the property data base in MS-Excel

- sheet “Overview“
- sheet “Data Points”

4 Access of the property data base to AA-CAES participants in June, 2003

5 Collection of data and algorithms from the literature

- Data sets from Eric Lemmon, NIST Boulder
- Data base LIDOS from Wolfgang Wagner, Ruhr-University of Bochum
- Literature inquiry of PTB Braunschweig
- Literature at NIST in Boulder
- Literature and articles from Jinyue Yan, University of Stockholm

total: 188 articles

But, only 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**

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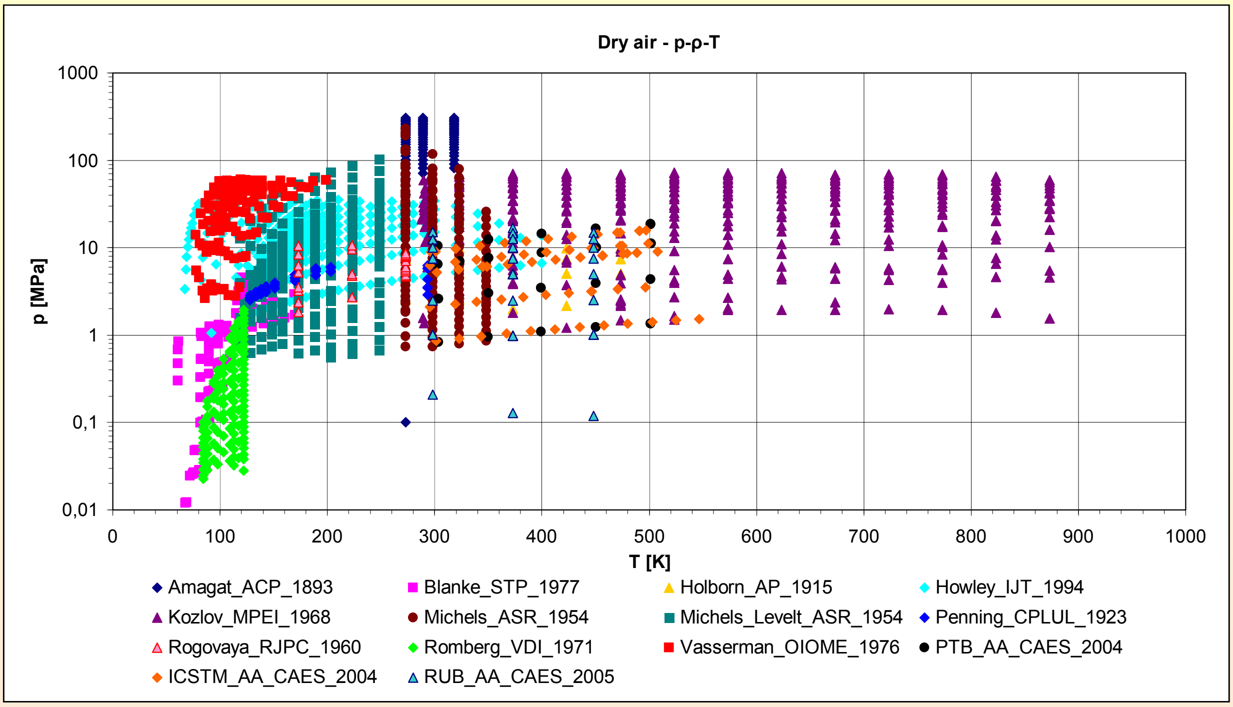
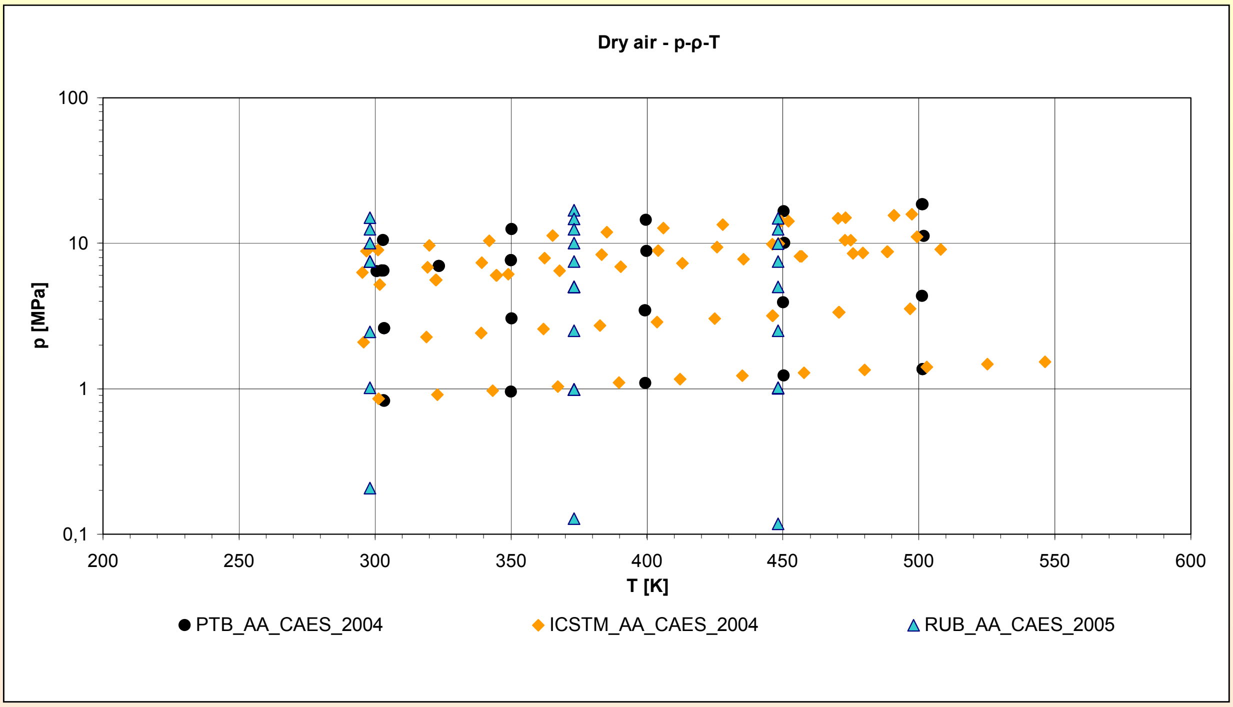
6 Collection of data from the AA-CAES experimental groups

- Formatted files for transferring the data were distributed in February 2004
- pρT-data of dry air were received from PTB, ICSTM and RUB
- Speed of sound data of dry air were received from ICSTM
- Viscosity data of dry air were received from RUB

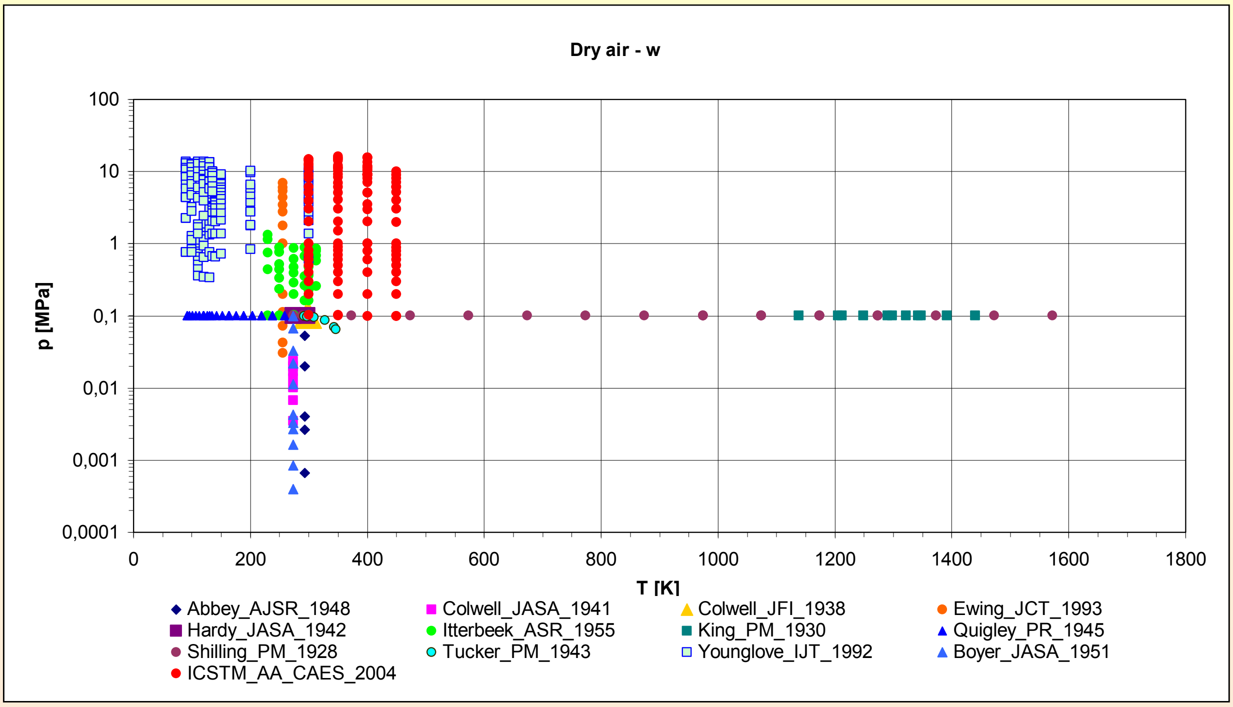
p-ρ-T data of Dry Air



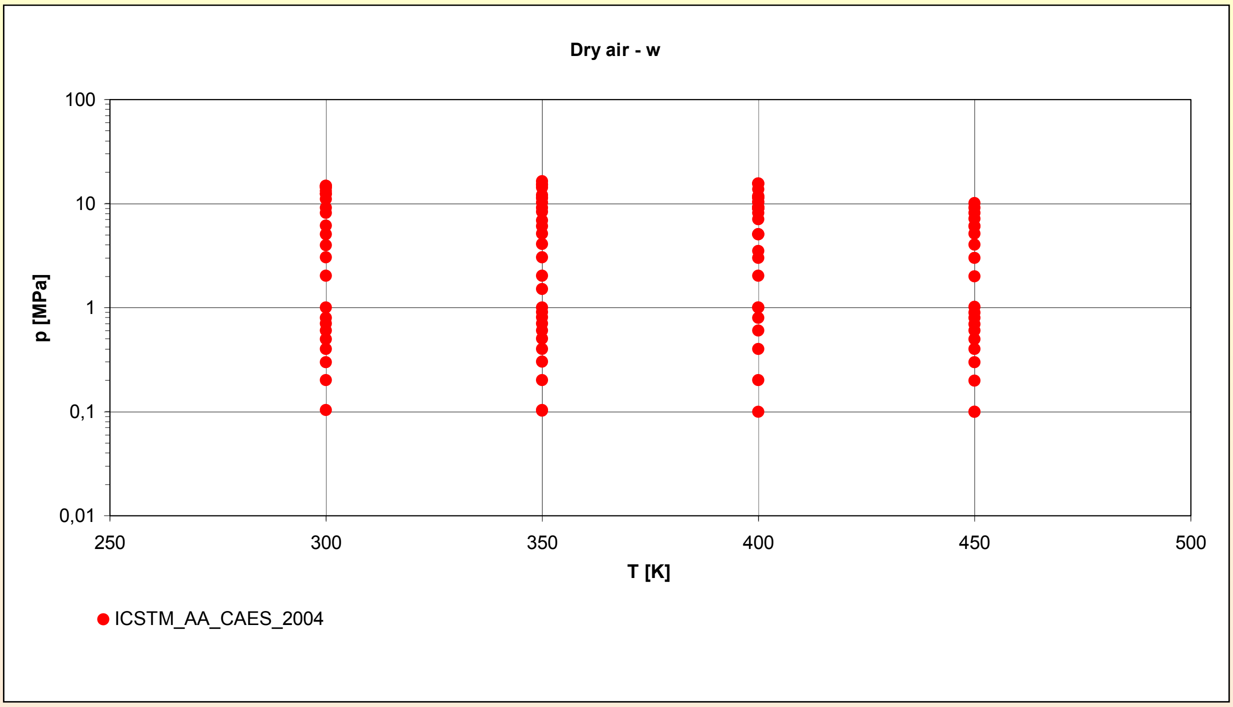
p-ρ-T data of Dry Air from AA-CAES experimental groups



Speed of sound data of Dry Air



Speed of sound data of Dry Air from AA-CAES experimental groups



Property data base – Final tasks

- **Collecting experimental data from the AA-CAES project groups**

- **D 4.2 "Database with thermodynamic and transport properties" (month 30)**
  - **Preparation of the report by the end of June 2005**
  - **Draft report – Revisions after receiving further experimental data will be necessary**

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

Existing algorithms for thermodynamic properties of humid air

Property library

- Algorithms for ambient pressure

Harris (1971)	20°C	
Wong (1985)	from 0°C to 30°C	
Cramer (1993)	from 0°C to 30°C	
Melling (1997)	from 100°C to 200°C	

- Ideal mixture of ideal gases

VDI-Guideline 4670 (2003) — **LibIDGAS**

- Ideal mixture of real fluids

Kretzschmar, Kleemann, Seibt (2002-2005) — **LibHuGas**
Ideal mixture of the real fluids N2, O2, Ar, and steam
up to 3000°C and 1000 bar

Kretzschmar, Hellriegel, Weidner (2001-2005) — **LibHuAir**
Ideal mixture of the real fluids dry air and steam
up to 3000°C and 1000 bar

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Property library

- Real mixture of real fluids

Hyland and Wexler (1973, 1975, 1983) — **MoistAirTab (in preparation)**
Virial equations of state for mixture
from 0°C to 200°C and from 0 bar to 50 bar

Carotenuto (1996)
Algorithms of Hyland 1983
from 0°C to 200°C and from 0 bar to 50 bar

Nelson (2001)
Improved virial equation of state of Hyland 1983
from 200°C to 320°C and from 1 bar to 50 bar

Rabinovich and Beketov (1995) — **(in preparation)**
Virial equation of state for mixture
from -73,15°C to 126,85°C and up to 100 bar

Wylie (1996)
Enhancement factor from poynting
from 0°C to 100°C and 1 bar to 150 bar

Yan and Ji (2003) — **(in preparation)**
Modified Redlich-Kwong equation of state for mixture

- Multi fluid model

Wagner (2005)
Fundamental equation for natural gas

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 (1997)
- Poynting correction for saturation pressure of steam
- Dissociation from VDI-4760

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 (1995)
- Poynting correction for saturation pressure of steam
- Dissociation from VDI-4760

Program MoistAirTab

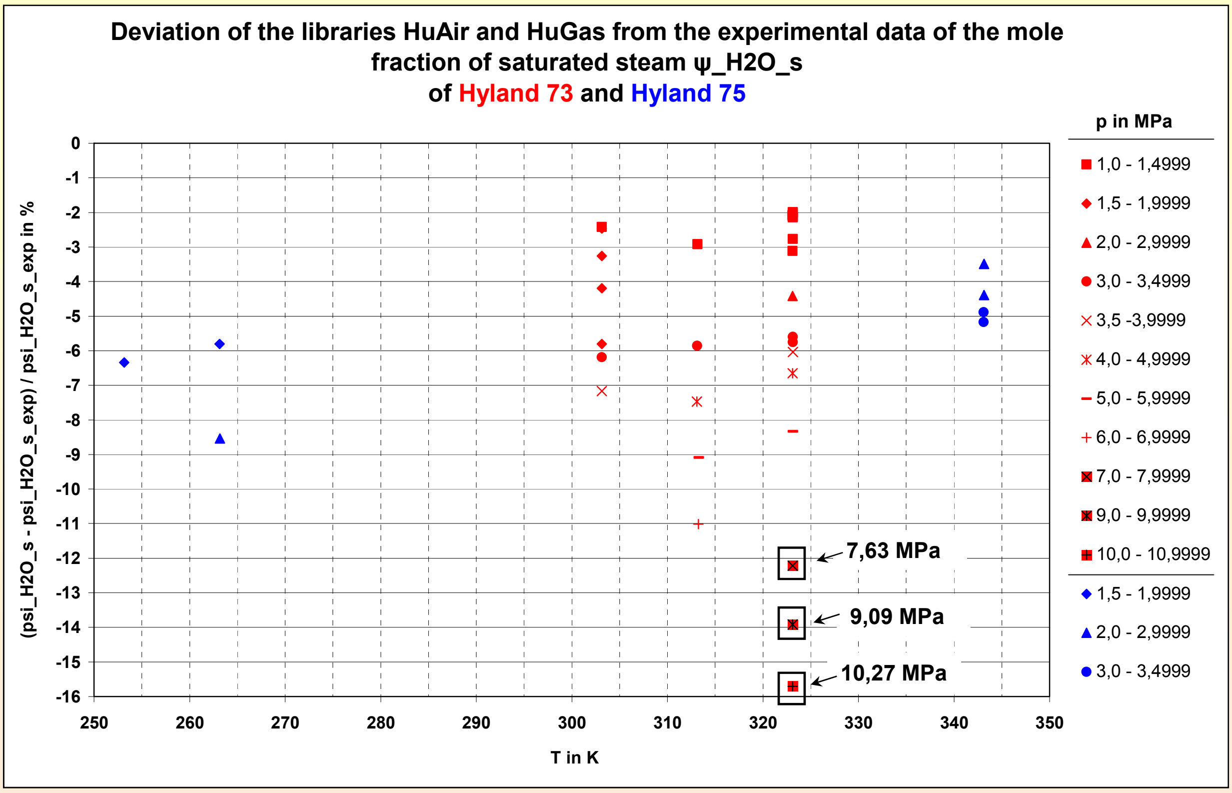
- Virial equation for the mixture of Hyland and Wexler (1983)
- Using enhancement factor for saturation pressure of steam

Program Refprop 7.0 (for dry air)

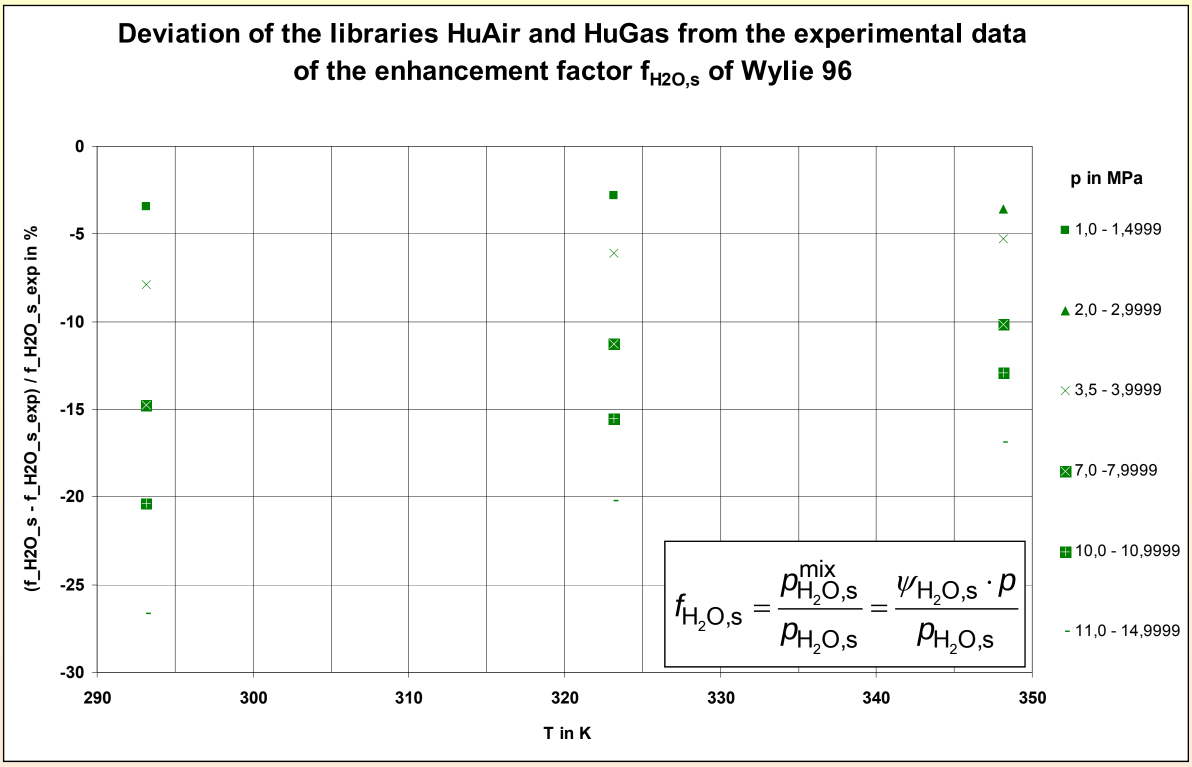
- Fundamental equation for the mixture dry air of Lemmon et al. (2000)
  → Refprop_pure
- Multifluid mixing model of the components N_2, O_2, and Ar of Lemmon et al. (2000)
  → Refprop_mix

Poynting Mole fraction

$\psi_{H2O,s}$ of Humid Air



$f_{H2O,s}$ of Humid Air



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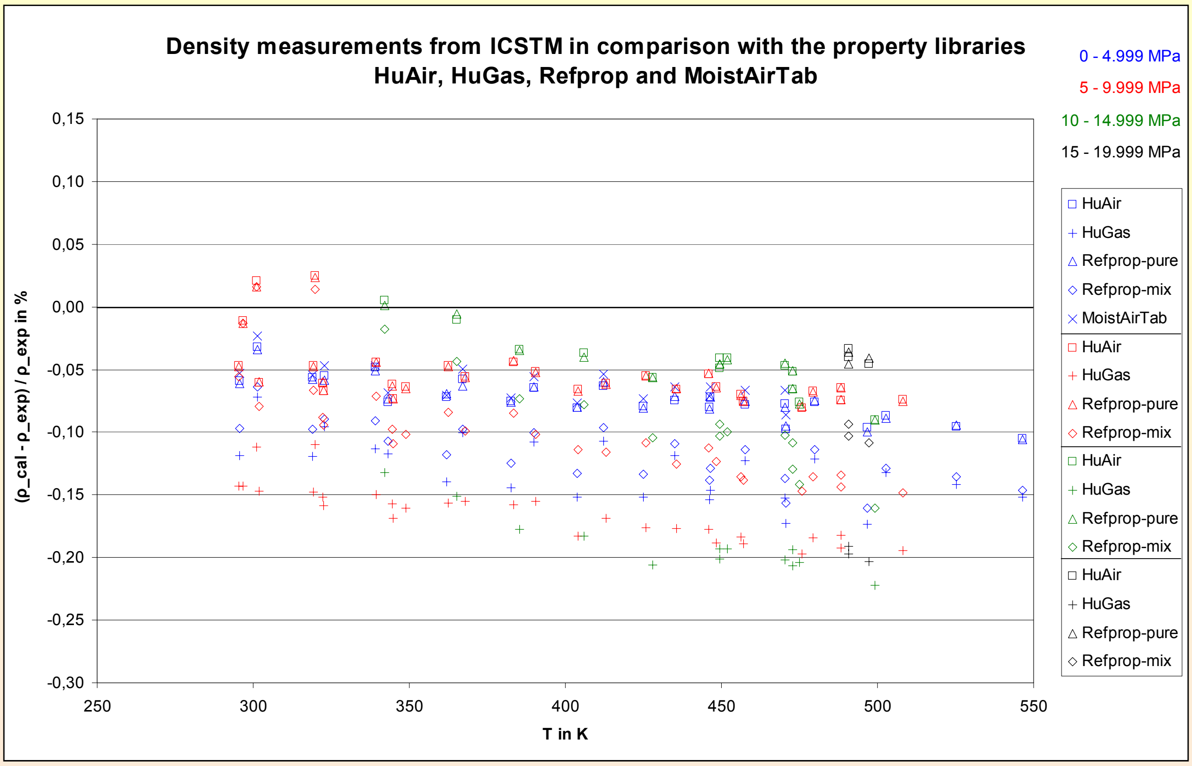
ρ of Dry Air - ICSTM



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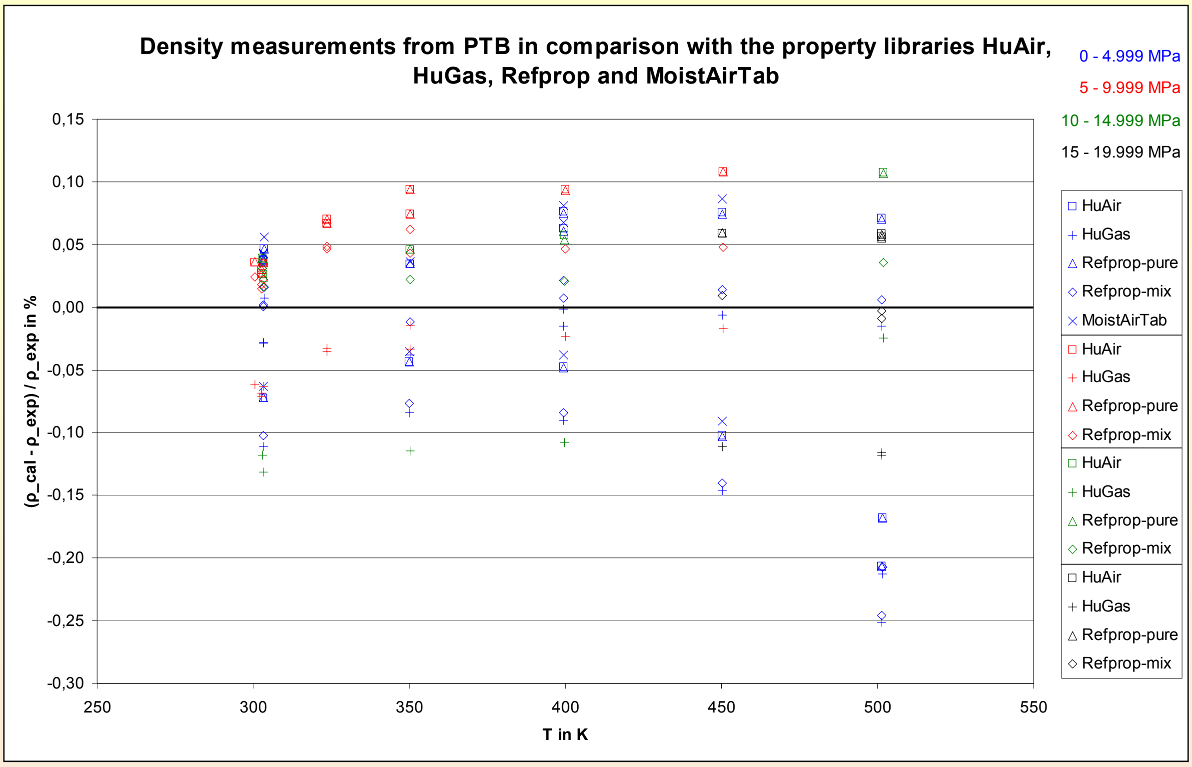
ρ of Dry Air - PTB



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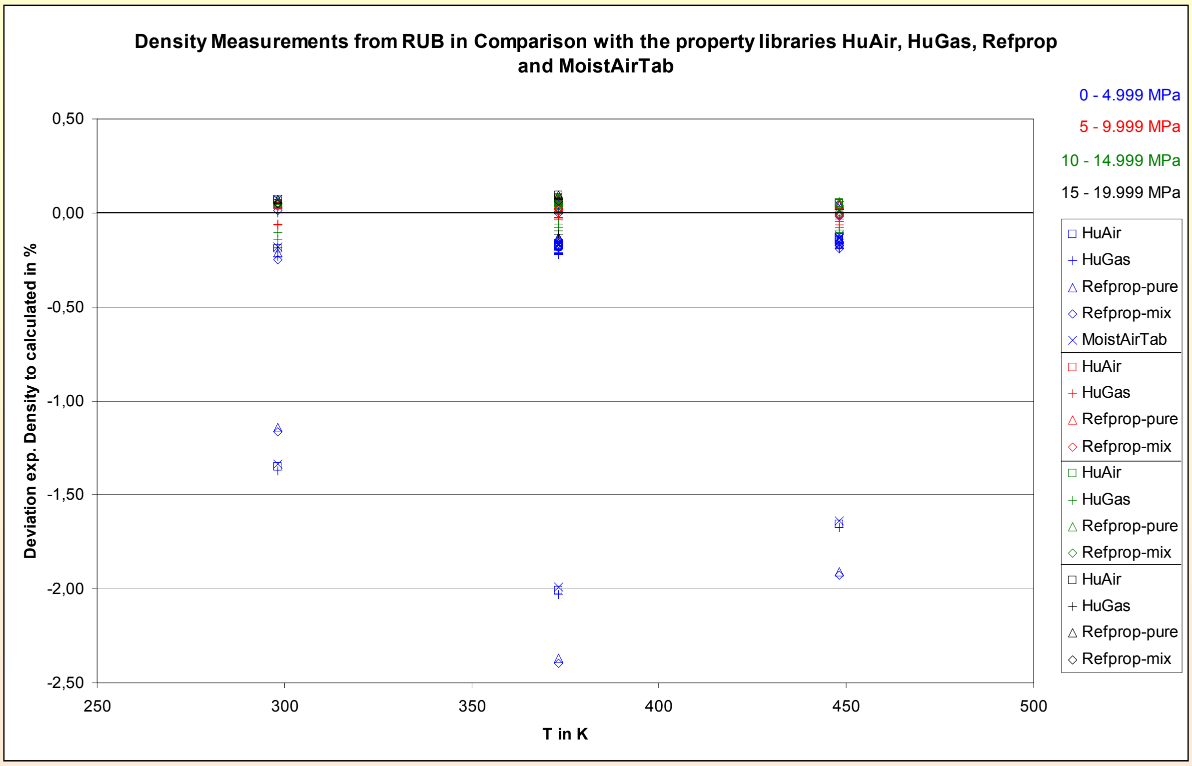
ρ of Dry Air - RUB



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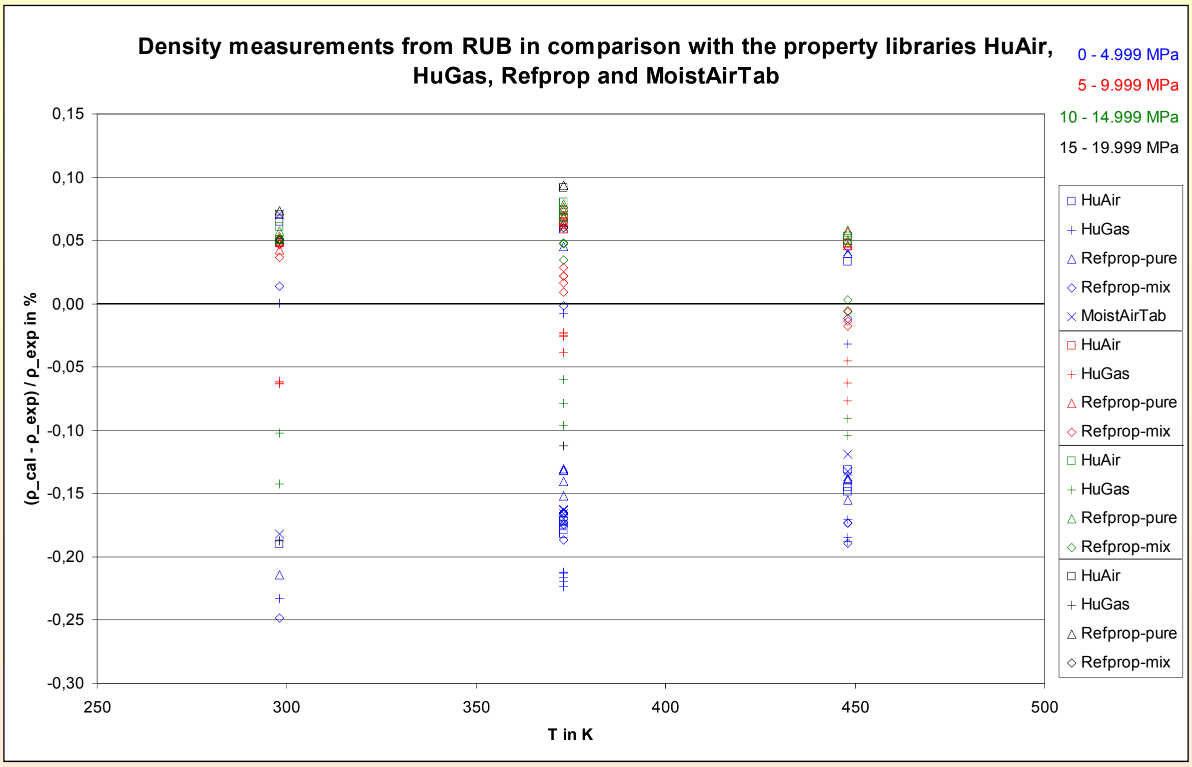
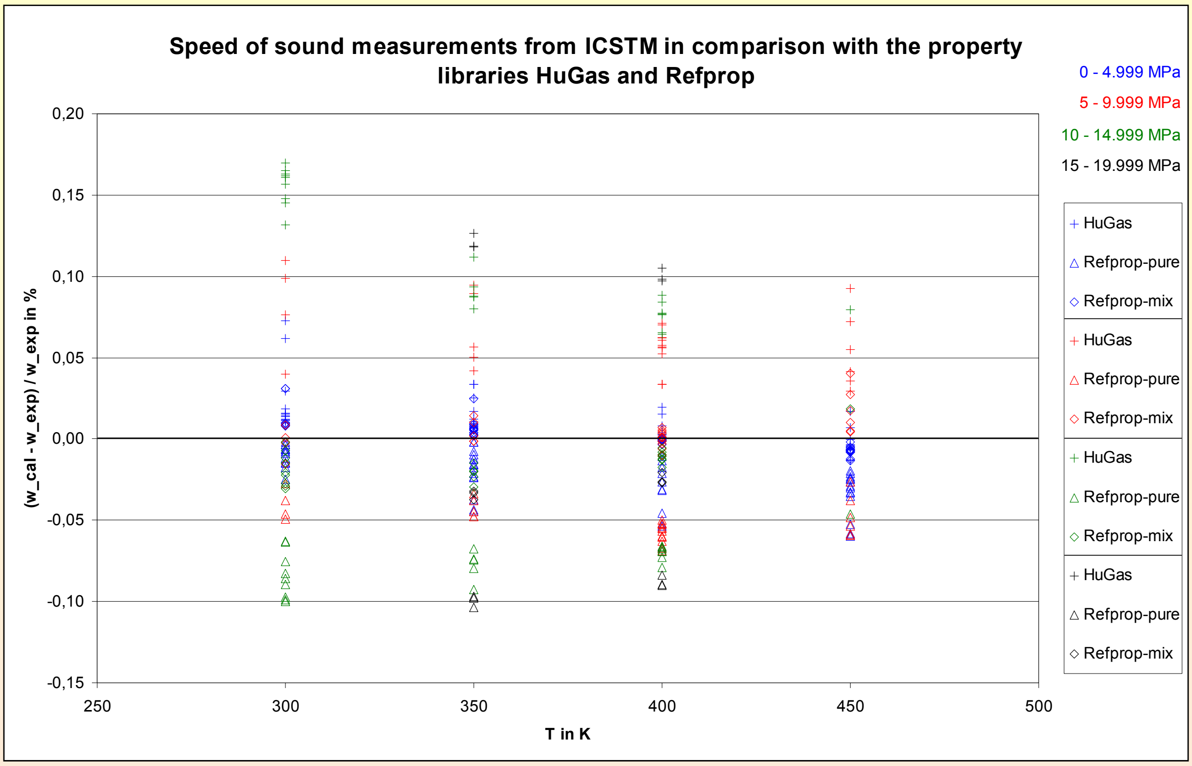
ρ of Dry Air – RUB (selected)



w of Dry Air – ICSTM



Conclusions

- Poynting correction for saturation pressure of steam is too weak

→ Models of Hyland and Wexler, Rabinovich and Beketov, and Yan will be investigated

- Model: ideal mixture of the real fluids dry air and steam is suitable for calculating thermodynamic properties of dry air

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

Thermodynamic property models – Further Tasks

- Inclusion of speed of sound and isentropic exponent in the library LibHuAir

- Comparison of different models for calculating the saturation pressure of steam in humid air under pressure

- Hyland and Wexler (1983)
- Rabinovich and Beketov (1995)
- Yan and Ji (2003 – 2005)

- Further comparison calculations for humid air after receiving new experimental data

- Comparison calculations using the multi fluid model of Wagner

- Preparation of a property library for humid air including the most accurate algoritms

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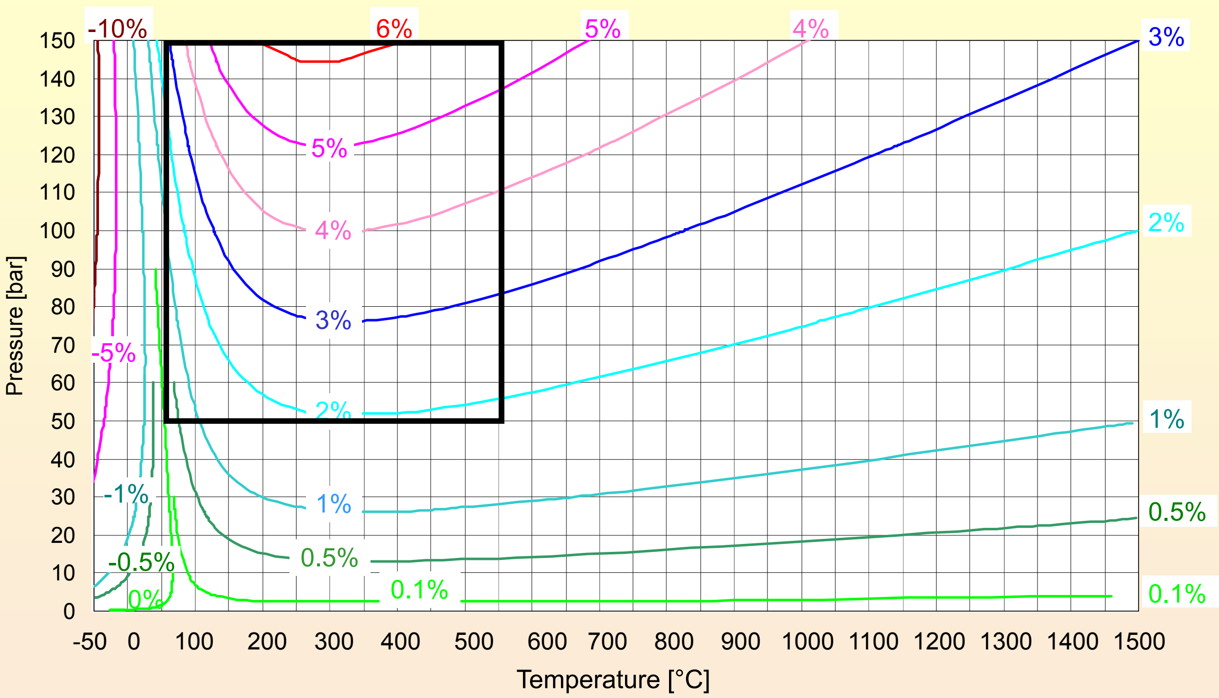
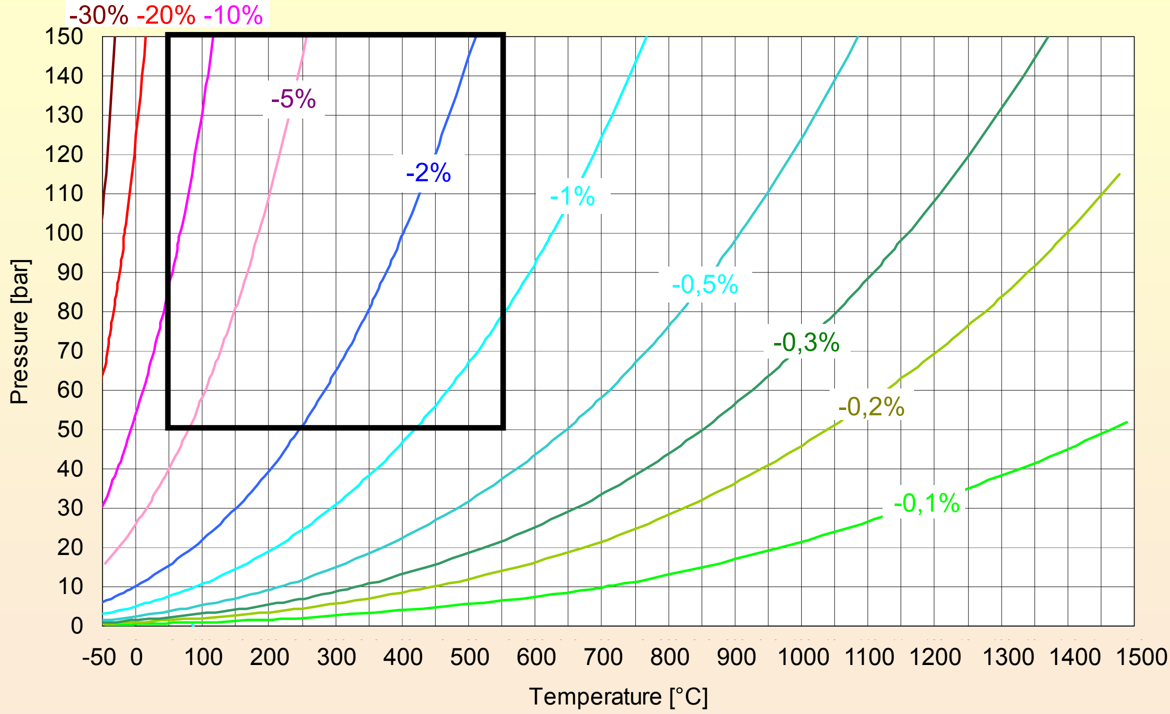
Real gas behavior of the density ρ of dry air



Real gas behavior of the isobaric heat capacity c_p of dry air



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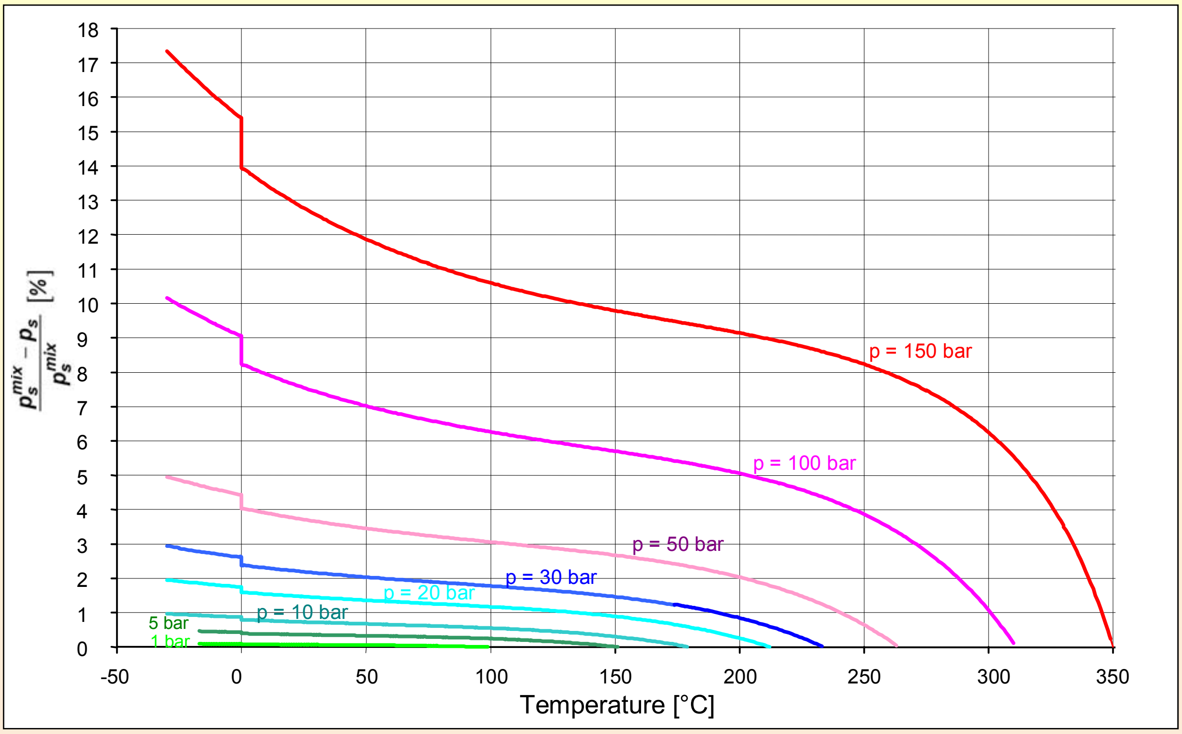
Increase of saturation pressure of steam in gas atmosphere under pressure



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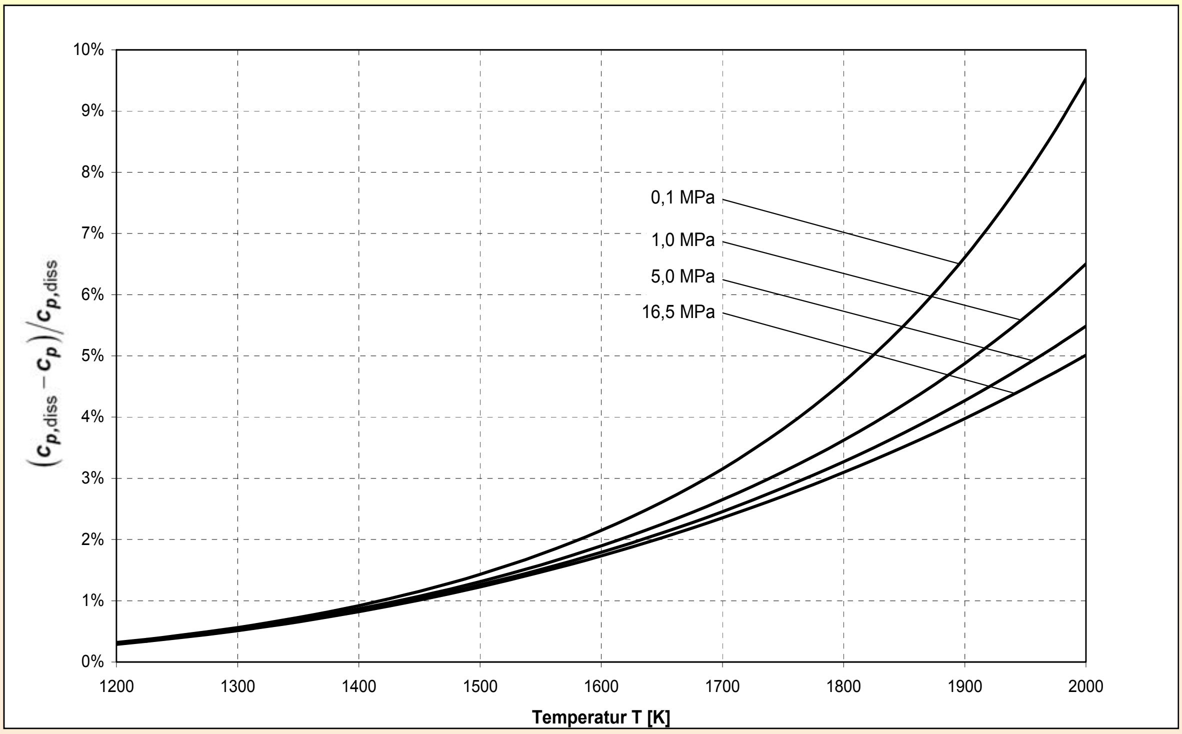
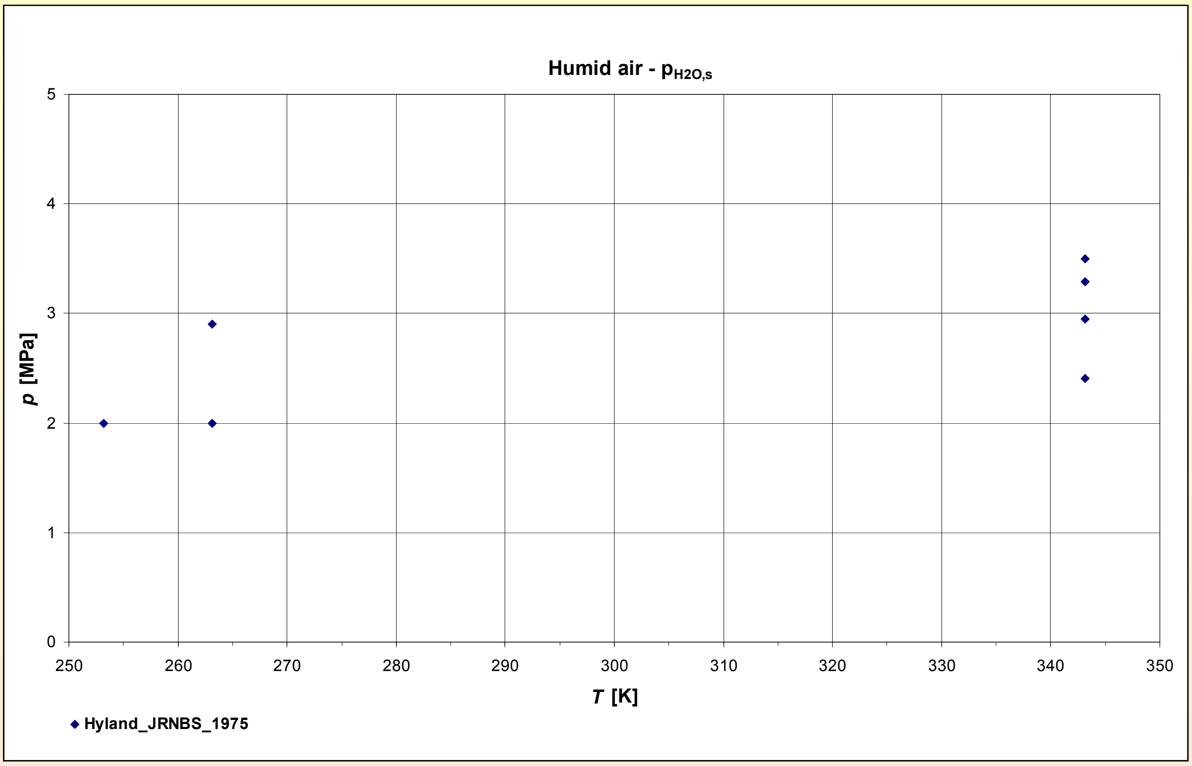
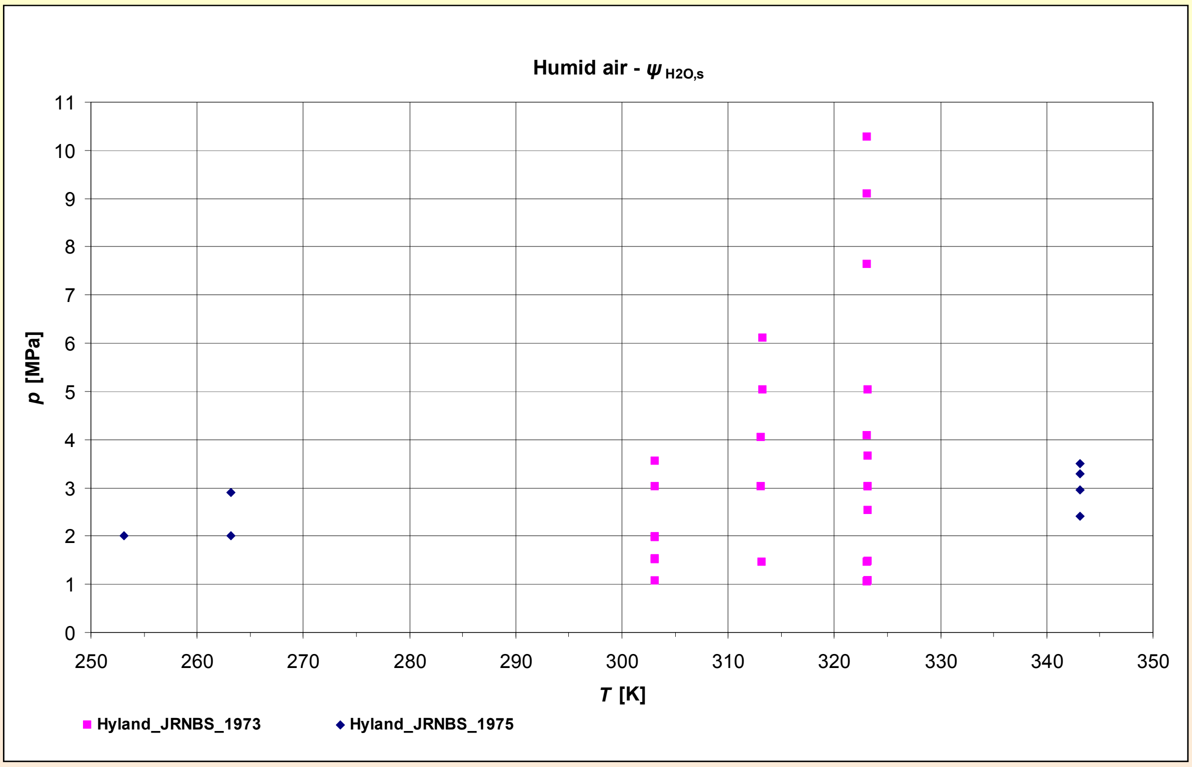
Influence of Dissociation: Example Dry Air



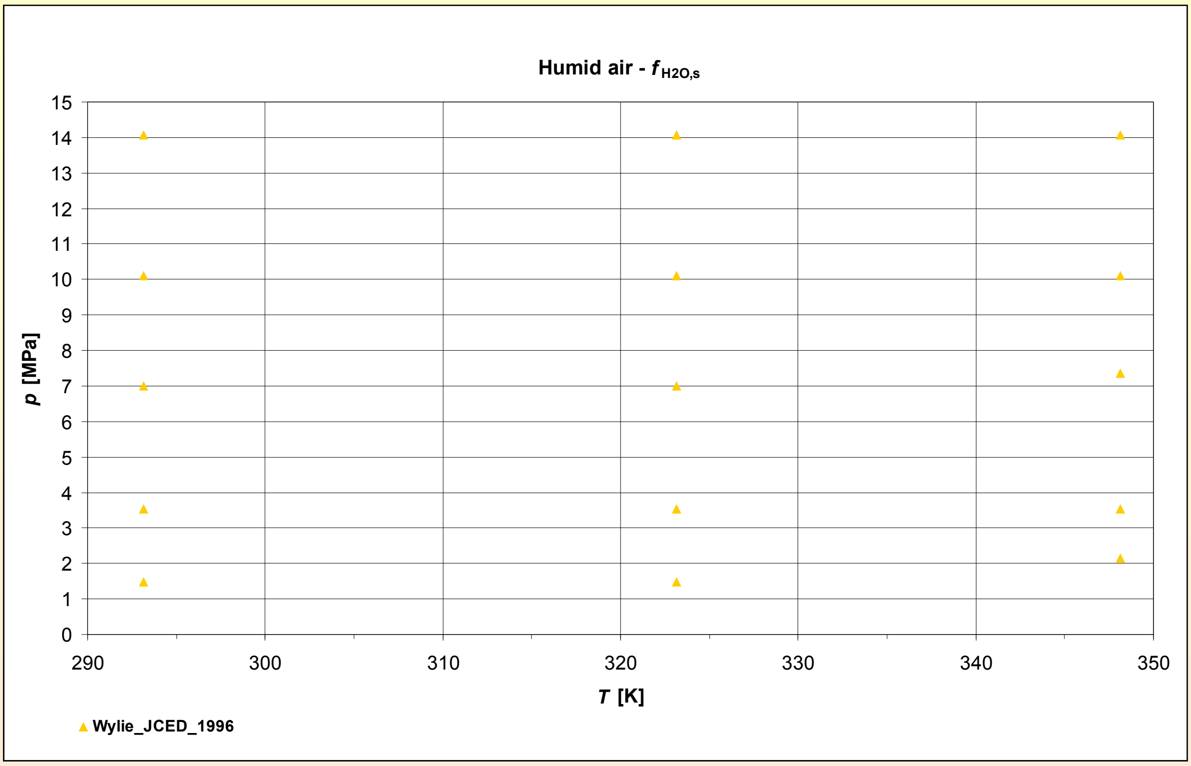
Saturation pressure of water $p_{H2O,\,s}$



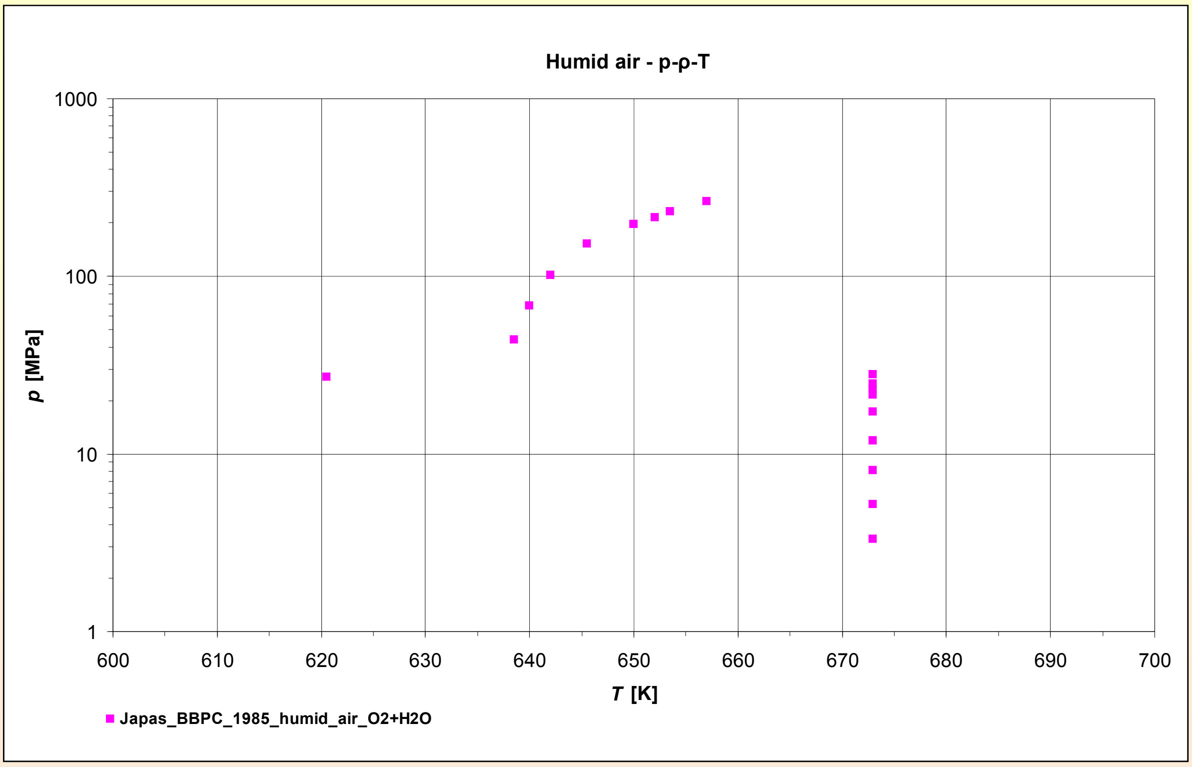
Mole fraction of saturated steam $\psi_{H2O,\,s}$



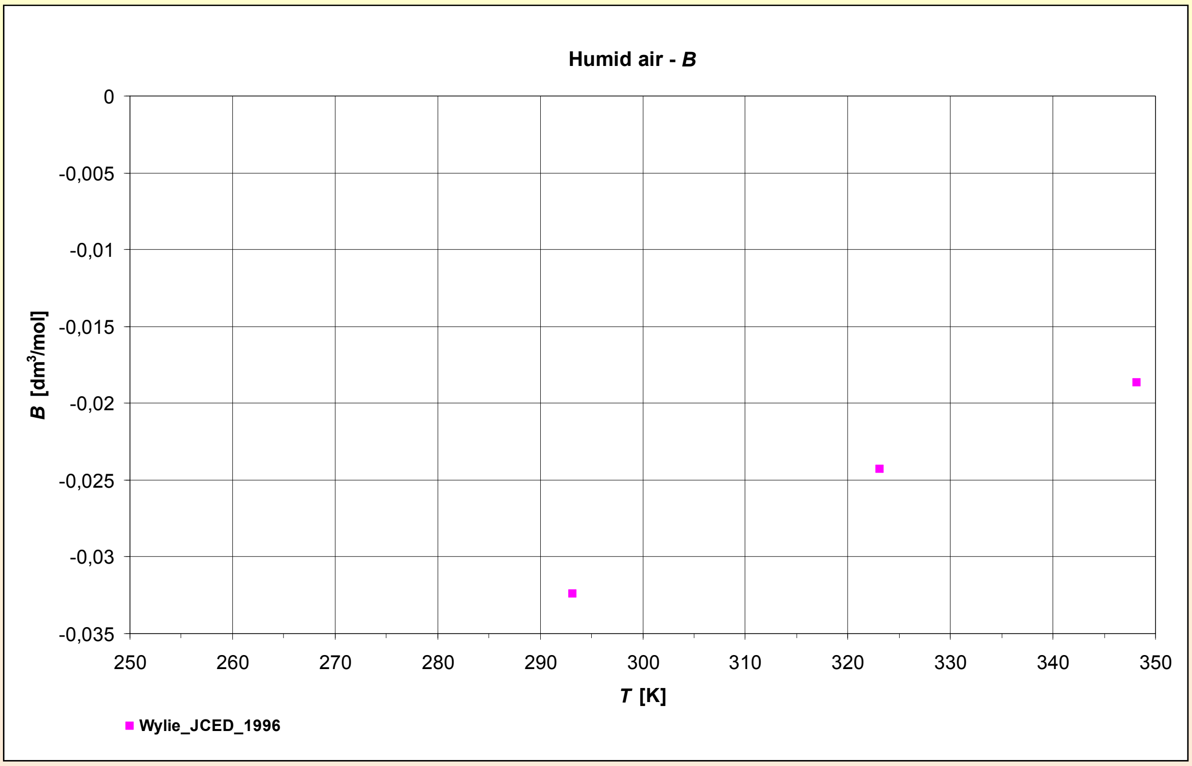
Enhancement factor $f_{H2O,\,s}$



p-ρ-T



Second virial coefficient *B*



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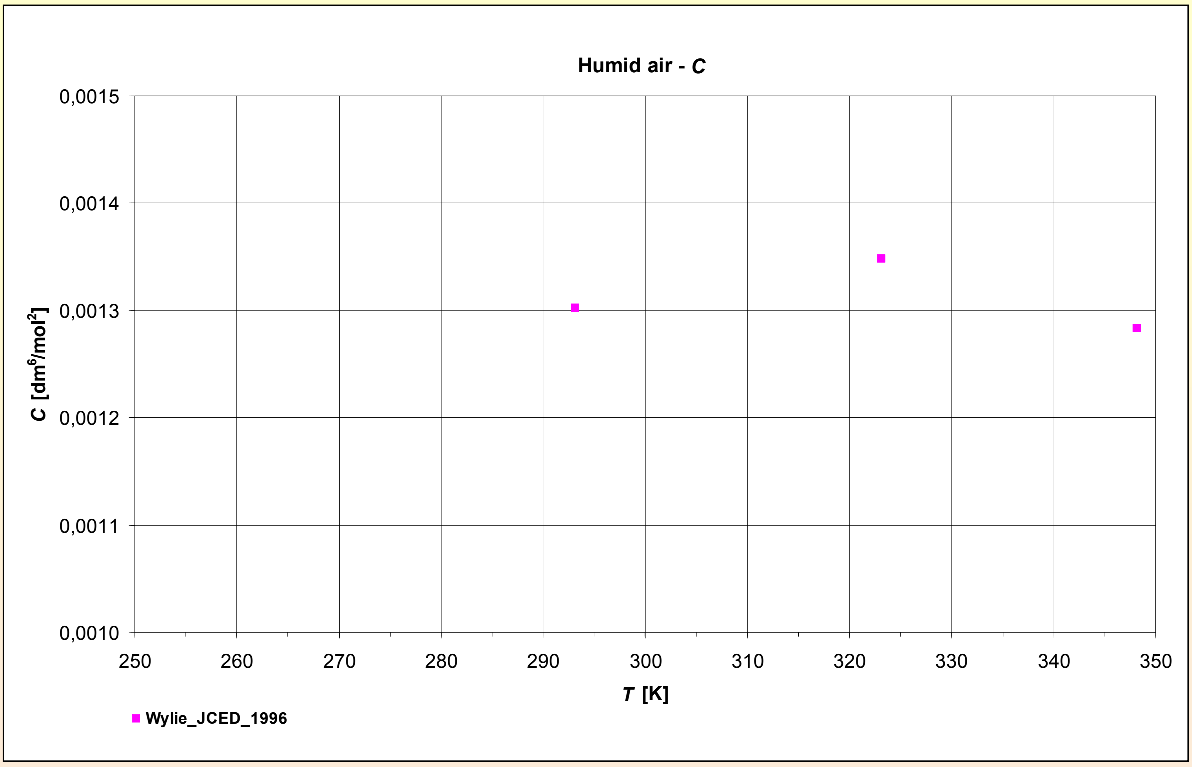
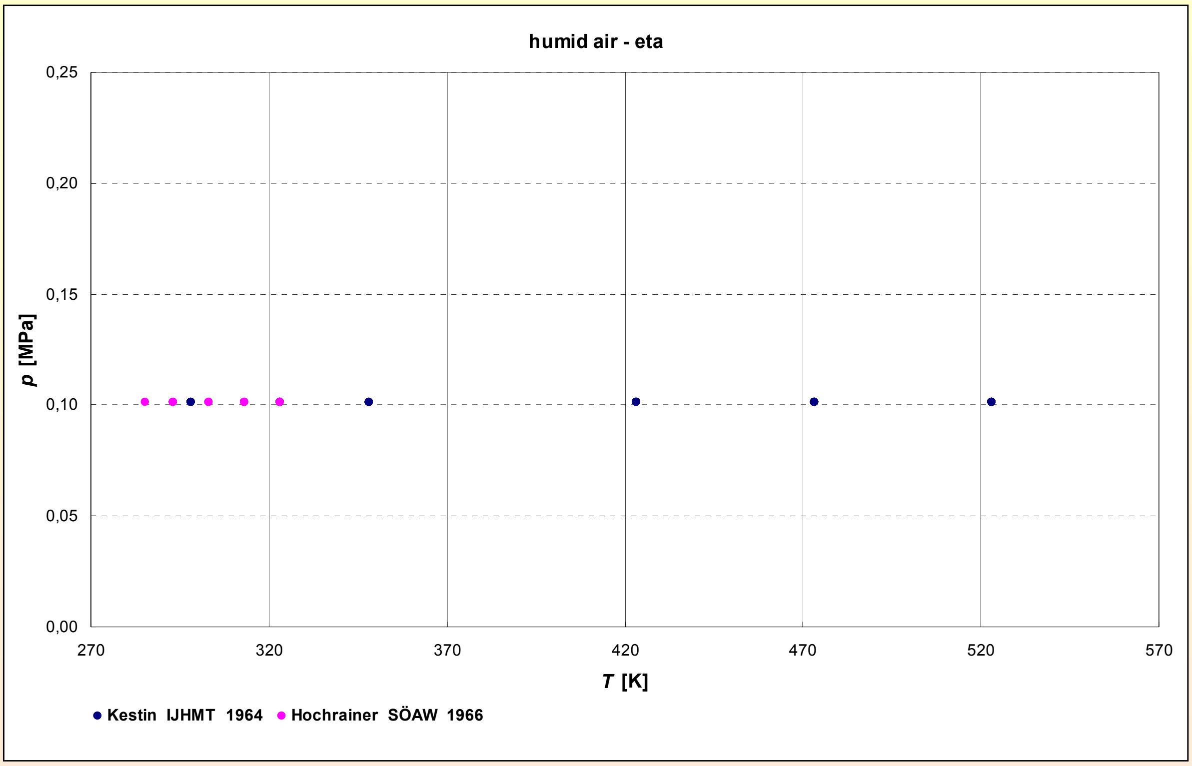
Third virial coefficient C



Viscosity η



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Thermal conductivity λ