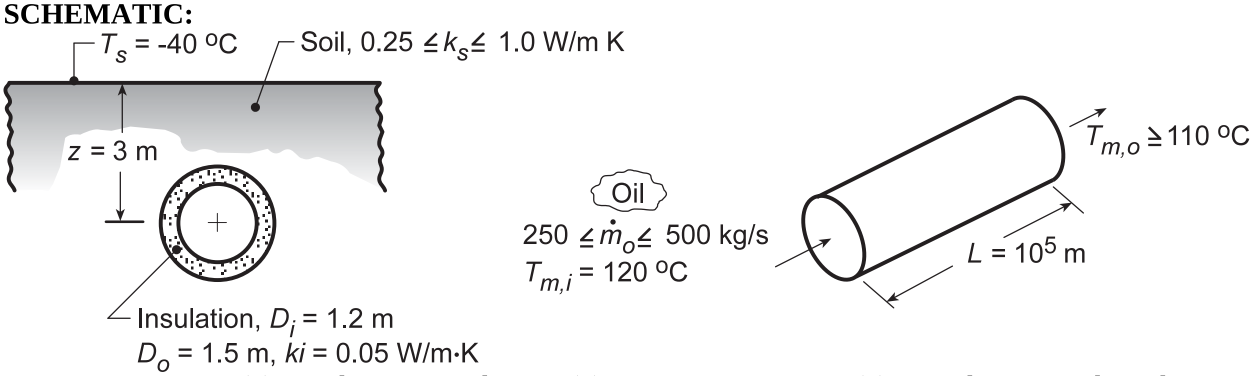
PROBLEM 8.64

KNOWN: Length, diameter, insulation characteristics and burial depth of pipe. Ground surface temperature. Inlet temperature, minimum allowable exit temperature, flow rate and properties of oil flow through pipe.

FIND: Effect of soil thermal conductivity and flowrate on heat rate and outlet temperature.

SCHEMATIC:



ASSUMPTIONS: (1) Steady-state conditions, (2) Constant properties, (3) Two-dimensional conduction in soil, (4) Negligible pipe wall thermal resistance, (5) Total resistance to heat loss is independent of x, (6) Oil is incompressible liquid with negligible viscous dissipation.

PROPERTIES: Oil (given): $\rho_o = 900\ \text{kg/m}^3$, $c_{p,o} = 2000\ \text{J/kg·K}$, $\nu_o = 8.5 \times 10^{-4}\ \text{m}^2/\text{s}$, $k_o = 0.140\ \text{W/m·K}$, $Pr_o = 10^4$.

ANALYSIS: From the analysis of Problem 8.63, the outlet temperature may be computed from the expression

$$\frac{T_{m,o} - T_s}{T_{m,i} - T_s} = \exp\left(-\frac{L}{\dot{m}c_{p,o}R'_{tot}}\right)$$

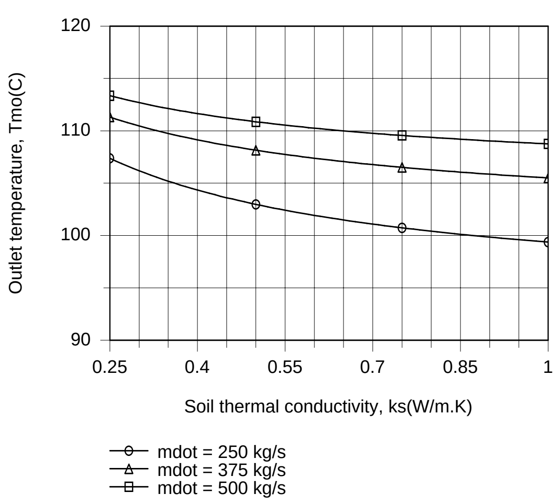
where

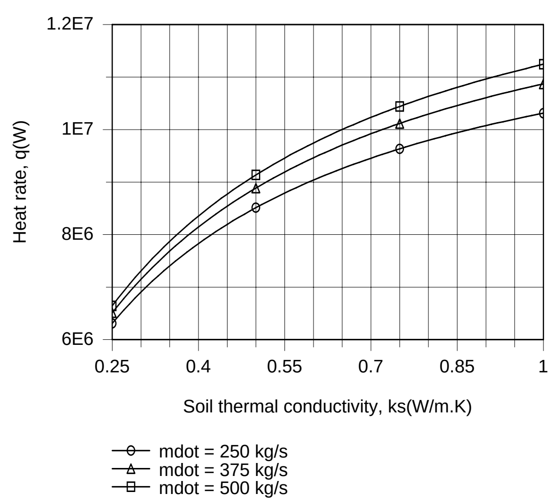
$$R'_{tot} = \frac{1}{\bar{h}\pi D_i} + \frac{\ln(D_o/D_i)}{2\pi k_i} + \frac{\cosh^{-1}(2z/D_o)}{2\pi k_s}$$

and $\bar{h}$ is determined from Eq. 8.57. The heat rate may then be obtained from the overall energy balance

$$q = \dot{m}c_p\left(T_{m,i} - T_{m,o}\right)$$

Using the *Correlations* Toolpad of IHT to perform the parametric calculations, the following results were obtained.





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PROBLEM 8.64 (Cont.)

Due to a reduction in the thermal conduction resistance of the soil with increasing k_s, there is a corresponding increase in the heat rate q from the pipe and a reduction in the oil outlet temperature. The heat rate also increases with increasing $\dot{m}$ (due to an increase in $\overline{h}$ and hence a decrease in the convection resistance), but the increase lags that of the flow rate, causing the outlet temperature to increase with increasing $\dot{m}$. Conditions for which $T_{m,o} \geq 110°C$ cannot be achieved for $\dot{m} = 250$ kg/s, but can be achieved for $k_s \leq 0.33$ W/m·K and $k_s \leq 0.65$ W/m·K for $\dot{m} = 375$ kg/s and 500 kg/s, respectively. The worst case condition corresponds to the smallest value of $\dot{m}$ and the largest value of k_s.

Measures to maintain $T_{m,o} \geq 110°C$ could include increasing the burial depth, increasing the insulation thickness, and/or using an insulation of lower thermal conductivity.

COMMENTS: The thermophysical properties of oil depend strongly on temperature, and a more accurate solution would account for the effect of variations in $\overline{T}_m$ on the properties.