Idaho National Engineering and Environmental Laboratory

The Addition of Noncondensable Gases into RELAP5-3D for Analysis of High-Temperature Gas-Cooled Reactors

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Introduction

- *RELAP5-3D/ATHENA is being developed for analysis of high-temperature gas-cooled reactors*
- *The graphite in the core can oxidize due to air ingress following a loss-of-coolant accident*
- *The oxidation results in the formation of carbon dioxide and carbon monoxide*
- *A graphite oxidation model was previously added to the code using internal laboratory funding*
- *Oxygen, carbon dioxide, and carbon monoxide noncondensable gases were added to the code to support the analysis of graphite oxidation in gas-cooled reactors*

Introduction (continued)

- *The temperature range of interest is from 395 to 2073 K*
- *The inclusion of an additional gas species requires a gas constant and correlations for specific internal energy, thermal conductivity, and viscosity, and diffusion parameters*
- *The implementation of the new gas species was funded by DOE's Korean International Nuclear Energy Research Initiative*

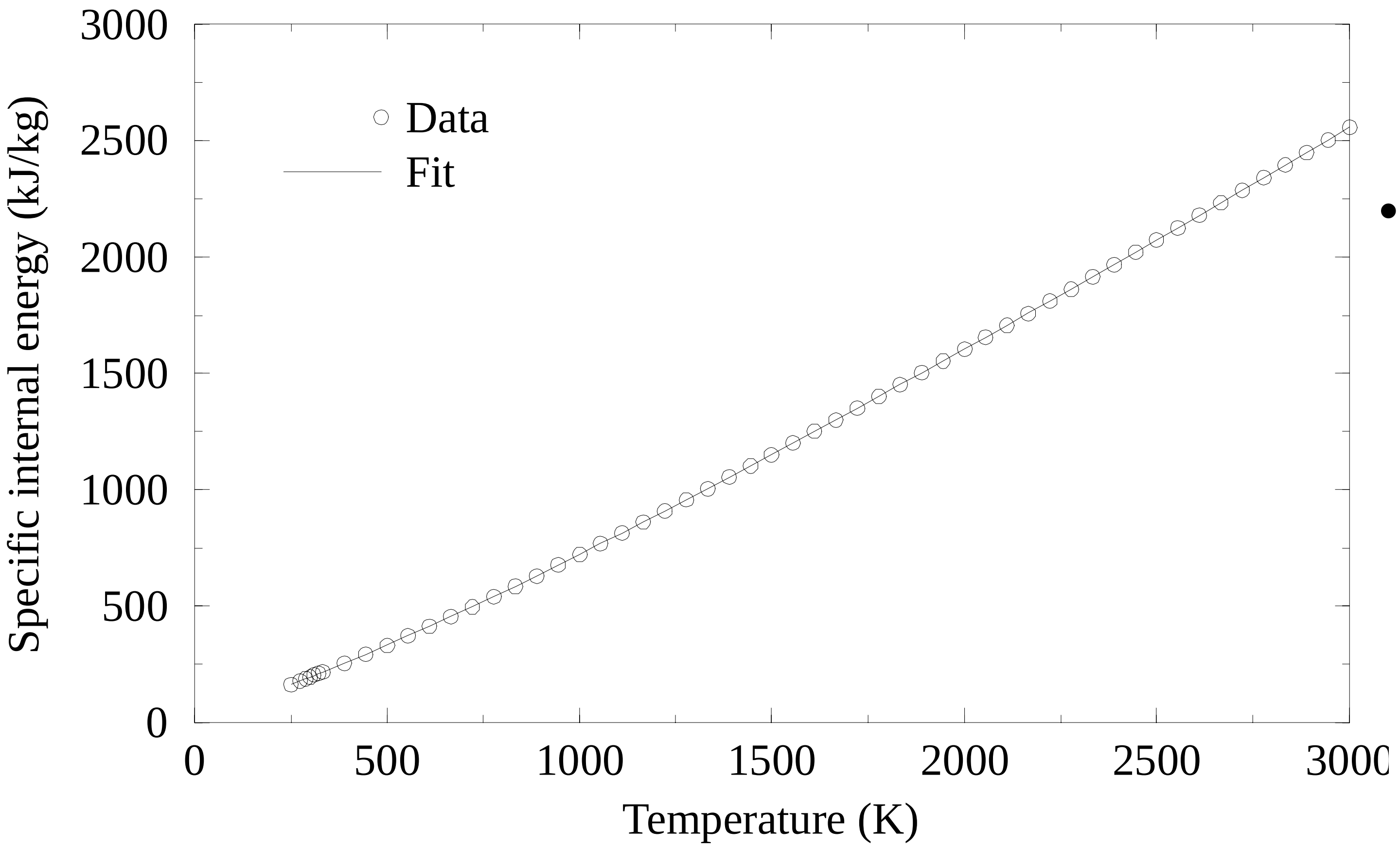
The original noncondensable model:

- *Assumes that each noncondensable species is an ideal gas with the specific internal energy a function of temperature alone*
  - *Linear for T < 250 K*
  - *Quadratic for T > 250 K*
- *This implies that the specific heat, C_v, is*
  - *Constant for T < 250 K*
  - *Linear for T > 250 K*
- *Internal energy correlations for the existing noncondensable gases (helium, hydrogen, nitrogen, etc) were fit from 250 to 700 K, much lower than the range of interest for gas-cooled reactors*

The original form of the equation was not adequate at high temperatures

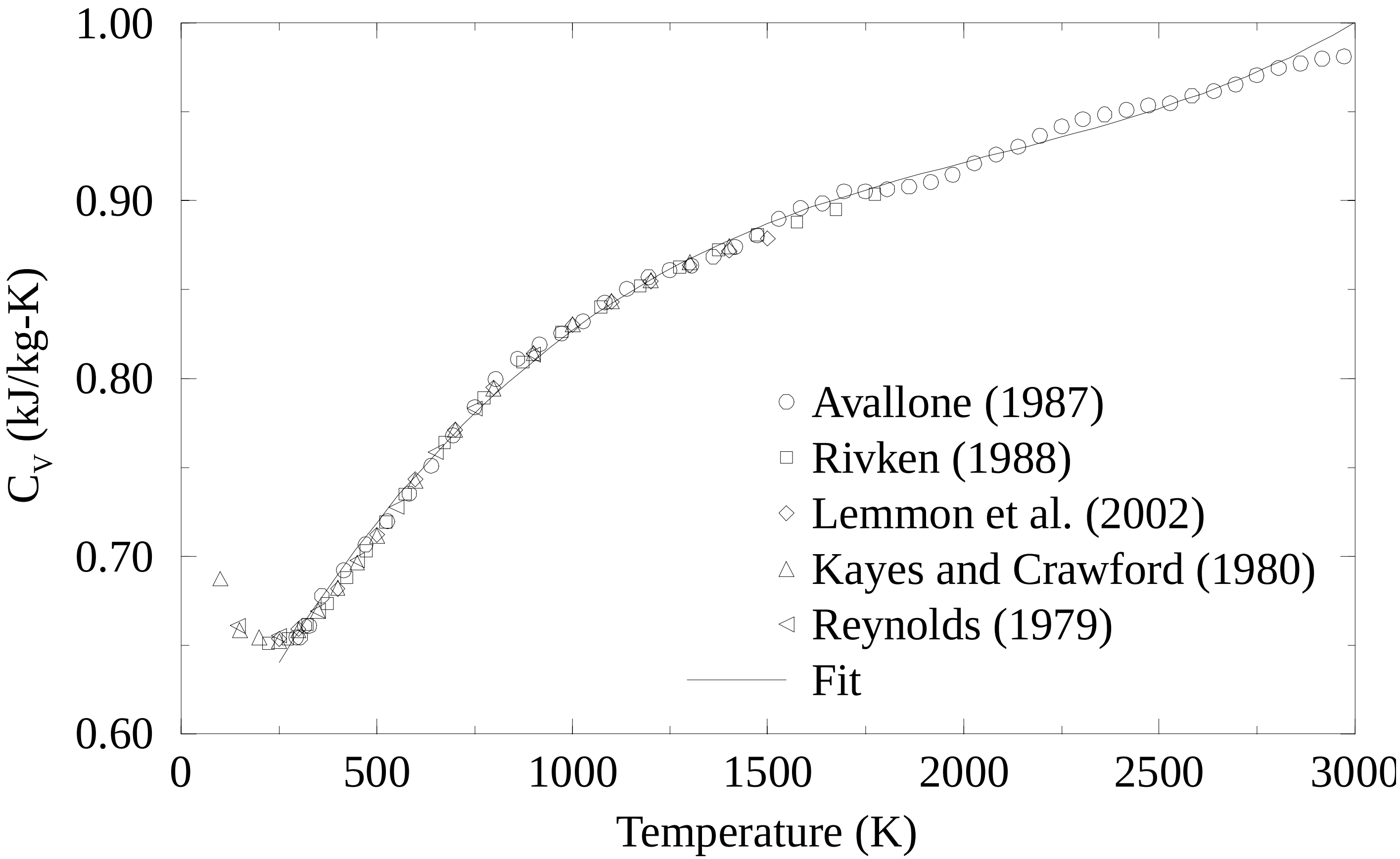
- C_v is not linear at temperatures above 700 K for the new noncondensable gases
- The original form of the equation was replaced by a more general, fourth-order polynomial
  - C_v is a cubic function of temperature for $T > 250$ K
- Coefficients were determined by least squares fits to data presented in Avalone (1987) and Rivken (1988)
- The higher order form was applied to all the code's noncondensable gases, but the higher order coefficients were set to zero for the original gases so that results were not altered

The new model represents the internal energy well over the required temperature range



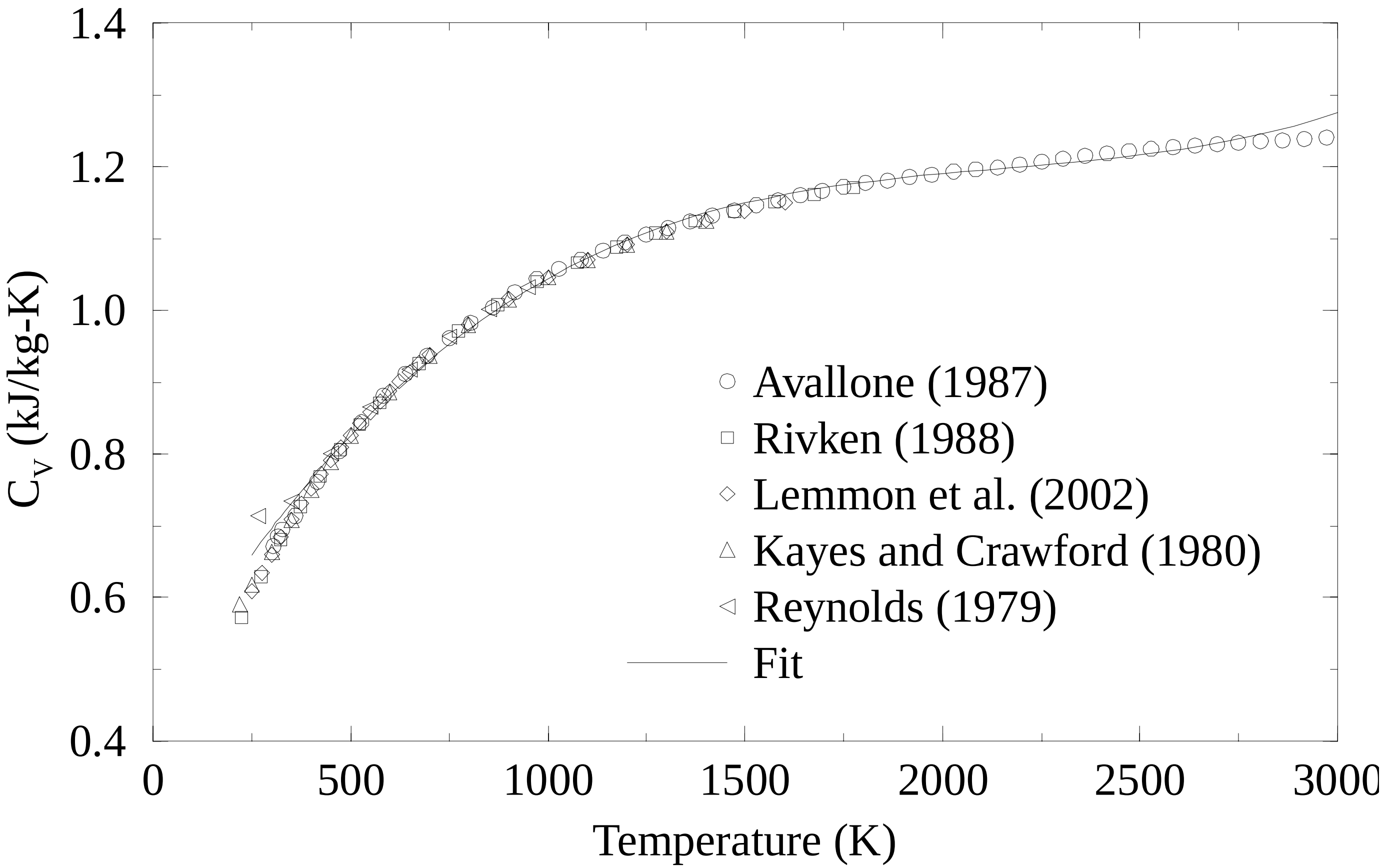
- Oxygen

The new model represents C_v well over the required temperature range



- Oxygen

Similar results were obtained for CO_2 and CO

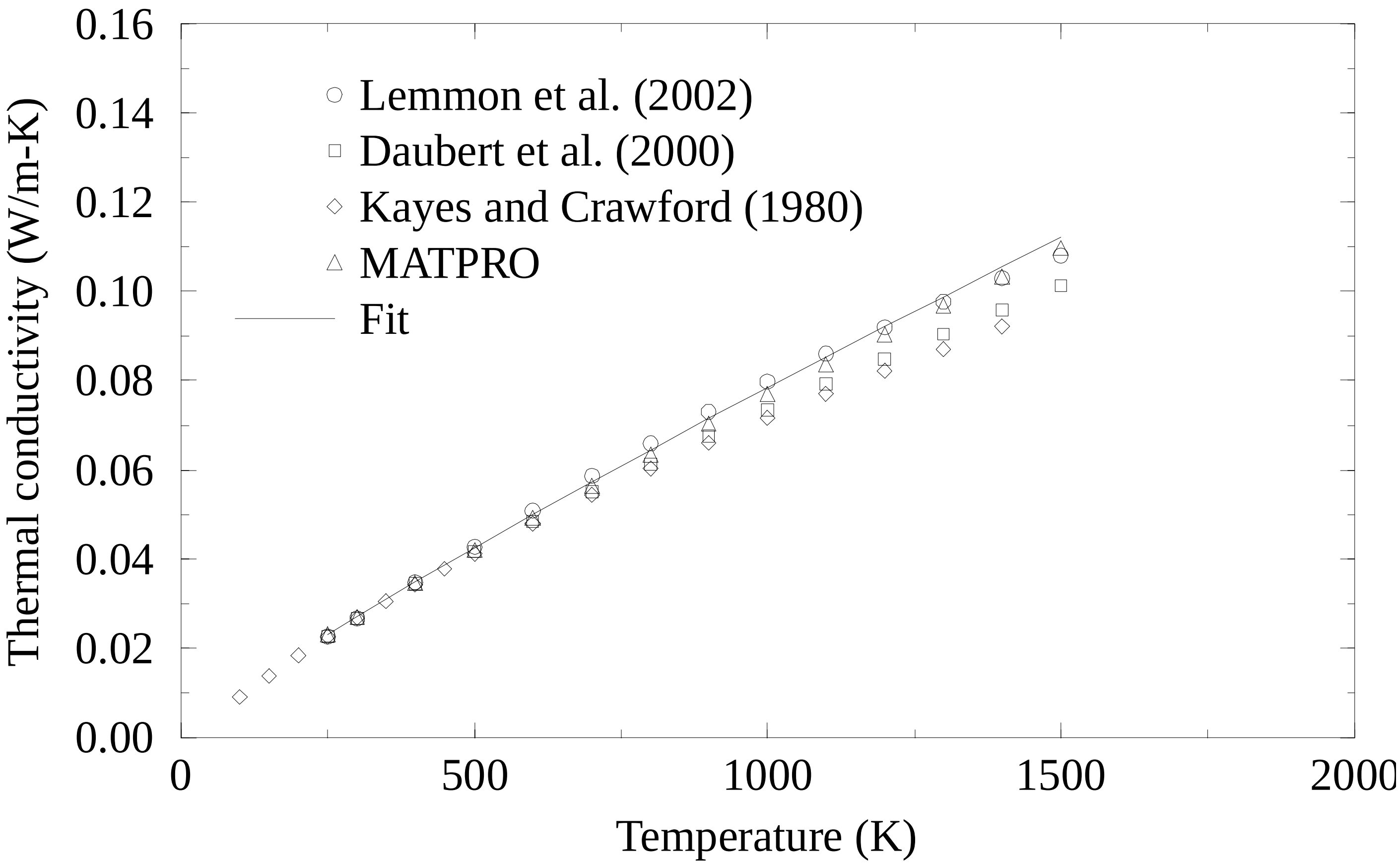


- CO_2

Transport properties were also implemented for the new species

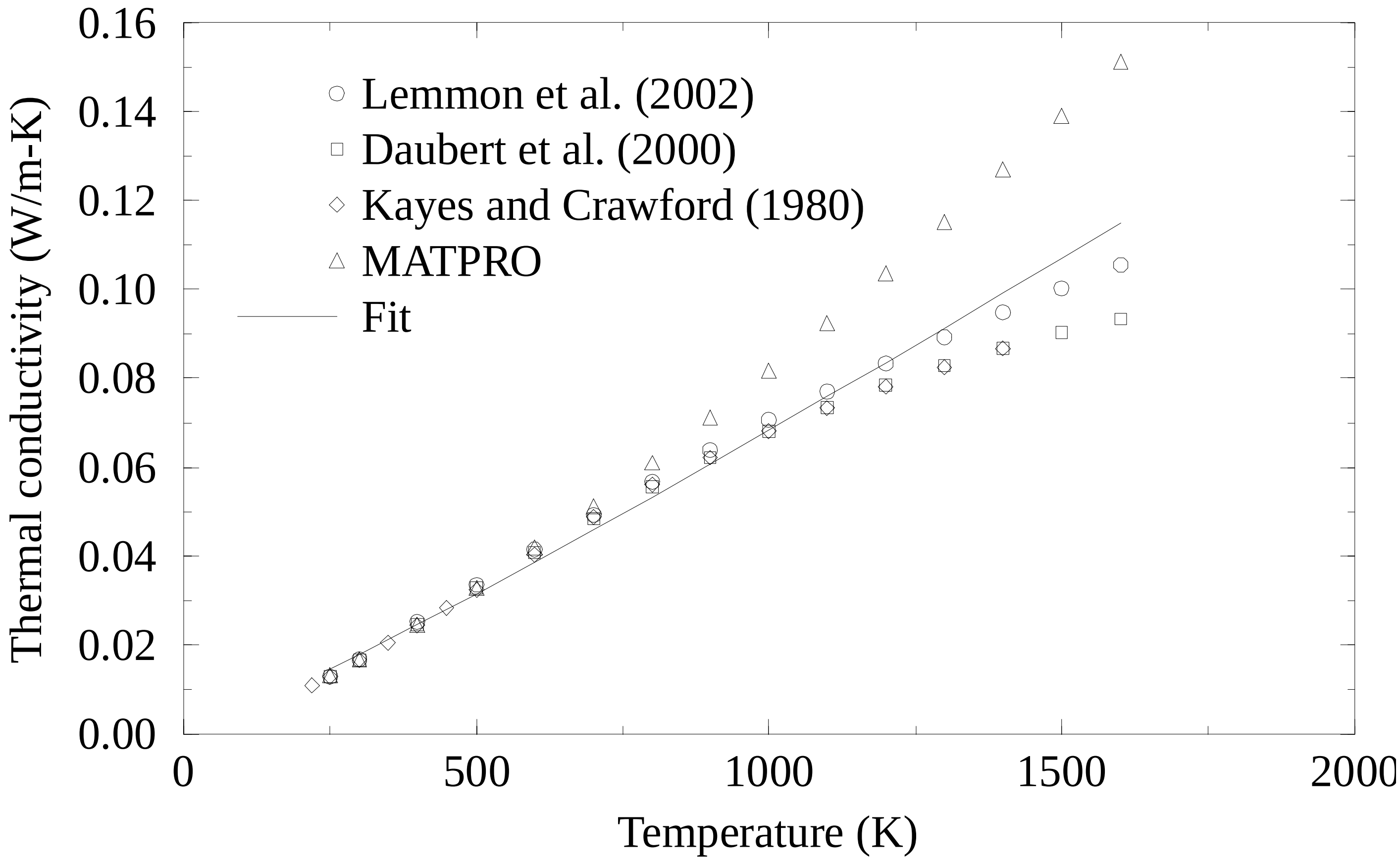
- *The same functional form was used as for the existing species*
  - *Coefficients were determined by least squares fits to the data presented by Lemmon et al. (2002)*

The new fits represent the thermal conductivity data reasonably well



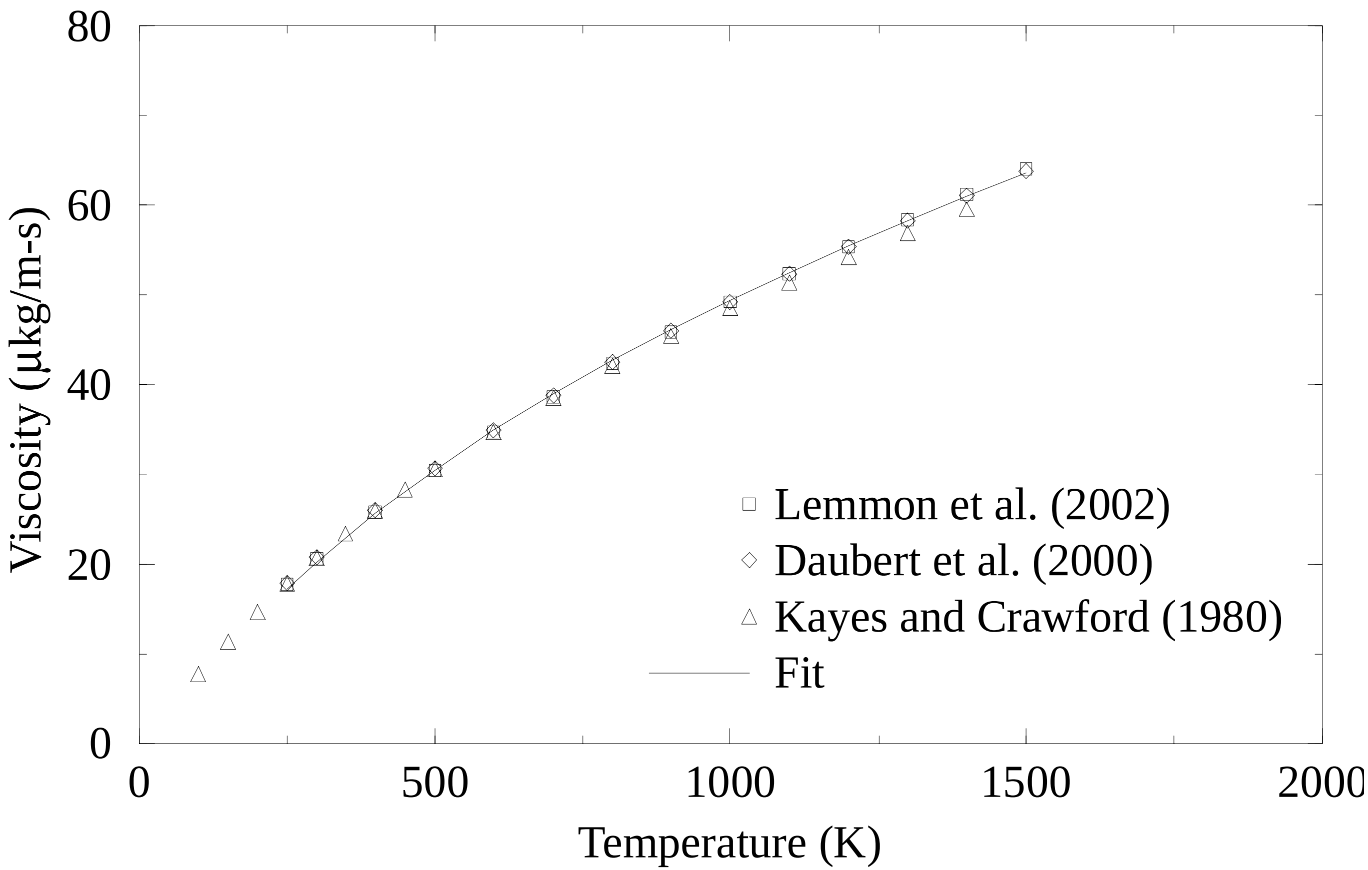
- O_2

The new fits represent the thermal conductivity data reasonably well



- CO_2

The new fits represent the viscosity data reasonably well



- O_2

Diffusion parameters were also implemented for the new species

- *The presence of a noncondensable gas can significantly affect the heat transfer coefficient during condensation*
- *Binary diffusion coefficients were calculated using the same method as for the existing noncondensable gases*
  - *The coefficients apply to diffusion of a steam/noncondensable mixture to the surface of a water film*

Conclusions

- *The code's original (quadratic) noncondensable gas model was not adequate for the new gas species at high temperatures*
- *A fourth order polynomial represented the internal energy well between 250 and 3000 K*
  - *Maximum deviations were 2.2% for internal energy and 7% for C_v*
  - *Maximum deviations occurred at the temperature extremes*

Conclusions (continued)

- *The transport properties were in reasonable agreement*
  - *Maximum deviations were less than 4% for O_2 and CO and less than 12% for CO_2*
- *The correlations for the original noncondensable gases could be improved using the new fourth order polynomial*