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Practical way to calculate molecular conductances of pipes with constant annular cross section

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Knudsen's formula in the molecular flow range[1] can be used to calculate conductances of ducts with any geometric configuration, utilizing a variable correction factor. The special case of annular ducts is important mainly when dealing with traps and baffles. For a constant annular cross section between two concentric tubes with diameters D_1 and D_2 ($D_2 > D_1$) and length L ($L \gg D_1$), we get, by applying Knudsen's formula for air at 20°C:

$$C = 12.1(D_2 - D_1)^2(D_1 + D_2)(K'/L) \qquad (1)$$

with L, D_1, and D_2 in cm for C in l/s. The correction factor K' as a function of D_1/D_2 is given in Fig. 1.

The conductance of a long tube with uniform circular cross section is well known and comes from Knudsen's formula too. For air at 20°C,

$$C = 12.1(D^3)/L \qquad (2)$$

As the throughput in the molecular flow is strongly dependent on the cross section, we assume the net throughput of the concentric tubes can be roughly approximated as the throughput of the larger pipe minus the throughput of the smaller one. If we apply Eq. (2) twice, we get

$$C = 12.1(D_2^3 - D_1^3)(H/L) \qquad (3)$$

where we have introduced a new correction factor H. As Eq. (3) must be equal to Eq. (1), we obtain

$$H = (1 - r^2)(1 + r + r^2)^{-1}K'$$

where $r = D_1/D_2$.

Using the values of $K' = K'(D_1/D_2)$ we get $H = H(D_1/D_2)$, as plotted in Fig. 1.

The new correction factor H follows the equation $H + r = 1.0$ with very good approximation. The new formula for the conductance of concentric tubes with constant annular cross section becomes

$$C = (12.1/L)(D_2^3 - D_1^3)(1 - D_1/D_2) \qquad (4)$$

Equation (4) is easier and more practical than Eq. (1), because it results from the subtraction of more familiar expressions in Eq. (2) and uses a simple correction factor $H = 1.0 - D_1/D_2$.

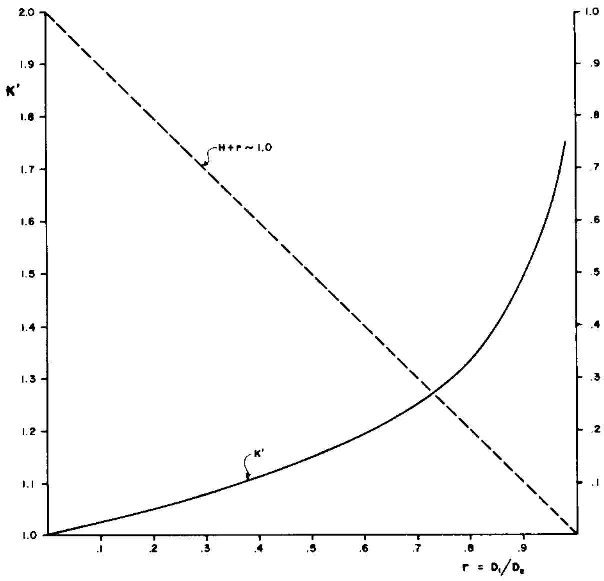

FIG. 1. Correction factors for the two ways of calculating conductances of concentric tubes.

For short tubes we add the conductance of the annular aperture in the way proposed by Dushmann. For other gases or other temperatures, we make the usual correction proportional to $(T/M)^{1/2}$, where T is the temperature in K and M is the molecular weight.

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[1]See, for example, A. Roth, *Vacuum Technology* (North-Holland, New York, 1976), pp. 78–83.