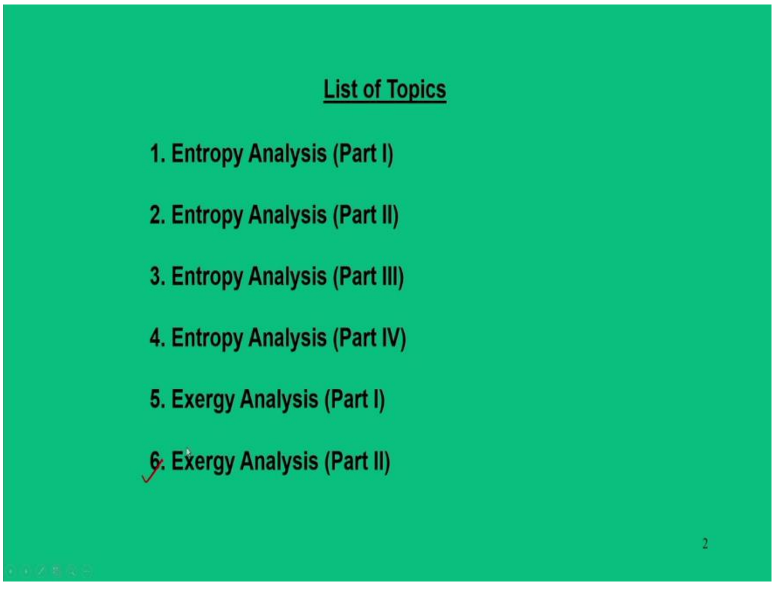
Advanced Thermodynamics and Combustion
Prof. Niranjan Sahoo
Department of Mechanical Engineering
Indian Institute of Technology, Guwahati

Module - 02
Entropy and Exergy
Lecture - 09
Exergy Analysis (Part II)

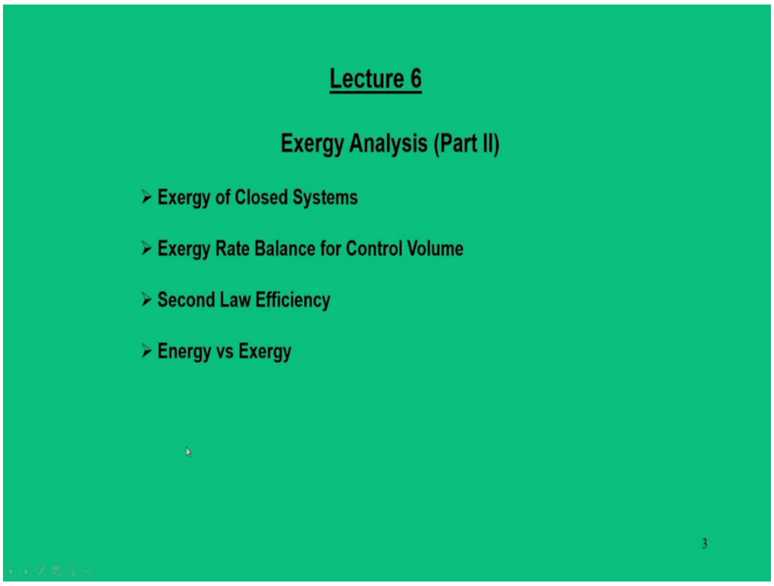
Dear learners, greetings from IIT Guwahati. We are in the MOOCs course, Advanced Thermodynamics and Combustions, module 2 Entropy and Exergy.

(Refer Slide Time: 00:44)



So, in this module we have covered entropy analysis and also partly exergy analysis. In today’s class, we will again discuss about exergy analysis part II. And in fact, it is the last lecture of this module.

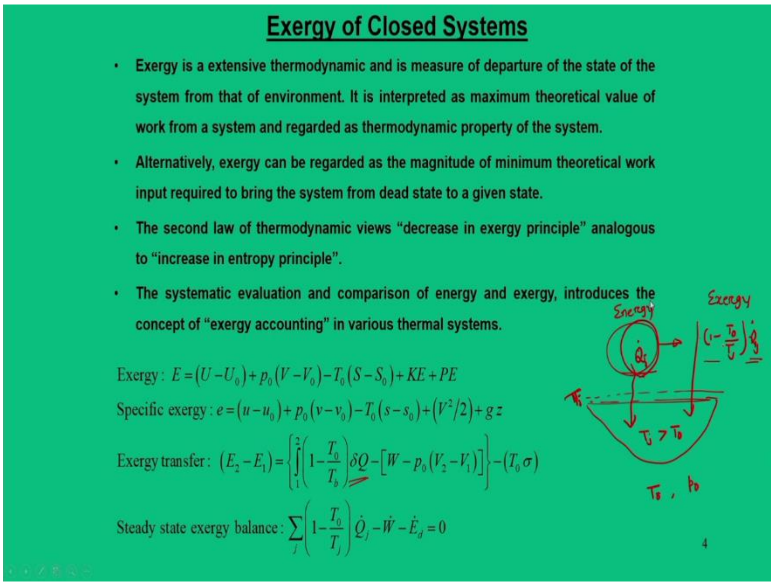
(Refer Slide Time: 01:05)



So, in this lecture, we will briefly discussed about exergy of the closed systems, which we have covered in the previous lecture. Then moving further we will discuss the exergy rate balance for a control volume. So, initially we started with closed systems, then we will move to control volume. Now, on this basics we will introduce another concept what we call as a second law efficiency.

Many a times it is also referred as exergetic efficiency and towards the end we will try to make a comparison what is energy and what is exergy. How they are viewed while doing the thermodynamic analysis.

(Refer Slide Time: 02:00)



So, let us start this lecture, we have already covered the exergy for the closed systems in our earlier lectures. In order to give the brief introductions, I can note down the following points that we all know that exergy is a thermodynamic property and it is an extensive property, it is a measure of departure of state from the system with respect to environment. And it is interpreted as maximum theoretical value of work from a systems and it is regarded as the thermodynamic properties like energy.

Now, in some situations, when there is a work input to the systems in that sense we can say that exergy is regarded as the magnitude of minimum theoretical work input or required to bring the systems from the dead state to given state. Or in other words when you say the system moves from its original state to dead state, it produces work output. When it moves from dead state to a given state or any arbitrary state, then it is the work input to the systems.

Now, with this concept, the second law of thermodynamics views this as a decrease in the exergy principle. So, in the context of entropy, where you say is that entropy of universe always increases. So, in that sense or we call this as an increase in the entropy principle, in similar way we can also view the exergy principle as decrease in exergy for the universe.

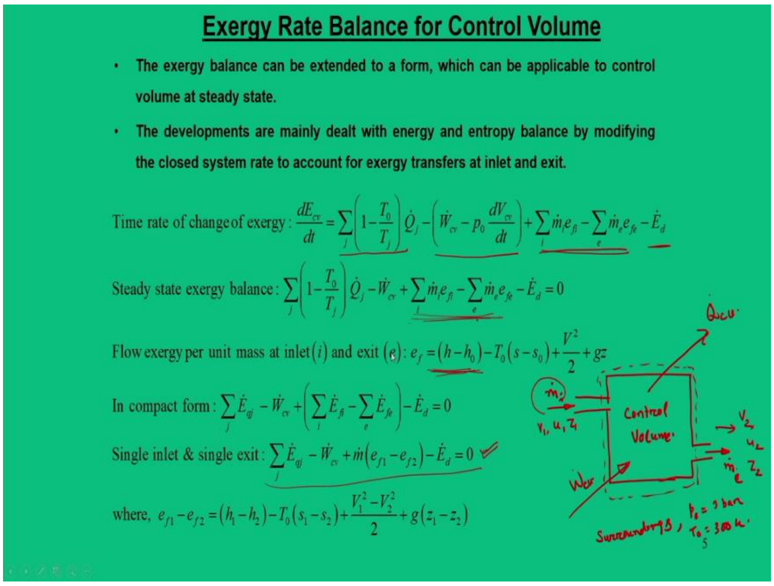
Now, why we require exergy? Because the systematic evaluation and comparison of energy and exergy introduces the concept of exergy auditing for various thermal systems. In our previous lecture we derived the expressions for exergy; that means, any systems which is at any arbitrary initial states, with internal energy U, volume V, entropy S with certain kinetic energy and potential energy. Then exergy for that systems can be considered with respect to environment for which the environment is in dead state or the when the system moves from its arbitrary state to dead state, when it reaches the dead state or in other words it is ambient or surrounding pressure and temperature which is p_0 and T_0, at that point the dead state will have internal energy of u_0, volume v_0, and entropy s_0. And the difference between these numbers we will talk about exergy for the systems when it goes from a given state to a dead state.

Similar way we can define the specific energy, we can find out the exergy transfer and we can get the steady state exergy balance. Or in other words, if you look at this exergy transfer we mainly concentrated about the heat part, because heat is a low grade energy and complete conversion of low grade energy to high grade energy is not possible.

Now, during this conversion, you can see that there is a ratio $1 - \frac{T_0}{T_b}$; T_b is the boundary temperatures. For example, if we can say that there is a system which exchanges heat to some environment. So, $\dot{Q}_j$ comes from as a heat into this systems T_j, which is greater than T_0. So, if this is the energy transfer, the corresponding exergy transfer would be we can say $\left(1 - \frac{T_0}{T_j}\right)\dot{Q}_j$, T_j will be the boundary temperature.

So, you can see here, although the energy is Q_j, but there is another term which is $\left(1 - \frac{T_0}{T_j}\right)\dot{Q}_j$, this information is about exergy. So, this is what the main difference when you deal with energy and exergy for a closed systems.

(Refer Slide Time: 07:20)



Now, we will move to the exergy rate balance for a control volume. So now, when I dealt with a control volume, I can say that both energy transfer and mass transfer is possible. That means, we can schematically represent a control volume in which certain mass flow rate is entering into the systems, we say inlet $\dot{m}_i$ and some mass flow which goes out we say $\dot{m}_e$.

Now, in this process, there could be heat transfer, there could be work transfer. So, there are lot of possibilities. Now, for this mass flow rate there may be the flow velocity which is entering V_1 and the flow velocity which may be leaving is V_2. It may have internal energy u1, u_2 and its elevation could be z_1 and this could be z_2.

So, all these possible terms can be included and apart from that when you when you do the analysis of exergy we need to think about the surroundings or environments and this environment condition is normally referred as p_0 1 bar, T_0 300 kelvin.

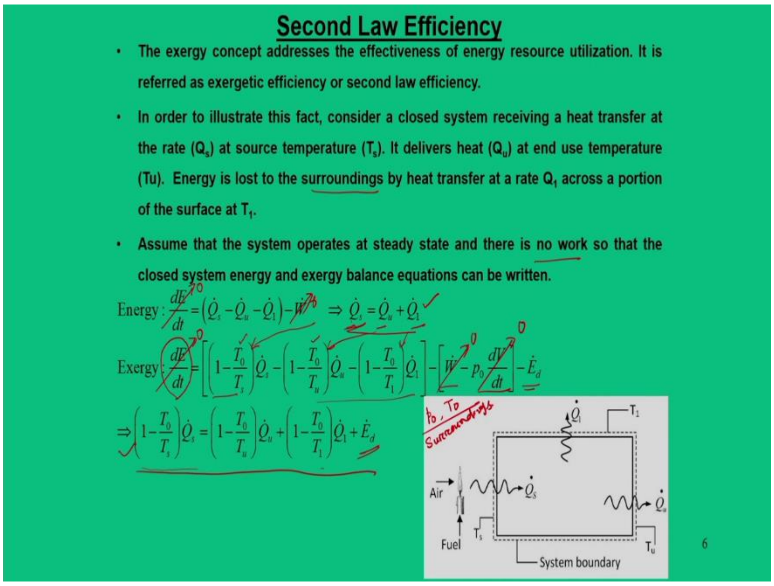
Now, for this control volume, we can find out time rate of change of exergy $\frac{dE_{cv}}{dt}$, this could be with respect to heat, could be respect to work; that means, work transfer to the control volume. Because when there is a work transfer, there is a another resistance to this work flow that is from the surrounding or environment and this particular terms comes by virtue of the flow and this is the this $\dot{E}_d$ is exergy destructions. $\frac{dE_{cv}}{dt} = \sum_j \left(1 - \frac{T_0}{T_j}\right)\dot{Q}_j - \left(\dot{W}_{cv} - p_0\frac{dV_{cv}}{dt}\right) + \sum_i \dot{m}_i e_{fi} - \sum_e \dot{m}_e e_{fe} - \dot{E}_d$.

So, first term refers to heat, second term refers to work, third term refers to mass transfer into and out of these things and last term is the exergy destructions. And these equations can be reduced for a steady state where $\frac{dE_{cv}}{dt} = 0$ and we can write that expression; subsequently in this case we can see that there could be multiple number of inlets and multiple number of outlets, for which we have summation of i or summation of e.

Now, if there is a single inlet and single exit, then this information will come in the form of enthalpy for unit mass. Then in a compact form, we can rewrite this expressions and subsequently single inlet and single exit we write this expressions. $\sum_j \dot{E}_{qj} - \dot{W}_{cv} + \dot{m}(e_{f1} - e_{f2}) - \dot{E}_d = 0$.

So, finally, exergy rate balance for the control volume can be expressed by this last expressions, where we have to find out $e_{f1} - e_{f2} = (h_1 - h_2) - T_0(s_1 - s_2) + \frac{V_1^2 - V_2^2}{2} + g(z_1 - z_2)$, that is exergy due to mass flow at inlet and outlet. In fact, these are the working formula to be used for solving the problems.

(Refer Slide Time: 11:26)



Now, the concept of exergy also introduces another term, we call this as a second law efficiency. And mostly this we will try to interpret with respect to an closed systems. And as you refer in this particular figure, we are going to see that for a closed system how energy and exergy can be related.

So, for that let us see this particular figure, we have a system it has a boundary, system boundary. Now, there are some source of heat which is available in the form of air or fuel mixture and this heat we are going to utilize in a suitable form.

So, I will say that $\dot{Q}_s$; that means, for this systems, the left side of the surface which is maintained at surface temperature T_s, it interacts with this air fuel mixture for which heat enters to the system is at a rate $\dot{Q}_s$. And in the another side of this closed systems, heat leaves out for its utilization and this temperature is maintained at T_u.

So, this is something like we have a Carnot cycle, which is similar to what one is source and other is sink. So, here we have one temperature is T_s other temperature is T_u and in this process you get $\dot{Q}_s$ as input and $\dot{Q}_u$output. But apart from this, in fact, when you do the energy analysis or in the second law analysis, this was viewed as a situation where environment is not taken into account.

Loss of heat to the environment is not taken into account or in other words you do not exactly quantify how much energy that is lost to the surroundings or environment due to irreversibility. So, for that another term is used here which is $\dot{Q}_1$ and this is not nothing but the energy lost to the surrounding by heat transfer and this heat loss is happening at a surface temperature T_1.

Now, we assume that the system operates at a steady state so that there is no work and so that we can write down the closed system energy and exergy balance equations. So, if you look at this particular figure, one angle we can write this rate of energy change with respect to time $\frac{dE}{dt}$ is difference of heat and work. And since we say there is no work transfer. So, this term vanishes and when there is a steady state $\frac{dE}{dt}$ also goes to 0. So, this expression becomes $\dot{Q}_s = \dot{Q}_u + \dot{Q}_1$. So, this is simply the energy balance.

Now, we are going to look at what is the exergy balance. So in fact, when you deal with exergy for same term $\frac{dE}{dt}$which is we will interpret as exergy, because E is your energy, we view this as a $\frac{dE}{dt}$. But same E when you interpret as exergy here we will have the exergy term which is associated with each of this heat transfer.

So, first one is $\dot{Q}_s$ which is the input to the systems, corresponding exergy value we can have $\left(1-\frac{T_0}{T_s}\right)\dot{Q}_s$ and for the $\dot{Q}_u$, the corresponding rate of exergy term will be $\left(1-\frac{T_0}{T_u}\right)\dot{Q}_u$ and for $\dot{Q}_1$ the corresponding exergy term is $\left(1-\frac{T_0}{T_1}\right)\dot{Q}_1$.

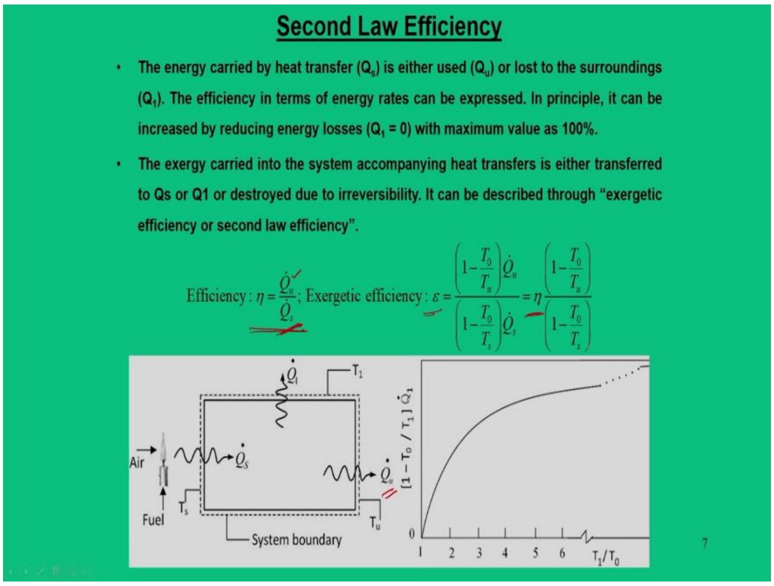
So, what we look at from this expression is that for each of the term, the ambient temperature was taken into account. So, I can say although this is a working system, your ambient conditions you can have p_0 and T_0 and that we say the surrounding temperatures.

Now, this is what we do for heat transfer. Now, the system also could do some work transfer. So, that work transfer comes in this form $\dot{W}-p_0\frac{dV}{dt}$. Now, in our closed system situations when there is no work. So, this term can vanish and steady state this term can vanish, even here $\frac{dE}{dt}$ is also 0 for the steady state.

Now, by neglecting these terms and rearranging this expressions, we arrive at the expression for exergy. So in fact, if you look closely between this energy relation and exergy relations, you can find out that in exergy relation there is a corresponding term $1-\frac{T_0}{T}$ that comes into picture. Apart from that there is another term $\dot{E}_d$ which we called as rate of exergy destructions.

So, the second law efficiency talks about that although we have energy gates balance is taken into account, but not necessarily that exergy will be balanced. So, that is what we say that exergy is a non-conserved property. Now, let us move further what the second law efficiency talks about.

(Refer Slide Time: 17:38)



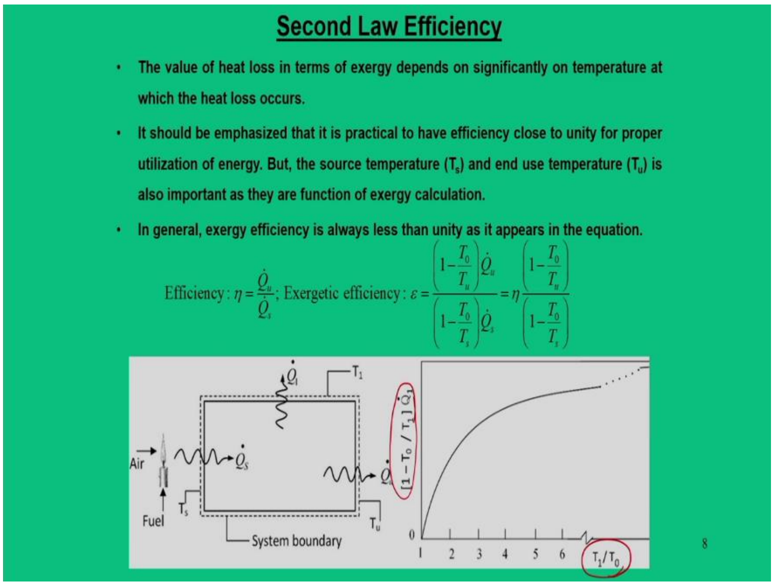
So, when you deal with the first low efficiency. In fact, while discussing about the Carnot cycle or during the second law analysis, we say that the efficiency term is $\eta = \frac{\dot{Q}_u}{\dot{Q}_s}$. Now, with respect to this particular term $\dot{Q}_s$ is input to the systems and $\dot{Q}_u$ is heat getting utilized. Of course, there is no work transfer here, so we can say efficiency calculation is this.

Now, if I want to calculate the exergetic efficiency, then we have to recall the same expression of efficiency, but we are going to write in a different way; that means, for this $\dot{Q}_u$, which is heat as a energy corresponding exergy value will be $\left(1 - \frac{T_0}{T_u}\right)\dot{Q}_u$. That where T_0 is your ambient temperature and T_u is the temperature of the surface at which heat is entering.

And similarly for $\dot{Q}_s$, which is the input for the system corresponding exergy term would be $\left(1 - \frac{T_0}{T_s}\right)\dot{Q}_s$ and here T_s is the surface temperature at which the heat is entering into the systems.

So, if you simplify this expressions, we will find this $\frac{\dot{Q}_u}{\dot{Q}_s}$ is efficiency. So, exergetic efficiency ϵ is function of efficiency and the temperature of surroundings, surface temperature of at heat is being rejected or utilized and surface temperature at which heat is entering into the systems. $\varepsilon = \eta \frac{\left(1-\frac{T_0}{T_u}\right)}{\left(1-\frac{T_0}{T_s}\right)}$

(Refer Slide Time: 19:47)



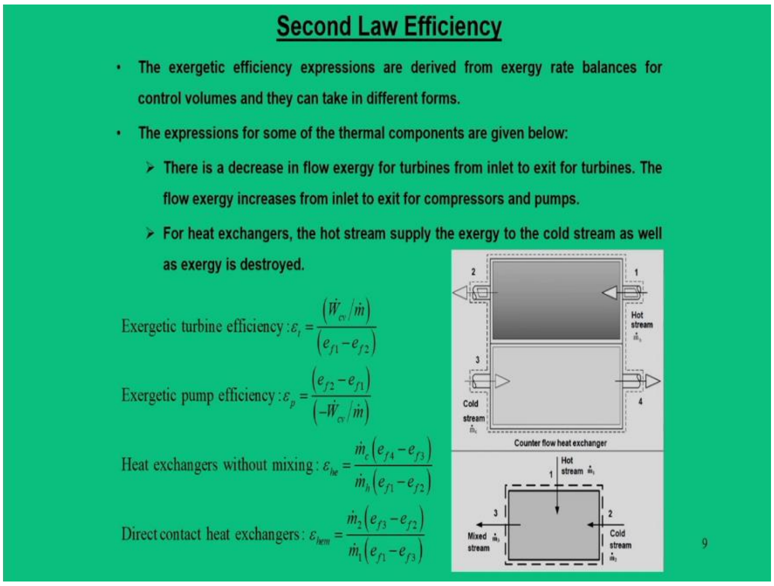
Now, if you look closely to this expressions, some more information we can gain that is the if you try to plot the T_1/T_0 as a function of the corresponding exergy. What it says is that the heat loss in terms of exergy depends significantly on temperature at which heat loss occurs. So, initially it starts increasing and it keeps on increasing that means, heat loss also increases significantly with respect to temperatures; that means, if a body at higher temperature, heat loss will also be more and more.

Second point is that it should be emphasized that when you find the efficiency value we can say it is $\frac{\dot{Q}_u}{\dot{Q}_s}$ and there is a possibility that all the heat gets utilized as if we have Carnot efficiency; that means, from the first law it says that all the heat gets utilized.

But reality that does not occur which means that there is something difference that drops in while calculating the energy. So, where it goes that we found out based on the source temperature T_s and end use temperature T_u. So, they are function of exergy calculations.

Another information you can gain here, that the exergy efficiency is always less than unity because in most of the situation your efficiency is also less than unity. So; obviously, when you multiply this term, which is less than unity exergy efficiency will also be less than unity.

(Refer Slide Time: 21:47)



So, having said the second law efficiency, we can really calculate the exergetic efficiency for some steady flow devices or components or thermal components. In the second law analysis of entropy we discussed about the thermal components like turbines, compressors, heat exchangers, pumps, nozzles all these components we have analyzed. And for them, one way to interpret is through their isentropic efficiency.

But having using the term isentropic efficiency, we really do not account how much heat is lost to the surroundings or what is the contribution of irreversibility in the systems. So, while talking about entropy, it just talks about maybe isentropic efficiency. It only talks about the internal reversibility analysis, but it does not talk anything about the irreversibility part.

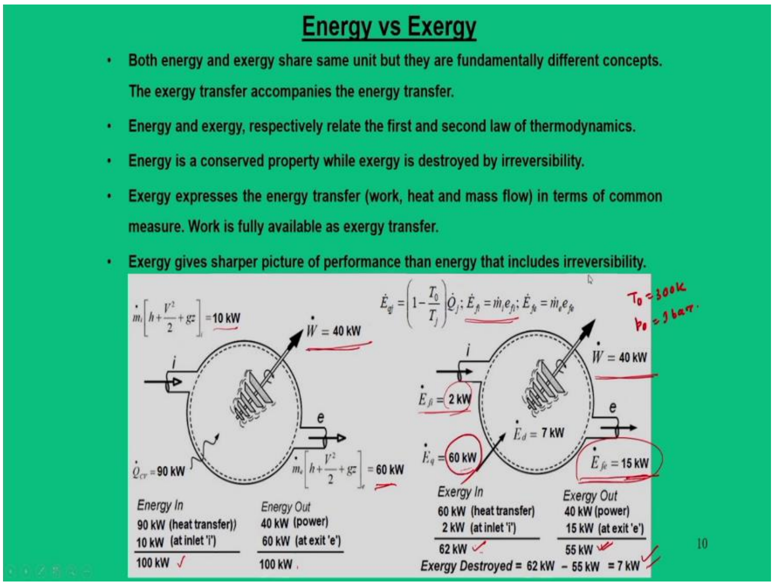
So, for this irreversibility part, exergy calculation is very vital for which we call this as a exergy auditing or the proper utilization of energy resources. So, based on this concept, we define exergetic turbine efficiency. So, when you say turbine, it is a work producing device. So, the work term; that means, work flow per unit mass is in the top. In the bottom part we have difference in the exergy due to flow in and flow out. $\varepsilon_t = \frac{\left(\frac{\dot{W}_{cv}}{\dot{m}}\right)}{(e_{f1}-e_{f2})}$

Similarly, for pump case, work is input to the systems so; that means, it is in the denominator and with a negative side and exergy in this case drops. So, there is a decrease in the flow exergy for turbine from inlet to exit and there is a increase in the flow exergy from inlet to exit for compressor and pumps. $\varepsilon_p = \frac{(e_{f2}-e_{f1})}{\left(\frac{-\dot{W}_{cv}}{\dot{m}}\right)}$

Another very vital part is about the exergy calculation for heat exchanger. In fact, heat is the source for which complete conversion is not possible. So, exergy calculation is very significant in terms of second law efficiency. So, heat exchangers can be of two types, first one is a counter flow type in which there is a hot stream entering and hot stream leaving condition 1 and 2 and there is a cold stream entering and cold stream out and both the hot fluid and cold fluid they do not mix. So, for each streams, we can find out the exergy expressions due to this cold fluid and hot fluid. $\varepsilon_{he} = \frac{\dot{m}_c\left(e_{f4}-e_{f3}\right)}{\dot{m}_h\left(e_{f1}-e_{f2}\right)}$. When we use a direct contact exchanger, where both hot fluids and cold fluids mix together and they come out as a common stream, then exergy calculation is little bit different. $\varepsilon_{hem} = \frac{\dot{m}_2(e_{f3}-e_{f2})}{\dot{m}_1(e_{f1}-e_{f3})}$

So, we have to find out exergy either for the cold stream or hot stream. So, in that way, we can rewrite this expressions in the form which is in terms of 3-2 or and 1 and 3. So, this is how we interpret exergy for heat exchanger calculations with mixing and without mixings.

(Refer Slide Time: 25:49)



And the last segment of our discussion today, in fact for this module is energy versus exergy. So, we have given all the concept of thermodynamic concept starting from zeroth law, first law, second law, entropy and exergy. All the after doing all the analysis, the very fundamental difference that still lies is that why we require exergy? Although energy analysis gives sufficient information why we require exergy?

When you use word exergy, we basically do energy auditing. And in fact, when you use this energy, we really do not bother about the surrounding conditions. And in fact, in some situations energy is available in variety of forms, it can be from fuel, it can be from solar energy, it can be from wind energy for variety of sources, but its proper utilization with a particular components needs attentions.

So, as you can look for this particular figure here, where I am just giving some benchmark or standard numbers. In fact, it is a work producing device or as if we have a thermal power systems which is producing a work or shaft work. And in which we are supplying some flow that enters into the systems and some flow that goes out of the systems.

And in fact, you can say it is a control volume analysis and there are possibility of work transfer and I will say that I will give some numbers that heat is being supplied to the systems is for example, its 90 kW and apart from that, there is also some mass flow which enters to the systems it gives energy into the system as 10 kW.

So, if I say that how much energy we are pumping into the systems, then we can say one is 90 kW by heat transfer and 10 kW through this mass transfer which is through inlet. So, total 100 kW energy is being supplied.

So, when you do the first law analysis. In fact, most of the things; that means, we will find out that entire work can be calculated, some work can be calculated as let say 40 kW through the shaft power and something which is which goes out is 60 kW.

So, you can say its efficiency, we have 40/100. So, 40 percent efficient, but most of the things if you say that energy balance is taken into account. So, energy auditing is clear, 100 is input, 100 is output.

Now, let us evaluate the exergy values for these heat transfer modes. First thing we have Q_{cv} which is exergy transfer as a heat which is 90 kW and if you use this for the corresponding exergy value, with surrounding temperature may be T_0 as 300 K and p_0 as 1 bar atmospheric pressure.

Then we can find out its value could be may be 60 kW. Although we give 90 kW of energy as a heat, corresponding exergy value is only 60 kW which is entering. Even for the mass flow it was 10 kW, corresponding exergy value with respect to flow inlet which can be calculated from this expression is about 2 kW.

Just to say that these are just gross numbers, more accurate numbers can be found out by putting appropriate values. Now, then moving further for work transfer and of course, we say that complete conversion of work is possible. So, we can say corresponding work transfer will be same. Exergy with respect to work transfer remains same and exergy with respect to flow that goes out it was 60 kW, but it is 15 kW.

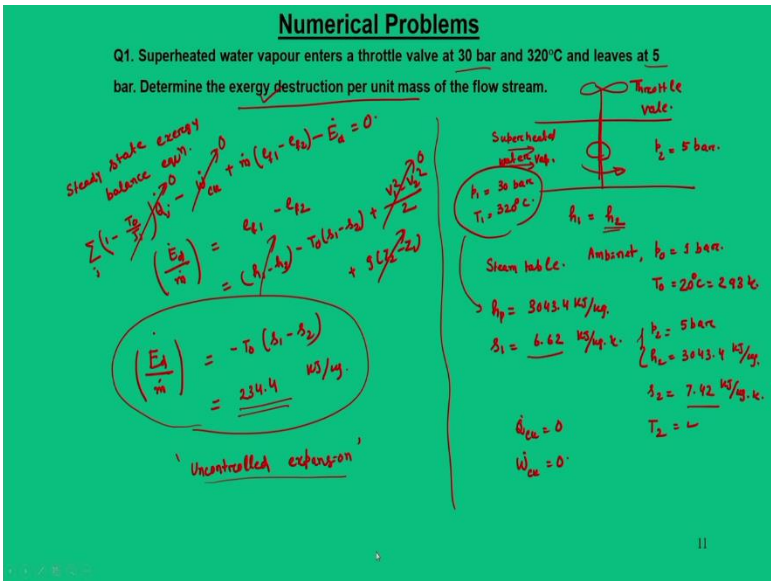
But ultimately when you recalculate, we supplied energy 100 kW, but its corresponding exergy value total exergy value is about 62 kW and the exergy that comes out it was 100 kW, but it is now 55 kW. So, basic difference lies here that 100 kW becomes 62 and 55 by taking into account of surrounding temperatures and pressure.

So, if you see here there is exergy in, there is exergy out, it is not balanced. So, it is not a conserved property, and exergy is destroyed from this process we can find out 7 kW which is nothing but your E_d and this amount is destroyed due to irreversibility and it is also recoverable.

Why this analysis is important, because that when you design a thermal systems, apart from energy analysis we must do the exergy analysis, that when you design the systems you have to do such a way that there will be minimal destruction of exergy. That means, 7 kW number should be as small as possible so that effective utilization of resources can be taken into account

So, this is how the importance or significance of exergy is realized because exergy gives a sharper picture of performance than energy because it includes the irreversibility.

(Refer Slide Time: 32:42)



Before I conclude this lecture, let me discuss some numerical problems pertaining to this particular lecture and it was mainly targeted for exergy balance for a control volume. So, we will try to see that how we can use the fundamental equations for exergy calculation of some thermal components. The first component is a throttle valve. So, you all know that throttle valve is a valve which regulates the flow conditions which is entering into a system or medium and through this throttling process, the thermodynamic parameter that remains constant is enthalpy.

So, here the problem that is given that we have a throttle valve which is kept into a medium. So, the valve opens and closes. So, some stream which is entering it is a superheated water vapour. So, it is at 30 bar 320 C.

So, condition p_1 and T_1 is given to us and when the valve opens it allows this flow and the stream leaves at p_2 = 5 bar. So, this thermodynamic process we can say enthalpy remains same which is $h_1 = h_2$. Now, apart from that we can say ambient or surrounding is at 1 bar and let say 20 C or 293 K.

Now, what you require is exergy destruction per unit mass of the flow streams. So, before you start these datas are given for super heated water vapours. So, we can use steam table. Initially it was a super heated state, for this conditions we can find out from the steam table enthalpy, $h_1 = h_2 = 3043.4\frac{kJ}{kg}; s_1 = 6.62\ kJ/kg-K$.

So, for p_2 is 5 bar and h_2, we can find out from steam table, $s_2 = 7.42\ kJ/kg - K$.

So, here we can say $\dot{Q}_{CV} = 0$, because there is no work transfer and no heat transfer and no data is given about the flow velocity. So, with this we can recall about the steady state exergy balance, $\sum_j \left(1 - \frac{T_0}{T_j}\right) \dot{Q}_j - \dot{W}_{cv} + \dot{m}\left(e_{f1} - e_{f2}\right) - \dot{E}_d = 0$.

So, this part $\dot{Q}_j, \dot{W}_{cv}$ is 0, and this equations now becomes exergy destruction per unit mass, would exergy transfer due to mass flow rate. $\frac{\dot{E}_d}{\dot{m}} = e_{f1} - e_{f2} = (h_1 - h_2) - T_0(s_1 - s_2) + \frac{V_1^2 - V_2^2}{2} + g(z_1 - z_2)$

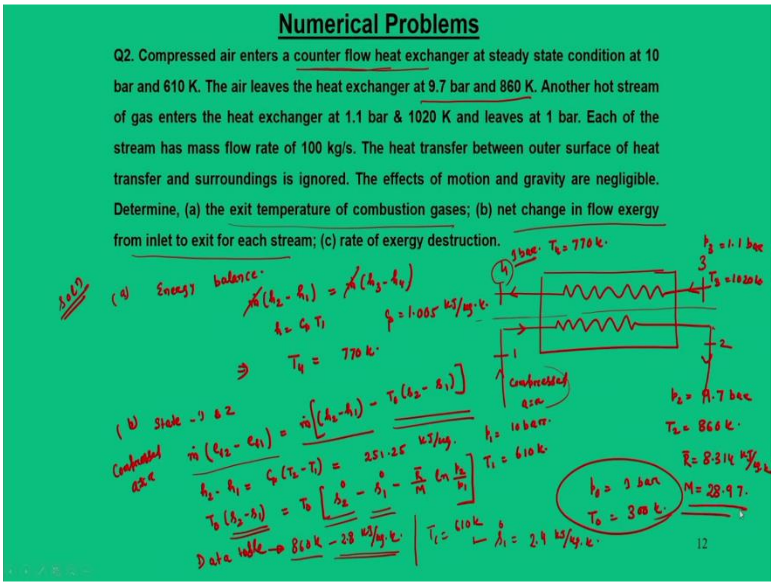
So, this PE, KE term vanishes because we have no information. In fact, $h_1 = h_2$. So, it will be $\frac{\dot{E}_d}{\dot{m}} = - T_0(s_1 - s_2) = 234.4\ kJ/kg$.

So, this means that due to this throttling valve the exergy destruction is $234.4\ kJ/kg$.

So, we all know that throttling process is an irreversible process. So, this is taken into account or proved. And why it is a irreversible process? It is mainly due to uncontrolled expansion. So, if you see that the stream expands from 30 bar to 5 bar, but this is expanded in a uncontrolled manner through a throttling device. Due to this uncontrolled expansion, there is a irreversibility comes into account

But this uncontrolled expansion can be put in a control mode through an expansion in a turbine process, which may be considered as internal reversible process.

(Refer Slide Time: 40:41)



Now, we will move to next problem where its a very common problem which you use in a gas turbine engines. And this gas turbine engine, we use some kind of a compressor in which the flow enters into an heat exchanger and the air gets reheated through combustion products.

So, the typical arrangement could be like this we have a counter flow heat exchanger. In this counter flow heat exchanger schematically if I write that is some flow which is comes in and the hot fluid and the cold fluid they come in a different path.

So, first fluid that goes we say compressed air and it enters to this heat exchanger and it leaves. So, initial condition of this compressed air is 10 bar. So, $p_1 = 10\ bar; T_1 = 610\ K$ whereas, air leaves at 9.7 bar, $p_2 = 9.7\ bar; T_2 = 860K$.

Then another stream that enters that is at state 3 and leaves at state 4. At state 3 the conditions are $p_3 = 1.1\ bar, T_3 = 1020\ K$ and $p_4 = 1\ bar$. Apart from that we have surrounding say $p_0 = 1\ bar; T_0 = 300\ K$.

So, first thing what we require is exit temperature of combustion gas. So, basically all the temperature as known except the condition 4. So, first analysis we can do energy analysis or energy balance. Since, it is a very simple systems we can write $\dot{m}(h_2 - h_1) = \dot{m}(h_3 - h_4); put\ h = C_pT; T_4 = 770K$.

.

Second analysis we are going to find out what is the net change of flow exergy from inlet to exit of each streams. So, flow exergy from inlet to exit for each stream; that means, we have to calculate separately one for stream of compressed air, other for the stream of hot stream. So that means, it can be divided in two loops, one is between 3 and 4 other would be for 1 and 2.

So, first one if you calculate for 1 and 2, state 1 and 2 if you want to calculate we can write

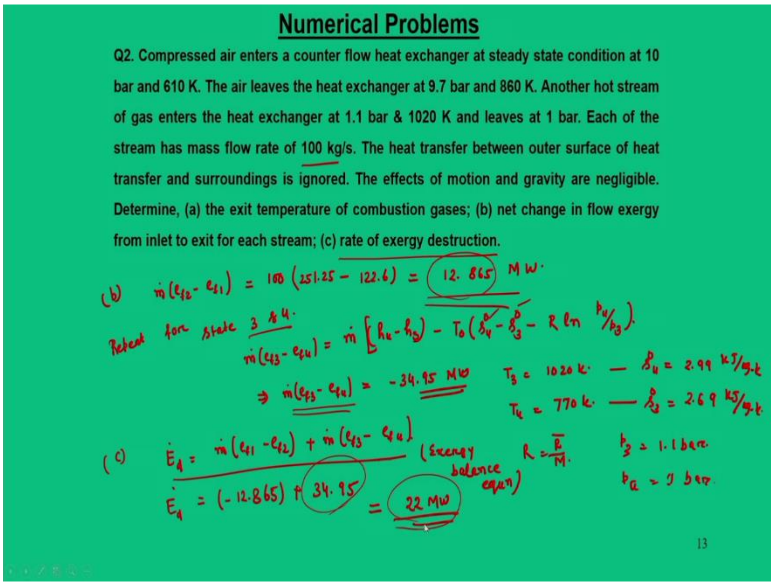
$$State\ 1-2:$$

$$\dot{m}(e_{f2}-e_{f1}) = \dot{m}[(h_2-h_1)-T_0(s_2-s_1)];\ h_2-h_1 = C_p(T_2-T_1) = 251.25\ kJ/kg$$

$$T_0(s_2-s_1) = T_0\left(s_2^0 - s_1^0 - \frac{\overline{R}}{M}\ln\frac{p_2}{p_1}\right) = 300\times\left(2.8-2.4-\frac{8.314}{28.97}\ln\frac{9.7}{10}\right)$$
$$= 122.6\ kJ/kg$$

$$\dot{m}(e_{f2}-e_{f1}) = 100(251.25-122.6) = 12.86\ MW$$

(Refer Slide Time: 48:05)



And similarly, you can repeat it for state 3 and 4, we will find out

$$\dot{m}(e_{f4} - e_{f3}) = \dot{m}[(h_4 - h_3) - T_0\left(s_4^0 - s_3^0 - \frac{\overline{R}}{M}\ln\frac{p_4}{p_3}\right)]$$

$$= 100\{1.005(1020 - 770) - 300\left(2.94 - 2.69 - \frac{8.314}{28.97}\ln\frac{1}{1.1}\right)\}$$

$$= -34.95\ kW$$

Now, so this is for the state 3 and 4 and last part of the analysis rate of exergy destruction. So, the rate of exergy distraction is $\dot{E}_d = \dot{m}(e_{f1} - \dot{e}_{f2}) + \dot{m}(e_{f3} - e_{f4})$. This expression we get again from exergy balance equation by neglecting terms of work transfer and heat transfer.

Now, but we have calculated in a reverse number. So, this number we can rewrite as $\dot{E}_d = -12.865 + 34.95 \approx 22\ MW$. So, this analysis tells that we are talking about inflow exergy numbers about 12.865 and 34.95, but we are losing 22 MWt of exergy. So, this means that substantial exergy is destroyed. In other words loss of energy is much higher due to irreversibility.

So, this needs attention that we should design a better counter flow heat exchanger which can still further reduce this number from 22 MW by considering the proper methods where the loss of irreversibility can be minimized. So, with this background and concept of energy and exergy, I conclude today's lectures and also I conclude module 2.

Thank you for your attention.