Thermodynamics 4
Tutorial 1 – Thermodynamics 2 Revision (Questions)

Properties of Pure Substances

1) Properties of Pure Substances

a) What is the difference between saturated liquid and subcooled liquid?

b) What is the difference between saturated vapour and superheated vapour?

c) Why are temperature and pressure-dependent properties in the saturated mixture region?

d) Is it possible to have water vapour a 0°C?

e) Consider a piston-cylinder device containing water at 1 MPa and 150°C (under these conditions, water is in the liquid phase). We decrease the pressure slowly (but steadily) and simultaneously keep the temperature constant at 150°C. Describe qualitatively what is going to happen and draw the corresponding P-v diagram for the process.

2) Ideal gas

a) Starting from the observations made by Boyle, Charles and Gay-Lussac (see Thermodynamics 2 notes) explain why, for an ideal gas:

$$Pv = RT$$

Where P is the pressure, v is the specific volume, T is the temperature and R is the gas constant (constant of proportionality).

b) Starting from the relationship in a), show that:

$$PV = mRT, \quad PV = NR_uT$$

c) A sealed, rigid container holds 2 kg of nitrogen at atmospheric pressure (1 atm) and 30°C. What is the volume of the container and how many moles of nitrogen are present? What is the molar mass of nitrogen? You can assume R_{N2} = 0.2968 kJ/kg·K and R_u = 8.314 kJ/kmol·K.

$V_1 = 1.78\ m^3,\ N_1 = 0.072\ kmol,\ M_{N2} = 28\ kg/kmol$

d) The container is heated so that the temperature of nitrogen increases by 100°C. What is the change in pressure in the container?

P increases by 0.334 bar

3) Explain the symbols and prove the relationship:

$$v = v_f + xv_{fg}$$

4) Determine the internal energy of refrigerant-134a at a temperature of 0°C and a quality of 60 %.

You can assume $u_{f@0°C} = 49.79\ kJ/kg$ and $u_{g@0°C} = 227.06\ kJ/kg$.

$u = 156.15\ kJ/kg$

5) Find the internal energy of water at the given states for 7 MPa and plot the states on T-v, P-v and P-T diagrams:

a) $P = 7$ MPa, saturated vapour

b) $P = 7$ MPa, saturated liquid

c) $P = 7$ MPa, $T = 600°C$

d) $P = 7$ MPa, $T = 100°C$

e) $P = 7$ MPa, $T = 455°C$

f) $P = 7$ MPa, dryness fraction = 95 %

$u_f = 2514.8$ kJ/kg

$u_a = 2580.9$ kJ/kg, $u_b = 1258$ kJ/kg, $u_c = 3261.0$ kJ/kg, $u_d = 419.0$ kJ/kg, $u_e = 2988.4$ kJ/kg,

6) Determine the enthalpy of 1.5 kg of water contained in a solid tank with volume 1.2 m^3 at 200 kPa.

$h = 2492.7$ kJ/kg

7) Complete the following table for the properties of water. Describe the phase as compressed liquid, saturated mixture, or superheated vapour. If the state is a saturated mixture, give the quality. Sketch a T-v or P-v diagram for each state.

P [MPa]	v [m^3/kg]	T [°C]	Phase description and quality if applicable
	0.42	300	
0.85	0.2269		
15.0		400	
	0.001127	180	
0.75	0.221		
	5.5	50	
0.20	0.095		
	0.040	350	
20.0		300	
2.0	0.202		
4.0	0.095		
10.0		220	
	0.580	86	
	0.055	500	
0.4	0.4624		

The first law of thermodynamics

8) The first law of thermodynamics

a) What is the first law of thermodynamics?

b) What is the classical sign convention for heat and work?

c) What is boundary work?

d) What is 'other' work? Give some practical examples.

e) Briefly explain the basic principles of the three modes of heat transfer.

9) Three kilograms of nitrogen gas at 27°C, 0.15 MPa are compressed isothermally to 0.3 MPa in a piston-cylinder device.

Show that nitrogen can be expected to behave as an ideal gas during this process and determine the minimum work of compression, in kJ. For nitrogen: R = 0.2968 kJ/kg·K, T_{cr} = 126.2K, P_{cr} = 3.39MPa.

W_{net} = 184.5 kJ

10) Air undergoes a constant pressure cooling process in which the temperature decreases by 100°C.

What is the magnitude and direction of the work for this process? Assume that air behaves as an ideal gas and that R_{air} = 0.287 kJ/kg·K.

Work done on the air is 28.7 kJ/kg

11) Starting from the definition of enthalpy, show that $C_p = C_v + R$ for an ideal gas.

a) How is the specific heat ratio k defined?

b) Find the relationships: (i) C_p in terms of k and R and (ii) C_v in terms of k and R.

c) Why does $C_p = C_v$ for solids and liquids?

d) Complete the table below (for substances that can be assumed to be ideal gases, where these are properties at 300K, R_u = 8.314 kJ/(kmol·K)).

Substance	Molar mass [kg/kmol]	R [kJ/kg·K]	C_p [kJ/kg·K]	C_v [kJ/kg·K]	k
Air		0.287			1.400
Carbon Dioxide			0.846	0.657	
Hydrogen	2.016			10.18	
Nitrogen	28.01		1.039		
Oxygen			0.918		1.395

[Air: M=28.97kg/kmol; C_p=1.005kJ/(kgK); C_v=0.718kJ/(kgK), Carbon dioxide: M=44.01kg/kmol; R=0.189kJ/(kgK); k=1.289, Hydrogen: R=4.124kJ/(kgK); C_p=14.31kJ/(kgK); k=1.405, Nitrogen: R=0.297kJ/(kgK); C_v=0.743kJ/(kgK); k=1.400, Oxygen: M=32.00kg/kmol; R=0.260kJ/(kgK); C_v=0.658kJ/(kgK)]

12) Air is expanded isothermally at 100°C from 0.4 MPa to 0.1 MPa.

Find the ratio of the final to initial volume, the heat transfer, and work. Assume air behaves as an ideal gas and use the ideal gas property relations with constant specific heats and R = 0.287 kJ/(kg·K).

$V_2/V_1 = 4$, $W_{net} = 148.4$ kJ/kg, $Q_{net} = 148.4$ kJ/kg heat transferred to the air

13) What makes a device steady-state and steady-flow?

a) State the conservation of mass for a general control volume and show how this is applied to a general steady-state, steady-flow device.
b) What is flow work and how does it affect the energy of a flowing fluid?
c) State the conservation of energy for a general control volume and show how it is applied to a steady-state, steady-flow device with one inlet and one exit.
d) Why are kinetic and potential energy often neglected in calculations related to steady state, steady flow devices?

14) Steam at 0.4 MPa, 300°C enters an adiabatic nozzle with a low velocity and leaves at 0.2 MPa with a quality of 90 %.

Find the exit velocity in m/s.

$v_2 = 1078$ m/s

15) Steam at 0.2 MPa, 300°C enters a mixing chamber and is mixed with cold water at 20°C, 0.2 MPa to produce 20 kg/s of saturated liquid water at 0.2 MPa.

What are the required steam and cold water flow rates?

steam $= 2.82$ kg/s, *cold water* $= 17.18$ kg/s

The second law of thermodynamics

16) The only significant energy input into a power cycle is 150 MW of heat energy. The cycle produces 50 MW of net work.

Determine the cycle thermal efficiency and the heat rejected by the cycle to the surroundings.

$\eta_{th} = 33.3\%, Q_L = 100\ MW$

17) A Carnot heat engine receives 500 kJ of heat per cycle from a high-temperature heat reservoir at 652°C and rejects heat to a low-temperature heat reservoir at 30°C.

Determine the thermal efficiency of this Carnot engine and the amount of heat rejected to the low-temperature heat reservoir.

$\eta_{th} = 67.2\ \%, Q_L = 164\ kJ$

18) An inventor claims to have developed a refrigerator with a COP of 13.5 that maintains the refrigerated space at 2°C while operating in a room where the temperature is 25°C.

Evaluate the maximum possible (Carnot) COP of a refrigerator operating in these conditions. Is the inventor's claim true?

COP = 11.96, No

19) 3150 kJ of heat is transferred into a cycle at 440°C. 1294.46 kJ of heat is rejected from the same cycle at 20°C. Heat transfer occurs at a constant temperature.

Is the Clausius inequality satisfied and is the cycle reversible or irreversible? Calculate the net work and cycle efficiency for this cycle.

Yes – reversible cycle. $W_{net} = 1855.4\ kJ, \eta_{th} = 58.9\ \%$

20) Complete the table using steam tables.

Pressure	T [°C]	State	Specific entropy s [kJ/kg·K]
5 MPa	120		
1 MPa	50		
1.8 MPa	100		
40 kPa		Wet, x=0.9	
40 kPa			7.1794

21) Steam at 1 MPa, 600°C expands in a turbine to 0.01 MPa.

If the process is isentropic, find the final temperature, the final specific enthalpy of the steam and the turbine specific work. You will need to use steam tables to solve this problem.

$T_2 = 46°C,\ h_2 = 2546\ \text{kJ/kg},\ w_{12} = 1152\ \text{kJ/kg}$

Analysis of thermodynamic cycles

For the ideal Brayton cycle, assume cold-standard air: C_v = 0.718 kJ/kg·K, C_p = 1.005 kJ/kg·K, R = 0.287 kJ/kg·K, and k = 1.4.

22) An ideal closed Brayton cycle has a pressure ratio of 8.56. Air enters the compressor at 300 K and has a temperature of 1100 K at the turbine inlet.

a) Draw the T-s diagram of the Brayton cycle.

b) Determine:

i) The gas temperature at the exits of the compressor and the turbine

554 K, 596 K

ii) Work input to the compressor and work output of the turbine

255 kJ/kg, 507 kJ/kg

iii) The back work ratio

50.4 %

iv) The net heat input and net heat output of the heat exchangers

549 kJ/kg, 297 kJ/kg

v) The thermal efficiency of the power cycle.

0.459

23) An ideal closed Brayton cycle has a pressure ratio of 6 and a maximum temperature of 1200 K. If the heat input (process 2-3) is 700 kJ/kg.

Determine:

a) The compressor exit temperature

503 K

b) The compressor inlet temperature

302 K

c) The turbine exit temperature

719 K

d) The back work ratio

42 %

e) The thermal efficiency of the power cycle

0.401

24) What is the Carnot vapour cycle, and why is it not used in reality?

a) What is the simple ideal Rankine cycle, and how does it address the practical difficulties associated with implementing the Carnot vapour cycle?

b) What approaches can be used to improve the efficiency of the simple ideal Rankine cycle?

25) Consider a steam power plant operating on the simple ideal Rankine cycle. Steam enters the turbine at 3 MPa and 350°C and is condensed in the condenser at a pressure of 75 kPa.

Determine the thermal efficiency of this cycle using steam tables to find water/steam properties.

26 %

26) Wet steam in an ideal Rankine cycle exits the turbine at 30 kPa with a dryness fraction of 90%. The pump work is 5 kJ/kg, and 3000 kJ/kg of heat is transferred into the cycle in the boiler.

Calculate the net work done by the cycle and the cycle's net thermal efficiency using steam tables to find water/steam properties.

868 kJ/kg, 30 %