

Concepts of Thermodynamics
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Lecture – 46
Supplementary Lecture: Problem Solving with the Aid of a Computer

Hello everyone, welcome to this session in which we will solve another problem pertaining to the topic of entropy by means of a computer.

(Refer Slide Time: 00:27)

The screenshot shows a MATLAB script on the left and a presentation slide on the right. The MATLAB script defines variables for a thermodynamic process:

```

p1 = 10000; T1 = 700; V1 = 0.1; v1 = volume(steam, T = T1, P = P1);
mass = V1/v1;
u1 = intenergy(steam, T = T1, P = P1);
x2 = 0; P2 = p1;
v2 = volume(steam, P = P2, x = x2);
u2 = intenergy(steam, P = P2, x = x2);
Q12 = mass*(u2 - u1) + W12;
W12 = mass*(v2 - v1)*p1;

```

The presentation slide on the right contains the following text and equations:

Problem 6.7: A cylinder fitted with a frictionless piston contains water, as shown in the figure. A constant hydraulic pressure on the back face of the piston maintains a cylinder pressure of 10 MPa. Initially, the water is at 700°C, and the volume is 100 L. The water is now cooled and condensed to saturated liquid. The heat released during this process is the Q supply to a cyclic heat engine that in turn rejects heat to the ambient air at 30°C. If the overall process is reversible, what is the net work output of the heat engine?

Handwritten equations on the slide:

$$T_1 = 700 \quad Q = 0$$

$$\rightarrow V_2 = 100 \text{ L} \Rightarrow \frac{P_1}{P_2} = 10 \text{ MPa}$$

$$P_1 = 10 \text{ MPa}$$

$$Q_{12} = m(u_2 - u_1) + W_{12}$$

$$W_{12} = p \times (V_2 - V_1)$$

$$= p \times m (v_2 - v_1)$$

A cylinder is fitted with a frictionless piston which contains water and back face maintains a pressure of 10 mega Pascal. Initially, the water is at 700 degree Celsius. So, T_1 is 700 and the volume of the whole container is 100 liter. It is now cooled to saturated liquid. So, what is the quantity here we have? So, we total is not a independent quantity.

So, the quantity is actually the pressure and it is going from this state to state 2 where it is a sub called liquid as saturated liquid. And so, here the pressure remains constant. So, P_2 is 10 mega Pascal, the heat release during this process is now used to sub is now supplied to a heat engine that rejects to the ambient at 30 degrees Celsius.

If the overall process is reversible, what is the network output of the heat engine? That is the question. So, let us see how we can do this. So, we have p_1 is equal to 10 mega Pascal, we have t_1 is equal to 700 degrees Celsius and V_1 is equal to 100 liter.

So, it is basically 0.1 meter cube. So, v_1 equal to volume steam T equal to T_1 P equal to P_1 this gives a specific volume. So, the mass is equal to the total volume divided by the specific volume that is the mass. State 2 x_2 is equal to 0 and we have P_2 is equal to p_1 .

So, now, Q_{12} which is if I consider this particular mass as a control mass then I can write Q_{12} is equal to $m(u_2 - u_1) + W_{12}$. But what will be W_{12} ? W_{12} will simply be, the external pressure multiplied by the change in volume. So, if I can write it in terms of the total volume, alternatively I can also write it in terms of the mass multiplied by the specific volume is one and the same.

So, then let me write down Q_{12} is equal to mass times $u_2 - u_1$ plus W_{12} ; where W_{12} is mass times $v_2 - v_1$ times the pressure. So, v_2 is equal to volume steam. We can use the pressure at state 2 and the state and the quality to find out the specific volume. So, with this you also need to fetch the internal energies. So, u_1 equal to intenergy steam T equal to T_1 and P equal to P_1 . Similarly, we have u_2 equal to intenergy steam P equal to P_2 and x equal to x_2 is basically the internal energy of the fluid ok. It is its completely saturated liquid.

(Refer Slide Time: 04:34)

The image shows a computer screen with two windows. The left window is the EES (Engineering Equation Solver) software interface. The right window is a handwritten slide with a diagram and calculations.

EES Software Window:

```

p1 = 10000; t1 = 700; V1 = 0.1; v1 = volume(Steam, T = T1, P = P1);
mass = V1/v1;
u1 = Intenergy(Steam, T = T1, P = P1);
x2 = 0; P2 = p1;
v2 = volume(Steam, P = P2, x = x2);
u2 = Intenergy(Steam, P = P2, x = x2);
Q12 = mass*(u2 - u1) + W12;
W12 = mass*(v2 - v1)*p1
  
```

Unit Settings: SI C kPa kJ mass deg

mass = 2.294	p1 = 10000	P2 = 10000	Q12 = -5647
t1 = 700	u1 = 3434	u2 = 1393	v1 = 0.0436
v2 = 0.001452	V1 = 0.1	W12 = -966.7	x2 = 0

4 potential unit problems were detected. EES suggested units (shown in purple) for p1 t1.

Calculation time = 15 ms

Handwritten Slide:

Problem 6.7: A cylinder fitted with a frictionless piston contains water, as shown in the figure. A constant hydraulic pressure on the back face of the piston maintains a cylinder pressure of 10 MPa. Initially, the water is at 700°C, and the volume is 100 L. The water is now cooled and condensed to saturated liquid. The heat released during this process is the Q supply to a cyclic heat engine that in turn rejects heat to the ambient air at 30°C. If the overall process is reversible, what is the net work output of the heat engine?

Diagram: A cylinder with a piston. The cylinder contains water. The piston is connected to a hydraulic system. The hydraulic system has a constant pressure of 10 MPa. The cylinder pressure is also 10 MPa. The cylinder is cooled from 700°C to 30°C. The heat released is Q_{12} . The work done by the piston is W_{12} .

Handwritten calculations:

$$T_1 = 700 \quad x_2 = 0$$

$$\rightarrow V_2 = 100 \text{ L} \Rightarrow P_2 = 10 \text{ MPa}$$

$$P_1 = 10 \text{ MPa}$$

$$Q_{12} = m(u_2 - u_1) + W_{12}$$

$$W_{12} = p \times (V_2 - V_1)$$

$$= p \times m (v_2 - v_1)$$

$$Q_{12} = -5647 \text{ kJ}$$

Net work output: $W_{net} = -Q_{12}$

So, with this we have Q_{12} equal to minus 5647 kilo Joules. So, that is heat transferred to the system. So, if this was the heat this much amount of heat would be minus 5 6 4 7 which means, if I draw the arrow like this it would be 5647. So, basically this particular Q is nothing but 5 6 4 7.

So, if I draw the heat engine now, this particular heat to the heat engine basically which is Q_H is nothing but minus of Q_{12} . Try to understand, because I have considered the control mass as H₂O the sign convention tells me, that if I take it as positive, than heat is to the system pardon me. So, that is why I have drawn there like this.

So, the numerical value comes out to be negative, it means actually the heat is going out of the system ok, the system is losing heat. So, Q_H is actually the Q_h to the heat engine is actually minus of Q_{12} . Let us just keep that in mind.

(Refer Slide Time: 05:43)

The screenshot shows a software interface with two main panes. The left pane contains a list of variables and their values, along with a 'Main Program' section. The right pane displays a handwritten solution for 'Problem 6.7'. The problem text describes a cylinder with a frictionless piston containing water, initially at 700°C and 100 L, which is cooled and condensed to saturated liquid at 30°C. A constant hydraulic pressure of 10 MPa is applied to the back face of the piston. The solution includes a schematic diagram of the cylinder and heat engine, and several equations: $T_1 = 700$, $x_2 = 0$, $V_2 = 100 \text{ L} \Rightarrow \bar{P}_2 = 10 \text{ MPa}$, $P_2 = 10 \text{ MPa}$, $Q_{12} = m(u_2 - u_1) + W_{12}$, $W_{12} = p \times (V_2 - V_1)$, $Q_{12} = -5647 \text{ kJ}$, $\Delta S_{\text{tot}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}}$, and $\Delta S_{\text{tot}} = m(s_2 - s_1) - \frac{Q_{12}}{T_{\text{amb}}} = 0$.

So, we write it over here. Q_h is basically minus of Q_{12} . So, now, it is given the overall process is reversible. So, what is the strategy we adopt over here? We consider this; so, forget about this arrow. We consider this to be the control volume. So, for this particular control volume we have some water which is changing its state from state 1 to state 2, and we have some heat rejection and some work.

So, the work does not contribute to the change of entropy. So, if I write down ΔS of the system is equal to ΔS of water plus ΔS because of the heat transfer. So, this

let us include, because we have been given that the overall process is reversible, we have to also include the heat transfer to the ambient ΔS of the surrounding.

So, what do we have? So, ΔS of the water is $ms_2 - ms_1$ and what is the entropy change of the surrounding? It will be equal to $-\frac{Q_L}{T_{\text{ambient}}}$ in Kelvin as per the sign convention. So, we write here and this overall as; obviously 0. So, then we have $ms_2 - ms_1 - \frac{Q_L}{T_{\text{ambient}}}$ which is basically 303.16 Kelvin which is equal to 0 ok. So, let us see what Q_L we obtain.

(Refer Slide Time: 08:35)

Problem 6.7: A cylinder fitted with a frictionless piston contains water, as shown in the figure. A constant hydraulic pressure on the back face of the piston maintains a cylinder pressure of 10 MPa. Initially, the water is at 700°C, and the volume is 100 L. The water is now cooled and condensed to saturated liquid. The heat released during this process is the Q supply to a cyclic heat engine that in turn rejects heat to the ambient air at 30°C. If the overall process is reversible, what is the net work output of the heat engine?

Handwritten Solution:

$T_1 = 700^\circ\text{C}$
 $V_2 = 100\text{ L} \Rightarrow \bar{P}_2 = 10\text{ MPa}$
 $P_1 = 10\text{ MPa}$
 $Q_{12} = m(u_2 - u_1) + W_{12}$
 $W_{12} = p \times (V_2 - V_1)$
 $= p \times m (v_2 - v_1)$
 $Q_{12} = -56.47\text{ kJ}$

$\Delta S_{\text{tot}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}}$
 $= m(s_2 - s_1) - \frac{Q_L}{T_{\text{amb}}} = 0$

Code in the left pane:

```

p1 = 10000; t1 = 700; V1 = 0.1; v1 = volume(Steam, T = T1, P = P1);
mass = V1/v1;
u1 = IntEnergy(Steam, T = T1, P = P1);
s1 = entropy(steam, T = T1, P = P1);

x2 = 0; P2 = p1;
v2 = volume(Steam, P = P2, x = x2);
u2 = IntEnergy(Steam, P = P2, x = x2);
s2 = entropy(steam, P = P2, x = x2);

Q12 = mass*(u2 - u1) + W12;
W12 = mass*(v2 - v1)*p1
Qh = -Q12 "Sign conventions"
mass*(s2 - s1) - Q1/(303.16) = 0
    
```

So, we have forgotten to fetch the properties of the property entropy s_1 is this s_2 equal to entropy steam P equal to P_2 x equal to x_2 . So, let us see what Q_L is.

(Refer Slide Time: 08:54)

The image shows a software interface for thermodynamic calculations on the left and handwritten notes on a whiteboard on the right.

Software Interface (Left):

```

p1 = 10000; t1 = 700; V1 = 0.1; v1 = volume(Steam, T = T1, P = P1);
mass = V1/v1;
u1 = IntEnergy(Steam, T = T1, P = P1);
s1 = Entropy(Steam, T = T1, P = P1);

x2 = 0; P2 = p1;
v2 = volume(Steam, P = P2, x = x2);
u2 = IntEnergy(Steam, P = P2, x = x2);

Unit Settings: SI C kPa kJ mass deg
mass = 2.294 p1 = 10000 P2 = 10000 Q12 = -5647
Qh = 5647 Qi = -2649 s1 = 7.169 s2 = 3.36
t1 = 700 u1 = 3434 u2 = 1393 v1 = 0.0436
v2 = 0.001452 V1 = 0.1 W12 = -966.7 x2 = 0

6 potential unit problems were detected.
Calculation time = 16 ms
  
```

Whiteboard (Right):

Handwritten notes include:

- $T_1 = 10 \text{ MPa}$
- $Q_{12} = m(u_2 - u_1) + W_{12}$
- $W_{12} = p \times (V_2 - V_1)$
- $= p \times m (v_2 - v_1)$
- $Q_{12} = -5647 \text{ kJ}$
- $Q_H = -Q_{12}$
- $\Delta S_{\text{tot}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}}$
- $= m(s_2 - s_1) - \frac{Q_L}{T_{\text{amb}}} = 0$
- $Q_L = -2649 \text{ kJ}$
- Diagram of a control volume with heat input Q_H and heat output Q_L , and work output $W = ?$.

So, Q_L as per this equation is minus 2649 kilo Joule. So, this was the ambient, if the ambient is absorbing and amount of heat Q_L , then the surrounding is losing an amount of it minus Q_L . So, this is that Q_L over here. So, this is the heat, this Q_L is the heat going into the system, because Q_L is negative it means that this sign this arrow is actually correct anyway, this is the sign convention that we have used to evaluate this part.

So, evaluate this particular equation. This as we have discussed several times in the previous problems this is the delta s of the total system. When Q_L is positive more over Q_H is like this. So, then what is W ?

(Refer Slide Time: 10:08)

The software window on the left shows the following code:

```

p1 = 10000; t1 = 700; V11 = 0.1; v1 = volume(Steam, T = T1, P = P1);
mass = V11/v1;
u1 = IntEnergy(Steam, T = T1, P = P1);
s1 = entropy(Steam, T = T1, P = P1);

x2 = 0; P2 = p1;
v2 = volume(Steam, P = P2, x = x2);
u2 = IntEnergy(Steam, P = P2, x = x2);
s2 = entropy(Steam, P = P2, x = x2);

Q12 = mass*(u2 - u1) + W12;
W12 = mass*(v2 - v1)/p1;
Qh = -Q12 "Sign conventions"
mass*(s2 - s1) - Qh/(303.16) = 0

W = Qh + Ql
    
```

The handwritten notes on the right include a schematic of a control volume (HE) with heat input Q_H and heat output Q_L . The energy balance is given as:

$$\Delta S_{\text{tot}} = \Delta S_{\text{sys}} + \Delta S_{\text{surr}} = m(s_2 - s_1) - \frac{Q_L}{T_{\text{amb}}} = 0$$

From this, $Q_L = -2649 \text{ kJ}$ is determined. The work output is then calculated as $W = 2999 \text{ kJ}$.

So, as per the sign convention Q_h and Q_l are both positive and W will then simply be Q_h plus Q_l .

(Refer Slide Time: 10:15)

The results window in the software shows the following values:

Unit	Settings	S	C	kPa	kJ	mass	deg	
Qh	mass	= 2.294	p1	= 10000	P2	= 10000	Q12	= -5647
W	Qh	= 5647	Ql	= -2649	s1	= 7.169	s2	= 3.36
W	t1	= 700	u1	= 3434	u2	= 1393	v1	= 0.0436
W	v2	= 0.001452	V11	= 0.1	W	= 2999	W12	= -966.7
W	x2	= 0						

Additional text in the results window: "6 potential unit problems were detected. Check Unit" and "Calculation time = 16 ms".

So, W comes out to be 2999 kilo Joule, that is the answer. So, in this; so, in both of the problems that we discussed a moments a few moments ago in this particular problem, one has to be very careful about what control mass what control volume we are choosing. For one control volume if the heat absorbed is positive; then obviously, for the

other control volume it is losing that amount of heat maybe. So, in this particular case this control mass was losing an amount of heat Q_h .

But that amount of heat lost is gained by the heat engine; hence we had this particular equation ok. Then if for this entire control volume we had some amount of heat entering into the control volume Q_l , then the reservoir is actually losing an amount of heat. So, the reservoir has a heat transfer of minus Q_l , which is appearing in the entropy equation. So, minus Q_l by T_{ambient} is the Δs for the surrounding, this is the entropy change for the system m into s_2 minus s_1 .

So, combining this, we have Δs of the system which is 0, because the overall process is set to be reversible there is no entropy generation in the entire process. The entire process is free of any entropy generation; and hence we could find out, what this final heat transfer should be? See, because in this particular control volume the only interactions are heat and work. This thing is internal and hence it does not figure, whatever is there inside the control volume is only water it is changing state from 1 to 2.

So, the change in entropy of water is known because, entropy is a state property we do not need to bother how that water went it is a constant pressure process, we do not need to really bother about that. As soon as I know states 1 and 2 I know what the change in the entropy of the water is. Now, because there is a heat transfer heat interaction with the ambient, this particular this particular sign means, if the system is absorbing an amount of heat Q_l . Then the reservoir is losing an amount of it minus Q_l .

Hence it comes over here that gave us Q_l and once that is known I can now take only this thing as the control volume the heat engine. So, for the heat engine you have Q_h going into the system which is basically minus of Q_l , because of the reasons we just discussed that, heat lost by the mass is heat gained by the heat engine. So, because of this Q_h is like this Q_l we just found out using the sign convention as like this minus 2649 and this if we consider the heat engine as the control volume, the work is nothing but Q_h plus Q_l and that is what we did. Please do this problem on your own try to understand which control volume is to analyze here we analyzed H_2O first, the whole system of the surrounding second and then the heat engine third.

Using this we were able to find out the work output of this particular heat engine this is the work done by the system, because as per convention work is coming out of this

control volume ok, work is coming out of this control volume. So, with this we stop here we conclude this particular example and I hope you will go through similar problems and try to have an intuition of which control mass, control volume to take to solve the various problem.

It is all very conceptual there is nothing fantastical about this the problem has to be first conceptualize and then you can just fix the values it does not matter how you fix the values you can use a table you can use a computer. The computer is very convenient, because you do not have to interpolate, you do not have to think about what the values will be. So, with this we conclude this session and I will be back next time with another question.

Thank you.