Thermophoretic Force

The presence of temperature gradient imposes thermophoretic force on the particle, which is given as

$$\underline{F}_t = -\frac{8}{15} d^2 \frac{\kappa^f}{\overline{|v^{f\,\prime}|}} \nabla T \exp\{-\frac{\hat{\theta} d}{2\lambda}\}, \quad \text{for} \quad 0.25 \le K_n \le \infty, \; M << 1. \tag{1}$$

where $\bar{c}^f = \overline{|v^{f\,\prime}|}$ is the mean thermal speed of the gas and

$$\hat{\theta} = 0.9 + 0.12\alpha_m + 0.21\alpha_m (1 - \frac{\alpha_t \kappa^f}{2\kappa^p}), \tag{2}$$

$$\bar{c}^f = \overline{|v^{f\,\prime}|} = (\frac{8kT}{\pi m^f})^{1/2}, \tag{3}$$

for monatomic gases. Here α_m and α_t are the momentum and thermal accommodation coefficients and κ^f and κ^p are the thermal conductivity of gas and the particle.

The accommodation coefficients vary between zero and infinity. For mono-atomic gases, $\alpha_t \approx \alpha_m$. Typical values are listed in Table 1.

Table 1. Variations of momentum and thermal accommodation factors.

System	α_m	α_t
Air on Brass	1.00	0.91-0.94
Air on Oil	0.895	
Air on Glass	0.89	
Air on Ag_2O	0.92	

For the continuum limit, the thermophoretic force is given as

$$\mathbf{F}_t = \frac{-3\pi\mu d^2 C_{tm} K_n [(\frac{\kappa^f}{\kappa^p} + C_t K_n)(1 + 1.33 C_m \kappa_n) - 1.33 C_m \kappa_n]\nabla T}{(1 + 3C_m \kappa_n)(1 + 2\frac{\kappa^f}{\kappa^p} + 2C_t K_n)}, \quad 0 \le K_n \le 0.2 \tag{4}$$

where

$$C_{tm} = \frac{3\mu}{4\rho^f T\lambda}$$

$$C_t = \hat{P}_t \frac{(2-\alpha_t)}{\alpha_t}, \qquad 1.87 \le \hat{P}_t \le 2.48 \tag{5}$$

$$C_m = \hat{P}_m \frac{(2-\alpha_m)}{\alpha_m} \approx 1.2 \qquad 1 \le \hat{P}_m \le 1.274$$

A simpler expression for thermophoretic force given by

$$\mathbf{F_t} = -\frac{9\pi\mu\nu d}{T_0} \nabla T \left[\frac{1}{2 + \frac{\kappa^p}{\kappa^f}} \right] \quad \text{for} \quad K_n \ge 1 \tag{6}$$

is more commonly used.

Photophoretic Force

The force generated by the electromagnetic radiation is referred to as the photophoretic force. For large K_n (free molecular) flow regimes, the photophoretic force is given by

$$\mathbf{F}_p = \frac{-\pi d^3 p \mathbf{I}}{48\left(\frac{1}{2\rho^f \sqrt{\overline{v^{f\prime 2}}} R + \kappa_p T}\right)}, \; K_n \to \infty, \tag{7}$$

where p is the gas pressure, $\mathbf{I}$ is the radiation flux, and R is the gas constant.

Diffusiophoretic Force

Non-uniformity in the composition of a gas mixture results in a diffusion (diffusiophoretic) force acting on the suspended particle. This force is proportional to the negative of concentration gradient and has a similar form as the thermophoretic force described earlier.