Underhood Thermal Management-Task

Deadline: 28^{th} of February, upload the script and your short report on Canvas under "Assignments".

You work in groups of 2 (same groups as for the Caster assignment). Hand in a short report in .pdf format where you explain each step in your method, your assumptions and results. Write your group number and names on the front page. Together with the report, send the Python script containing your solution. In your code use comments to clearly explain each step and indicate the units of each physical variable that you define.

A hybrid car is being driven at 80km/h (varies for each group) in the Alps at an altitude of 1500m above sea level where the static pressure and temperature are 84300 Pa and 287.15K, respectively. The underhood compartment of the car consists of 4 circuits: the air circuit, low-temperature(LT) circuit, high-temperature(HT) circuit and a refrigeration(RF) circuit as shown in Figure 1.

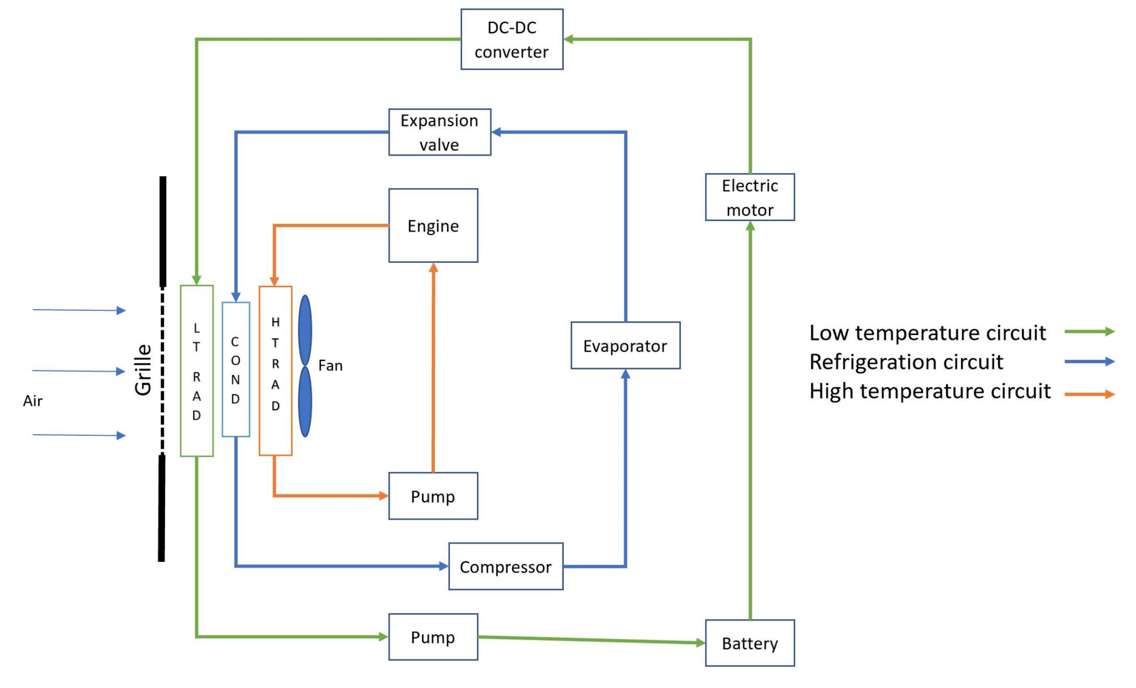

Figure 1: Circuit diagram of the cooling system

The frontal area of the LT radiator is $489mm \times 980mm$. A stagnation region can be assumed to be present all over the air intake area. The bars of the grille occupy 58% of it. Flow through the grille causes loss in static pressure which amounts to 35% of the dynamic pressure between the bars of the grille. Analytical correlations (given below) were obtained from curve-fits to calculate the pressure drop across the heat exchangers. A fan is present to meet the cooling needs and pressure recovery.

The low temperature circuit consists of a radiator(LT RAD), a pump, a 15kWh-battery, a small electric motor(EM) and a DC-DC converter in series. The battery consists of 60 cells and generates heat at the rate of 6W/cell (varies for each group). The motor and DC-DC converter produce 8kW (varies for each group) and 6.2kW heat, respectively. Using an electro-magnetic flowmeter, the flow rate was measured to be 0.58L/s when the pump runs at 4000rpm. The total length of the pipes and effective diameter of the pipes in the circuit are 4.3m and 23mm, respectively.

The high-temperature circuit consists of a radiator (HT RAD), a pump and an engine connected in series. The specifications of the pump and coolant are the same as the low-temperature circuit. Finally, the refrigeration circuit consists of a condenser (COND), a compressor, an evaporator and an expansion valve which aid in the climatization of the cabin. The condenser rejects 6kW(varies for each group) heat to the incoming air.

Note: A model code has been provided in Canvas to aid in formulating a structured code that answers the questions below.

Questions

1. Calculate the temperature of the coolant at each point in the LT circuit and the heat transferred across the LT radiator if the temperature of the coolant entering the pump is 25°C.
2. Calculate the pressure drop across each component in the LT circuit. Include frictional pressure drop using the Darcy-Weisbach equation (see Data and correlations section).
3. Write a function named '$air\_circuit$' that solves for the state variables, pressure, temperature and density, at each step in the air circuit, with mass flow rate and heat transferred across the radiators as inputs.
4. Design of Experiment (DOE) analysis: Vary the heat transferred across the 'HT RAD' from 40kW-120kW and mass flow rate of air at the inlet from 1kg/s to 12kg/s. Use the function '$air\_circuit$' to compute the state variables in the circuit for all the scenarios. Create contour plots for pressure, temperature and density downstream of the fan.
5. Identify the mass flow rates such that the total pressure downstream of the fan is equal to the stagnation pressure upstream of the grille at different values of heat transferred at the 'HT RAD'. Plot the heat transferred vs mass flow rates and explain the trend with supporting arguments.
6. Explain what happens to the heat exchanger in the RF circuit if the RF circuit acts as a heat pump.

Assumptions

1. Consider the flow in the air circuit as a 1-D problem. There are 6 points of interest, a stagnation point before the grille (point 0), one after the grille (point 1) and so on with point 5 after the fan.
2. Consider the frontal area of the low-temperature radiator and the grille are equal.
3. The density of air can be considered to be the same around the vehicle and in front of the LT radiator(point 0 and point 1).
4. The specific heat of air and the coolant are constant and independent of temperature. $C_{p,air}$ = 1.004 KJ/kgK and $C_{p,coolant}$ = 3.3 KJ/kgK. The density of the coolant ($\rho_{coolant}$) is 1070 kg/m^3 and independent of temperature.
5. While calculating the pressure drop across a heat exchanger, the density of air in front of the corresponding heat exchanger can be used.
6. Assume uniform heat generation across all the cells in the battery.
7. Assume that the pumps in the coolant circuits are adiabatic.

Data and correlations

1. Pressure drop for heat exchanger:
   $\Delta P_{HX} = k_0\frac{\dot{m}^2}{\rho} + k_1\frac{\dot{m}}{\rho} + k_2$
   LT/HT radiator: k_0 = 4.58 m^{-4}, k_1 = 40.11 $kgm^{-4}s^{-1}$, k_2 = -16.98 $kgm^{-1}s^{-2}$.
   Condenser: k_0 = 1.96 m^{-4}, k_1 = 8.9 $kgm^{-4}s^{-1}$, k_2 = 6.37 $kgm^{-1}s^{-2}$.
2. Pressure drop correlations in kPa:
   Electric motor: $\Delta P_{EM} = 0.02Q_{flow}^2 - 0.18Q_{flow}$
   DC-DC converter: $\Delta P_{DC-DC} = 0.001Q_{flow}^3 - 0.0035Q_{flow}^2 + 0.016Q_{flow}$
   Battery: $\Delta P_{Bat} = 0.00375Q_{flow}^{2.5} - 0.2797Q_{flow}$
   Q_{flow} should be in L/min.
3. Darcy-Weisbach equation: $\frac{\Delta P}{L} = \frac{f\rho v^2}{2D}$ where f is the Darcy friction factor. Take f=0.005.

Q_{flow}(L/min)	Pressure rise (kPa)
0	127.92
25.2	130.47
44.12	126.82
65.32	117.58
93.83	94.62
120.67	55.43

Table 1: Coolant pump characteristics data at 4000rpm

$Q_{flow}(m^3/s)$	Pressure drop (Pa)
0	4000
1.6	3500
2	3250
3	3000
4	2750
4.9	2500
5.05	2400
5.2	2300
6	2200
7.2	2100
8	2000
9.9	1500
11.1	1000
12.3	500
13.2	0

Table 2: Fan characteristics data at 3500rpm and D_{fan}=780mm

Parameters for each group

Group no.	**Vehicle speed(km/h)**	**Cell heat rate(W/cell)**	**Condenser heat rate(kW)**	**Electric motor heat rate(kW)**
1	80	3.5	5	8
2	80	4	6	8.3
3	80	4.5	7	8.6
4	80	5	8	8.9
5	80	5.5	5	9.2
6	85	6	6	9.5
7	85	3.5	7	10
8	85	4	8	8
9	85	4.5	5	8.3
10	85	5	6	8.6
11	90	5.5	7	8.9
12	90	6	8	9.2
13	90	3.5	5	9.5
14	90	4	6	10
15	90	4.5	7	8
16	95	5	8	8.3
17	95	5.5	5	8.6
18	95	6	6	8.9
19	95	3.5	7	9.2
20	95	4	8	9.5
21	92	4.5	5	10
22	92	5	6	8
23	92	5.5	7	8.3
24	92	6	8	8.6
25	92	3.5	5	8.9