Thermodynamics 4
Tutorial 5 – Ideal Gas Mixtures (Questions)

Gas Mixtures

1) Amagat and Dalton Models

a) Describe the Amagat model for gas mixtures and define the volume fraction.

b) Describe the Dalton model for gas mixtures and define the partial pressure.

2) The Earth's Atmosphere

The Earth's atmosphere is 0.93% argon by volume. The molecular weight of Argon is 34.95 g/mol and the apparent molecular weight of air is 28.97 g/mol. Find:

a) The fraction of the Earth's atmosphere that is argon, in terms of moles (mole fraction)

$9.3 * 10^{-3}$

b) The fraction of the Earth's atmosphere that is argon, in terms of the mass (mass fraction)

0.011

c) The partial pressure of Argon in atmospheric air at 100k Pa

0.93 kPa

3) Mixing

Three pure gases (A, B, C) are initially kept in three separate compartments of a box. Each gas is initially at 300 K. There is 1 kg of gas A, 1.5 kg of gas B and 2.5 kg of gas C. The heat capacities of the gases and their molecular weights are given in the table below. Find:

a) The entropy change upon mixing

0.817 kJ/K

b) The apparent molar mass for the mixture

54.3 g/mol

c) The apparent specific heat at constant pressure of the mixture

Gas	Molecular weight [g/mol]	C_p [kJ/kg·K]
A	45	1.1
B	52	1.4
C	61	0.9

1.09 kJ/kgK

Gas-Vapour Mixtures

4) Sketch a T-V graph (T on the y-axis, V on the x-axis) for liquid/vapour phases showing:

- the saturated liquid line
- the saturated vapour line
- the critical point
- the compressed liquid region
- the superheated vapour region
- the saturated liquid-vapour region

- a trajectory through the T-V space for a substance undergoing a phase transition from compressed liquid through the saturated liquid-vapour region into the superheated vapour region

5) Consider a mixture of air and water vapour at a temperature of 17°C. The relative humidity is 70% and the pressure of the mixture is 100 kPa. The molecular weight of water is 18.016 g/mol and the apparent molecular weight of air is 28.97 g/mol.

What is the absolute humidity and what is the dew point?

8.65*10-3, 11.5°C

6) Consider an adiabatic saturator. The pressure of the mixture entering and leaving is 90 kPa. At the inlet, the temperature is 25°C and at the exit, the temperature is 15°C. For dry air, the heat capacity at constant pressure is *Cp* = 1.004 kJ/kg·K.

If the mass flow rate for air is 1kg/s (dry air), find the mass flow rate of liquid water.

41.3 *10-3 kg/s

Gas-vapour Mixtures and Psychrometry

7) Consider 100 m^3 of an air–water vapour mixture at 0.1 MPa, 35°C, and 70% relative humidity. Calculate the humidity ratio (absolute humidity), dew point, mass of air, and mass of vapour. Calculate the amount of water vapour condensed if the mixture is cooled to 5°C in a constant-pressure process.

0.0255, 28.6°C, 108.6 kg, 2.77 kg, 2.172 kg

8) Consider a room containing air at a pressure of 1 atmosphere, 80% relative humidity, and 14°C. Using the psychrometric chart, find…

a) The specific humidity

0.0078

b) The specific enthalpy (per mass of dry air)

34.2 kJ/kg_{air}

c) The wet bulb temperature

11.8°C

d) The dew point temperature

10.3°C

9) Air enters an air conditioning unit at 100 kPa, 40°C, and 5% relative humidity, at the steady rate of 1.0 m^3/s. Liquid water at 20°C is sprayed into the air in the AC unit at a rate of 20 kg/hr. The exit temperature is 10°C and the exit pressure is 100 kPa.

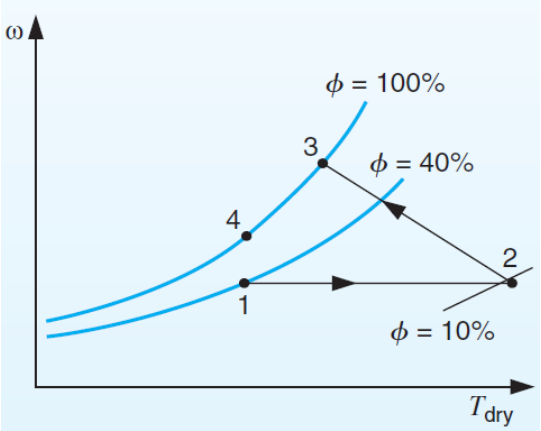
What is the relative humidity at the exit, and at what rate is heat rejected from the unit?

95%, approximately 20 kW

10) A tank has a volume of 0.5 m^3 and contains nitrogen and water vapour. The temperature of the mixture is 50°C, and the total pressure is 2 MPa. The partial pressure of the water vapour is 5 kPa. Calculate the heat transfer when the contents of the tank are cooled to 10°C.

−338.8 kJ

11) Air at (1) 20°C, ϕ = 40% flows through a 400 W heater coming out at (2) 46°C, and is blown over a wet surface, so it absorbs water and becomes saturated (3) without heat input. Finally, the air flows over the walls in the room, where it cools to 20°C (4) (see the figure below). We would like to know the mass flow rate of air and the rate of water condensation in the room, if any.



0.0154 kg/s, 0.0154 g/s

12) Air at 1 atm, 15°C, and 60 percent relative humidity is first heated to 20°C in a heating section and then humidified by introducing water vapour. The air leaves the humidifying section at 25°C and 65 percent relative humidity. Determine (a) the amount of steam added to the air, and (b) the amount of heat transfer to the air in the heating section.

(a) 0.0065 kg H_2O/kg dry air, (b) 5.1 kJ/kg dry air

13) (i) Why is heated air sometimes humidified? (ii) Why is cooled air sometimes reheated in summer before it is discharged to a room?

14) Humid air at 101.3 kPa, 39°C dry bulb, and 50 percent relative humidity is cooled at constant pressure to a temperature 10°C below its dew-point temperature. (a) Sketch the system diagram and the psychrometric diagram for the process. (b) If it has been determined that the rate of heat transfer from the atmospheric air is 1340 kW, what is the inlet volume flow rate of atmospheric air, in m^3/s, for this process?

25.1 m^3/s

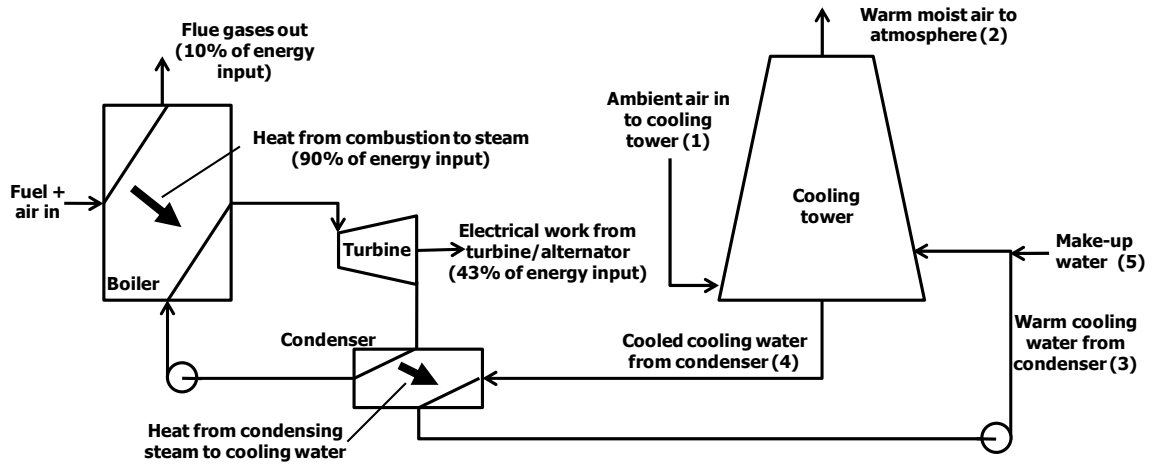
15) Wet cooling tower

How much water does an 800 MW supercritical power plant with wet cooling evaporate per second at an ambient air dry bulb temperature of 20ºC and an RH of 60%?

As indicated in the figure below, assume the plant efficiency is 43% (LHV basis) and the boiler efficiency 90%, and that all heat losses take place in the main condenser. Water circulating through the condenser is fed to the cooling tower at 32ºC and leaves the tower at 17ºC, and the air/vapour mix leaves *saturated* at 30ºC. Make-up water at 20ºC is added to the incoming water to the tower to maintain the required water flow circulated through the condenser. Water liquid and vapour enthalpies can all be assumed to be equal to saturated values.

Use the following data:

- Molar mass of water: 18.01 g/mol
- Molar mass of dry air: 28.96 g/mol
- *Cp* of dry air: 1.01 kJ/kg/K



a) What flow rate of cooling water is required?

13936 kg/s

b) Per kg of dry air flowing through the cooling tower:

i) How much moisture enters with the ambient air?

8.7 g/kgs

ii) How much moisture leaves at the top of the tower?

27.2 g/kg

iii) What flow of make-up water is required?

18.5 g/kg

iv) Write an energy balance for the tower that includes only the mass flow rates of cooling water and dry air, and hence calculate the mass flow rate of dry air.

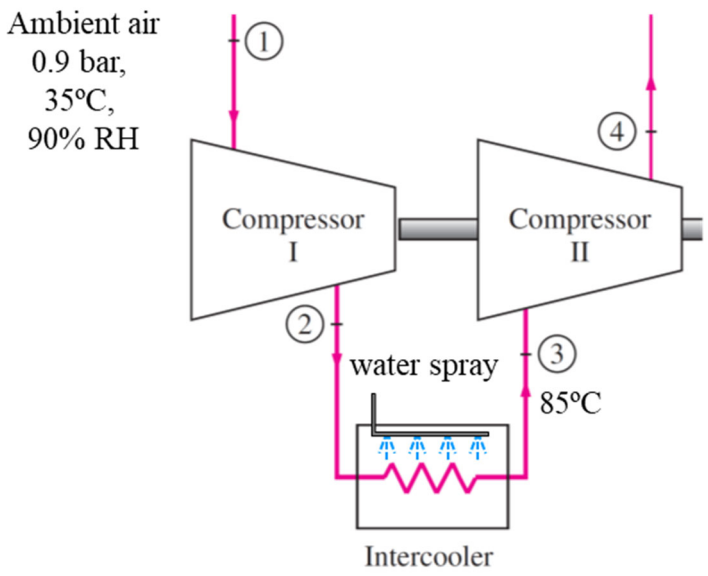
15640 kg/s

c) Use the mass flow rate of dry air to calculate the make-up water flow.

289 kg/s

16) Spray intercooling

A spray intercooler follows the first stage of a gas turbine compressor with an isentropic efficiency of 85%. The exit pressure from the stage is 4 bar, and the pressure drop in the intercooler can be neglected.



Data is as follows:

Ambient pressure: 0.9 bar, Ambient temperature: 35ºC, RH (or ϕ) = 90%

Cooling water temperature: 20ºC

In the compressor, air and water vapour can be modelled as ideal gases with constant specific heats, with the following properties used to calculate average mixture properties:

Cp_a = 1.05 kJ/kg/K, R_a = 0.287 kJ/kg/K, M_a = 28.96 g/mol,

Cp_v = 1.95 kJ/kg/K, R_v = 0.461 kJ/kg/K. M_v = 18.01 g/mol

In the spray cooler, more accurate results can be obtained by modelling the air as an ideal gas, but the water/vapour as having enthalpies equal to the saturation values.

a) Calculate the compressor work for the air/vapour mixture for a dry air flow of 100 kg/s

20.3 MW

b) Calculate the water spray flow required to achieve a cooled gas temperature of 85ºC

5.55 kg/s

c) Verify that this should give no droplets of water to damage the next compressor stages.

RH = 90% after spray