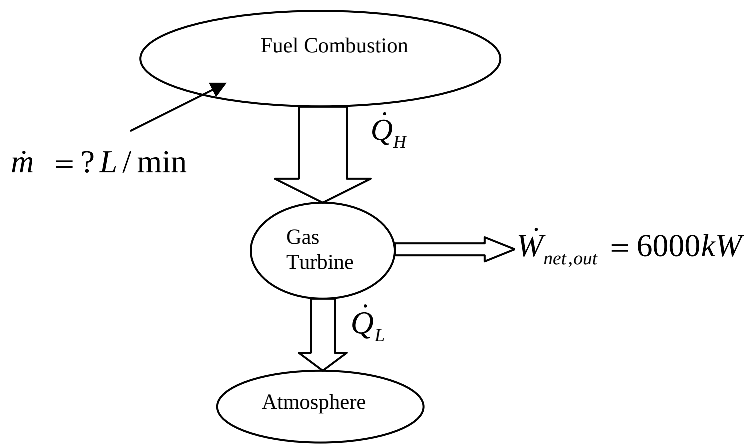
Thermodynamics and Heat transfer
ECE 309 Tutorial 5#
The Second law of Thermodynamics

Problem 1 A gas turbine has an efficiency of 17 percent and develops a power output of 6000 kW. Determine the fuel consumption rate of this gas turbine, in $L/\min$, if the fuel has a heating value of 46,000 kJ/kg and a density of 0.8 g/cm^3.

Solution:

Step 1: Draw a diagram to represent the system



Step 2: Write out what you need to solve for

The fuel consumption rate of this gas turbine.

Step 3: State what you have known and your assumptions

1) The thermal efficiency of the gas turbine
2) The heat value and density of the fuel
3) The power output to the wheels
4) Assuming the car operates steadily

Step 4: Prepare a table of properties

Parameter	Symbol	Properties
Thermal efficiency	η_{th}	17%
Fuel density	ρ	0.8 g/cm^3
Heat value of fuel	u	46,000 kJ/kg
Power output	$\dot{W}_{net,out}$	6000 kW

Step 5: Analysis

The amount of energy input required to produce a power output of 6000 kW is determined from the definition of thermal efficiency.

$$\dot{Q}_H = \frac{\dot{W}_{net,out}}{\eta_{th}} = \frac{6000kW}{0.17} = 35{,}294kW$$

To supply energy at this rate, the engine must burn fuel at a rate of

$$\dot{m} = \frac{\dot{Q}_H}{u} = \frac{35{,}294kW}{46{,}000kJ/kg} = 0.767kg/s$$

Since the 46000 kJ of thermal energy is released for reach kg of fuel burned, the corresponding volume flow rate of the fuel can be determined by

$$\dot{V} = \frac{\dot{m}}{\rho} = \frac{0.767kg/s}{0.8g/cm^3} = \frac{0.767kg/s}{0.8kg/L} = 0.959L/s = 57.5L/\min$$

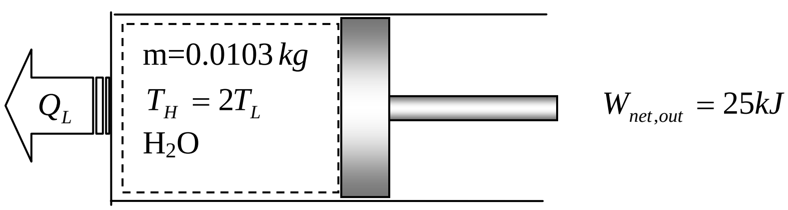
Step 6: Conclusion statement

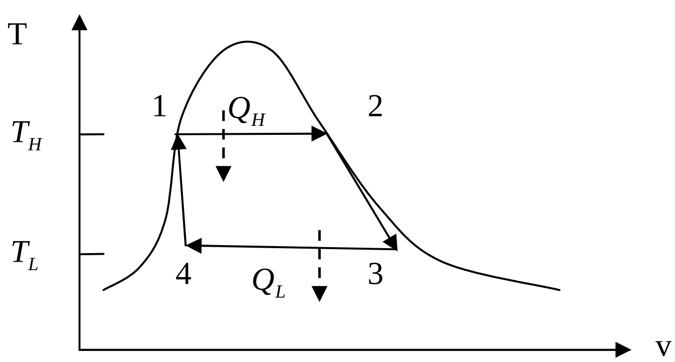
The fuel consumption rate of this gas turbine is 57.5 $L/\min$.

Problem 2 Consider a Carnot heat-engine cycle executed in a closed system using 0.0103 *kg* of steam as the working fluid. It is known that the maximum absolute temperature in the cycle is twice the minimum absolute temperature, and the net work output to the cycle is 25 *kJ* . If the steam changes from saturated vapor to saturated liquid during the heat rejection process, determine the temperature of the steam during the heat rejection process.

Solution:

Step 1: Draw a diagram to represent the system





Step 2: Write out what you need to solve for

Determine the temperature of the steam during the heat rejection process.

Step 3: State what you have known and your assumptions

1) The mass of the working fluid is 0.0103 kg
2) The net work input to the cycle is 25 kJ
3) The maximum absolute temperature is 2 times the minimum absolute temperature, $T_H = 2T_L$
4) Assuming the engine is said to operate on the Carnot cycle, which is totally reversible
5) The steam changes from saturated vapor to saturated liquid during the heat rejection process

Step 4: Analysis

The thermal efficiency of a heat engine is defined as

$$\eta_{th} = \frac{W_{net,out}}{Q_H} = 1 - \frac{Q_L}{Q_H} \quad (1)$$

The Carnot heat engine is a reversible heat engine, and so its efficiency calculation becomes

$$\eta_{th} = 1 - \frac{T_L}{T_H} = 1 - \frac{1}{2} = 0.5$$

The amount of heat input required to produce a net work output is determined by

$$Q_H = \frac{W_{net,out}}{\eta_{th}} = \frac{25kJ}{0.5} = 50kJ$$

The amount of heat rejected by this reversible heat engine is determined by

$$Q_L = Q_H - W_{net,out} = 50kJ - 25kJ = 25kJ$$

The amount of the heat rejected equals to the heat released when the steam changes from saturated vapor to saturated liquid during the heat rejection process.

$$q_L = \frac{Q_L}{m} = \frac{25kJ}{0.0103kg} = 2427kJ/kg = h_{fg@T_L}$$

Since the enthalpy of evaporation h_{fg} at a given T or P represents the amount of heat transferred by $1\,kg$ substance changing from saturated liquid to saturated vapor. Therefore, T_L is the temperature that corresponds to the h_{fg} value of $2427\,kJ/kg$, and can be determined from the saturated water tables (Table A-4) by interpolation.

The corresponding enthalpies of evaporation at 30 and 35 $°C$ are:

	Temperature ($°C$)	Enthalpy of evaporation, h_{fg} (kJ/kg)
1	30	2430.5
2	35	2418.6

Therefore

$$T_L = 30 + (30 - 35) * \frac{2430.5 - 2427}{2430.5 - 2418.6} = 31.5°C$$

Step 5: Conclusion statement

The low temperature in the cycle is $31.5°C$.