تعداد سؤالات: تستی: تشریحی: ۵
زمان آزمون (دقیقه): تستی: -- تشریحی: ۱۲۰

نام درس: ترمودینامیک۲

رشته تحصیلی /کد درس: مهندسی مکانیک حرارت وسیالات- مهندسی مکانیک جامدات- مهندسی مکانیک ساخت وتولید- مهندسی مکانیک تبدیل انرژی۱۳۱۵۰۲۲

بارم نمره هرسوال ۲/۸۰ می باشد.

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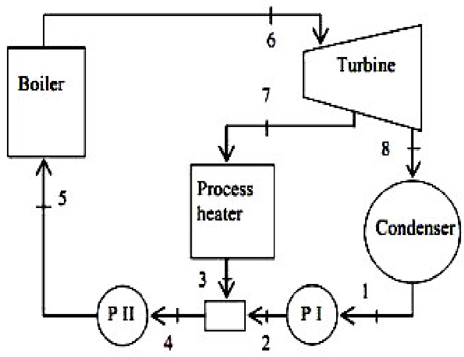


$$h_1 = h_{f\,@\,10\,\text{kPa}} = 191.81\ \text{kJ/kg}$$
$$v_1 = v_{f\,@\,10\,\text{kPa}} = 0.00101\ \text{m}^3/\text{kg}$$

$$w_{\text{pI,in}} = v_1(P_2 - P_1) = (0.00101\ \text{m}^3/\text{kg})(600 - 10\ \text{kPa})\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) = 0.60\ \text{kJ/kg}$$

$$h_2 = h_1 + w_{\text{pI,in}} = 191.81 + 0.60 = 192.41\ \text{kJ/kg}$$

$$h_3 = h_{f\,@\,0.6\,\text{MPa}} = 670.38\ \text{kJ/kg}$$

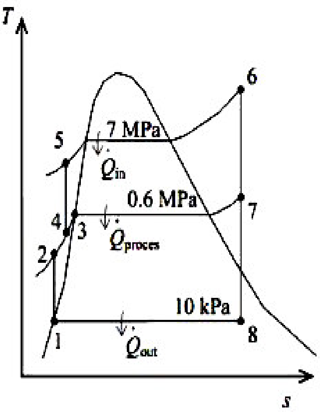
Mixing chamber:

$$\dot{E}_{\text{in}} - \dot{E}_{\text{out}} = \Delta\dot{E}_{\text{system}}^{\ \nearrow 0\,(\text{steady})} = 0 \longrightarrow \dot{E}_{\text{in}} = \dot{E}_{\text{out}}$$
$$\sum \dot{m}_i h_i = \sum \dot{m}_e h_e \longrightarrow \dot{m}_4 h_4 = \dot{m}_2 h_2 + \dot{m}_3 h_3$$

or,
$$h_4 = \frac{\dot{m}_2 h_2 + \dot{m}_3 h_3}{\dot{m}_4} = \frac{(22.50)(192.41) + (7.50)(670.38)}{30} = 311.90\ \text{kJ/kg}$$
$$v_4 \cong v_{f\,@\,h_f = 311.90\,\text{kJ/kg}} = 0.001026\ \text{m}^3/\text{kg}$$

$$w_{\text{pII,in}} = v_4(P_5 - P_4) = (0.001026\ \text{m}^3/\text{kg})(7000 - 600\ \text{kPa})\left(\frac{1\ \text{kJ}}{1\ \text{kPa}\cdot\text{m}^3}\right) = 6.57\ \text{kJ/kg}$$

$$h_5 = h_4 + w_{\text{pII,in}} = 311.90 + 6.57 = 318.47\ \text{kJ/kg}$$



$$\left.\begin{array}{l} P_6 = 7\ \text{MPa} \\ T_6 = 500^\circ\text{C} \end{array}\right\} \begin{array}{l} h_6 = 3411.4\ \text{kJ/kg} \\ s_6 = 6.8000\ \text{kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_7 = 0.6\ \text{MPa} \\ s_7 = s_6 \end{array}\right\} h_7 = 2774.6\ \text{kJ/kg}$$

$$\left.\begin{array}{l} P_8 = 10\ \text{kPa} \\ s_8 = s_6 \end{array}\right\} \begin{array}{l} x_8 = \dfrac{s_8 - s_f}{s_{fg}} = \dfrac{6.8000 - 0.6492}{7.4996} = 0.8201 \\ h_8 = h_f + x_8 h_{fg} = 191.81 + (0.8201)(2392.1) = 2153.6\ \text{kJ/kg} \end{array}$$

Then,

$$\dot{W}_{\text{T,out}} = \dot{m}_6(h_6 - h_7) + \dot{m}_8(h_7 - h_8) = (30\ \text{kg/s})(3411.4 - 2774.6)\text{kJ/kg} + (22.5\ \text{kg/s})(2774.6 - 2153.6)\text{kJ/kg} = 33{,}077\ \text{kW}$$

$$\dot{W}_{\text{p,in}} = \dot{m}_1 w_{\text{pI,in}} + \dot{m}_4 w_{\text{pII,in}} = (22.5\ \text{kg/s})(0.60\ \text{kJ/kg}) + (30\ \text{kg/s})(6.57\ \text{kJ/kg}) = 210.6\ \text{kW}$$

$$\dot{W}_{\text{net}} = \dot{W}_{\text{T,out}} - \dot{W}_{\text{p,in}} = 33{,}077 - 210.6 = \mathbf{32{,}866\ kW}$$

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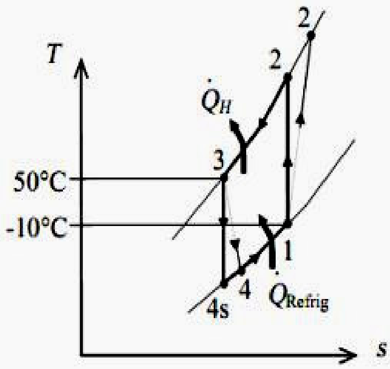
Assumptions **1** Steady operating conditions exist. **2** Helium is an ideal gas with constant specific heats. **3** Kinetic and potential energy changes are negligible.

Properties The properties of helium are $c_p = 5.1926$ kJ/kg·K and $k = 1.667$ (Table A-2).

Analysis (*a*) From the isentropic relations,

$$T_{2s} = T_1\left(\frac{P_2}{P_1}\right)^{(k-1)/k} = (263\text{K})(3)^{0.667/1.667} = 408.2\text{K}$$

$$T_{4s} = T_3\left(\frac{P_4}{P_3}\right)^{(k-1)/k} = (323\text{K})\left(\frac{1}{3}\right)^{0.667/1.667} = 208.1\text{K}$$



and

$$\eta_T = \frac{h_3 - h_4}{h_3 - h_{4s}} = \frac{T_3 - T_4}{T_3 - T_{4s}} \longrightarrow T_4 = T_3 - \eta_T(T_3 - T_{4s}) = 323 - (0.80)(323 - 208.1) = \mathbf{231.1\ K} = T_{\min}$$

$$\eta_C = \frac{h_{2s} - h_1}{h_2 - h_1} = \frac{T_{2s} - T_1}{T_2 - T_1} \longrightarrow T_2 = T_1 + (T_{2s} - T_1)/\eta_C = 263 + (408.2 - 263)/(0.80) = 444.5\text{ K}$$

(*b*) The COP of this gas refrigeration cycle is determined from

$$\text{COP}_R = \frac{q_L}{w_{\text{net,in}}} = \frac{q_L}{w_{\text{comp,in}} - w_{\text{turb,out}}} = \frac{h_1 - h_4}{(h_2 - h_1) - (h_3 - h_4)} = \frac{T_1 - T_4}{(T_2 - T_1) - (T_3 - T_4)} = \frac{263 - 231.1}{(444.5 - 263) - (323 - 231.1)} = \mathbf{0.356}$$

(*c*) The mass flow rate of helium is determined from

$$\dot{m} = \frac{\dot{Q}_{\text{refrig}}}{q_L} = \frac{\dot{Q}_{\text{refrig}}}{h_1 - h_4} = \frac{\dot{Q}_{\text{refrig}}}{c_p(T_1 - T_4)} = \frac{18\text{ kJ/s}}{(5.1926\text{ kJ/kg}\cdot\text{K})(263 - 231.1)\text{K}} = \mathbf{0.109\ \ kg/s}$$

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Analysis (*a*) A relation for Δu is obtained from the general relation

$$\Delta u = u_2 - u_1 = \int_{T_1}^{T_2} c_v dT + \int_{v_1}^{v_2} \left(T\left(\frac{\partial P}{\partial T}\right)_v - P \right) dv$$

The equation of state for the specified gas can be expressed as

$$P = \frac{RT}{v-a} \longrightarrow \left(\frac{\partial P}{\partial T}\right)_v = \frac{R}{v-a}$$

Thus,

$$T\left(\frac{\partial P}{\partial T}\right)_v - P = \frac{RT}{v-a} - P = P - P = 0$$

Substituting, $\quad \Delta u = \int_{T_1}^{T_2} c_v dT$

(*b*) A relation for Δh is obtained from the general relation

$$\Delta h = h_2 - h_1 = \int_{T_1}^{T_2} c_p dT + \int_{P_1}^{P_2} \left(v - T\left(\frac{\partial v}{\partial T}\right)_P \right) dP$$

The equation of state for the specified gas can be expressed as

$$v = \frac{RT}{P} + a \longrightarrow \left(\frac{\partial v}{\partial T}\right)_P = \frac{R}{P}$$

Thus,

$$v - T\left(\frac{\partial v}{\partial T}\right)_P = v - T\frac{R}{P} = v - (v - a) = a$$

Substituting,

$$\Delta h = \int_{T_1}^{T_2} c_p dT + \int_{P_1}^{P_2} a dP = \int_{T_1}^{T_2} c_p dT + a(P_2 - P_1)$$

(*c*) A relation for Δs is obtained from the general relation

$$\Delta s = s_2 - s_1 = \int_{T_1}^{T_2} \frac{c_p}{T} dT - \int_{P_1}^{P_2} \left(\frac{\partial v}{\partial T}\right)_P dP$$

Substituting $(\partial v/\partial T)_P = R/T$,

$$\Delta s = \int_{T_1}^{T_2} \frac{c_p}{T} dT - \int_{P_1}^{P_2} \left(\frac{R}{P}\right)_P dP = \int_{T_1}^{T_2} \frac{c_p}{T} dT - R\ln\frac{P_2}{P_1}$$

For an isothermal process $dT = 0$ and these relations reduce to

$$\Delta u = 0, \quad \Delta h = a(P_2 - P_1), \quad \text{and} \quad \Delta s = -R\ln\frac{P_2}{P_1}$$

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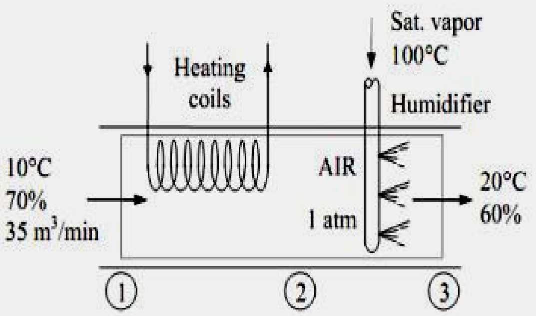
Properties The inlet and the exit states of the air are completely specified, and the total pressure is 1 atm. The properties of the air at various states are determined from the psychrometric chart (Figure A-31) to be

$$h_1 = 23.5 \text{ kJ/kg dry air}$$
$$\omega_1 = 0.0053 \text{ kg H}_2\text{O/kg dry air } (= \omega_2)$$
$$v_1 = 0.809 \text{ m}^3\text{/kg dry air}$$

$$h_3 = 42.3 \text{ kJ/kg dry air}$$
$$\omega_3 = 0.0087 \text{ kg H}_2\text{O/kg dry air}$$



Analysis (*a*) The amount of moisture in the air remains constant it flows through the heating section ($\omega_1 = \omega_2$), but increases in the humidifying section ($\omega_3 > \omega_2$). The mass flow rate of dry air is

$$\dot{m}_a = \frac{\dot{V}_1}{v_1} = \frac{35 \text{ m}^3/\text{min}}{0.809 \text{ m}^3/\text{kg}} = 43.3 \text{ kg/min}$$

Noting that $Q = W = 0$, the energy balance on the humidifying section can be expressed as

$$\dot{E}_{in} - \dot{E}_{out} = \Delta\dot{E}_{system}^{\nearrow 0 \text{ (steady)}} = 0$$
$$\dot{E}_{in} = \dot{E}_{out}$$
$$\sum \dot{m}_i h_i = \sum \dot{m}_e h_e \longrightarrow \dot{m}_w h_w + \dot{m}_{a2} h_2 = \dot{m}_a h_3$$
$$(\omega_3 - \omega_2) h_w + h_2 = h_3$$

Solving for h_2,

$$h_2 = h_3 - (\omega_3 - \omega_2) h_{g@100°C} = 42.3 - (0.0087 - 0.0053)(2675.6) = 33.2 \text{ kJ/kg dry air}$$

Thus at the exit of the heating section we have $\omega_2 = 0.0053$ kg H_2O dry air and $h_2 = 33.2$ kJ/kg dry air, which completely fixes the state. Then from the psychrometric chart we read

$$T_2 = \mathbf{19.5°C}$$
$$\phi_2 = \mathbf{37.8\%}$$

(*b*) The rate of heat transfer to the air in the heating section is

$$\dot{Q}_{in} = \dot{m}_a (h_2 - h_1) = (43.3 \text{ kg/min})(33.2 - 23.5) \text{ kJ/kg} = \mathbf{420 \text{ kJ/min}}$$

(*c*) The amount of water added to the air in the humidifying section is determined from the conservation of mass equation of water in the humidifying section,

$$\dot{m}_w = \dot{m}_a (\omega_3 - \omega_2) = (43.3 \text{ kg/min})(0.0087 - 0.0053) = \mathbf{0.15 \text{ kg/min}}$$

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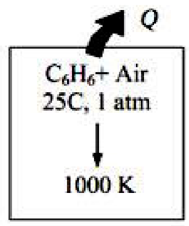
Assumptions **1** Both the reactants and products are ideal gases. **2** Combustion is complete.

Analysis The theoretical combustion equation of C_6H_6 with stoichiometric amount of air is



$$C_6H_6(g) + a_{th}(O_2 + 3.76N_2) \longrightarrow 6CO_2 + 3H_2O + 3.76a_{th}N_2$$

where a_{th} is the stoichiometric coefficient and is determined from the O_2 balance,

$$a_{th} = 6 + 1.5 = 7.5$$

Then the actual combustion equation with 30% excess air becomes

$$C_6H_6(g) + 9.75(O_2 + 3.76N_2) \longrightarrow 5.52CO_2 + 0.48CO + 3H_2O + 2.49O_2 + 36.66N_2$$

The heat transfer for this constant volume combustion process is determined from the energy balance $E_{in} - E_{out} = \Delta E_{system}$ applied on the combustion chamber with $W = 0$. It reduces to

$$-Q_{out} = \sum N_P\left(\bar{h}_f^\circ + \bar{h} - \bar{h}^\circ - P\bar{v}\right)_P - \sum N_R\left(\bar{h}_f^\circ + \bar{h} - \bar{h}^\circ - P\bar{v}\right)_R$$

Since both the reactants and the products behave as ideal gases, all the internal energy and enthalpies depend on temperature only, and the $P\bar{v}$ terms in this equation can be replaced by R_uT.

It yields

$$-Q_{out} = \sum N_P\left(\bar{h}_f^\circ + \bar{h}_{1000\text{ K}} - \bar{h}_{298\text{ K}} - R_uT\right)_P - \sum N_R\left(\bar{h}_f^\circ - R_uT\right)_R$$

since the reactants are at the standard reference temperature of 25°C. From the tables,

Substance	$\bar{h}_f^\circ$ kJ/kmol	$\bar{h}_{298\text{ K}}$ kJ/kmol	$\bar{h}_{1000\text{ K}}$ kJ/kmol
C_6H_6 (*g*)	82,930	---	---
O_2	0	8682	31,389
N_2	0	8669	30,129
H_2O (*g*)	-241,820	9904	35,882
CO	-110,530	8669	30,355
CO_2	-393,520	9364	42,769

Thus,

$$\begin{aligned}-Q_{out} = &(5.52)(-393{,}520 + 42{,}769 - 9364 - 8.314\times1000)\\ &+(0.48)(-110{,}530 + 30{,}355 - 8669 - 8.314\times1000)\\ &+(3)(-241{,}820 + 35{,}882 - 9904 - 8.314\times1000)\\ &+(2.49)(0 + 31{,}389 - 8682 - 8.314\times1000)\\ &+(36.66)(0 + 30{,}129 - 8669 - 8.314\times1000)\\ &-(1)(82{,}930 - 8.314\times298) - (9.75)(4.76)(-8.314\times298)\\ =& -2{,}200{,}433 \text{ kJ}\end{aligned}$$

or $\quad Q_{out} = \mathbf{2{,}200{,}433\ kJ}$