International Master's Programs of Chemical Engineering in the Graduate School of Engineering, Kyushu University (Academic Year from October, 2026)

Subject：Heat Transfer（1 sheet）

1. (50 points)

Consider a hollow cylindrical material with inner radius r_1, outer radius r_2, and length L [m]. The inner and outer surfaces are maintained at constant temperatures T_1 [K] and T_2 [K], respectively. The thermal conductivity, density, and specific heat capacity of the material are k [W m^{-1} K^{-1}], ρ [kg m^{-3}], C_p [J kg^{-1} K^{-1}], respectively. Answer the following questions.

(1.1) Derive the radial heat conduction equation for a non-steady state from the shell energy balance in the radial direction. Show the derivation process.

(1.2) Derive the equation for the radial temperature distribution in the material at a steady state.

(1.3) Draw a graph of the temperature distribution at a steady state. Ensure that the shape is clearly visible.

(1.4) Derive the radial heat flux (q_r [W m^{-2}]) equation at a steady state in the material.

(1.5) Derive the radial heat flow (Q_r [W]) equation at a steady state in the material.

(1.6) Given the inner surface area A_1 [m^2] and the outer surface area A_2 [m^2] of the material, derive an equation that describes the heat flow (Q_r [W]) at a steady state without using the length L of the material.