工程热力学单元习题及答案

习题 1-4：

解：两容器和大气存在以下关系：

$$\begin{cases} P_{右} - P_0 = P_A \\ P_{右} - P_{左} = P_B \\ P_{左} - P_0 = P_C \end{cases}$$

(1) $P_c = P_A - P_B = 2.5bar - 1.1bar = 1.4bar$

(2) $P_{左} = P_c + P_0 = 2.5bar$

习题 1-10：

解：压力计使用前后右端有 $\frac{P_0V_0}{T_0} = \frac{P_1V_1}{T_1}$ 。

则 $P_1 = \frac{P_0V_0}{T_0}\frac{T_1}{V_1} = \frac{1*(400+150)}{288}\frac{303}{400} = 1.447bar$

又 $P_1 + \rho_{水银}gh_1 = P_{测} + \rho_{水}gh_2$

$$P_{测} = P_1 + \rho_{水银}gh_1 - \rho_{水}gh_2$$
$$= 1.447*10^5 + 13600*9.8*300*10^{-3} - 1000*9.8*1000*10^{-3}$$
$$= 174884pa = 1.75bar$$

习题 2-4：

答：根据题意，初始时

$$Ka_1 = P_1A$$

$$V_1 = a_1A = 3 \times 10^{-5}m^3$$

代入数据得

$$P_1 = 4.5 \times 10^5Pa$$

$$m_1 = \frac{P_1 V_1}{R_{CO^2} T_1} = 2.335 \times 10^{-3} kg$$

末端时

$$Ka_2 = P_2 A$$

$$V_2 = a_2 A = 2.55 \times 10^{-5} m^3$$

代入数据得

$$P_2 = 3.825 \times 10^5 Pa$$

已知$m_1 = m_2$

$$T_2 = \frac{P_2 V_2}{R_{CO^2} m_2} = 216.47\text{K}$$

此系统为一闭口系统，有能量方程

$$Q = \Delta U + W$$

过程中气体放出的热量

$$Q = mc_v(T_2 - T_1) + \int_{a_1}^{a_2} \frac{ka}{A} d(Aa)$$

$$mc_v(T_2 - T_1) = 2.335 \times 10^{-3} \times \frac{29.1}{44} \times (-83.68) J = -129.2J$$

因为$1kg \cdot m = 9.81 \times 10^{-3} kJ$

$$\int_{a_1}^{a_2} \frac{ka}{A} d(Aa) = \int_{a_1}^{a_2} kada = \frac{k(a_2^2 - a_1^2)}{2} = -187.31 kg \cdot cm$$
$$= -18.37J$$

$$Q = \Delta U + W = -147.57J$$

过程中气体放出的热量$147.57J$。

习题 2-5：

答：　　q=5.69kJ/kg　T_2=-20℃ T_1=15℃

$q=c_n \Delta T$　$c_n = q/\Delta T == 2.857 kJ/(\text{kg K})$

已知气体为氧气

$c_n = \frac{n-k}{n-1} c_v$

可得 n=1.53

$\left(\frac{P_2}{P_1}\right)^{\frac{n-1}{n}} = \frac{T_2}{T_1}$

$P_2 = 103bar$

习题 2-9：

答： $Q = W$

$200 + 20 + 0 - 210 = 1400 + 0 + 2250 + W_4$

$W_4 = -3640KJ$

习题 3-9：

解：

根据熵的计算

$$S_2 - S_1 = C_V \ln\frac{P_2}{P_1} + C_P \ln\frac{V_2}{V_1}$$

$$\frac{S_2 - S_1}{C_V} = \ln\frac{P_2}{P_1} + k \ln\frac{\rho_1}{\rho_2}$$

$$\frac{P_2}{\rho_2^k} = \frac{P_1}{\rho_1^k} e^{\frac{S_2 - S_1}{C_V}}$$

习题 3-16：

解：由$\frac{T_1}{T_2} = \left(\frac{V_2}{V_1}\right)^{n-1}$得

$$\frac{273 + 300}{60 + 300} = 3^{n-1}$$

n=1.42

$$q_n = mC_n(T_2 - T_1)$$

$$W_n = m\frac{R_g}{1-n}(T_1 - T_2)$$

由

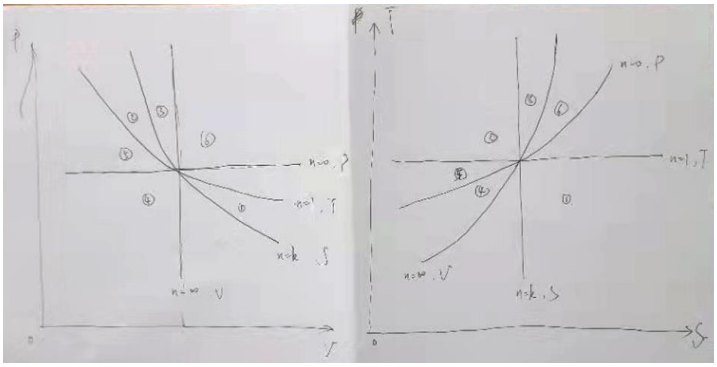
$$\begin{cases} 20 = 2 \times \dfrac{1.42-k}{0.42} \times \dfrac{1}{k-1} R_g \times (60-300) \\ -100 = 2 \times \dfrac{R_g}{1-1.42} \times (300-60) \end{cases}$$

得

$R_g = 0.0875kJ/(kg \cdot K)$，$k = 1.35$

$$C_n = \frac{1.42-1.35}{0.42} \times \frac{1}{1.35-1} \times 0.0875 = 0.04167kJ/(kg \cdot K)$$

习题 3-24：



习题 3-25：

解：①已知$T_{A1} = T_{B1} = 300K$，$P_{A1} = P_{B1} = 1bar$，$V_{A1} = V_{B1} = 0.5m^3$，$P_{A2} = 202bar$，活塞是自由的，故$P_{B2} = P_{A2} = 202bar$。

$$Rg_{N_2} = \frac{R}{M_{N_2}} = 296.95J/(kg \cdot k)$$

$$Rg_{O_2} = \frac{R}{M_{O_2}} = 259.83J/(kg \cdot k)$$

$$m_A = \frac{P_{A1}V_{A1}}{Rg_{N_2}T_{A1}} = 0.56kg$$

$$m_B = \frac{P_{B1}V_{B1}}{Rg_{O_2}T_{B1}} = 0.64kg$$

由于 B 内进行可逆绝热过程，

$$T_{B2} = T_{B1}(\frac{T_{B2}}{T_{B1}})^{\frac{k-1}{k}} = 1367.08K$$

$$V_{B2} = \frac{m_B R g_{O_2} T_{B2}}{P_{B2}} = 0.01m^3$$

②

$$V_{A2} = 1 - V_{B2} = 0.99m^3$$

$$T_{A2} = \frac{P_{A2} V_{A2}}{R g_{N_2} m_A} = 120258.34K$$

③

$$Cv_{N_2} = \frac{R g_{N_2}}{k-1} = 742.375J/(kg \cdot k)$$

$$Cv_{O_2} = \frac{R g_{O_2}}{k-1} = 649.575J/(kg \cdot k)$$

取 A+B 为热力系，则

$$Q = \Delta U_A + \Delta U_B = m_A Cv_{N_2}(T_{A2} - T_{A1}) + m_B Cv_{O_2}(T_{B2} - T_{B1}) = 50313.9kJ$$

取 B 为热力系，则

$$W_B = -\Delta U_B = -m_B Cv_{O_2}(T_{B2} - T_{B1}) = -443.62kJ$$

故$W_A = -W_B = 443.62kJ$

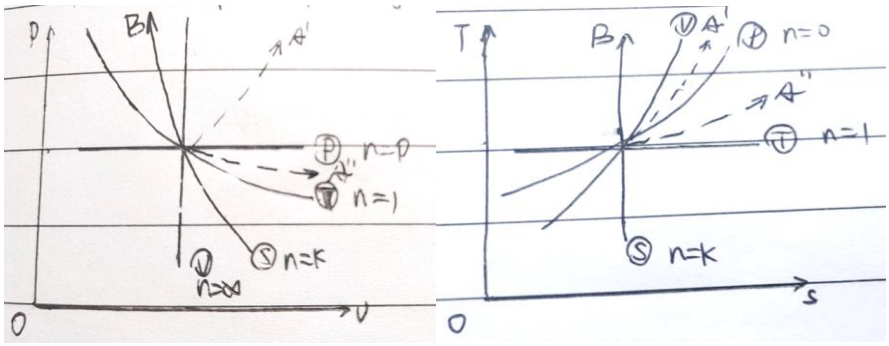
④

$$\Delta S_{O_2} = 0$$

$$Cp_{N_2} = Cv_{N_2} + R g_{N_2} = 1039.325J/(kg \cdot k)$$

$$\Delta S_{N_2} = m_A \left(Cp_{N_2} \ln \frac{T_{A2}}{T_{A1}} - R g_{N_2} \ln \frac{P_{A2}}{P_{A1}} \right) = 2.61kJ/K$$

⑤



习题 4-4：

解：$\eta_1 = \left(1 - \frac{T_2}{T_1}\right)/2 = \left(1 - \frac{200+273}{1000+273}\right)/2 = 0.314$

$\eta_2 = \left(1 - \frac{T_2}{T_1'}\right)/2 = \left(1 - \frac{200+273}{1100+273}\right)/2 = 0.328$

$Q_1 = \frac{w}{\eta_1}$　　$Q_1' = \frac{w'}{\eta_2}$　　取　$\mathrm{w} = 1\mathrm{J}$　　$w' = 1\mathrm{J}$

$\frac{Q_1 - Q_1'}{Q_1} = \frac{1/\eta_1 - 1/\eta_2}{1/\eta_1} = 4.3\%$

习题 4-6：

①两机输出功相等。②两机热效率相等。

解：(1) $w_1 = w_2$　　$\eta_1 Q_1 = \eta_2 Q_A$

$\eta_1/\eta_2 = Q_A/Q_1$　　$\eta_1 = 1 - Q_A/Q_1$　　$Q_A/Q_1 = 1 - \eta_1$

$\eta_1/\eta_2 = 1 - \eta_1$

$\frac{1 - T/T_1}{1 - T_2/T} = 1 - (1 - T/T_1) = T/T_1$

T_1=627+273=900K　　T_2=27+273=300K

$\mathrm{T} = \frac{1}{2}(T_1 + T_2) = 600K$

(2) $\eta_1 = \eta_2$　　$1 - T/T_1 = 1 - T_2/T$

$\mathrm{T} = \sqrt{T_1 T_2} = 519.6K$

习题 4-9：

解：(1) $Q_{排}=0.65\times[20-(-10)]=19.5kW$

$$\varepsilon_{max}=\frac{T_1}{T_1-T_2}=\frac{273+20}{20-(-10)}=9.77$$

$$w_{min}=\frac{Q_{排}}{\varepsilon_{max}}=\frac{19.5}{9.77}=2kW$$

(2) $\frac{Q_{吸}}{w}=\frac{T_2}{T_1-T_2}$ $\frac{Q_{吸}}{2}=\frac{273+20}{T_1-(273+20)}$

$Q_{排}=0.65\times(T_1-T_2)$ $\frac{w}{T_1-T_2}=\frac{Q_{吸}}{T_2}=\frac{Q_{排}}{T_1}$

$\frac{293\times2}{(T_1-293)\times293}=\frac{0.65\times(T_1-293)}{T_1}$ $T_1=324K$

习题 4-14：

解：(1)T_m可由计算熵增办法证明。将热源T_A、冷源T_B和热机考虑为一个孤立系，因整个过程是可逆，因此$\Delta S_{孤}=0$

$$\begin{aligned}\Delta S_{孤}&=\Delta S_A+\Delta S_{热机}+\Delta S_B\\&=m\int\frac{\delta Q_A}{T}+m\int\frac{\delta Q_B}{T}+0\\&=mC_p\int_{T_A}^{T_m}\frac{dT}{T}+mC_p\int_{T_B}^{T_m}\frac{dT}{T}\\&=mC_p\ln\frac{T_m}{T_A}++mC_p\ln\frac{T_m}{T_B}=0\end{aligned}$$

$\ln\frac{T_m}{T_A}=\ln\frac{T_B}{T_m}$ $\frac{T_m}{T_A}=\frac{T_B}{T_m}$

所以 $T_m=\sqrt{T_A\cdot T_l}$

(2)可逆热机作出的总功 $W_o=Q_A-Q_B$

$$\begin{aligned}W_o&=mC_p(T_A-T_B)-mC_p(T_m-T_B)\\&=mC_p(T_A-2T_m+T_B)\\&=mC_p\left(T_A+T_B-2\sqrt{T_A\cdot T_B}\right)\end{aligned}$$

(3)抽掉 A，B 之间的热机后，则$Q_A=Q_B$即

$$mC_p\left(T_A-T_m\right)=mC_p\left(T_m-T_B\right)$$

所以 $$T_m=\frac{1}{2}\left(T_A+T_B\right)$$

热源熵增 $$\Delta S_A=m\int\frac{\delta Q_A}{T}=mC_p\int_{T_A}^{T_m}\frac{dT}{T}=mC_p\ln\frac{T_m}{T_A}=mC_p\frac{T_A-T_B}{2T_A}$$

冷源熵增 $$\Delta S_B=m\int\frac{\delta Q_B}{T}=mC_p\int_{T_B}^{T_m}\frac{dT}{T}=mC_p\ln\frac{T_m}{T_B}=mC_p\frac{T_A-T_B}{2T_B}$$

整个孤立系熵增：

$$\Delta S_{孤}=\Delta S_A+\Delta S_B$$

$$=mC_p\ln\left[\frac{T_A+T_B}{2T_A}\cdot\frac{T_A+T_B}{2T_B}\right]$$

$$\Delta S=mC_p\,ln\frac{\left(T_A+T_B\right)^2}{4T_AT_B}$$

习题 4-16：

解：将两个物体和制冷机组成的整体视为一孤立系，则有：

$$\triangle S=\triangle S_{热}+\triangle S_{冷}+\triangle S_{机}\geq 0$$

其中，$\triangle S_{机}=0$，$\triangle S_{热}=\int_{T_i}^{T_1}cm\frac{dT}{T}$，$\triangle S_{冷}=\int_{T_i}^{T_f}cm\frac{dT}{T}$

则有：$$\left(\int_{T_i}^{T_1}cm\frac{dT}{T}+\int_{T_i}^{T_f}cm\frac{dT}{T}\right)\geq 0$$

可求得：$$T_1\geq\frac{T_i^2}{T_f}$$

可逆热机做功为：

$$W=Q_1-Q_2=cm\left(T_1-T_i\right)+cm\left(T_f-T_i\right)\geq cm\left(\frac{T_i^2}{T_f}+T_f-2T_i\right)$$

则最小做功

$$W_{min} = cm\left(\frac{T_i^2}{T_f} + T_f - 2T_i\right)$$

习题 5-12：

解：从水蒸气表中查出，4bar 时的状态参数为：

$T_1 = 143.642\ ℃$

$v_1' = 0.0010835\ m^3/kg$

$v_1'' = 0.46246\ m^3/kg$

$h_1' = 604.87\ kJ/kg$

$h_1'' = 2738.49\ m^3/kg$

$s_1' = 1.7769\ kJ/K/kg$

$s_1'' = 6.8961\ kJ/K/kg$

从水蒸气表中查出，0.6 bar 时的状态参数为：

$T_2 = 85.9496\ ℃$

$v_2' = 0.0010331\ m^3/kg$

$v_2'' = 2.7324\ m^3/kg$

$h_2' = 359.91\ kJ/kg$

$h_2'' = 2652.97\ m^3/kg$

$s_2' = 1.1454\ kJ/K/kg$

$s_2'' = 7.531 kJ/K/kg$

设膨胀过程为可逆过程，则熵保持不变，膨胀后干度为 x_2，则有：

$x \cdot s_1'' + (1-x) \cdot s_1' = x_2 \cdot s_2'' + (1-x_2) \cdot s_2'$

代入后解得：$x_2 = 0.74$

膨胀后的容积：

$$m = \frac{V_1}{x \cdot v_1'' + (1-x_1) \cdot v_1'} = 3.2417\ kg$$

$$V_2 = m\left(x_2 \cdot v_2'' + (1-x_2) \cdot v_2'\right) = 6.5556\ m^3$$

$$h_1 = x \cdot h_1'' + (1-x) \cdot h_1' = 2311.766\ kJ/kg$$

$$h_2 = x_2 \cdot h_2'' + (1-x_2) \cdot h_2' = 2056.7744\ kJ/kg$$

在此过程中，

δQ=δW+dU=δW+dh-δPV=0

因此，$W=-(H_2-P_2V_2)+(H_1-P_1V_1)=-85813.3924$

习题 5-13：

解：（1）用完全气体状态方程

$$V = \frac{RT}{P} = \frac{\frac{8314}{18} \times (273+600)}{80 \times 10^5} = 0.05 m^3/kg$$

（2）用对比态方程

$$P_r = \frac{P}{P_{Cr}} = \frac{80}{220.9} = 0.362$$

$$T_r = \frac{T}{Tcr} = \frac{873}{647.3} = 1.349$$

查图 5-2 通用压缩因子图得

Z≈0.96

则 $v = \frac{ZRT}{P} = 0.96X0.05 = 0.048 m^3/kg$

（3）查水蒸汽表，

$$v = 0{,}048394 m^3 / kg$$

习题 5-14：

解：4bar、200℃为过热蒸汽，查表得$h_1 = 2860.4 kJ/kg$，

$v_1 = 0.53426 m^3/kg$，$\delta = 7.1708 kJ/kg \cdot k$。而$x = 0.2$　$P_2 = P_1 = 4\ bar$

查饱和蒸汽表，$t_2 = 143.63\ ℃$

而$h' = 604.7$、$h'' = 2737.6$

则$h_2 = h''x + (1-x)h' = 0.2 \times 2737.6 + 0.8 \times 604.7 = 1031.28$

$|q_p| = h_1 - h_2 = 2860.4 - 1031.28 = 1829.12 kJ/kg$

$$\dot{M} = \frac{10^6}{1829.12} = 546.71 kg$$

习题 6-5：(题中有两 H_2,将 5%的 H_2 改为 N_2)

解析：设煤气摩尔数 n_1 为 1mol；

$m_{CO} = 0.07*28 = 1.96$　$m_{H2} = 0.48*2 = 0.96$　$m_{CH4} = 0.40*16 = 6.4$
$m_{N2} = 0.05*28 = 1.4$;

煤气质量 $m_1 = 10.72$ g 空气质量 $m_2 = 10.72*8 = 85.76$ g

混合气质量 m =96.48　　;

空气摩尔数 $n_2 = \frac{m_2}{M} = 2.9786$ mol

混合气质量数 $M = \frac{m}{n} = \frac{10.72*9}{1+2.9879} = 24.2479$ g/mol;

各组分质量成分：

$\omega_{co} = \frac{1.96}{96.48} = 2.03\%$　$\omega_{H2} = \frac{0.96}{96.48} = 1\%$　$\omega_{CH4} = \frac{6.4}{96.48} = 6.63\%$

$\omega_{N2} = \frac{1.4+85.76*78\%}{96.48} = 70.78\%$ $\omega_{o2} = \frac{85.76*21\%}{96.48} = 19.56\%$

当 P = 1.2 bar , T = 373 K , V = 10m^3 时；

$R_g = \sum \omega R_{gi}$ = 2.03%*296.928 + 1%*4157 + 6.63%*519.635 + 70.78%*296.928 + 19.56%*259.8125= 343.03;

又 PV = mRgT

m = 9.378 kg

习题 6-7：

解：（1）$Rg = \omega_{o2}Rg_{o2} + \omega_{H2O}Rg_{H2O}$

$= \frac{1}{1+0.34} * Rg_{o2} + \frac{0.34}{1+0.34} * Rg_{H2O}$

= 193.89 + 117.1957

= 311.0856 J/(Kg K)

$C_P = \omega_{o2}C_{Po2} + \omega_{H2O}C_{PH2O}$

$= \frac{1}{1+0.34} * 1.006 + \frac{0.34}{1+0.34} * 1.873$

= 1226 J/(Kg K)

$C_P = Rg * \frac{\lambda}{\lambda-1}$ $\lambda = 1.34$

（2） $\frac{T_2}{T_1} = (\frac{P_2}{P_1})^{\frac{k-1}{k}}$ 代入数据 $T_2 = 468.57$ K

（3） $\Delta S_{水} = m_{水}（C_P \ln\frac{T2}{T1} - Rg \ln\frac{p2}{p1}）= 3.258$J/(Kg K)

$\Delta S_{气} = m_{气}（C_P \ln\frac{T2}{T1} - Rg \ln\frac{p2}{p1}）= -22.002$ J/(Kg K)

习题 6-18：

解析：

$t=30$，$t_\infty=20$，由t_{30}可知$P_{sg}=0.0424bar$，

$$d=\frac{1.005\times10^3(20-30)+d_3L_3}{1.86(t_1-t_\infty)+L_3}=\frac{-10050+36561.8}{18.6+2454.3}=10.7g_a/Kg_a$$

$$\varphi=\frac{Bd}{(622+d_1)P_{s\dot{g}}}=\frac{1\times10.7}{(622+17)\times0.0424}=39.9\%$$

$$P_v=\varphi P_{sg}=39.9\%\times0.0424=0.01692bar$$

蒸汽饱和，可知$t_p=10+4.176=14.176℃$

习题 6-24：

解析：由 0.8 及 0℃查图

h_1=7 kJ/kg

其 d 加热至 18℃查图

h_2=27 kJ/kg，$\varphi=23\%$

得 $\Delta h=27-7=20$ kJ/kg

习题 7-2：

解：水的比热容是$C_W=4.187KJ/(kg\cdot℃)$，温升 14℃时，水套吸热。

$$Q=q_{m,w}\cdot C_w\cdot\Delta t=\frac{465\text{kg/h}}{3600\text{s/h}}\times4.187\text{kJ}(\text{kg}\cdot°c)\times14°\text{c}=7.5715\text{kJ/s}$$

进气流量：$q_{m,a}=\dfrac{p_1V_1}{R_gT_1}=\dfrac{0.1\times10^6\times250}{3600\times287\times293}=0.08258\text{kg/s}$

单位质量空气放热：$q=\dfrac{Q}{q_{m,a?}}=91.6868\text{kJ/kg}$，因此加负号后换热量 $q=-91.6868\text{k7kJ/kg}$

根据 $q=\dfrac{n-K}{n-1}C_W(T_2-T_1)$ 得到：$\dfrac{n-k}{n-1}=\dfrac{q}{C_W(T_2-T_1)}$

$$C_W=\frac{1}{k-1}R_g=\frac{1}{1.4-1}\times287J/(kg\cdot k)=717.5J/(kg\cdot k)$$

所以 $\dfrac{n-k}{n-1}=\dfrac{-91.6868\times10^3\text{J/kg}}{717.5J(\text{kg}\cdot\text{k})\times(150-20)}=-0.983$

n=1.2

所以 $\frac{P_2}{P_1}=\left(\frac{T_2}{T_1}\right)^{\frac{n}{n-1}}, P_2=\left(\frac{150+273}{20+273}\right)^{\frac{1.2}{1.2-1}}, P_1=0.905\text{MPa}$

（2）压气机的功率 $P=W_c\cdot q_{m,a}$

根据热力学第一定律： $q=\Delta h+W_c$

$$W_c=q-\Delta h=-91.6868\text{kJ/g}-\frac{k}{k-1}R(T_2-T_1)$$

$$=-91.6868\text{kJ/kg}-\frac{1.4}{1.4-1}\times 287\times(150-20)\text{J/kg}$$

$$=-222,2718\text{kJ)kg}$$

习题 7-7：（删除原题中压比的已知条件）

解：压气机增压比为 $\pi_c=7.047$

压气机为绝热过程，消耗的功：

$W=\Delta h=Cp\times(T_2-T_1)=1.004\text{kJ/(kg}\cdot\text{k)}\times(534\text{K}-288\text{K})=246.8\text{kJ/kg}$

功率： $P=q_m\cdot\omega=13.28\text{kg/s}\times 246.98\text{kJ/kg}=3279.95\text{kw}$

（2）若看作等熵过程，压缩后温度为 $T_{2S}=\pi_c^{\frac{k-1}{k}}T_1=7.047^{\frac{1.4-1}{1.4}}\times 288K=503.13\text{K}$

绝热效率： $\eta_c=\frac{T_{2s}-T_1}{T_2-T_1}=\frac{503.13-288}{534-288}=0.875$

(3)若将它看作一个多变过程，则多变指数为：

$n=\frac{\ln P_2-\ln P_1}{\ln V_2-\ln V_1}=1.46,$ 其中 $V_1=\frac{RgT_1}{P_1}=0.9246\text{m}^3$ $V_2=\frac{\text{RgT}_2}{P_2}=0.2433\text{m}^3$

习题 7-9：

解： $q=\Delta h+w_s+\Delta\frac{1}{2}C^2{}_f, q=0$

$\Delta h=C_p(T_2-T_1)=1.004\text{kJ/kg}\times(150^\circ\text{C}-20^\circ\text{C})=130.52\text{kJ/kg}$

$\frac{1}{2}\Delta C_f{}^2=\frac{1}{2}\times(50^2-10^2)=1.2\text{kJ/kg}$

$W_S=-\Delta h-\frac{1}{2}\Delta C_f{}^2=131.72\text{kJ/kg}$ 每千克消耗 131.72kJ 的功

② $T_{2S}=T_1\cdot\left(\frac{p_2}{p_1}\right)^{\frac{k-1}{k}}=293\mathrm{K}\times\left(\frac{3}{1}\right)^{\frac{1.4-1}{1.4}}=401.04\mathrm{K}$

$$\eta_c=\frac{T_{2s}-T_1}{T_2-T_1}=\frac{401.04-293}{150-20}=0.831$$

③ $\Delta S=C_p\ln\frac{T_2}{T_1}-Rg\cdot\frac{P_2}{P_1}=1.004\mathrm{kJ(kg\cdot k)}\times\ln\frac{423}{293}-0.287\mathrm{kJ(kg\cdot k)}\times\ln\frac{3}{1}=0.05337\mathrm{kJ/(kg\cdot k)}$

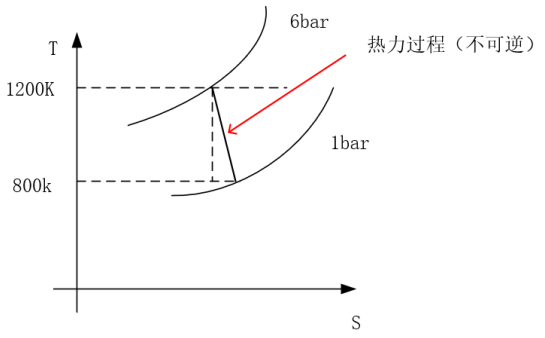
习题 7-12：

解：$W_T=-\Delta h=C_p\left(T_1-T_2\right)$

$$T_2=T_1-\frac{W_T}{C_p}=1200-\frac{404kJ/kg}{1.01\mathrm{kJ/(kg\cdot k)}}=800\mathrm{K}$$

$$S_g=\Delta S=C_pln\frac{T_2}{T_1}-Rg\ln\frac{p_2}{p_1}=1.01\mathrm{kJ}(kg\cdot\mathrm{k})\times\ln\frac{800}{1200}-0.286\mathrm{kJ/(kg\cdot k)}\times\ln\frac{1}{6}=102.92\mathrm{J(kg\cdot k)}$$

表示在 T-S 图上为：



习题 8-3：

答：

$$\mathrm{T^*=T+\frac{Cf^2}{2Cp}}$$

$$C_P=1.005$$

$$\Delta\mathrm{T1=T1^*-T1=1120.52K}$$

$$\Delta\mathrm{T2=T2^*-T2=31.12K}$$

习题 8-6：

答：

$$C_P = \frac{k}{k-1}Rg$$

$$\mathrm{Ma} = \frac{cf}{c}$$

$$T^* = T + \frac{C_f^2}{2C_P} = T + \frac{k-1}{2}Ma^2T = Tcr + \frac{k-1}{2}Tcr$$

得证，

$$\frac{T}{T_{cr}} = \frac{(k+1)/2}{1+\frac{k-1}{2}M^2}$$

习题 8-11：

答：$T^* = T + \frac{C_f^2}{2C_P} = 850 + \frac{318^2}{2*1004} = 900.34K$

$$P^* = P_1(\frac{T^*}{T})^{\frac{k}{k-1}} = 1.82bar$$

$$\mathrm{Pcr} = (\frac{2}{k+1})^{\frac{k}{k-1}}P^* = 0.962bar > 0.9bar$$

$$Cf_2 = 549m/s$$

习题 8-14：

答：

$p_1 = 1\times10^5 Pa$，$p_2 = 1.4\times10^5 Pa$

$T_1 = 273+30 = 303K$

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{k-1/k} = 303K\times\left(\frac{1.4}{1}\right)^{1.4-1/1.4}$$

=333.6K

出口速度为零时，所需的进口速度最小为：

$c_p = 1.004kJ/(kg\cdot K)$

$c_{f1} = \sqrt{2c_p(T_2 - T_1)}$

$= \sqrt{2\times 1004(333.6-303)}$

$= 247.9m/s$

习题 8-15：

答：

$p_1 = 3\times 10^5 Pa$，$p_2 = 2\times 10^5 Pa$

$T_1 = 273+800 = 1073K$

$$T_2 = T_1\left(\frac{p_2}{p_1}\right)^{k-1/k} = 1073K\times\left(\frac{2}{3}\right)^{1.4-1/1.4}$$

=955.6K

忽略进口速度时，出口流速为：

$c_p = 1.004kJ/(kg\cdot K)$

$c_{f2} = \sqrt{2c_p(T_1 - T_2)}$

$= \sqrt{2\times 1004(1073-955.6)}$

$= 485.5m/s$

$$v_2 = \frac{R_g T_2}{p_2} = \frac{287\times 955.6}{2\times 10^5} m^3/kg = 1.37m^3/kg$$

出口截面积：

$$\dot{m} = \frac{c_{f,2}A_2}{v_2}$$

$$A_2 = \frac{\dot{m}v_2}{c_{f,2}} = \frac{1\times 1.37}{485.5} = 0.0028m^2$$

习题 8-16：

答：

$p_1 = 5\times 10^5 Pa$，$p_2 = 3\times 10^5 Pa$

$T_1 = 1000K$

若过程为可逆绝热过程：

$T_{2s}=T_1\left(\frac{p_2}{p_1}\right)^{k-1/k}=1000K\times\left(\frac{3}{5}\right)^{1.4-1/1.4}$ =864.2K

（1）根据能量守恒方程：

$T_2=T_1\text{-}\frac{c_{f2}^2}{2c_p}=1000K-\frac{470^2}{2\times1004}$ =890K

（2）过程的熵增

$\Delta s=c_p\ln\frac{T_2}{T_1}-R_g\ln\frac{p_2}{p_1}$ 或

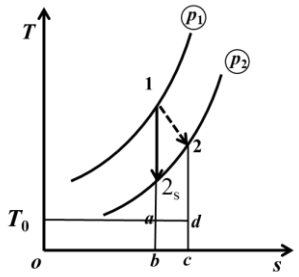
$\Delta s=c_p\ln\frac{T_2}{T_{2s}}$

$=1.004\times\ln\frac{890}{864.2}$

$=0.0295kJ/(kg\cdot K)$

（3）做功力损失：T-S 上面积 $A_{abcd,}$ $I=T_0\Delta s$

摩擦产生的热量：T-S 图上面积 $A_{22sbc,}$ $Q=c_p(T_2-T_{2s})$



习题 9-4

解：

$\eta_t=1-\frac{1}{\varepsilon^{k-1}}=0.5$

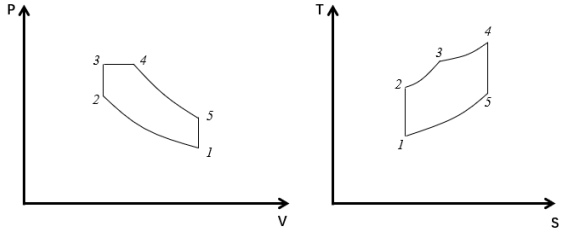
$\therefore\varepsilon^{0.4}=2$

$\frac{T_2}{T_1}=\varepsilon^{k-1}=2$

$\therefore T_2=2T_1=2\times288=576K$

习题 9-5

答：



循环中工质吸热 q_1，放热 q_2

T_1=363.15K，T_2=673.15K，T_3=863.15K，T_5=573.15K

$$p_2=p_1(\frac{T_2}{T_1})^{\frac{k}{k-1}}=0.867Mpa$$

$$p_3=p_2\frac{T_3}{T_2}=1.11Mpa$$

$$p_4=p_3$$

$$p_5=p_1(\frac{T_5}{T_1})=0.1578\text{Mpa}$$

$$T_4=T_5(\frac{p_4}{p_5})^{\frac{k-1}{k}}=T_5(\frac{p_3}{p_5})^{\frac{k-1}{k}}=1000.7K$$

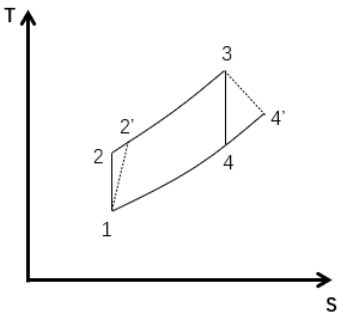
$$q_{in}=q_{2-3}+q_{3-4}=c_v(T_3-T_2)+c_p(T_4-T_3)=136.42+138.1=274.52K$$

$$q_{out}=c_v(T_5-T_1)=150.78K$$

$$\eta=\frac{q_{in}-q_{out}}{q_{in}}=45.07\%$$

习题 9-12

答：



$\eta_c = 0.85$，$\eta_t = 0.9$，$T_1 = 288K$

$$\pi = \frac{P_2}{P_1} = \frac{P_3}{P_4} = 9.5$$

$T_3 = 1000K$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{k-1}{k}} = 288\times 9.5^{\frac{1.4-1}{1.4}} = 548K$$

$$\eta_c = \frac{h_2 - h_1}{h_{2'} - h_1} = \frac{T_2 - T_1}{T_{2'} - T_1}$$

$$\therefore T_{2'} = T_1 + \frac{T_2 - T_1}{\eta_c} = 594K$$

$$\eta_c = \frac{h_3 - h_{4'}}{h_3 - h_4} = \frac{T_3 - T_{4'}}{T_3 - T_4}$$

$$T_4 = T_3\left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}} = 526K$$

$$T_{4'} = T_3 + \eta_c\left(T_3 - T_4\right) = 573K$$

$$\omega_0 = \omega_{34'} - \omega_{12'} = \left(h_3 - h_{4'}\right) - \left(h_{2'} - h_1\right) = 121\text{kJ/kg}$$

$$\eta_t = \frac{\omega_0}{q_{x0}} = \frac{\omega_0}{c_p\left(T_3 - T_{2'}\right)} = 0.29$$

习题 9-14

答：

1）当$\pi = \frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} = \frac{1273.15^{\left(\frac{1.4}{0.4}\right)}}{288.15}$ =181.3 时，η_t最大

2）当π为0时，η_t最小

3）$T_1 = 288.15K, T_3 = 1273.15K$

$$\eta_t = 1 - \frac{1}{\pi^{\frac{k-1}{k}}}$$

η_t随π的增大而提高

$$\omega_{net} = \omega_T - \omega_c = c_p\left(T_3 - T_4\right) - c_p\left(T_2 - T_1\right)$$

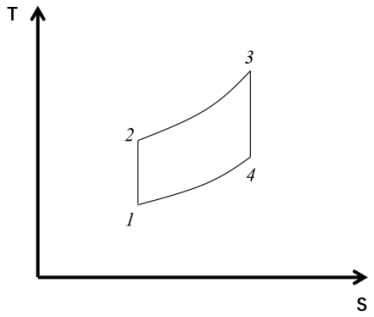
$$= c_p T_1\left(\frac{T_3}{T_1} - \frac{T_4}{T_1} - \frac{T_2}{T_1} + 1\right) = c_p T_1\left(\tau - \tau\pi^{\frac{1-k}{k}} - \pi^{\frac{1-k}{k}} - 1\right)$$

令$\frac{d\omega_{net}}{d\pi} = 0$，$\pi_{opt} = \tau^{\frac{k}{2(k-1)}} = 13.46$, w最大

习题 9-18

答：

$T_1 = 223.13K$，$P_1 = 0.3bar$，$c_p = 1.004kJ/(kg \cdot K)$



$c_{f1} = 900m/s$，$c_{f2} = 100m/s$

$$h_1 + \frac{1}{2}{c_{f1}}^2 = h_2 + \frac{1}{2}{c_{f2}}^2$$

$$T_2 = \frac{1}{2c_p}\left({c_{f1}}^2 - {c_{f2}}^2\right) + T_1 = 622.3K$$

$$\pi = \frac{P_2}{P_1} = \left(\frac{T_2}{T_1}\right)^{\frac{k}{k-1}} = 36.23$$

$$q_1 = c_p\left(T_3 - T_2\right) = 400kJ/kg$$

$$T_3 = 1020.7K$$

$$T_4 = T_3\left(\frac{P_4}{P_3}\right)^{\frac{k-1}{k}} = T_3\left(\frac{P_1}{P_2}\right)^{\frac{k-1}{k}} = 366K$$

$$q_2 = c_p\left(T_4 - T_1\right) = 143.44kJ/kg$$

$$w = q_1 - q_2 = 256.56kJ/kg$$

$$\eta = \frac{w}{q_1} = 64.14\%$$

习题 9-22

1）不带回热

$T_2=T_1\left(\pi\right)^{\frac{k-1}{k}}=577.52K$

$q_{in}=c_p(T_3-T_2)=738.72\,\mathrm{KJ/\,K\,g}$

$T_4=T_3\left(\frac{1}{\pi}\right)^{\frac{k-1}{k}}=662K$

$q_{out}=c_p(T_4-T_1)=372.35\,\mathrm{KJ/\,K\,g}$

$\eta=\frac{q_{in}-q_{out}}{q_{in}}=49.6\%$

2)带回热

$T_2=T_1\left(\pi\right)^{\frac{k-1}{k}}=577.52K$

$T_5=T_4\left(\frac{1}{\pi}\right)^{\frac{k-1}{k}}=662K$

$T_3=T_5$

$T_6=T_2$

$q_{in}=c_p(T_4-T_3)=651.3\,\mathrm{KJ/\,K\,g}$

$q_{out}=c_p(T_6-T_1)=286.42\,\mathrm{KJ/\,K\,g}$

$\eta=\frac{q_{in}-q_{out}}{q_{in}}=56.02\%$

习题 10-3

解：

① p_2=0.004MPa

v_3=0.0010041m^3/kg，h_3=121.30kJ/kg，h_3''=2553.45kJ/kg，s_3=0.4221kJ/(kg·K)，s_3''=8.4725kJ/(kg·K)，$x_2=\frac{s_2-s_3}{s_3''-s_3}=\frac{6.9676-0.4221}{8.4725-0.4221}=0.813$

$h_2=h_3+x_2'(h_3''-h_3)=2098.64$ kJ/kg

$w_p=v_3(p_1-p_2)=0.0010041\times(3.5-0.004)\times10^3=3.51$kJ/kg

$h_4=h_3+w_p=124.81$kJ/kg

循环热效率：$\eta_t=\frac{h_1-h_2-w_p}{h_1-h_4}=37.8\%$

② p_2=0.01MPa

v_3=0.0010103m^3/kg，h_3=191.76kJ/kg，h_3''=2583.72kJ/kg，

s_3=0.649kJ/(kg·K)，s_3''=8.1481，$x_2 = \frac{s_2 - s_3}{s_3'' - s_3} = \frac{6.9676 - 0.649}{8.1481 - 0.649} = 0.843$

$h_2 = h_3 + x_2'(h_3'' - h_3) = 2208.18$ kJ/kg

w_p=v_3(p_1-p_2)=0.0010103×(3.5-0.01)×10^3=3.53kJ/kg

h_4=h_3+w_p=195.29kJ/kg

循环热效率：$\eta_t = \frac{h_1 - h_2 - w_p}{h_1 - h_4} = 35.1\%$

③ p_2=0.1MPa

v_3=0.0010432m^3/kg，h_3=417.52kJ/kg，h_3''=2675.14kJ/kg，

s_3=1.3028kJ/(kg·K)，s_3''=7.3589，$x_2 = \frac{s_2 - s_3}{s_3'' - s_3} = \frac{6.9676 - 1.3028}{7.3589 - 1.3028} = 0.935$

$h_2 = h_3 + x_2'(h_3'' - h_3) = 2528.39$ kJ/kg

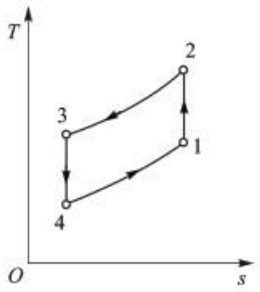
w_p=v_3(p_1-p_2)=0.001010432×(3.5-0.1)×10^3=3.55kJ/kg

h_4=h_3+w_p=421.07kJ/kg

循环热效率：$\eta_t = \frac{h_1 - h_2}{h_1 - h_4} = 26.8\%$

习题 11-1

答：空气制冷循环 T-S 图



由题目已知：$T_1 = 293K$ $T_3 = 263K$　　$P_1 = P_4 = 1bar$　　$P_2 = P_3 = 6bar$

1) 求每千克空气制冷量

$$T_4 = T_3\left(\frac{P_4}{P_3}\right)^{\frac{K-1}{K}} = 263\times\left(\frac{1}{6}\right)^{\frac{0.4}{1.4}} = 157.6K$$

$$T_2 = T_1\left(\frac{P_2}{P_1}\right)^{\frac{K-1}{K}} = 293\times 6^{\frac{0.4}{1.4}} = 488.9K$$

每千克空气制冷量：

$$q_c = h_1 - h_4 = 1.004\times(293-157.6) = 136KJ/Kg$$

2）每千克空气所需压缩功：

$$W_C = h_2 - h_1 = 1.004\times(488.9-157.6) = 332.6KJ/Kg$$

3）制冷系数：

$$\varepsilon = \frac{h_1 - h_4}{(h_2 - h_3)-(h_1 - h_4)} = \frac{1.004\times(293-157.6)}{1.004\times[(488.9-263)-(293-157.6)]} = 1.5$$

4）在相同的温度范围内，逆向卡诺循环是制冷系数最高的循环

$$\varepsilon_{\max} = \varepsilon_c = \frac{T_3}{T_1 - T_3} = \frac{263}{293-263} = 8.8$$