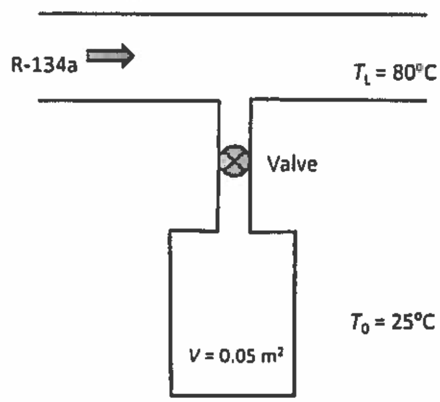
QUESTION 1

Saturated liquid R-134a at $T_L = 80°C$ is available through a supply line. A rigid tank that is empty initially is to be filled by the supply line, as shown in the figure below. Make suitable assumptions and be sure to indicate your assumptions in your answer.

(a) Given that the volume of the tank is $V = 0.05\ m^2$. After the valve is opened, the refrigerant R-134a quickly enters the tank so that it reaches the same pressure as the supply line. Find the temperature and the mass of R-134a inside the tank immediately after the filling.

(b) The valve is left open while the tank is slowly cooled by the ambient at temperature $T_0 = 25°C$. Assume that the supply line is maintained as saturated liquid at the same temperature as before. After a long time, what is the final mass inside the tank? How much heat is transferred out of the tank to the ambient in this process?



QUESTION 2

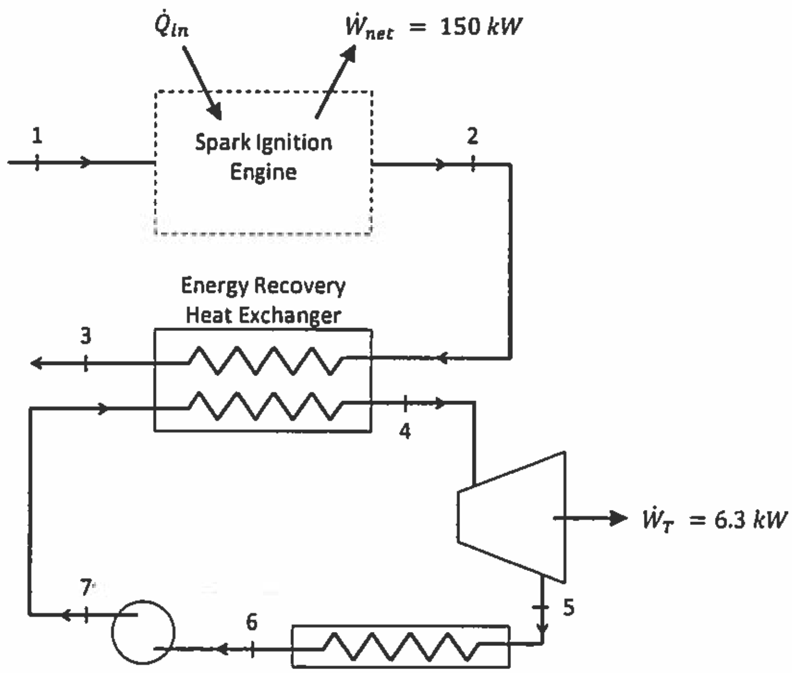
An Organic Rankine Cycle (ORC) operates with R-134a as a bottoming cycle to recover waste energy from the exhaust stream of a spark ignition engine. The spark ignition engine has a compression ratio of 11:1 and executes an Otto cycle with air as the working fluid and a peak cycle temperature of 4500 K, producing a net power output of 150 kW at steady state. The combustion energy input to the cycle is modeled as a heat addition, $\dot{Q}_{in}$, and the engine operates adiabatically so that all energy addition via combustion is either converted to power or carried out with the exhaust stream. Air enters the spark ignition engine at 1 bar and 330 K and exits at 1 bar and 1080 K, after which it is passed isobarically through the exhaust energy recovery heat exchanger before it exhausts to the atmosphere. Within the Organic Rankine Cycle, a steady-state flow of R-134a at 0.329 kg/s enters the turbine as a saturated vapor at 30 bar. Expansion through the adiabatic turbine produces 6.30 kW of power. The R-134a then passes isobarically through the condenser, exiting as a saturated liquid at 8 bar, and is then pumped to the turbine inlet pressure via an adiabatic and reversible pump.

Assumptions:

1. The system operates at steady state.
2. The air behaves as an ideal gas with constant specific heats: $k = 1.4$, $C_p = 1.005$ kJ/kg-K, and $C_v = 0.718$ kJ/kg-K.
3. Kinetic and potential energy effects are negligible.
4. The pump, turbine, and heat exchangers operate adiabatically.
5. Negligible pressure losses in the piping and across heat exchangers.
6. The dead state conditions are $p_o = 1$ bar and $T_o = 300$ K.

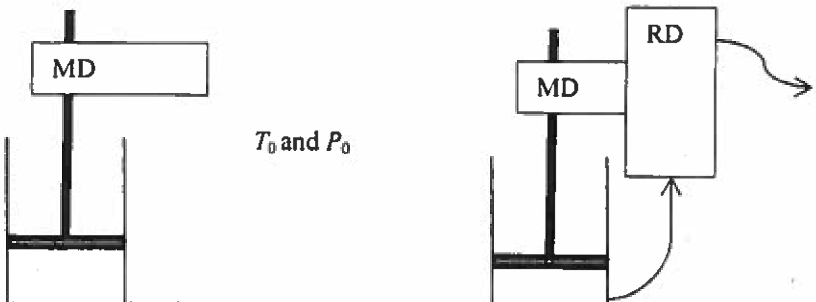
Determine:

a) The mass flow rate of air through the spark ignition engine.
b) The thermal efficiency of the spark ignition engine without exhaust energy recovery.
c) The thermal efficiency of the combined engine-ORC cycle.
d) The rate of exergy destruction in the exhaust energy recovery heat exchanger.



QUESTION 3

Consider a friction-free piston cylinder shown on left below containing 1.0 kg of air. Assume air is an ideal gas with constant specific heats and constant specific heat ratio = 1.40 and molar mass = 28.97 kg/kmole. The piston is connected to a friction free reversible mechanical device (MD) that can receive work and store mechanical energy. Assume the air is at T_1 =300 K and P_1 = 500 kPa. Surrounding atmosphere is at 100 kPa and 300 K.



A. Assuming the air in the cylinder is adiabatic, what is the lowest temperature the air can reach in a reversible expansion against the piston? $T_{F,A}$ = ____________ K

B. In the expansion of part A, how much work is done on the piston by the air inside the cylinder?

W_{AIR} = ____________ kJ

C. In the expansion of part A, how much work is stored as mechanical energy in the MD?

W_{ST} = ____________ kJ

D. Consider the modification on the right. The MD can now drive a reversible refrigeration device (RD) that can cool the air in the cylinder by rejecting heat to the atmosphere. Assuming this cooling system is now used, the minimum air temperature after expansion is to be found. What do you expect to be the final air pressure (P_F) to achieve the minimum possible temperature? P_F = ____________ kPa

E. Explain briefly below your answer for part D:

F. Derive an algebraic equation that can be solved to find the minimum air temperature that can be achieved by the system of part D. The resulting equation may be nonlinear, so it is not necessary to find a numerical solution. The equation should be expressed in terms of the final minimum temperature (T_{MIN}), and other simple intensive properties such as the initial temperature and pressure (T_1 and P_1), the ambient temperature and pressure (T_0 and P_0), and fluid properties such as the specific heats and gas constant (C_v and C_P and R). Note that in this analysis you are expected to assume that the MD and the RD go through an integral number of cycles with no overall change in their thermodynamic states and that the air in the cylinder is cooled only by expansion and by rejecting heat through the refrigeration device, the RD. Insert the resulting equation the box below:
