Basic Thermodynamics

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Lecture – 12

Second Law and Available Energy – III

Good morning. I welcome you to this session. In the last session, we discussed the concept of availability and the conservation of availability or the availability balance in a closed system. We recognized that the availability is not conserved the way energy is conserved which means that if you take the accountability of the energy interactions and the change of energy within the system which is defined as internal energy, we see that energy is neither created nor destroyed. The total amount of energy at the beginning of a process becomes exactly equal to that at the end of a process. It is not so for the availability or exergy. We see that exergy is destroyed in all natural processes, because of the irreversibility.

If the process is reversible then the exergy is conserved. Otherwise, in a natural process which always has irreversibility, exergy is destroyed. The amount of destruction of exergy equals to the irreversibility of the process which was defined quantitatively, as the entropy generation or change of entropy of the universe times the fixed reference temperature of the environment. That is the irreversibility.

So, this we recognized for a closed system. Today, we will discuss the same thing for an open system and there are also, as one of you mentioned, I will discuss parallely, what is the entropy balance for a closed and open system. To do that, let us again recapitulate what we did last class hurriedly, just in brief not fully that we will reduce just information we gathered in the last class or last session.

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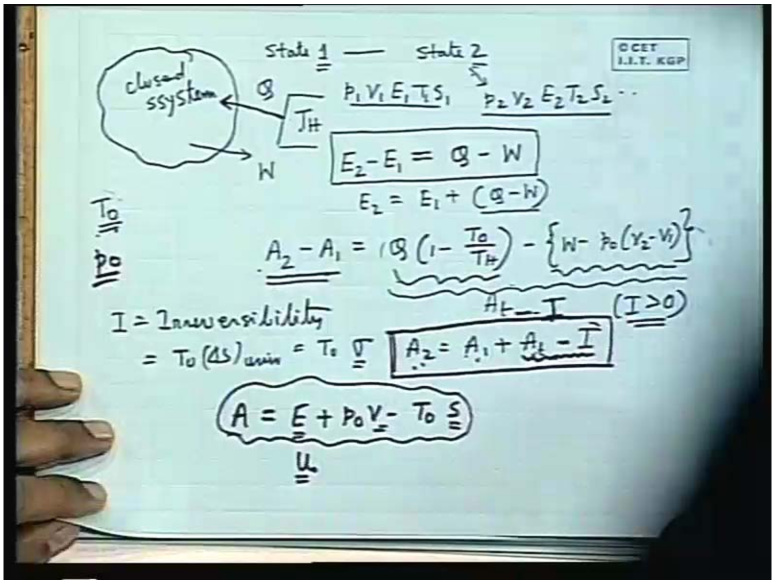

State 1 — State 2

$p_1 V_1 E_1 T_1 S_1$ $p_2 V_2 E_2 T_2 S_2 \cdots$

$$\boxed{E_2 - E_1 = Q - W}$$

$$E_2 = E_1 + (Q - W)$$

$$A_2 - A_1 = \underbrace{Q\left(1 - \frac{T_0}{T_H}\right) - \left\{W - p_0(V_2 - V_1)\right\}}_{A_t - I} \quad (I > 0)$$

I = Irreversibility $= T_0 (\Delta S)_{univ} = T_0 \sigma$

$$\boxed{A_2 = A_1 + A_t - I}$$

$$\boxed{A = \underset{U}{E} + p_0 V - T_0 S}$$

What I have told, if there is a closed system and if it goes from equilibrium state one to another equilibrium state two, during which it interacts with the surrounding in the form of heat received. Let us consider, the heat is received from a thermal reservoir at temperature $T_{H,}$ where, the environment temperature is T_0 which is a fixed undisturbed surrounding. This environment word is used in thermodynamics, distinguishing it from surrounding. Surrounding is that part of the environment with which a system interacts in; that means that in case of two interacting systems, one is the surrounding of the other, but environment is the rest part of the surrounding which is undisturbed in the process. That is the environment which is at a temperature $T_{0,}$ based on which we calculate the exergy or availability.

Let us consider the system develops some work W which we already considered in the last class. If it goes form state one to state two and if we designate all the properties like pressure, volume, then internal energy $E_{1;}$ we consider E. If it contains some movable particles that means kinetic energy, also potential energy with respect to a referenced datum, so, that we consider as a whole the internal energy not only the intermolecular energy. T_1 S_1 and correspondingly, the state two is p_2 V_2 E_2 T_2 S_2 and so on, and all the properties at state one and state two.

Again, recapitulating the fact that conservation of energy tells, that the change in energy stored within the system, that internal energy is equal to the total energy received by the system.

Here, we do not care where the Q is coming from, from which temperature. We are only concerned with the amount of Q which is coming. This is purely the energy balance and our classical statement of conservation of energy or first law; that means the change in internal energy equals to the net amount of energy received by the system in the form of heat and work. That means the final energy E_2 of the system will be denoted accordingly like that. It will increase or decrease depending upon whether this is plus or minus so that there is a net energy inflow or outflow from the system. But the mass is constant. That is the definition of the closed system.

What about the availability? If you do the availability balance, we know that if A which was defined earlier. A_2 is the availability of the system at state two. Then if availability could have been conserved or availability was neither destroyed or nor created the way energy the energy quantities do. We could have written that the change in availability equals to the availability added to the system; that means, the availability associated with this heat. From a thermal reservoir at T_H with respect to exergy environment temperature or reference environment temperature Q is 1 minus T.

This is the availability which has come into the system with Q minus the availability which has gone out. This will be W minus the work which is loss in comprising the surrounding. This is the net availability coming out and this is the net availability coming in. So, this could have been like this, but we have seen that this change is not equal to this; rather, this is minus I, where I is greater than 0 which is the irreversibility. I is equal to irreversibility and is defined as T_0 into delta S $_{\text{universe,}}$ or T_0 into sigma entropy generation.

What is this? Delta is entropy change of the universe or entropy generation in this process, by which the system goes from state one to state two by interacting with surrounding in the form of heat and work. Therefore, we see the change in the availability is not equal to the net availability transfer; that means, the availability A_2 should be A_1 plus A_t minus I. This is the basic equation for the availability transfer.

Here, one thing you have to understand. We see that entropy of the universe increases, but not that entropy of a system. It may increase or it may decrease depending upon the conditions. Similarly, the availability, the total availability is reduced or destructed, but the system availability may increase or may decrease. Here, A_2 may decrease or A_2 may increase depending upon the relative magnitude of A_t and I. A_t is the total availability transfer.

In the case availability transfer is positive and it is more than the availability destroyed then obviously A_2 will increase. A_2 may increase or decrease depending upon the relative magnitude of this quantity. When there is a net inflow of availability to the system that are transferred in then definitely A_2 will increase, provided the destruction is less. But its increase will not be equal to A_1 plus A_t, but A_1 plus A_t minus some quantity; that means, the availability is destroyed in the process. Whether the system gains in availability or reduces or decreases in availability, but this change in availability will not be equal to the total availability transfer, but with a quantity minus I which is the availability destroyed.

This we discussed in the last class, how we proved it. We first proved that what the availability function at any state is. This availability function or availability is defined as E plus p_0 V minus T_0 S where S V E are the properties of the system; that is, the internal energy, volume and entropy, and p_0 T_0 are temperature of the surrounding.

In case of a stationary system, these E quantities will be substituted by u that is intermolecular energy. Stationary system means where we consider that the kinetic energy is 0. Also, if we consider the change as in potential energy to be negligible then E can be replaced as u. This is known as the availability function or simply availability refers to a single state. First, we proved this from the concept of availability by its definition; then we proved that availability is destroyed in a closed system.

The same thing we will discuss, now for an open system, but before that I feel as you have pointed out rightly, side by side we should write the equation for entropy.

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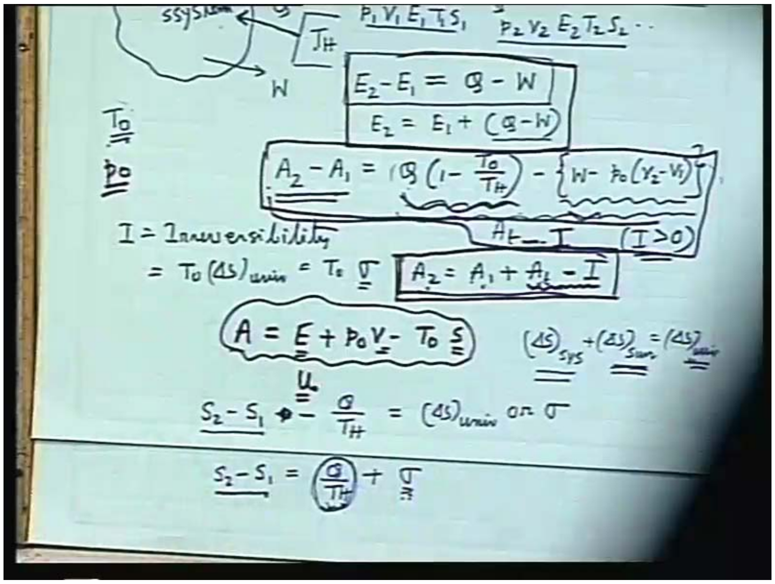

$P_1 V_1 E_1 T_1 S_1$ $\quad$ $P_2 V_2 E_2 T_2 S_2 \cdots$

$$\boxed{E_2 - E_1 = Q - W}$$

$$E_2 = E_1 + (Q - W)$$

$$\boxed{A_2 - A_1 = Q\left(1 - \frac{T_0}{T_H}\right) - \left\{W - p_0(V_2 - V_1)\right\}} = A_t - I \quad (I > 0)$$

I = Irreversibility

$$= T_0 (\Delta S)_{univ} = T_0 \sigma$$

$$\boxed{A_2 = A_1 + A_t - I}$$

$$A = \underset{U}{E} + p_0 V - T_0 S$$

$$(\Delta S)_{sys} + (\Delta S)_{sur} = (\Delta S)_{univ}$$

$$S_2 - S_1 - \frac{Q}{T_H} = (\Delta S)_{univ} \text{ or } \sigma$$

$$S_2 - S_1 = \frac{Q}{T_H} + \sigma$$

Now, This is the equation for energy balance. This is the equation for availability balance including this I. This is the availability balance, or we can see this where A_t is this minus this net availability transferred in. So why not side by side we write the entropy equation. That is why this question which one of you asked me sir entropy flow and all these things will be sorted out.

Now, in case the entropy equation, we can write as S_2 minus S_1 minus Q by T_H is equal to delta S $_{universe}$ or whatever. You can write, sigma S_2 minus S_1 is the change of entropy of the system. This we can consider as in this side, Q by T_H plus sigma. You see that the change of entropy of the system does not equal to Q by T_H. This Q by T_H is actually, if you follow this classical reversible thermodynamics terminology delta S $_{system}$ plus delta S $_{surrounding}$ is delta S $_{universe}$ which is nothing but the entropy generation. So, this is delta S $_{surrounding}$.

Q by T_H can be considered as an entropy flow to the system. This can be considered as an equivalent entropy flow of the system. If we consider this, then we see from this equation, the increase in entropy is not equal to the entropy flow of the system; that means, the entropy is also not conserved the way energy is conserved, rather it is conserved the way exergy is conserved. That means exergy is destroyed and entropy is created.

You see, somewhere we have gained and somewhere we have lost. The usefulness is reduced, but the unusefullness is increased; that means, we do not want an increase in entropy. Entropy is increased, but availability is reduced. Then they are linked. Because of the increase in the entropy, the availability is reduced. You understand the total entropy. That means, if you consider an entropy, an entropy reservoir and entropy bank you consider; an exergy reservoir and exergy bank of the universe. While the entropy bank is increased, the amount of entropy is increased. Due to any natural processes encountered day to day, the availability bank or reserve in the availability is destroyed.

We see that the increase in entropy of the system is more than the entropy which is received. If we consider this in terms of the entropy received plus the entropy production, or entropy generation which is nothing but the delta S $_{\text{universe}}$, and earlier also, I have shown that three equations simultaneously. The same form where we can recognize, one is delta S $_{\text{system,}}$ another is delta S $_{\text{surrounding}}$, or entropy flow to the system that becomes equal to the sigma is equal to the total change in the entropy of the universe or the entropy generation. This is the closed system entropy balance.

For an open system, things will little change because of the mass flux across the system boundary. The energy balance, the availability balance and the entropy balance of a closed system; these are given by this equation. We see whether energy quantity remains constant. The availability and the entropy quantity are not constant. Availability is reduced and entropy is increased. Now, we come to the same thing for an open system.

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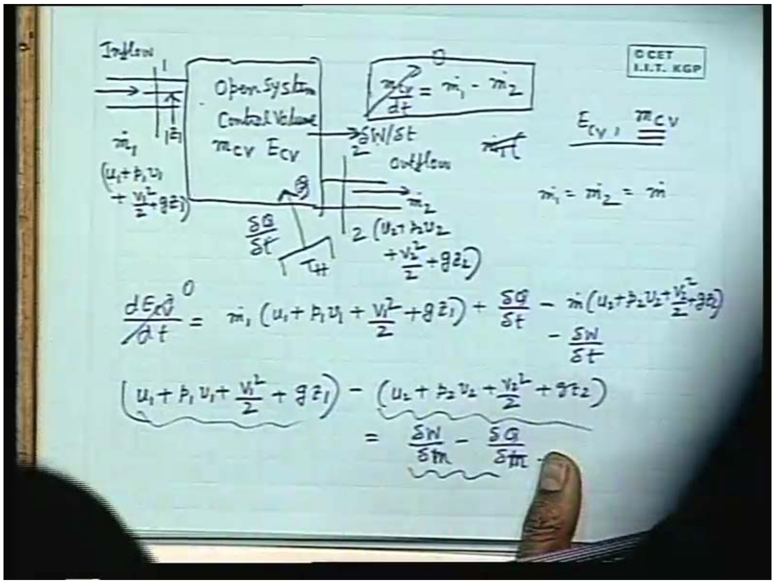

Let us consider an open system or a control volume. Let us consider one single stream of inflow and outflow. Let us consider this is inflow and let us consider this as outflow. The only difference is that there is a continuous inflow and continuous outflow. Since an open system always operates in this way, there is a continuous inflow and continuous outflow. So, that is why open system is a continuous system. So, things are always analyzed in terms of the rate process.

Therefore, I first designate section one and section two, the way I designated state one state two for a closed system. For the open system one two, I designate everything in terms of the rate that means dot. dot means the derivative with respect to time. m_1 dot is the rate at which mass enters the open system. Similarly, here the specific values of these properties are required. Internal energy, as we have already seen that u_1 plus p_1 v_1 plus V_1 square by 2 plus gz_{1}; z_1 is the elevation measured from any reference datum. Then this quantity represents the total energy per unit mass associated with the flowing stream. It is a repetition that it is the internal energy, this is the flow of work, this is the kinetic energy and this is the potential energy.

That means when this flux is introduced into the open system, along with this flux, this amount of specific energy that is flow energy, sometimes we call it as energy flow, is being introduced into the open system. Similar is the case here, if we write that m_2 dot is the mass flow rate then we can write the similar way, this quantity plus p_2 v_2 plus $V_{2 \text{ square by}}$ 2 plus $gz_{2.}$ This is the specific energy coming in. First is the mass balance.

To do that, we consider, in general that m_{cv} is the control volume mass and E_{cv} is the control volume energy; recapitulation of the earlier thing. So, mass balance, the conservation of mass in an open system; the way energy is conserved. The mass is neither created nor destroyed. So, that m_1 dot minus m_2 dot that equal to m_{cv} by dt; that means, the change of mass that is the first mass conservation. Then what is energy conservation? Energy conservation, if you write here then we can write m_1 dot into that is the energy. Apart from that, we can consider, the open system also interrupts energy in the form of heat and work.

Let some heat is coming to the open system Q from any reservoir T_H and let the system develops some work W. Here also, we consider in terms of the rate. del Q divided by del T_0 Q and we consider del W divided by del T; that means, this is the rate at which heat is being added and this is the rate at which work is being extracted from an open system which is usually the shaft work. Now, we make energy balance and we can write here that the change in the energy dE_{cv} divided by dt of the control volume, is nothing but the net energy coming into the control volume.

Energy is coming in two ways; one due to mass and another due to this heat and work interaction. So, what is the net coming in? One is the m_1 dot u_1 plus p_1 v_1 plus V_1 square by 2 plus g z_1 plus del Q divided by del t it is coming. What is going out is minus m_2 into u_2 plus p_2 V_2 plus v_2 square by 2 plus g z_2 minus del W del.

In case of a steady state, we consider this is zero and this is zero which is most important in case of a control volume or open system. This influx and afflux may not be same, both in terms of mass and energy. So, the property within this open system or control volume may change, but there is a steady state operation, where these properties or state variables at inflow and outflow may change because of W and Q interactions. But the total energy coming in and total energy going out, and this delta W del Q makes the things steady, which means that the properties within the system does not change with time. That is both E_{cv} and m_{cv} remains invariant with the time.

In that case what happens? m_1 dot is equal to m_2 dot; that means, the mass flow rate at inlet and outlet. That simulates this as m dot. If this is 0 and if m_1 dot m_2 dot are equal then conventionally, we write this equation, under steady flow condition in terms of the mass balance. You understand in terms of the not mass balance, in terms of per unit mass. Then we can write u_1 plus p_1 v_1 plus V_1 square by 2 plus gz_1 minus u_2 plus p_2 v_2 plus V_2 square by 2 plus gz_2 is equal to del W divided by del t minus del Q by del t. This gives you a clear picture that there is a balance between the energy transfer, because of the mass flow and because of the heat work interaction. This we started earlier. This is for the steady state. Any problem this is clear.

[Conversation between Student and Professor – Not audible ((00:20:50 min))]

Sorry. this is del m. clear, because this is the recapitulation of the earlier thing.

Along with this, we go for an availability balance. What will be the picture? Let us draw the same diagram again.

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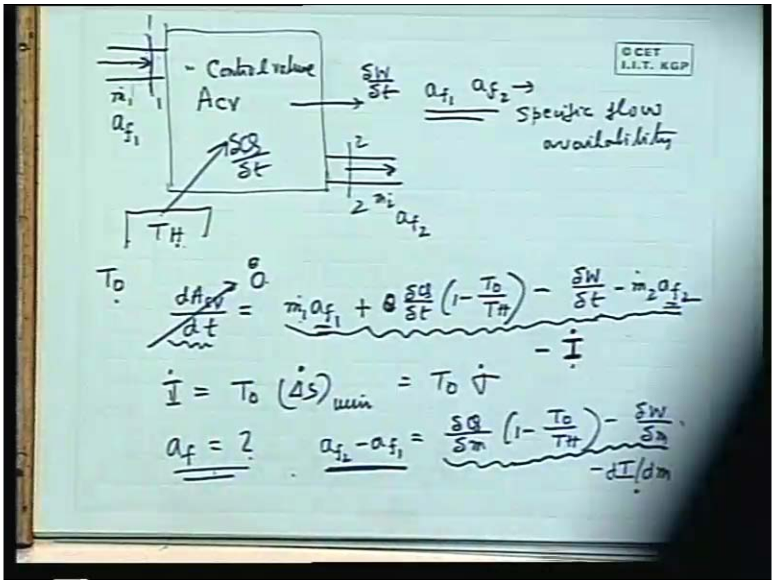

$$\cancel{\frac{dA_{cv}}{dt}}^{\,0} = \dot{m}_1 a_{f_1} + \frac{\delta Q}{\delta t}\left(1-\frac{T_0}{T_H}\right) - \frac{\delta W}{\delta t} - \dot{m}_2 a_{f_2} - \dot{I}$$

$$\dot{I} = T_0 (\dot{\Delta S})_{univ} = T_0 \dot{\sigma}$$

$$a_f = ?$$

$$a_{f_2} - a_{f_1} = \frac{\delta Q}{\delta m}\left(1-\frac{T_0}{T_H}\right) - \frac{\delta W}{\delta m} - dI/dm$$

This is control volume. Here, we will consider only the availability. Similar way, m_1 dot similar way m_2 dot, section two to section one. We know that with m_1 dot, there is an energy coming in.

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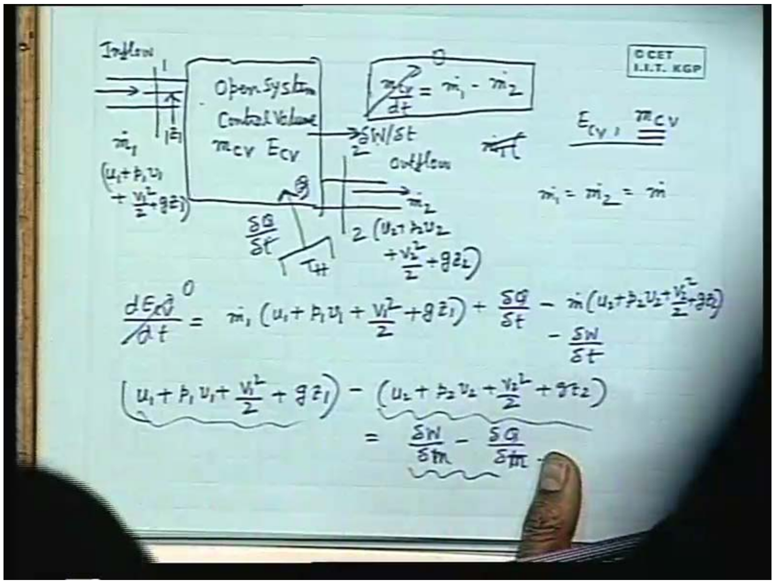

$$\boxed{\frac{\cancel{dm_{cv}}}{dt} \overset{0}{=} \dot m_1 - \dot m_2}$$

$$\dot m_1 = \dot m_2 = \dot m$$

$$\frac{\cancel{dE_{cv}}}{\cancel{dt}} \overset{0}{=} \dot m_1\left(u_1+p_1v_1+\frac{V_1^2}{2}+gz_1\right)+\frac{\delta Q}{\delta t}-\dot m\left(u_2+p_2v_2+\frac{V_2^2}{2}+gz_2\right)-\frac{\delta W}{\delta t}$$

$$\left(u_1+p_1v_1+\frac{V_1^2}{2}+gz_1\right)-\left(u_2+p_2v_2+\frac{V_2^2}{2}+gz_2\right)=\frac{\delta W}{\delta m}-\frac{\delta Q}{\delta m}$$

That is m_1 into u_1 plus p_1 v_1 plus v_1 square by 2 plus gz_1.

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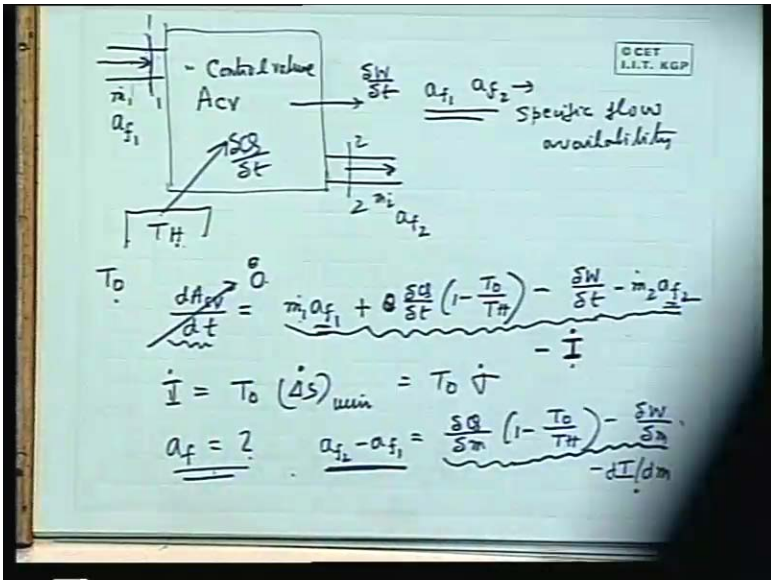

$$\frac{\cancel{dA_{cv}}}{\cancel{dt}} \overset{0}{=} \dot m_1 a_{f_1} + \frac{\delta Q}{\delta t}\left(1-\frac{T_0}{T_H}\right) - \frac{\delta W}{\delta t} - \dot m_2 a_{f_2} - \dot I$$

$$\dot I = T_0\,(\dot{\Delta S})_{univ} = T_0\,\dot\sigma$$

$$a_f = ?$$

$$a_{f_2}-a_{f_1} = \frac{\delta Q}{\delta m}\left(1-\frac{T_0}{T_H}\right)-\frac{\delta W}{\delta m} - dI/dm$$

With m_1 mass flux there is an energy flux. Similarly, the m_2 mass flux; there is an energy flux. In the similar way, if we consider there is an availability flux which is coming into the control volume. Because of the state of this flowing stream of fluid of the working system, there is an availability whose specific value we denote as $a_{f1.}$ This is because of the flow and this is known as flow availability. Let us define flow availability as a_{f2}. a_{f1} and a_{f2} are known as specific flow availability. Because this space is very small; otherwise I could have shown everything in comparison that energy flux availability flux that could have been even better. In case of energy, there is a specific energy associated with its flow that is H.

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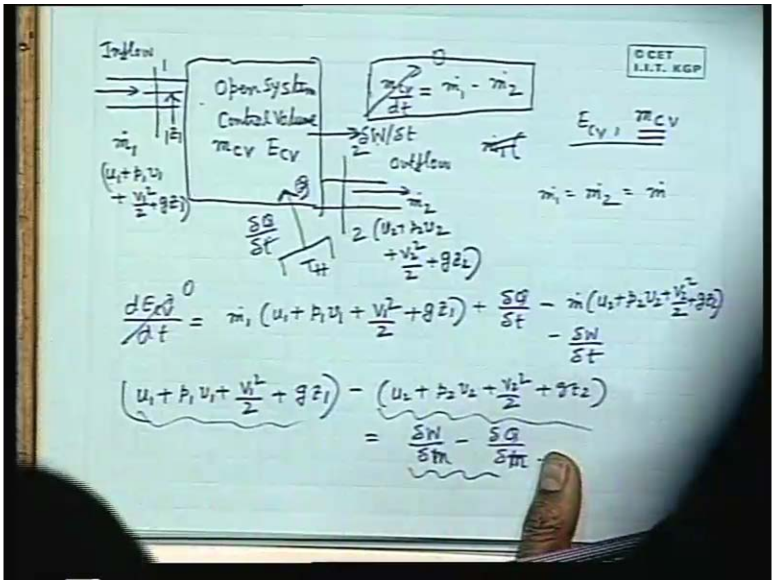

$$\cancel{\frac{dm_{cv}}{dt}}^{0} = \dot m_1 - \dot m_2$$

E_{cv}, m_{cv}

$$\dot m_1 = \dot m_2 = \dot m$$

$$\cancel{\frac{dE_{cv}}{dt}}^{0} = \dot m_1\left(u_1+p_1v_1+\frac{V_1^2}{2}+gz_1\right)+\frac{\delta Q}{\delta t} - \dot m\left(u_2+p_2v_2+\frac{V_2^2}{2}+gz_2\right) - \frac{\delta W}{\delta t}$$

$$\left(u_1+p_1v_1+\frac{V_1^2}{2}+gz_1\right) - \left(u_2+p_2v_2+\frac{V_2^2}{2}+gz_2\right) = \frac{\delta W}{\delta m} - \frac{\delta Q}{\delta m}$$

That means u_1 plus p_1 v_1 plus v_1 square by 2 plus gz_1.

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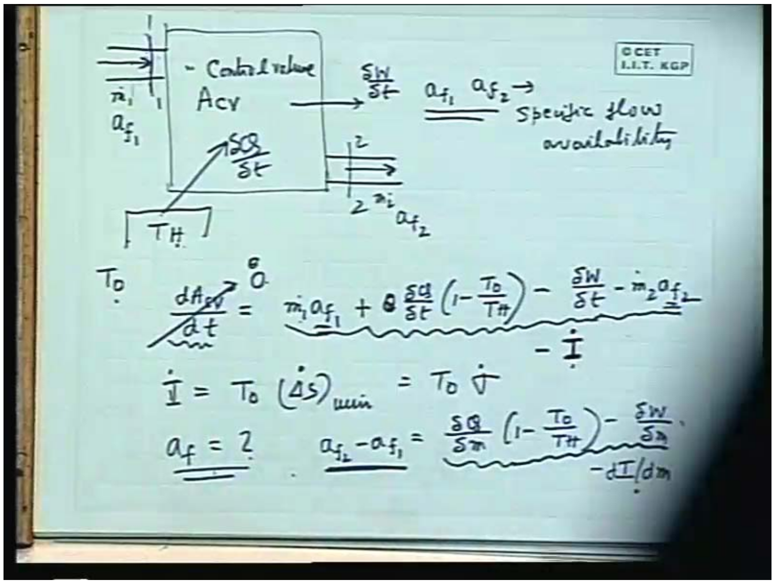

a_{f_1} a_{f_2} → Specific flow availability

$$\cancel{\frac{dA_{cv}}{dt}}^{0} = \dot m_1 a_{f_1} + \frac{\delta Q}{\delta t}\left(1-\frac{T_0}{T_H}\right) - \frac{\delta W}{\delta t} - \dot m_2 a_{f_2} - \dot I$$

$$\dot I = T_0(\dot{\Delta S})_{univ} = T_0\dot\sigma$$

$$a_f = ?$$

$$a_{f_2} - a_{f_1} = \frac{\delta Q}{\delta m}\left(1-\frac{T_0}{T_H}\right) - \frac{\delta W}{\delta m} - d\dot I/dm$$

Similarly, if we consider for the time being, there is a specific flow availability or the availability per unit mass along with the flow in stream exist. Then we can consider, in the similar way as we did for the energy at certain rate the availability is coming into the control volume; at certain rate availability is going at out of the control volume. This is the most important concept. That means in a control volume, what is the difference with respect to a closed system? mass flux is there across its boundary.

When mass comes in along with it, it brings energy to the control volume whose value is m_1 dot into the specific flow energy with this, which is the sum of the enthalpy plus the kinetic and potential energy. Similarly, it brings into the control volume some availability. To do that, we define some availability per unit mass with the flow stream at inlet and outlet. These are defined as specific flow availability. At the time being, first we take for our understanding, then I will find outs its expression.

In the similar way, if we consider that Q is given here from a temperature reservoir T_H whereas the environment is at $T_{0,}$ and if we consider similar way that is del Q divided by del t and if we consider del W divided by del t, the rate at which work is coming out. Similar to the case of energy and mass, if we consider A_{cv} is the total availability within the control volume at any instant. Then one thing we can appreciate; just by the method of induction that dA_{cv} divided by dt is never equal to the total availability balance.

If we make dA_{cv} divided by dt is equal to net availability come what is the now this side I write net availability coming into the control volume. One is coming with the the way I did for the energy; then another is coming with the heat. So, it is not the heat quantity. This is the temperature of the reservoir from which it is coming, compared to T_0. So, there will be minus del Q divided by del t. So, this part will be there.

In case of energy, it was only del Q divided by del t minus del W divided by del t, because it is the shaft work; no displacement work. Control volume is fixed in its volume in this space. So, minus del is the net energy. So, this is plus. So, this is the net availability transfer to the control volume. Therefore, we see. minus m_2 dot $a_{f2;}$ that is, the change in the availability of the system is the net availability coming in. This is coming in due to the mass. This is coming in due to the heat flow. This is going out due to the work. This is going out due to the outlet stream. If we do that by the process of induction, what we have done so far we can tell this equally it will not hold good. There will be something destroyed. The change in the availability with time will not be equal to the rate at which the availability comes. Net weight of availability coming into the control volume always we have seen, where I is the irreversibility and that becomes equal to T_2 into delta S $_{universe}$ or T_2 sigma of the system.

Sir whether it is I or I dot.

I dot. Very good. I dot very correct very correct I dot. I dot is T_0 into delta S dot, the rate at which the entropy is being generated; the rate of change of entropy of the universe. Thank you very much it is I dot very good so by our commonsense and method of induction we can tell. In a steady state, obviously this will be zero and accordingly this minus I. So, this net rate of availability in flux minus I dot is equal to zero. This is the precise concept parallel to the availability balance of a control volume. Now, question comes what is a_f?, the flow availability.

We will first define this flow availability and find out its expression. Then we will be able to prove this in closed system. What we did? We first found out the expression of availability then we proved this; the availability destructed. But in the control volume, to appreciate it in a better way, we have drawn the control volume in terms of the availability. Here, we have assumed a concept of flow availability; that is, the availability per unit mass associated with the flowing stream both at inlet and outlet. Then we had written from the method of induction and from our intuition, what we have seen in closed system that this equals to this minus the irreversibility rate. Of course, everything is in the rate basis. Then these becomes this.

Now, we will prove these. Find out the expression of this and if we know the expression automatically, this equation will be satisfied. When it is at steady state, this will be zero. Then m_1 dot m_2 is same and then everything can be written in terms of the mass basis; that is, in a steady state. I also write that m_1 and m_2 is same. In a steady state, one can write this equation a_{f2} minus a_{f1} this side, if I take then it becomes del Q divided by del m. I write for steady state T_0 divided by T_H minus del W divided by del m minus dI divided by dm.

In steady state, it is again clear that the increase or change in the flow availability is not that the net availability transfer into the system, but minus some quantity which is the irreversibility per unit mass. The similar way, as we have seen in the case of closed system. All right this equation is all right? Now, this will be understood. We have written it as information, following the sequence of this in a closed system. Now, what is this flow availability?

Then, we have to find out the expression for the flow availability, the concept of which we have taken like this as if there is a control volume and there is an inflow.

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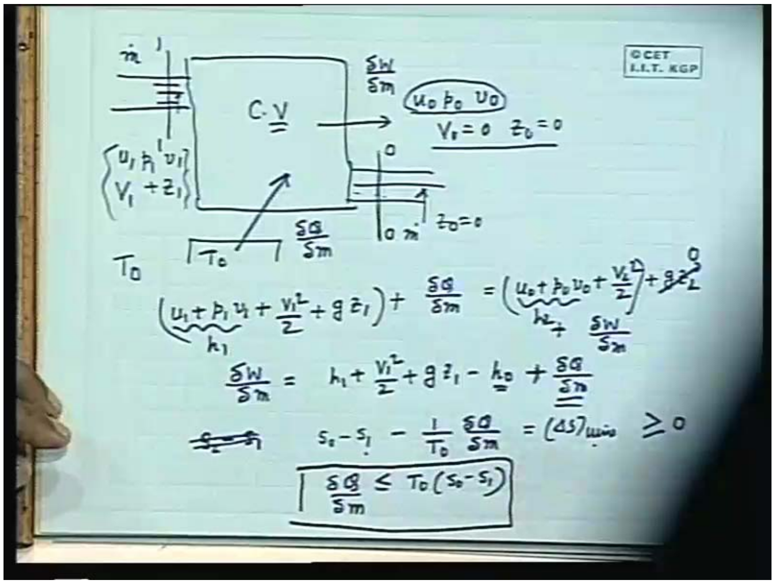

$$\left(\underbrace{u_1 + p_1 v_1}_{h_1} + \frac{V_1^2}{2} + g z_1\right) + \frac{\delta Q}{\delta m} = \left(\underbrace{u_0 + p_0 v_0}_{h_0} + \frac{V_0^2}{2}\right) + g \overset{0}{\cancel{z_0}} + \frac{\delta W}{\delta m}$$

$$\frac{\delta W}{\delta m} = h_1 + \frac{V_1^2}{2} + g z_1 - h_0 + \frac{\delta Q}{\delta m}$$

~~$s_2 - s_1$~~ $$s_0 - s_1 - \frac{1}{T_0}\frac{\delta Q}{\delta m} = (\Delta S)_{univ} \geq 0$$

$$\boxed{\frac{\delta Q}{\delta m} \leq T_0 (s_0 - s_1)}$$

The flow availability is defined in this way that if there is streams of fluids coming into a control volume whose states are specified. For example, u_1 p_1 v_1 this v is the velocity, some z_1 from the term the potential energy per unit mass whose specific values are fixed. Then the flow availability of this mass of fluid flowing into is defined as the maximum work that can be extracted from this stream of fluid by an operation through a control volume on an open system by which this stream comes into equilibrium with the fixed environment.

The similar way as we have defined the availability in case of a closed system; that closed system is at a state which is different from that of the fixed environment so that there exists an opportunity to develop work. What is the maximum work that can be obtained which is only possible in a reversible process when the system comes to the dead state.

Here also when the flow of fluid stream comes to a dead state, what is that dead state?

When its property will be equal to the ambient property and there will be no kinetic energy. because if a system at the same pressure temperature of the surroundings, but its velocity is there V but surrounding means is a fixed reference environment which is at rest that means its velocity also has to be 0.

Similar way, if we consider the gravitational potential energy then this state has to coincide with the reference datum of the gravitational potential energy, where from you have measured. It can not be the absolute skill, the centre of the arc, but somewhere from where we measure the gravitational potential energy. But fortunately, in the analysis of thermodynamic system or thermodynamic processes, the change in the gravitational energies for all practical cases is quite negligible as compared to the changes of other quantity. Therefore, we are not much bothered about the gravitational potential energy and where is the datum and all these things. But kinetic energy has to be 0; otherwise, a flowing stream cannot come to a dead state.

Dead state means if this has got a velocity, we can develop more work by reducing that velocity. Therefore, a dead state has to be considered. Be careful, where I give you the same thing zero zero, not two two; zero zero as the stream outlet section, where all these conditions will be denoted at u_0 ,p_0,v_0 and v_0 has to be 0. Let us consider $z_{0,}$ where from we have measured our z_1. Therefore, z_0 is equal to 0 because from z zero, zero we have measured this z_1.

If the potential energy kinetic energy has become zero and the fluid stream state has become to that of the surrounding. This is the easiest way. You go through books and there are different ways, different books follow to find out the expression of the flow availability. I think this is the easiest way how you can prove it.

Let us consider the environment temperature T_0. The similar way, we consider the way we thought in or we did in case of a closed system that from the same environment temperature $T_{0,}$ some amount of heat is being added. Let us consider a steady state system; that means m dot is the flow which is coming through the system. Consider a steady state and we consider del Q divided by del m is the heat added and at the same time, we consider del W divided by del m is the work done.

Whatever may be the case, we can write that from our energy balance which we did earlier on the mass basis that u_1 plus p_1 v_1 plus V_1 square by 2 plus gz_1 plus del Q divided by del m is equal to u_2 plus p_2 v_2 plus V_2 square by 2 plus gz_2 plus del W divided by del m but del W divided by del m is 0. We make u_1 plus p_1 v_1 plus V_1 square by 2 plus gz_1 as h_1 and u_2 plus p_2 v_2 plus V_2 square by 2 plus gz_2 as h_2.

We can write del W divided by del m please any problem you tell me h_1 plusV_1square by 2 plus gz_1 minus h_0 plus del Q divided by del m, where h_0 is the enthalpy corresponding to the dead state of the fluid stream. del Q divided by del m is the most important part, I am leaving it. Similar way, as we did earlier, we take the entropy balance which is very important. Entropy balance is S_2 minus $S_{1.}$ What is $S_{2,}$ what is S_1? which is very important; that is why, at the beginning you asked me, sir entropy flow in a closed open system, what is this?

S_2 minus S_1 is the specific entropy change of this flowing stream. I will not write $S_{2;}$ rather, I will write S_0 minus S_1. That is the entropy increase and the system surrounding rejects it is minus 1 by T_0 del Q divided del m. This is the entropy change of the universe or delta S $_{\text{universe}}$ which has to be greater than equal to zero.

I keep the equality sign, because for a reversible process which covers all processes. Here, the control volume is at steady state. Things are not being complicated by considering the control volume on steady state. that is the change of the entropy of this fluid flowing through the working system, flowing through it per unit mass minus the change of entropy of the system per unit mass of this. If we are considering everything per unit mass of the working system through this control volume is greater than 0. So, from which, one can conclude del Q divided by del m is less than equal to T_0 into S_0 minus S_1. So, simply, I will now substitute this value of del Q divided by del m here, and what we will get? We will get, if you just substitute this thing, what we will get?

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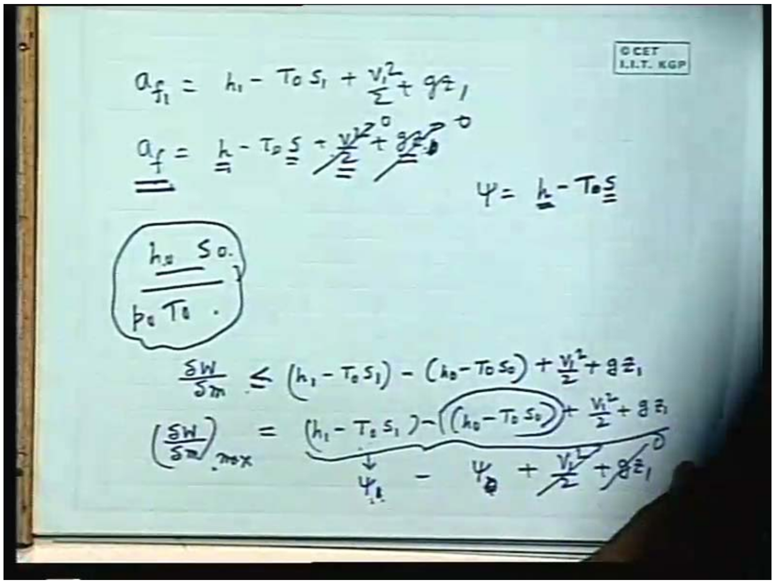

$$a_{f_1} = h_1 - T_0 s_1 + \frac{V_1^2}{2} + gz_1$$

$$\underline{\underline{a_f}} = \underline{\underline{h}} - T_0 \underline{\underline{s}} + \cancel{\underline{\underline{\frac{V^2}{2}}}}^{0} + \cancel{\underline{\underline{gz}}}^{0}$$

$$\psi = \underline{\underline{h}} - T_0 \underline{\underline{s}}$$

$h_0 \quad s_0$

$p_0 \quad T_0$

$$\frac{\delta W}{\delta m} \leq (h_1 - T_0 s_1) - (h_0 - T_0 s_0) + \frac{V_1^2}{2} + gz_1$$

$$\left(\frac{\delta W}{\delta m}\right)_{max} = \underbrace{(h_1 - T_0 s_1) - (h_0 - T_0 s_0)}_{\psi_1 \; - \; \psi_0} + \frac{V_1^2}{2} + gz_1$$

$$\psi_1 - \psi_0 + \cancel{\frac{V_1^2}{2}} + \cancel{gz_1}^{0}$$

We will get the same thing as we did earlier. del W divided by del m will be less than equal to h_1 minus T_0 S_1 minus h_0 minus T_0 $_{S0}$ plus V_1 square by 2 plus gz_1. So, this is clear, what I am doing? del Q divided by del m; I am substituting these inequality relationships here. So, I get an inequality relationship. It is clear that the maximum del W divided by del m which we can get. That is the maximum work which pertains to the reversible process. Therefore, equality signs will be there. Therefore, obviously mathematically this is the maximum value, because it is less than equals to and physically it corresponds to that. So, this again I am writing. Therefore, the maximum del W divided by del m is equal to h_1 minus T_0 S_1 minus h_0 minus T_0 S_0 plusV_1 square by 2 plus $gz_{1.}$ This is the equation we get.

By definition, maximum del W divided by del m is the flow availability. If I give this as a function, for example, psi; that means, if I define now psi is equal to h_1 minus T_0 S, where h is the specific enthalpy. S is the specific entropy of a system in a control volume at any section; that means that inlet or outlet. But if we are not bothered about the changes in the kinetic and potential energy, we can neglect it and simply we can tell psi one minus psi zero is flow availability at the inlet section one, or any section outlet section the flow availability will be psi two minus psi zero if outlet section two is not coinciding with the surrounding environment state 0.

This is clear. Since this part is constant, we simply tell that a_{f1} is equal to h_1 minus T_0 S_1 plus V_1 square by two plus gz_1. That means at any state a_f by denoting h and S as the state variable. Whether it is one or two, I can write this. That means if this h and S is different from h_0 S_0. If v and z exist there is flow availability with respect to the reference data, where the enthalpy is h_0 s_0 p_0 T_0, all these things. With reference to an environment, the availability of a flowing stream is defined by specific flow availability as specific enthalpy minus T_0 into specific entropy plus the kinetic energy per unit mass and potential energy. This part we can neglect, if we neglect the changes in kinetic or potential energy.

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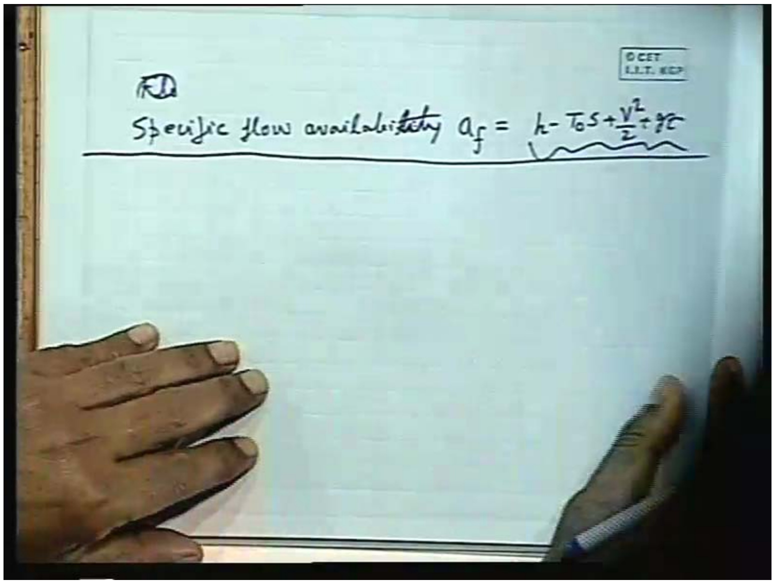

Specific flow availability $a_f = h - T_0 s + \frac{V^2}{2} + gz$

Therefore, now we come to the specific flow availability. In solving problems, this will be very very important. Specific flow availability a_f is equal to h minus T_0 S plus V square by 2 plus gz. This is the definition of specific flow availability.

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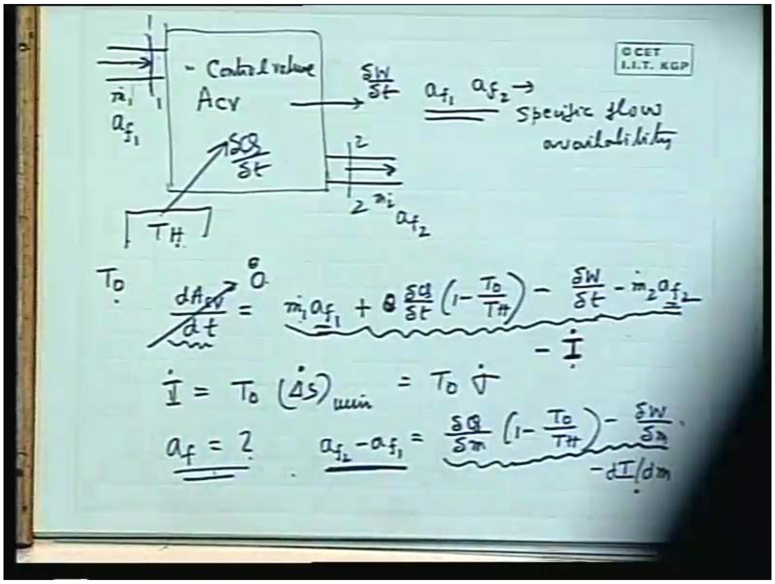

If you go back to our control volume analysis, we will see that if we substitute these flow availabilities like this, then we will get this same relationship delta S $_{\text{universe}}$ is the same.

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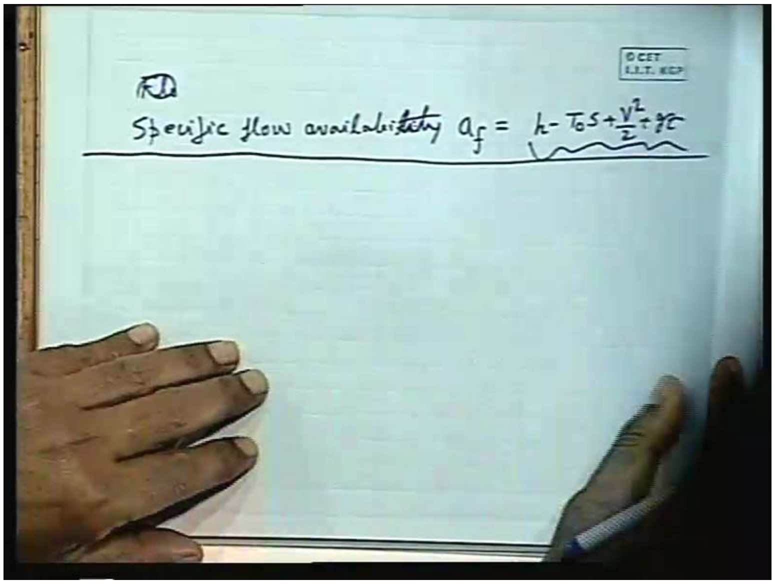

Therefore, now I write all these three equations to a control volume. Then it will be clear I am not writing the diagram again.

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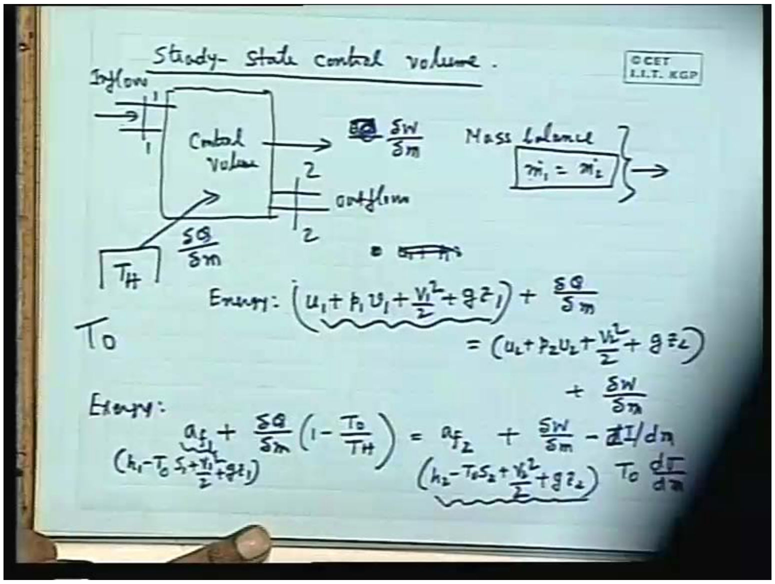

Steady- State control volume.

$\frac{\delta W}{\delta m}$

Mass balance $\boxed{\dot m_1 = \dot m_2}$

Energy: $\left(\underbrace{u_1+p_1v_1+\frac{V_1^2}{2}+gz_1}\right)+\frac{\delta Q}{\delta m} = \left(u_2+p_2v_2+\frac{V_2^2}{2}+gz_2\right) + \frac{\delta W}{\delta m}$

Exergy:

$$\underbrace{a_{f_1}}_{(h_1-T_0s_1+\frac{V_1^2}{2}+gz_1)} + \frac{\delta Q}{\delta m}\left(1-\frac{T_0}{T_H}\right) = \underbrace{a_{f_2}}_{(h_2-T_0s_2+\frac{V_2^2}{2}+gz_2)} + \frac{\delta W}{\delta m} - \underset{T_0\frac{d\sigma}{dm}}{dI/dm}$$

Let us consider a steady state control volume. Let me draw the diagram. So, this is inflow section one and this is outflow steady state. This is control volume which gives shaft work. When it is a steady state, I write in terms of per unit mass del W divided by del m as it is coming and let heat is added from a reservoir T_H.

Now you ask any questions if you have any doubt. Mass balance is m_1 dot is equal to m_2 dot and because of this mass balance at exit and inlet, we are writing everything per unit mass. Therefore, mass balance equation has not to be repeated. This is implicit; otherwise, we cannot write the energy balance or balance of exergy and other quantities in terms of mass, mass balance equation, though I have written it is automatically implicit.

I write in terms of energy balance. So, what is this energy balance? Energy balance is the inflow energy. Energy is equal to u_1 plus p_1 v_1 plus V_1 square by 2 plus gz_1; that is, the inflow energy plus del Q divided by del m is obviously equal to this is the easiest way of understanding u_2 plus p_2 v_2 plus V_2 square by 2 plus gz_2 plus del W del m, this is the energy balance.

What is exergy balance? Exergy balance is similarly a_{f1} plus del Q del m. a_{f1} takes care of u_1 plus p_1 v_1 plus V_1 square by 2 plus gz_1. This is the specific flow energy. Similarly, af_1 plus del Q divided by del m. What is a_{f1}? Similarly, reference environment is T_0. That is a_{f1} is h_1 minus T_0 S_1

plus V_1 square by 2 plus gz_1. I write in terms of a_{f1} plus del Q divided by del m into 1 minus T_0 by T_H is equal to a_{f2}.

What is a_{f2} again? a_{f2} is h_2 minus T_0 S_2 plus V_2 square by 2 plus gz_2. So, these quantities together define a_{f2} plus del W divided by del m minus dI by dm. dI by dm is T_0 into d sigma dI by dm, that is the rate of entropy generation per unit mass. Now, what is entropy flow as you asked at the beginning? Let us write the entropy balance equation.

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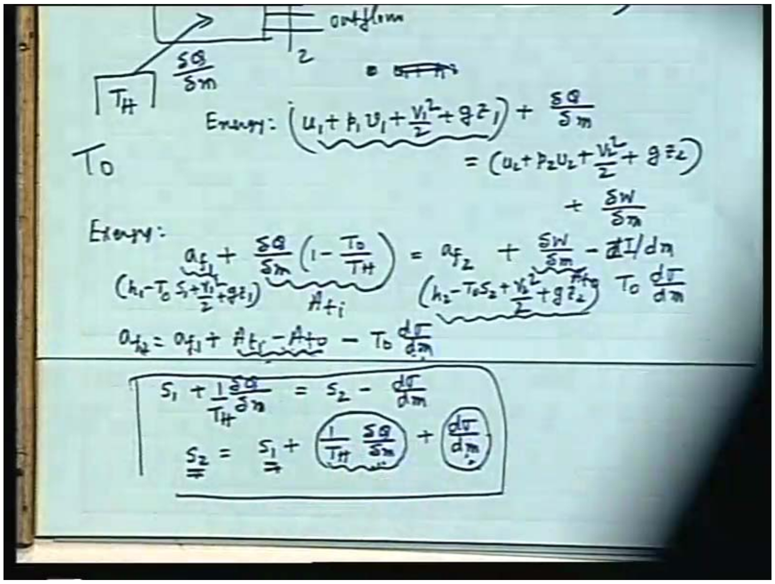

Energy: $\left(\underbrace{u_1 + p_1 v_1 + \frac{V_1^2}{2} + g z_1}\right) + \frac{\delta Q}{\delta m}$

$= \left(u_2 + p_2 v_2 + \frac{V_2^2}{2} + g z_2\right) + \frac{\delta W}{\delta m}$

Exergy:

$$\underbrace{a_{f_1}}_{(h_1 - T_0 s_1 + \frac{V_1^2}{2} + g z_1)} + \underbrace{\frac{\delta Q}{\delta m}\left(1 - \frac{T_0}{T_H}\right)}_{A_{ti}} = \underbrace{a_{f_2}}_{(h_2 - T_0 s_2 + \frac{V_2^2}{2} + g z_2)} + \underbrace{\frac{\delta W}{\delta m}}_{A_{to}} - \underbrace{dI/dm}_{T_0 \frac{d\sigma}{dm}}$$

$$a_{f_2} = a_{f_1} + \underbrace{A_{ti} - A_{to}} - T_0 \frac{d\sigma}{dm}$$

$$s_1 + \frac{1}{T_H}\frac{\delta Q}{\delta m} = s_2 - \frac{d\sigma}{dm}$$

$$s_2 = s_1 + \underbrace{\frac{1}{T_H}\frac{\delta Q}{\delta m}} + \frac{d\sigma}{dm}$$

What is the entropy balance equation per unit mass basis? What is the entropy flow?

That is S_1 plus del Q divided by del m into 1 by T_H; that is, the entropy coming in is equal to entropy going out. Then, minus the entropy generation per unit mass rather S_2 will be this plus this plus d sigma dm. Therefore, S_2 will be equal to S_1 plus one by T_H del Q divided by del m plus d sigma dm. So, this you can consider as the entropy flow from the surrounding. This is the entropy flowing out and this is the flowing in. So, entropy flowing out from the control volume is equal to entropy flowing into the control volume plus the entropy received, because of the heat transfer process plus the d sigma dm.

Any question here please This is the typical entropy balance. We see, the entropy balance and exergy balance or availability balance is this same thing. If you write, the a_{f2} is a_{f1} plus availability transferred in. Let us consider this At_i and availability transfer out is At_o. Then a_{f1} plus At_i minus At_o that means net availability transferred in minus T_0. The equations are almost same. Because of this this is there that means the outlet availability. Specific flow availability equals to the inlet flow availability plus the transfer minus the destruction. Here, outlet entropy is the inlet entropy that is the entropy flow out is entropy flow in plus the entropy transferred in plus the generation of the entropy. This availability at the outlet may increase or decrease depending upon the relative values of these two when there is a net availability transferred in. whereas the destruction is not equal to that, less than that there will be an increase, but that increase is not in proportion by which it has come in something minus you understood?

Similar way, the entropy going out may be less than this or greater than this depending upon whether this quantity is positive or negative. If this quantity is positive, it is greater than S_1 by another more quantity which is this. Because of generation, if it is less than this, it is not less by this amount which is negative in that case, but it is by a lesser amount, because some positive quantity is being added which the generation of entropy.

That is as simple as that. In a reversible thermodynamics there are many ways. This is being defined. This is defined as, entropy transferred in this is defined as, entropy flow; entropy flow in entropy flow out. So, anyway you define it, but does not matter. If you write the equations correctly following any particular nomenclature, things will be all right. This is exactly what is your availability or exergy balance for on open system v is minus a minus v is the exergy and availability balance of a closed system, as we discussed earlier.

The most important thing comes; what is mean by second law efficiency? Before that, I like to tell you that if you recapitulate the entire thing, you see one thing that in any natural process the work potential of a certain quantity of energy whether it is in the form of transit that is heat, or it is in the form of stored energy in a system because of a state, or it is in a flowing stream of fluid because of its state.

In three cases, we have seen that availability of a closed system; Specific flow availability or flow availability of an open system and also the availability or exergy of a heat flow. We have seen all these things have continuously reduced this work potential because of the natural process. So, this work potential is the availability and known as quality of energy which is being continuously reduced.

In any natural process, we see that this reduction is more when the process is more irreversible; that means, more and more is the reversibility more and more is the destruction of the work potential or quality of energy and more and more is the increase in the entropy of the universe, the generation of entropy. So, less is the irreversibility less is the destruction, less is the generation and in the limit, when the process comes to an irreversible process then the quality is not destructed. That is, if we could have made all natural processes are reversible and so, the work potential could never be destroyed. It was conserved the way the energy is conserved and there could not be any generation of entropy.

Therefore, we see that this destruction of availability is a criterion of irreversibility and that is why the irreversibility is defined as some reference temperature of the environment T_0 into the entropy generations. Therefore, one gauging parameter should come which measures this departure of the process from the reversibility towards the irreversibility.

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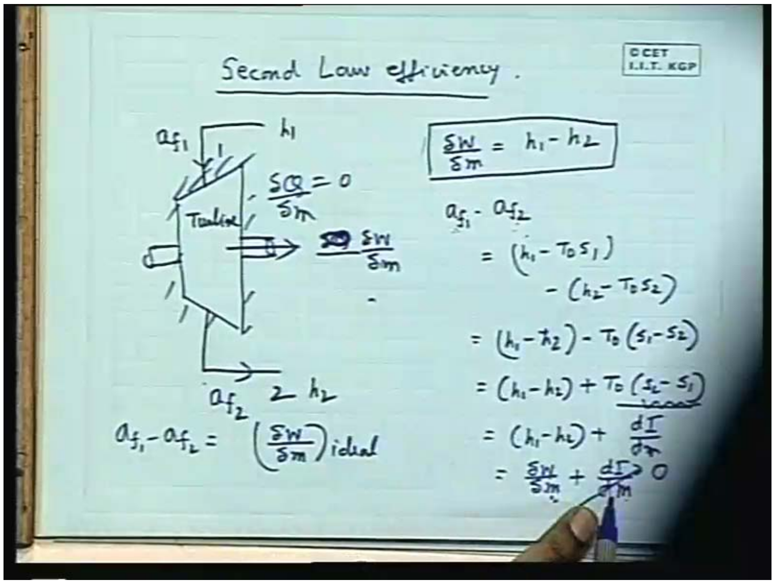

Second Law efficiency.

$$\boxed{\frac{\delta W}{\delta m} = h_1 - h_2}$$

$$\begin{aligned} a_{f_1} - a_{f_2} &= (h_1 - T_0 s_1) - (h_2 - T_0 s_2) \\ &= (h_1 - h_2) - T_0 (s_1 - s_2) \\ &= (h_1 - h_2) + \underline{T_0 (s_2 - s_1)} \\ &= (h_1 - h_2) + \frac{dI}{dm} \\ &= \frac{\delta W}{\delta m} + \frac{dI}{dm} > 0 \end{aligned}$$

$$a_{f_1} - a_{f_2} = \left(\frac{\delta W}{\delta m}\right)_{ideal}$$

That gauging parameter is known as second law of efficiency. Why it is called second law efficiency also I will tell. What is this second law efficiency? If we define this second law of efficiency, let us consider first, a case of a compressor where there is a work producing unit. Let us consider a case of a turbine rather you just leave this i think this is odd.

Let us consider second law efficiency. What is the time time is up what is the time another five minutes but i don't know whether i will be able to do it.

Let us consider the case of a turbine a work producing device. There is an inflow of gas there is an outflow of gas state one and state two. Let us consider the change of a kinetic and potential energy is zero. So let h one h_1 and h_2 are the specific enthalpy and let it develops del W divided by del m amount of shaft work. We know from the energy balance what is del W divided by del m? It is $h_1$minus h_2 that means this is the actual work which we obtain. We measure the h_1, h_2 two we get this.

If we define availability at the section a_{f1} and availability at that section $a_{f2,}$ what is this a_{f1} minus $a_{f2.}$ It is h_1 minus T_0S_1. I neglect the changes in kinetic and potential energy that is why I have derived this I could write this T_0S_2. This becomes is equal to h_1 minus h_2 minus T_0 S_1 minus S_2.Or we can write, h_1 minus h_2 plus T_0 into S_2minus S_1. Before that, I should have told one thing. Forgotten that the turbine is adiabatic; that means, del Q divided by del m is 0. That is why I can write this equation to form the energy balance.

Time is up that is why I am in hurry I will repeat it again in the next class.

What is S_2 minus S_1? Irreversibility dI by dm. Because this is the entropy generation of the universe S_2 minus S_1 is the change of entropy of the system. Because it is adiabatic, there is no change of entropy of the surrounding.

We see that del W divided by del m the actual work obtained plus the irreversibility is the change in the flow availability. If the process could have been reversible, it is a natural case that is irreversible but adiabatic. But if it is a reversible adiabatic, then this term could have been 0. Then del W divided by del m could have been exactly equal to the change in flow availability. That means, there was no destruction of availability. It is the availability which we are getting in terms of the work transfer. In that case, a_{f1} could have minus a_{f2} could have become del W divided by del m, but in this case, it is not that in a natural case, a_{f1} minus a_{f2} is work done plus the irreversibility that is a_{f1}minus a_{f2} is described as the ideal work. What is equals to the actual work plus the irreversibility?

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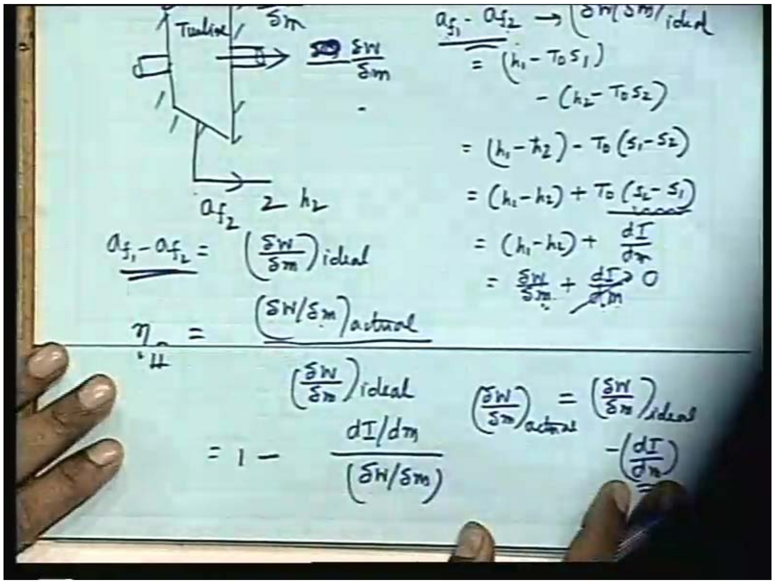

$$a_{f_1} - a_{f_2} \rightarrow \left(\delta W/\delta m\right)_{ideal}$$

$$= (h_1 - T_0 s_1) - (h_2 - T_0 s_2)$$

$$= (h_1 - h_2) - T_0 (s_1 - s_2)$$

$$= (h_1 - h_2) + T_0 (s_2 - s_1)$$

$$= (h_1 - h_2) + \frac{dI}{dm}$$

$$= \frac{\delta W}{\delta m} + \frac{dI}{dm} > 0$$

$$a_{f_1} - a_{f_2} = \left(\frac{\delta W}{\delta m}\right)_{ideal}$$

$$\eta_{II} = \frac{(\delta W/\delta m)_{actual}}{\left(\frac{\delta W}{\delta m}\right)_{ideal}} = 1 - \frac{dI/dm}{(\delta W/\delta m)}$$

$$\left(\frac{\delta W}{\delta m}\right)_{actual} = \left(\frac{\delta W}{\delta m}\right)_{ideal} - \left(\frac{dI}{dm}\right)$$

With this, we define the second law efficiency eta two as this del W divided by del m; actual work is less than the ideal work del W divided by del m. So, the actual work is less than the ideal work. By this quantity, we can write minus dI by dm by del W divided by del m. This is because the ideal work is what is actual work plus dI by dm.

Therefore, we can write del W divided by del m. This also, we can write, actual is ideal work that means the actual work which we get is less than the ideal work by the irreversibility per unit mass basis calculations. So, this is clear. This is defined as the second law efficiency. If the process could have been reversible then decrease in availability could be the work that is the ideal work.

In this case, the work is $h_1$minus h_2 which is the ideal work minus this thing; this is the ideal work del W divided by del m. This way, we define the second law efficiency that means the ideal work by actual work. If the process could have been reversible, there could not be any irreversibility dI by dm zero and the availability difference is equal to the enthalpy difference. An enthalpy difference is always equal to the work done. There is no doubt whether the process is reversible or irreversible. In case of reversible, the enthalpy difference becomes exactly equal to the availability different because they are related by this quantity T_0 into S_2 minus S_1.

[Conversation between Student and Professor – Not audible ((00:56:22 min))]

Which one please?

eta two

Eta two theoretical it can be made equal to one very good and very very intelligent question now I must tell it well I think time is up few minutes left time is up know. I can explain it again it is a very good question that Theoretically, second law efficiency can be one while theoretically heat engine efficiency Carnot efficiency can never be equal to one.

[Conversation between Student and Professor – Not audible ((00:56:51 min))]

Even in a reversible process, you cannot have a hundred percent efficiency, Carnot efficiency whereas in second law efficiency can be one. This is because the reversible process is not deriving the laws of physics: a frictionless system, a mass less particle, an inelastic system and inviscid fluid. These are all with the laws of physics, but which cannot be conceived in practice.

Therefore, all these systems constitute an ideal process or ideal system. Things are reversible there. Therefore, irreversibility is 0 and we can achieve theoretical value of second law efficiency is one. But if all these things are ideal that we make a machine without friction, we make a system inviscid. We make everything free of the dissipative effect. Then also, you cannot have a 100 percent Carnot efficiency, theoretically.

This is very very important and vital question. I will ask this question in all the time whenever I meet you in any stage of your viva voce including the final grand viva because my student must answer this question what is the difference between that very good question that second law efficiency can become unity just like the efficiency of a transmission system; fluid transmission or power transmission mechanical system efficiency of a generator or motor but Carnot’s engine cannot have 100 percent efficiency even in the theoretical (( )) (00:58:18).

So it is a very good question which can be related to this consequence.

Thank you