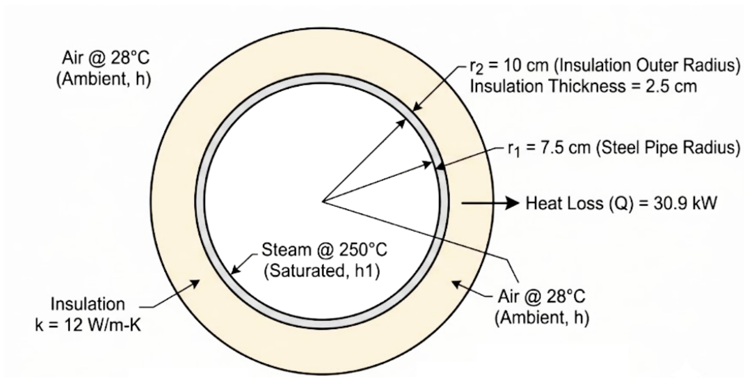
<u>Step 1:</u> Analyze the Thermodynamic Phase Change & Enthalpy Drop

First, we determine the energy lost by the steam as it travels through the pipe. The steam enters as a saturated vapor at 250ºC, meaning its initial enthalpy equals the saturated vapor enthalpy (h_g).



As heat escapes through the pipe walls, a portion of the steam condenses into liquid water, resulting in a mixture with 12% moisture at the discharge end.

- **Initial Enthalpy (h_1):** h_g = 2801.5 kJ/kg
- **Discharge Quality (x_2):** Quality represents the mass fraction of vapor. Since the moisture content is 12% (0.12), the vapor quality is:

$$x_2 = 1 - 0.12 = 0.88$$

- **Discharge Enthalpy (h_2):**

$$h_2 = h_f + x_2 h_{fg} = 1085 + (0.88)(1716.2) = 2595.256\,\frac{kJ}{kg}$$

<u>Step 2:</u> Calculate the Total Heat Loss Rate (Q)

Using the steady-flow energy equation for a control volume, the total rate of heat transfer (Q) rejected by the steam to the surroundings is equal to the mass flow rate multiplied by the change in enthalpy:

$$Q = m_s\left(h_1 - h_2\right) = \left(0.15\,\frac{kg}{s}\right)(2801.5 - 2595.256)\frac{kJ}{kg} = 30,936.6\,W$$

<u>Step 3:</u> Define System Geometry & Radii

The steel pipe has a nominal outer diameter of 15 cm. Because the thermal conductivity of steel is exceptionally high relative to insulation, and its wall thickness is not specified, its thermal resistance is safely neglected. The dimensions of the insulation layer are defined as:

- **Inner radius of insulation (r_1):** $\frac{15}{2}\,cm = 7.5\,cm = 0.075\,m$
- **Outer radius of insulation (r_2):** $7.5\,cm + 2.5\,cm\,(thickness) = 10cm = 0.10\,m$

Step 4: Apply the Radial Heat Transfer Equation to Find Film Conductance (h)

Using the electrical resistance analogy for a composite radial system, the heat transfer from the steam inside the pipe to the ambient air involves two main resistances in series: conduction through the cylindrical insulation layer and convection from the outer surface to the air. The integrated master equation is:

$$Q = \frac{2\pi L\left(T_{steam} - T_{ambient}\right)}{\frac{ln\left(\frac{r_2}{r_1}\right)}{k} + \frac{1}{h \cdot r_2}}$$

Substituting our known values into the equation:

$$30,936.6\ \frac{J}{s} = \frac{2\pi(180\ m)\ (250 - 28)\circ C}{\frac{ln\left(\frac{10\ cm}{7.5}\right)}{12\ W/m-K} + \frac{1}{h\ (0.1cm)}}$$

$$h = 1.2357\ \frac{W}{m^2 - \circ C}$$

This problem highlights the critical role of **insulation performance evaluation** in utility thermal piping. A film coefficient of $1.2357\ \frac{W}{m^2-\circ C}$ is exceptionally low for ambient air under standard conditions, which typically ranges between 5 to $25\ \frac{W}{m^2-\circ C}$ for natural convection.

This tells us that the surrounding air layer is highly stagnant or acting as an excellent secondary thermal barrier. In real-world thermal power plants, managing this overall heat transfer rate prevents excessive premature condensation in steam lines, protecting downstream equipment like steam turbines from catastrophic blade erosion caused by moisture droplets.