EN 410
Energy Management

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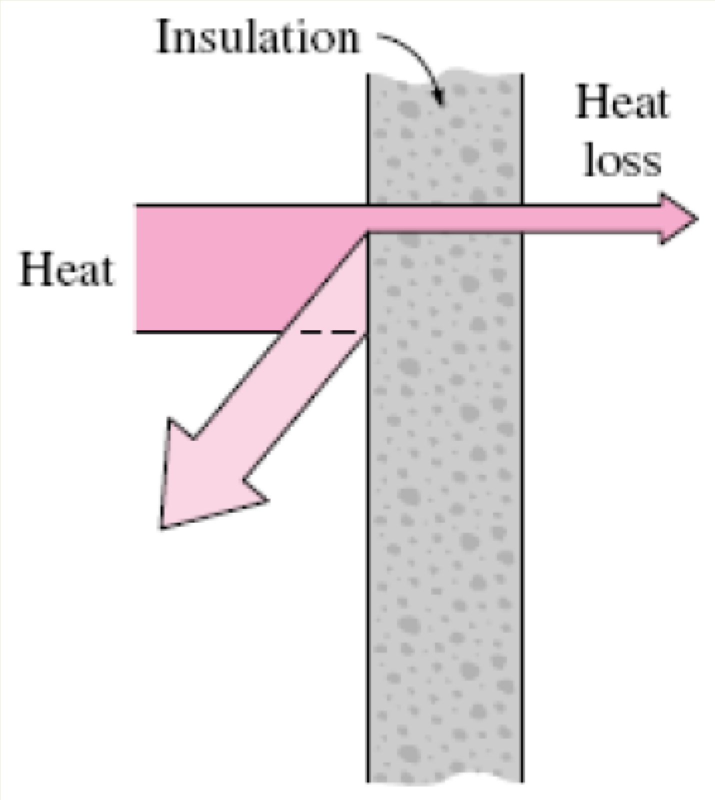
Insulation

- Thermal insulations are materials or combinations of materials that are used primarily to provide resistance to heat flow
- Most insulations are heterogeneous materials made of low thermal conductivity materials, and they involve air (low k and cheap) pockets
- Payback period < 1year.



Benefits of insulation

- Reduces overall energy consumption by reducing heat loss/gain
- Personal safety (OSHA, any surface should be T<60℃)
- Reducing temperature fluctuations
- Avoiding condensation and thereby corrosion and mold prevention
- Provides fire protection
- Absorbs noise and vibration

Types and materials

- Low (<90°C), Medium (90-325°C) and High (>325°C)
- **Blanket** - flexible fibers - comes in the form of batts or rolls - mineral (rock and slag) wool, plastic fibers, and natural fibers, such as cotton and sheep's wool
- **Foam -** closed-cell and open-cell – cells are filled with air
- **Sprayed foam** - isocyanate and polyol resin - 30-60 times its liquid volume – Air pockets

Fiberglass

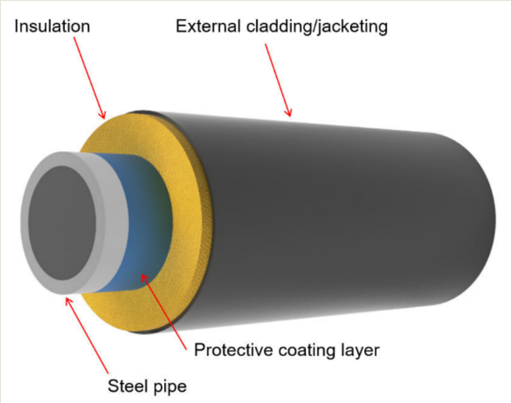
Polyurethane foam

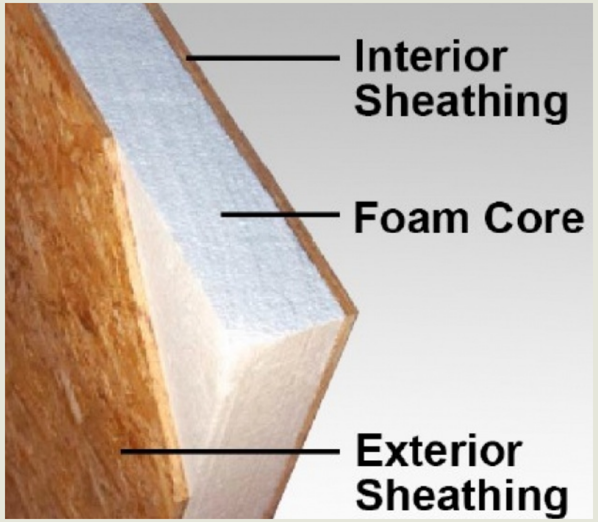
Sprayed foam

Types and materials

- **Loose fill** - small particles of fiber, foam, or other materials, lower initial cost
- **Radiant barriers -** incorporates reflective surfaces - typically aluminum foil- over conventional insulation material
- **Structural insulation**

Structural insulation





Loose fill

Radiant barriers

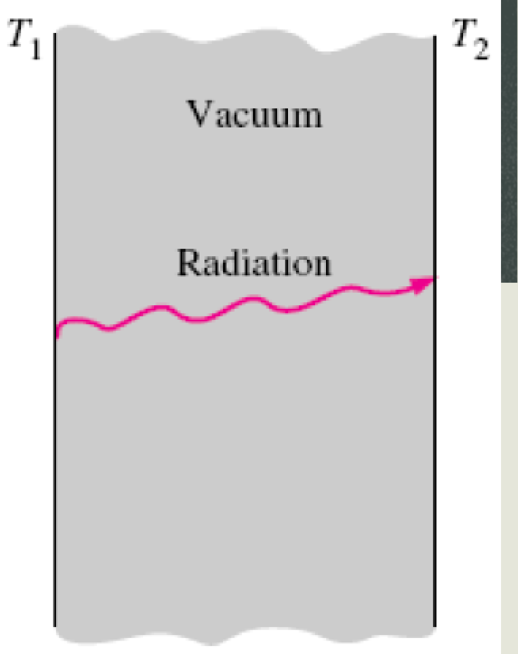
Commonly used insulations

What is the thermal conductivity of air?

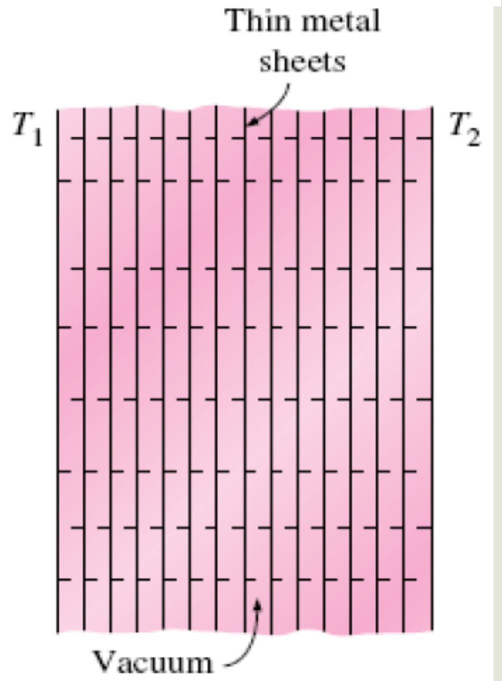
Subgroup	Insulation Material	Temperature °C	Thermal conductivity W / (m.K)
Fibrous	Glass wool	-100-500	0.03-0.045
	Rock wool	-100-750	0.033-0.045
Cellular	Calcium silicate	300	0.045-0.065
	Cellular glass	-260-430	0.04-0.06
	Vermiculite	700-1600	0.046-0.07
	Ceramic	N.A.	0.03-0.07
Foamed	EPS	-80-80	0.035-0.04
	XPS	-60-75	0.03 0.04
	PUR	-50-120	0.024-0.03
	PIR	-20-100	0.018-0.028
Foamed, expanded	Cork	110-120	0.037-0.050
	Melamine foam	N.A.	0.035
	Phenolic foam	150	0.022-0.04
	Polyethylene foam	-40-105	0.033
Fibrous	Fiberglass	-4-305	0.033-0.04
	Sheep wool	130-150	0.04-0.045
	Cotton	100	0.035-0.06
	Cellulose fibers	60	0.04 0.045
	Jute	N.A.	0.038 0.055
	Rice straw	24	0.046-0.056
	Hemp	100-120	0.04-0.05
	Bagasse	160-200	0.046-0.055
	Coconut	180-220	0.04-0.05
	Flax	N.A.	0.03-0.045
Boards	Gypsum foam	N.A.	0.045
	Wood wool	110-180	0.09
	Wood fibers	110	0.04-0.09
	VIPS	N.A.	0.002-0.008
	Aerogel	N.A.	0.013-0.014

Super-insulators

- Superinsulators are commonly used in space applications and cryogenics (temperatures below 100 K (–173°C))
- **Is vacuum a good insulation?**



- Insulation against radiation heat transfer between two surfaces is achieved by placing highly reflective thin metal sheets
- Space between the layers is evacuated to form a vacuum pressure to minimize conduction or convection heat transfer through the air space between the layers
- Thermal conductivity < 2×10^{-5} W/m·°C, **< air or other insulation by 1000 times.**



Heat Transfer

- Conduction (Fourier's Law): $Q = k\,A\,(\Delta T/\,\Delta x)$
- Convection (Newton's Law): $Q = h\,A\,\Delta T$

  - Electrical resistance = Voltage difference/Current
  - Thermal resistance = Temperature difference/Heat
  - Thermal resistance ($\Delta T/Q$)
    - Conduction in slab = $\Delta x/k\,A$
    - Convection = $1/h\,A$

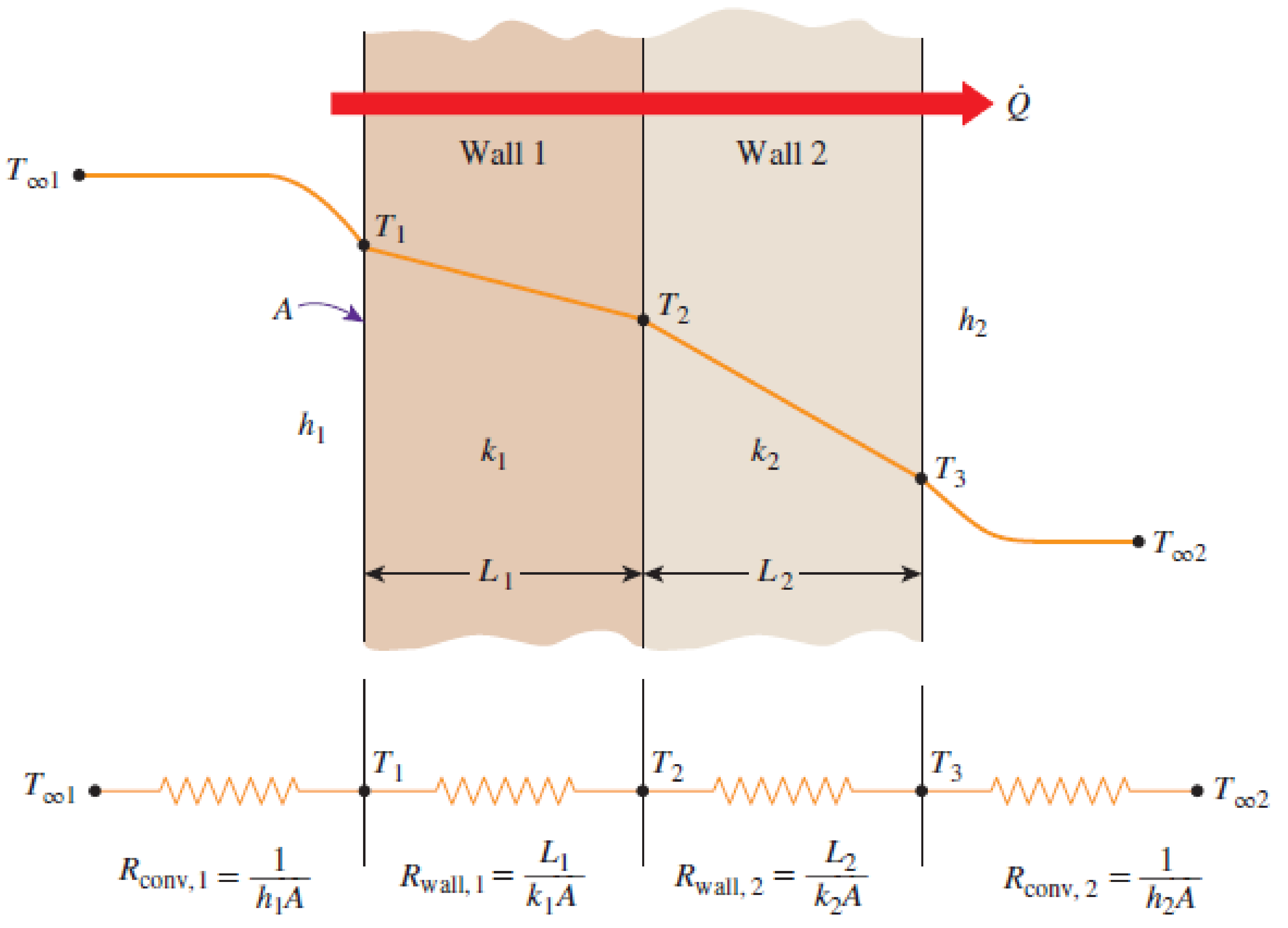
Plane Wall

$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{total}}$$

$$\dot{Q} = \frac{T_{\infty 1} - T_1}{R_{conv,1}}$$

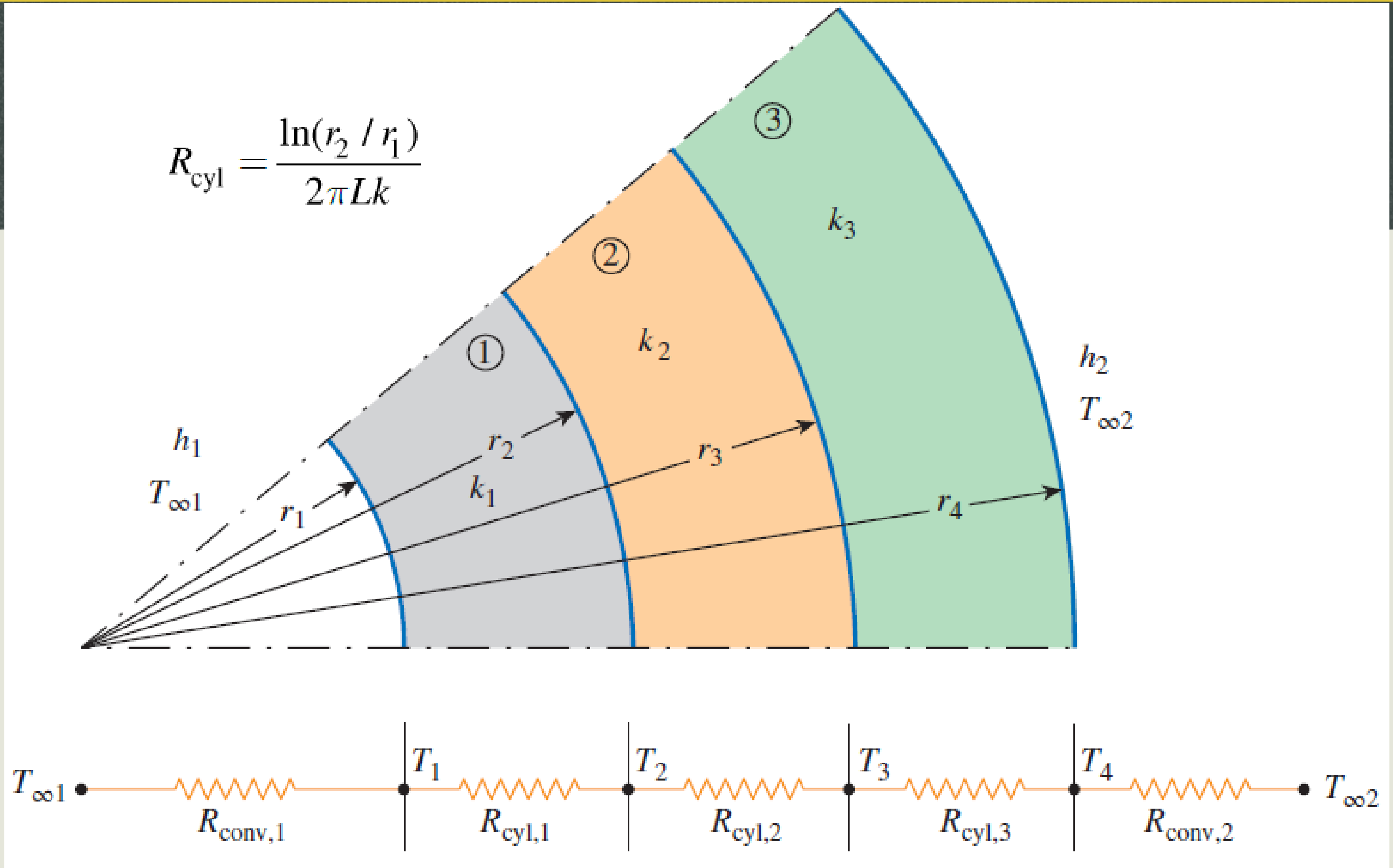
$$\dot{Q} = \frac{T_{\infty 1} - T_2}{R_{conv,1} + R_{wall,1}}$$

$$\dot{Q} = \frac{T_3 - T_{\infty 2}}{R_{conv,2}}$$



$$R_{total} = R_{conv,1} + R_{wall,1} + R_{wall,2} + R_{conv,2} = \frac{1}{h_1 A} + \frac{L_1}{k_1 A} + \frac{L_2}{k_2 A} + \frac{1}{h_2 A}$$

Cylindrical pipes



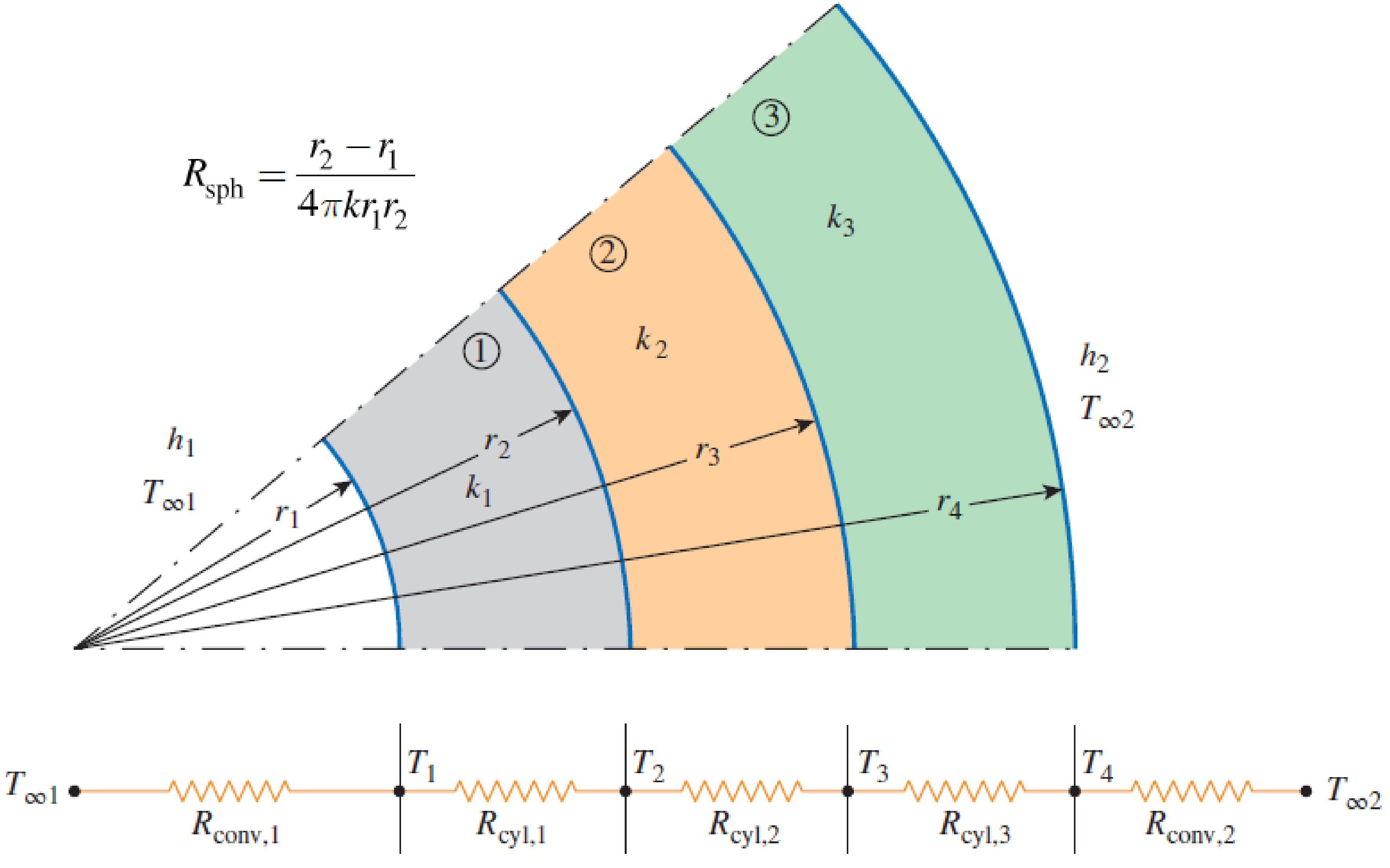
$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{total}}$$

$$A_1 = 2\pi r_1 L \text{ and } A_4 = 2\pi r_4 L$$

$$\begin{aligned} R_{total} &= R_{conv,1} + R_{cyl,1} + R_{cyl,2} + R_{cyl,3} + R_{conv,2} \\ &= \frac{1}{h_1 A_1} + \frac{\ln(r_2/r_1)}{2\pi L k_1} + \frac{\ln(r_3/r_2)}{2\pi L k_2} + \frac{\ln(r_4/r_3)}{2\pi L k_3} + \frac{1}{h_2 A_4} \end{aligned}$$

Spherical tanks

$$R_{\text{sph}} = \frac{r_2 - r_1}{4\pi k r_1 r_2}$$



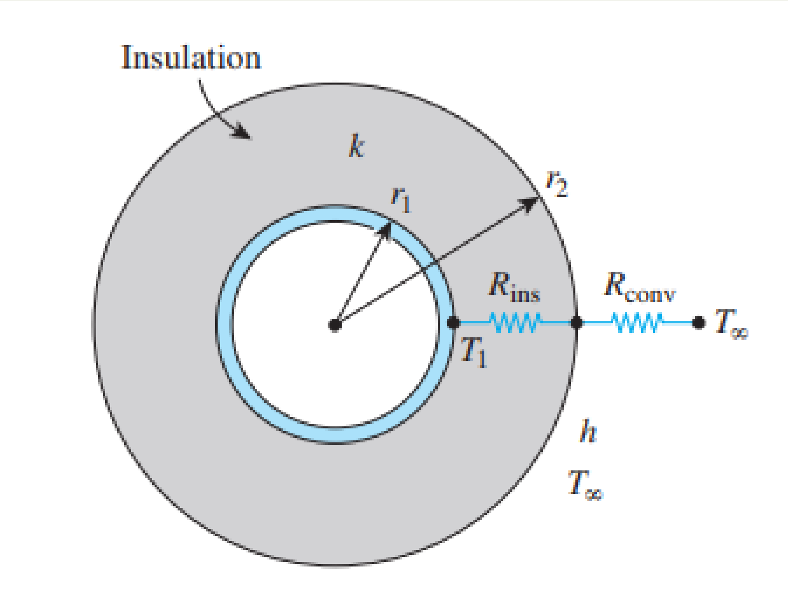
$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{\text{total}}}$$

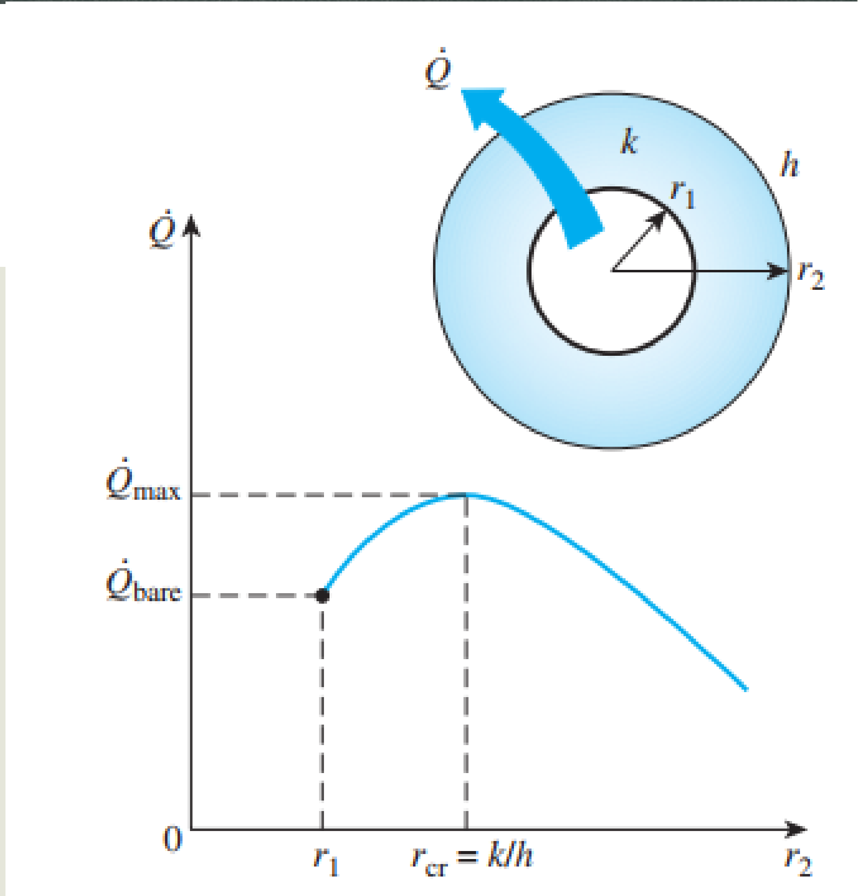
$$A_1 = 4\pi r_1^2 \text{ and } A_2 = 4\pi r_2^2$$

$$\begin{aligned} R_{\text{total}} &= R_{\text{conv},1} + R_{\text{sph},1} + R_{\text{sph},2} + R_{\text{sph},3} + R_{\text{conv},2} \\ &= \frac{1}{h_1 A_1} + \frac{r_2 - r_1}{4\pi r_1 r_2 k_1} + \frac{r_3 - r_2}{4\pi r_2 r_3 k_2} + \frac{r_4 - r_3}{4\pi r_3 r_4 k_3} + \frac{1}{h_2 A_4} \end{aligned}$$

Critical insulation

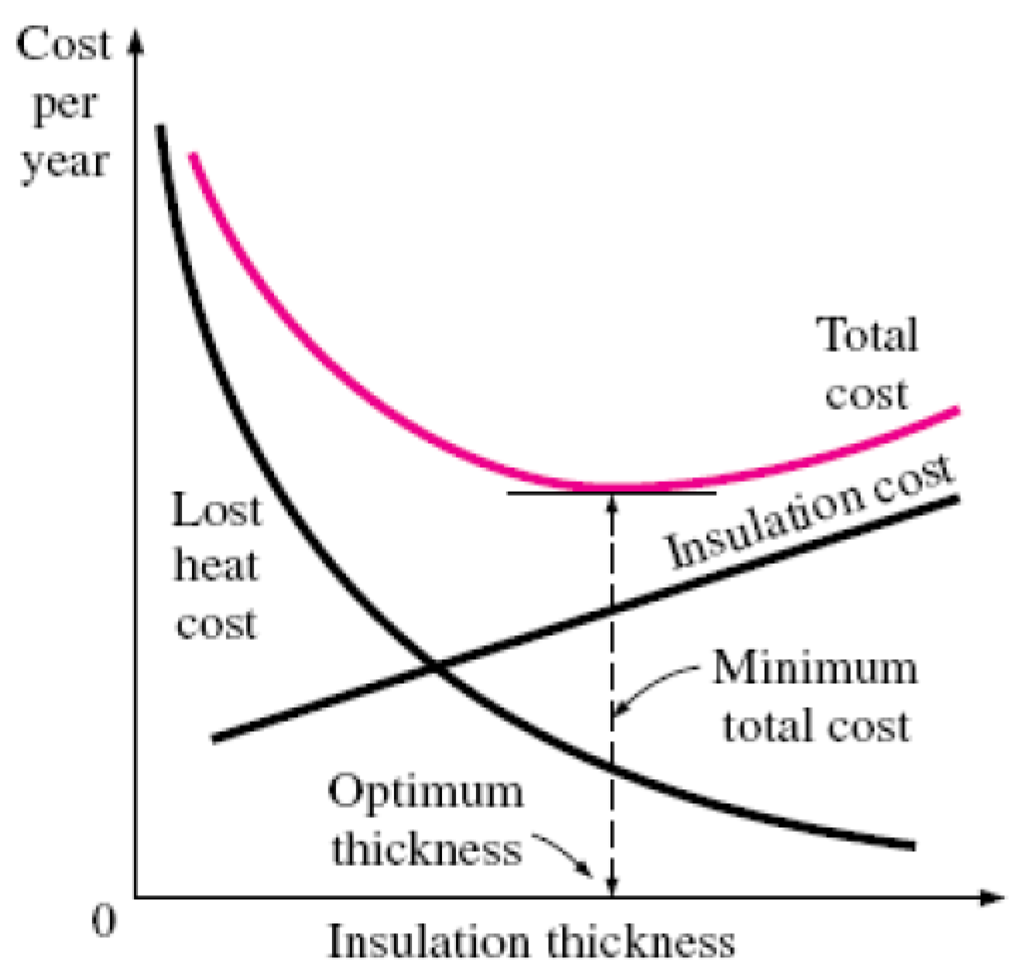
$$\dot{Q} = \frac{T_1 - T_\infty}{R_{ins} + R_{conv}} = \frac{T_1 - T_\infty}{\dfrac{\ln(r_2/r_1)}{2\pi L k} + \dfrac{1}{h(2\pi r_2 L)}}$$

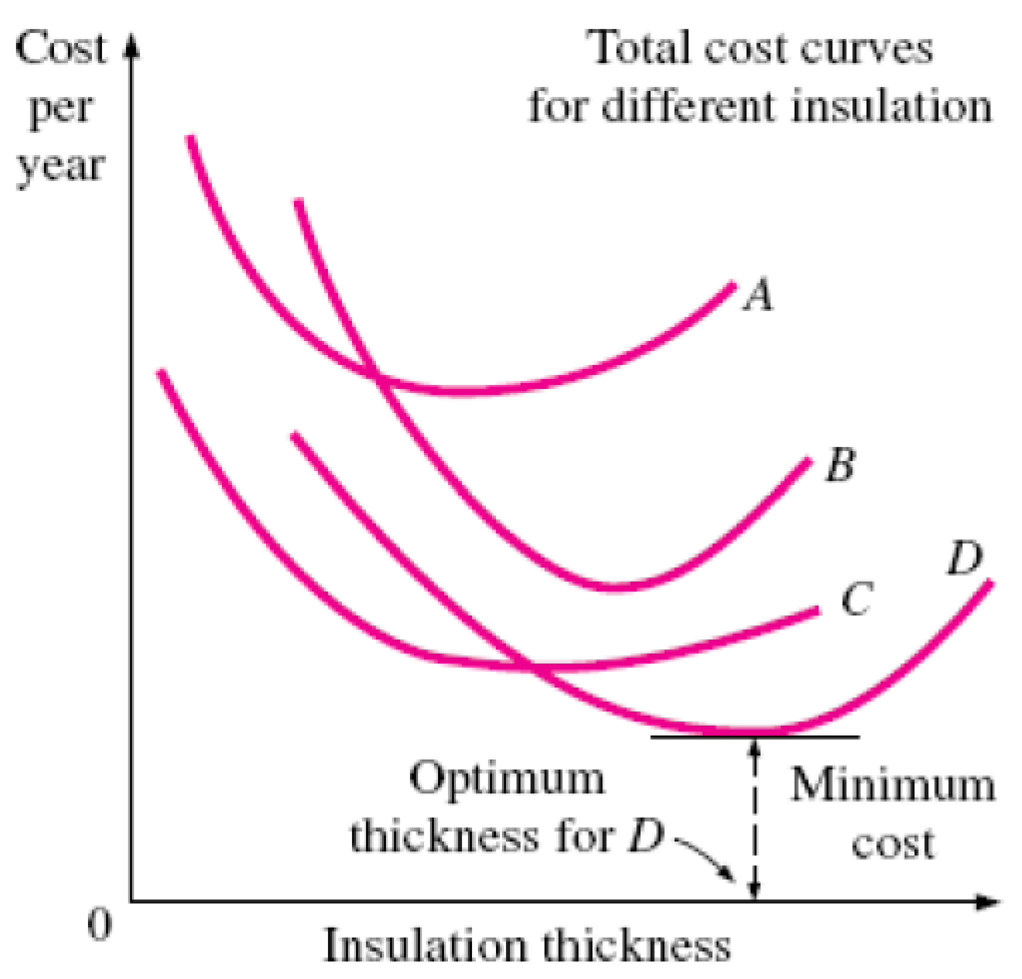




$$r_{cr,\,max} = \frac{k_{max,\,insulation}}{h_{min}} \approx \frac{0.05\ \text{W/m·K}}{5\ \text{W/m}^2\text{·K}} = 0.01\ \text{m} = 1\ \text{cm}$$

Optimum thickness of insulation





Insulation of a LNG tank

When the transportation of natural gas is not possible in a pipeline for economic reason, it is liquified ($\rho = 425$ kg/ m^3, Cp = 3.475 kJ/kg.K) at about -160°C and then transported in insulated tanks in ships.

- Tank diameter is 4 m
- Ambient temperature = 24°C
- Ambient air heat transfer coefficient = 22 W/m^2.K
- Tank is insulated with 5 cm thick super-insulator with k= 0.00008 W/m.K
- Estimate how long it take it to rise to -158°C

$$\dot{Q} = \frac{T_{\infty 1} - T_{\infty 2}}{R_{\text{total}}}$$

$$R_{\text{total}} = R_{\text{conv},1} + R_{\text{sph},1} + R_{\text{sph},2} + R_{\text{sph},3} + R_{\text{conv},2} = \frac{1}{h_1 A_1} + \frac{r_2 - r_1}{4\pi r_1 r_2 k_1} + \frac{r_3 - r_2}{4\pi r_2 r_3 k_2} + \frac{r_4 - r_3}{4\pi r_3 r_4 k_3} + \frac{1}{h_2 A_4}$$

$$A_1 = 4\pi r_1^2 \text{ and } A_2 = 4\pi r_2^2$$

References

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