On the accuracy of HITEMP-2010 calculated emissivities of Water Vapor and Carbon Dioxide

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\[ K_{a,\eta}(\eta, T, P_t, x_j, L) = S_H(T) \cdot N(p_j, T) \cdot g(\eta - \eta_i) \]

- 7 Parameter for each line are needed from Spectral database
- Equation of state: Ideal gas law
- Lineshape: Lorentz
- \( a_\eta = \sum_{\text{all lines}} K_{a,\eta} \)
Line-by-Line Method

\[ T = 1800 \text{ K}, \quad P_t = 1 \text{ atm}, \quad \text{pure CO}_2, \quad L = 50 \text{ cm} \]

\[ \tau_\eta = \exp(-a_\eta \cdot L) \quad \varepsilon_\eta = 1 - \tau_\eta \]
Line-by-Line Method

$T = 1800 \text{ K}, \ P_t = 1 \text{ atm}, \ pure \ H_2O, \ L = 50 \text{ cm}$

\[
\varepsilon_{\text{tot}} = \frac{1}{\sigma \cdot T^4} \cdot \int_0^\infty \varepsilon_\eta \cdot \frac{c_1 \cdot \eta^3}{\exp \left( \frac{c_2 \cdot \eta}{T} \right) - 1} \cdot d\eta
\]
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Important Measurements (without any claim to completeness)

- Modest & Bharadwaj (2002-2007) [5, 6, 10]
  - up to 1550 K, CDSD-1000 and HITEMP-1995, 4 cm\(^{-1}\)
  - also compared with HITEMP-2010, see Alberti et. al. [1]

- Becher et. al. (2012) [4]
  - up to 1770 K, HITEMP-2010, Measurements performed at DTU, 32 cm\(^{-1}\)

- Alberti et. al. (2015) [3]
  - 22 cases, 500 - 1770 K, also mixtures, DTU, 1 cm\(^{-1}\)
  - whole spectral range from 450 to 7600 cm\(^{-1}\)
High Temperature - Alberti et. al. (2015)

\[ \text{CO}_2 \text{ at } 1770 \text{ K, } x_{\text{CO}_2} = 0.43, \ x_{\text{N}_2} = 0.57, \ P_t = 1 \text{ atm, } L = 54 \text{ cm} \]

\[ \text{Difference} = \tau_{\eta, \text{Measured}} - \tau_{\eta, \text{HITEMP} - 2010} \]

see Alberti et. al. [3]
High Temperature - Alberti et. al. (2015)

$H_2O$ at 1770 K, $x_{H_2O} = 0.43$, $x_{N_2} = 0.57$, $P_t = 1$ atm, $L = 54$ cm

\[ \text{Difference} = \tau_\eta, \text{Measured} - \tau_\eta, \text{HITEMP–2010} \]

see Alberti et. al. [3]
High Temperature - Alberti et. al. (2015)

\[ H_2O \text{ and } CO_2 \text{ at } 1770 \text{ K, } x_{H_2O} = x_{CO_2} = 0.43, \ P_t = 1 \text{ atm, } L = 54 \text{ cm} \]

Difference \[ = \tau_{\eta,\text{Measured}} - \tau_{\eta,\text{HITEMP–2010}} \]

see Alberti et. al. [3]
High Temperature - Alberti et. al. (2015)

CO₂ Emissivity Chart, \( x_{CO₂} = x_{N₂} = 0.5 \)

![Graph showing CO₂ emissivity as a function of temperature and pressure.]

- Red line: Calculated using HITEMP-2010
- Crossed line: Calculated using Measurements of Alberti et. al. (2015)

\[
pL = p_{CO₂} \cdot L
\]

55 bar cm
38 bar cm
24 bar cm
9 bar cm
High Temperature - Alberti et. al. (2015)

$H_2O$ Emissivity Chart, $x_{H_2O} = x_{N_2} = 0.5$

$\rho L = \rho_{H_2O} \cdot L$

Calculated using HITEMP-2010

Calculated using Measurements of Alberti et. al. (2015)
High Temperature - Alberti et. al. (2015)

$\mu L = (p_{CO_2} + p_{H_2O}) \cdot L = 47 \text{ bar cm}$

$\frac{p_{H_2O}}{p_{CO_2}} = 4.0$

$1.0$

$0.25$

$pL = (p_{CO_2} + p_{H_2O}) \cdot L$

Calculated using HITEMP-2010

Calculated using Measurements of Alberti et. al. (2015)
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Important Results for CO$_2$ (without any claim to completeness)

- **Measurements**
  - Fukabori et. al. (1986) [7]
  - Hartmann and Perrin (1989) [8, 11]
  - Scutaru et. al. (1993) [12]

- **Models / Adjustments**
  - Full Line-Mixing software of Lamouroux [9]
  - $\chi$-factors of Tran (2011) [13]
  - Cut-off criterion of Alberti et. al. (2015) [2]
    - Number Lorentz-half-widths
      \[
      n(T, P_t) = 4.0 \times \left( \frac{T}{P_t} \right)^{0.822}
      \]
High Pressure - Alberti et. al. (2015)

\[ T = 303 \text{ K}, \quad P_t = 11.1 \text{ bar}, \quad \text{pure CO}_2, \quad L = 5.02 \text{ cm} \]

Transmissivity \( \tau \)

\[ T = 303 \text{ K}, \quad P_t = 11.1 \text{ bar}, \quad \text{pure CO}_2, \quad L = 5.02 \text{ cm} \]

Fukabori (1986) No Limit Limited \((60 \Delta)\) \(\chi\)-Tran (2011) \(\cdots\) FLM

see also Ref. [2]
High Pressure - Alberti et. al. (2015)

$T = 623 \text{ K}, \ P_t = 52 \text{ bar}, \text{ pure CO}_2, \ L = 4.4 \text{ cm}$

see also Ref. [2]
High Pressure - Alberti et. al. (2015)

Temperature $T = 300$ K

Total Emissivity

Total pressure in bar

No Limit
Limited
$\chi$-Tran (2011)
FLM

see also Ref. [2]
High Pressure - Alberti et. al. (2015)

Temperature $T = 1500$ K

![Graph showing total emissivity vs. total pressure for different pressures (5 bar cm, 80 bar cm, 500 bar cm). The graph includes lines for No Limit, Limited, and χ-Tran (2011)].

see also Ref. [2]
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Summary and Conclusion

- High temperature and atmospheric pressures
  - $\text{CO}_2$: maximum 2\% difference (up to 1770 K)
  - $\text{H}_2\text{O}$: maximum 9\% difference (up to 1770 K)
  - $\text{CO}_2 + \text{H}_2\text{O}$: maximum 7\% difference (up to 1770 K)

- High pressure / density
  - Measurements for small spectral regions
  - New, full spectrum measurements are needed
  - Lineshape adjustment seems to be essential

- CO measurements for gasification applications
Acknowledgments

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Bibliography I


Bibliography II


Appendix

The gas cell design can be traced back to Hottel & Mangelsdorf (1935). [3]
Appendix

\[ \tau_\eta = \frac{(I_{\text{hot gas}} - I_{\text{cold gas}})}{(I_{\text{hot N}_2} - I_{\text{cold N}_2})} \]

See also Ref. [3]
Appendix

\[ T = 1770.15 \text{ K}, \quad x_{\text{H}_2\text{O}} = 0.9811, \quad P_t = 1.0262 \text{ atm}, \quad L = 54.00 \text{ cm}, \quad \text{Voigt Lineshape} \]

See also Ref. [3]