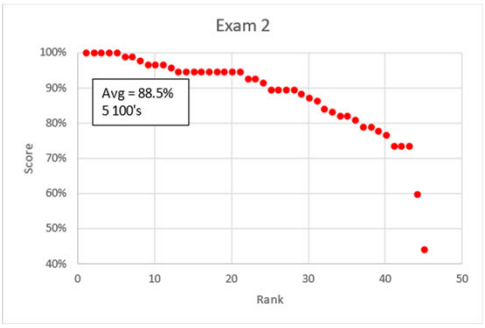
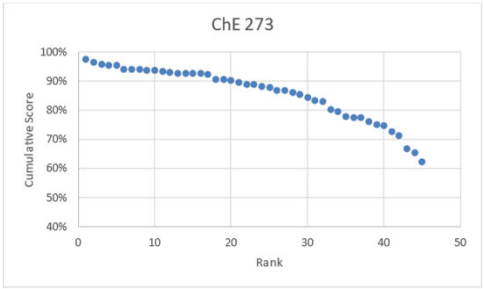




1

Dr. Fletcher's Sanity Rules

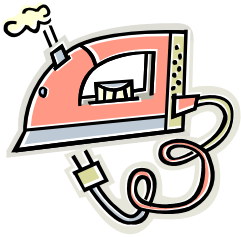
- Wait 24 hours to come see me about points
- Please come see me if you think it was graded wrong or unfairly
  - Don't be afraid to come see me (please!)

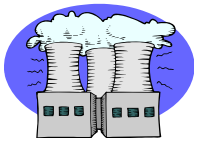
2

Exam 3
(In case you were wondering)

- Closed Book
- Closed Notes
- 3 hrs
- One 8.5 x11 page with equations and notes (one side)
- All tables and data will be provided

3





Enthalpy & Steam Tables

Class 24

4

Shaft Work vs Flow Work

- W_s = shaft work
  - Work done by moving parts
  - Axle, turbine, pump
- W_{fl} = flow work
  - Work by fluid to push through the system

  - $W_{fl} = P_{in}\dot{V}_{in} - P_{out}\dot{V}_{out}$ *(positive when W added to system)*
    $= -\Delta(P\dot{V})$ since the Δ means "out" minus "in"
  - Cannot be ignored (friction happens!)

5

Enthalpy

- An energy term made up for convenience

$$\boldsymbol{H = U + PV}$$

$$\boldsymbol{\hat{H} = \hat{U} + P\hat{V}}$$ (per kg or kgmole)

- Commonly used for open systems
  - For those of us who hate converting pressure units to energy units!!!

6

Open System Energy Balance

- At Steady State:

$$\Delta\dot{H} + \Delta\dot{E}_K + \Delta\dot{E}_P = \dot{Q} + \dot{W}_s$$

Units: Btu/hr or J/s or kW

where

$$\Delta\dot{H} = \dot{m}\Delta\hat{H} = \dot{m}(\hat{H}_{out} - \hat{H}_{in})$$

7

Compare with Closed System Energy Balance

$$\Delta\dot{H} + \Delta\dot{E}_K + \Delta\dot{E}_P = \dot{Q} + \dot{W}_s$$
$$\Delta U + \Delta E_K + \Delta E_P = Q + W$$

- What are the differences?
- Where did H come from?

$W = W_s + W_{fl}$

$= W_s - \Delta(PV)$

$\Delta U + \Delta(PV) = \Delta H$

8

How Do You Calculate Enthalpy?

1. Tables
2. Equations
3. Graphs

9

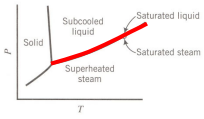
Steam Tables

- Tables are always with respect to some reference state
- ΔH from reference state is the value in the table
- If you use data from different tables, you will need to adjust for the reference state
  - This can cause huge errors
- Enthalpy is a state property
  - Does not depend on path

10

1. Liquid Water

2. Steam (vapor)



3. ΔH_{vap}

4. P^*_{H2O}

Table B.5 Properties of Saturated Steam: Temperature Table[a]

		$\hat{V}$(m³/kg)		$\hat{U}$(kJ/kg)		$\hat{H}$(kJ/kg)		
T(°C)	P(bar)	Water	Steam	Water	Steam	Water	Evaporation	Steam
0.01	0.00611	0.001000	206.2	zero	2375.6	+0.0	2501.6	2501.6
2	0.00705	0.001000	179.9	8.4	2378.3	8.4	2496.8	2505.2
4	0.00813	0.001000	157.3	16.8	2381.1	16.8	2492.1	2508.9
6	0.00935	0.001000	137.8	25.2	2383.8	25.2	2487.4	2512.6
8	0.01072	0.001000	121.0	33.6	2386.6	33.6	2482.6	2516.2
10	0.01227	0.001000	106.4	42.0	2389.3	42.0	2477.9	2519.9
12	0.01401	0.001000	93.8	50.4	2392.1	50.4	2473.2	2523.6
14	0.01597	0.001001	82.9	58.8	2394.8	58.8	2468.5	2527.2
16	0.01817	0.001001	73.4	67.1	2397.6	67.1	2463.8	2530.9
18	0.02062	0.001001	65.1	75.5	2400.3	75.5	2459.0	2534.5
20	0.0234	0.001002	57.8	83.9	2403.0	83.9	2454.3	2538.2
22	0.0264	0.001002	51.5	92.2	2405.8	92.2	2449.6	2541.8
24	0.0298	0.001003	45.9	100.6	2408.5	100.6	2444.9	2545.5
25	0.0317	0.001003	43.4	104.8	2409.9	104.8	2442.5	2547.3
26	0.0336	0.001003	41.0	108.9	2411.2	108.9	2440.2	2549.1
28	0.0378	0.001004	36.7	117.3	2414.0	117.3	2435.4	2552.7
30	0.0424	0.001004	32.9	125.7	2416.7	125.7	2430.7	2556.4
32	0.0475	0.001005	29.6	134.0	2419.4	134.0	2425.9	2560.0
34	0.0532	0.001006	26.6	142.4	2422.1	142.4	2421.2	2563.6
36	0.0594	0.001006	24.0	150.7	2424.8	150.7	2416.4	2567.2
38	0.0662	0.001007	21.6	159.1	2427.5	159.1	2411.7	2570.8
40	0.0738	0.001008	19.55	167.4	2430.2	167.5	2406.9	2574.4
42	0.0820	0.001009	17.69	175.8	2432.9	175.8	2402.1	2577.9
44	0.0910	0.001009	16.04	184.2	2435.6	184.2	2397.3	2581.5
46	0.1009	0.001010	14.56	192.5	2438.3	192.5	2392.5	2585.1
48	0.1116	0.001011	13.23	200.9	2440.9	200.9	2387.7	2588.6
50	0.1234	0.001012	12.05	209.2	2443.6	209.3	2382.9	2592.2
52	0.1361	0.001013	10.98	217.7	2446	217.7	2377	2595
54	0.1500	0.001014	10.02	226.0	2449	226.0	2373	2599
56	0.1651	0.001015	9.158	234.4	2451	234.4	2368	2602
58	0.1815	0.001016	8.380	242.8	2454	242.8	2363	2606
60	0.1992	0.001017	7.678	251.1	2456	251.1	2358	2609
62	0.2184	0.001018	7.043	259.5	2459	259.5	2353	2613
64	0.2391	0.001019	6.468	267.9	2461	267.9	2348	2616
66	0.2615	0.001020	5.947	276.2	2464	276.2	2343	2619
68	0.2856	0.001022	5.475	284.6	2467	284.6	2338	2623

[a]From R. W. Haywood, *Thermodynamic Tables in SI (Metric) Units*, Cambridge University Press, London, 1968. $\hat{V}$ = specific volume, $\hat{U}$ = specific internal energy, and $\hat{H}$ = specific enthalpy. *Note:* kJ/kg × 0.4303 = Btu/lb_m.

(continued)

Reference Enthalpy for Steam Tables ($\hat{H}$=0 at triple pt, 0.01°C and 0.00611 bar)

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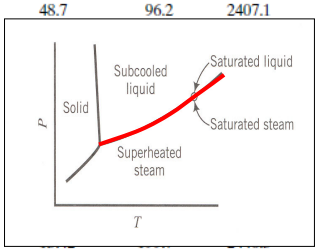
Table B.6 Properties of Saturated Steam: Pressure Table[a]

		$\hat{V}$(m³/kg)		$\hat{U}$(kJ/kg)		$\hat{H}$(kJ/kg)		
P(bar)	T(°C)	Water	Steam	Water	Steam	Water	Evaporation	Steam
0.00611	0.01	0.001000	206.2	zero	2375.6	+0.0	2501.6	2501.6
0.008	3.8	0.001000	159.7	15.8	2380.7	15.8	2492.6	2508.5
0.010	7.0	0.001000	129.2	29.3	2385.2	29.3	2485.0	2514.4
0.012	9.7	0.001000	108.7	40.6	2388.9	40.6	2478.7	2519.3
0.014	12.0	0.001000	93.9	50.3	2392.0	50.3	2473.2	2523.5
0.016	14.0	0.001001	82.8	58.9	2394.8	58.9	2468.4	2527.3
0.018	15.9	0.001001	74.0	66.5	2397.4	66.5	2464.1	2530.6
0.020	17.5	0.001001	67.0	73.5	2399.6	73.5	2460.2	2533.6
0.022	19.0	0.001002	61.2	79.8	2401.7	79.8	2456.6	2536.4
0.024	20.4	0.001002	56.4	85.7	2403.6	85.7	2453.3	2539.0
0.026	21.7	0.001002	52.3	91.1	2405.4	91.1	2450.2	2541.3
0.028	23.0	0.001002	48.7	96.2	2407.1	96.2	2447.3	2543.6
0.030	24.1	0.001003				101.0	2444.6	2545.6
0.035	26.7	0.001003				111.8	2438.5	2550.4
0.040	29.0	0.001004				121.4	2433.1	2554.5
0.045	31.0	0.001005				130.0	2428.2	2558.2
0.050	32.9	0.001005				137.8	2423.8	2561.6
0.060	36.2	0.001006				151.5	2416.0	2567.5
0.070	39.0	0.001007				163.4	2409.2	2572.6
0.080	41.5	0.001008				173.9	2403.2	2577.1
0.090	43.8	0.001009				183.3	2397.9	2581.1
0.10	45.8	0.001010				191.8	2392.9	2584.8
0.11	47.7	0.001011				199.7	2388.4	2588.1
0.12	49.4	0.001012	12.36	206.9	2442.8	206.9	2384.3	2591.2
0.13	51.1	0.001013	11.47	213.7	2445.0	213.7	2380.4	2594.0
0.14	52.6	0.001013	10.69	220.0	2447.0	220.0	2376.7	2596.7



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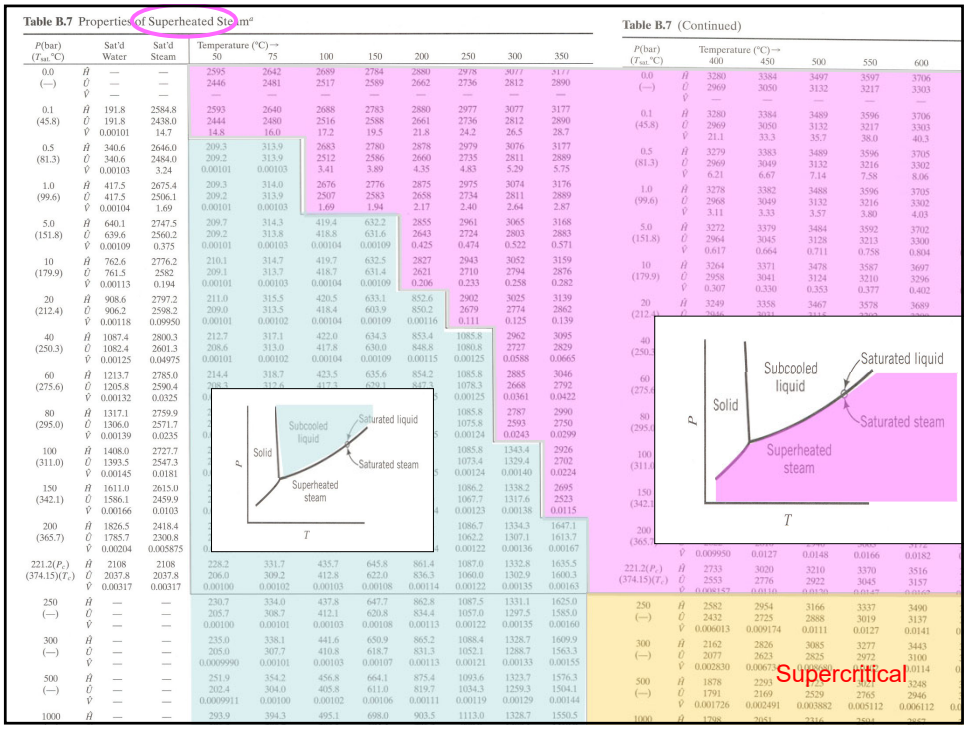

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Energy Equation Information Sheet

What they say…	What they mean…
Well insulated	$Q = 0$, but $\Delta T \neq 0$
Adiabatic	$Q = 0$, but $\Delta T \neq 0$
Isothermal	$\Delta T = 0$, but $Q \neq 0$
Rigid Container	Volume doesn't change $W_{PV} = 0$
Isochoric	Constant Volume $W_{PV} = 0$
No mechanical parts, or no moving parts	$W_S = 0$

14

1. What is ΔH_{vap} at 30 bar? **1793.9 kJ/kg (Table B.6)**
2. What is P^*_{H2O} at 311°C? **100 bar (Table B.6)**
3. What is $\hat{V}_{water}$ at 84°C? **0.001032 m^3/kg (Table B.5)**
4. What is $\hat{H}_{water}$ at 200 bar and 100°C? **434.0 kJ/kg (Table B.7)**
5. What is $\hat{H}_{steam}$ at 80 bar and 600°C? **3640 kJ/kg (Table B.7)**
6. What is the dew point temperature (T_{dp}) for question #5? **295.0°C (Table B.7)**
7. What is the temperature and enthalpy of saturated steam at 80 bar? **295.0°C, 2759.9 kJ/kg (Table B.6)**
8. What is the enthalpy of 10% quality steam at 30 bar? (Quality is defined as the wt% steam in a steam-water system).

0.9*1008.4 + 0.1*2802.3 = 1187.8 kJ/kg (Table B.6)

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Rule of Thumb

- Closed Systems
  - Use internal energy (U)
- Open Systems
  - Use enthalpy (H)

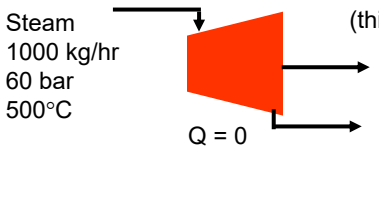
16

Examples

17

Example: Steam Turbine

18



(this $\dot{W}_s$ turns the generator to make electricity)

Find the work done by the fluid on the turbine blades.

$$\Delta\dot{H} + \Delta\dot{E}_K + \Delta\dot{E}_P = \dot{Q} + \dot{W}_s$$

$\hat{H}_{in}$ = 3422 kJ/kg $\hat{H}_{out}$ = 3278 kJ/kg

$\Delta\dot{H} = \dot{m}(\hat{H}_{out} - \hat{H}_{in}) = ?$

(1000 kg/hr)(3278 kJ/kg – 3422 kJ/kg) = W_s = -1.44 × 10^5 kJ/hr

= -40 kJ/s = -40 kW

W_s = -40 kW

Work done by fluid on the turbine blades

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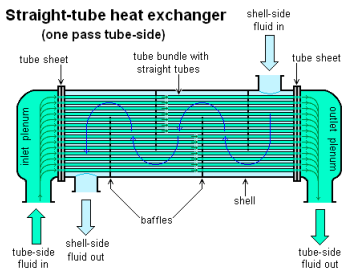
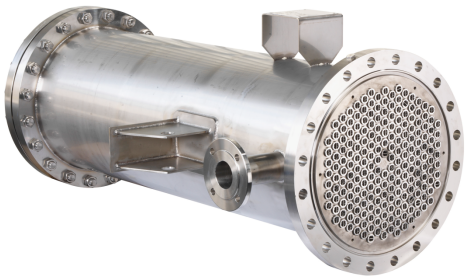
Example: Condenser
(Heat Exchanger)





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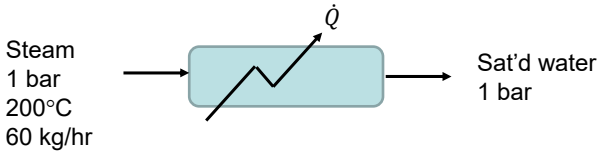

Find $\dot{Q}$

$\hat{H}_{in} = 2875\ kJ/kg$ $\hat{H}_{out} = 417.5\ kJ/kg$

$\Delta\dot{H} + \Delta\dot{E}_K + \Delta\dot{E}_P = \dot{Q} + \dot{W}_s$

$\dot{Q} = \dot{m}(\hat{H}_{out} - \hat{H}_{in}) = ?$

$\dot{Q}$ = (60 kg/hr)(417.5 kJ/kg – 2875 kJ/kg)(hr/3600 s) = - 40.96 kJ/s

Out - In

$\dot{Q}$ = -41 kW

(Heat removed)

21

HW Hint

- On problem 21.4, use the saturated conditions to find the enthalpy of liquid H_2O at 27°C. This enthalpy is not at the correct pressure, but the effect of pressure on liquid water enthalpy is very small.

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