Basic Thermodynamics
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Lecture – 13
Thermodynamic Property Relations-I

Good morning. In the last two classes, we discussed in detail, the concept of availability or exergy balance in both open and close system. We should have a hurried recapitulation of what we did. We are appreciated that availability that is the work potential of low grade energy is not conserved the way energy is conserved.

There is always a destruction or reduction of the availability in any natural process. This was the outcome of the availability balance. It can be put in this way that if there is a closed system which executes a process from one initial state to another final state and in doing so, if it interacts with the surrounding in the form of heat and work energy then associated with that heat and work, there is an availability transfer to the system.

If we equate or determine the availability at the final state and availability at the initial state, and if we find out what is the net availability transfer into the system, then we see that, what we have seen; rather, the availability at the final state is not equal to the availability at the initial state plus the net availability transferred in which it should be if it could have been conserved, but it equals to this thing; that means, the availability at the final state equals to the availability at the initial state plus the net availability transferred into the system minus the destruction of availability which equals to the temperature of a reference environment times the entropy change of the universe and it is termed as irreversibility.

For a reversible process, this is 0 and the availability is conserved in the same way as the energy is conserved. Similarly, if we think of a control volume, in that case what is the difference between a control volume and a close system that is a mass inflow and outflow? Then we have to take balance of the energy coming in, associated with that what is the availability coming in and availability going out these are known as flow availability.

In the similar way, we can tell the flow availability at the outlet should be equal to the flow availability at the inlet plus the net availability transferred into the control volume, if it was conserved like energy quantity. Net availability transferred in comes because there is an energy interaction in terms of heat and work with the surrounding but it does not happen so.

In the similar line as it is stated in close system, for close system this balance is that availability coming out; that means, the flow availability at the outlet stream equals to the flow availability at the inlet stream plus the net availability transferred into the control volume minus the availability destruction which is the irreversibility that is T_0 times entropy change of the universe.

Next, we recognize that for any natural process. Therefore, this destruction of availability is because of the irreversibility and more is the departure from the reversible process; that means, more is irreversibility then more is the destruction of the availability and this is gauged or measured by a parameter known as the second law efficiency which we started for the different operators or different equipment. We started with the work to different devices rather work producing device turbine. We will do it again now.

Before that, one should know what should be our target. Our target should be to make the process as close as possible to the reversible process, so that the destruction of availability is minimum. The destruction of work potential of the low grade energy from which our main object is to find the useful work should be minimum, so that always the energy which is available to us for converting into work should have a higher potential. We start with this second law efficiency.

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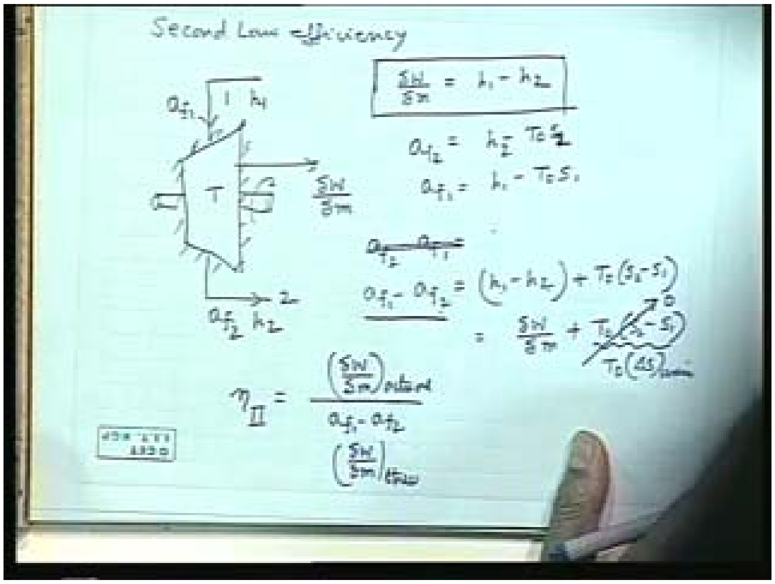

Second law efficiency, first part is the repetition. Again, I must start second law efficiency. We started with a turbine. We just recognize a turbine first. What is a turbine? Consider an adiabatic turbine. In all practical cases, a turbine is insulated; that means an adiabatic, that is mounted on a shaft so that we get and work at the rate of let per unit mass. In a steady state as I have told that everything is done in unit mass so this is section one this is section two that is the outlet section that is the inlet stick that is the outlet stick.

The gas or air whatever is the working fluid, comes at section one with an enthalpy h_1 and goes out with an enthalpy h_2. If we neglect the changes in kinetic and potential energies, we know that del w divided by dell m. That is the first law or the energy balance for the steady flows open system is $h_1$minus h_2.

If we neglect the changes in kinetic and potential energy that means we get work out of the difference in enthalpy. If at the same time, we defined af_1 and af_2. What is af_2? By definition, af_2 is equal to h_2 minus T_0s_2. This is specific flow availability. h_2 and af_1 is equal to h_1 minus T_0 s_1; then, af_2 minus af_1, if I just write this from their definitions. Let us write af_1 minus af_2 instead of af_2 minus af_1. That will be equal to $h_1$minus h_2 plus T_0 s_2 minus s_1.

We see the decrease in availability is equal to enthalpy change plus this quantity. But the change in enthalpy is what? del w divided by del m plus T_0 s_2 minus s_1. What is T_0 s_2 minus $s_{1?}$ It is T_0 delta s $_{\text{universe}}$, because it is adiabatic. So, change in entropy of this working system is the entropy change of the universe.

If the process could have been reversible, so this part could have been 0, because entropy changes of the universe is 0. In that case, we see, it is the difference of availability which could have been the work done per unit mass. Therefore, we see, the actual work done which is the difference between h_1 minus h_2 is less than the ideal work done which is equal to af_1 minus $af_{2;}$ decrease in flow availability.

Therefore, we could have got more work which is equal to the difference in flow availability at the inlet and outlet, if the process could have been reversible. This is gauged by an efficiency known; second law efficiency, which is defined as del w divided by del m that is the actual work divided by af_1 minus af_2 which is nothing but sometimes we can write this as theoretical work, where this we can write as actual work and this becomes equal to 1 when process is reversible.

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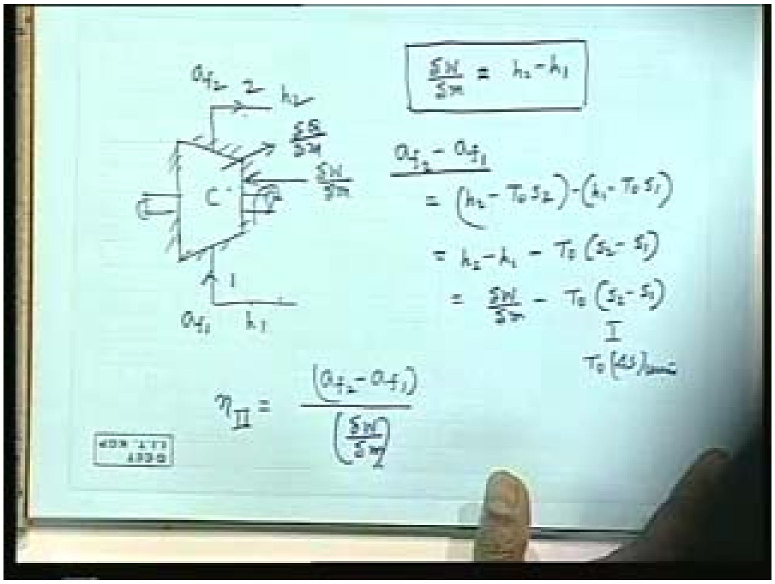

$$\boxed{\frac{\delta W}{\delta m} = h_2 - h_1}$$

$$\begin{aligned} a_{f_2} - a_{f_1} &= (h_2 - T_0 s_2) - (h_1 - T_0 s_1) \\ &= h_2 - h_1 - T_0 (s_2 - s_1) \\ &= \frac{\delta W}{\delta m} - \underbrace{T_0 (s_2 - s_1)}_{T_0 (\Delta s)_{\text{univ}}} \end{aligned}$$

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

Similar is the case, if we consider an adiabatic compressor. The difference between the turbine and the compressor is that it is also an work interacting device, but not work producing device, but it takes work per unit mass basis. del w divided by del m is the work which is being added to the compressor and let this is state section one inlet and section two outlet.

Similar is the case, let h_1 and h_2 and corresponding af_1 and $af_{2.}$ Again, from the steady flow energy equation, we can write h_2 minus $h_{1.}$ Here, I am always writing the positive value of del w divide by del m; that means, again a work is added. So, it will be negative. So, if we write, it will become h_1 minus h_2. I am writing in terms of the positive value. Obviously, when work is added enthalpy will be more at the outlet than at the inlet provided we change. We neglect the changes in kinetic and potential energy. I always write the positive value of the work and we always recognize, before that this is the work taken by the compressor. If I tell that there is no harm. If I apply the positive value that is true.

Here, if we find out the increase in availability rather af_2 minus af_1. Therefore, af_2 minus $af_1$is equal to h_2 minus T_0 s_2 minus h_1 minus T_0s_1. This becomes equal to h_2 minus h_1 minus T_0 s_2 minus $s_{1,}$ just the reverse. Here, you see that h_2 minus h_1 is the work required by the compressor to go from state one to state two, but the change in availability, increase in availability is less than the work required; that means the availability is destructed. If you compare these with your availability balance equation, this is alright. That means the availability here is availability here plus the availability taken in by the compressor; that means, del w divide by del m minus some amount which is I, that means T_0 delta s $_{\text{universe}}$.

In this case, this is a compressor that demands more work as compared to that which it could have taken if the process was reversal; if the process was reversible. So, that was 0; that means, this I can write af_2 minus af_1 could have been the work requirement. Therefore, we see, the actual work requirement is more than the ideal work requirement. In this case, this will go this side.

Therefore, here eta 2, the second law efficiency is written as the work which is needed is more. But the ideal work that means af_2 minus af_1 that is the ideal work is less, because it is taking work divided by the del w divided by del m. del w divided by dell m is the actual the work required which is af_2 minus af_1 plus T_0 s_2 minus s_1 divided by del w divided by del m. This is the way by which we define the second law efficiency of a compressor.

Make your concept clear at this stage. So, if your concept is clear, slowly, you write down the equations and you will arrive at the correct answer.

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Compressor is not adiabatic then the Q quantity will come here definitely. If the compressor is not adiabatic, I am just giving you a simple case that compressor is adiabatic.

If compressor is not adiabatic then Q term will come here. Then you have to consider that Q is coming or going. In case of compressor, if you do not consider it is adiabatic, then Q may come out. In case of turbine also, Q may come out or deliberately Q may be given. So, it has to be specified. In that case, the energy equations will be modified. At the same time, the availability equations will be modified. Everything we are writing forms that concept. We will see automatically that when there is a heat transfer, also the change in availability will correspond to availability balance equation, but the definition is same; that is at the ideal work requirement by the actual work requirement.

That is left as an exercise, you do it. If there is any heat interaction, let us consider some heat is coming out from the system. Then what it will be if you change this thing. Definition of the availability will remain the same, but h_1 minus h_2 simply will not account for the del w divide by del m. Some heat quantity will come in that case.

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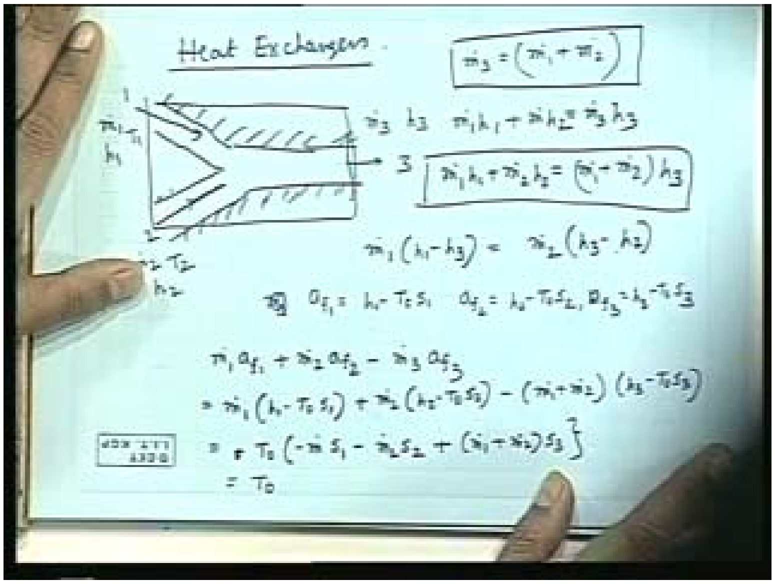

Heat Exchangers.

$\boxed{\dot{m}_3 = (\dot{m}_1 + \dot{m}_2)}$

$\dot{m}_3\ h_3$ $\quad \dot{m}_1 h_1 + \dot{m}_2 h_2 = \dot{m}_3 h_3$

$\boxed{\dot{m}_1 h_1 + \dot{m}_2 h_2 = (\dot{m}_1 + \dot{m}_2) h_3}$

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

$a_{f_1} = h_1 - T_0 s_1 \quad a_{f_2} = h_2 - T_0 s_2, \; a_{f_3} = h_3 - T_0 s_3$

$\dot{m}_1 a_{f_1} + \dot{m}_2 a_{f_2} - \dot{m}_3 a_{f_3}$
$= \dot{m}_1 (h_1 - T_0 s_1) + \dot{m}_2 (h_2 - T_0 s_2) - (\dot{m}_1 + \dot{m}_2)(h_3 - T_0 s_3)$
$= T_0 (-\dot{m}_1 s_1 - \dot{m}_2 s_2 + (\dot{m}_1 + \dot{m}_2) s_3 \}$
$= T_0$

Next is heat exchanger; non-work producing devices. let us consider heat exchangers. There are two types of heat exchangers. So, we will read afterwards. One is a mixing type. Let us consider simply, without telling in terms for the heat exchanger rather a mixing device; that means, two fluids are mixed, one and two and goes at three.

Let the fluid stream. The flow rate is m_1 dot. Let the fluid or the working fluid of the system be m_2 dot and m_1 comes at a temperature T_1, and m_2 comes at a temperature T_2 corresponding enthalpy h_1 and entrusted with enthalpy h_2. This is the m_3 dot with the enthalpy h_3. How to define this second law efficiency of the process? How to analyze this process?

There are three things: one is the mass balance another is the energy balance another is the availability balance. Availability balance and entropy balance are almost parallel. If these four things can be determined then one can determine everything. Let us consider the entire system as adiabatic; that means these two streams at different enthalpy mix and goes out. So, no heat and work transfer from this entire system. That means if we take this as the control volume, the control volume does not have any work and heat interactions.

Then mass balance tells m_3 dot is equal to m_1 dot plus m_2 dot. Then what is your energy balance? Energy balance is m_1 dot $h_{1,}$ this is the energy coming in, plus m_2 dot $h_{2.}$ Here, I neglect the changes in potential and kinetic energy so that the kinetic energy is part of the flowing energy. I am neglecting with all these streams or if it is there, specified that one side kinetic energy is very high, whereas the outlet kinetic energy is very low or between the two streams that there is a large difference between kinetic energies. Then, we will have to take into account. But if the kinetic energies are almost same for all the fluids then we can neglect the kinetic energy part. This must be equal to m_3 dot h_3.

[Conversation between Student and Professor minus Not audible ((00:15:54 min))]

That means m_1 dot h_1 plus m_2 dot h_2 is equal to m_1 dot plus m_2 dot into h_3. How will h relate to T? That depends upon the property relationship of the working system. So, this is energy balance. This is the mass balance and this is energy balance. This energy balance can be written in this fashion also; that is, m_1 dot into h_1 minus h_3 is equal to m_2 dot h_3 minus h_2. Let us consider m_1 as the hot fluid and this as the relatively cold fluid but does not matter. The energy released by one will be energy gained by the other. This is clear from this type of expression.

Now what will be the availability? What is the af_1? af_1 is h_1 minusT_0 s_1. What is af_2? af_2 is h_2 minus T_0 s_2. These are the specific flow availability. Then af_3 is h_3 minus T_0s_3. Now I write the availability balance. Without writing availability balance, let us write m_1 dot af_1 plus m_2 dot af_2 minus m_3 dot af_3. What is the result? m_1 dot af_1 plus m_2 dot af_2 minus m_3 dot $af_{3.}$ So what is m_1 dot $af_{1?}$ It is m_1 dot into h_1 minus $T_0s_{1,}$ plus m_2 dot. What is af_2? It is h_2 minus T_0 s_2 and what is m_3 dot $af_{3?}$ m_1 dot plus m_2 dot into h_3 minusT_0s_3. If we write, We get, m_1 dot into h_1 minus T_0s_1 plus m_2 dot into h_2 minusT_0s_2 minus m_1 dot plus m_2 dot into h_3 minusT_0s_3.

If we write m_1 dot h_1 plus m_1 dot h_2 and m_1 dot plus m_2 dot they cancels each other. So, I am leaving with minus T_0 which is constant. So, we get T_0 into minus m_1 dot s_1 minus m_2 dot s_2 plus m_1 dot plus m_2 dot s_3.

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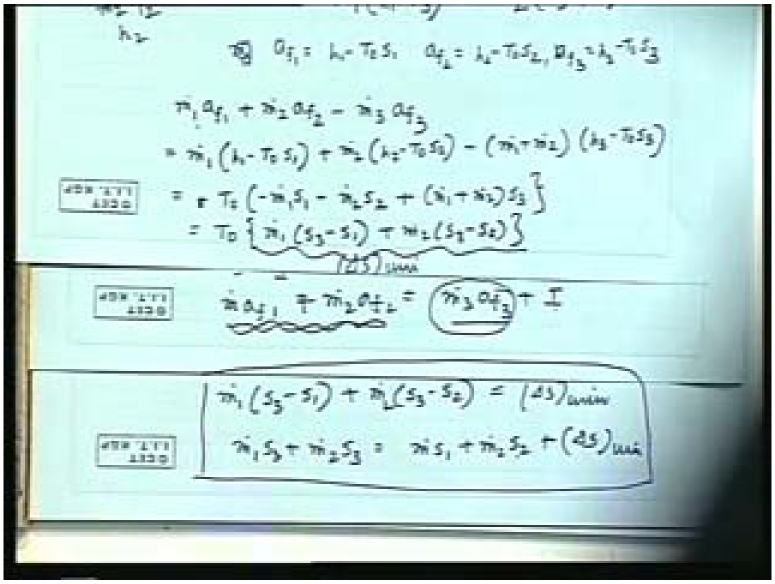

$$a_{f_1} = h_1 - T_0 s_1 \quad a_{f_2} = h_2 - T_0 s_2, \ a_{f_3} = h_3 - T_0 s_3$$

$$\dot{m}_1 a_{f_1} + \dot{m}_2 a_{f_2} - \dot{m}_3 a_{f_3}$$
$$= \dot{m}_1 (h_1 - T_0 s_1) + \dot{m}_2 (h_2 - T_0 s_2) - (\dot{m}_1 + \dot{m}_2)(h_3 - T_0 s_3)$$
$$= T_0 \{ -\dot{m}_1 s_1 - \dot{m}_2 s_2 + (\dot{m}_1 + \dot{m}_2) s_3 \}$$
$$= T_0 \{ \underbrace{\dot{m}_1 (s_3 - s_1) + \dot{m}_2 (s_3 - s_2)}_{(\Delta S)_{univ}} \}$$

$$\dot{m} a_{f_1} + \dot{m}_2 a_{f_2} = \boxed{\dot{m}_3 a_{f_3}} + \dot{I}$$

$$\boxed{\begin{aligned} &\dot{m}_1 (s_3 - s_1) + \dot{m}_2 (s_3 - s_2) = (\Delta S)_{univ} \\ &\dot{m}_1 s_3 + \dot{m}_2 s_3 = \dot{m} s_1 + \dot{m}_2 s_2 + (\Delta S)_{univ} \end{aligned}}$$

This becomes T_0 into m_1 dot s_3 minus s_1 plus m_2 dot s_3 minus s_2. What is this quantity? This is delta s $_{universe}$. That is T_0 into delta s $_{universe}$. This is the irreversibility rate.

If we make an availability balance, I see that availability outlet; that means, availability in plus m_2 dot af_2 is equal to m_3 dot af_3 plus I dot or other way. That m_3 dot af_3 is the availability out is equal to availability in, in terms of rate minus the destruction.

This is the availability balance. In this case, entropy balance also. Side by side, everything will be clear. Entropy balance is that m_1 dot s_3 minus s_1 m_2 dot s_3 minus s_2 is the change of the other.

If anybody writes this entropy balance, we will be writing m_1 dot s_3 minus s_1 plus m_2 dot s_3 minus s_2 is the delta s universe, where this m_1 dot s_3 plus m_2 dot s_3 are the entropy going out; that means, for a better understanding one can write this. Everything will be very clear and this is the entropy which came into the system with the flow. That means always entropy is being added, while going out you take more entropy. That means it is generated while that exergy or the availability is going out something is being taken for that, is the concept.

So, this is the entropy balance. Any way you can write. This shows a clear picture. Entropy going out is entropy coming in plus increase in entropy generation. Availability is same thing; availability going out is availability coming in minus the irreversibility.

In this case, how do you define the second law efficiency? Second law efficiency in this case, is defined like this.

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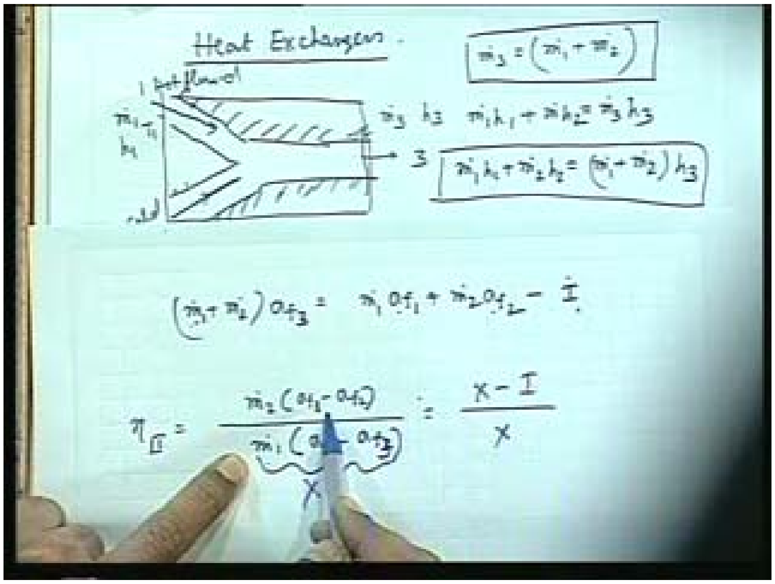

$\boxed{\dot{m}_3 = (\dot{m}_1 + \dot{m}_2)}$

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

$\boxed{\dot{m}_1 h_1 + \dot{m}_2 h_2 = (\dot{m}_1 + \dot{m}_2) h_3}$

$$(\dot{m}_1 + \dot{m}_2) a_{f_3} = \dot{m}_1 a_{f_1} + \dot{m}_2 a_{f_2} - \dot{I}$$

$$\eta_{II} = \frac{\dot{m}_2 (a_{f_3} - a_{f_2})}{\underbrace{\dot{m}_1 (a_{f_1} - a_{f_3})}_{X}} = \frac{X - \dot{I}}{X}$$

We have taken the availability balance. You can see the availability balance. Let us write the availability balance again. Let us write, availability balance. Let me write again. Availability balance is m_1 dot plus m_2 dot into af_3 is m_1 dot $af_{1.}$ Again, plus m_2 dot af_2 minus I dot. If I write the second law efficiency, second law efficiency in this case can be written in terms of any of the fluid.

Let this is the hot fluid. Sometimes, it is written in terms of cold fluid. This is the cold fluid which has gained the availability; that means m_2 dot af_3 minus $af_{2.}$ Corresponding loss of availability by the hot fluid is af_1 minus $af_{3,}$ this is the definition; that means, the availability increase in the cold fluid divided by the availability decrease in the hot fluid.

If you transfer it, term irreversibility will come into picture. That means this is the gain which is less than this by the amount irreversibility. If you transfer here m_2 dot af_3 minus

m_2 dot af_2, it will be m_1 dot af_1 minus m_1 dot af_3 minus I dot. That means it will be this thing. Let this thing is x; x minus I.

That means the availability released by this fluid, if I consider this as the hot fluid, is the convention we define in terms of the cold fluid that is not being taken by the cold fluid. Cold fluid availability gain will be less than the reverse by the hot fluid.

This way, we define the second law efficiency for heat exchangers. This is a mixing type. There may be non-mixing type that the masses are not mixed. They go separately with a separating wall. That will be clear, if we solve a problem.

There is one interesting problem after this, I like to place before you. So, after all these things, I think we are in solid positions.

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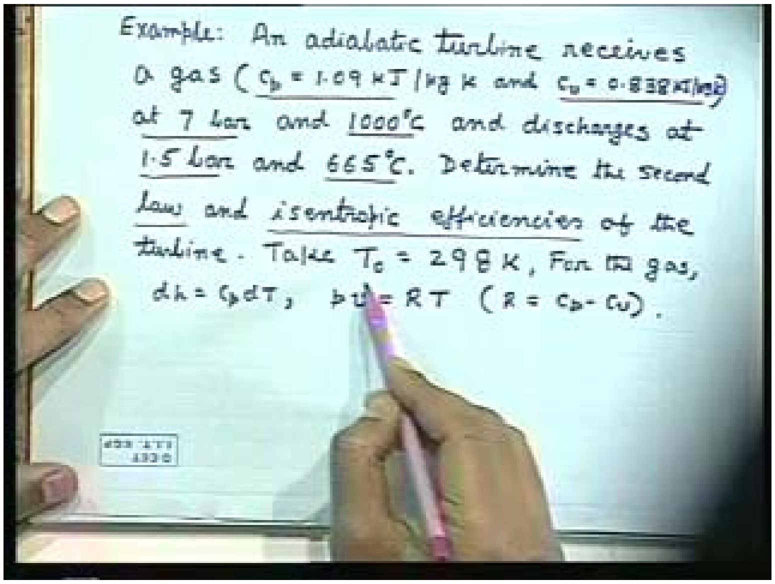

Example: An adiabatic turbine receives a gas (c_p = 1.09 kJ/kg K and c_v = 0.838 kJ/kgK) at 7 bar and 1000°C and discharges at 1.5 bar and 665°C. Determine the second law and isentropic efficiencies of the turbine. Take T_0 = 298 K, For the gas, $dh = c_p dT$, $pv = RT$ ($R = c_p - c_v$).

We are in a solid position to solve the problems. Let us consider a problem. An adiabatic turbine receives a gas whose properties are given c_p, c_v. and this type of gas always you take h is equal to c_pT. that is not given in this problem, you can take if it is required. I do not know. At seven bar and 1000 degree Celsius these are the important.

Discharges at 1.5 bar and 665 degree Celsius. Determine the second law and isentropic efficiencies. What is the difference between second law and isentropic efficiencies?

Isentropic efficiencies of the turbine; means take T_0 that is the environment temperature and it is already given for the problem $c_p dT$ and p v you take RT, where R is c_p minus c_v.

So, what is this problem? Now let us draw the sketch. The problem is like this.

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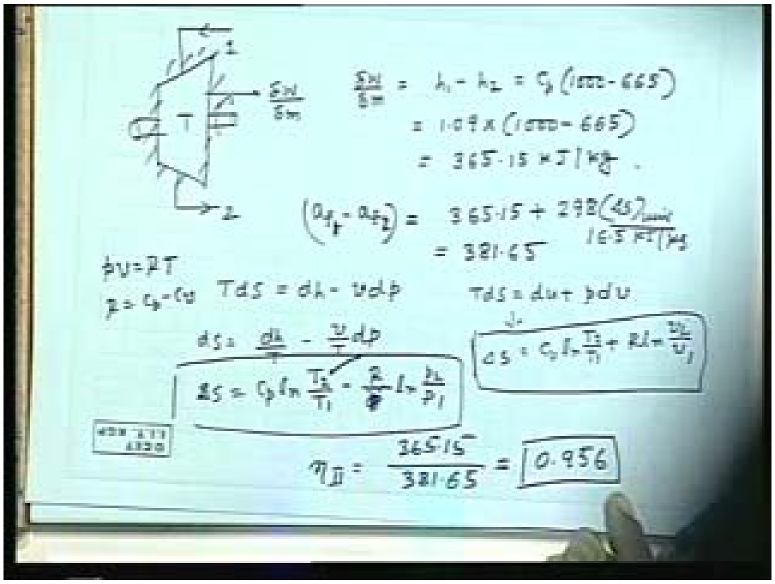

$$\frac{\delta W}{\delta m} = h_1 - h_2 = c_p(1000-665)$$
$$= 1.09 \times (1000-665)$$
$$= 365.15 \text{ kJ/kg}.$$

$$(a_{f_1} - a_{f_2}) = 365.15 + \underbrace{298(\Delta s)_{univ}}_{16.5 \text{ kJ/kg}}$$
$$= 381.65$$

$pv = RT$

$R = c_p - c_v$

$$T ds = dh - v dp \qquad T ds = du + p dv$$

$$ds = \frac{dh}{T} - \frac{v}{T} dp$$

$$\boxed{\Delta s = c_p \ln \frac{T_2}{T_1} - R \ln \frac{p_2}{p_1}} \qquad \boxed{\Delta s = c_v \ln \frac{T_2}{T_1} + R \ln \frac{v_2}{v_1}}$$

$$\eta_{II} = \frac{365.15}{381.65} = \boxed{0.956}$$

There is an adiabatic turbine which gives del w divided by del m is the work. It is coming in section one, the working fluid goes at section two that is one and two. Then, what is the value of del w divided by del m? del w divided by del m is h_1 minus $h_{2,}$ per unit mass basis I am doing.

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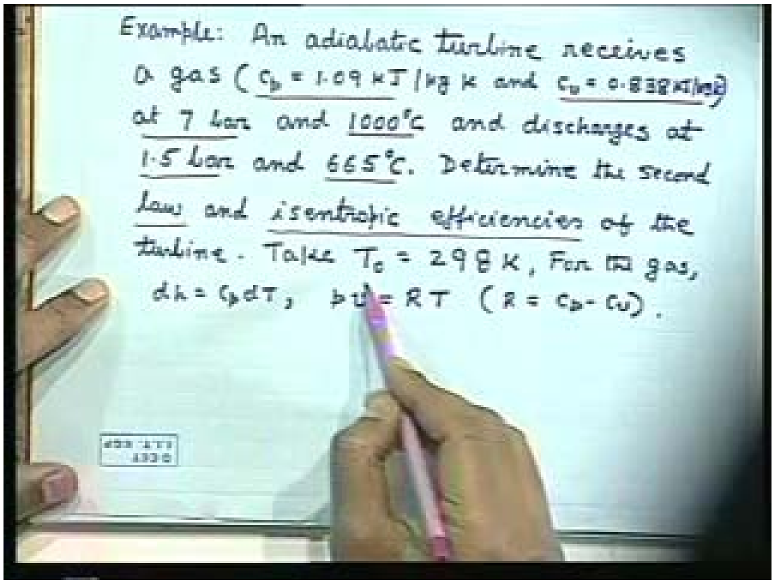

Example: An adiabatic turbine receives a gas ($c_p = 1.09$ kJ/kg K and $c_v = 0.838$ kJ/kg K) at 7 bar and 1000°C and discharges at 1.5 bar and 665°C. Determine the second law and isentropic efficiencies of the turbine. Take $T_0 = 298$ K, For the gas, $dh = c_p dT$, $pv = RT$ $(R = c_p - c_v)$.

h is given. Then dh is $c_p dT$.

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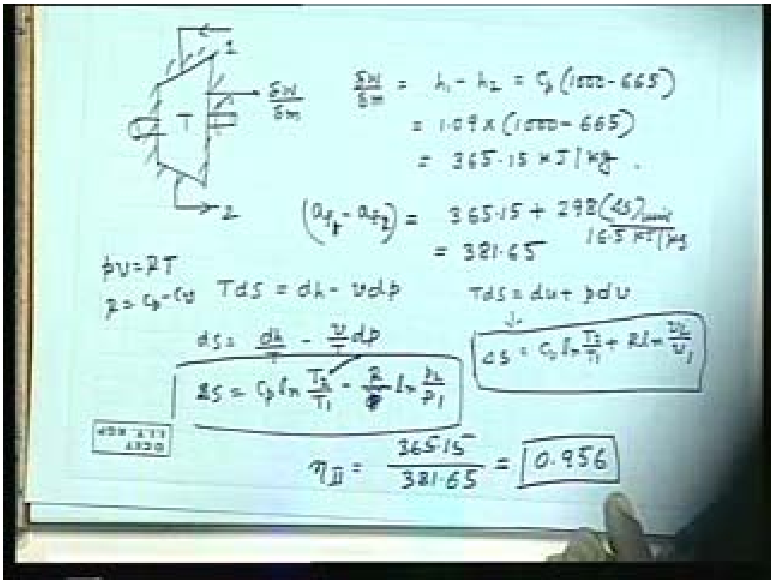

$$\frac{\delta W}{\delta m} = h_1 - h_2 = c_p(1000 - 665)$$
$$= 1.09 \times (1000 - 665)$$
$$= 365.15 \text{ kJ/kg}.$$

$$(a_{f_1} - a_{f_2}) = 365.15 + 298(\Delta s)_{univ}$$
16.5 kJ/kg
$$= 381.65$$

$pv = RT$

$R = c_p - c_v$ $\quad T\,ds = dh - v\,dp$ $\quad T\,ds = du + p\,dv$

$$ds = \frac{dh}{T} - \frac{v}{T}dp$$

$$\boxed{\Delta s = c_p \ln\frac{T_2}{T_1} - R \ln\frac{p_2}{p_1}}$$

$$\boxed{\Delta s = c_v \ln\frac{T_2}{T_1} + R \ln\frac{v_2}{v_1}}$$

$$\eta_{II} = \frac{365.15}{381.65} = \boxed{0.956}$$

That means I can write $c_{p.}$ T_1 minus $T_{2,}$ where T_1 is 1000 degree Celsius and T_2 is 665 degree Celsius. I can write in terms of Celsius, because it is the difference and c_p value quals to the value of c_p given. c_p is 1.09 kilo Joule per kg. So, this comes out to be 365.15 kilo Joule per kg. So, per unit mass basis I find out what is the actual work done.

Now, what is the ideal work done af_1 minus af_2? What is that? af_1 minus af_2 is 365.15 plus which could have become if the process was reversible plus T_0, T_0 is 298 into delta s $_{universe}$. What is delta s $_{universe?}$ It is the delta s of the system. So, delta s of the system in this case if you have to find out, you have to use this equation.

Tds is why I am writing? This is not du plus vdp, because it is better to write in this fashion. You can write, Tds du plus also does not matter I write both this. So, if we write this, then ds is dh divided by T minus v divided by T into dp. dh is c_pdT that means delta s is $c_p l_n$ into T_2 divided by T_1 minus, what is v by t? p v into RT that means R by P. R is c_v l_n into p_2 divided by p_1. So this is the expression. If we equate this, this will be

[Conversation between Student and Professor minus Not audible ((00:28:26 min))]

I am extremely sorry very good you are following nicely. So I am very happy. c_v l_n into T_2 divided by T_1 plus R into l_n into v_2 divided by $v_{1.}$ These two expressions are identical. So, any of these two equations I can write.

Here, if you calculate T_2 is what given 665 degree Celsius. Corresponding to that, you can find out what is the absolute temperature T_1, p_2 by p_1 ratio we can put it in any unit seven and 1.5 bar accordingly. You put it and get the value. af_1 minus af_2 will be equal to 381.65. What is second law efficiency?

Second law efficiency we will be 365.15 divided by 381.65 and that comes to be

[Conversation between Student and Professor minus Not audible ((00:29:36 min))]

0.956 You have already done it very good. But what is isentropic efficiency? The evaluation of second law efficiency is the routine job. As we have already applied, this thing, in general for a turbine compressor, this is a routine job by putting the numerical values.

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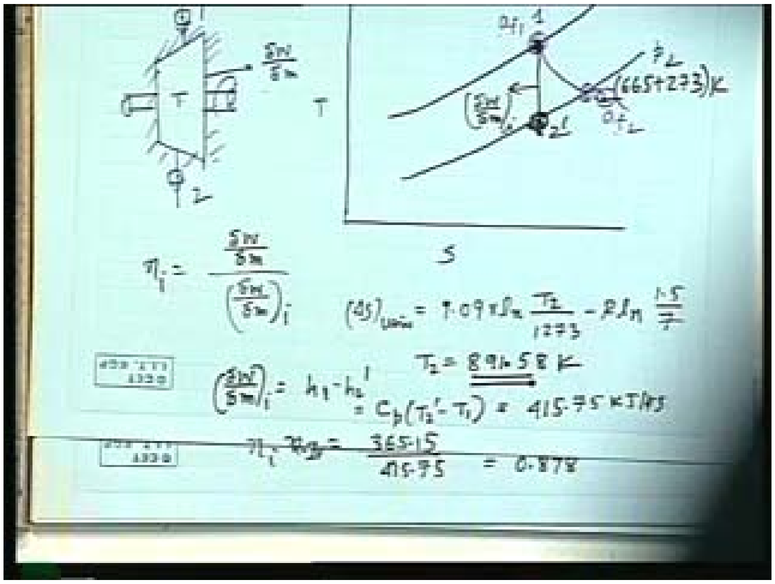

Now, isentropic efficiency concept is like this. This is a turbine. It comes at state one and it goes at state two. Isentropic efficiency will come afterwards in the cycle analysis. This state one is fixed and state two is fixed. This is the turbine and we get a work del w divided by del m.

Now, isentropic efficiency is like this. If I plot a Ts diagram, let us consider this is the constant pressure line p_1 and let us consider this as a constant pressure line p_2. If we consider this as a gas, either a superheated vapor or air or any gas, where the constant pressure line looks like this. If this is state one and this is adiabatic, but this is not a reversible process; that means, adiabatic reversible [.] will be isentropic. Otherwise, it is not isentropic. Now, the question comes. It is isentropic means it will be vertical. If it is not isentropic that means a natural process that means irreversible adiabatic. From the figure or the graph, it can be either this side or this side healing but it cannot heal on this left side. This is because the entropy of the system will decrease which will lead to the decrease in the entropy of the universe, since the process is adiabatic. So, entropy change of the surrounding is zero.

Therefore, the only solution is that the entropy of the system will increase. That is because internal irreversibility. So, the process is like this. So, this is the end two. What we have considered in the second law efficiency that between the same state point one and two, if we could have considered hypothetically that irreversibility part is zero then the efficiency which I arrive is this second law efficiency.

It is very difficult to understand. I am telling you, think yourself so that you can understand.

This difference is very subtle between the second law and isentropic efficiency. Second law efficiency is that we fix these two states, but there is an irreversibility between the two states. If irreversibility could not have been there but the system state two that means we are finding out af_1 and af_2 difference that we are telling the af_1 minus af_2 is the ideal work, provided the system comes from state one to state two, is the theoretical abstraction or theoretical concept. Because this availability is always designated to the state point. Though it is a composite property, but if we consider the environment fixed that this composite property becomes a function of the state points of the system.

When the two states are fixed then af_1 and af_2 are fixed and their difference is the ideal work; that means, the work which could have been obtained if we discard the irreversibility If we discard the irreversibility for the process connecting the same state points. But now, if I consider another picture that this system starts from same initial state but it goes under a reversible adiabatic process.

If we consider a reversible adiabatic process or isentropic process with the same initial state, then this process could have ended here and not there; that means, this is the ideal process. That means if the process could have been ideal, we give a relaxation on the final state point very important no book has defined this thing. I am telling you. You will not get such illusion explanation in any book the difference between second law and isentropic efficiency.

If we are not bothered about the final state point but if we consider that for the same initial state point, what could have been the final state point? If I could have made a reversible adiabatic process then the work output of this process del w divided by del m.

if I consider this as the work for the isentropic process. Then the isentropic efficiency is del w divided by del m divided by del w divided by del m into i.

How to find out the work done in this process? That means the same initial state, but a reversible adiabatic process which ends up to a difference states, then we have to find out s_2 and corresponding h_2. So, how to find out this h_2? That means, we have to find out this $T_{2;}$ that means s_2 means the change of the entropy of the universe will be zero.

How do you write the change of the entropy of this thing? We can write delta s $_{universe}$ is equal to dh that means c_p which is 1.09 into l_n into T_2 divided by T_1. What is T_1 is 1273 minus Rl_n between the same pressure. So, pressure ratio remains the fix; same remains fix that means l_n 1.5 divided by 7 this gives you a temperature T_2 .

Let me tell you I have done it. This gives you a temperature T_2 which is equal to 891. I am sorry there is a problem. What was your temperature there? c_pl_n T_2 divided by $T_{1.}$ This T_2 has to be more than this. So, there may be a calculation mistake. T_2 in this case isentropic expansion is 891.58 k that is less than this, because this is 665 degree Celsius. This T_2 is 665 plus 273 k. This T_2 comes out to be this. The del w divide by del m into I will be then h_1 minus h_2 dash which becomes equals to c_p into T_2 dash minus $T_{1,}$ because the property relationship is dh is c_pdT.

We can find out this del w divide by del m and this becomes isentropic work; so, that becomes equal to 415.75 kJ per kg and accordingly eta two is 365.15 divided by 415.75 which becomes equal to 0.878.

[Conversation between Student and Professor minus Not audible ((00:37:20 min))]

Sorry Sorry eta I eta I so clear.

Isentropic efficiency and the second law efficiency are proportional to each other. Both of them are the measure of the departure from the irreversibility, but it is visualize to different concept. There is nothing great in it. Just the way we characterize it. Sometime we characterize it with the same end state points by this formula; that is eta. Second law efficiency or we characterize the process in this way that if for the same initial state, within the same pressure ratio, there could have been an isentropic process. What could have been the end and what could have been the ideal work? That we gauge the departure from reversibility and define that parameter as the ratio of these two works that is the actual work by ideal work as the isentropic efficiency.

Another very simple problem. After this conceptual problem, we should have one very simple problem. You just see this problem.

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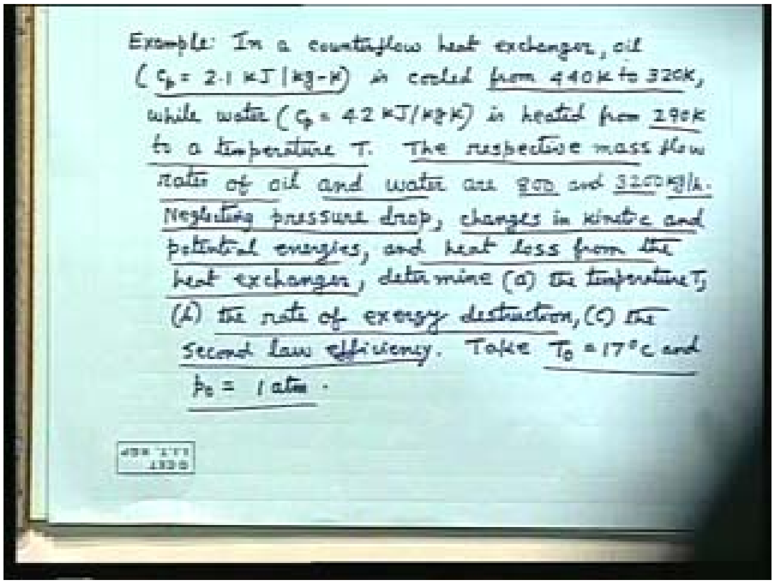

Example: In a counterflow heat exchanger, oil (c_p = 2.1 kJ/kg-K) is cooled from 440K to 320K, while water (c_p = 4.2 kJ/kgK) is heated from 290K to a temperature T. The respective mass flow rates of oil and water are 800 and 3200 kg/h. Neglecting pressure drop, changes in kinetic and potential energies, and heat loss from the heat exchanger, determine (a) the temperature T, (b) the rate of exergy destruction, (c) the second law efficiency. Take T_0 = 17°C and p_0 = 1 atm.

In a counter flow heat exchanger, oil whose property values are given; oil at c_p is 2.1kilo Joule per kgk is cooled from 440k to 320k. This is the problem of heat exchanger. While water is heated from 290k to a temperature of T unknown temperature and this is a heat exchanger, where there is separation; they do not mix. The respective mass flow rates of oil and water are 800 and 3200kg per hour. Neglecting pressure drop, these are usual assumptions. If they are not given, you will assume this there is a steady flow process. So, pressure drop, we will neglect.

If there is a incompressible fluid flowing steadily through a duct, so pressure drop is only because of the viscosity. So, one can neglect that viscous pressure drop within a short length of duct. This is the practical thing. Changes in kinetic and potential energies and heat loss from the heat exchanger; that means there is no heat loss from the heat exchanger. That means the transfer of heat is between the two fluids oil and water. Determine the temperatures T, the rate of exergy destruction, the second law efficiency. Take the environment temperature.

It is a straightforward application for the definition of second law efficiency or application of second law efficiency in a heat exchanger. Let us think of this problem. You have taken the problem. I am drawing this block diagram then it will be clear. Not necessarily always you will have to take in language. However, again I am repeating; in a counter flow heat exchanger oil, specific heat at constant pressure 2.1 kilo Joule per kgk is cooled from 440k to 320k. While, specific heat at constant pressure 4.2kilo Joule per kgk is heated from 290k to a temperature of T; unknown temperature that we have to find out. The respective mass flow rates of oil and water are 800 and 3200kg per hour neglecting pressure drop changes in kinetic and potential energies and heat loss from the heat exchanger, determine the temperature T, while the rate of exergy destruction in the process the second law efficiency, given the reference the ambient temperature.

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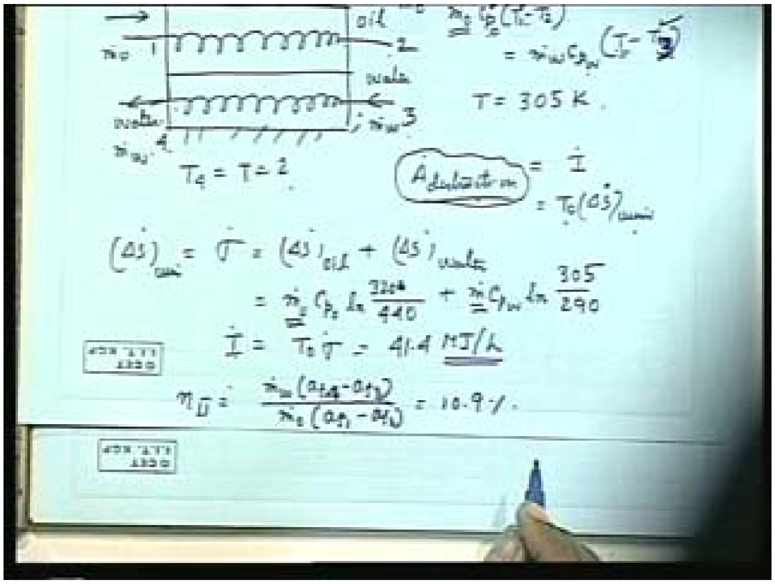

First of all, we must draw the figure here. This is the heat exchanger. This is divided into two partitions. In this, there is coil for the oil. Let oil goes in this direction and this is the inflow. Counter flow means they go in the opposite direction. They are parallel flowing parallel but in the opposite direction, water going out.

Let m dot o is the mass flow rate of oil and m dot w is the flow rate of water. They remain same. From the conservation of mass, entire thing is adiabatic. Very simple problem. Let this section is one, this section is two, this is three and this is four. So, one pertains to the inlet of oil, two pertains to the outlet of oil, three pertains to the inlet of water, and four outlet of water.

So this T_1, T_2, T_3 given T_4 has to be found. T_4 is to be found out .Now, write the energy balance equation. Energy balance equation is m dot o h_1 plus m dot w h_3 must be equal to leaving out m dot o h_2 plus m dot w h_4. In this problem, we have to consider, again the same thing that dh is c_pdT that means dh is c_pdT for the water; also, water and oil that is the fluid.

Therefore, we can take in one side c_p into T_1 minus T_2 is equal to m dot w that is c_{p0} oil and c_{pw} into h_4 minus h_3 that means T minus T_3. Everything is given; T_1 is given, m dot o is given, c_{p0} is given and T_w is given. We may convert the unit in kg per second. We may put it in kg per hour, because this will cancel each other, all in the consistent units. So, we can find out the T.

Everything is given Tw now sorry I am extremely sorry this will be T minus T three I am sorry T three. Value of T will be what 305 k, a school level thing. Enthalpy coming in; that means, the energy coming in with oil with water these are the energy coming in, because there is no heat, work interaction. changes in kinetic potential energies are same sorry negligible and this is going out.

So, I bring it in one. Since dh is c_pdT; therefore, h_1 minus h_2 is c_p divided T_1 minus T_2 and h_4 minus h_3 is c_pw T minus $T_{3.}$ Now, you are not told to find out the change in the flow availability, because calculation will be little more. But if you are asked to find out the irreversibility, or what rate of exergy destruction? That means a dot that is exergy destruction which is nothing but I dot which is nothing but T_0 delta s $_{\text{universe}}$.

We do not bother to find out the availability at the terminal points and make an availability balance. It is not required. We can simply write that, from the availability balance concept, we know the rate of destruction of the availability is the rate of irreversibility which is T_0 into delta s $_{universe}$. What is delta s $_{universe}$ dot? Delta s $_{universe}$ dot looks better if you write in terms of rate of generation of entropy which is oil is from one to two that means this is delta s dot oil plus delta s dot water that is m dot o c_{po} $l_{n.}$ Then you tell l_n T_2 divided by T_1. So, what is T_2?

[Conversation between Student and Professor minus Not audible ((00:45:45 min))]

T_2 is 320, because now it is cooled and it becomes 320 divided by 440 plus m dot. c_{pw} l_n T, T is 305 and T_1 is 290.

[Conversation between Student and Professor minus Not audible ((00:46:05 min))]

So, you find out this. I dot is T_0 sigma dot and the value is what? Destruction in the availability. That value will come 41.4. If we do not convert here also per hour then this rate will also be in the same time unit for T_1 does not matter, Mega Joule per hour. Why unnecessarily you convert it? There is no need. Nobody has asked this question. Just like a primary school boy that you find out the I dot in terms of jper Second. If it is not told then let us find it in terms of hour.

How to find out second law efficiency? Second law efficiency here the same way we can find out that m dot water into af_4 minus af_3 divided by

[Conversation between Student and Professor minus Not audible ((00:47:15 min))]

m dot oil into

[Conversation between Student and Professor minus Not audible ((00:47:16 min))]

af_1 minus af_2 two. You can find out the second law efficiency will be equals to 10.9 percent. You see this heat transfer through a very very finite temperature difference in such irreversibility loss 10.9 percent. This is the definition of this second law efficiency.

We can express one in terms of the other through this, because this will be this minus I dot so that you can calculate only this one, because since the I dot is calculated, you can make the calculation. It does not matter.

Anyway you can do it clear please tell me this concept is clear.

[Conversation between Student and Professor minus Not audible ((00:48:08 min))]

I can expect that you can solve any problems in availability. Now I will start a new chapter today. I could have left you but you see this is a studio class, where I cannot leave you before one hour. Let us start the next one; the important property relations.

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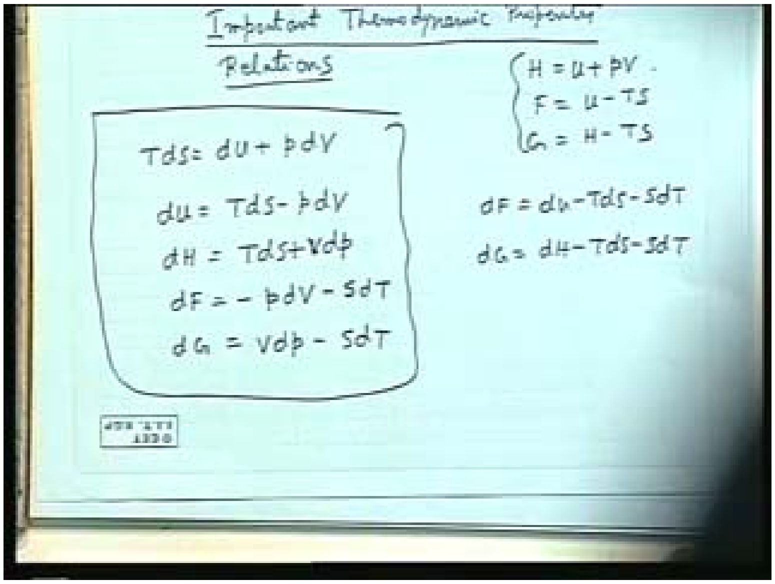

Important Thermodynamic Property Relations

$Tds = du + pdV$

$du = Tds - pdV$

$dH = Tds + Vdp$

$dF = -pdV - SdT$

$dG = Vdp - SdT$

$H = u + pV$

$F = u - TS$

$G = H - TS$

$dF = du - Tds - SdT$

$dG = dH - Tds - SdT$

Important thermodynamic property relations; let us find out what we have known up to the date. You know Tds is equal to du plus pdV. This is the property relations we know and at the same time, this can be written in a form du is equal to Tds minus p dV. I can write dH is equal to Tds plus vdp where from it comes H plus .very good so you are more knowledgeable than me. H is equal to u plus pV. So, from there we can find du plus pdV is Tds plus Vdp. I will introduce two new properties one is Helmholtz function.

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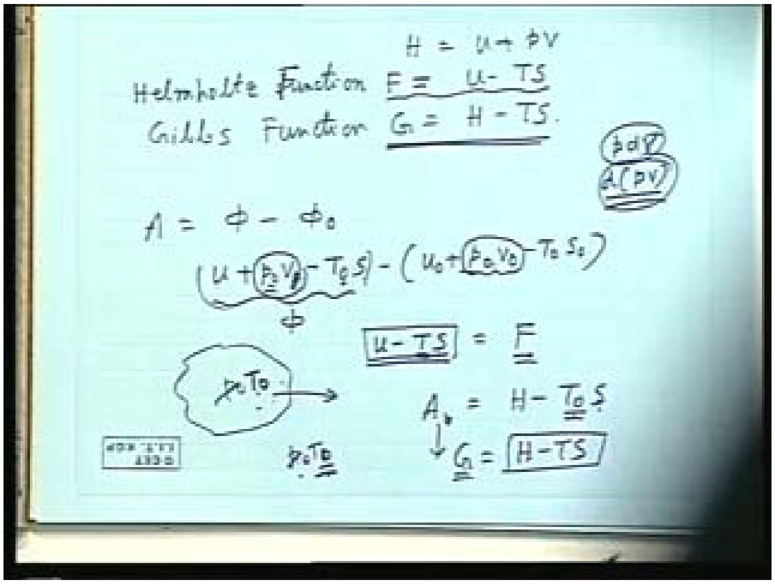

I told you that any jugglery between the properties will be another property, but just like that we cannot define a number of millions of millions properties. These must have a physical significance. The way, u plus pV has been made like that. A combination u minus pV or u by pV does not bear any physical sense, but u plus pV has an enormous physical significance that enthalpy.

Similarly, Helmholtz function F is defined as u minus Ts such a combination and Gibbs function. These are the names of the scientists who discovered Gibbs function.

[Conversation between Student and Professor minus Not audible ((00:50:35 min))]

H minus Ts. I think that some physical significance have to be told that the moment otherwise, you will not feel interested. For mathematical operation, it is enough to know the definition mathematically that F is equal to u minus Ts. G is equal to H minus Ts, the way you define the enthalpy u plus V.

This Helmholtz function, if we recollect that our availability that is the maximum work is some phi, at any state minus phi zero, where phi u plus p_0 V minus T_0 s and phi zero is corresponding to that u_0 plus p_0 sorry not V zero V . p_0V_0 minus T_0s_0. This is our availability function which is a composite function or a composite property of system and surrounding. Why because this p_0 that is $T_{0.}$

This p_0 part, if I neglect that means if I consider that the system, the work which is being done. The work to compress the surrounding I neglect or I consider a system whose pressure and temperature is same as that of the surrounding. but you can tell, sir if it is a single component system then both the properties are same; that means, they are in the same state and that is a dead state. So, nothing will happen.

Therefore, I relax. I consider the system temperature $T_{0;}$ if any process be same as that of the environment, and system performs a process isothermally; that means, the temperature remaining the same then this T_0 can be written as simply temperature of the systems, because temperature remains constant and that becomes equals to the temperature of the environment.

I can express a property of the system which is F. Let me denote it by F which is u minus Ts, whose physical significance is that the changes in this function represent the maximum work, reversible work. That we can obtain from a close system under an isothermal condition, where the constant temperature of the system equals to that of the surrounding.

Again, I am telling then you will ask it is the maximum work obtained along with the non useful work, unuseful work; that means, inclusive of the displacement work obtained by a system. This is a concept. You try to think, if it executes an isothermal process means that constant temperature and that temperature equals to the environment temperature.

For example, when I equate pdV, sometimes at a constant pressure process becomes equal to d of pV. No pressure is constant. So, this and this is the same thing. Similarly, if the temperature of the environment and temperature of the system remains same throughout; that means, we can take T_0 and we can replace T_0 as T. That means one can tell, sir it is u minus Ts; that means, if I know the system property I can find out. So, surrounding has not to be spelled. If I tell that is system has got this internal energy, this entropy and this temperature and it comes to a state where this is the internal energy and the same temperature and the entropy and the surrounding has a temperature of which is same as the system temperature under isothermal condition. Then though the surrounding temperature is given, but only thing is that I have to take into mind that system temperature and surrounding temperature is the same.

It is the difference between the Helmholtz function which gives the reversible work or the maximum work in that process. This is very important in chemical reactions; reaction process which takes place at constant volume where the isothermal condition is maintained.

This is not beyond the scope of our study here. How this Helmholtz function is being used. Similar is the case in the Gibbs function, but it is with respect to a control volume or open system. We have seen in open system, what is the availability A. A is equal to H minus T_0 s. Changes in this composite function, because T0 is there not only of the system. Change of this is responsible for the maximum work, reversible work by a particular system at a different state flowing through a control volume.

If I consider that the system is an isothermal system sorry process and the working system maintains the isothermal condition, where the end and the initial temperature remains the same. That becomes equal to reference environment temperature. Then I can replace T_0 as Ts and can define a property or function which is a property of the system. Only that is the Gibbs function.

Gibbs function is the maximum work available from a control volume for a given a state of its working system at the inlet, provided the process is isothermal and the temperature constant temperature equals to the surrounding temperature. For example, again I am telling if I have a control volume, if I have a system at state one and system at state two, no isothermal condition, no constant pressure, then the maximum work which we can get is the difference between the two functions at outlet and inlet, which are the composite functions of system and the environment, where only temperature of the environment comes into picture.

What is that? H minus T_0 s is that function; that is H_1 minus T_0 s_1 minus H_2 minus T_0 $s_{2,}$ difference of these two. But if I tell that similar thing, but with added restriction, or constant that the process is isothermal and that temperature equals to the temperature of the surrounding. In that case, the maximum work which we could obtain is the difference between Gibbs function which is purely a system property, not the composite environment property, because does not matter, environment temperature and system temperature thy are same and this is very important in a constant pressure reaction process, where the reactor is continuously cooled to the ambient temperature at a fix reference temperature and the reaction takes place in an isothermal process. They are the availability loss or the maximum work obtained. From a chemical reaction, no work is obtained, but we are interested in finding out the destruction of the availability or exergy in this chemical reaction.

The difference in Gibbs function gives you that concept. This physical concept, I think enough for our class because we are not going to implement this in the physical processes because this is beyond our scope. This difference in Helmholtz or Gibbs function, but for the time being, this physical understanding is enough. We should only remember this formula that F is equal to u minus Ts that is Helmholtz function. G is equal to H minus s. We add two extra properties. Now what is dF? and what is dG? please tell me. dF is equal to du minus Tds minus sdT.

What is du? du minus Tds is minus pdV. So, this is minus pdV minus sdT. What is dG? dG is equal to dH minus Tds minus sdT. dH minus Tds is Vdp minus sdT. These four relations are the very basic property relations of thermodynamics, from which we will derive many important and interesting relations afterwards in the next class, because time is up.

We will start from this point; that means, four properties internal energy important property, enthalpy Helmholtz and Gibbs function are expressed in terms of their differentials and in terms of other two properties. So up to this today.

Thank you.