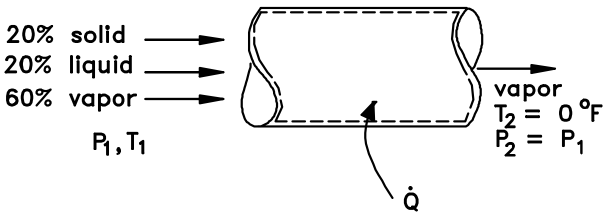
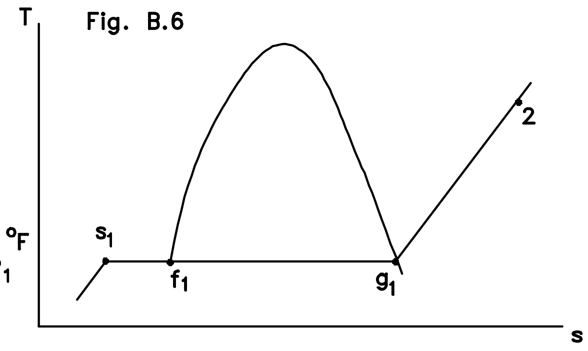
Problem: 5.33

Given: CO_2 Inlet mixture: 20% solid, 20% liquid, 60% vapor
Outlet conditions: Inlet pressure, 0 $^\circ F$
Flow rate: 4 lbm/s

Find: Energy transfer rate





Assumptions

1. Steady state, steady flow
2. $\Delta pe = \Delta ke = 0$
3. $\dot{W} = 0$
4. $\dot{m}_1 = \dot{m}_2$

First law Energy Balance

$$\dot{m}(h_1 + \cancel{pe_1} + \cancel{ke_1}) + \dot{Q} + \cancelto{0}{\dot{W}} = \dot{m}(h_2 + \cancel{pe_2} + \cancel{ke_2}) + \cancelto{0}{\frac{dE}{dt}}$$

$$\dot{Q} = \dot{m}(h_2 - h_1)$$

The three phases (solid, liquid and vapor) can only coexist at equilibrium at the triple point.

From Fig. B.6:

$$
\begin{aligned}
P_1 &= P_2 = 75\ psia \quad T_1 = -70\ ^\circ F \\
h_{s_1} &= 47\ Btu/lbm \\
h_{f_1} &= 130\ Btu/lbm \\
h_{g_1} &= 277\ Btu/lbm
\end{aligned}
$$

Also at $0\ ^\circ F, 75\ psia \quad h_2 = 295\ Btu/lbm$

$$
\begin{aligned}
h_1 &= 0.2h_{s_1} + 0.2h_{f_1} + 0.6h_{g_1} \\
&= 0.2(47) + 0.2(130) + 0.6(277) \\
&= 201.6\ Btu/lbm
\end{aligned}
$$

Then

$$
\begin{aligned}
\dot{Q} = \dot{m}(h_2 - h_1) &= 4\ lbm/s \times (295 - 201.6)\ Btu/s \\
&= 373.6\ Btu/s
\end{aligned}
$$

The heat transferred to the pipe is $\boxed{373.6\ Btu/s}$