

Investigation of the thermophysical properties of binary system CO₂ and Hydro-fluoro-olefins

P.-A Artola, B. Rousseau, R Fauve, C. Houriez, E. El Ahmar, C Coquelet

► **To cite this version:**

P.-A Artola, B. Rousseau, R Fauve, C. Houriez, E. El Ahmar, et al.. Investigation of the thermophysical properties of binary system CO₂ and Hydro-fluoro-olefins. ESAT 2017, May 2017, Bucarest, Romania. <hal-01633874>

HAL Id: hal-01633874

<https://hal-mines-paristech.archives-ouvertes.fr/hal-01633874>

Submitted on 13 Nov 2017

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Investigation of the thermophysical properties of binary system CO₂ and Hydro-fluoro-olefins

P.-A. Artola¹, B. Rousseau¹, R. Fauve^{1,2}, C. Houriez², E. El Ahmar², C. Coquelet²

¹Laboratoire de Chimie Physique UMR 8000 CNRS, Bâtiment 349, Université Paris Sud, 91405 Orsay, France
²MINES ParisTech, PSL - Research University, CTP - Centre for Thermodynamics of Processes, 35 rue Saint Honoré, 77300 Fontainebleau, France

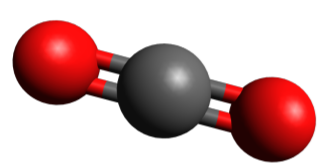


Introduction

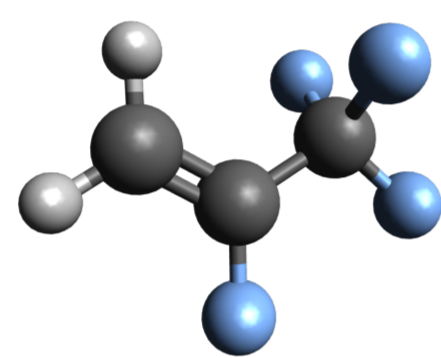
- In the context of reduction of global greenhouse gas emissions, the development and study of refrigerants with low Global Warming Potential (GWP) is crucial. Fluorinated gases are currently considered as promising low-GWP refrigerants. These compounds are used as pure or as components of refrigerant blends. The knowledge of their thermophysical properties is of great importance in the design and optimization process of air-conditioning and refrigeration systems.
- In the following, we illustrate how molecular simulations are used to predict relevant properties for refrigerants fluid mixtures. The studies are applied to the mixture CO₂+CH₂CFCl₃ (R1234yf). Equilibrium properties, including liquid-vapour equilibrium, phase density, enthalpy of vaporization, enthalpy of mixing, specific heat, are obtained using Monte Carlo simulations. Transport properties (viscosity and thermal conductivity) are predicted by means of molecular simulation techniques.

Molecular Simulations

► Systems studied



Carbon dioxide



2,3,3,3 tetrafluoropropene (R1234yf)

► Force fields

- CO₂: TraPPE model¹. All atom model, rigid molecule, multipole described with partial charges
- R1234yf: Raabe model². All atom model, flexible molecule, multipole described with partial charges

► Monte Carlo simulations

- Gibbs code (CNRS-UPSud/IFPEN)^{3,4}
- ELV: Gibbs ensemble⁵ at constant pressure⁶

► Molecular Dynamics simulations

- Newton code (CNRS-UPSud)⁷
- Viscosity: equilibrium molecular dynamics and Green-Kubo relationship
- Thermal conductivity: non equilibrium Heat Exchange Algorithm⁸

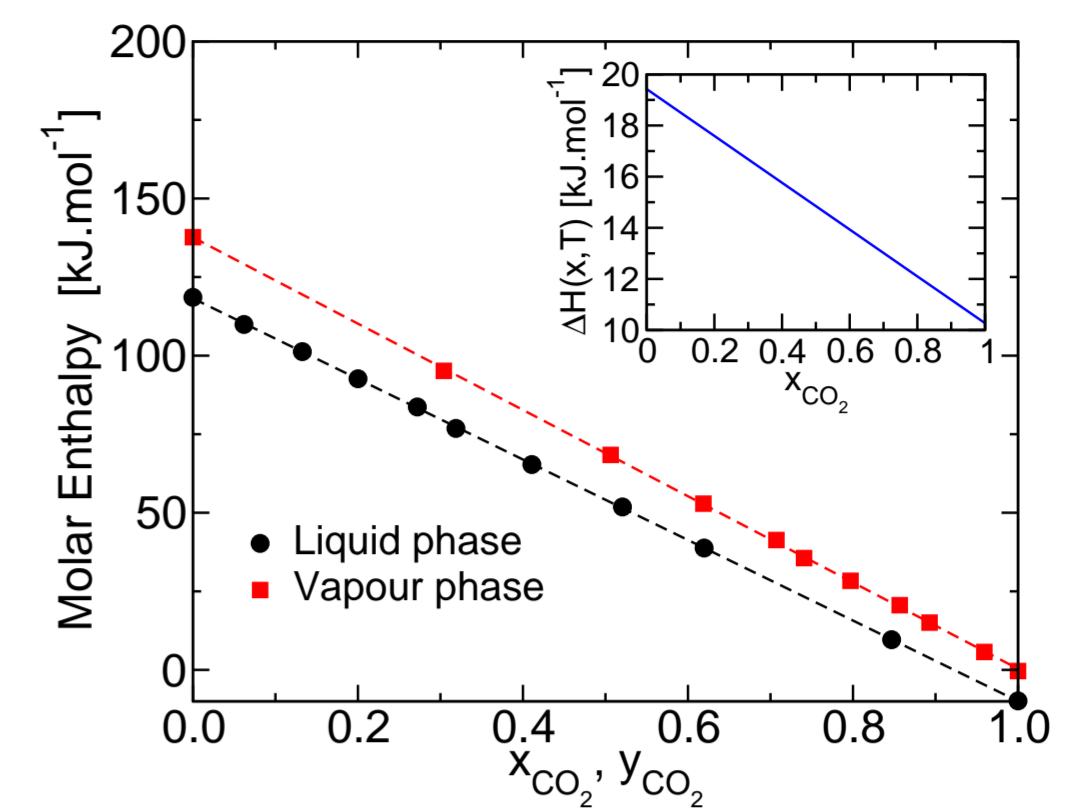
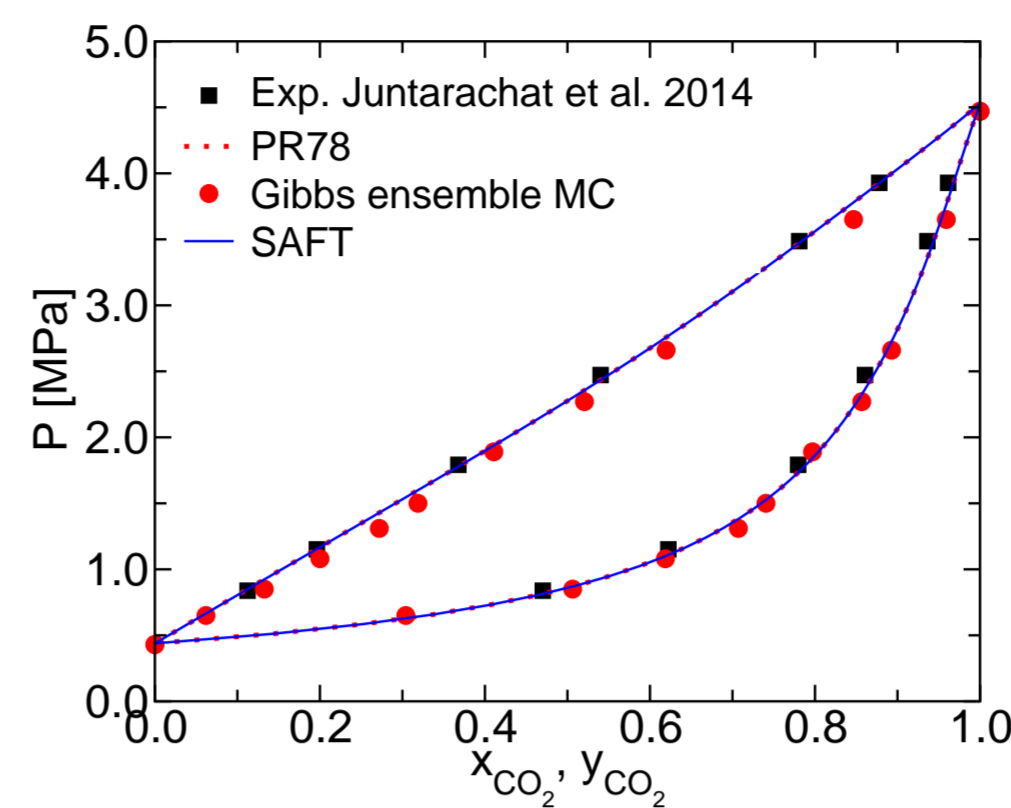
Conclusion

- Molecular simulation is able to predict several thermophysical properties for the CO₂-R1234yf mixture
- New *numerical data* have been produced for thermal conductivity. Predicted values show a reasonable agreement with RefProp data for pur components.
- The full set of data can be used to compute quantities of interest for applications in cooling and heating devices such as the Prandtl number ($C_p\eta/\lambda$)

References

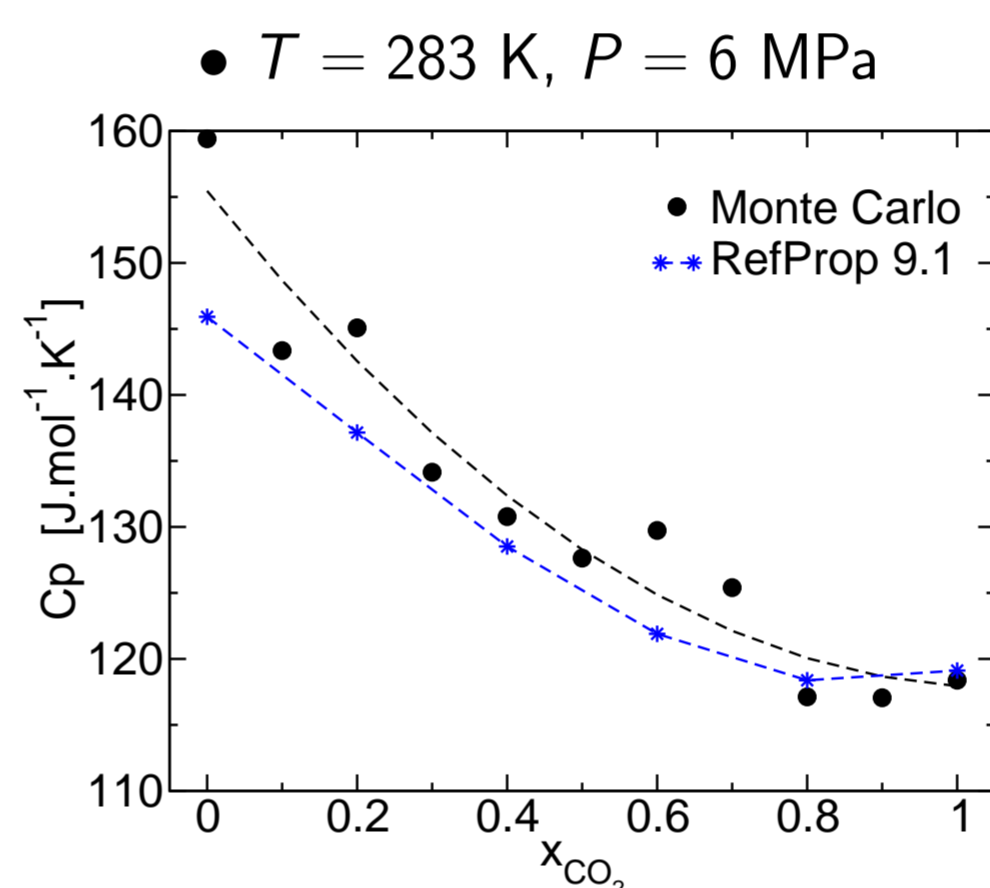
- [1] Potoff, J. J.; Siepmann, J. I. *AIChE Journal* **2001**, *47*, 1676–1682.
- [2] Raabe, G.; Maginn, E. J. *The Journal of Physical Chemistry B* **2010**, *114*, 10133–10142.
- [3] Ungerer, P.; Tavitiyan, B.; Boutin, A. *Applications of molecular simulation in the oil and gas industry: Monte Carlo methods*; Editions Technip, 2005.
- [4] Medea@ Gibbs - Materials Design Web Page, <http://www.materialsdesign.com/medea/gibbs>.
- [5] Panagiotopoulos, A. Z. *Molecular Physics* **1987**, *61*, 813–826.
- [6] Panagiotopoulos, A.; Quirke, N.; Stapleton, M.; Tildesley, D. *Molecular Physics* **1988**, *63*, 527–545.
- [7] Van-Oanh, N.-T.; Houriez, C.; Rousseau, B. *Phys. Chem. Chem. Phys.* **2010**, *12*, 930–936.
- [8] Hafskjold, B.; Ikeshoji, T.; Ratkje, S. *Molecular Physics* **1993**, *80*, 1389–1412.
- [9] Juntarachat, N.; Valtz, A.; Coquelet, C.; Privat, R.; Jaubert, J.-N. *International Journal of Refrigeration* **2014**, *47*, 141–152.
- [10] Artola, P.; Rousseau, B.; Jaubert, J.; Paricaud, P.; Chapoy, A.; Coulier, Y.; Coxam, J. Y.; Bouteiller, P.; Tobaly, P.; Masella, M.; Houriez, C.; Coquelet, C. Investigation of the thermophysical properties of binary system R744 + R1234yf. TPTPR2017 - 5th IIR International Conference on Thermophysical Properties and Transfer Processes of Refrigerants, April 23-26, Seoul, South Korea, 2017.
- [11] Lagache, M.; Ungerer, P.; Boutin, A.; Fuchs, A. H. *Physical Chemistry Chemical Physics* **2001**, *3*, 4333–4339.
- [12] Kano, Y.; Kayukawa, Y.; Fujii, K.; Sato, H. *International Journal of Thermophysics* **2010**, *31*, 2051–2058.
- [13] Daisvis, P. J.; Evans, D. J. *The Journal of Chemical Physics* **1994**, *100*, 541–547.

Liquid-vapour equilibrium



ELV curve (left) at 283 K including experimental data⁹, PR78 correlation (with adjustable k_{ij}), Multipolar SAFT-Mie (courtesy P. Paricaud, ENSTA ParisTech, Univ. Paris-Saclay)¹⁰ and GIBBS predictions. Enthalpy of liquid and gas phases along the bubble and dew curves (right). Inset: enthalpy difference versus composition.

Specific Heat



► Specific heat at constant pressure

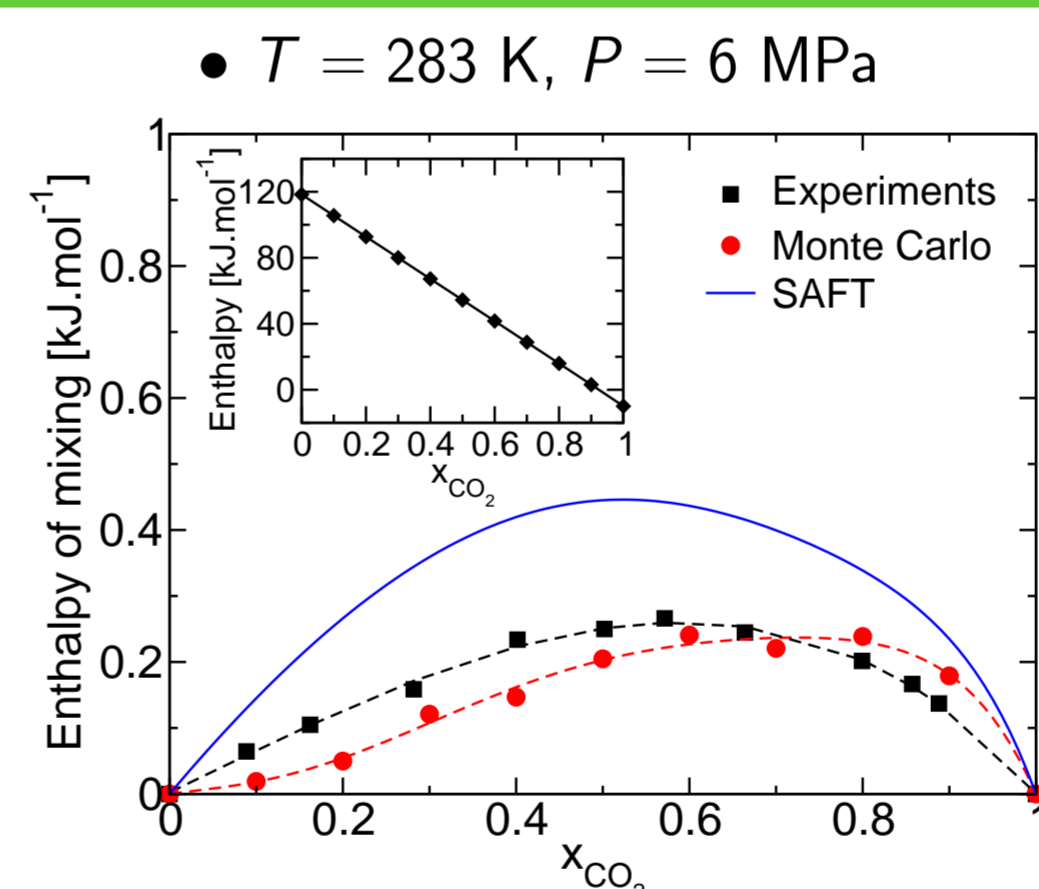
$$C_p(P, T) = C_p^{id}(T) + C_p^{res}(P, T)$$

► C_p^{res} from fluctuations in NpT ensemble¹¹

$$C_p^{res}(P, T) = \frac{1}{k_B T^2} \left(\langle U_{ex} \hat{H} \rangle - \langle U_{ex} \rangle \langle \hat{H} \rangle \right) + \frac{P}{k_B T^2} \left(\langle V \hat{H} \rangle - \langle V \rangle \langle \hat{H} \rangle \right) - Nk_B$$

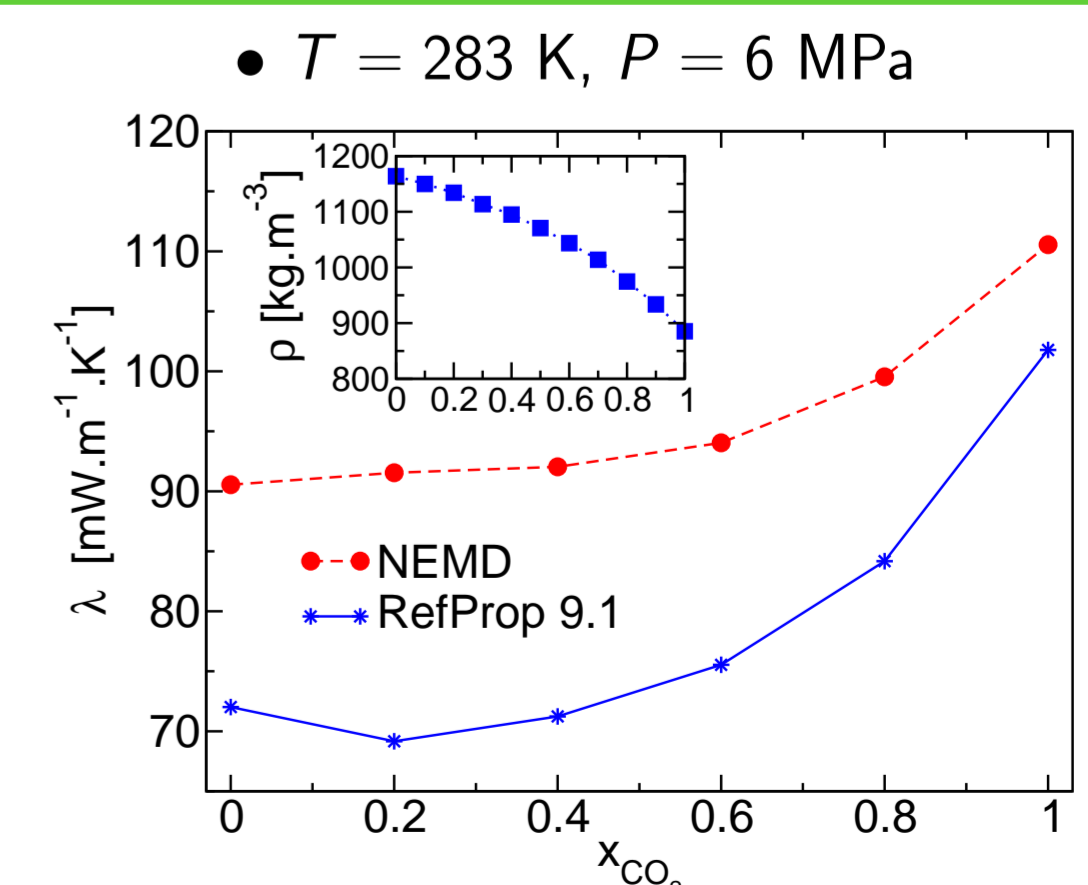
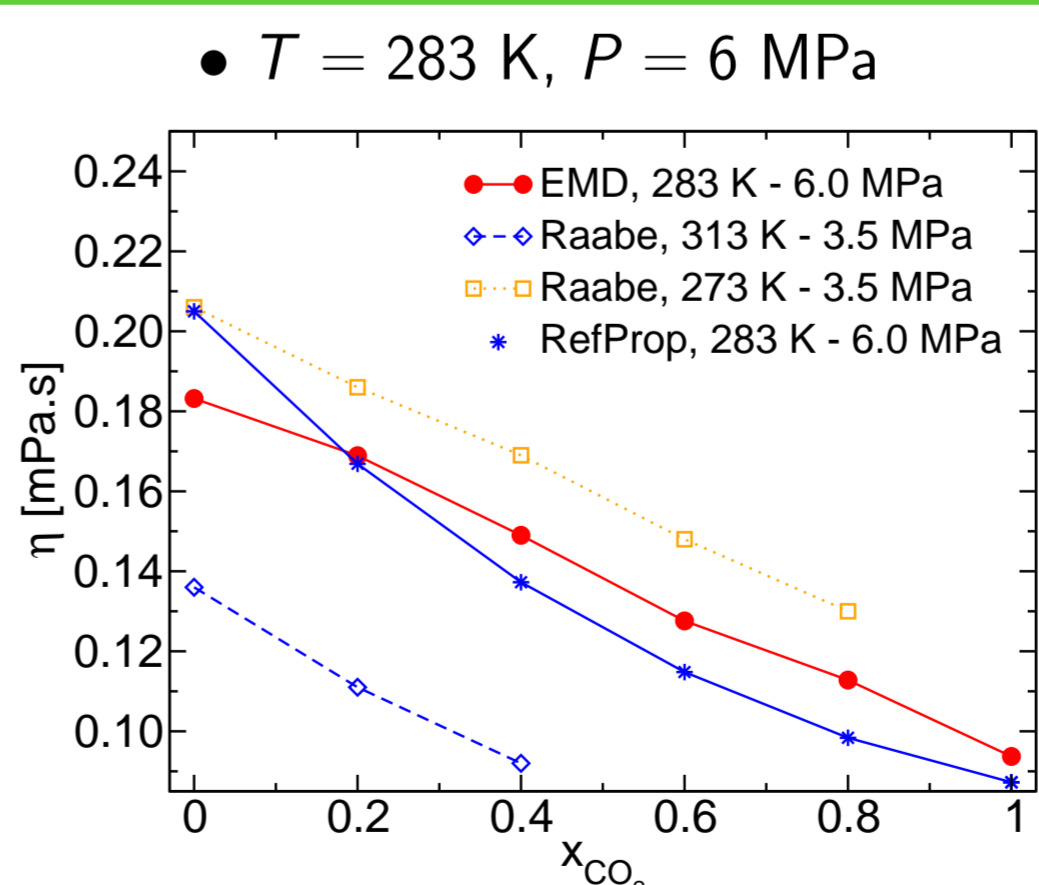
► $C_p^{id}(T)$ from NIST (CO₂) and Kato et al.¹² (R1234yf) using speed of sound measurements

Mixing enthalpy



- Experimental data obtained using a customized BT2-15 calorimeter from Setaram, courtesy J.Y. Coxam (Univ. Blaise Pascal, Clermont-Ferrand)¹⁰
- SAFT model: Multipolar SAFT-Mie model, courtesy P. Paricaud (ENSTA ParisTech, Univ. Paris Saclay)¹⁰
- Monte Carlo simulations in the NpT ensemble

Transport properties



$$\eta = \frac{V}{10k_B T} \int_0^\infty \langle \sigma(t) \cdot \sigma(0) \rangle_{NVT}$$

with¹³

$$\sigma = \left(\sigma_{xx}, \sigma_{yy}, \sigma_{zz}, \sqrt{2}\sigma_{xy}, \sqrt{2}\sigma_{xz}, \sqrt{2}\sigma_{yz} \right)$$

$$\lambda = -\frac{J_{q,z}}{\nabla T} = -\frac{\Delta K}{L_x L_y \delta t \Delta T} \frac{L_z}{L_x L_y}$$

with ΔK the kinetic energy exchanged between hot and cold boundary layers⁸