ME 201
Thermodynamics

Exam #3
Solution

Problem 1

Steam at 0.5 MPa and 350°C is used to fill a 0.1 m^3 tank, which is initially empty. After filling, the tank is cooled to 50°C and the contents become saturated liquid. Determine

(a) the heat transfer required

(b) the mass of water added to the tank

Solution:

System Type: Transient
Working Fluid: Compressible
Process: Constant total volume
State 1: Fixed
State 2: Fixed
State 3: Fixed
$W_{bnd} = 0$
$W_{sh} = 0$
Q=???
conserv. of mass: $m_2 = m_3$
1st Law: $m_2 u_2 = m_3 h_3 + Q$

State 1 (initial)	State 2 (final)	State 3 (inlet)
T_1	T_2 = 50°C	T_3 = 350°C
P_1	P_2 = *12.352 kPa*	P_3 =0.5 MPa
u_1	u_2 = *209.33 kJ/kg*	h_3 = *3168.1 kJ/kg*
m_1 =0 kg	m_2 = **98.81 kg**	m_3 = **98.81 kg**
	v_2 = *0.001012 m^3/kg*	

Italicized values are from steam tables. **Bold** values are calculated.

Approach: We go to the steam tables and read the remaining properties fr states 2 and 3. The mass in final state can then be calculated from V_3/v_3. Finally the first law is used to calculate Q.

First we go to the air tables and find

u_2 = 209.33 kJ/kg , v_2 = 0.001012 m^3/kg, and h_3 = 3168.1 kJ/kg

Next we calculate the final mass from

$$m_2 = \frac{V_2}{v_2} = \frac{(0.1)}{(0.001012)} = 98.81\,\text{kg}$$

Conservation of mass then gives

$$m_3 = m_2 = 98.81 \text{ kg}$$

Using the 1st law to solve for the heat transfer we have

$$Q = m_2u_2 - m_3h_3 = (98.81)(209.33\text{-}3168.1) = -292{,}369 \text{ kJ}$$

Problem 2

In the Kentucky Derby a racehorse exerts a force of 36 Nt over a distance of 1900 m. Model the racehorse as a heat engine operating under the following conditions

Net work is the force exerted times the distance traveled (W_{net} = F x d)

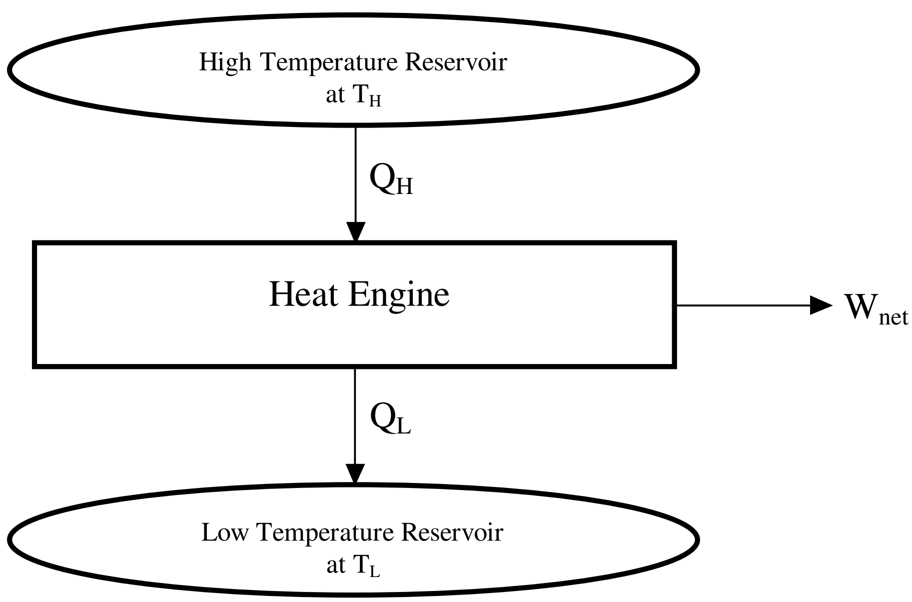
Low temperature heat reservoir is the environment at 20°C

High temperature heat reservoir is the internal temperature of the horse at 55°C

If the heat from the high temperature heat source comes from the digestion of grain with an energy content of 53 kJ/kg, determine the minimum amount of grain required for the horse to run the Derby.

Solution:

We begin with our interaction diagram for a heat engine.



Our appropriate equations are:

$$\eta_{th} = \frac{W_{net}}{Q_H}$$

$$Q_H = W_{net} + Q_L$$

$$\eta_{Carnot} = 1 - \frac{T_L}{T_H}$$

We have been given the following conditions:

$T_H = 55°C = 328$ K

$T_L = 20°C = 293$ K

Wnet = F x d = (36)(1900) = 68,400 J = 68.4 kJ

The energy for Q_H must come from the grain so that

$Q_H = m_{grain}$ x 53 kJ/kg

Then the problem reduces to determine QH. We begin by noting that since we want the minimum amount of grain, we can use our Carnot efficiency or

$$\eta_{Carnot} = 1 - \frac{T_L}{T_H} = 1 - \frac{293}{328} = 0.1067$$

Then Q_H can be calculated

$$Q_H = \frac{W_{net}}{\eta_{th}} = \frac{68.4}{0.1067} = 641\,\text{kJ}$$

Finally

$$m_{grain} = \frac{Q_H}{(53\,\text{kJ/kg})} = \frac{(641)}{(53)} = 12.09 \text{ kg}$$

Problem 3

Air is expanded in a closed system from a state where the pressure is 500 kPa and the temperature is 285 K to a final state at 200 kPa and 450 K. Can this process occur adiabatically? If yes, determine the work per mass. If no, determine the direction of the heat transfer.

Solution:

We need to determine whether

$$(\Delta S)_{universe} \geq 0$$

holds for this situation. Since we have a closed system we can write this equivalently as

$$(\Delta S)_{universe} = (\Delta S)_{system} + (\Delta S)_{surrounds} \geq 0$$

$$= m(s_2 - s_1) - \frac{Q_{sys}}{T_{surr}} \geq 0$$

Assuming that the process is adiabatic, we have

$Q_{sys} = 0$

Treating air as an ideal gas we have

$s_2 - s_1 = \phi_2 - \phi_1 - R\ \ln(P_2/P_1)$

Going to the air tables we find

$\phi_2 = 2.11161$ kJ/(kg·K)

$\phi_1 = 1.65055$ kJ/(kg·K)

Then substituting gives

$s_2 - s_1 = 2.11161 - 1.65055 - (0.287)\ln(200/500) = 0.724035$ kJ/(kg·K)

Hence the process can be adiabatic. The work can be calculated form the 1st law or

$w = u_1 - u_2$

Going to the air tables we find

$u_2 = 322.62$ kJ/kg

$u_1 = 203.33$ kJ/kg

Then substituting gives

$w = 203.33 - 322.62 = -119.29$ kJ/kg