Da. 290D

ME 219b Thermodynamics Spring 2010

Instructor:

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Grading

1. Quizzes: Average counts as 15%. Subject tends to be from recent homework. If you miss a quiz you get a 50 for that quiz; otherwise, the lowest individual quiz grade is 60.
2. Tests: There are four tests. Each counts as 15%. The dates of these are: Feb. 10, March 10, April 14, and May 5.
3. Final Exam: 20%. Comprehensive, 8:00am, Tues., May 11, place to be announced.

4. Class attendance: 5%. Can miss 3 classes without penalty. Thereafter, 0.4 % per absence, until all of the 5% credit for attendance is used up.

5. Homework: Assigned and discussed, but not graded or collected.

Other points about grading:

a. Open book and **class** notes; for quiz, test, final. No cell phones or files from other classes.

b. Under almost all circumstances there won't be make-up tests, or quizzes.
This is because it is difficult to interpret whether a make-up test is harder, easier, or the same difficulty as the test taken by the rest of the class. I do not discriminate between excused versus unexcused absences.

c. The cutoffs for letter grades of A, B, C, D, and F will be 90, 80, 70, and 60, respectively.

d. The midterm grade is just the average of tests 1 and 2.

appeal process

If the student is unsatisfied about some aspect of this course, and does not want to talk to the instructor about it, or has tried this avenue and is not satisfied, the student can appeal to the chair of the Mechanical & Aerospace Engr. & Engr Mech. Dept. (Ashok Midha, 194I Toomey Hall, phone 341-4662, e-mail: midha@mst.edu) .

David Maloney Thermo 4-6) 4-11) 4-21)

2.1) ~~7, 10, 14, 15~~

3.476 ~~cu~~ ft^3

$T = 75°F = 535°R$

$P = 174$ psia

200psi 1.075 lb/ft^3

80°F

$PV = mRT$ R(air) 80° = .06855 $\frac{Btu}{lbm}$

$174\text{ psia}(3.476\ ft^3) = (m).06855 \frac{Btu}{lbm}(535°R)$

4-6) N_2 2kg

$_1W_3 = \int_1^2 P dV + \int_2^3 P dV$

~~$V_1 = 2\ kg(.5\ m^3/kg) = 1m^3$~~ ($\forall$ not needed)

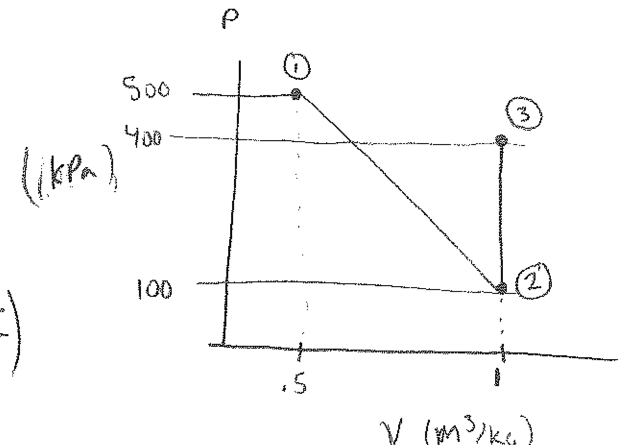
~~$V_2 = 2kg(1m^3/kg) = 2m^3$~~

~~$V_3 = V_2 = 2m^3$~~

$kPa\left(\frac{500+100}{2}\right)(\forall_2 - \forall_1) = 300\ kPa \cdot m^3 \left(1\frac{kN/m^2}{kPa}\right)$

~~100~~ $1m^3$

$= 300\ kN\cdot m = 300\ kJ$



4-11) 5kg H_2O saturated vapor

300kPa

constant pressure

$T_2 = 200°C$

$T_1 = T_{sat}\langle 300kPa\rangle = 133.52$

$x = 1$

$V_1 = v_g = .60582\ m^3/kg$

② 200° > 133.52 ∴ SHV

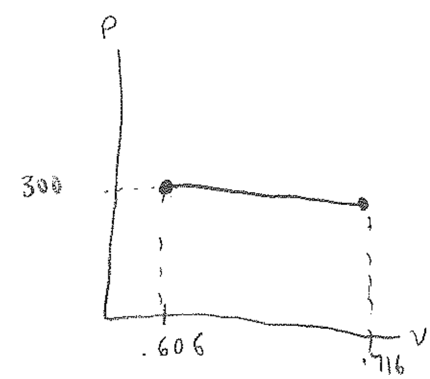
.3MPa, 200°, .71643 m^3/kg

$_1W_2 = m\int_1^2 P dv = 5kg\,(300kPa)\,(.71643 - .60582)\,m^3/kg$

$= 165.915\ kPa\cdot m^3 \left(1\frac{kN/m^2}{kPa}\right) =$

$= 165.915\ kN\cdot m$

$\boxed{_1W_2 = 165.915\ kJ}$ done on surroundings by system

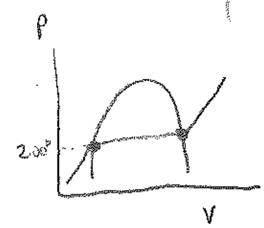


4-29)

① H_2O sat. vapor
200°c
1554.9 kPa

② sat. liquid
200°c
1554.9 kPa

${}_1Q_2$? in kJ/kg
${}_1W_2$?



$V_f = .001157 \quad V_g = .12721 \; m^3/kg$

${}_1W_2 = \int P dV = 1554.9^{kPa}(.001157 - .12721 \; m^3/kg)$

$\boxed{{}_1W_2 = -196 \text{ kJ}}$ on system

$U_2 = U_v = 850.46 \quad U_1 = U_g = .12721$

${}_1Q_2 = {}_1W_2 + U_2 - U_1$

$= -196 \frac{kJ}{kg} + 850.46 \frac{kJ}{kg} - 2594.2 \frac{kJ}{kg}$

$\boxed{{}_1Q_2 = -1939.74}$

Thermo Ch. 7

25) ✓ dQ/T

27) ✓ $\frac{dQ}{T}$

52) ✓ isothermal, $dQ = \Delta S(T)$ closed system

72) ✓ incompressible solids $\frac{dQ}{T}$, C_p,

95) ✓

83) ✓ find ΔS ideal gas, const. specific heats

difficult 98) ✓ isent. turbine $\dot{W}_{out} = ?$ [P_1, T_1, P_2, Velocities] given

128) ✓ turbine, adiab., X

med. 118) ✓ incompressible, pump energy bal. VdP, gz

147) ✓ $\dot{Q}$ from liquid → condense steam

152) ✓ H_2O Liq → ice ; R134 liq → vapor $\dot{m} s_{fg}$ water, $\frac{\dot{Q}}{T}$ R134a

quiz 8) ✓ Q internally reversible, closed system

* flow process uses h
* closed system uses u

$$1\ \text{Btu} = 5.40395\ \frac{\text{lb}}{\text{in}^2} \cdot \text{ft}^3 \left(\frac{144\ \text{in}^2}{\text{ft}^2}\right) = 778.169\ \text{lbf} \cdot \text{ft}$$

$$\frac{\text{psia} \cdot \text{ft}^3}{\text{lbm}\, R} = \left(\frac{\text{lbf}/\text{in}^2 \cdot \text{ft}^3}{''}\right) \quad \text{gas const. } R = \frac{\text{Btu}}{\text{lbm} \cdot R} = \frac{\text{lbf} \cdot \text{ft}}{\text{lbm} \cdot R} = \frac{\cancel{\text{lbm}}(32.2)\ \text{ft}}{\cancel{\text{lbm}} \cdot R} = \frac{32.2\ \text{ft}/\text{s}^2 \cdot \cancel{\text{ft}}}{R} = \frac{32.2}{\text{s}^2 R}$$

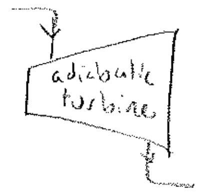
$$.06855\ \frac{\text{Btu}}{\text{lbm} \cdot R} = \frac{\text{lbf} \cdot \text{ft}}{\text{lbm} \cdot R}\left(\frac{1}{\text{in}^2}\right.$$

$$\frac{\text{ft}^3}{\text{in}^2} = \frac{1\ \text{ft}^3}{.006944\ \text{in}^2}$$

reversible adiabatic → isentropic

7-128) ① Steam 3MPa 400°C SHV

v .09938 u 2932.6 h 3231.7 s 6.9235



$\eta_T = 92\% = \dfrac{W_a}{W_s}$

power = ?

$\dot{m} = 2 kg/s$

② 30kPa

$$w_{rev} = -\int_1^2 v\,dP - \cancel{\Delta ke}^{0} - \cancel{\Delta pe}^{0}$$

$$s_2 = s_1 = 6.9235$$

$$x_2 s_g + (1 - x_2) s_f = s_2$$

$$x_2 (s_g - s_f) + s_f = s_2$$

$$x_2 = \frac{s_2 - s_f(30kPa)}{(s_{fg}(30kPa))} = \frac{6.9235 - .9441}{6.8234} \doteq .8763$$

$$h_2 = h_f + x_2 h_{fg} = 289.27 + .8763(2335\ \ )$$

$$= 2335.7$$

$$\dot{m}(h_2 - h_1) = 2 kg/s\,(2335 - 3231.7)$$

$$\cancel{\Delta E}^{0} - W_s = 1793.4\ kJ/s$$

$$W_a = .92 W_s = 1650\ kJ/s = 1650\ kW$$

7-128 Steam is expanded in an adiabatic turbine with an isentropic efficiency of 0.92. The power output of the turbine is to be determined.

Assumptions **1** This is a steady-flow process since there is no change with time. **2** Kinetic and potential energy changes are negligible. **3** The device is adiabatic and thus heat transfer is negligible.

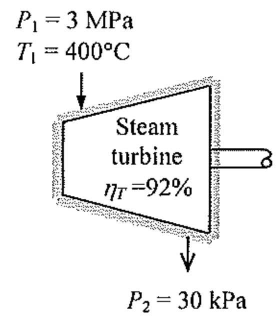
Analysis There is only one inlet and one exit, and thus $\dot{m}_1 = \dot{m}_2 = \dot{m}$. We take the actual turbine as the system, which is a control volume since mass crosses the boundary. The energy balance for this steady-flow system can be expressed in the rate form as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta \dot{E}_{system}^{\nearrow 0 \text{ (steady)}}}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc. energies}}} = 0$$

$$\dot{E}_{in} = \dot{E}_{out}$$

$$\dot{m}h_1 = \dot{W}_{a,out} + \dot{m}h_2 \quad (\text{since } \dot{Q} \cong \Delta\text{ke} \cong \Delta\text{pe} \cong 0)$$

$$\dot{W}_{a,out} = \dot{m}(h_1 - h_2)$$



From the steam tables (Tables A-4 through A-6),

$$\left.\begin{array}{l} P_1 = 3 \text{ MPa} \\ T_1 = 400°\text{C} \end{array}\right\} \begin{array}{l} h_1 = 3231.7 \text{ kJ/kg} \\ s_1 = 6.9235 \text{ kJ/kg}\cdot\text{K} \end{array}$$

$$\left.\begin{array}{l} P_{2s} = 30 \text{ kPa} \\ s_{2s} = s_1 \end{array}\right\} \begin{array}{l} x_{2s} = \dfrac{s_{2s} - s_f}{s_{fg}} = \dfrac{6.9235 - 0.9441}{6.8234} = 0.8763 \\ h_{2s} = h_f + x_{2s}h_{fg} = 289.27 + (0.8763)(2335.3) = 2335.7 \text{ kJ/kg} \end{array}$$

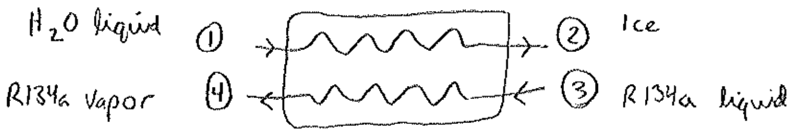
The actual power output may be determined by multiplying the isentropic power output with the isentropic efficiency. Then,

$$\begin{aligned} \dot{W}_{a,out} &= \eta_T \dot{W}_{s,out} \\ &= \eta_T \dot{m}(h_1 - h_{2s}) \\ &= (0.92)(2 \text{ kg/s})(3231.7 - 2335.7)\text{kJ/kg} \\ &= \mathbf{1649 \text{ kW}} \end{aligned}$$

Ch 7 practice

152)

$\dot{m}_{ice} = 4000\ kg/hr$



① H_2O liq. 0°C

② H_2O ice 0°C

$\dot{S}_{gen} = ?$

③ R134 -10°C liquid

④ R134 -10°C vapor

$h_{34} = h_{fg} \langle 10° \rangle = 205.96\ kJ/kg$ $\quad S_{fg} = .78263\ kJ/kg \cdot K$

$\dot{Q}_{12} = \dot{m} h_{if} = 4000\ kg/hr \left(\frac{1hr}{3600\ sec}\right)(333.7\ kJ/kg) = 370.8\ kJ/s$

$\dot{Q}_{23} = \dot{Q}_{12} = 370.8\ kJ/s = \dot{m}_r h_{fg} = \dot{m}(205.96\ kJ/kg)$

$\dot{m}(R134a) = 1.800\ kg/s$

$S = \frac{dQ}{T} \quad \dot{S} = \frac{d\dot{Q}}{T} = -\frac{370.8\ kW}{(0°c + 273)} + \cancel{\frac{370.8\ kW}{(-10° + 273)}}$ $\quad \dot{m}_r S_{fg} = 1.800(.78263)$

$-1.358 \quad + \cancel{1.410\ kW/K} \quad + 1.408$

$\boxed{\cancel{\dot{S}_{gen} = .0520\ kW/K}}$ ✓

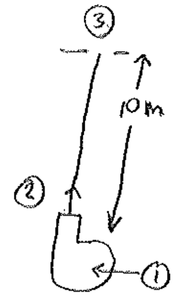
$.0505\ \frac{kW}{K}$

Thermo Ch 7 practice

7-118) $\dot{m} = ?$

① 120 kPa

② 5 MPa



liquid H_2O

7kW

$v = .001\ m^3/kg$

incompressible

Max $\dot{m} \Rightarrow$ isentropic

$$\dot{E}_{in} - \dot{E}_{out} = \frac{dE}{dt} = 0$$

$$w_{rev} = v(P_2 - P_1) + \cancel{\Delta ke}^{\,0} + \Delta pe$$

$$\dot{W}_{rev} = \dot{m}\left[v(P_2 - P_1) + g(z_2 - z_1)\right]$$

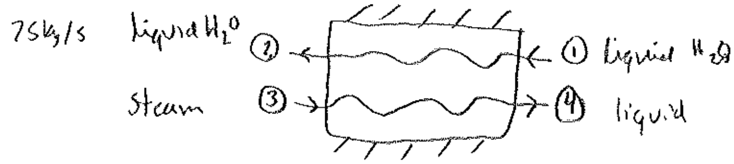
$$7kW = \dot{m}\left[(.001)(5000 - 120\ kPa) + (9.81\ m/s^2)(10m)\left(\frac{kW/kg}{1000\ m^2/s^2}\right)\right]$$

$$7 = \dot{m}\,(4.88 + .0981)$$

$$\boxed{\dot{m} = 1.406\ kg/s}$$

Ch 7 practice

7-147) rate of condensation ?
rate of entropy generation



insulated condenser

③ 60°C $X=1$
④ 60°C $X=0$

① 18°C
② 27°C $\dot{Q} = \dot{m}(h_2 - h_1) = \dot{m}\, C_p (T_2 - T_1)$ $\cdot\, C_{p\,avg} \langle 22.5 \rangle = 4.18$

$= 75\,kg/s \;\; 4.18 \frac{kJ}{kg \cdot k} (27° - 18°C)$

$\dot{Q} = 2821.5 \frac{kJ}{s}$

3→4 $h_{fg}\langle 60°C \rangle = 2345.4 \frac{kJ}{kg}$

$h_{fg}\, \dot{m} = \dot{Q} \implies \dot{m}_{condense} = \frac{2821.5\, kJ/s}{2345.4\, kJ/kg} = 1.2030\ kg/s$

$\dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} = \Delta S/dt$

$S_2 - S_1 = C_{p\,avg} \ln\left(\frac{27+273}{18+273}\right)$
$= \dot{m}\ .127319$
$\dot{S}_{12} = 9.549\ kJ/kg \cdot k \cdot s$

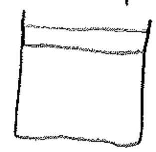
$S_4 - S_3 = -S_{fg} = -7.0769\, \dot{m}$
$= -8.51351$ 8.4923

$\dot{S}gen = 9.549 - 8.51351$
$= \boxed{1.035 \frac{kJ}{\cdot k \cdot s}}$

Book says 1.06 kW/s, got this by using only 3 sig. figs for $\dot{Q}_{3\to4}$

Practice

closed system



7.52) R134a isothermal $w = ?$ $q = ?$

$\Delta KE \approx \Delta PE \approx 0$

① 240 kPa 20°C SHV $s = 1.0134$ $u = 246.74$ kJ/kg

② $x = .20$ 20°C $u = u_f + x u_{fg} = 78.86 + (.2)(162.16) = 111.29$ kJ/kg

$Q_{in} - W_{out} = \Delta U = (111.29 - 246.74) = \boxed{-135.45}$ kJ/kg

$\Delta S = \frac{dQ}{T}$

$S_2 = .30063 + (.2)(.62172) = .42497$

$.42497 - 1.0134 = \frac{dQ}{(20+273)}$ $\boxed{dQ = -172.41 \text{ kJ/kg}}$ Q is out

$-172.41 - W_{out} = -135.45$ $\boxed{W_{out} = 36.96 \text{ kJ/kg}}$ W is in

7-72) $\Delta S = ?$

$ds = \frac{dQ}{T}$

iron 50 kg 80°C $\Rightarrow$ 20° lake

Cu 20 kg 80°C

① Fe $C_p = .45$ kJ/kg $\Delta E = .45(50)(15 - 80) = -1462.5$ kJ

Cu $C_p = .386$ kJ/kg $\Delta E = \Delta Q = .386(20)(15 - 80) = 501.8$ kJ

$= 1964.8$ kJ into lake

$\Delta S_{Fe} = .45 \ln\left(\frac{15+273}{80+273}\right)(50\text{kg}) = -4.5789$ $\Delta S_{Cu} = .386 \ln\left(\frac{15+273}{80+273}\right)(20\text{kg}) = 1.57108$

$\frac{dQ}{T_{lake}} = +6.8205$ $\Delta S_{Fe} = -4.5789$ $\Delta S_{Cu} = -1.57108$

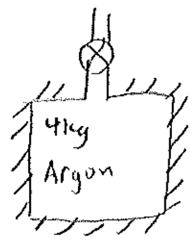
$dS = 6.8205 - (4.5789 + 1.5711)$

$\boxed{dS = +6.706 \text{ kJ/K}}$ ✓

David Malawey

7-95) rigid tank ① 450 kPa 30°C 4kg

$m_2 = ?$ ② 200 kPa



reversible, adiabatic

$k = 1.667$

$$V_1: \quad P_1 v_1 = RT_1 \qquad v_1 = \frac{R_1 T_1}{P_1} = \frac{.2081\,(30° + 273)}{450} = .1401\ m^3/kg$$

$$\frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^k \qquad \left(\frac{P_2}{P_1}\right)^{\frac{1}{k}} = \frac{V_1}{V_2} \qquad V_2 = \frac{V_1}{\left(\frac{P_2}{P_1}\right)^{1/k}} \qquad \frac{.1401}{\left(\frac{200}{450}\right)^{(1/1.667)}}$$

$$V_2 = .22788 \qquad \frac{m_2}{m_1} = \frac{V_1}{V_2} = \frac{.1401}{.22788} = \boxed{2.459\ kg}\ \checkmark$$

7-27) $\dot{Q} = 2kW$

$$\dot{S}_1 = \frac{-2kW}{800} = -2.5\ W/K$$

$$\dot{S}_2 = \frac{2kW}{300} = +6.667\ W/K.$$

$$\dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} = dS/dt = \boxed{4.167\ W/K = \dot{S}_{gen}}$$

Practice

7-83) Air expanded const C_p $\Delta s = ?$

① 200 psia 500°F

$$S_2 - S_1 = C_{p,avg} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

② 100 psia 50°F

$$C_{p_{avg}} = \frac{.240 + .248}{2} = .244 \text{ Btu/lbm}\cdot R$$

Use for C_p avg

C_p <temp avg> ✓

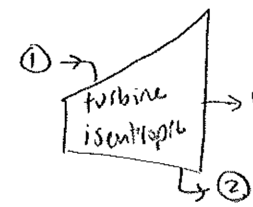
$R = .06855$ Btu/lbm·R

$$\Delta S = .244 \ln\left(\frac{50+460}{500+460}\right) - .06855 \ln(.5)$$

$$\boxed{\Delta S = -.10682 \text{ Btu}/R}$$ ✓

7.98) ① 150 psia 900°F $.5 ft^2$ 500 ft/s $\dot{V} =$

Air



$T_2 = ?$
$\dot{W} = ?(hp)$

② 15 psia 100 ft/s

$$\frac{T_2}{\cancel{T_1}} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k} (T_1) = \left(\frac{15}{150}\right)^{(1.4-1)/1.4} (900+460) = \boxed{704.41 \text{ °R}} = 244.41 \text{ °F}$$

$$\cancel{Q}^{0} - W = \Delta U + \Delta KE + \cancel{\Delta PE}^{0}$$

$$W_{out} = \dot{m}(h_2 - h_1) + \tfrac{1}{2}\dot{m}(V_2^2 - V_1^2)$$

$$\dot{m}\left[(C_{p_{avg}} T_2 - T_1) + \tfrac{1}{2}(V_2^2 - V_1^2)\right] =$$

$$74.44 \left[.250(244 - 900) + \tfrac{1}{2}(100^2 - 500^2)\left(\frac{1}{25037}\right)\right]$$

$= -12564.9$ Btu/s

$C_{p_{avg}} = C_p\langle 572°F\rangle = .250$ Btu/lbm R

$$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{250 \text{ ft}^3/s}{3.35829 \text{ ft}^3/\text{lb}} = 74.44 \text{ lbm/s}$$

$$v_1 = \frac{RT}{P} = \frac{.3704\,(900+460)}{150} = 3.35829$$

$$\frac{100 \text{ ft}^2}{s^2}\left(\frac{\text{Btu/lbm}}{25037 \text{ ft}^2/s^2}\right)$$

$$\times \frac{1 \text{ hp}}{.7068 \text{ Btu/s}} = \boxed{17,777}$$ ✓ ≈ book answer $\boxed{17250 \text{ hp}}$

change k_{air} to 1.377 and this happens.

~~$T_1 = 900 + 460 = 1360$, $k_{air} =$~~

Ch 8

51) $\dot{Q}$ out of solid, X_{dest} by heat transfer STEEL Balls

54) throttling, h_{const}, X_{dest}/kg interpolate s by h

65) $W_{out} = \Delta h + \Delta ke$, adiabatic turbine find $\dot{m}$ & get $W_{rev} = \dot{m}(\psi_1 - \psi_2)$

16 E) heat added to liquid → steam, find heat transfered q, $S_{gen} = \frac{dQ}{T} + \Delta s$ steam, $X_{dest} = T_0 S_{gen}$

24) $W_{rev,in} = ?$ $COP_{HP,rev.}$ $\dot{W}_{rev} = \frac{\dot{Q}_H}{COP_{HP,rev}}$ $I = W_u - W_{rev}$

32) Work potential of 2 pressurized vessels $= \phi m$

√ Ex 17) compressor into closed space, $W_{rev} = (X_{dest} = 0) = m(\phi_2 - \phi_1)$

Ex 14) heat added to closed system, gas piston/cyl $W_u = W - W_{surr}$ X_{dest}

Ex 15) Steam turbine, $\dot{W}_{actual}$, ΔE $W_{rev} = -\dot{m}(\Delta\psi)$ η_{II}

√ Ex 16) mixing chamber,

√ Ex 13) drop iron into water

Ex 12) stirring a gas

Ex 11) X_{dest} during steam expansion

√ 10) Q through brick wall

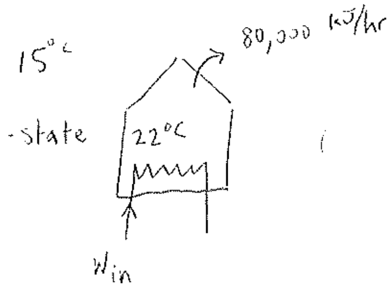
9) closed sys

8) ΔX compression

24) $W_{rev\ in} = ?$

$I = ?$

Steady-state



$$W_{in} = Q_{out} = 80{,}000\ kJ/hr \left(\frac{1\ hr}{3600\ s}\right) = 22.22\ kW$$

$$COP_{HP,\ rev} = \frac{1}{1 - T_L/T_H} = \frac{1}{1 - \frac{15+273}{22+273}} = 42.143$$

$$W_{rev\ in} = \frac{\dot{Q}_H}{COP_{HP,\ rev}} = \frac{22.22}{42.14} = \boxed{0.53\ kW}$$

$$\dot{I} = \dot{W}_{u,in} - \dot{W}_{rev,in} = 22.22 - 0.53 = \boxed{21.69\ kW}$$

32) $T_0 = 25°C$ $P_0 = 100\ kPa$

Work potential?

$$\phi = (U - U_0) + P_0 (V - V_0) - T_0 (S - S_0) + \cancel{ke}^{\,0} + \cancel{pe}^{\,0}$$

Steam 1 kg 800 kPa 180°C

$U = 2594.7$

$V = .24720$

$S = 6.7155$

dead state $\begin{cases} U_0 = 104.83 \\ V_0 = .001003 \\ S_0 = .3672 \end{cases}$

$$\phi = (2489.9 + 24.6197 - 1891.8)\ 1\ kg = 622.72 \quad H_2O$$

R134a: 1 kg 800 kPa 180°C

$U = 396.99$ $\quad U_0 = 85.85$

$V = .044854$ $\quad V_0 = .0008286$

$S = 1.3327$ $\quad \underbrace{S_0 = .32432}$

$\phi = $

$= 301.14 + 4.372 - 300.50$

$= 5.02\ kJ$

X wrong! this shows sat. liq. & state is SHV actually

$U_0 = 252.62$

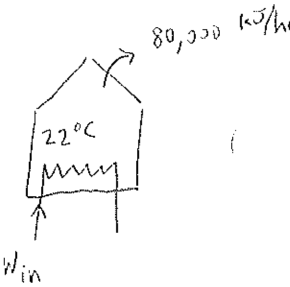
$V_0 = .23803$ $\quad \phi = 47.73$

$S_0 = 1.106$

24) $W_{rev\ in} = ?$

$I = ?$

Steady-state



$W_{in} = Q_{out} = 80{,}000\ kJ/hr \left(\frac{1hr}{3600s}\right) = 22.22\ kW$

$COP_{HP,rev} = \dfrac{1}{1 - T_L/T_H} = \dfrac{1}{1 - \frac{15+273}{22+273}} = 42.143$

$W_{rev\ in} = \dfrac{\dot{Q}_H}{COP_{HP,rev}} = \dfrac{22.22}{42.14} = \boxed{0.53\ kW}$

$\dot{I} = \dot{W}_{u,in} - \dot{W}_{rev,in} = 22.22 - 0.53 = \boxed{21.69\ kW}$

32) $T_0 = 25°C \quad P_0 = 100\ kPa$

Work potential?

Steam 1kg 800kPa 180°C

$\phi = (U - U_0) + P_0(V - V_0) - T_0(S - S_0) + \cancel{ke}^{0} + \cancel{pe}^{0}$

$U = 2594.7$

$V = .24720$

$S = 6.7155$

dead state $\begin{cases} U_0 = 104.83 \\ V_0 = .001003 \\ S_0 = .3672 \end{cases}$

$\phi = (2489.9 + 24.6197 - 1891.8)\ 1kg = 622.72 \quad H_2O$

R134a: 1kg 800kPa 180°C

$U = 336.99 \quad U_0 = 85.85$

$V = .044554 \quad V_0 = .0008286$

$S = 1.3327 \quad \underbrace{S_0 = .32432}$

X wrong! this shows sat. liq & state is SHV actually

$U_0 = 252.62$

$V_0 = .23803$

$S_0 = 1.106$

$\phi = 47.73$

$\phi = 301.14 + 4.372 - 300.50$

$= 5.02\ kJ$

8-51) $\rho = 7833 \, kg/m^3$ $\quad C_p = .465 \frac{kJ}{kg \cdot C}$ $\quad$ 8mm diam $\Rightarrow \frac{4}{3}\pi r^3 = 2.681E^{-7} \, m^3 \, (7833 \, kg/m^3)$

$$= .0021 \, kg/ball \left(\frac{1200 \, ball}{hr}\right)\left(\frac{1hr}{3600 \, sec}\right) = 7E\text{-}4 \, kg/s = \dot{m}$$

① 900°C

② 100°C

$$\dot{m} \, C_p (T_2 - T_1) = \dot{Q}_{out \, of \, balls} = 7(10^{-4}) \frac{kg}{s} \; .465 \frac{kJ}{kg \cdot K} (-800°C) = \boxed{-.2604 \frac{kJ}{s}}$$

air: 35°C $\qquad \dot{X}_{dest} = ? = \cancel{T_0 (S_2 - S_1)} = \Delta\psi = (h_2 - h_1) - T_0 (s_2 - s_1)$

$$S_2 - S_1 = \dot{m} C_{avg} \ln \frac{T_2}{T_1} = 7(10^{-4}) \frac{kg}{s} \left(.465 \frac{kJ}{kg \cdot K}\right)\left(\ln \frac{373}{1173}\right) = -3.73(10^{-4}) \frac{kJ}{kg \cdot K \cdot s}$$

$$T_0 (s_2 - s_1) \Rightarrow 35 + 273 \; (3.73)(10^{-4}) = -.1149 \frac{kW}{kg}$$

$$h_2 - h_1 = U_2 - U_1 = C_{avg} (T_2 - T_1) = -372 \frac{kJ}{kg} \, (\dot{m}) \Rightarrow -.2604$$

$$\Delta X = U_2 - U_1 - T_0 (S_2 - S_1)$$

$$= -.2604 - (-.1149) = -.1455 \frac{kJ}{s} = \boxed{146 \, kW}$$

8-54) Steam $\quad$ 8MPa 450°C $\quad$ ⊗ $\quad$ 6MPa

25°C surrounding

$$X_{dest} = ? = \psi = (h - h_0) - T(s - s_0) + \cancel{\frac{V^2}{2}}^{\,0} + \cancel{gz}^{\,0}$$

$$\Delta\psi = h_2 - h_1 - T_0 (s_2 - s_1)$$

$\Delta h = 0$

$h_2 = h_1 = 3273.3 \quad s_1 = 6.5579 \quad s_2 = 6.6795$

	h	s
	3178.3	6.5432
.76244	★ 3273.3	
	3302.9	6.7219

$$= -(25 + 273)(6.6795 - 6.5579)$$

$$\boxed{\Delta\psi = 36.24 \, kJ/kg}$$

8-51)

$\rho = 7833 \, kg/m^3$ $\quad C_p = .465 \frac{kJ}{kg \cdot C}$ $\quad$ 8mm diam $\Rightarrow \frac{4}{3}\pi r^3 = 2.681E^{-7} \, m^3 \, (7833 \, kg/m^3)$

$= .0021 \, kg/ball \left(\frac{1200 \, ball}{hr} \right) \left(\frac{1 hr}{3600 \, sec} \right) = 7E-4 \, kg/s = \dot{m}$

① 900°C

② 100°C

$\dot{m} \, C_p (T_2 - T_1) = \dot{Q}_{out \, of \, balls} = 7(10^{-4}) \frac{kg}{s} \, .465 \frac{kJ}{kg \cdot K} (-800°C) = \boxed{-.2604 \frac{kJ}{s}}$

air: 35°C $\quad \dot{X}_{dest} = ? = \cancel{T_0 (S_2 - S_1)} = \Delta\psi = (h_2 - h_1) - T_0 (s_2 - s_1)$

$S_2 - S_1 = \dot{m} C_{avg} \ln \frac{T_2}{T_1} = 7(10^{-4}) \frac{kg}{s} \left(.465 \frac{kJ}{kg \cdot K} \right) \left(\ln \frac{373}{1173} \right) = -3.73 (10^{-4}) \frac{kJ}{kg \cdot K \cdot s}$

$T_0 (s_2 - s_1) = 35 + 273 \, (3.73)(10^{-4}) = -.1149 \frac{kW}{kg}$

$h_2 - h_1 = U_2 - U_1 = C_{avg} (T_2 - T_1) = -372 \frac{kJ}{kg} (\dot{m}) \Rightarrow -.2604$

$\Delta X = U_2 - U_1 - T_0 (S_2 - S_1)$

$= -.2604 - (-.1149) = -.1455 \frac{kJ}{s} = \boxed{146 kW}$

8-54)

Steam $\quad$ 8 MPa, 450°C $\quad \otimes \quad$ 6 MPa

25°C surrounding

$X_{dest} = ? = \psi = (h - h_0) - T(s - s_0) + \cancel{\frac{V^2}{2}}^{0} + \cancel{gz}^{0}$

$\Delta\psi = h_2 - h_1 - T_0 (s_2 - s_1)$

$\Delta h = 0$

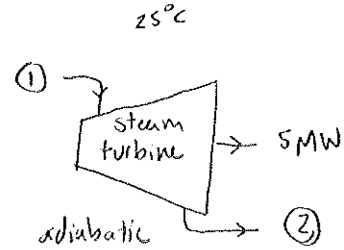
$h_2 = h_1 = 3273.3 \quad s_1 = 6.5579 \quad s_2 = 6.6795$

h	s
3178.3	6.5432
.76244 * 3273.3	
3302.9	6.7219

$= -(25 + 273)(6.6795 - 6.5579)$

$\boxed{\Delta\psi = 36.24 \, kJ/kg}$

8-65)



① 6 MPa 600°C 80 M/s

② 50 kPa, 100°C, 140 m/s

a) reversible power output = ? $X_{dest} = 0$

$W_{rev} =$

$E_{in} = E_{out}$

$h_1 = 3658.8$ $\quad h_2 = 2682.4$

$s_1 = 7.1693$ $\quad s_2 = 7.6953$

$\dot{m}\left(h_1 + \frac{V_1^2}{2}\right) = \dot{m}\left(h_2 + \frac{V_2^2}{2}\right) + \dot{W}$

$3658.8 + \frac{80^2}{2}\frac{m^2}{s^2}\left(\frac{1}{1000}\right) = 2682.4 + 9800\left(\frac{1}{1000}\right)$

$\dot{X}_{in} - \dot{X}_{out} - \cancel{\dot{X}_{dest}}^{0} = \cancel{\Delta X_{sys}}^{0}$

$3662 \frac{kW}{kg} = \dot{W}_{out} + 2692.2$

$\dot{X}_{in} = \dot{X}_{out}$

$5000\,kW = 969.8\,\dot{m}$ $\quad \dot{m} = 5.156$

$\dot{W}_{rev,out} = \dot{m}\left[(h_1 - h_2) - T_0(s_1 - s_2)\right]$

$5.156\,kg/s\left[(3658.8 - 2682.4) - 298°K\,(7.1693 - 7.6953)\right]$

$= 5842.51\ kW$

$\eta_{II} = \frac{W_{actual}}{W_{rev}} = .8558 \Rightarrow \boxed{85.6\%}$

$$180 = 5421 + m_2(1162.8) - 97m_2 - 300(97.99)$$
$$180 = -23976 + m_2(1065.3)$$

---

ex) 8-17 Air $200m^3$ ① 100kPa 300°K $P_0 = 100kPa$

$W_{rev} = ?$ ② 1MPa 300°K $T_0 = 300k$

$X_{dest} = 0$

	u	m
① =	214.07 $\frac{kJ}{kg}$	232.3 kg
② =	214.07	2323 kg

$PV = mRT$ $100(200) = m(.2870)(300)$

$1000(200) = m(.2870)(300)$

$$s_2 - s_1 = -R\ln\left(\frac{P_2}{P_1}\right) = -.6608$$

$$X_{in} - X_{out} - \cancel{X_{dest}}^{0} = \Delta X_{sys}$$

$$\cancel{X_1}^{0} + W_{in} = X_2 \quad W_{in} = X_c = \cancel{u - u_0}^{0} + P_0(v - v_0) - T_0(s - s_0) + \cancel{ke}^{0} + \cancel{pe}^{0}$$

$$= 100(-.7749) - 300(-.6608)$$

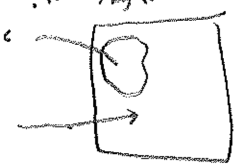
$$\phi_2 = 120.75 \qquad -77.49 + 198.24$$

$$W_{rev} = m_2\,\phi_2 = 120.75(2323) = \boxed{280.5\ MJ}$$

Ex 8-13 $m_1 c_p T_1 + m_2 c_p T_2 = m_1 c_p T_3 + m c_p$

.45 kJ/kg k

Fe, 5kg, 350°c



H_2O, 100kg, 30°c

$T_0 = 20°c$ $P_0 = 100 kPa$

$$E_g = .45(350+273)(5) + 100(4.18)(303k) = 128,056\ kJ$$

a) $T_{final} = \frac{*}{5(.45) + 100(4.18)} = 304.71 = \boxed{31.71°C}$

b) X_1 & X_2 : $X_1 = m(\phi - \phi_0)$

$$= m[(u - u_0) - T_0(s - s_0)]$$

$$Fe, \longrightarrow = 5\left[.45(350-20) - 293(.45)\ln\left(\frac{350+273}{20+273}\right)\right] + H_2O\ [\qquad]$$

$$X_1 = X_{Fe} + X_{H_2O}$$

$X_1 - X_2$ = wasted work potential

$$180 = 5421 + m_2(1162.8) - 97 m_2 - 300(97.99)$$
$$180 = -23976 + m_2(1065.3)$$

---

ex) 8-17 Air $200 m^3$ ① 100kPa 300°K $P_0 = 100kPa$

$W_{rev} = ?$ ② 1MPa 300°K $T_0 = 300k$

$X_{dest} = 0$

	u	m
①	$= 214.07 \frac{kJ}{kg}$	232.3 kg
②	$= 214.07$	2323 kg

$P\forall = mRT$ $100(200) = m(.2870)(300)$

$1000(200) = m(.2870)(300)$

$$s_2 - s_1 = -R\ln\left(\frac{P_2}{P_1}\right) = -.6608$$

$$X_{in} - X_{out} - \cancel{X_{dest}}^{\,0} = \Delta X_{sys}$$

$$\cancel{X_1}^{\,0} + W_{in} = X_2 \qquad W_{in} = X_2 \qquad = \cancel{u - u_0}^{\,0} + P_0(\forall - \forall_0) - T_0(s - s_0) + \cancel{ke}^{\,0} + \cancel{pe}^{\,0}$$

$$= 100(-.7749) - 300(-.6608)$$

$$\phi_2 = 120.75 \qquad -77.49 + 198.24$$

$$W_{rev} = m_2 \phi_2 = 120.75(2323) = \boxed{280.5\ MJ}$$

Ex 8-13 $m_1 c_p T_1 + m_2 c_p T_2 = m_1 c_p T_3 + m c_p$

$.45\ kJ/kg\,K$

Fe, 5kg, 350°C

H_2O, 100kg, 30°C

$T_0 = 20°C$ $P_0 = 100 kPa$

$$E_1 = .45(350+273)(5) + 100(4.18)(303k) = 128,056\ kJ$$

a) $T_{final} = \frac{*}{5(.45) + 100(4.18)} = 304.71 = \boxed{31.71°C}$

b) X_1 & X_2 : $X_1 = m(\phi - \phi_0)$

$$= m[(u - u_0) - T_0(s - s_0)]$$

Fe, $\longrightarrow = 5\left[.45(350-20) - 293(.45)\ln\left(\frac{350+273}{20+273}\right)\right] + H_2O\ [\qquad]$

$$X_1 = X_{Fe} + X_{H_2O}$$

$X_1 - X_2$ = wasted work potential

QUIZZES

QUIZZES

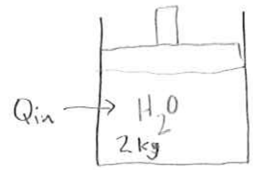
David Malaver 4-8-10

Quiz 8

60

① 3.5 MPa $x=1$

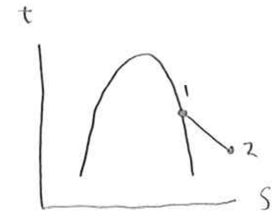
② .2 MPa 150°C



reversible

$\Delta ke \approx 0$

$\Delta pe \approx 0$



${}_1Q_2 = ?$ ${}_1W_2 = ?$

① v_g @ 3500 MPa $= .057061\ m^3/kg$ $V_1 = .1141\ m^3$ $h_1 =$

② SHV $v = .95986\ m^3/kg$ $V_2 = 1.9197$

$W_b = \int_1^2 PdV = P_{avg}(V_2 - V_1) = 1850\ kPa\ (1.920 - .1141)$

$\boxed{W_{out} = 3340.92\ kJ}$ ✗

$E_1 + Q_{in} = E_2 - W_{out} \Rightarrow Q_{in} = E_2 - E_1 - W_{out}$

$\frac{T_2}{T_1} = \left(\frac{V_1}{V_2}\right)^{k-1} \Rightarrow \frac{1}{T_1} = \left(\frac{.1141}{1.920}\right)^{(1.400-1)} / (150+273)$ $T_1 = 1308.42\ °K$

$h_1 = 4632.7$ $\Delta h = (h_2 - h_1)\ 2kg = -3727.1$

$h_2 = 2769.1$

$Q_{in} = (h_2 - h_1)m - W_{out}$

$= 387.1\ kJ$

David Malawey

$\boxed{\text{Quiz } 7}$ 3-23-10

90

compressor, steady flow ① in ② out rev. adiabatic

① 15 psia $x = .92$

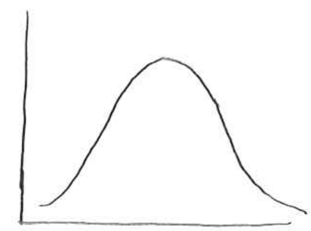
② 90 psia

$w = ?$ (Btu/lbm)

$h_1 = (.08)(7.835) + (.92)(100.99)$ btu/lbm $\overset{5}{=}$ 93.538 Btu/lbm ✓

$S_1 = (.08)(.01808) + (.92)(.22715)$ $= .210424$ btu/lbm·R ✓

$S_2 \overset{10}{=} S_1 = .210424$ btu/lbm·R ✓ 5



$w_{rev,in} = \int_1^2 v\,dP = \int_1^2 dh = h_2 - h_1$

$$\boxed{\begin{array}{l} \overset{s}{.210424} = (1-x)\overset{s_f}{.07481} + x(\overset{s_g}{.22006}) \\ s = (1-x)\, s_f + x(s_g) \\ s = s_f - x s_f + x s_g \\ s - s_f = + x(-s_f + s_g) \\ x = \dfrac{s - s_f}{s_g - s_f} = .9337 \ \checkmark 5 \end{array}}$$

get x_2

$h_2 = \underset{(x)}{.9337}(\underset{(h_g)}{113.46}) + \underset{(1-x)}{.0663}(\underset{(h_f)}{35.715})$ ✓

$= 108.306$ ✗

$$\boxed{w \overset{5}{=} h_2 - h_1 = 14.7675 \text{ btu/lbm}}$$ (into system)

David Malawey Quiz 6 3-3-10

100

600 lbm/hr ① 30 lbf/in^2 abs sat liq. $T = 250.3°$

② 30 psia sat. vapor $T = 250.3°$

$$COP_{HP,rev} = \frac{1}{1 - T_L/T_H}$$

$\dot{W} = ?$

$T_L = 60°F + 459.67 = °R$

$T_L = 520° R$

$T_H = 250.3 + 460$

$T_H = 710.3 °R$

600 lbm/hr (ft^3/lbm 13.749) = $\dot{V} =$ 8249 ft^3/hr

$$COP = \frac{1}{1 - 520/710.3} = 3.7325$$

$Q = \dot{m}h_2 - \dot{m}h_1 = 600(1164.1 - 218.93) = 567{,}126$ Btu/hr

$$\dot{W}_{net\,in} = \frac{\dot{Q}_H}{COP_{HP}} = \frac{567{,}126}{3.7325} = \frac{151{,}943 \text{ Btu/hr}}{55^0\ 3412.14} = \cancel{44.53 \text{ kW}}$$

276.26 hp

---

rework

	P	T	
①	30 psia	250.3° F	sat liq
②	30	250.3	sat vapor

600 lbm/h $\Delta h = 945.21$ $T_L = 60°F$ $T_H = 250.3$ $\dot{W} = ?$

$$COP_{HP,rev} \frac{1}{1 - T_L/T_H} = 3.733 = \frac{\dot{Q}_H}{W_{net\,in}}$$

$$\dot{Q}_H = 945.21 \text{ Btu/lbm} \left(600 \text{ lbm/h}\right)\left(\frac{1 \text{ hp}}{2544.5 \text{ Btu/h}}\right)$$

$\dot{Q}_H = 222.88$ hp

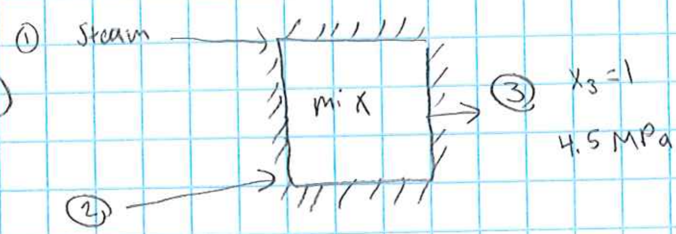
$\boxed{W_{net\,in} = 59.71 \text{ hp} \quad \text{correct}}$

David Malawey 73 Quiz 5

Quiz 2-24-10

① $\dot{m} = .5\ \frac{kg}{s}$ 5MPa 400°C (SHV)

② $\dot{m}_2 = ?$ 5 MPa 40°C (comp. liquid)



$\dot{E}_{in} = \dot{E}_{out}$

$\dot{m}h_1 = \dot{m}h_2$

$h_3 = \frac{h_f(5\,m) - (4\,m)}{2}$

$h_3 = \frac{2794.2 + 2803.8}{2} + \boxed{2797.2}$ kJ/kg

$y(h_1 + h_2) = (y+1)\, h_3$

$y\ 3196.7 + 11\cancel{4}8.1 = (y+1)\ 2797.27$

$y(3196.7 - 2797.2) = 2797.2 - 1148.1$ $y = \frac{\dot{m}_1}{\dot{m}_2}$

$y(399.5) = 1649.1$

$y = 4.12791$

$\frac{\dot{m}_1}{\dot{m}_2} = 4.1279.1$ $\boxed{\dot{m}_2 = .12113}$ kg/s

0.5 kg/s

Redo this before exam, use correct approximation for h_3

$\approx h$ Tsat<4.5>Mpa + pressure × something ← find Notes 2-24

$h = h_f\langle T\rangle + (P - P_{sat}\langle T\rangle)(v\langle T\rangle)$

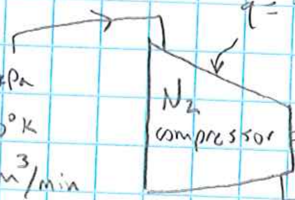
$167.53 + (5{,}000 - 7.39)(.001008) = 172.563$

Quiz — David Malawey   2-17-10   100

4

$q = -5 kJ/kg$

① $P = 100 kPa$
$T = 300°K$
$\dot{V} = 50 m^3/min$



$\dot{W} = ?$ (kJ/sec)

② $P = 500 kPa$
$T = 500°K$

Ideal gas
$R = .2968$
$P\forall = mRT$
$\dot{m} = \frac{P\dot{\forall}}{RT} = \frac{100\ 50/(60)}{.2968\ (300)}$

$\dot{m} = .9359$ kg/s ✓

$Pd\forall =$ $\Delta m_{cv} = 0$ $\Delta E_{cv} = 0$ $\Delta ke = \Delta pe = 0$

$\dot{E}_{in} = \dot{E}_{out}$

$\dot{W}_{in} + \dot{m}h_1 = \dot{Q}_{out} + \dot{m}h_2$

1.044

$h_1 = C_pT_1 = 1.039\ (300 + 273) = 311.7$

$h_2 = C_pT_1 = 1.039\ (500 + 273) = 519.5$

$W_{in} = \dot{Q}_{out} + \dot{m}(h_2 - h_1)$

$(.9359)$

$= (5 kJ/s) + \cancel{.9327}\ .9359\ kg/s\ (519.5 - 311.7)$

$\boxed{\dot{W}_{in} = \cancel{198.64}\ kJ/s}$

$\boxed{\cancel{199.48}}$

$\boxed{199.16}$ kJ/s

Quiz answer: in class 2-17-10

9.11 $R = .2981 \frac{kJ}{kg \cdot K}$

9.12 @ 400°K C_p 1.044 "

$$v_1 = \frac{RT_1}{P_1} = \frac{.2968 \frac{kN \cdot m}{kg \cdot K} \; 300K}{100 \, kN/m^2} = .8904 \; m^3/kg$$

$$\dot{m} = \frac{\dot{V}_1}{v_1} = \frac{50 \, m^3}{60 \, sec \cdot .8904 \, m^3/kg} = .9359 \; kg/sec$$

$$\dot{Q} = \dot{m} q = .93591 \; kg/sec \; \frac{-5 \, kJ}{kg} = -4.6795 \; kJ/sec$$

~~1st law $\dot{Q}$~~ $h_2 - h_1 = C_p(T_2 - T_1) = 1.044\,(200) = 208.8 \; kJ/kg$

1st law $\dot{Q} + \dot{m} h_1 = W + \dot{m} h_2$

$\dot{W} = .93591 \frac{kg}{s} \left(-208.8 \frac{kJ}{kg}\right) - 4.6795 \frac{kJ}{s}$ $\quad \dot{W} = -200 \; kJ/sec$

Hz = cycle / second

Torque: $T_1 \left(\frac{\text{teeth f}}{\text{teeth i}}\right)$ on shaft

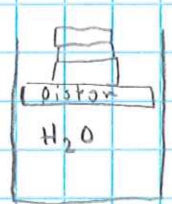
Power: same throughout

1hp = 550 ft·lb

Rotation: $\omega_1 \left(\frac{\text{teeth i}}{\text{teeth f}}\right)$ of shaft

David Malawey Quiz 3

90



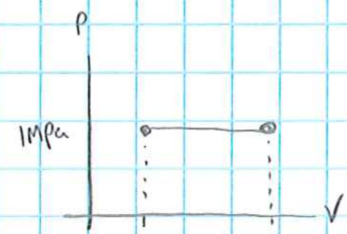
2kg

① $P = 1MPa$ const press. ② $350°C$

$x = .88$ $1MPa$

$v_1 = .88\,v_g^{.19436} + .12\,v_f^{.00127} = .171189$ ✓ 10

$\boxed{{}_1Q_2 = {}_1W_2 + E_2 - E_1 \qquad {}_1W_2 = P\,dV}$ ✓



$W = 1000kPa\,(V_2 - V_1)$

$= 2kg\,(1000kPa)(v_2 - v_1)$

${}_1W_2 = 222.6\,kJ$ ✓

10

② SHV

$v_2 = v_g(1MPa)$

$= .28250$

$u_1 = 761.39(.12) + 2582.8(.88)$

$u_1 = 2364.23\ (m)$

$u_2 = C_v T_2 = 2875.7\ (m)$

${}_1Q_2 = 222.6kJ + 2kg\,(u_2 - u_1)$ 10

$= 222.6 + 2($

David Malawey
Quiz 2

75

H_2O rigid container $V = .02\ m^3$

state 1 200kPa $x = 1.0$ $u_g = 2529.1$
state 2 100kPa $u_g = 2505.6$

mass: $\dfrac{.02\,m^3}{.88578\,m^3/kg} =$
$= .0226\ kg\ H_2O$

10

$\int_1^2 P\,dV = 0$

${}_1Q_2 = \cancel{{}_1W_2}^{\,0} + U_2 - U_1$

${}_1Q_2 = .0226\ kg\left(2505.6\ \frac{kJ}{kg} - 2529.1\ \frac{kJ}{kg}\right)$

$\boxed{{}_1Q_2 = -.5311\ kJ}$

* must find the x for state (2) and get appropriate heat capacity

David Malawey Jan 20, 2010

90

Quiz 1)

State 1 200 kPa $x = 0.8$ $T = ?$ $v = ?$

$\boxed{T = 120.21\,^{\circ}C}$, in mix of liquid & gas

$v = 0.8(\cancel{.001061})\ (.88578) + .2(.001061)$

$\boxed{v = .7088\ m^3/kg}$ ✓

2) 200 kPa 300°C v?

~~pressure~~ SHV, $\boxed{v = 1.31623}$ m^3/kg ✗

3) 150°C $v = .361\ m^3/kg$ $x = ?$ $v = (1-x)V_f + xV_g$

$(1-x)(.001091) + x(.39248) = .361$

$.391389x = \cancel{.361} .359909$

$\boxed{x = .9196}$ ✓

4) 500 kPa 100°C v

compressed liquid, $\cong$ saturated liquid b/c low pressure

$\boxed{v \approx .001093\ m^3/kg}$ ✓

EXAMS

David Malawey 96.9 ~~95~~ 85.3

1. Find the flow exergy (Ψ) for air at 25°C, 50 kPa if T_0 = 25°C and P_0 = 100 kPa. Assume idal gas; neglect knetic energy and potential energy.

50%

$$\text{adjusted} = 100 - \frac{20}{32.6}(100 - \text{raw})$$

2. Find $\Psi_1 - \Psi_2$, $\Psi_3 - \Psi_4$, and the reversible work per unit time (kW) for the condenser described in example 5-10, page 244. Assume T_0 = 25°C and P_0 = 100 kPa.

50%

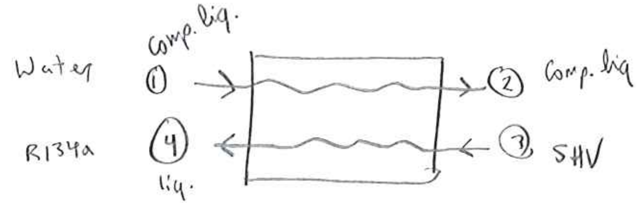
100
64.6
94.0
96.9

Final Exam, Tues. 8:00 am
Rm 120 Civil, first 4 rows

David Malawey Exam 4 5-5-10

2)

		T	P	h	$\dot{m}$	
H_2O	①	15°C	300 kPa	62.982	29.1 kg/min	
	②	25°C		104.83		
R134a	③	70°C	1 MPa	303.85	6 kg/min	SHV
	④	35°C	1 MPa	100.87		comp. liq.



$T_0 = 25°C$ $P_0 = 100$ kPa

$$\psi_2 - \psi_1 = (h_2 - h_1) - T_0(s_2 - s_1) + 0 + 0$$

$$= 41.848 - 298(.1427)$$

$$\boxed{-(\psi_1 - \psi_2) = -.6766}$$ ≈ ✓

$$s_2 - s_1 = C_{avg} \ln \frac{T_2}{T_1}$$

$$= 4.18 \ln\left(\frac{25+273}{15+273}\right)$$

$$= .1427 \text{ kJ/kg·K}$$ ≈

$$\psi_4 - \psi_3 = (h_4 - h_3) - T_0(s_4 - s_3) + 0 + 0$$

$$= -202.98 - 298(-.6446)$$

$$\boxed{-(\psi_3 - \psi_4) = -10.8892}$$ ✓

$$s_4 \approx s_f \langle 35° \rangle = \frac{.36670 + .37609}{2}$$

$$= .37140$$

$$s_3 = 1.0160$$

$$s_4 - s_3 = -.6446$$

$W_{rev} = ?$

$$X_{in} - X_{out} - \cancel{X_{dest}}^{0} = \cancel{\Delta X_{system}}^{0}$$

$$W_{rev,in} + \dot{m}_1(\psi_1 - \psi_2) + \dot{m}_3(\psi_3 - \psi_4) = 0$$

$$W_{rev,in} = \dot{m}_1(\psi_2 - \psi_1) + \dot{m}_3(\psi_4 - \psi_3)$$

$$= 29.1 \frac{kg}{min}\left(\frac{1 min}{60 sec}\right)(-.6766) + 6 \frac{kg}{min}\left(\frac{1 min}{60 sec}\right)(-10.8892)$$

$$= -(.3282) + -(1.0889)$$

$$= -1.417 \text{ kJ/s}$$

$$\boxed{\dot{W}_{rev,out} = 1.417 \text{ kW}}$$ ✓

50

s Table A4
.3672 - .2245 = .1427
s_2 - s_1

David Malawey Exam 4 5-5-10

$T_0 = 25°C$ $P_0 = 100$ kPa $R = .2870$

1) $\psi = ?$ air 25°c 50kPa

$\psi = (h - h_0) - T_0(s - s_0) + \cancel{pe}^{0} + \cancel{ke}^{0}$

Ideal gas $\Delta h = C_{p\,avg}(T_1 - T_0) = 0$

$s - s_0 = \cancel{C_p \ln \frac{T_2}{T_1}}^{0} - R \ln \frac{P_0}{P_1} = -.2870 \ln(2) = -.1989\ kJ/kg \cdot K$

$\psi = -(25+273)(-.1989) = \boxed{59.27\ kJ/kg}$

Should be -

45

$s - s_0 = -R \ln \frac{P}{P_0}$

$- .2870 \ln\left(\frac{1}{2}\right) = +.1989$

$-T_0(s - s_0) = -298(.1989)$

$=$

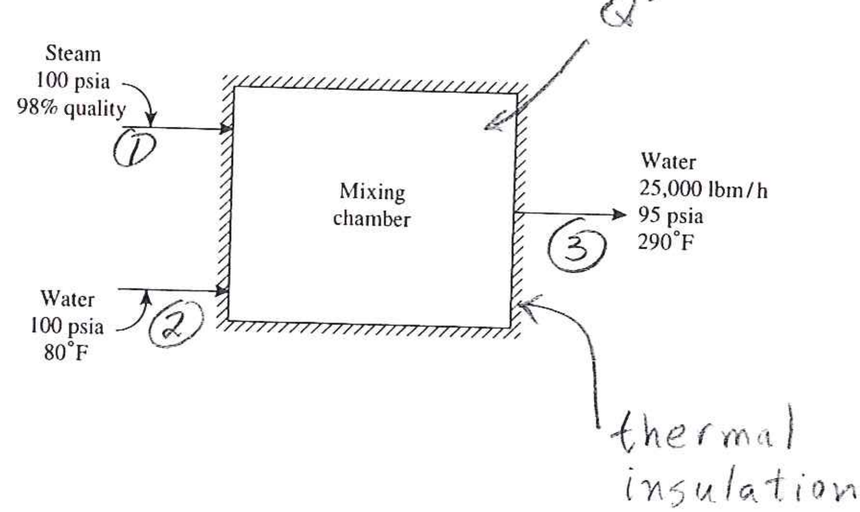
David Malawey Test 3 4-13-10 ~~90~~ 94.5

1\. Water in a cylinder-piston arrangement expands reversibly and isothermally from $x_1 = 0.65$, $T_1 = 200^{\circ}C$ to 500 KPa. Calculate the specific work (w, KJ/Kg).

2\. An "open heater" mixes steam and liquid water to form heated water. The incoming steam is at 100 psia and 98% quality; the incoming water is at 100 psia and 80°F; and the outgoing heated water has a flow rate of 25,000 lbm/h and is at 95 psia and 290°F. Assuming a steady-flow, steady-state adiabatic mixing process, determine the hourly entropy production for the mixing process.

$\left(\dot{S}_{gen}, \frac{Btu}{{}^{\circ}R\ hour} \right)$

$\dot{S}_{gen} = ?$



1)

D. Malawey

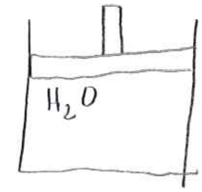
$w = ?$

① $x = .65$

$T = 200°C$

$q - w = \Delta U + \cancel{\Delta KE}^{0} + \cancel{\Delta PE}^{0}$

closed system



reversible expansion

isotherm.

② 500 kPa (SHV)

$T = 200°C$

$U_1 = U_f + x\, U_{fg} = 850.46 + .65(1743.7)$

$= 1983.87\ kJ/kg$ 5

$U_2 = 2643.3\ kJ/kg$ 5

$U_2 - U_1 = 659.44\ kJ/kg$

$+ 413.139\ kJ/kg - w = +659.44$

$\boxed{w = 246.3\ kJ/kg \text{ into system}}$

$S_2 = 7.0610$ $S_1 = 2.3305 + .65(4.0997)$

$S_2 - S_1 = 2.0657\ \frac{kJ}{kg \cdot K}$

$Q_{int\ rev} = \int_1^2 T\,ds$

$= T_{avg}(S_2 - S_1)$

$= 200(2.0657)$

$= 413.139\ kJ/kg$

use °K

-5

45

D. Malawey

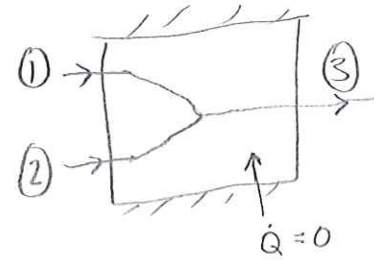
2]

Steady flow
Steady state
adiabatic

① $P = 100\ psia$ $X = .98$ Steam, $T = 327.81°$

② $P = 100\ psia$ $T = 80°F$ Comp. liq.

③ $\dot{m} = 25000\ lbm/hr$ $P = 95\ psia$ $T = 290°F$
comp. liq



$S_{gen}/hr = ?$

$h_1 = 298.51 + .98(888.99) = 1169.72$

$\dot{m}_3 = \dot{m}_2 + \dot{m}_1$

$h_2 = h_f \langle 80°F \rangle = 48.07$

$h_3 = h_f \langle 290°F \rangle = 259.45$

$h_3 \dot{m}_3 = h_1(m_1) + h_2(m_3 - m_1) = h_1 m_1 + h_2 m_3 - h_2 m_1$

$-h_2 m_3 \quad h_3 \dot{m}_3 = m_1(h_1 - h_2)$

$\dot{m}_1 = \dfrac{h_3 m_3 - h_2 m_3}{(h_1 - h_2)} = \dfrac{25000(259.45 - 48.07)}{(1169.72 - 48.07)}$

$\dot{m}_1 = 4711.4\ lbm/hr$

$\dot{m}_2 = 20288.6\ lbm/hr$

$s_1 = .47427 + .98(1.12888) = 1.58057$

$s_2 = s_f \langle 80°F \rangle = .09328$

$s_3 = s_f \langle 290°F \rangle = .42361\ Btu/lbm \cdot R$

$\dot{S}_{in} - \dot{S}_{out} = -\dot{S}_{gen}$

$\dot{S}_{in} - \dot{S}_{out} + \dot{S}_{gen} = \cancel{\Delta S_{system}}^{\,0}$

$\dot{m}_1 s_1 + \dot{m}_2 s_2 - \dot{m}_3 s_3 = -\dot{S}_{gen}$

$4711(lbm/hr)\ 1.58057\left(\frac{Btu}{lbm \cdot R}\right) + 20289(.09328) - 25000(.42361) = -S_{gen}$

$+ 2\cancel{6}3716 \quad -10590 = -S_{gen}$

$\boxed{7953\ \frac{Btu}{R \cdot hr} = \dot{S}_{gen}}$

entropy of matter in

entropy of matter out

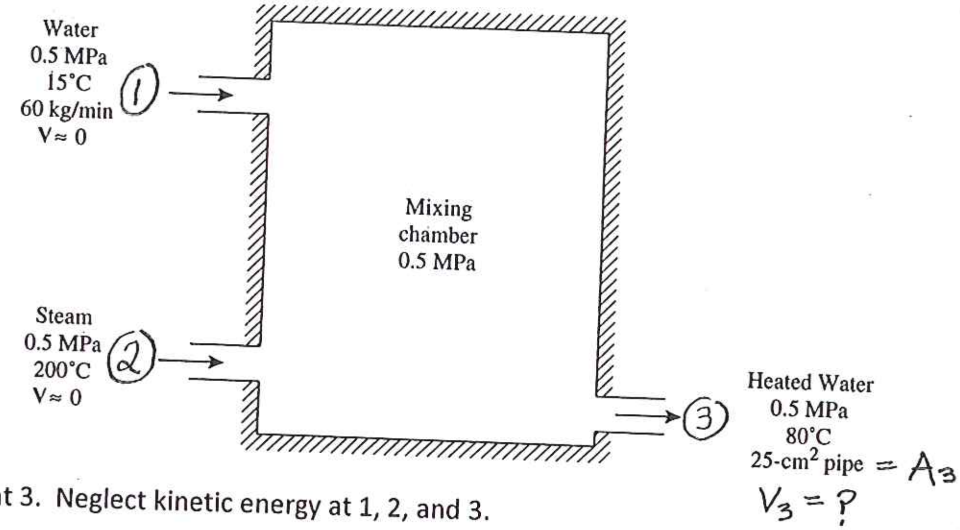
45

David Malawey 3-10-10 Exam 2

~~60~~ → 64.6

1.

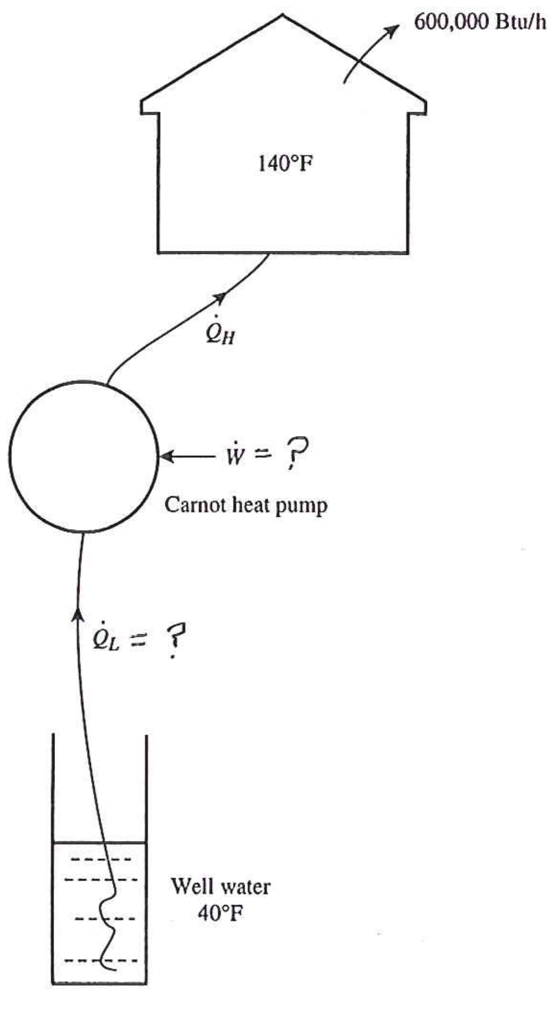
Water at 0.5 MPa and 15°C flows through a large pipe at a rate of 60 kg/min into an insulated tank. Steam at 0.5 MPa and 200°C flows into the same tank through another pipe with negligible velocity. The steam then condenses and mixes with the water to form heated water that leaves the tank through a $\boxed{25\text{-cm}^2}$ pipeline at a pressure of $\boxed{0.5\text{ MPa}}$ and $\boxed{80°C}$. Calculate the exit velocity of the heated water.



Hints: Calculate the mass flow rate at 3. Neglect kinetic energy at 1, 2, and 3.

2.

A Carnot heat pump is used to supply heat to a building at 140°F by removing heat from well water at 40°F. The building requires 600,000 Btu/h for heating. Determine the kilowatt input required by the machine and the heat removed per hour from the well water. If electric resistance heaters are used, what kW input is needed?



Answer :

velocity $V_3 = ?$

① H_2O .5 MPa
15°C
60 kg/min

② steam
0.5 MPa
200°C

③ .5 MPa
80°C
$A_3 = 25 cm^2$

1 & 3 are comp. liquid
2 SHV p 920 $h_2 = 2855.8$

cannot use specific heats because it is not all liquid water

eq. 438. $h = h_f\langle T\rangle + v_f\langle T\rangle [P - P_{sat}\langle T\rangle]$

$h_1 = 62.982 + (500 - 1.7057)\ .001001$
$.499\ kJ/kg$
$= \boxed{63.481}$

$h_3 = 335.02 + \underbrace{(500 - 47.416)\ .001029}_{.466}$

$= \boxed{335.48}$

$1 \frac{kg}{sec}\ (63.481) + \dot{m}_2\ (2855.8) + (1 \frac{kg}{s})(335.48)$ $\dot{m}_2 = .10792\ kg/s$

$V_3 = v_f\langle 80°C\rangle = .001029\ m^3/kg$

$\dot{V}_3 = \dot{m}_3 V_3 = 1.10792\ (.001029)\ m^3/kg$

$.00114\ m^3/sec$ $A_3 = 25(.01)^2$

David Maloney 3-10-10 Test 2

(1) $\dot{m}_3 h_3 = \dot{m} h_2 + \dot{m} h_1$ 5 No pressure changes

$h_1 = C_p(T_1) = 4.18 \frac{kJ}{kg \cdot K}(15+273) = \cancel{\underline{1203.84}}\ kJ/kg + [.001 m^3/kg \cdot 500 kPa = .5 kPa]$

$h_2 = \underline{2855.8}\ kJ/kg$ 5

$h_3 = 4.18 \frac{kJ}{kg}(80+273) = \cancel{\underline{1475.54}} + [.001 m^3/kg\ 500 kPa = .5 kPa]$

5

$(M_1 + M_2) h_3 = M_1 h_1 + M_2 h_2$

$M_2 h_3 = M_1 h_1 + M_2 h_2 - M_1 h_3$

$M_2 (h_3 - h_2) = M_1 (h_1 - h_3)$

$M_2 = \frac{M_1 (h_1 - h_3)}{(h_3 - h_2)}$

~~$(60 kg/min + M_2)(1475.54) = 1203.84(60 kg/min) + 2855.8(M_2)$~~

~~$M_2(1475.54 - 2855.8) = 1203.84(60) - (1475.54)(60)$~~

$M_2 = 11.8177$ kg/min

$\boxed{M_3 = 71.8177\ kg/min}$

$v_3 = .001 \frac{m^3}{kg}$ $\dot{V}_3 = .71813\ m^3/min = \underline{.012\ m^3/sec}$ 5

$.25\ cm^2 \left(\frac{1m}{100cm}\right)^2 = 2.5E^{-5}\ m^2$ 5

$\frac{.012\ m^3/sec}{2.5(10^{-5})\ m^2} = \boxed{480\ m/s}$

25

David Malawey

2)

$T_H = 140°F = 599.67$ ✓ $\eta_{th,rev} = 1 - \frac{T_L}{T_H} = .1668$

$T_L = 40°F = 499.67$ ✓

$Q_{in} = 600,000$ Btu/h ✓

$$\boxed{COP_{HP} = \frac{Q_H}{W_{net\,in}} = \frac{1}{1 - \frac{T_L}{T_H}}}$$

$$\frac{Q_H}{W_{net\,in}} = \frac{1}{1 - T_L/T_H}$$

$\dot{Q}_L = ?$
-5

-10

$600,000 \text{ Btu/hr} \left(\frac{\cancel{1}}{.1668}\right) = W_{net\ in} = 3.5971 E^6$ Btu/hr

a) $3.5971(10^6)$ Btu/hr $\left(\frac{1 \text{ kW}}{3412.14 \text{ Btu/hr}}\right) = \boxed{1054.21 \text{ kW}}$

b) electric resistance: $60,000 \text{ btu/hr} \left(\frac{1}{3412.14}\right) = \boxed{175.84 \text{ kW}}$ ✓

35

Answer $\frac{\dot{Q}_H}{\dot{Q}_L} = \frac{T_H}{T_L}$ $\dot{W} = 100,000$ $W_{net\ in} = Q_H - Q_L$

$\dot{W} + \dot{Q}_L = \dot{Q}_H$ $W_{net\ in} = \frac{Q_H}{1 - T_L/T_H}$

David. Malawey 100 100

1.

A rigid container with a volume of 0.170 m^3 is initially filled with steam at 200 kPa, 300°C. It is cooled to 90°C.

(*a*) At what temperature does a phase change start to occur? (5°C temp. range is good enough)

(*b*) What is the final pressure?

(*c*) What mass fraction of the water is liquid in the final state?

(*d*) Calculate the work done during the cooling process.

state 1
200 KPa
300°C

state 2
when phase change first happens

state 3, 90°C

2.

One kilogram of oxygen is compressed isothermally in a closed system from 100 kPa and 25°C to 300 kPa. Calculate (*a*) work, (*b*) heat transfer, and (*c*) change in internal energy.

Assume ideal gas.
Isothermal means constant temperature
See equation 4-7 page 170.

David Malawey EXAM 1

2-10-10

① $V = .170\ m^3$ $P = 200\ kPa$ $T = 300°C$ SHV $v = 1.31623\ m^3/kg$ $m = .1292\ kg$

② $V = .170\ m^3$ $T = 90°C$ $0 < x < 1$ $v = V/m = 1.31623$

$v =$ x

90°: $v_f = .001036$

$v_g = 2.3593$

a) Temp range where $v = v_g$ $\boxed{105° - 110°C}$ ✓

c) $x_2 = \dfrac{v - v_f}{v_g - v_f} = .5577 \leftarrow$ gas

mass frac liquid $= 1 - x = \boxed{.4423}$ ✓

50

b) $P_2 = P_{sat}\langle 90°C\rangle = \boxed{70.183\ kPa}$ ✓

d) ${}_1W_2 = \int_1^2 P \cancel{dV} = \boxed{0}$ ✓

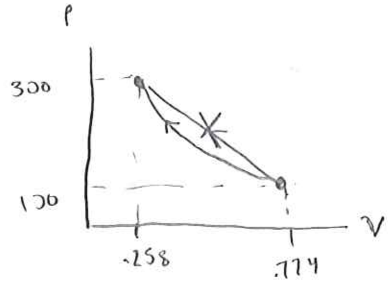
0

2) 1 kg O_2 ① $P_1 = 100\ kPa$ $T_1 = 25°C$ $V_1 = ?$ .7742

$R = .2598$ ② $P_2 = 300\ kPa$ $T_2 = 25°C$ $V_2 = ?$ .2581

$c_v = .658$

$c_p = .918$



$V_1 = \dfrac{mRT}{P} = \dfrac{(1)(.2598)(25+273)}{100} = .7742$

$V_2 = .2581$

a) ${}_1W_2 = \int P\,dV =$ ~~$P_{avg}(V_2 - V_1) = \dfrac{300+100}{2}(.2581 - .7742) = \boxed{-103.22\ kJ}$~~

$W_b = P_1 V_1 \ln \dfrac{P_1}{P_2} = \boxed{-85.055\ kJ}$ work done on system by surroundings

b) ${}_1Q_2 = {}_1W_2 + \cancel{\Delta U} = \boxed{-85.06\ kJ}$ heat gained by sys.

0

c) $\Delta U =$ $du = c_v(T)\cancel{dT}$

0

$\boxed{\Delta U = 0}$

50

Exam 1 rework

1) ① $.170\ m^3$ steam P 200kPa T 300°C cooled to 90°C

a) Temp of phase change begin?

b) $P_2 = ?$ c) $X_2 = ?$ d) $W = ?$

$U_1 = 2808.8$ $v = 1.31623\ m^3/kg$ $m = \frac{.173\ m^3}{1.31623\ m^3/kg} = .13144\ kg$

② 90°C, .13144kg $v = 1.31623$ a) $\boxed{T_{change} = 105\text{-}110°C}$

b) $\boxed{P_2 = 70.183\ kPa}$

$x(2.3593) + (1-x)(.001036) = 1.31623$

$x(2.35826) = 1.31519$

c) $\boxed{X_2 = .5577}$

should be 1-x for liquid

d) $Q_{in} - Q_{out} - \cancel{W_{out}}^{0} = Q_2 - Q_1$

$-Q_{out} = U_2 - U_1 = 376.97 + .558(2117) - 2808.8$

$\boxed{Q_{out} = 1250.54\ kJ}$

$W = \int P\, \cancel{dV}^{0}$ $\boxed{W = 0}$

Exam 1 rework

2) 1kg closed system isothermal Oxygen compressed

	T	P	V	u
①	25°C	100 kPa		
②	25°C	300 kPa		

$W_b = P_1V_1 \ln\frac{V_2}{V_1} = P_1V_1 \ln\left(\frac{P_1}{P_2}\right) = RT \ln\left(\frac{P_1}{P_2}\right) = .2598(298)\ln\left(\frac{1}{3}\right)$

$\boxed{W_b = -85.06 \text{ kJ/kg } (1\text{kg})}$ ← this work is in W ✓

$PV = RT$

$V = \frac{RT}{P} = \frac{.2598(25+273)}{100} = .7742$

$\Delta U = C_{v,avg}(\cancel{T_2 - T_1})^{0} = \boxed{0}$ internal energy ✓

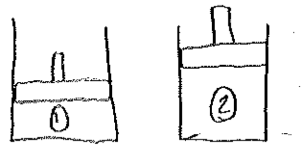
$Q_{in} - Q_{out} + W_{in} = \cancel{\Delta U}^{0}$

$\boxed{W_{in} = \dot{Q} = 85.06\text{kJ } \underline{out}}$ ✓

easy ✓

Exam 3 rework

1)



	X	T	P	S	V
1	X = .65	200°C		2.0657	.083091
2	X = 1	200°C	500kPa	7.0610	SHV .42503

$w = ?\ \frac{kJ}{kg} = ?$

$s_1 = 2.3305 + .65(4.0997) = 2.0657$

$v_1 = .65(.12721) + .35(.001157) = .083091$

$W = \int P dV$, v not const.

$W = dQ$

$Q_1 - W_{out} = Q_2 \qquad W = Q_1 - Q_2 = u_1 - u_2 \qquad u_1 = u_f + x(u_{fg})$

$Q_{in} - Q_{out} - W_{out} = Q_2 \qquad U_2 = (\text{table, SHV})$

$Q_{in} - W_{out} = Q_2 - Q_1$

$\int_1^2 Tds - W_{out} = U_2 - U_1 \qquad Tds = (200+273)(7.061 - 2.0657)$

$2362.78 - W_{out} = 659.44 \qquad = \cancel{263}\ 2362.78$

$\boxed{W_{out} = 1703.34}$

Exam 3 rework 2)

	State	P	X	T	h	s
①	Steam	100 psia	.98	327.8		
②	CLW	100		80°F	48.07	.09328
25000 lbm/hr ③	CLW	95		290°F	259.45	.42361

steady flow steady state adiabatic

$\dot{S}_{gen}$ (per hour) = ?

$h_1 = 298.51 + .98(888.99) \Rightarrow 1169.72$

$s_1 = .47427 + .98(1.12888) \Rightarrow 1.58057$

$m_1 h_1 + (1-m_1) h_2 = 1 h_3$

$m_1(h_1 - h_2) = h_3 - h_2$

$m_1 = (h_3 - h_2)/(h_1 - h_2)$

$m_1 = .1885\, h_3 = 4711$ lb/hr

$m_2 = 20{,}289$ lb/h

$S_{in} - S_{out} + S_{gen} = 0$

$S_{gen} = S_{out} - S_{in}$

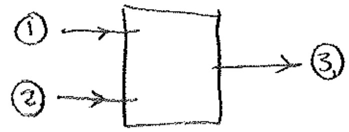
$= \dot{m}_3 s_3 - (\dot{m}_1 s_1 + \dot{m}_2 s_2)$

$= 25000(.42361) - [4711(1.58057) + 20289(.09328)]$

$= 10590 \quad - 9339$

$\boxed{S_{gen} = 1252 \ \frac{Btu}{°R\ h}}$

Exam 2 rework



① mixing chamber

	P	T	h	$\dot{m}$	v	
①	.5 MPa	15°	63.4808 ~~62.982~~	1kg/s	.001001	CLW
②	.5MPa	200°C	2855.8		.42503	SHV
③	.5MPa	80°C	335.487 ~~336.02~~		.001032	CLW

$$h_1 = h\langle T\rangle + v\left[P - P_{sat}\right] = 62.982 + .001001(500 - 1.7057)$$

$$h_3 = 335.02 + .001032(500 - 47.41)$$

$$h_3(m_1 + m_2) = h_1 m_1 + h_2 m_2$$

$$h_3 m_2 + h_3 m_1 = h_1 m_1 + h_2 m_2$$

$$m_2(h_3 - h_2) = h_1 m_1 - h_3 m_1$$

$$m_2 = \frac{m_1(h_1 - h_3)}{(h_3 - h_2)} = 1\,kg/s\,\frac{(63.481 - 335.49)}{(335.49 - 2855.8)} = .1079\ kg/s \qquad m_3 = 1.1079\ kg/s$$

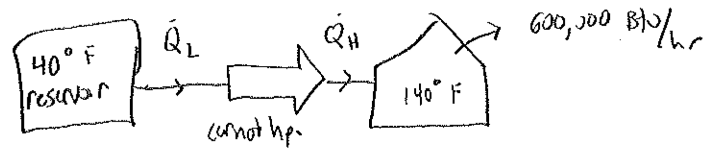
$$\dot{V} = 1.1079\ \frac{kg}{s}\left(\frac{.001032\ m^3}{kg}\right) = .001143\ m^3/s, \qquad 25(.01m)^2 =$$

$$V_3 = \frac{.001143\ m^3/s}{.0025\ m^2} = \boxed{.4572\ m/s}$$

Exam 2 rework 2)

find $\dot{Q}_{hp} = ?$

$\dot{Q}_L = ?$



$$COP_{HP,rev} = \frac{1}{1-\frac{T_L}{T_H}} = \frac{1}{1-\frac{(500)}{(600)}} \Rightarrow 6$$

$$Q_H = \frac{600{,}000 \text{ Btu/hr}}{} \; \frac{1 \text{ kW}}{3412.14 \text{ Btu/hr}} = 175.843 \text{ kW}$$

$$W_{net,in} = \frac{\dot{Q}_H}{COP_{HP}} = \frac{175.843}{6} = \boxed{29.307 \text{ kW}}$$ req'd by hp.

$W_{in} = Q_{out} - Q_{in}$

$W = \dot{Q}_H - \dot{Q}_L$

$29.307 = 175.843 - \dot{Q}_L$ $\quad \boxed{\dot{Q}_L = 146.54 \text{ kW}}$ heat removed from water

kW req'd by resistance heaters = $\boxed{175.84 \text{ kW}}$

Chapter 5

$$m_{in} - m_{out} = \Delta m_{system} \quad \text{and} \quad \dot{m}_{in} - \dot{m}_{out} = dm_{system}/dt$$

$$\dot{m} = \rho V A$$

$$\dot{V} = VA = \dot{m}/\rho$$

$$\theta = h + ke + pe = h + \frac{V^2}{2} + gz$$

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Changes in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

Chapter 6

$$\text{COP}_R = \frac{Q_L}{W_{net,in}} = \frac{1}{Q_H/Q_L - 1}$$

$$\text{COP}_{HP} = \frac{Q_H}{W_{net,in}} = \frac{1}{1 - Q_L/Q_H}$$

Heat engines

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

absolute temps

$$\left(\frac{Q_H}{Q_L}\right)_{rev} = \frac{T_H}{T_L}$$

carnot heat engine

$$\eta_{th,rev} = 1 - \frac{T_L}{T_H}$$

reversible processes

$$\text{COP}_{R,rev} = \frac{1}{T_H/T_L - 1}$$

$$\text{COP}_{HP,rev} = \frac{1}{1 - T_L/T_H}$$

- water, liquid only ; $h_2 - h_1 = C(T_2 - T_1) + v_f\langle T_1\rangle[P_2 - P_1]$
  - $* \; h = u + PV$
- otherwise, Steam table
- ideal gas : $h_2 - h_1 = C_p(T_2 - T_1)$
  - $* \; h$ is function of T only

$C_p(\text{Water}) = 4.18 \frac{kJ}{kg \cdot k}$

$1L = .001 \, m^3$

$\rho_{water} = 1000 \, kg/m^3$

$$Q + \sum_{in} h_m = W + \sum_{out} mh + [M_2 U_2 - M_1 U_1]_{c.v.}$$

adiabatic : no heat transfer

thermal Energy $\dot{E} = \dot{m}(u_2 - u_1) =$

fluid: $\dot{E}_{Mech\,out} - \dot{E}_{Mech\,in} = \dot{m}\left[\frac{P_2}{\rho} + \frac{V_2^2}{2} + gz_2\right] - \dot{m}[\quad " \quad]$

water, with vapors $\quad h = h_f\langle t\rangle + \underbrace{v_f\langle t\rangle[P - P_{sat}\langle t\rangle]}_{\text{probably negligible}}$

Thermo

Exam 2 formulas:

$\dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$ where $\dot{m}_3 = \dot{m}_1 + \dot{m}_2$

heat transferred: $\dot{Q} = \dot{m} C_p (T_{in} - T_{out})$ * arrange in/out to be positive & note direction for Q value

$v = \frac{RT}{P}$ $\quad V = \frac{mRT}{P}$ $\quad h = C_p T$ $\quad u = C_v T$ $\quad h = u + Pv$

coefficient of performance $COP_R = \frac{\dot{Q}_L}{\dot{W}_{net,in}}$

closed system = Δu internal energy $= 0$ $\therefore$ $W_{net\ out} = Q_{in} - Q_{out}$

η_{th} = thermal efficiency = $\frac{\text{net } W_{out}}{\text{net } Q_{in}}$ or $1 - \frac{Q_{out}}{Q_{in}}$ $\quad \eta = 1 - \frac{Q_L}{Q_H}$

T_H high temp $\quad Q_H$ heat transferred at T_H medium

T_L low temp $\quad Q_L$ heat transferred at T_L medium

magnitudes

Formulas

ideal gasses

$$\left[\begin{array}{l} h = u + Pv \\ Pv = RT \end{array}\right\} h = u + RT$$

$$du = c_v(T)\,dT$$

$$dh = c_p(T)\,dT$$

$$v = x(v_g) + (1-x)v_f$$

$$x = \frac{v - v_f}{v_g - v_f}$$

$$\text{Watt} = \frac{J}{s} \quad [VI = P]$$

$$I = \frac{V}{R}$$

Find V for an Ideal gas:

$$V = \frac{mRT}{P}$$

$$P = \frac{\text{energy}}{\text{time}}\left(\frac{J}{s}\right)$$

Find power: ① find ${}_1Q_2$ (kJ) *
② divide by t (s)
* this includes W & U
- can use h if $p =$ const.

$${}_1Q_2 = {}_1W_2 + E_2 - E_1 \overset{\text{No other energy}}{=} {}_1W_2 + \Delta U$$

${}_1Q_2$ = heat tr. into system

E_2 = energy, state 2

E_1 = energy, state 1

if PV^n = const. THEN ${}_1W_2 = \frac{P_2V_2 - P_1V_1}{1-n}$ $n \neq 1$

OR

$${}_1W_2 = P_1V_1 \ln\frac{V_2}{V_1}, \; n = 1$$

$${}_1Q_2 = {}_1W_2 + m(u_2 - u_1)$$

— OR —

$${}_1Q_2 = m(h_2 - h_1) \text{ if } P = \text{constant}$$

p 200 $\frac{P_2}{P_1} = \left(\frac{V_2}{V_1}\right)^n$ ← find n

if PV^n = const: $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

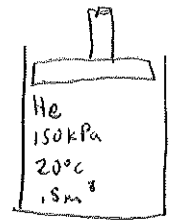
$$W_{B,\text{out}} = \int P\,dV = P_{\text{average}}(v_2 - v_1)(m)$$

if P = constant

Homework 2-1-10

4-133, 147, 152

133)



①

He → ideal gas, constant specific heats

$R\langle He \rangle = 2.0769 \frac{kJ}{kg} \cdot k$

$C_v = 3.1156 \ kJ/kg \cdot k$

$PV = mRT \quad m = \frac{PV}{RT} = \frac{150kPa\,(.5m^3)}{2.0769\left(\frac{kJ}{kg \cdot K}\right)(293°K)} = .1232\,kg$

② polytropic $PV^n = Const$

400 KPa

140°C

${}_1Q_2 = ?$

$\frac{P_1V_1}{RT_1} = \frac{P_2V_2}{RT_2} = V_2 = .2643 m^3$

$P_2V_2^{\,n} = P_1V_1^{\,n} \qquad \frac{P_2}{P_1} = \left(\frac{V_1}{V_2}\right)^n \qquad \frac{400}{150} = \left(\frac{.5}{.2643}\right)^n \qquad 2.667 = 1.892^n \qquad n = 1.538$

$\ln 2.667 = n \ln(1.892)$

$W_b = \int_1^2 PdV = \frac{P_2V_2 - P_1V_1}{1-n} = \frac{mR(T_2-T_1)}{1-n}$

$\frac{(P_2-P_1)}{2}\frac{(V_2-V_1)}{2}$

$= \frac{.1232kg\,(2.0769 \frac{kJ}{kg \cdot k})(120°c)}{1-1.538}$

$= -57.072 \ kJ$

$= \boxed{57.07 \ kJ \ in}$

$E_{in} - E_{out} = \Delta E_{sys}$

$Q_{in} + W_{b\,in} = \Delta U = m(u_2 - u_1)$

$Q_{in} = m(u_2 - u_1) - W_{b\,in}$

$Q_{in} = mc_v(T_2 - T_1) - W_{b\,in}$

$.1232\,kg\left(3.1156 \frac{kJ}{kg \cdot k}\right)(120°k) - 57.07\,kJ$

$\boxed{Q_{in} = -11.009 \ kJ}$ heat is lost

— Homework — THERMO

4-147, 152

4-147) $.4m^3$ air, 400kPa, 30°c

200kPa required to raise piston

② T= 30°
P= 200kPa
$V_2 = ? = .8m^3$

$R_{AIR} = .2870 \frac{kJ}{kg\cdot K}$

$C_v = .718 \frac{kJ}{kg\cdot K}$

$_1Q_2 = ?$

$\frac{P_1V_1}{\cancel{n}RT_1} = \frac{P_2V_2}{nRT_2}$ $\quad V_2 = \frac{P_1V_1 \; T_2}{P_2 \; T_1} = \frac{400}{200}(1)(.4m^3)$

$\boxed{V_2 = .8m^3}$

$P_1V_1^n = P_2V_2^n \quad \frac{P_1}{P_2} = \left(\frac{V_2}{V_1}\right)^n \quad .5 = (2)^n$

pressure @ piston face = constant 200kPa $\quad W_b = \int_1^2 PdV = 200kPa\,(.8m^3 - .4m^3)$

$\boxed{W_b = 80\text{ kJ}}$ by system on surroundings

$_1Q_2 = W_b + \cancel{\Delta U}$ 0, const. temp

$= 80kJ + 0$

$\boxed{_1Q_2 = 8kJ \text{ in}}$

4-152) ① m = 1.4 kg T = 200°C H_2O saturated liquid $V_2 = 4V_1$ $h = h_f = 852.26$

P = 1554.9 kPa $P_{constant}$ $\quad x = 0 \quad V_1 = .001157\ m^3$

V = ?
$T_2 = ?$
P(resistor) = ?

② 1.4kg T = ? V = $.004628 m^3$ P = 1554.9 kPa

$V_2 = x_2(V_g) + (1-x_2)V_f \quad V_2 - V_f = x_2(V_g - V_f)$

$\boxed{V_2 = .006479 m^3}$

$x_2 = \frac{V_2 - V_f}{V_g - V_f} = \frac{.004628 - .001157}{} = .0275$

$\boxed{T_2 = T_1 = 200°C}$

$h_2 = 905.6 \quad h_2 - h_1 =$

$_1Q_2 = m(h_2 - h_1) = 74.68kJ$ (out)

1200 seconds

$P = \frac{\text{energy}}{\text{time}} = \frac{74.68}{1200} = .0622\ kJ/s = \boxed{.0622\text{ kW}}$

4-89) 1000W = 1000 $\frac{kJ}{s}$ V = .00015 2770 kg/m^3 $\quad C_p = 875\ J/kg°C$ $\quad T_1 = 22°C \quad T_2 = 140° \quad \Delta T = 118°$

m = .4155

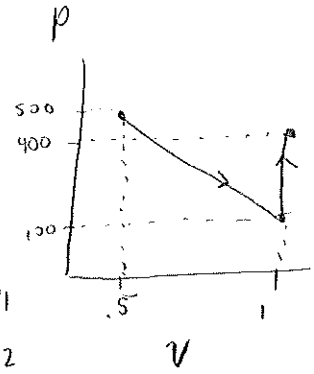
ε = .85 $\quad 850\frac{kJ}{s}(t) = \Delta T(m)(C_p)$

$850kJ\,(t) = 118°\,(.4155)(.875\ kJ/kg°C)$

$\boxed{t = 50.47\ s}$

4-6) $2\,kg\ N_2$ $\quad {}_1W_2 = \int P\,dV = \left(\frac{500+100}{2}\right)(1-.5) = \underline{150}$

$150(2\,kg) = 300\,kJ$



4-11) ① 5kg sat. H_2O vapor 300 kpa $P_{const.}$ $V_1 = (.60582)(5) = 3.0291$

${}_1W_2 = ?$ $\quad T_1 = 133.52$

② $T_2 = 200°C$ $\quad P_2 = 300\,kPa$

SHV $\quad V_2 = (.71643)(5) =$

$\int_1^2 P\,dv = P[m(V_2 - V_1)] = 300(5)(.71643 - .60582) = 165.9\,kJ$

4-29) H_2O sat. vapor $\quad$ ① $T = 200°C$ $\quad P = 1554.9$ $\quad v = .12721$

${}_1Q_2 = ?$ $\quad {}_1W_2 = ?$ $\quad$ ② sat. liquid $\quad P = 1554.9$ $\quad v = .001157$

${}_1W_2 = P\int dV = 1554.9(\quad) = \boxed{-196\ kJ/kg}$ Work in

${}_1Q_2 = W_b + m(u_2 - u_1)$ $\boxed{1939.7\ kJ/kg}$

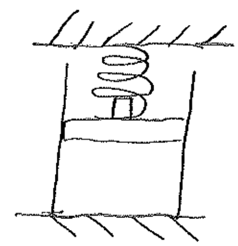
4-76) 5kg He $\quad$ ① $P = 100\,kPa$ $\quad T = 20°C$ $\quad V = 30.43$ $\quad \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

$Q = ?\ W = ?$ $\quad$ ② $P = 800\,kPa$ $\quad T = 160°C$ $\quad V_2 = 5.621$

$R = 2.0769$

$C_p = 5.1926$ $\quad PV = nRT$ $\quad V = \frac{mRT}{P}$

$C_v = 3.1156$ $\quad 100(v) =$



$Q_{in} - W_{b,out} = \Delta U = mc_v(T_2 - T_1) = 2181\,kJ$

$W_b = \int P\,dV = \left(\frac{100+800}{2}\right)(V_2 - V_1) = -11{,}164\,kJ$ (Work in)

${}_1Q_2 = {}_1W_2 + \Delta U = +2181 - (11{,}164)$

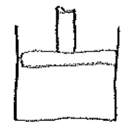
$\boxed{{}_1Q_2 = -8983}\ kJ$

H/W

	3-27, 33, 39E
1-25	4-6, 11, 29
2-1	4-133, 147, 152

3-33) ① 1kg R134a .14m³ -26.4°C

② 1kg R134a V=? T=100°C



P = constant = 100kPa

$v_1 = .14 \, m^3/kg \quad 0<x<1$

$P_1 = P_{sat}\langle -26.4°C\rangle = 100kPa$

Table A-13 $v = .30138 \, m^3/kg$

$V_2 = m v_2 = \boxed{.30138 \, m^3}$

3-39E) ① $V = 2ft^3$ m = 1lb P = 100 psia find U & H

H_2O $v = 2 \, ft^3$ $0<x<1$ $T = T_{sat}\langle 100psia\rangle = 327.81$

$2 ft^3 = x(v_g) + (1-x) v_f = x(4.4327) + (1-x)(.01774)$

$1.98226 ft^3 = x(4.41496) \Rightarrow \underline{x = .449}$

$u = x(u_g) + (1-x)(u_f)$

$(.449)1105.5 + .551(298.19) = 660.67 \frac{Btu}{lbm}$ $\underline{661}$

$h = (.449)1187.5 + (\ )(298.51) = 697.67 \frac{Btu}{lbm}$ $\underline{698}$

4-133) He ① P=150kPa T=20°C V=.5m³

example 186

② P=400kPa T=140°C

$PV^n = const.$

$R = 2.0769 \, kJ/kg\cdot K$

$C_p = 5.1926$

$C_v = 3.1156$

${}_1Q_2 = ?$

$\frac{P_1V_1}{RT_1} = m = \underline{.1232 kg.}$

$\frac{P_1V_1}{T_1\cancel{R}} = \frac{P_2V_2}{\cancel{R}T_2} \quad V_2 = \underline{.2643 \, m^3}$

${}_1Q_2 = {}_1W_2 + E_2 - E_1$

$= m(u_2 - u_1) = .1232 = .1232 \, (\overset{3.1156}{\cancel{5.1926}})(140° - 20°) = 46.061$

$\frac{400}{150} = \left(\frac{.5}{.2643}\right)^n \quad n = 1.539 \quad {}_1W_2 = \frac{P_2V_2 - P_1V_1}{1-n} = -57.0 \, kJ$

$\ln(\ ) = n\ln(\ )$

4.152) Final try

20 min = 1200 s

$V = ?$ .006479

$T_2 = ?$ 200°C

$P = ?$

① 1.4kg 200°C sat. liquid. $P = 1554.9$ $V_1 = .001157$

② 1.4kg 200°C $P = 1554.9$ $V_2 = .004628$ $0 < x < 1$

* should be Δh

$\Delta U = 1.4(U_2 - U_1) = \underline{67.116 \text{ kJ}}$

850.46

$P = \frac{J}{s}$

$x = \frac{V - V_f}{V_g - V_f} = .0275$

$U_f = x(U_g) + (1-x)(U_f) = \underline{898.4}$

$= \frac{67.116}{1200} = .0559 \text{ kW}$

The energy content of the universe is constant, just as its mass content is. Yet at times of crisis we are bombarded with speeches and articles on how to "conserve" energy. As engineers, we know that energy is already conserved. What is not conserved is *exergy,* which is the useful work potential of the energy. Once the exergy is wasted, it can never be recovered. When we use energy (to heat our homes for example), we are not destroying any energy; we are merely converting it to a less useful form, a form of less exergy.

The useful work potential of a system at the specified state is called *exergy.* Exergy is a property and is associated with the state of the system and the environment. A system that is in equilibrium with its surroundings has zero exergy and is said to be at the *dead state.* The exergy of heat supplied by thermal energy reservoirs is equivalent to the work output of a Carnot heat engine operating between the reservoir and the environment.

Reversible work W_{rev} is defined as the maximum amount of useful work that can be produced (or the minimum work that needs to be supplied) as a system undergoes a process between the specified initial and final states. This is the useful work output (or input) obtained when the process between the initial and final states is executed in a totally reversible manner. The difference between the reversible work W_{rev} and the useful work W_u is due to the irreversibilities present during the process and is called the *irreversibility I.* It is equivalent to the *exergy destroyed* and is expressed as

$$I = X_{destroyed} = T_0 S_{gen} = W_{rev,out} - W_{u,out} = W_{u,in} - W_{rev,in}$$

where S_{gen} is the entropy generated during the process. For a totally reversible process, the useful and reversible work terms are identical and thus exergy destruction is zero. Exergy destroyed represents the lost work potential and is also called the *wasted work* or *lost work.*

The *second-law efficiency* is a measure of the performance of a device relative to the performance under reversible conditions for the same end states and is given by

$$\eta_{II} = \frac{\eta_{th}}{\eta_{th,rev}} = \frac{W_u}{W_{rev}}$$

for heat engines and other work-producing devices and

$$\eta_{II} = \frac{\text{COP}}{\text{COP}_{rev}} = \frac{W_{rev}}{W_u}$$

for refrigerators, heat pumps, and other work-consuming devices. In general, the second-law efficiency is expressed as

$$\eta_{II} = \frac{\text{Exergy recovered}}{\text{Exergy supplied}} = 1 - \frac{\text{Exergy destroyed}}{\text{exergy supplied}}$$

The exergies of a fixed mass (nonflow exergy) and of a flow stream are expressed as

Nonflow exergy: $$\phi = (u - u_0) + P_0(v - v_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$$
$$= (e - e_0) + P_0(v - v_0) - T_0(s - s_0)$$

Flow exergy: $$\psi = (h - h_0) - T_0(s - s_0) + \frac{V^2}{2} + gz$$

Then the *exergy change* of a fixed mass or fluid stream as it undergoes a process from state 1 to state 2 is given by

$$\begin{aligned}\Delta X = X_2 - X_1 &= m(\phi_2 - \phi_1)\\ &= (E_2 - E_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1)\\ &= (U_2 - U_1) + P_0(V_2 - V_1) - T_0(S_2 - S_1)\\ &\quad + m\frac{V_2^2 - V_1^2}{2} + mg(z_2 - z_1)\end{aligned}$$

$$\begin{aligned}\Delta\psi = \psi_2 - \psi_1 &= (h_2 - h_1) - T_0(s_2 - s_1)\\ &\quad + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\end{aligned}$$

Exergy can be transferred by heat, work, and mass flow, and exergy transfer accompanied by heat, work, and mass transfer are given by

Exergy transfer by heat: $$X_{heat} = \left(1 - \frac{T_0}{T}\right)Q$$

Exergy transfer by work: $$X_{work} = \begin{cases} W - W_{surr} & \text{(for boundary work)}\\ W & \text{(for other forms of work)}\end{cases}$$

Exergy transfer by mass: $$X_{mass} = m\psi$$

The exergy of an isolated system during a process always decreases or, in the limiting case of a reversible process, remains constant. This is known as the *decrease of exergy principle* and is expressed as

$$\Delta X_{isolated} = (X_2 - X_1)_{isolated} \le 0$$

Exergy balance for *any system* undergoing *any process* can be expressed as

General: $$\underbrace{X_{in} - X_{out}}_{\substack{\text{Net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{X_{destroyed}}_{\substack{\text{Exergy}\\ \text{destruction}}} = \underbrace{\Delta X_{system}}_{\substack{\text{Change}\\ \text{in exergy}}}$$

General, rate form: $$\underbrace{\dot{X}_{in} - \dot{X}_{out}}_{\substack{\text{Rate of net exergy transfer}\\ \text{by heat, work, and mass}}} - \underbrace{\dot{X}_{destroyed}}_{\substack{\text{Rate of exergy}\\ \text{destruction}}} = \underbrace{dX_{system}/dt}_{\substack{\text{Rate of change}\\ \text{in exergy}}}$$

General, unit-mass basis: $$(x_{in} - x_{out}) - x_{destroyed} = \Delta x_{system}$$

where

$$\dot{X}_{heat} = (1 - T_0/T)\dot{Q}$$
$$\dot{X}_{work} = \dot{W}_{useful}$$
$$\dot{X}_{mass} = \dot{m}\psi$$

For a *reversible process,* the exergy destruction term $X_{destroyed}$ drops out. Taking the positive direction of heat transfer to be to the system and the positive direction of work transfer to be from the system, the general exergy balance relations can be expressed more explicitly as

$$\sum\left(1 - \frac{T_0}{T_k}\right)Q_k - [W - P_0(V_2 - V_1)] + \sum_{in} m\psi - \sum_{out} m\psi - X_{destroyed} = X_2 - X_1$$

$$\sum\left(1 - \frac{T_0}{T_k}\right)\dot{Q}_k - \left(\dot{W} - P_0\frac{dV_{CV}}{dt}\right) + \sum_{in} \dot{m}\psi - \sum_{out} \dot{m}\psi - \dot{X}_{destroyed} = \frac{dX_{CV}}{dt}$$

Work is the energy transferred as a force acts on a system through a distance. The most common form of mechanical work is the *boundary work,* which is the work associated with the expansion and compression of substances. On a *P-V* diagram, the area under the process curve represents the boundary work for a quasi-equilibrium process. Various forms of boundary work are expressed as follows:

(1) General $$W_b = \int_1^2 P\,dV$$

(2) Isobaric process

$$W_b = P_0(V_2 - V_1) \quad (P_1 = P_2 = P_0 = \text{constant})$$

(3) Polytropic process

$$W_b = \frac{P_2V_2 - P_1V_1}{1-n} \quad (n \neq 1) \quad (PV^n = \text{constant})$$

(4) Isothemal process of an ideal gas

$$W_b = P_1V_1 \ln\frac{V_2}{V_1} = mRT_0 \ln\frac{V_2}{V_1} \quad (PV = mRT_0 = \text{constant})$$

The first law of thermodynamics is essentially an expression of the conservation of energy principle, also called the energy balance. The general energy balances for *any system* undergoing *any process* can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Change in internal, kinetic,}\\ \text{potential, etc., energies}}} \quad \text{(kJ)}$$

It can also be expressed in the *rate form* as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer}\\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt}_{\substack{\text{Rate of change in internal,}\\ \text{kinetic, potential, etc., energies}}} \quad \text{(kW)}$$

Taking heat transfer *to* the system and work done *by* the system to be positive quantities, the energy balance for a closed system can also be expressed as

$$Q - W = \Delta U + \Delta KE + \Delta PE \quad \text{(kJ)}$$

where

$$W = W_{other} + W_b$$
$$\Delta U = m(u_2 - u_1)$$
$$\Delta KE = \tfrac{1}{2}m(V_2^2 - V_1^2)$$
$$\Delta PE = mg(z_2 - z_1)$$

For a *constant-pressure process,* $W_b + \Delta U = \Delta H$. Thus,

$$Q - W_{other} = \Delta H + \Delta KE + \Delta PE \quad \text{(kJ)}$$

The amount of energy needed to raise the temperature of a unit mass of a substance by one degree is called the *specific heat at constant volume* c_v for a constant-volume process and the *specific heat at constant pressure* c_p for a constant-pressure process. They are defined as

$$c_v = \left(\frac{\partial u}{\partial T}\right)_v \quad \text{and} \quad c_p = \left(\frac{\partial h}{\partial T}\right)_p$$

For ideal gases u, h, c_v, and c_p are functions of temperature alone. The Δu and Δh of ideal gases are expressed as

$$\Delta u = u_2 - u_1 = \int_1^2 c_v(T)\,dT \cong c_{v,avg}(T_2 - T_1)$$

$$\Delta h = h_2 - h_1 = \int_1^2 c_p(T)\,dT \cong c_{p,avg}(T_2 - T_1)$$

For ideal gases, c_v and c_p are related by

$$c_p = c_v + R \quad \text{(kJ/kg}\cdot\text{K)}$$

where R is the gas constant. The *specific heat ratio* k is defined as

$$k = \frac{c_p}{c_v}$$

For *incompressible substances* (liquids and solids), both the constant-pressure and constant-volume specific heats are identical and denoted by c:

$$c_p = c_v = c \quad \text{(kJ/kg}\cdot\text{K)}$$

The Δu and Δh of imcompressible substances are given by

$$\Delta u = \int_1^2 c(T)\,dT \cong c_{avg}(T_2 - T_1) \quad \text{(kJ/kg)}$$

$$\Delta h = \Delta u + v\Delta P \quad \text{(kJ/kg)}$$

The *conservation of mass principle* states that the net mass transfer to or from a system during a process is equal to the net change (increase or decrease) in the total mass of the system during that process, and is expressed as

$$m_{in} - m_{out} = \Delta m_{system} \quad \text{and} \quad \dot{m}_{in} - \dot{m}_{out} = dm_{system}/dt$$

where $\Delta m_{system} = m_{final} - m_{initial}$ is the change in the mass of the system during the process, $\dot{m}_{in}$ and $\dot{m}_{out}$ are the total rates of mass flow into and out of the system, and dm_{system}/dt is the rate of change of mass within the system boundaries. The relations above are also referred to as the *mass balance* and are applicable to any system undergoing any kind of process.

The amount of mass flowing through a cross section per unit time is called the *mass flow rate*, and is expressed as

$$\dot{m} = \rho V A$$

where ρ = density of fluid, V = average fluid velocity normal to A, and A = cross-sectional area normal to flow direction. The volume of the fluid flowing through a cross section per unit time is called the *volume flow rate* and is expressed as

$$\dot{V} = VA = \dot{m}/\rho$$

The work required to push a unit mass of fluid into or out of a control volume is called *flow work* or *flow energy*, and is expressed as $w_{flow} = Pv$. In the analysis of control volumes, it is convenient to combine the flow energy and internal energy into *enthalpy*. Then the total energy of a flowing fluid is expressed as

$$\theta = h + \text{ke} + \text{pe} = h + \frac{V^2}{2} + gz$$

The total energy transported by a flowing fluid of mass m with uniform properties is $m\theta$. The rate of energy transport by a fluid with a mass flow rate of $\dot{m}$ is $\dot{m}\theta$. When the kinetic and potential energies of a fluid stream are negligible, the amount and rate of energy transport become $E_{mass} = mh$ and $\dot{E}_{mass} = \dot{m}h$, respectively.

The *first law of thermodynamics* is essentially an expression of the conservation of energy principle, also called the *energy balance*. The general mass and energy balances for *any system* undergoing *any process* can be expressed as

$$\underbrace{E_{in} - E_{out}}_{\substack{\text{Net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{\Delta E_{system}}_{\substack{\text{Changes in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

It can also be expressed in the *rate form* as

$$\underbrace{\dot{E}_{in} - \dot{E}_{out}}_{\substack{\text{Rate of net energy transfer} \\ \text{by heat, work, and mass}}} = \underbrace{dE_{system}/dt}_{\substack{\text{Rate of change in internal, kinetic,} \\ \text{potential, etc., energies}}}$$

Thermodynamic processes involving control volumes can be considered in two groups: steady-flow processes and unsteady-flow processes. During a *steady-flow process*, the fluid flows through the control volume steadily, experiencing no change with time at a fixed position. The mass and energy content of the control volume remain constant during a steady-flow process. Taking heat transfer *to* the system and work done *by* the system to be positive quantities, the conservation of mass and energy equations for steady-flow processes are expressed as

$$\sum_{in} \dot{m} = \sum_{out} \dot{m}$$

$$\dot{Q} - \dot{W} = \sum_{out} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each exit}} - \sum_{in} \underbrace{\dot{m}\left(h + \frac{V^2}{2} + gz\right)}_{\text{for each inlet}}$$

These are the most general forms of the equations for steady-flow processes. For single-stream (one-inlet–one-exit) systems such as nozzles, diffusers, turbines, compressors, and pumps, they simplify to

$$\dot{m}_1 = \dot{m}_2 \rightarrow \frac{1}{v_1} V_1 A_1 = \frac{1}{v_2} V_2 A_2$$

$$\dot{Q} - \dot{W} = \dot{m}\left[h_2 - h_1 + \frac{V_2^2 - V_1^2}{2} + g(z_2 - z_1)\right]$$

In these relations, subscripts 1 and 2 denote the inlet and exit states, respectively.

Most unsteady-flow processes can be modeled as a *uniform-flow process*, which requires that the fluid flow at any inlet or exit is uniform and steady, and thus the fluid properties do not change with time or position over the cross section of an inlet or exit. If they do, they are averaged and treated as constants for the entire process. When kinetic and potential energy changes associated with the control volume and the fluid streams are negligible, the mass and energy balance relations for a uniform-flow system are expressed as

$$m_{in} - m_{out} = \Delta m_{system}$$

$$Q - W = \sum_{out} mh - \sum_{in} mh + (m_2 u_2 - m_1 u_1)_{system}$$

where $Q = Q_{net,in} = Q_{in} - Q_{out}$ is the net heat input and $W = W_{net,out} = W_{out} - W_{in}$ is the net work output.

When solving thermodynamic problems, it is recommended that the general form of the energy balance $E_{in} - E_{out} = \Delta E_{system}$ be used for all problems, and simplify it for the particular problem instead of using the specific relations given here for different processes.

The *second law of thermodynamics* states that processes occur in a certain direction, not in any direction. A process does not occur unless it satisfies both the first and the second laws of thermodynamics. Bodies that can absorb or reject finite amounts of heat isothermally are called *thermal energy reservoirs* or *heat reservoirs*.

Work can be converted to heat directly, but heat can be converted to work only by some devices called *heat engines*. The *thermal efficiency* of a heat engine is defined as

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H}$$

where $W_{net,out}$ is the net work output of the heat engine, Q_H is the amount of heat supplied to the engine, and Q_L is the amount of heat rejected by the engine.

Refrigerators and heat pumps are devices that absorb heat from low-temperature media and reject it to higher-temperature ones. The performance of a refrigerator or a heat pump is expressed in terms of the *coefficient of performance*, which is defined as

$$COP_R = \frac{Q_L}{W_{net,in}} = \frac{1}{Q_H/Q_L - 1}$$

$$COP_{HP} = \frac{Q_H}{W_{net,in}} = \frac{1}{1 - Q_L/Q_H}$$

The *Kelvin–Planck statement* of the second law of thermodynamics states that no heat engine can produce a net amount of work while exchanging heat with a single reservoir only. The *Clausius statement* of the second law states that no device can transfer heat from a cooler body to a warmer one without leaving an effect on the surroundings.

Any device that violates the first or the second law of thermodynamics is called a *perpetual-motion machine*.

A process is said to be *reversible* if both the system and the surroundings can be restored to their original conditions. Any other process is *irreversible*. The effects such as friction, non-quasi-equilibrium expansion or compression, and heat transfer through a finite temperature difference render a process irreversible and are called *irreversibilities*.

The *Carnot cycle* is a reversible cycle that is composed of four reversible processes, two isothermal and two adiabatic. The *Carnot principles* state that the thermal efficiencies of all reversible heat engines operating between the same two reservoirs are the same, and that no heat engine is more efficient than a reversible one operating between the same two reservoirs. These statements form the basis for establishing a *thermodynamic temperature scale* related to the heat transfers between a reversible device and the high- and low-temperature reservoirs by

$$\left(\frac{Q_H}{Q_L}\right)_{rev} = \frac{T_H}{T_L}$$

Therefore, the Q_H/Q_L ratio can be replaced by T_H/T_L for reversible devices, where T_H and T_L are the absolute temperatures of the high- and low-temperature reservoirs, respectively.

A heat engine that operates on the reversible Carnot cycle is called a *Carnot heat engine*. The thermal efficiency of a Carnot heat engine, as well as all other reversible heat engines, is given by

$$\eta_{th,rev} = 1 - \frac{T_L}{T_H}$$

This is the maximum efficiency a heat engine operating between two reservoirs at temperatures T_H and T_L can have.

The COPs of reversible refrigerators and heat pumps are given in a similar manner as

$$COP_{R,rev} = \frac{1}{T_H/T_L - 1}$$

and

$$COP_{HP,rev} = \frac{1}{1 - T_L/T_H}$$

Again, these are the highest COPs a refrigerator or a heat pump operating between the temperature limits of T_H and T_L can have.

The second law of thermodynamics leads to the definition of a new property called *entropy*, which is a quantitative measure of microscopic disorder for a system. Any quantity whose cyclic integral is zero is a property, and entropy is defined as

$$dS = \left(\frac{dQ}{T}\right)_{\text{int rev}}$$

For the special case of an internally reversible, isothermal process, it gives

$$\Delta S = \frac{Q}{T_0}$$

The inequality part of the Clausius inequality combined with the definition of entropy yields an inequality known as the *increase of entropy principle*, expressed as

$$S_{\text{gen}} \geq 0$$

where S_{gen} is the *entropy generated* during the process. Entropy change is caused by heat transfer, mass flow, and irreversibilities. Heat transfer to a system increases the entropy, and heat transfer from a system decreases it. The effect of irreversibilities is always to increase the entropy.

The *entropy-change* and *isentropic relations* for a process can be summarized as follows:

1. *Pure substances:*

Any process: $\Delta s = s_2 - s_1$

Isentropic process: $s_2 = s_1$

2. *Incompressible substances:*

Any process: $s_2 - s_1 = c_{\text{avg}} \ln \dfrac{T_2}{T_1}$ (7-29)

Isentropic process: $T_2 = T_1$

3. *Ideal gases:*

a. Constant specific heats (approximate treatment):

Any process:

$$s_2 - s_1 = c_{v,\text{avg}} \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}$$

$$s_2 - s_1 = c_{p,\text{avg}} \ln \frac{T_2}{T_1} - R \ln \frac{P_2}{P_1}$$

Isentropic process:

$k = \frac{c_p}{c_v}$

$$\left(\frac{T_2}{T_1}\right)_{s=\text{const.}} = \left(\frac{v_1}{v_2}\right)^{k-1}$$

$$\left(\frac{T_2}{T_1}\right)_{s=\text{const.}} = \left(\frac{P_2}{P_1}\right)^{(k-1)/k}$$

$$\left(\frac{P_2}{P_1}\right)_{s=\text{const.}} = \left(\frac{v_1}{v_2}\right)^{k}$$

b. Variable specific heats (exact treatment):

Any process:

$$s_2 - s_1 = s_2^\circ - s_1^\circ - R \ln \frac{P_2}{P_1}$$

Isentropic process:

$$s_2^\circ = s_1^\circ + R \ln \frac{P_2}{P_1}$$

$$\left(\frac{P_2}{P_1}\right)_{s=\text{const.}} = \frac{P_{r2}}{P_{r1}}$$

$$\left(\frac{v_2}{v_1}\right)_{s=\text{const.}} = \frac{v_{r2}}{v_{r1}}$$

where P_r is the *relative pressure* and v_r is the *relative specific volume*. The function s° depends on temperature only.

The *steady-flow work* for a reversible process can be expressed in terms of the fluid properties as

$$w_{\text{rev}} = -\int_1^2 v\,dP - \Delta\text{ke} - \Delta\text{pe}$$

For incompressible substances (v = constant) it simplifies to

$$w_{\text{rev}} = -v(P_2 - P_1) - \Delta\text{ke} - \Delta\text{pe}$$

The work done during a steady-flow process is proportional to the specific volume. Therefore, v should be kept as small as possible during a compression process to minimize the work input and as large as possible during an expansion process to maximize the work output.

The reversible work inputs to a compressor compressing an ideal gas from T_1, P_1 to P_2 in an isentropic (Pv^k = constant), polytropic (Pv^n = constant), or isothermal (Pv = constant) manner, are determined by integration for each case with the following results:

Isentropic: $$w_{\text{comp,in}} = \frac{kR(T_2 - T_1)}{k-1} = \frac{kRT_1}{k-1}\left[\left(\frac{P_2}{P_1}\right)^{(k-1)/k} - 1\right]$$

Polytropic: $$w_{\text{comp,in}} = \frac{nR(T_2 - T_1)}{n-1} = \frac{nRT_1}{n-1}\left[\left(\frac{P_2}{P_1}\right)^{(n-1)/n} - 1\right]$$

Isothermal: $$w_{\text{comp,in}} = RT \ln \frac{P_2}{P_1}$$

The work input to a compressor can be reduced by using multistage compression with intercooling. For maximum savings from the work input, the pressure ratio across each stage of the compressor must be the same.

Most steady-flow devices operate under adiabatic conditions, and the ideal process for these devices is the isentropic process. The parameter that describes how efficiently a device approximates a corresponding isentropic device is called *isentropic* or *adiabatic efficiency*. It is expressed for turbines, compressors, and nozzles as follows:

$$\eta_T = \frac{\text{Actual turbine work}}{\text{Isentropic turbine work}} = \frac{w_a}{w_s} \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

$$\eta_C = \frac{\text{Isentropic compressor work}}{\text{Actual compressor work}} = \frac{w_s}{w_a} \cong \frac{h_{2s} - h_1}{h_{2a} - h_1}$$

$$\eta_N = \frac{\text{Actual KE at nozzle exit}}{\text{Isentropic KE at nozzle exit}} = \frac{V_{2a}^2}{V_{2s}^2} \cong \frac{h_1 - h_{2a}}{h_1 - h_{2s}}$$

In the relations above, h_{2a} and h_{2s} are the enthalpy values at the exit state for actual and isentropic *processes*, respectively.

The entropy balance for any system undergoing any process can be expressed in the general form as

$$\underbrace{S_{\text{in}} - S_{\text{out}}}_{\substack{\text{Net entropy transfer}\\ \text{by heat and mass}}} + \underbrace{S_{\text{gen}}}_{\substack{\text{Entropy}\\ \text{generation}}} = \underbrace{\Delta S_{\text{system}}}_{\substack{\text{Change}\\ \text{in entropy}}}$$

or, in the *rate form*, as

$$\underbrace{\dot{S}_{\text{in}} - \dot{S}_{\text{out}}}_{\substack{\text{Rate of net entropy}\\ \text{transfer by}\\ \text{heat and mass}}} + \underbrace{\dot{S}_{\text{gen}}}_{\substack{\text{Rate of entropy}\\ \text{generation}}} = \underbrace{dS_{\text{system}}/dt}_{\substack{\text{Rate of change}\\ \text{in entropy}}}$$

For a general *steady-flow process* it simplifies to

$$\dot{S}_{\text{gen}} = \sum \dot{m}_e s_e - \sum \dot{m}_i s_i - \sum \frac{\dot{Q}_k}{T_k}$$