LELME2150 - Thermal cycles
Homework 1 - Basic cycles

The following two exercises remind what are the basic cycles seen in previous course LMECA1855 - Thermodynamics and energetics. The basic cycles rely on several assumptions, such as perfect gas (usually only air) for a gas turbine or constant calorific value for the different fluids.

Through this exercise session, the students will have to (i) refresh their minds about the basic cycles; (ii) code the basic cycles; (iii) start getting accommodate with parametric cycles. The two first tasks of each exercise (a) and (b) can be done without a laptop. The last point (c) must be done with a laptop in `Python`.

Exercice 1 - Gas turbine

Consider a gas turbine power plant as shown in Figure 1. The problem data are as follows:

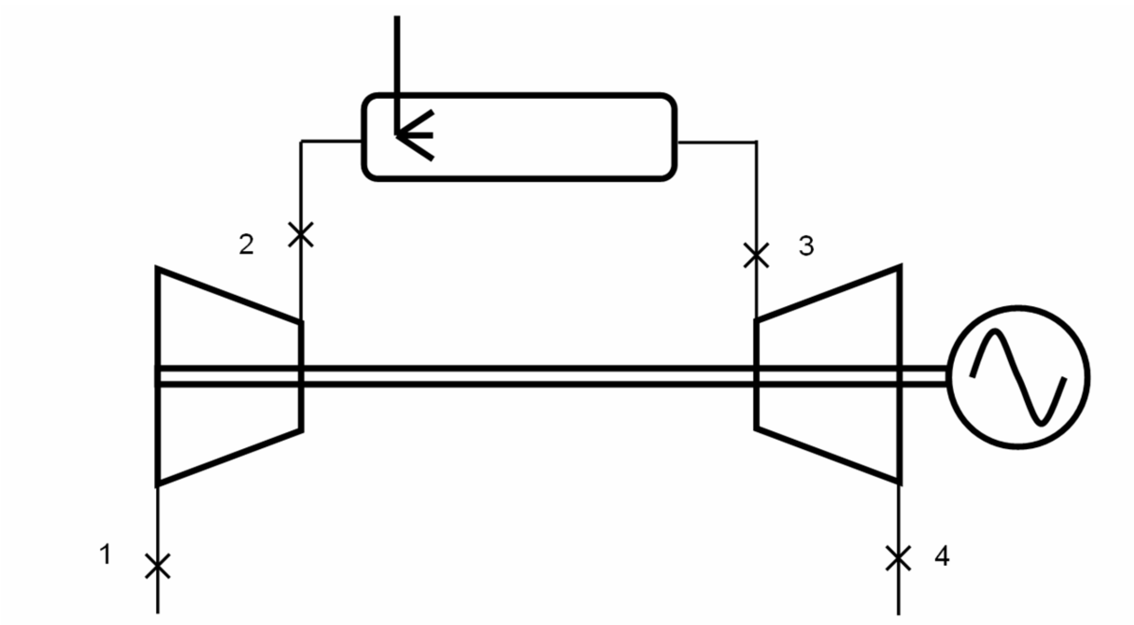

Figure 1: Basic gas turbine.

- state 1 is characterised by the values: $p_1 = 100kPa$ and $t_1 = 20^oC$;
- the pressure at which the combustion takes place is: $p_2 = p_3 = 1780kPa$;
- the combusted gases have, at the exit of the combustion chamber, a temperature $t_3 = 1000^oC$;
- the change in composition between the air and the combusted gases is neglected. Moreover, the addition of mass during combustion is also neglected. The air has a composition of 21% of O_2 and the rest of N_2.

- the transformations in the turbine and the compressor are characterized by a polytropic efficiency $\eta_{pi} = 0.9$;
- the mechanical efficiencies of the turbine and compressor are $\eta_{mec,C} = \eta_{mec,T} = 0.98$.

a) In the case where we consider a constant value for c_p ($c_p = 1.005 kJ/kg/K$) and isentropic transformations for the turbine and the compressor, you are asked to calculate:

1. the states $(p, T, (s - s_1), (h - h_1))$ of the gas during the cycle;
2. the calorific action Q released by the combustion, the available mechanical work and the global efficiency of the cycle.

b) In the case where c_p is considered to vary with temperature (i.e. reality), we suggest you use the `Python` library `CoolProp` (see documentation here: `http://www.coolprop.org/coolprop/HighLevelAPI.html` and for installation see here: `http://www.coolprop.org/coolprop/wrappers/Python/index.html`) thanks to the following guidelines:

Installation of the package:

```
pip install CoolProp
import CoolProp.CoolProp as CP
```

Obtaining a value (example for the heat capacity of gaseous oxygen at $1 bar$ and $300K$):

```
CP.PropsSI('CPMASS','P',1e+5,'T',300,'O2')
```

Compute the states $(p, T, (s - s_1), (h - h_1))$ of the gas during the cycle (hint: to compute the entropy and enthalpy difference, the c_p must be integrated).

Are the following assumptions correct: c_p can be considered constant, and the transformations can be considered isotropic? You can evaluate the impact of these assumptions on the overall efficiency of the cycle.

c) Upgrade your code so that the following values are parametrised: p_1, T_1, p_2, p_3, t_3, eta_{pi}, $eta_{mec,t}$ et $eta_{mec,t}$. Please refer to the function signatures provided on the `Moodle` webpage.

Plot the overall efficiency of the cycle for the following three parameters: p_3, t_3 et eta_{pi}. Please refer to the results presented in the introduction video.

Exercice 2 - Steam turbine

A coal-fired power plant uses steam as working fluid. It is a closed-cycle power plant consisting of 4 elements: a steam generator, an expansion turbine, a condenser and a pump. The cycle, represented by Figure 2, is characterised by the following states: at the outlet of the steam generator (state 3), the steam is in a superheated state ($p = 100$ $[bar]$ et $T = 540$ $[^oC]$). This expands adiabatically in a turbine down to the saturation pressure corresponding to a temperature of 30^oC, the later being set by the condenser. Then the fluid is condensed isobarically to state 1, which is a saturated liquid.

The characteristics of the power plant are the following:

- the efficiency of the steam generator is: $\eta_{gen} = 0.6$;
- the calorific value of the coal is: $LHV = 25\ [\frac{MJ}{kg}]$;
- the electrical power output of the cycle $P_{el} = 95\ [MW]$;
- the mechanical efficiency of the turbine is: $\eta_{mec,t} = 0.985$;
- the internal isentropic efficiency of the turbine is: $\eta_{si,t} = 0.85$;
- the internal efficiency of the pump is: $\eta_{pump} = 0.8$.

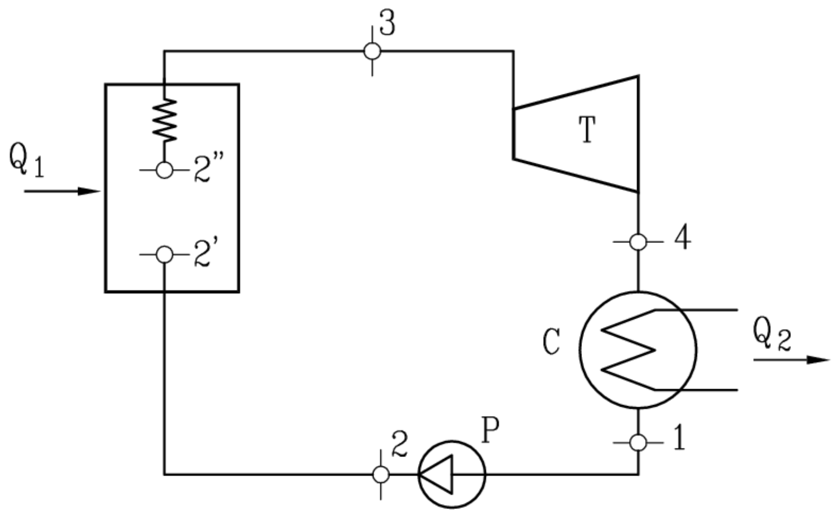

Figure 2: Basic steam cycle.

a) Considering first that the steam describes a Rankine-Hirn cycle (i.e. isentropic transformation for the pump and the turbine), you are asked to calculate:

1. the states (p,t,h,s,x);
2. the mechanical work of the turbine;
3. the overall efficiency of the cycle.

b) Then, considering the transformations with the isentropic efficiencies, you are asked to calculate:

1. the states (p,t,h,s,x);
2. the mechanical work of the turbine;
3. the overall efficiency of the cycle;
4. the water flow in the cycle;
5. the massflow of coal used;

6. the minimum water flow used to cool down the cycle at the condensor. We assume an inlet temperature of $8\,^oC$ when entering the condensor.

c) Finally, we propose to study the cycle in a parametric way, i.e. with the following states parameterized: T_1, p_3, T_3, η_{gen}, LHV, P_{el}, $\eta_{mec,t}$, $\eta_{si,t}$ et η_{pump}. To do this, you will also use the `CoolProp` tables.

Obtaining a value (example for the enthalpy at state 3 based on p_3 and T_3):

```
CP.PropsSI('H','P',p_3,'T',T_3,'H2O')
```