First International Conference on ORC Power Systems

Delft, September 23, 2011

SPEED OF SOUND OF

HEXAMETHYLDISILOXANE

AS WORKING FLUIDS FOR ORGANIC RANKINE CYCLES

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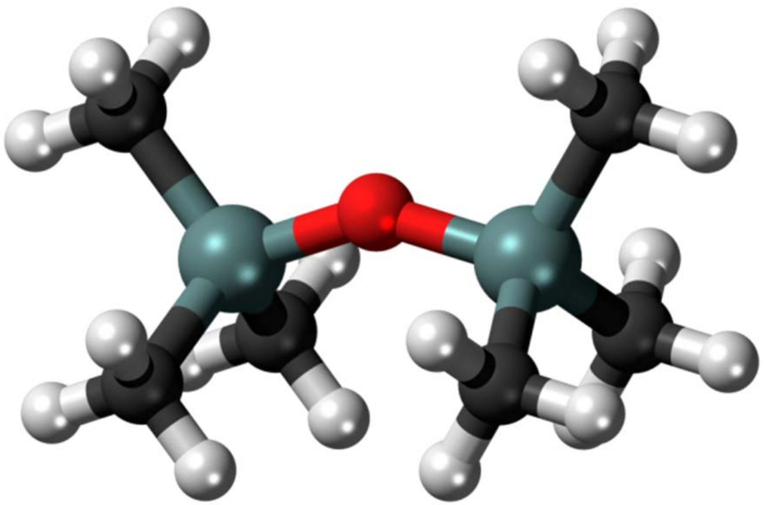
Working fluids for ORC power systems

- Working fluids play an important role for power cycle efficiency
- Design and optimization of power cycles depend on fluid properties
- Siloxanes are appropriate working fluids for ORC plants due to their fluid properties and enviromental safety
- Hexamethlydisiloxane belongs to the wider class of organosilicone compounds



- Several ORC suppliers employ Hexamethyldisiloxane (MM)

Lack of accurate fluid property data for siloxanes may lead to sub-optimally designed ORC power cycles, reducing their efficiency

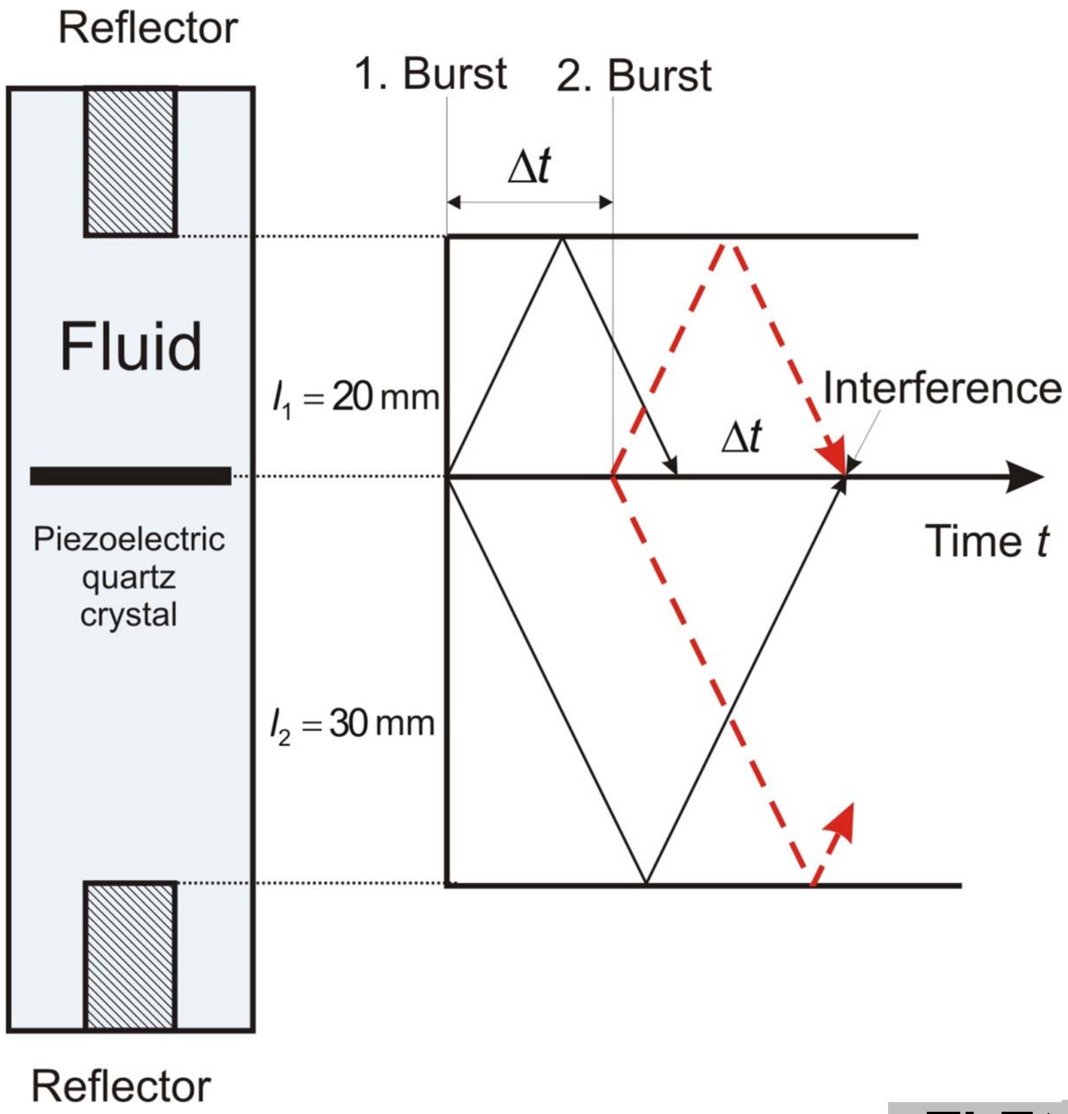
Speed of sound – measurement principle

$$c = \sqrt{\left(\frac{\partial p}{\partial \rho}\right)_s}$$

- Puls-echo technique
- Speed of sound is determined from propagation distance Δl and propagation time Δt

$$c = \frac{2\Delta l}{\Delta t}$$

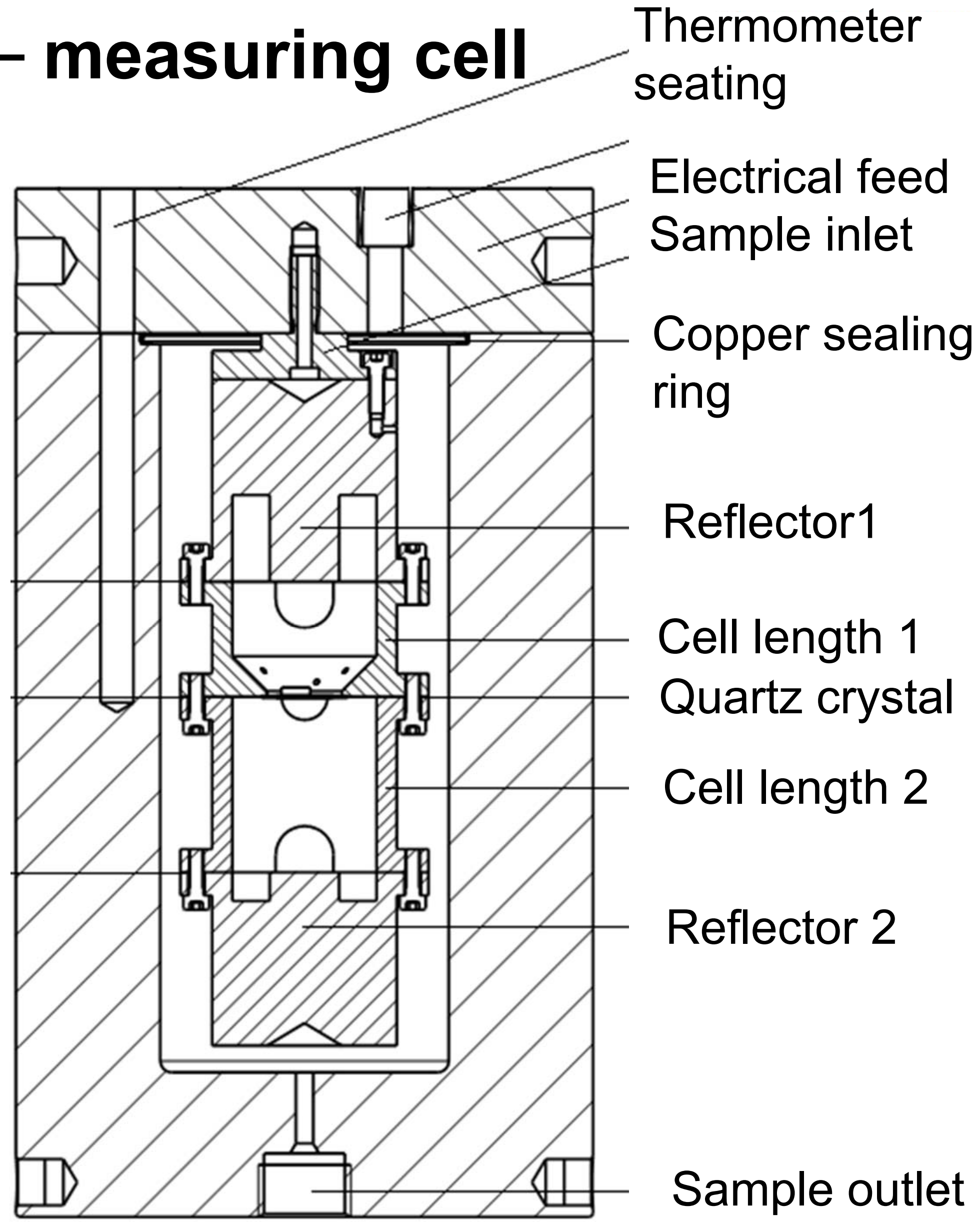
- Interference approach (Muringer et al. 1985)



Speed of sound – measuring cell

- Cell is made of stainless steel (1.4571)
  - good surface characteristics
  - well known thermal expansion coefficient
- Cell reflectors are polished

- Cell is enclosed in stainless steel cylinder and operates up to 180 MPa



Speed of sound – measuring apparatus

- Cell is embedded in a double copper thermostat which was isolated under vacuum conditions
- 4 layers of aluminum foil minimize thermal radiation losses
- PID controls cell temperature within 2 mK
- Electrical heating system operates up to 650 K

Construction by Gedanitz

Calibration and uncertainties

- Calibration of propagation distance as a function of thermal expansion coefficient was calibrated with purified water, based on the EOS by Wagner and Pruss, 2002 (IAPWS)
- Successfully tested on water, acetone and hexadecane
- Pressure sensor calibrated by deadweight tester up to 15 MPa
- Thermometers (PT 100) were calibrated up to 425 K (extrapolated to 650 K)
- Uncertainty is around 0.3%
- Intended operation range T = 270… 650 K, p = 0…180 MPa
- Hexamethyldisiloxane (MM), CAS-No: 107-46-0 (Merck purity ≥ 99%); degased in ultrasonic bath under vacuum

Fundamental EOS by Colonna et al., 2006

Massieu-Planck energy ϕ T = 300 … 500 K, p = 0 … 15 MPa

$$\frac{F}{R \cdot T} = \phi(\tau,\delta) = \phi^0(\tau,\delta) + \phi^{res}(\tau,\delta)$$

$$\tau = T_C / T \qquad \delta = \rho / \rho_c$$

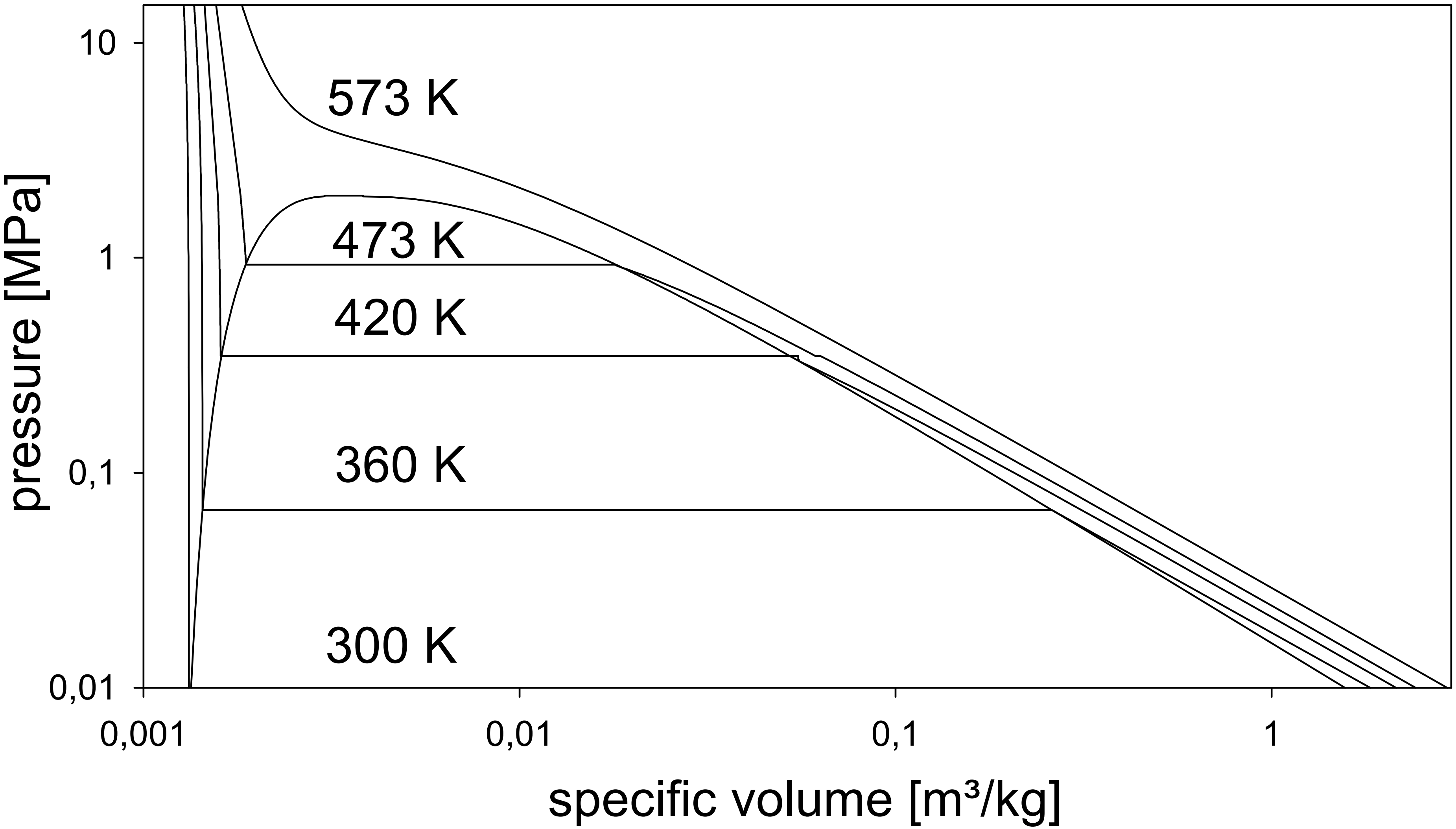
Ideal part
$$\phi^0 = \ln\delta + c_\tau \ln\tau + \sum_{i=1}^{5} c_i \tau^{2-i}$$

Residual part
$$\phi^{res} = \sum_{i=1}^{6} a_i \tau^{t_i} \delta^{d_i} + \sum_{i=7}^{12} a_i \tau^{t_i} \delta^{d_i} \exp(-\delta^{e_i})$$

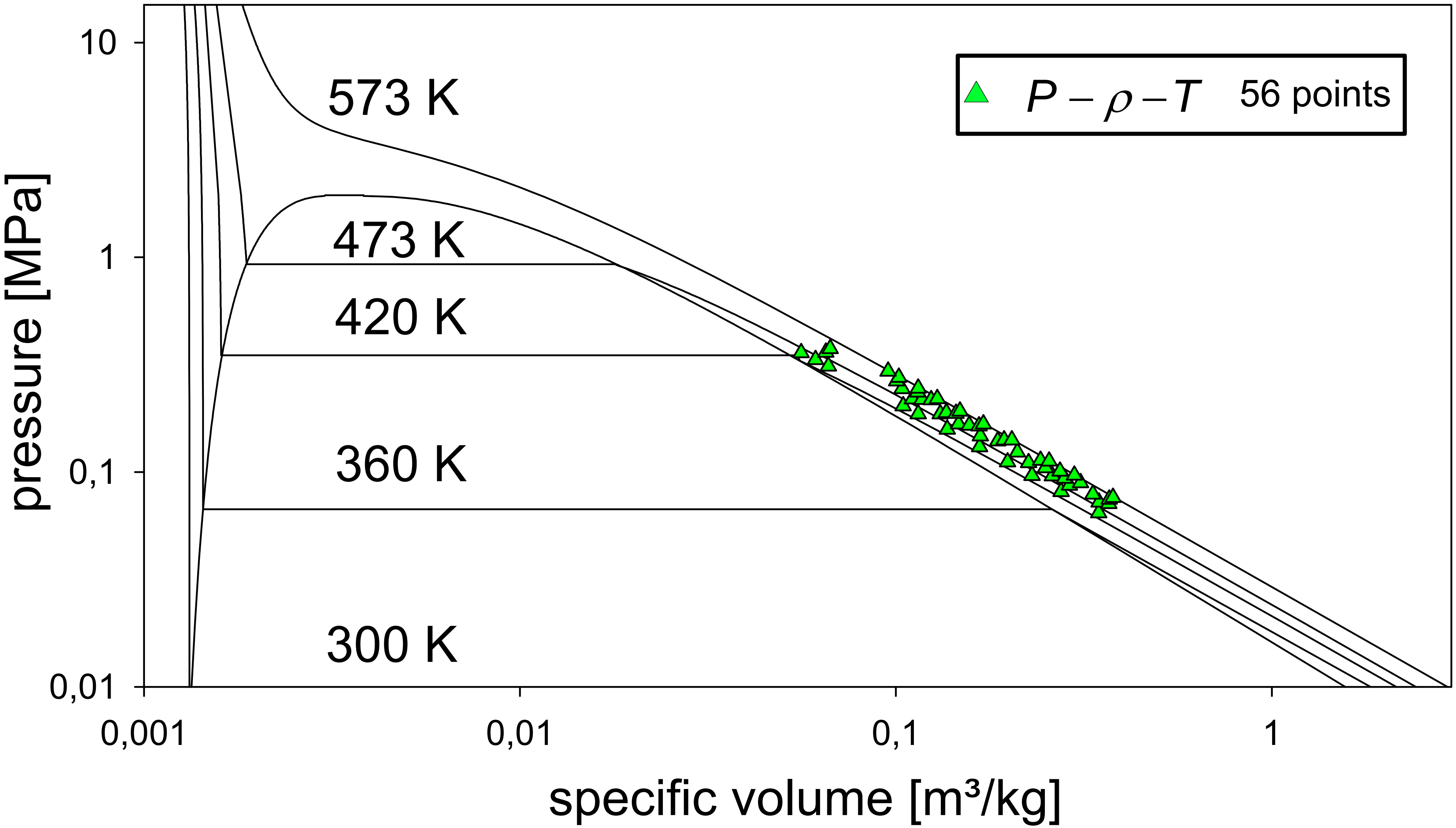
Total:
18 Parameters
14 Stat. mech. data (Ideal)
99 Exp. data (Residual)

Due to the fundamental formulation, all (static) thermodynamic properties are accesible by derivation

EOS by Colonna et al.



Adjustment of EOS by Colonna et al.



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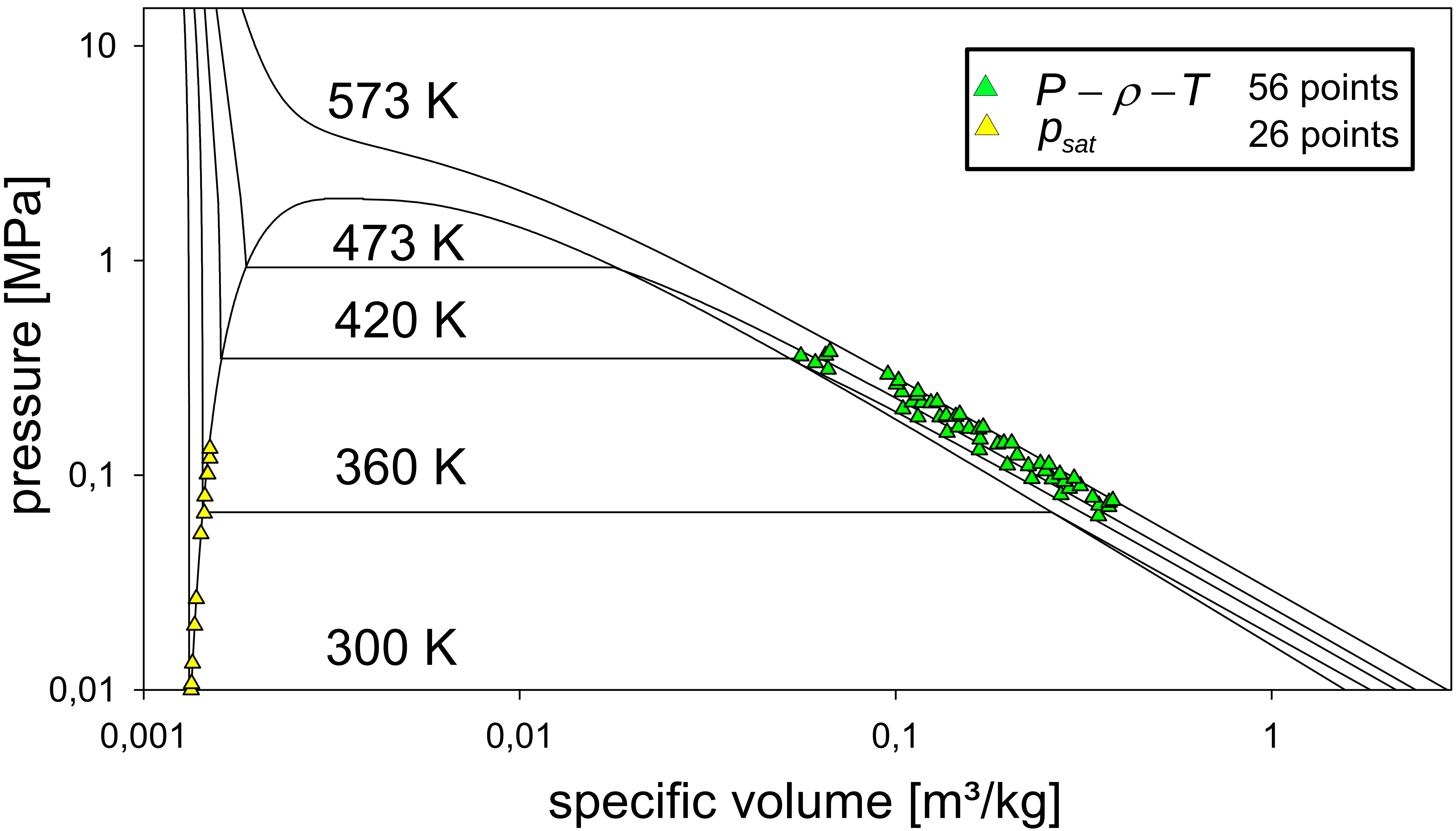

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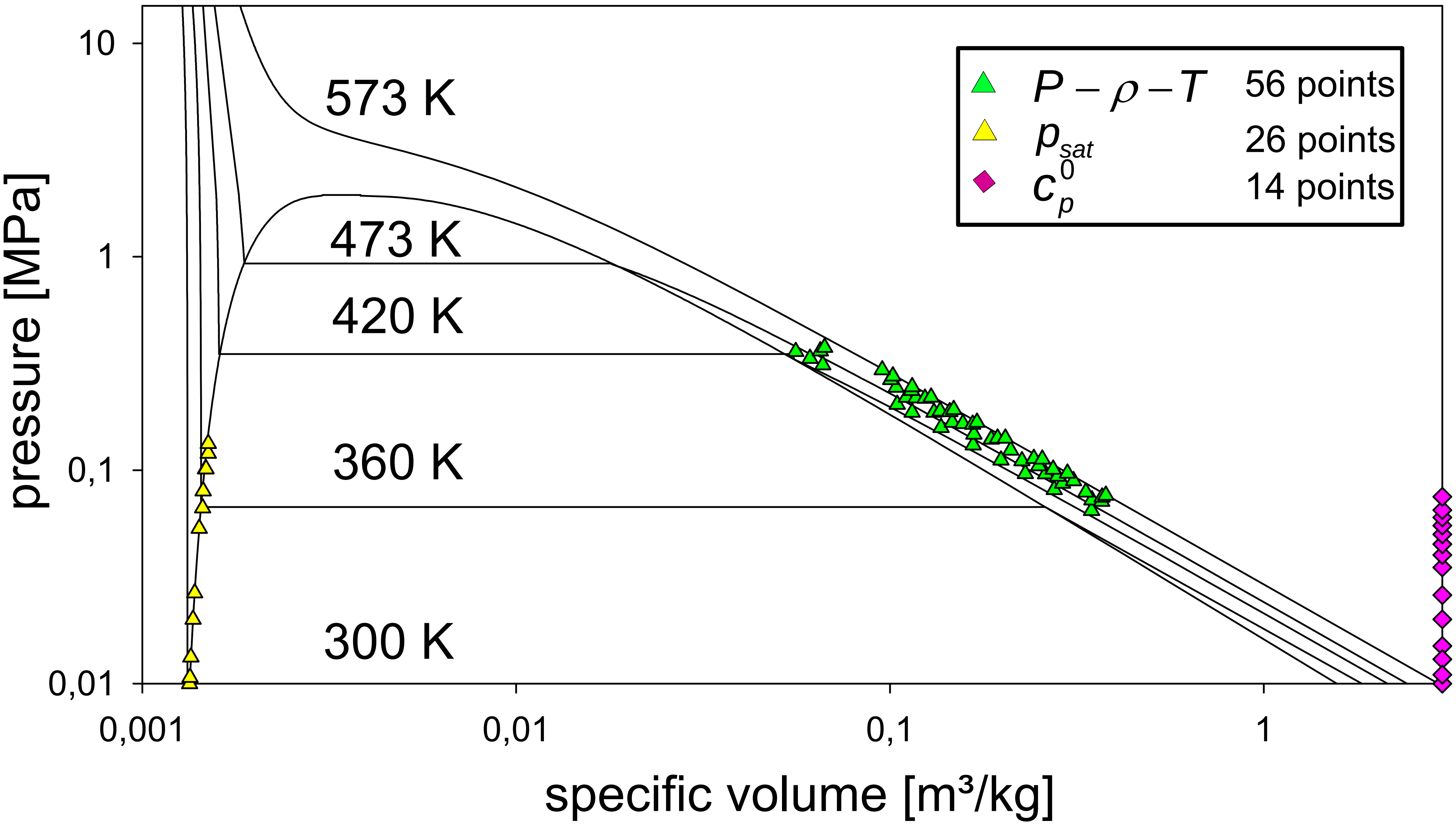

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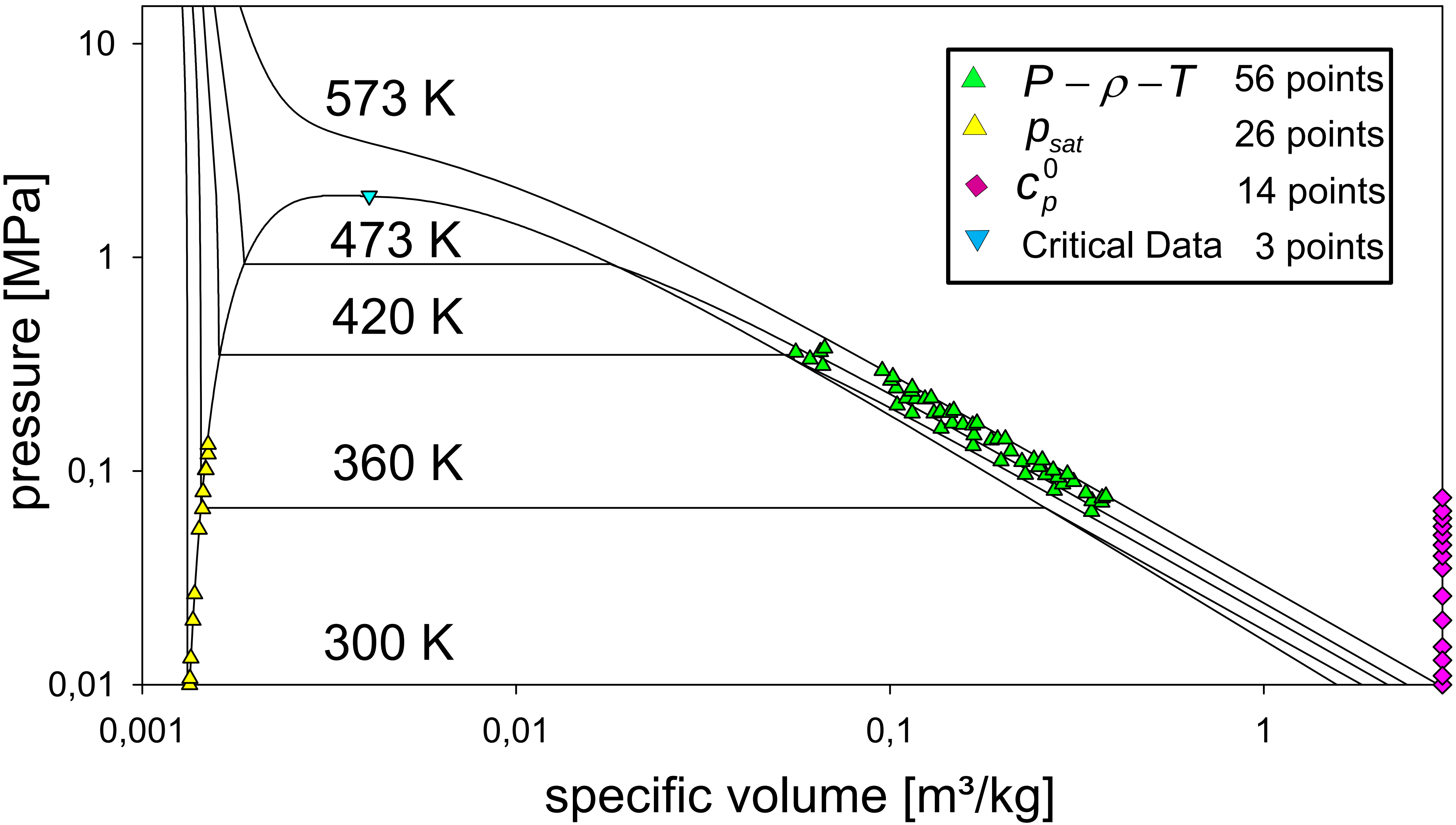

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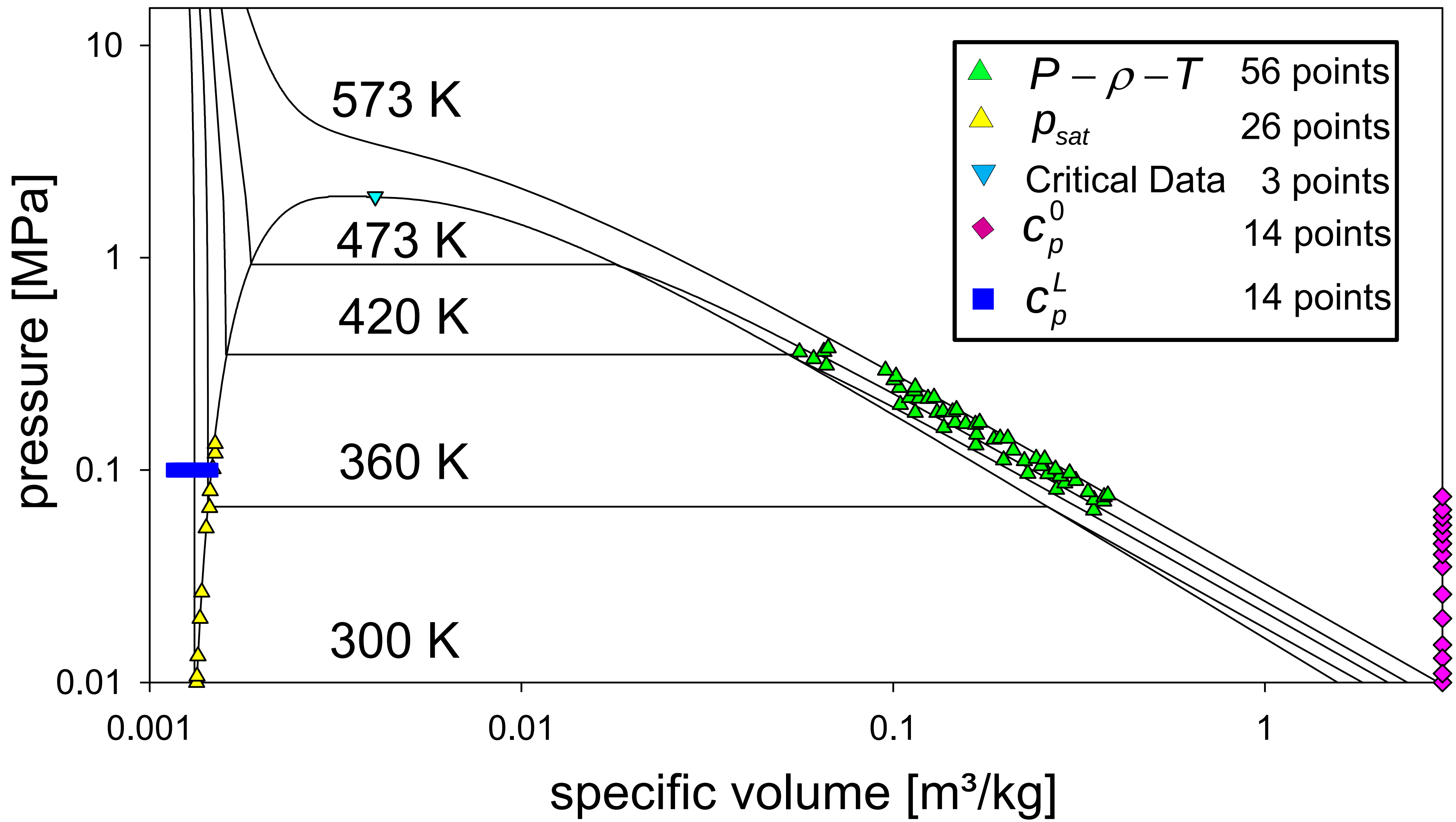
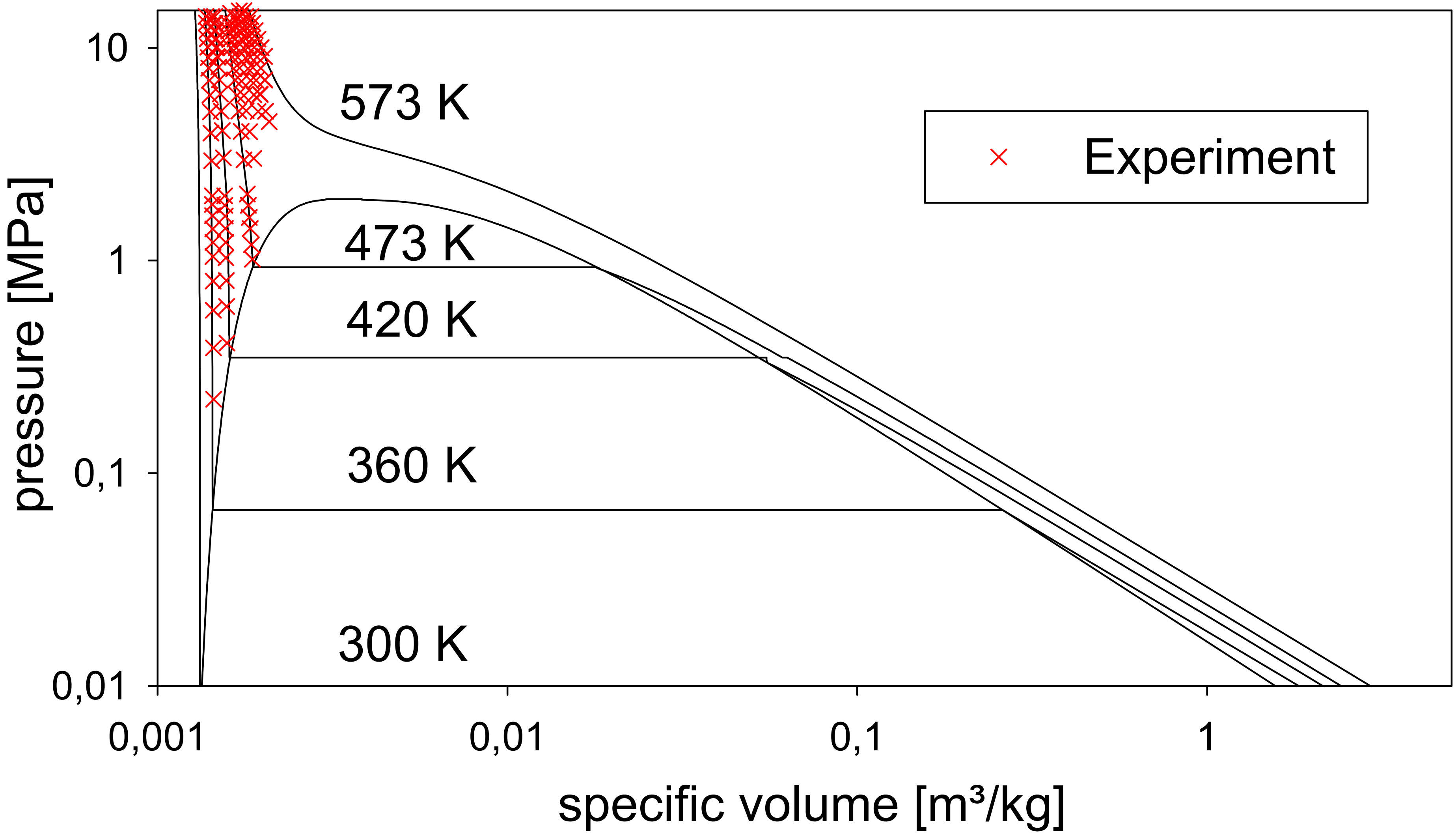
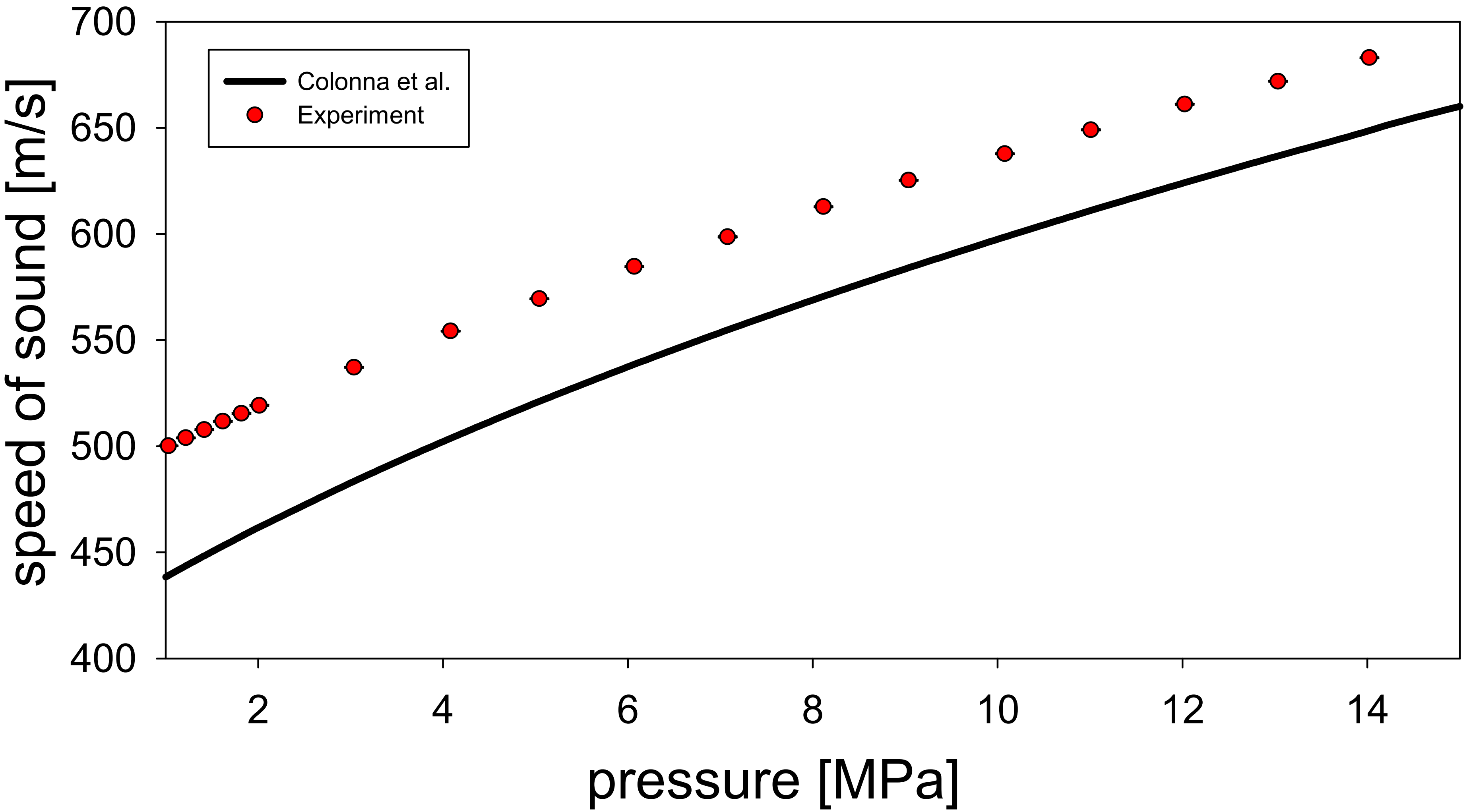


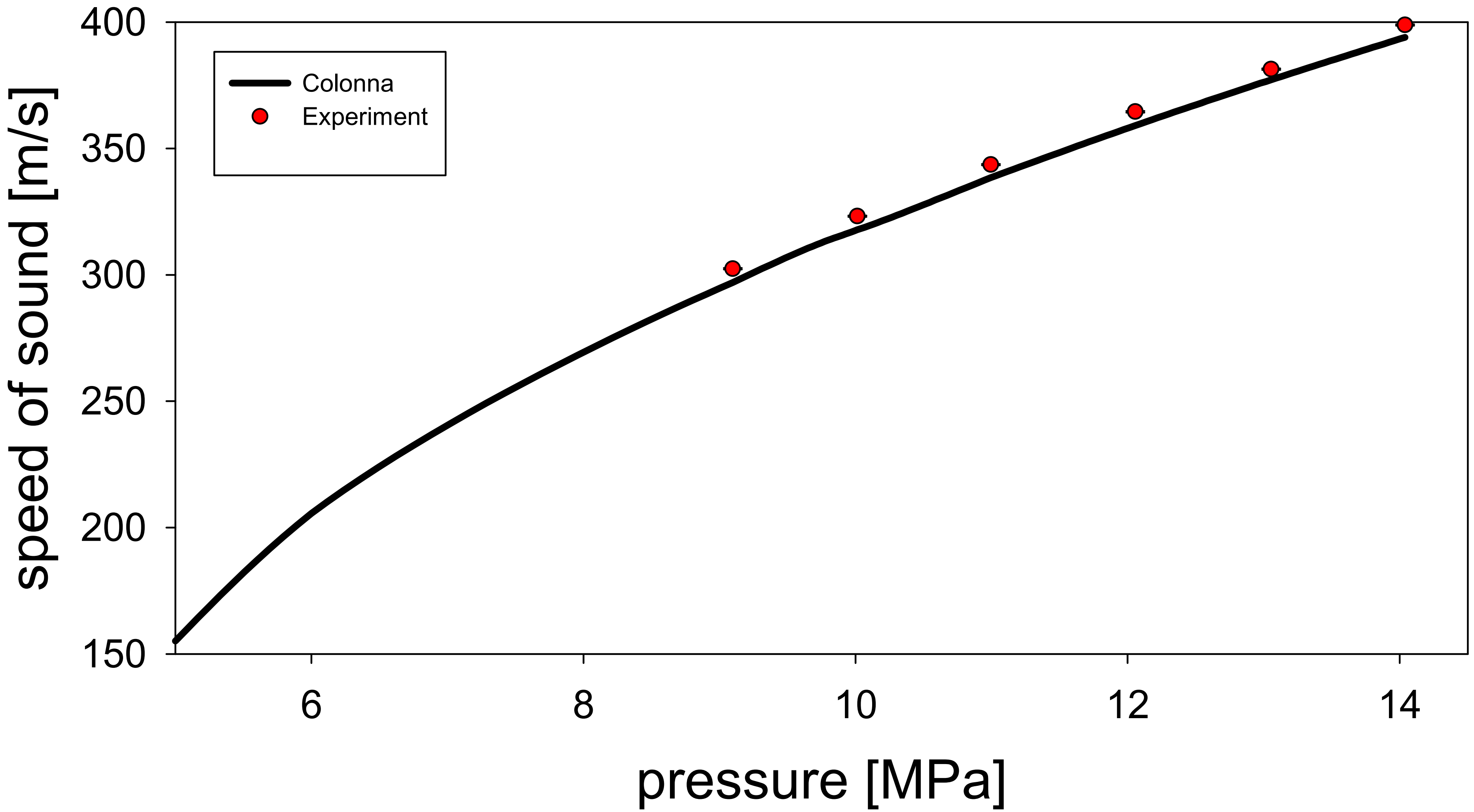
Range of present experiments



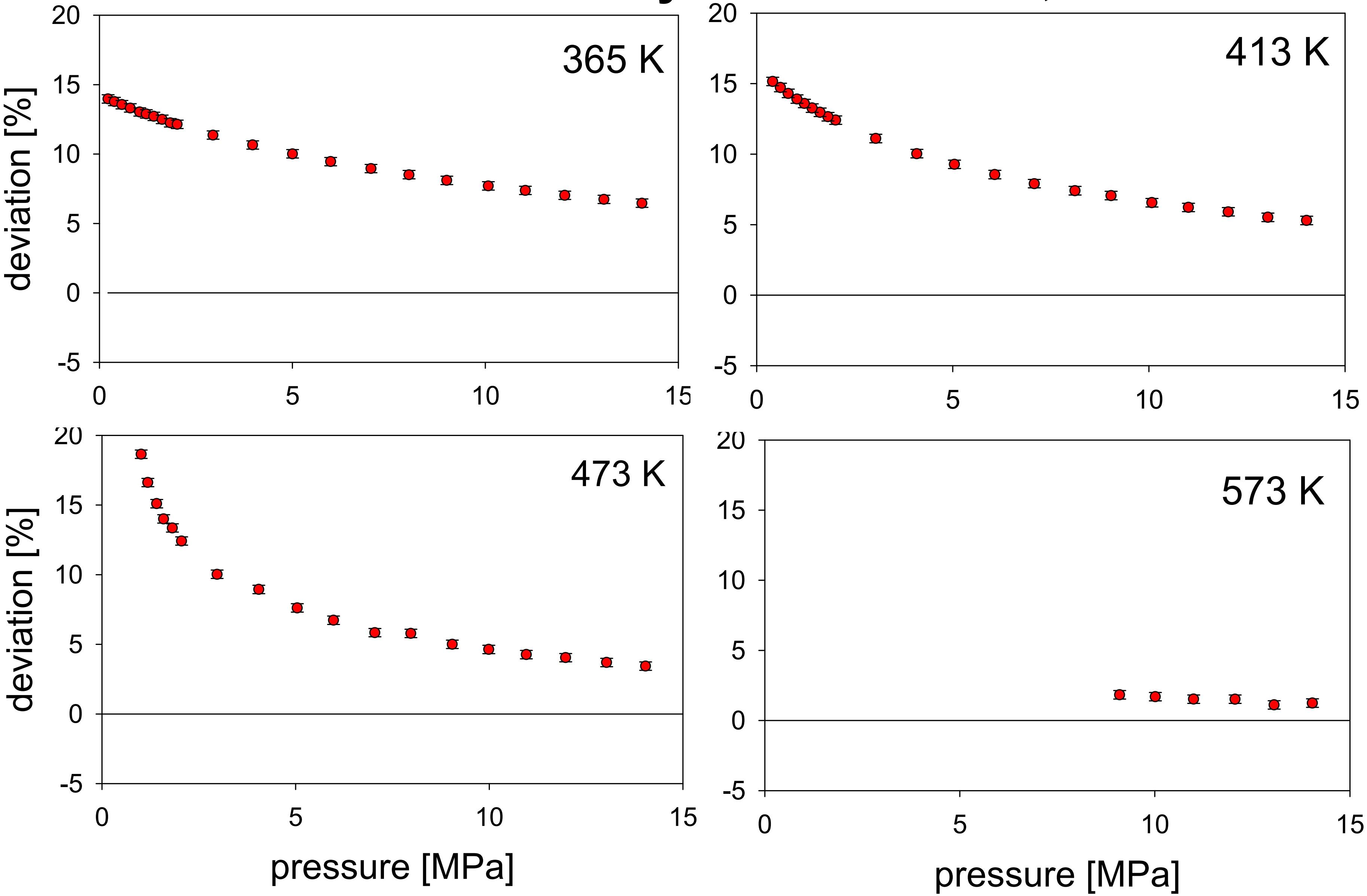
Experimental results at 413 K



Experimental results at 573 K



Deviations to EOS by Colonna et al., 2006



Conclusion

- The measurement of the speed of sound is an efficient route to gather thermodynamic data on the fluid behavior
- Such data are useful for the development of EOS
- Even for well known fluids such as MM, EOS can misrepresent their thermodynamic properties
- Significant effort has to be invested in measurements and reliable predictive methods of thermodynamic properties