ME 201
Thermodynamics

Homework 17 Solution

1. Two kilograms of Refrigerant-134a is contained in a piston-cylinder system. It is initially at 160 kPa and 0°C and is compressed to saturated vapor at 0°C. The heat transfer from the cylinder is reported to be 30 kJ. Can this value be correct? What is the minimum work input required to carry out this process?

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

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

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

To evaluate this we will need to perform a 1st law analysis. Setting up our table

System: Closed System

Fluid: Refrigerant-134a (compressible substance)

State 1	State 2
$T_1 = 0°C$	$T_2 = 0°C$
$P_1 = 160$ kPa	$P_2 =$ *293.01 kPa*
$u_1 =$ *232.86 kJ/kg*	$u_2 =$ *230.16 kJ/kg*
$s_1 =$ *0.9915 kJ/(kg·K)*	$s_2 =$ *0.9314 kJ/(kg·K)*
phase:sup.vap.	phase:sat.vap.

Italicized values are from R-134a tables

m = 2 kg

State 1: Fixed

State 2: Fixed

W: UNKNOWN

Q = -30 kJ

1st Law: $m(u_2 - u_1) = Q - W$

Since both states are fixed we can go to the R-134a tables and find u and s for each state. Now calculating the entropy change of the universe

$$(\Delta S)_{universe} = m(s_2 - s_1) - \frac{Q_{sys}}{T_{surr}}$$

$$= (2)(0.9314 - 0.9915) - \frac{-30}{273} = -0.01031\,kJ/K$$

which violates our 2nd law, so that the heat transfer measurement is wrong. To determine the minimum work, we must have a reversible process that satisfies

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

This allows to calculate our Q from

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

or solving for Q_{sys}

$$Q_{sys} = T_{surr} m(s_2 - s_1)$$

$$= (273)(2)(0.9314 - 0.9915) = -32.82\,kJ$$

Then the work may be calculated from the 1st law

$$W = -m(u_2 - u_1) + Q = -(2)(230.16 - 232.86) + (-32.82)$$

$$= -27.41\,kJ$$

2. An inventor claims to have developed a device that has an inlet flow of air at 20°C, 300 kPa, and 5 kg/s and two outlet flows, air at 60°C and 270 kPa and air at 0°C and 270 kPa. He claims that there is no work or heat transfer involved in the device. Evaluate this claim.

Solution:

To evaluate this claim we will want to calculate the rate of entropy production for the process and see if it is greater than or equal to zero, or

$$\dot{S}_{prod} = \dot{m}_3 s_3 + \dot{m}_2 s_2 - \dot{m}_1 s_1$$

Our states our fixed, but to determine our mass flow rates we need to satisfy conservation of mass and conservation of energy. Hence, we will need to work a first law problem

System: Control Volume

Fluid: Air (ideal gas)

Process: $\dot{Q} = 0$ and $\dot{W} = 0$

State 1	State 2	State 3
P_1 = 300 kPa	P_2 = 270 kPa	P_3 = 270 kPa
T_1 = 20°C = 293 K	T_2 = 60°C = 333 K	T_3 = 0°C = 273 K
$\dot{m}_1$ = 5 kg/s	$\dot{m}_2$ = **1.66 kg/s**	$\dot{m}_3$ = **3.34 kg/s**
ϕ_1 = *1.6783 kJ/(kg·K)*	ϕ_2 = *1.8069 kJ/(kg·K)*	ϕ_3 = *1.6073 kJ/(kg·K)*
h_1 = *293.166 kJ/kg*	h_2 = *333.364 kJ/kg*	h_3 = *273.116 kJ/kg*

Bold values are calculated, *italicized* values are from air tables.

Our conservation of mass is given by

$$\dot{m}_1 = \dot{m}_2 + \dot{m}_3$$

and our conservation of energy is given by

$$\dot{m}_1 h_1 - \dot{m}_2 h_2 - \dot{m}_3 h_3 = 0$$

Substituting for $\dot{m}_3$ from mass into our energy equation we have

$$\dot{m}_1 h_1 - \dot{m}_2 h_2 - (\dot{m}_1 - \dot{m}_2) h_3 = 0$$

Now solving for $\dot{m}_2$

$$\dot{m}_2 = \frac{\dot{m}_1 (h_1 - h_3)}{h_2 - h_3} = \frac{(5)(293.166 - 273.116)}{(333.364 - 273.116)} = 1.66 \text{ kg/s}$$

and

$$\dot{m}_3 = \dot{m}_1 - \dot{m}_2 = 5 - 1.66 = 3.34 \text{ kg/s}$$

So we could now calculate our rate of entropy production , except we need to have entropy changes. To achieve this we substitute for $\dot{m}_1$ from conservation of mass to write

$$\dot{S}_{prod} = \dot{m}_3 s_3 + \dot{m}_2 s_2 - (\dot{m}_2 + \dot{m}_3) s_1$$

Now factoring the mass flow rates

$$\dot{S}_{prod} = \dot{m}_3 (s_3 - s_1) + \dot{m}_2 (s_2 - s_1)$$

For air as an ideal gas

$$\dot{S}_{prod} = \dot{m}_3 \left(\phi_3 - \phi_1 - R \cdot \ln \frac{P_3}{P_1} \right) + \dot{m}_2 \left(\phi_2 - \phi_1 - R \cdot \ln \frac{P_2}{P_1} \right)$$

$$= (3.34) \left(1.6073 - 1.6783 - (0.287) \ln \frac{270}{300} \right) + (1.66) \left(1.8069 - 1.6783 - (0.287) \ln \frac{270}{300} \right)$$

$$= 0.1275 \text{ kW/K}$$

So the device is possible.