EG3521: Engineering Thermodynamics Continuous Assessment

Computational Problems

School of Engineering

March 12, 2014

Computational Problem-Solving Exercise – Individual Work

1. PSE comprises solving a computational thermodynamic problem with the following deliverables: source code (Fortran, C, C++, Python or Matlab) + oral presentation.

2. The PSE will be awarded either 1 or 0 CAS mark.

3. Source code should be submitted by email **before May 2nd at 5pm**. The 'Subject' of the email (jefferson.gomes@abdn.ac.uk) must be 'EG3521-PSE'.

4. (Informal) Presentation will take place during week 43.

5. Feedback will be given 1 week after the last presentation (before May 16).

1   Part A

Mass conservation for a compressible gas flowing in a pipe implies

$$\frac{\mathrm{d}}{\mathrm{d}x}\left(\rho u A\right) = 0, \tag{1a}$$

where ρ is the fluid density, u is the fluid velocity, A is the cross sectional area of the pipe and x is the distance along the pipe. In the absence of heat sources and work done by the gas, energy conservation for a compressible ideal gas flowing in a pipe implies

$$c_p\frac{\mathrm{d}T}{\mathrm{d}x} + u\frac{\mathrm{d}u}{\mathrm{d}x} - g\cos\theta, \tag{1b}$$

where c_p is the specific heat capacity of the gas at constant pressure, T is the gas temperature, g is the acceleration due to gravity and θ is the angle the pipe makes with the vertical. Momentum conservation implies

$$\rho u\frac{\mathrm{d}u}{\mathrm{d}x} = -\frac{\mathrm{d}p}{\mathrm{d}x} - \rho g\cos\theta, \tag{1c}$$

where p is the pressure in the pipe. This system is completed by the ideal gas equation

$$p = \rho R T, \tag{1d}$$

where R is the specific gas constant.

Problem 1

Enter this system of ordinary differential equations into Matlab and solve them for suitable initial conditions when the pipe has uniform cross section. Investigate how the flow properties vary when the pipe has either a constriction or a bulge by modifying how the cross section $A(x)$ varies along the length of the pipe.

Problem 2

Enter this system of ordinary differential equations into Matlab and solve them for suitable initial conditions when the pipe has uniform cross section. Investigate how the momentum equation can be modified to incorporate friction between the gas and the pipe wall, and assess how the flow properties vary when this effect is included.

Hint: in EG3007 we looked at systems of equations of the form $\frac{\mathrm{d}\boldsymbol{u}}{\mathrm{d}t} = f(t,\,\boldsymbol{u})$, where $\boldsymbol{u}$ is a vector of different variables. In this problem you need to solve a system of equation $M(\boldsymbol{u})\frac{\mathrm{d}\boldsymbol{u}}{\mathrm{d}t} = f(t,\,\boldsymbol{u})$, where $M(\boldsymbol{u})$ is a matrix. If you can form the matrix $M(\boldsymbol{u})$, then we can reduce this system of equations to one we can solve, by premultiplying both sides by M^{-1}.

2   Part B

Problem 3

An ice plant operates on the ideal vapour-compression cycle with superheated state using refrigerant fluid R134a. The refrigerant enters the compressor as saturated vapour at 0.15 MPa and leaves the condenser as saturated liquid at 0.7 MPa. Water enters the refrigerator cavity at 30ºC and leaves as ice at -5ºC. For an ice production rate of 10 kg per hour, determine the power input to the ice plant and the COP of the cycle. Also, sketch the PH and TS diagrams. Specific heats of ice and water are 2.1 and 4.18 kJ/(kg.K), respectively, and the latent heat of fusion of ice is 334 kJ/kg. Repeat the same procedure for ammonia and propane as refrigerat fluid.

Hint: This problem was fully solved in Tutorial 4, but here you need to generate an algorithm to solve a generic vapour-compression refrigeration cycle. Also for the thermodynamic properties, you should either (a) use external public libraries or (b) produce libraries based on spline-based lookup tables.

Problem 4

A Thermal engineer is hired to design coupled steam-power and refrigeration plants (Fig. 1). The thermal plant (I) operates 100 kg/h steam in 3-turbines reheat Rankine cycle with initial conditions and efficiencies described in Tables 1 and 2. 0.1% of the power generated by the set of turbines in **I** is used in the compressor of the refrigeration unit **II**. The refrigeration system operates with a working fluid, $\mathcal{X}$. Tasks:

1. Calculate the enthalpies of all stages assuming $\mathcal{X} = \{\text{Ammonia and R-134a}\}$.

2. For both cases, calculate the mass flow rate of the refrigerant fluid and the refrigerant capacity.

3. Calculate the net work for the thermal cycle **I** $\left(\dfrac{\dot{W}_{\text{cycle}}}{\dot{m}_{\text{water}}} \right)$ and the power produced by the set of turbines $\left(\dot{W}_c \right)$.

Hint: This problem is similar to Question 14 in Tutorial 4, but here you need to generate an algorithm to solve the coupled generic thermal power and vapour-compression refrigeration cycle. Also for the thermodynamic properties, you should either (a) use external public libraries or (b) produce libraries based on spline-based lookup tables.

Flow	Pressure (bar)	Temperature (ºC)
1	200.0	600
2	5.0	–
3	5.0	240
4	1.0	–
5	1.0	99.63
6	0.23	–
7	–	–
8	–	–
9	2.0	–
10	16.0	–
11	–	–
12	–	–

Table 1: Information on the steam-power and refrigeration cycles.

	Turbine 1	Turbine 2	Turbine 3	Pump	Compressor
Efficiency	0.88	0.85	0.85	0.92	1.00

Table 2: Efficiencies of the equipment used in the coupled units.
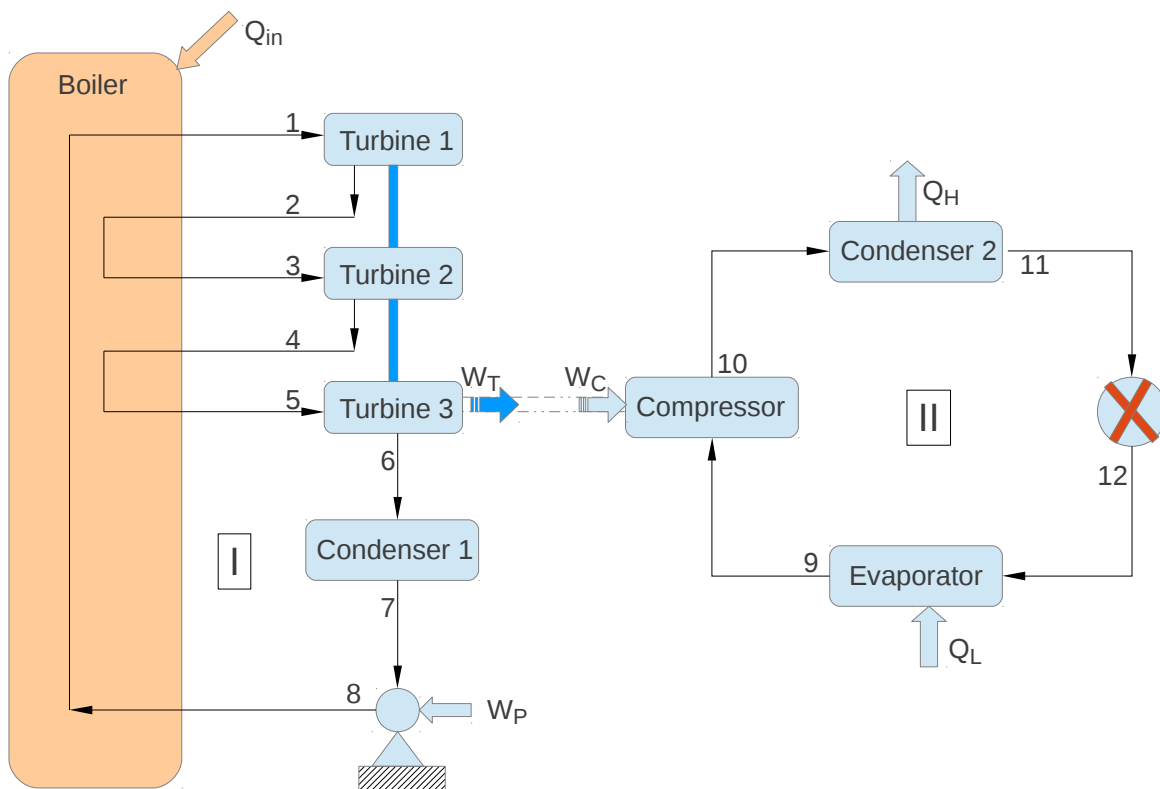
Figure 1: Coupled reheat Rankine steam and reversed-Rankine refrigeration units.