ME 354 THERMODYNAMICS - 2

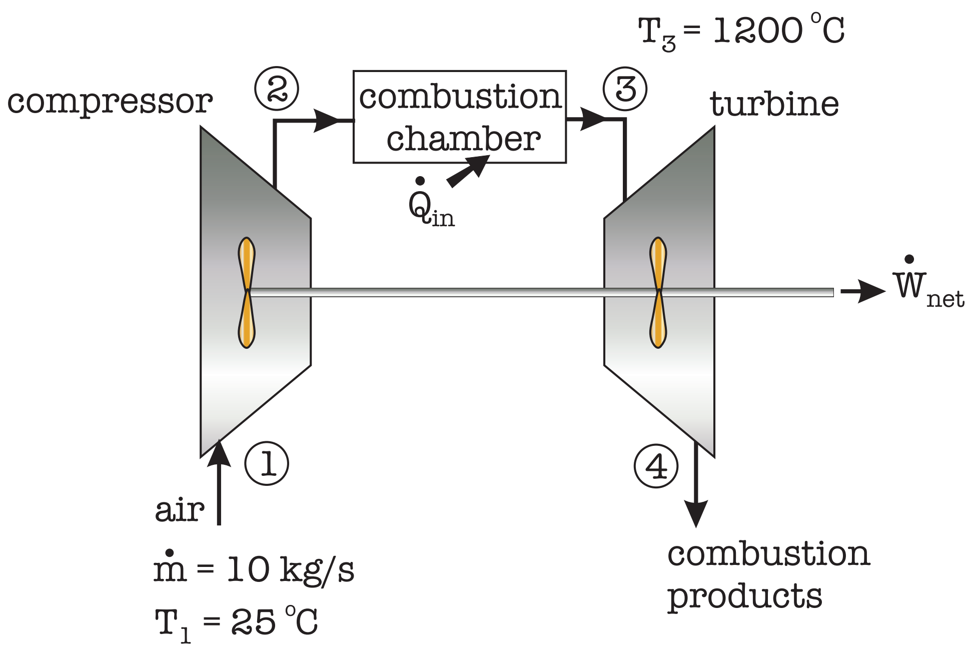
08 April 2004 — Final Examination — R. Culham

- This is a three-hour, closed-book examination.
- You are permitted to use one 8.5 in.× 11 in. crib sheet. (both sides) and the Property Tables and Figures from *Thermodynamics: An Engineering Approach*
- There are 5 questions to be answered. Read the questions very carefully.
- Clearly state all assumptions.
- It is your responsibility to write clearly and legibly.
- Good luck.

Question 1 (20 marks)

A gas turbine engine, as shown below, uses air as the working fluid with a constant specific heat of $\boldsymbol{c_p = 1.005\ kJ/(kg \cdot K)}$ and $\boldsymbol{k = 1.4}$. The compressor has an isentropic efficiency of **85%** and a pressure ratio of **18 : 1**, while the turbine has an isentropic efficiency of **90%** and a pressure ratio of **18 : 1**. Find the following:

i) the net power output ($\boldsymbol{kW}$)
ii) the overall thermal efficiency of the engine
iii) the thermal efficiency of an equivalent ideal cycle
iv) the optimum pressure ratio to maximize work output for the ideal cycle

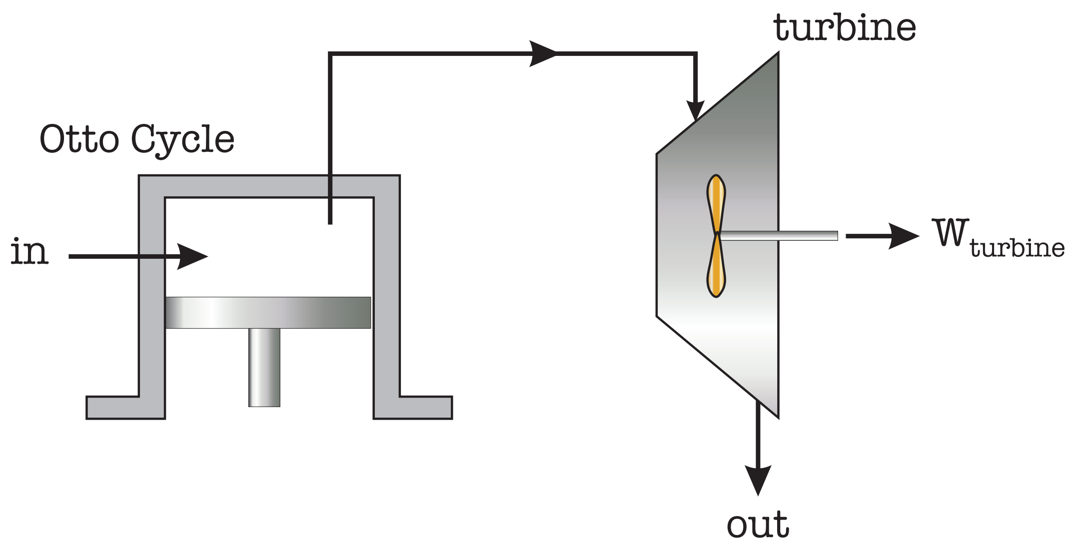


Question 2 (20 marks)

An open, ideal Otto-cycle engine has a compression ratio of **10 : 1**. The air just prior to the compression stroke is at $\mathbf{20°}\boldsymbol{C}$ and $\mathbf{100}\ \boldsymbol{kPa}$. The maximum cycle temperature is $\mathbf{2000}\ °\boldsymbol{C}$. The thermal efficiency of the Ideal Otto cycle is **0.60**.

Rather than simply discharging the air to the atmosphere after expansion in the cylinder, an isentropic turbine is installed in the exhaust to produce additional work. Assume constant specific heats, the mass flow rate through the turbine is steady and the pressure at the inlet to the cylinder is identical to the pressure at the discharge of the turbine.

i) draw a $\boldsymbol{T-s}$ process diagram for the compound engine
ii) determine the work output of the turbine, ($\boldsymbol{kJ/kg}$)
iii) determine the overall thermal efficiency of the compound engine



Question 3 (20 marks)

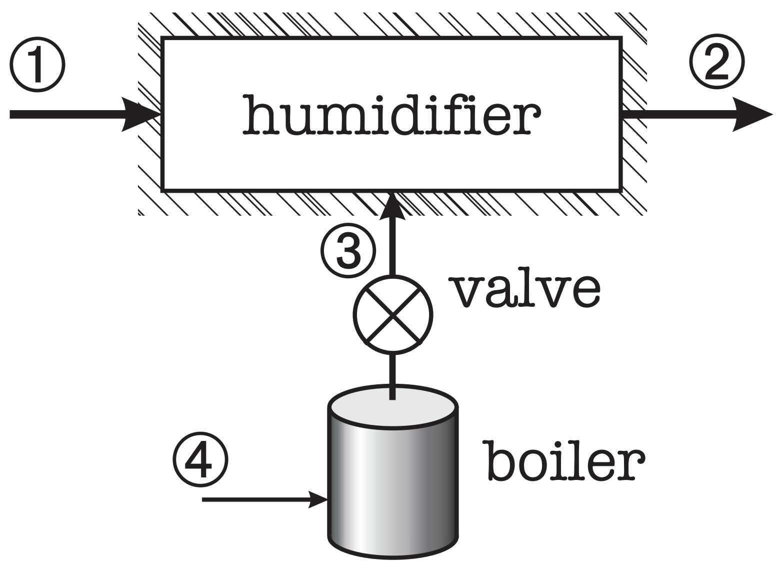
A centrifugal compressor is installed in a natural gas pipeline to overcome the line friction pressure drop. The gas, which is **25%** hydrogen and **75%** methane by volume, enters the compressor at $\mathbf{20}\ °\boldsymbol{C}$ and $\mathbf{100}\ \boldsymbol{kPa}$ and leaves at $\mathbf{200}\ \boldsymbol{kPa}$. Assuming a reversible, adiabatic process and that the properties are independent of temperature;

i) determine the outlet mixture temperature, ($°\boldsymbol{C}$)
ii) determine the work required to drive the compressor, ($\boldsymbol{kJ/kg}$)
iii) determine the final partial pressures, ($\boldsymbol{kPa}$)
iv) determine the change in entropy of the hydrogen and the methane. Verify that the overall process is isentropic.

Question 4 (20 marks)

Moist air enters an adiabatic humidifier at state 1 at $\mathbf{20\ ^\circ C}$ and **10%** relative humidity with a volumetric flow rate of $\mathbf{0.25\ m^3/s}$. The air leaves the humidifier at state 2 at $\mathbf{22.5\ ^\circ C}$ and **70%** relative humidity. The change in the condition of the moist air is brought about by the injection of steam at state 3 from a boiler. The boiler is supplied with $\mathbf{22.5\ ^\circ C}$ water at state 4. An adiabatic valve between the boiler and the humidifier causes the steam pressure to drop from boiler pressure to the humidifier pressure of $\mathbf{101.325\ kPa}$.

i) determine the mass flow rate [$\boldsymbol{kg/hr}$] of the water at state point 4
ii) determine the heat transfer rate [$\boldsymbol{kW}$] to the boiler
iii) determine the pressure [$\boldsymbol{kPa}$] in the boiler when the temperature of the superheated steam is $\mathbf{300\ ^\circ C}$



Question 5 (20 marks)

An abandoned gas storage tank contains a mixture of ethane (5% by volume) and air (Hint: air consists of **1** $\boldsymbol{kmole}$ of $\boldsymbol{O_2}$ and **3.76** $\boldsymbol{kmoles}$ of $\boldsymbol{N_2}$ for each $\boldsymbol{kmole}$ of fuel). The mixture is at $\mathbf{25\ ^\circ C}$ and **1** $\boldsymbol{atm}$.

An eight-year old boy, standing on the tank lighting his first cigarette, excitedly throws the match into the storage tank. Assuming complete combustion happens so fast that the process occurs adiabatically at constant volume;

i) determine the final temperature [$\boldsymbol{K}$]
ii) determine the pressure, [$\boldsymbol{atm}$], inside the tank
iii) determine the air/fuel ratio on a per mass basis