2.3 Beginning with a differential control volume in the form of a spherical shell, derive the heat diffusion equation for a one-dimensional, spherical, radial coordinate system with internal heat generation. Compare your result with Equation 2.24.

2.34 Beginning with a differential control volume in the form of a spherical shell, derive the heat diffusion equation for a one-dimensional, spherical, radial coordinate system with internal heat generation. Compare your result with Equation 2.27.

2.35 Derive the heat diffusion equation, Equation 2.24, for cylindrical coordinates beginning with the differential control volume shown in Figure 2.12.

2.36 Derive the heat diffusion equation, Equation 2.27, for spherical coordinates beginning with the differential control volume shown in Figure 2.13.

2.37 A steam pipe is wrapped with insulation of inner and outer radii, \( r_1 \) and \( r_2 \), respectively. At a particular instant the temperature distribution in the insulation is known to be of the form

\[
T(r) = C_1 \ln \left( \frac{r}{r_2} \right) + C_2
\]

Are conditions steady-state or transient? How do the heat flux and heat rate vary with radius?

2.38 For a long circular tube of inner and outer radii \( r_1 \) and \( r_2 \), respectively, uniform temperatures \( T_1 \) and \( T_2 \) are maintained at the inner and outer surfaces, while thermal energy generation is occurring within the tube wall (\( r_1 < r < r_2 \)). Consider steady-state conditions for which \( T_1 > T_2 \). Is it possible to maintain a linear radial temperature distribution in the wall? If so, what special conditions must exist?

2.39 Passage of an electric current through a long conducting rod of radius \( r \) and thermal conductivity \( k \) results in uniform volumetric heating at a rate of \( \dot{q} \). The conducting rod is wrapped in an electrically nonconducting cladding material of outer radius \( r_o \) and thermal conductivity \( k_c \), and convection cooling is provided by an adjoining fluid.

For steady-state conditions, write appropriate forms of the heat equations for the rod and cladding. Express appropriate boundary conditions for the solution of these equations.

2.40 Two-dimensional, steady-state conduction occurs in a hollow cylindrical solid of thermal conductivity \( k = 16 \text{ W/m} \cdot \text{K} \). Outer radius \( r_2 = 1 \text{ m} \), and overall length \( 2z_o = 5 \text{ m} \), where the origin of the coordinate system is located at the midpoint of the centerline. The inner surface of the cylinder is insulated, and the temperature distribution within the cylinder has the form

\[
T(r, z) = a + br^2 + c \ln r + dz^2,
\]

where \( a = 20^\circ \text{C}, b = 150^\circ \text{C/m}^2, c = -12^\circ \text{C}, d = -300^\circ \text{C/m}^2 \) and \( r \) and \( z \) are in meters.

(a) Determine the inner radius \( r_1 \) of the cylinder.

(b) Obtain an expression for the volumetric rate of heat generation, \( \dot{q} \text{ (W/m}^3 \text{)} \).

(c) Determine the axial distribution of the heat flux at the outer surface, \( q_o(r_o, z) \). What is the heat rate at the outer surface? Is it into or out of the cylinder?

(d) Determine the radial distribution of the heat flux at the end faces of the cylinder, \( q_o^2(r_1 + z_o) \) and \( q_o^2(r_1 - z_o) \). What are the corresponding heat rates? Are they into or out of the cylinder?

(e) Verify that your results are consistent with an overall energy balance on the cylinder.

2.41 An electric cable of radius \( r_1 \) and thermal conductivity \( k_c \) is enclosed by an insulating sleeve whose outer surface is of radius \( r_2 \) and experiences convection heat transfer and radiation exchange with the adjoining air and large surroundings, respectively. When electric current passes...