

Thermodynamics and energetics I: Exercise 12

In the first part of the exercise you model and analyze a non-ideal refrigeration cycle. In the second part of the exercise you will analyze a Rankine cycle and use a software implementation of IAPWS-IF97 steam tables to compute thermodynamic properties.

1. Consider an air conditioning system using refrigerant 134a as working fluid, operating at steady state, shown in Figure 1. The system cools the cold side down to $T_C = 15^\circ\text{C}$. Heat is rejected at $T_H = T_0 = 32^\circ\text{C}$ to the surroundings. Refrigerant 134a enters the compressor as saturated vapor at a temperature of $T_1 = 4^\circ\text{C}$ and is compressed adiabatically to a pressure of $p_2 = 1103\text{ kPa}$. The isentropic efficiency of the compressor is 80%. At the condenser exit, the refrigerant is saturated liquid. The refrigerant mass flow is given as 0.07 kg/s . Neglect kinetic and potential energy changes, assume that condenser and evaporator operate at constant pressure, and the expansion valve is isenthalpic.

- (a) Sketch the T-s diagram

Find:

- (b) The enthalpy and entropy at each point **1-4**
- (c) The power required to drive the compressor
- (d) The coefficient of performance of the cooling cycle
- (e) The exergy destruction rate in the compressor and the expansion valve.
- (f) The exergy destruction rate in the control volume around the condenser illustrated in the graphic below.
- (g) The exergy destruction rate in the control volume around the evaporator illustrated in the graphic below.
- (h) Does the sum of transferred exergies by means of heat transfer minus destroyed exergies in all processes equal the value of the work input by the compressor? Verify numerically.

Note: Please use CoolProp database to find the properties that you need for the numerical calculation. (Example code here)

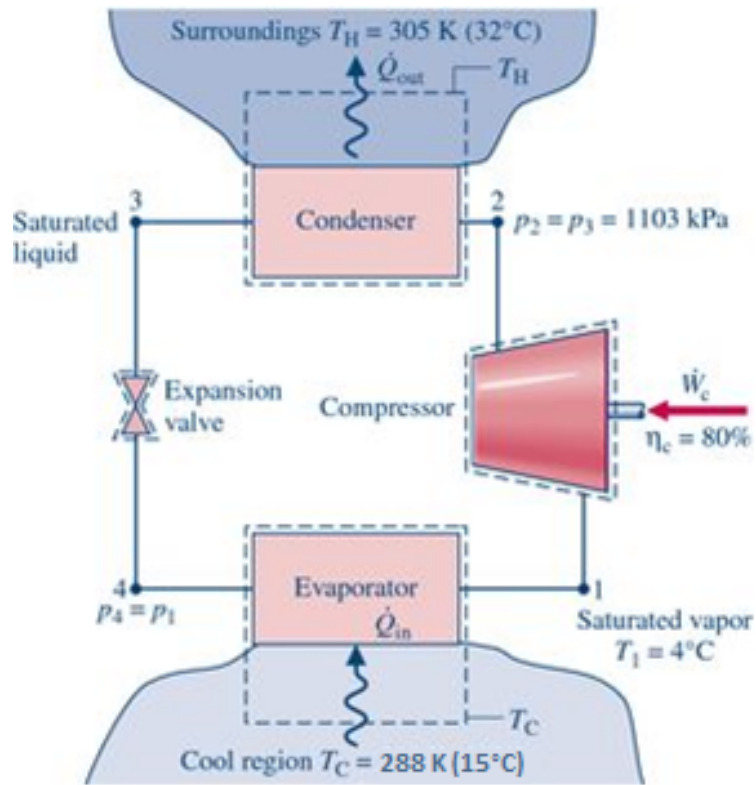


Figure 1: Schematics of the refrigeration cycle.

2. We have previously asked to use CoolProp to find thermodynamic properties. If the working fluid is water, another option is for property lookup XSteam [1] which is a free implementation of the IAPWS-IF97 standard [2]. This standard is commonly used in industry. XSteam can be used in MATLAB, with which some of you may be more familiar with than python. In this exercise, you are asked to solve the **first question in exercise 10** again, but this time using the XSteam MATLAB implementation instead of CoolProp. It consists of one file “XSteam.m” that is available from [1]. Putting that file in the current MATLAB directory allows you to evaluate steam properties using the following syntax, e.g.:

$$h = \text{XSteam}('h_pT', p, T)$$

Three arguments are required, first, a string ('h_pT') indicating which quantity you want to compute from which two other quantities and then the other two quantities (p,T). The input units are:

°C , bar , kJ/kg , kJ/(kg·m) and m³/kg.

A full list of possible strings as first arguments are given in the PDF file that you can download from [1]. In this exercise you will use the following:

h_pT , s_pT , h_ps , s_ph , T_ph , hL_p , sL_p , Tsat_p , vL_p

where **h** is specific enthalpy, **s** is specific entropy, **L** after parameter means saturated liquid and **V** saturated vapor, **T** is temperature and **p** is pressure. The supplement sat can be used after **T** or **p** to evaluate saturation temperature or pressure. Note that when evaluating properties at saturation, only one value will be required (e.g. **Tsat_p** or **vL_p**).

- (a) To solve this exercise you are asked to complete the MATLAB script “Ex13.2.m” available on moodle. All of these signs ## must be replaced for the script to run.

Hints: If you want to evaluate parts of the script, put that part between two percentage signs.

```
%%
```

```
[What should be evaluated]
```

```
%%
```

Click into that region with your mouse and press Ctrl + Enter.

- (b) How would the (overall) thermal efficiency change, if the isentropic efficiency of the low pressure turbine was increased to 0.9 (instead of 0.8)?

References:

- [1] <http://www.mathworks.com/matlabcentral/fileexchange/9817-x-steam-thermodynamic-properties-of-water-and-steam>
- [2] International Association for the Properties of Water and Steam, 1997, “Release on the IAPWS Industrial Formulation 1997 for the Thermodynamic Properties of Water and Steam”, available at www.iapws.org.