Calibration laws of near-critical fluid

Thermal gravity-driven convection in steady gravity field is characterised by the Rayleigh number Ra and the Prandtl number $\Pr$. If the body force varies quickly or a cavity containing fluid oscillates, convection of vibrational type is induced. This motion can be described by the vibrational Rayleigh number Rv (ω' and A' are the frequency and the amplitude of oscillations) defined as

$$Rv = \frac{1}{2}\left(\frac{A'\omega'\Theta'\rho'_c l'}{T'_c}\right)^2 \frac{c'_{v0}+B'}{\eta'_0\lambda'_0}$$

Near-critical features are associated with the temperature distance from the critical point (or reduced temperature) $\varepsilon = (T'-T'_c)/T'_c$. It is known that with approach to the critical point, the criteria of similarity tend to infinity, while the values of Ra, $\Pr$ and Rv (for vibrational convection) in the governing equations don't change. To describe the near-critical dynamics completely the criteria of similarity based on the real physical properties near the critical point are introduced. They are signed by subscript "r" and defined by the following relations (critical isochore is considered). These relations are named as

Calibration laws

$$Ra_r = \frac{2}{3}\varepsilon^{-1}\left(\frac{1}{\gamma_0}+\frac{\gamma_0-1}{\gamma_0}\frac{1+\varepsilon}{\varepsilon}\right)\frac{1}{\lambda}Ra$$

$$\Pr_r = \left(\frac{1}{\gamma_0}+\frac{\gamma_0-1}{\gamma_0}\frac{1+\varepsilon}{\varepsilon}\right)\frac{1}{\lambda}\Pr$$

$$Rv_r = \frac{4}{9}\varepsilon^{-2}\left(\frac{1}{\gamma_0}+\frac{\gamma_0-1}{\gamma_0}\frac{1+\varepsilon}{\varepsilon}\right)\frac{1}{\lambda}Rv$$

The calibration laws allow to reveal some analogy in dynamics and heat transfer of near-critical fluid and perfect gas. According to these laws near-critical convection described by the numbers Ra, $\Pr$ and Rv in the governing equations is associated with convection of perfect gas described by enlarged values Ra_r, $\Pr_r$, Rv_r. At the present time the field of application of the calibration laws is estimated.

The coefficient of thermal conductivity λ tends to infinity when $\varepsilon \to 0$ (temperature approaches to critical) and may be fitted by the relation $\lambda = 1 + \Lambda\varepsilon^{-\Psi}$. In the near-critical region with $\varepsilon \to 0$, the "real" criteria of similarity strongly increase and asymptotically diverge: $Ra_r \sim \varepsilon^{\Psi-2} \to \infty$, $\Pr_r \sim \varepsilon^{\Psi-1} \to \infty$, $Rv_r \sim \varepsilon^{\Psi-3} \to \infty$ ($\psi < 1$).

See [7, 12, 16] in PUBLICATIONS

Back