http://www.phy.anl.gov/div/esh/Cryogenic/Appendix%202/appendix%202a.htm

Physics Division

Cryogenic Safety Manual

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APPENDIX 2a: CONVECTIVE HEAT TRANSFER

The convective heat transfer coefficient, h_c, is given by (from Heat Transmission, W. H. McAdams, McGraw-Hill, NY (1942) pp 242-245):

$$\frac{h_c L}{k_f} = \frac{1}{2}\left[\left(\frac{L^3\ \rho_f^2\ g\Delta T}{\mu_f^2 T_f}\right)\left(\frac{C_p \mu_f}{k_f}\right)\right]^{0.25}$$

or

$$h_c = \frac{1}{2}\left[\frac{k_f^3 \rho_f^2 g C_p}{\mu_f T_f}\right]^{0.25}\left(\frac{\Delta T}{L}\right)^{0.25} \quad \text{Watt/cm}^2\ \text{K}$$

where k = thermal conductivity, ρ = density, C_p = specific heat, μ = viscosity, g = gravitational acceleration. Note that CGS units are used.

The subscript f means the quantities are to be evaluated at the "gas film" temperature, the arithmetic means of the temperature at the surface of the solid, and the temperature of the bulk of the gas.

The quantity L is the characteristic dimension of the system: e.g. diameter of a cylinder, spacing of parallel plates, or the edge length of a plane square. Equation (1) is valid so long as

$$\chi = \left[\frac{L^3\ \rho_f^2\ g\Delta T c_p}{\mu_f T_f k_f}\right] > 10^3$$

The actual heat flow Q is given by:

$$Q = h_c\ \Delta T \ \text{Watts/cm}^2$$

We evaluate expression (1) for several gases and conditions (using CGS units):

I. Nitrogen at 293 K and 1 ATM

$k_f = 2.5\text{x}10^{-4}$ w/cm K, $\rho f = 1.16\text{x}10^{-3}$, $C_p = 1.04$ J/gm K, and $\mu f = 17.4\text{x}10^{-6}$ poise, so that

$$h_c = \frac{1}{2}\left[\frac{(2.51x10^{-4})^3(1.16 \bullet 10^3)^2 x\, 980\, x\, 1.04}{174x10^{-6}\, x193}\right]^{1/4} \left(\frac{\Delta T}{L}\right)^{1/4}$$

$$= 4.04x10^{-4} \left(\frac{\Delta T}{L}\right) \text{ Watt/cm}^2 \text{ K}$$

II. Nitrogen from 77 K to 293 K (T_f = 185 K, ΔT = 216 K)

$k_f = 1.8x10^{-4}$ W/cm K, ρ_f = $1.84x10^{-3}$, $\mu_f = 121x10^{-6}$ and

$$h_c = \frac{1}{2}\left[\frac{(1.8 \bullet 10^{-4})^3(1.84 \bullet 10^{-3})^2 x\, 980\, x\, 1.04}{121x10^{-6}\, x185}\right]^{1/4} \left(\frac{\Delta T}{L}\right)^{1/2}$$

$$= 4.89x10^{-4} \left(\frac{\Delta T}{L}\right)^{1/4} \text{ Watt/cm}^2 \text{ K}$$

III. Helium from 15 K to 293 K (T_f = 154, ΔT = 278)

$k_f = 9.9x10^{-4}$ W/cm K, $\rho_f = 3.17x10^{-4}$, C_p = 5.5 J/gm K, $\mu_f = 131x10^{-6}$ poise, so that

$$h_c = \frac{1}{2}\left[\frac{(9.9x10^{-4})^3(3.17x10^{-4})^2 x\, 980\, x\, 5.5}{131x10^{-6}\, x154}\right]^{1/4} \left(\frac{\Delta T}{L}\right)^{1/4}$$

$$= 1.13\ x10^{-3} \left(\frac{\Delta T}{L}\right)^{1/4} \text{ Watt/cm}^2 \text{ K}$$

IV. Helium from 15 K to 77 K (T_f = 46 K, ΔT = 26 K)

$k_f = 4.52x10^{-4}$ W/cm K, $\rho_f = 1.06x10^{-3}$, $\mu_f = 60x10^{-6}$ poise, thus

$$h_c = \frac{1}{2}\left[\frac{(4.52 \bullet 10^{-4})^3(1.06 \bullet 10^{-3})^2 x\, 980\, x\, 5.5}{60 \bullet 10^{-6} \bullet 46}\right]^{1/4} \left(\frac{\Delta T}{L}\right)^{1/4}$$

$$= 1.89x10^{-3} \left(\frac{\Delta T}{L}\right)^{1/4} \text{ Watt/cm}^2 \text{ K}$$

V. Helium from 77 K to 293 K (T_f = 185, ΔT = 216)

$k_f = 1.11x10^{-3}$ W/cm K, $\rho f = 2.64x10^{-4}$, C_p = 5.5 J/gm K, $\mu f = 148x10^{-6}$ poise

$$h_c = \frac{1}{2}\left[\frac{(1.11x10^{-3})^3(2.64 \bullet 10^{-4})^2 x\, 980\, x\, 5.5}{148x10^{-6}\, x\, 185}\right]^{1/4} \left(\frac{\Delta T}{L}\right)^{1/4}$$

$$= 1.04\text{x}10^{-3} \left(\frac{\Delta T}{L}\right)^{1/4} \text{Watt/cm}^2\ \text{K}$$