June 24, 2003
Final Exam
Wed 7/2/2003 2-4:30
Test #3 6/24/2003 Thursday

4-234

\[ T_1 = 16^\circ C \quad T_2 = 43^\circ C \]
\[ V = 10L/min \quad Q_{\text{leak}} \]
\[ S_{H_2O} = 1 \, \text{kg/L} \]

Find: \( Q_{\text{leak}} \)

C.V. as shown:

\[ m_1 h_1 + Q_{\text{leak}} = m_2 h_2 \]
\[ m_1 = 8.7 = 10 \, \text{kg/min} \]
\[ Q_2 - h_1 = c (T_2 - T_1) \quad c = 4.18 \, \text{kJ/kg} \]
\[ Q_{\text{leak}} = 10 \, \text{kg/min} \times \frac{1 \, \text{min}}{60 \, \text{s}} \times 4.18 \, \text{kJ/kg} \times (27^\circ C) \]
\[ = 18.84 \, \text{kJ} \]
\[ \text{effectiveness} = \frac{Q_{\text{act}}}{Q_{\text{max}}} \]
\[ Q_{\text{max}} = \text{heat transferred to Texit} = \text{Tinlet} \times \text{Qin} \]
\[ T_{\text{in}} = \frac{3}{4} \times 1.6 \times 0.05 = 0.015 \text{ mGal} \]

\[ \Delta T = 10.18 - 1.3 = 8.88 \text{ mGal} \]

\[ Q_{\text{act}} = \frac{10.18}{C_p} (T_{\text{in}} - T_{\text{out}}) \]

\[ Q_{\text{act}} = \frac{8.88}{C_p} (T_{\text{in}} - T_{\text{out}}) \]

\[ T_{\text{out}} = \frac{10.18}{2.8} (T_{\text{in}} - T_{\text{out}}) \]

\[ Q_{\text{act}} = \frac{10.18}{2.8} (T_{\text{in}} - T_{\text{out}}) \]

\[ Q_{\text{act}} = (10.18)(1.6 - T_{\text{out}}) \]

\[ Q_{\text{act}} = (10.18)(0.5) \]

\[ Q_{\text{act}} = 5.09 \text{ mGal} \]

\[ Q_{\text{act}} = \frac{10.18}{C_p} (0.5) \]

\[ Q_{\text{act}} = \frac{10.18}{2.8} (0.5) \]

\[ Q_{\text{act}} = 1.79 \text{ mGal} \]
\[
\epsilon = \frac{Q_{act}}{Q_{max}} = \frac{(\text{h}_{\text{cp}} - \text{h}_{\text{CP}})_{\text{h}}(T_{\text{cont}} - T_{\text{cin}})}{(\text{h}_{\text{cp}} - \text{h}_{\text{CP}})_{\text{h}}(T_{\text{h}} - T_{\text{cin}})}
\]

\[
T_{\text{cont}} = \epsilon \Delta T_{\text{max}} + T_{\text{cin}} = 0.5(33 - 16) + 16 = 23.5 \text{ F}
\]

\[
\Delta T_{\text{water}} = T_{\text{h}} - T_{\text{cont}} = 43 - 23.5 = 15.5 \text{ F}
\]

\[
P_2 = 120 \text{ psia}
\]

(adiabatic \rightarrow Q_{\text{cv}} = 0)

\[
\dot{W} = 60 \text{ hp}
\]

\[
R-134a \quad P_1 = 15 \text{ psia} \quad T_1 = 20 \text{ F} \quad h_1 = 10.4 \text{ ft}^3/\text{s}
\]

Find: \(\dot{m}\) and \(T_2\)

\[\dot{m} = ? \quad R-134a \rightarrow \dot{m} = \frac{\dot{W}}{T_1}
\]

State 1: \((P_1, T_1) \rightarrow u_1 = 3.2468 \text{ ft}^3/\text{lbm}

\[
\dot{m}_1 = \frac{10.4 \text{ ft}^3/\text{s}}{3.2468 \text{ ft}^3/\text{lbm}} = 3.08 \text{ lbm/s}
\]
\[ t_2 = ? \]

\[ Q_{cv} + m_1 h_1 = m_2 h_2 + W_{cv} \]

(neglecting \( \Delta h_e, \Delta p_e \))

Find \( h_2 \), then state (2) \( P_{out} \)

\[ h_2 = h_1 - \frac{W_{cv}}{m_2} \]

\[ W_{cv} = \frac{60}{60} \text{ hp} \]

\[ = 106.34 - 60 \text{ hp} \]

\[ = \frac{106.34 - 60}{308.8 \text{ Btu/lbm}} \times 2544.5 \text{ Btu/lbm/hr} \times \frac{1 \text{ Btu}}{3600} \]

\[ = 106.34 + 13.77 \]

\[ = 120.11 \text{ Btu/lbm} \]

Interpolate to estimate for \( T_2 \)

\[ T_2 = 100 + \frac{(120.11 - 116.32)(120 - 100)}{(121.52 - 116.32)} \]

\[ = 114.6 \text{ F} \]

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Entropy - a big picture is that this is "just another property"

The inequality of Clausius -

For any cycle \[ \oint \frac{\delta Q}{T} \leq 0 \]
\[ \oint = \" \text{integral around a cycle} \" \]

\[ \oint \frac{\delta Q}{T} \rightarrow \text{add up all heat transfers divided by temperature of system where } \oint \text{ occurs} \]

\[ \text{take into account } Q > 0 \text{ for loss and } Q < 0 \text{ for gain} \]

**Inequality of Clausius**

\[ \oint \frac{\delta Q}{T} \leq 0 \]

for all cycles (heat engines and refrigerators)

\[ \oint \frac{\delta Q}{T} = 0 \] for any (internally) reversible cycle

\[ \oint \frac{\delta Q}{T} < 0 \] for any cycle with internal irreversibilities

\[ \int dp = 0 \]

\[ \oint du = 0 \]

\[ \int \rightarrow 0 \] \rightarrow "" is a property
Since \( \int_{\text{rev}} \left( \frac{\delta Q}{T} \right)_{\text{rev}} = 0 \)

Then \( \left( \frac{\delta Q}{T} \right)_{\text{int}} \) is a property.

This property is called entropy - \( S = m \Delta S = m \Delta \phi \)

\( dS = \left( \frac{\delta Q}{T} \right)_{\text{int}} \)

\( S_2 - S_1 = \int_{S_1}^{S_2} \left( \frac{\delta Q}{T} \right)_{\text{int}} \)

3 things linked together by this definition

1) change in entropy
2) heat transfer
3) reversibility

Note: A reversible, adiabatic process is a constant entropy process.

is entropic \( \rightarrow \) "constant entropy"
Inequality of Clausius
\[ \oint \frac{dQ}{T} < 0 \text{ for cycle w/ internal irreversibilities} \]

For any real process
\[ \int_{S_1}^{S_2} dS = \int_{S_1}^{S_2} \frac{dQ}{T} + S_{\text{gen}} \]

\( S_{\text{gen}} = \) entropy generated/created due to irreversibilities

\( S_{\text{gen}} \) cannot be negative!!

Recall 3 substance models
1) "Real substance"
2) Ideal gas
3) Incompressible

Need to find \( P \) as for each of these
1) "Real Substance" model

Fig 6-10

Tomorrow we will cover 2) Ideal gas

3) Incompressible Substance

Examples:

6-26 Carnot cycle: $1 \rightarrow 2 \quad T = \text{const}
\quad \text{heat added}

$Q_+ = 900 \text{kJ}$

$T_\text{source} = 400 \text{ K}$

Carnot cycle = all reversible processes

$\delta S_2 - \delta S_1 = \int_{1}^{2} \frac{\delta Q}{T} \text{ (rev)}$

Since 1 - 2 is reversible, then this definition applies

Since isothermal process

$\delta S_2 - \delta S_1 = \frac{1}{T_+} \int_{1}^{2} Q = \frac{Q_+}{T_+} = \frac{900 \text{kJ}}{673 \text{K}}$

$\delta S_2 - \delta S_1 = +1.337 \frac{\text{kJ}}{\text{K}}$

For working fluid, $Q > 0$ (heat added)

$(\delta S_2 - \delta S_1)\text{fluid} = +1.337 \frac{\text{kJ}}{\text{K}}$

For the source, $Q < 0$

$(\Delta S)_\text{source} = - \Delta S_{\text{system}} = -1.337 \frac{\text{kJ}}{\text{kg}}$

$\Delta S_{\text{overall}} = \Delta S_{\text{system}} + \Delta S_{\text{source}} = 0 \ (\text{zero})$
$V_1 = 0.05 \text{ m}^3$, $P_1 = 0.8 \text{ MPa}$

"Saturated Vapour" $X_1 = \frac{1}{4}$, $x_i = 1.0$

Expands reversibly until $P_2 = 0.4 \text{ MPa}$

Find: a) $T_2$  b) $W_{1-2}$

Reversible + adiabatic = isentropic

$S_2 = S_1$

$S_2 = S_1$

State $\odot$: $(P_2, S_2) \rightarrow T_2$

State $\odot\odot$: $(P_1, X_1) \rightarrow S_1 = S_g|_{P=0.8 \text{ MPa}} = 9066 \text{ J/k}$

at $P_2 = 0.4 \text{ MPa}$, $S_g|_{P=0.4 \text{ MPa}} = 9066 \text{ J/k}$

$\Rightarrow$ Two-phase mixture $\Rightarrow T_2 = T_{SAT} |_{P=0.4 \text{ MPa}} = 89.3 \text{ C}$

$W_{1-2} = ?$  $W_{1-2} = \int_{S_1}^{S_2} P\,dA$

$\text{must know } h = h(P) \text{ varies with } T$ - ?

Icau $\dot{Q}_{1-2} + \text{work} = m_2 u_2 + W_{1-2}$

"$u$" because closed system!!!
\[ W_{1-2} = U_1 - U_2 \]
\[ = U_g \left|_{0.8 \text{ m/s}} \right. - U_2 \]
\[ U_2 = U_g \left|_{0.4 \text{ m/s}} \right. \times X_2 \frac{U_f}{U_g} \left|_{0.4 \text{ m/s}} \right. \]

\[ X_2 = ? \quad \text{use } S_2 = S_f + X_2 \frac{S_f}{S_g} \]
\[ X_2 = \frac{S_2 - S_f}{S_f} = \frac{0.9066 - 0.2399}{0.9145 - 0.2399} \]
\[ X_2 = 0.988 \]

\[ U_2 = U_f + X_2 U_f = (61.69 + (0.988)(231.97 - 61.69)) \]
\[ = 229.98 \text{ kJ/kg} \]

\[ W_{1-2} = (243.78 - 229.98) = 13.8 \text{ kJ/kg} \]

\[ M = ? \quad M W_1 = \frac{V_1}{\rho} \Rightarrow M = \frac{V_1}{\rho} = \frac{0.05 \text{ m}^3}{0.625 \text{ kg/m}^3} \]
\[ M = 1.96 \text{ kg} \]

\[ W_{1-2} = M W_{1-2} \]
\[ = 1.96 \times 13.8 \frac{\text{kJ}}{\text{kg}} = 27.1 \text{ kJ} \]