Engineering Thermodynamics
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Lecture 36
Entropy balance in closed system and control volume

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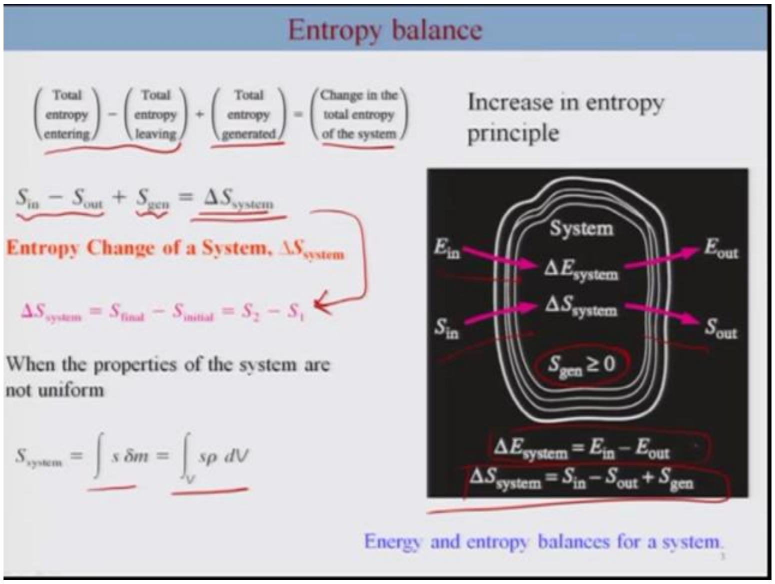

Entropy balance

$$\begin{pmatrix}\text{Total}\\ \text{entropy}\\ \text{entering}\end{pmatrix} - \begin{pmatrix}\text{Total}\\ \text{entropy}\\ \text{leaving}\end{pmatrix} + \begin{pmatrix}\text{Total}\\ \text{entropy}\\ \text{generated}\end{pmatrix} = \begin{pmatrix}\text{Change in the}\\ \text{total entropy}\\ \text{of the system}\end{pmatrix}$$

$$S_{in} - S_{out} + S_{gen} = \Delta S_{system}$$

Entropy Change of a System, ΔS_{system}

$$\Delta S_{system} = S_{final} - S_{initial} = S_2 - S_1$$

When the properties of the system are not uniform

$$S_{system} = \int s\,\delta m = \int_V s\rho\, dV$$

Increase in entropy principle

$$\Delta E_{system} = E_{in} - E_{out}$$

$$\Delta S_{system} = S_{in} - S_{out} + S_{gen}$$

Energy and entropy balances for a system.

Ok welcome back, so in this particular lecture we are going to look at the Entropy Balance for various system. So as we know that your delta as for an isolated system that is change in entropy for an isolated system is greater than or equal to zero. For the case of the case of a reversible, off course delta change in eh entropy is going to be zero but for other cases it always increasing. Thus isolated system is said to be always increasing entropy or in another word for the case of a universe which we can consider to be an isolated system, the entropy keeps increasing all the time.

So we can write this more formally which we call as a increase in entropic principal. The change in the entropy of the system is due to the total entropy or net entropy transfer from the surrounding plus the total energy generated due to any irreversibility. Ok, or in another word we can write this S in minus S out plus any generation term, this would be the total entropy change of the system. Ok and total entropy system is nothing but S2 minus S1 because this is a state function or the property of the system.

Ok, in case the property of the system are not uniform, you make use of integral or the small volume or mass of the system and you can write this expression as we have written for any other properties ok. So thus we can depict this entropy balance in the following form that you have a system which is depicted in this form and here your energy is shown as in and out and as well as the entropy transfer in and as well as out and this there is a generation of entropy which is more than or equal to zero ok, thus you can write this in this form as I already mentioned.

So this is entropy balance and this would be your energy balance, ok, so energy cannot be generated or created, thus you have a state volume, there is not e generation term here, on the other hand the entropy can be generated due to the irreversibility.

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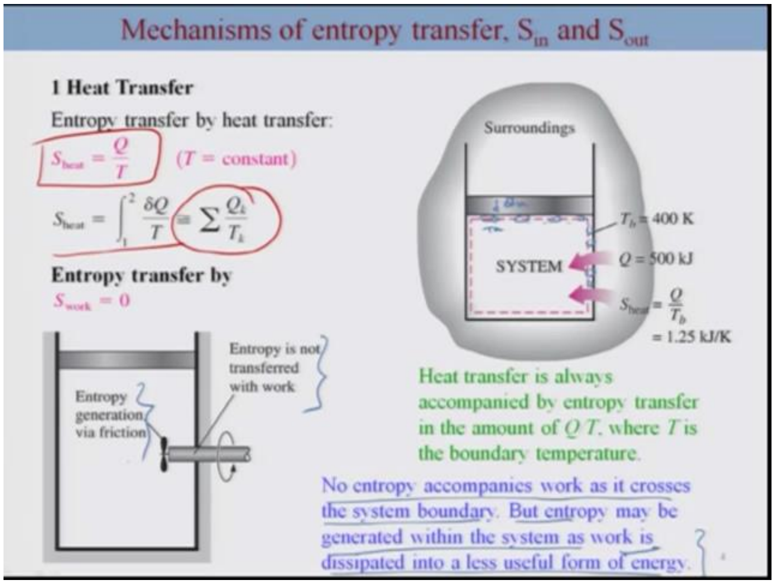

Mechanisms of entropy transfer, S_{in} and S_{out}

1 Heat Transfer

Entropy transfer by heat transfer:

$$\boxed{S_{heat} = \frac{Q}{T}} \quad (T = \text{constant})$$

$$S_{heat} = \int_1^2 \frac{\delta Q}{T} \cong \sum \frac{Q_k}{T_k}$$

Entropy transfer by

$S_{work} = 0$

Heat transfer is always accompanied by entropy transfer in the amount of Q/T, where T is the boundary temperature.

No entropy accompanies work as it crosses the system boundary. But entropy may be generated within the system as work is dissipated into a less useful form of energy.

So what are the mechanism of the entropic transfer? So let us first look at it, there are two mechanism, one due to the heat transfer and the other mechanism is due to the mass transfer, so that would be for the case of open system ok. So let me just first look at the heat transfer, so as we already mentioned earlier that the entropy transfer by heat can be written as in this form, ok or in another word this is what we assume it to be reversible case.

So as heat is nothing but it can be written as in terms of Del cube Qt and for example if this is a system and if there is a heat transfer from the surrounding then this also can be approximated that various part, there is a small you know Q k coming from this different part of this boundary and a cross (())(3:00) temperature is Tk and this can be approximated as sum of all possible transfer in this way, ok.

We have already (me) mentioned the entropy associated with the work interactions are as zero, ok, in other word, entropy is not transferred with work, so there is a entropy transfer due to the heat and later we are going to talk about the particular case where with mass work and also transfer the entropy. So no entropy accompanies work as it crosses the system boundary but entropy maybe generated within in the system, as work is dissipated into less useful form of the energy. So when the work is transferred to the internal energy that due to the deception into less useful form, this particular aspect can generate the entropy within the system.

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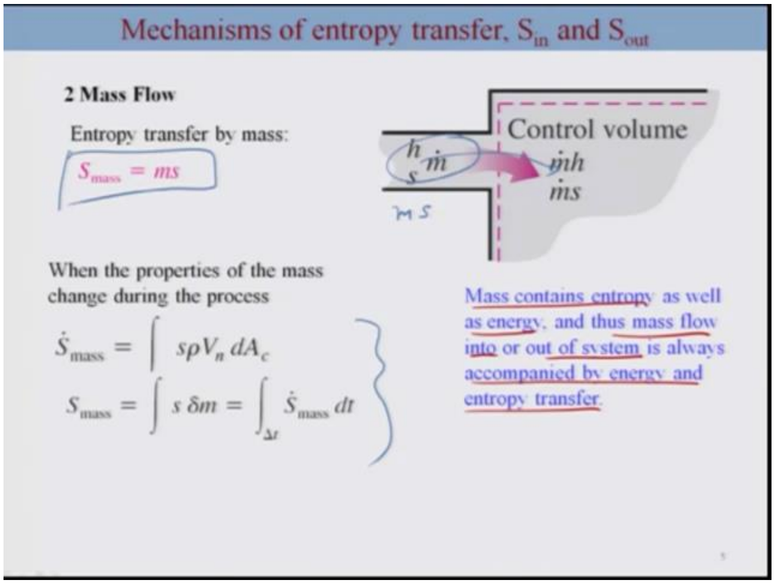

Mechanisms of entropy transfer, S_{in} and S_{out}

2 Mass Flow

Entropy transfer by mass:

$$\boxed{S_{mass} = ms}$$

When the properties of the mass change during the process

$$\left.\begin{aligned}\dot{S}_{mass} &= \int s\rho V_n \, dA_c \\ S_{mass} &= \int s \, \delta m = \int_{\Delta t} \dot{S}_{mass} \, dt\end{aligned}\right\}$$

Mass contains entropy as well as energy, and thus mass flow into or out of system is always accompanied by energy and entropy transfer.

Ok, so let me look at the second aspect that is mass flow entropy transfer due to the flow of mass in the control volume is nothing but simply M mass multiplied by and occupy with mass cross point to the, this is simply the entropy due to the mass, ok and if the properties are not constant that means they are changing during the process then we make use of the definition as we have done for other properties you know during the discussion of control volume. So thus your mass contains entropy as well as energy and thus mass flow in and out of the system is always accompanied by energy and entropy transfer.

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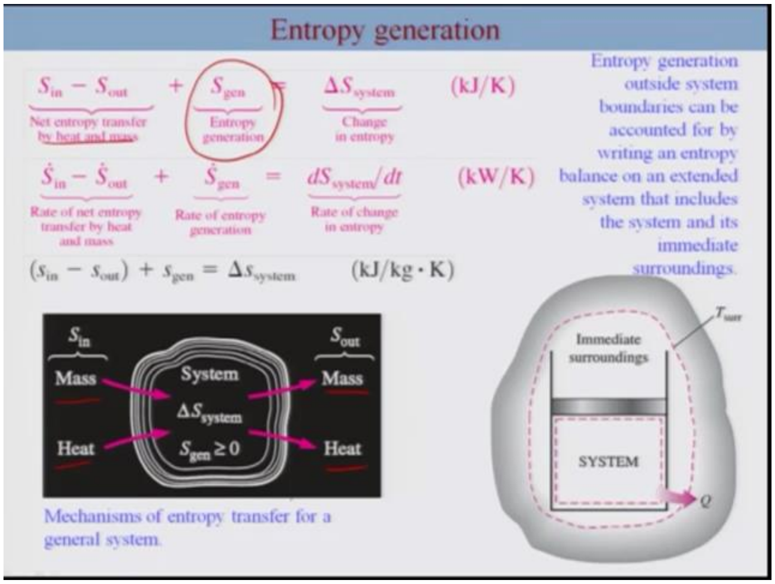

Entropy generation

$$\underbrace{S_{in} - S_{out}}_{\text{Net entropy transfer by heat and mass}} + \underbrace{S_{gen}}_{\text{Entropy generation}} = \underbrace{\Delta S_{system}}_{\text{Change in entropy}} \qquad (\mathrm{kJ/K})$$

$$\underbrace{\dot{S}_{in} - \dot{S}_{out}}_{\text{Rate of net entropy transfer by heat and mass}} + \underbrace{\dot{S}_{gen}}_{\text{Rate of entropy generation}} = \underbrace{dS_{system}/dt}_{\text{Rate of change in entropy}} \qquad (\mathrm{kW/K})$$

$$(s_{in} - s_{out}) + s_{gen} = \Delta s_{system} \qquad (\mathrm{kJ/kg \cdot K})$$

Entropy generation outside system boundaries can be accounted for by writing an entropy balance on an extended system that includes the system and its immediate surroundings.

Mechanisms of entropy transfer for a general system.

So now you can summarise this the entropy generation that you have S in and out, this is due to the entropy transfer by heat and mass and then you have is S entropy generation ok and that will be your delta S system, you can write this in terms of rate expression ok, and thus you can pictorially show in this form that S in is due to the mass due to the heat ok, S out is off course also may be due to the mass out and heat transfer from the system to surrounding and your delta S is greater or less than zero ok.

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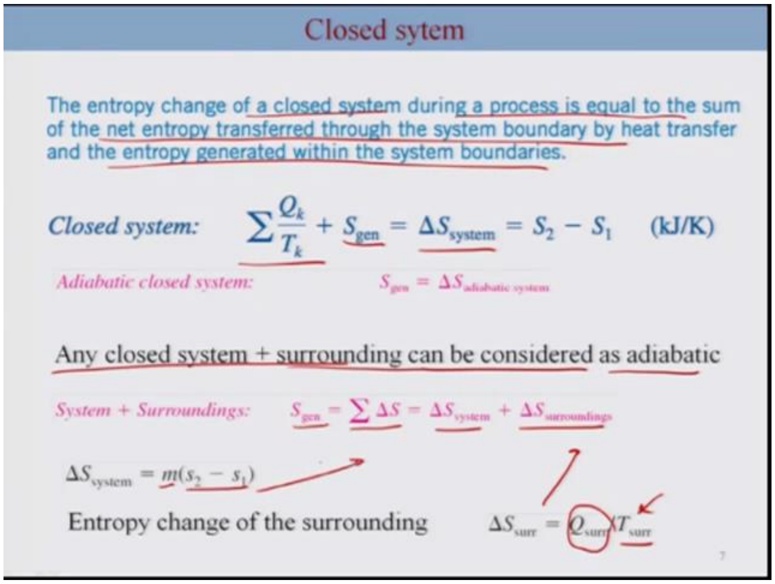

Closed sytem

The entropy change of a closed system during a process is equal to the sum of the net entropy transferred through the system boundary by heat transfer and the entropy generated within the system boundaries.

Closed system: $\sum \frac{Q_k}{T_k} + S_{gen} = \Delta S_{system} = S_2 - S_1 \qquad (\mathrm{kJ/K})$

Adiabatic closed system: $S_{gen} = \Delta S_{adiabatic\ system}$

Any closed system + surrounding can be considered as adiabatic

System + Surroundings: $S_{gen} = \sum \Delta S = \Delta S_{system} + \Delta S_{surroundings}$

$\Delta S_{system} = m(s_2 - s_1)$

Entropy change of the surrounding $\Delta S_{surr} = Q_{surr}/T_{surr}$

Now we can specifically look at a close system and later we going to look at the control volume or open system. For a close system your mass contribution is zero, the entropy change is only due to the heat transfer or heat interaction. So the entropy change of a close system during a process is equal to the sum of the net transfer through the system boundary by heat transfer and the entropy generated within the system boundary.

Ok, in other word, this is entropy generated due to the heat interaction plus the generation term that would be the change in the entropy of the system. For the case of adiabatic close system that means your Q's are zero, your S generation is simply delta S system, so any close system plus the surrounding can be considered adiabatic. Ok, so that means you can consider any differential change from the system boundary to the surrounding where the temperature raise the temperature grading and you can consider completely your surrounding as well to make it adiabatic.

In that case you can write as generation nothing but as we already mentioned earlier that this can be written as a sum of all sub system that can be written as now delta S system plus surrounding ok, that would be the S generation of this particular combined closed system or the system plus surrounding.

Delta S system is nothing but your mass time the change in the entropy in mass in it ok. Thus and as well as the entropy changes the surrounding can be written as simply your delta S surrounding is equal to Q surrounding by T surrounding considering it to be constant. Ok, so this is the simple expression of your entropy generation, so you can plug this information to obtain the S generation of the system plus surrounding.

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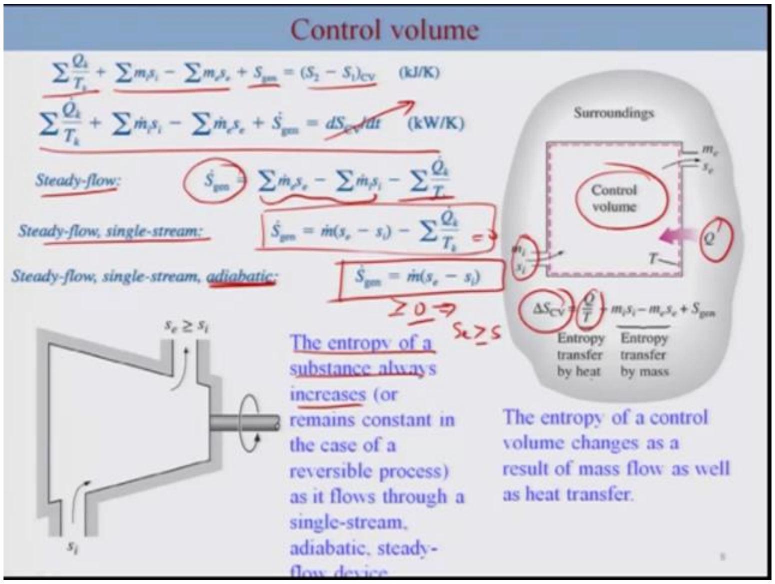

Control volume

$$\sum \frac{Q_k}{T_k} + \sum m_i s_i - \sum m_e s_e + S_{gen} = (S_2 - S_1)_{CV} \quad \text{(kJ/K)}$$

$$\sum \frac{\dot{Q}_k}{T_k} + \sum \dot{m}_i s_i - \sum \dot{m}_e s_e + \dot{S}_{gen} = \cancel{dS_{CV}/dt} \quad \text{(kW/K)}$$

Steady-flow: $\dot{S}_{gen} = \sum \dot{m}_e s_e - \sum \dot{m}_i s_i - \sum \frac{\dot{Q}_k}{T_k}$

Steady-flow, single-stream: $\boxed{\dot{S}_{gen} = \dot{m}(s_e - s_i) - \sum \frac{\dot{Q}_k}{T_k} = 0}$

Steady-flow, single-stream, adiabatic: $\boxed{\dot{S}_{gen} = \dot{m}(s_e - s_i)}$

$\geq 0 \Rightarrow$ $s_e \geq s$

The entropy of a substance always increases (or remains constant in the case of a reversible process) as it flows through a single-stream, adiabatic, steady-flow device.

The entropy of a control volume changes as a result of mass flow as well as heat transfer.

$\Delta S_{CV} = \frac{Q}{T} + m_i s_i - m_e s_e + S_{gen}$

Ok, so for the case of a control volume you have to also consider due to the transfer, due to the heat, entropy transfer due to the heat and as well as entropy transfer due to the mass ok, so that will be in addition to the entropy transfer by heat, so you have to also include the mass contribution, as well as the heat contribution.

So thus you can write this expression of the control volume the change in the entropy of the control volume, ok which is here. As due to the heat interaction and due to the mass interaction that means your inlet minus outlet plus the generation. Ok, you can write this expression in terms of rate for the case study flow you this the Scv by dt is going to be zero and thus your S generation can be written as your exit entropy due to mass minus inlet minus the heat contribution or the entropy due to the heat interaction.

For the case of a single stream you can write this much simpler expression, ok, you can take one single and this is can be written as this and if it is a adiabatic that means this expression is zero, so this is zero for adiabatic and thus your S generation is simply entropy of the exit stream minus entropy of the inlet stream, that will be S generation. Ok, so that is the way to look into this aspect of entropy, so thus from this analysis, so entropy of the substance always increase or remain constant in the case of a reversible process as it flows through a single stream adiabatic steady flow.

So this tells you that entropy is going to be greater than equal to zero which essentially means that your Sa is going to be greater than equal to Si, ok for a steady state single process. So this is your control volume, now we can do some examples umm.

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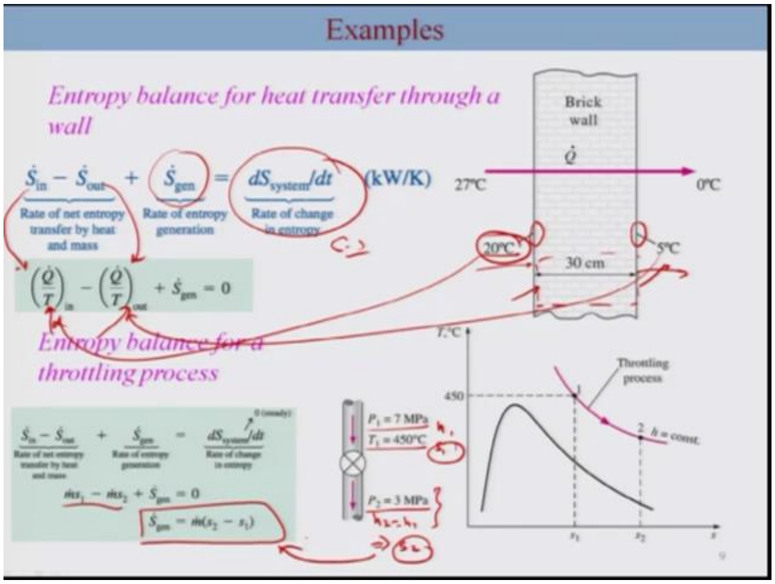

Examples

Entropy balance for heat transfer through a wall

$$\underbrace{\dot{S}_{in} - \dot{S}_{out}}_{\text{Rate of net entropy transfer by heat and mass}} + \underbrace{\dot{S}_{gen}}_{\text{Rate of entropy generation}} = \underbrace{dS_{system}/dt}_{\text{Rate of change in entropy}} \quad \text{(kW/K)}$$

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$$\left(\frac{\dot{Q}}{T}\right)_{in} - \left(\frac{\dot{Q}}{T}\right)_{out} + \dot{S}_{gen} = 0$$

Entropy balance for a throttling process

$$\underbrace{\dot{S}_{in} - \dot{S}_{out}}_{\text{Rate of net entropy transfer by heat and mass}} + \underbrace{\dot{S}_{gen}}_{\text{Rate of entropy generation}} = \underbrace{\overset{0\ (\text{steady})}{dS_{system}/dt}}_{\text{Rate of change in entropy}}$$

$$\dot{m}s_1 - \dot{m}s_2 + \dot{S}_{gen} = 0$$

$$\boxed{\dot{S}_{gen} = \dot{m}(s_2 - s_1)}$$

So let’s look at entropy balance for a heat transfer through a wall. Now we can write down the entropy general balance here, entropy transfer by heat and this is your generation, there is no mass expect here ok. So we will look at the entropy due to the heat transfer they are too expect here, so one is inlet and is another is outlet, so inlet is at so that is your in and this is your out, there is no mass contribution here, ok and this is nothing but the temperature at inlet and this is at a pressure outlet, which is in this case if you consider this to be a system here, your temperature is at the this boundary.

Ok, so this boundary temperature is 20 and this boundary temperature is 5 degree Celsius ok, and thus you will be considering Q which is going to be same and temperature here would be 20 plus 273 and here is going to be 5 degree Celsius plus 273. You can also apply simpler exercise to a throttling process, ok so this is a throttling process and you have to find again the S generation.

Ok remember this in the previous one we’ve considered this to be a steady state and hence your ds system by dt is zero. So in this throttling process the pressure and temperature for the inlet is given and the outlet is P2, ok. Now you know that your entropy is going to be constant for the throttling process, ok, so we can calculate here your H and S and here off course this going to be S2 is equal to H1, so based on that you can find out S2 from the table, ok.

Now you can look at this entropy balance here, this here this assume it to be adiabatic, so there is no contribution due to the heat transfer, the contribution is mainly due to the mass flow, so this can be written as ms1 minus ms2 because mass m dot is fixed considering single stream study flow system. Thus you can write your S generation in this form. From this analysis you can find S1 and from the conditions of P2 is equal to 3 mega pass and (S) H is constant, you can find S2 and thus you can calculate S generation for this throttling process, ok.

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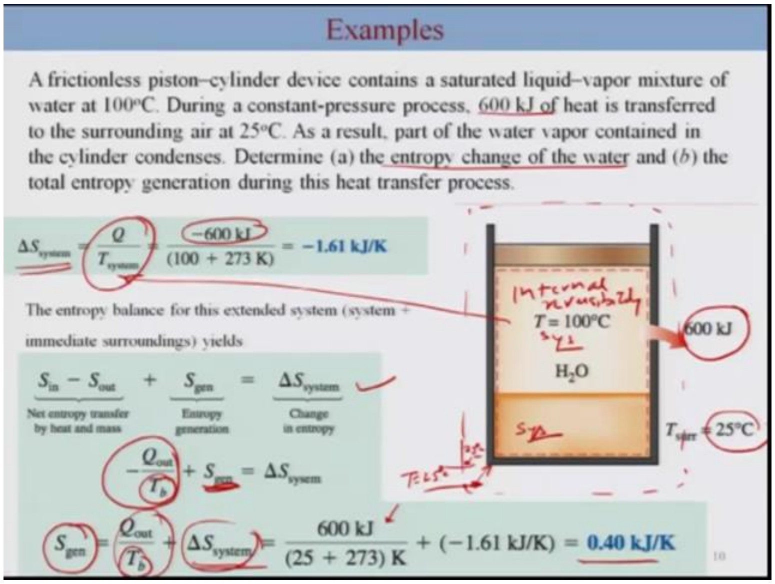

Examples

A frictionless piston–cylinder device contains a saturated liquid–vapor mixture of water at 100°C. During a constant-pressure process, 600 kJ of heat is transferred to the surrounding air at 25°C. As a result, part of the water vapor contained in the cylinder condenses. Determine (a) the entropy change of the water and (*b*) the total entropy generation during this heat transfer process.

$$\Delta S_{system} = \frac{Q}{T_{system}} = \frac{-600\text{ kJ}}{(100 + 273\text{ K})} = -1.61\text{ kJ/K}$$

The entropy balance for this extended system (system + immediate surroundings) yields

$$\underbrace{S_{in} - S_{out}}_{\substack{\text{Net entropy transfer}\\\text{by heat and mass}}} + \underbrace{S_{gen}}_{\substack{\text{Entropy}\\\text{generation}}} = \underbrace{\Delta S_{system}}_{\substack{\text{Change}\\\text{in entropy}}}$$

$$-\frac{Q_{out}}{T_b} + S_{gen} = \Delta S_{sysem}$$

$$S_{gen} = \frac{Q_{out}}{T_b} + \Delta S_{system} = \frac{600\text{ kJ}}{(25 + 273)\text{ K}} + (-1.61\text{ kJ/K}) = 0.40\text{ kJ/K}$$

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So let me end this lecture with this example, so this is an example of a frictionless piston cylinder which contains a saturated liquid vapour mixture of water at 100 degree Celsius and during a constant pressure process 600 kiloJoules is transferred to the surrounding at 25 degree Celsius. As a result part water vapour contain in the cylinder condenses ok, because you have taken out the heat from the system.

What we have to find out is entropy change of the water that is the first question which because very simple, if you consider this to be your system, so this is your system ok and what we are going to consider that there is no irreversibility within the system and thus you can clearly write your delta S system is due to the heat interaction ok and which will be simply your Q divided by T of system. Ok, so this we are going to consider based on internal reversibility ok.

Now in order to find out the total entropy generated we would be considering slightly region outside the system which will include the immediate surrounding where the irreversibility is associated with and where you have the temperature gradient for that matter ok, because of the temperature gradient from 100 degree Celsius and outside is 25, so irreversibility is associated within here ok, and thus when you have considering this extended system, which includes the system plus immediate surrounding, this entropy balance can be written in this way which is a general entropy balance and here you will be considering Q out because Sn is zero, the Q out is due to the heat transfer will be at, Q out at the boundary plus the generation which terms within this particular extended system.

So this is the same term which we have used earlier, the only difference is in terms of T, ok T is at the boundary. So earlier what we have done is when we calculate the system we have considered T as for the system but now here when you consider the external system, we are considering the boundary temperature at which your T is 25 degree Celsius, we are assuming this temperature here is also at the boundary is 25 degree Celsius ok. This expression is nothing but 600 kiloJoules divided by 25 degree Celsius that means 25 plus to 73 ok. So with this rearrangement you can calculate S generation which would be this term plus your delta S of the system which we have already calculated earlier and thus you have final expression as this.

So the key to solve this problem is clearly that the assumption that we have made, the inter reversibility for the system and by considering the extended system plus surrounding include the entropy associated with the outside the system that is around the boundary between the system and the surrounding ok, that is the region where the temperature gradient is there. this is kind of an example where you can take this message and apply to other kind of systems. So we will be ending this particular lecture now with this and we will try to summarise what we have gone through this particular module.

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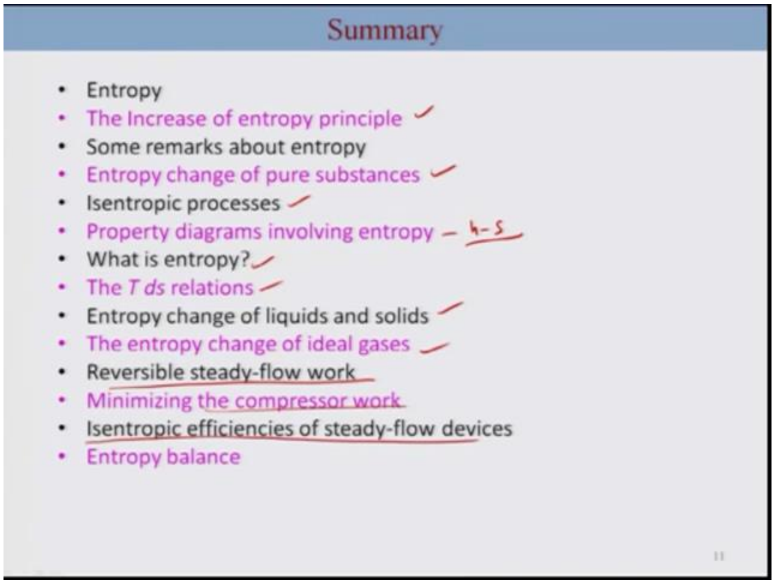

Summary

- Entropy
- The Increase of entropy principle
- Some remarks about entropy
- Entropy change of pure substances
- Isentropic processes
- Property diagrams involving entropy – h-s
- What is entropy?
- The *T ds* relations
- Entropy change of liquids and solids
- The entropy change of ideal gases
- Reversible steady-flow work
- Minimizing the compressor work
- Isentropic efficiencies of steady-flow devices
- Entropy balance

So we have looked into the definition of entropy understand the increase of entropy principal which means entropy is generated and all the time it increase if not remain constant. We made remarks of entropy in terms of what are the reasons for irreversibility ok, we talked about entropy change of pure substances and Isentropic process where entropy is constant, property diagram such as H (F) S where it becomes very useful to describe the process where the entropy is involved ok.

We also looked into the molecular behaviour of entropy, the relations such as T ds in terms internal energy or changes or the enthalpy changes, entropy change for liquid and solid we have looked into and particularly for the ideal gas and once we looked into the idea gas, we also drive the reversible steady flow work and specifically how to minimize a compressor work by considering inter cooling in the middle stage of the compression.

And in the end we compare the efficiency of the steady flow (device) (by) defining Isentrophy efficiency and in this particular lecture we looked into the entropy balance derived the expression or demonstrated how to calculate the S generation of a particular processes ok. So with that we will end this particular lecture and in the next lecture we are going to take up another topic ok, so I will see you in the next lecture.