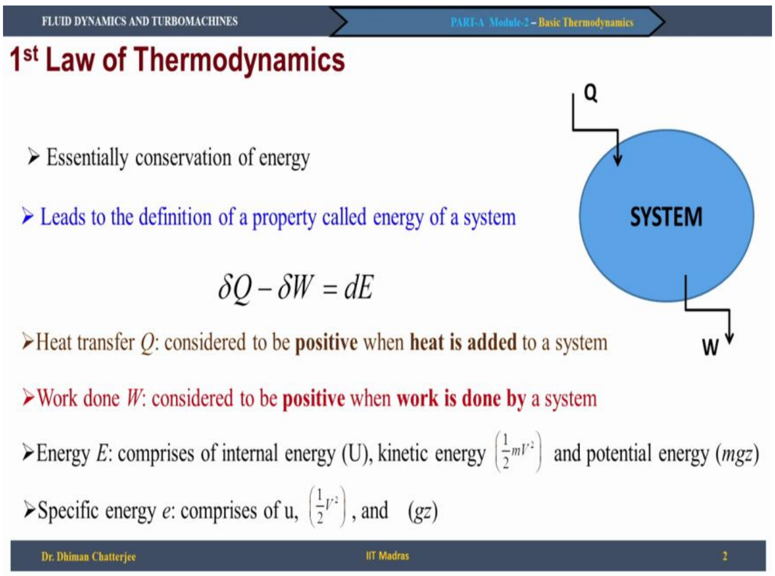
**Fluid Dynamics And Turbo Machines.**
**Professor Dr Dhiman Chatterjee.**
**Department Of Mechanical Engineering.**
**Indian Institute Of Technology Madras.**
**Part A.**
**Module-2.**
**Lecture-1.**
**Basic Thermodynamics: Recapitulation.**

Good morning, I welcome you all for this lecture on basic thermodynamics in the module 2 of fluid dynamics and Turbo machines. In the last 4 weeks you have studied basically different aspects of fluid dynamics. From now on we will talk about Turbo machines, its types and different features. As we have been told that fluid dynamics forms an essential background information that is required for understanding and appreciating the performance of Turbo machines.

Another fundamental subject which you require to better appreciate Turbo machine is thermodynamics. So today we will start with some basic thermodynamics, a recapitulation of what you have studied in your course. If you are not comfortable with thermodynamics you may look at some textbooks on thermodynamics as you can also refer to Prof SK Shom from IIT Kharagpur's excellent lectures on thermodynamics available in NPTEL, because in this course I will talk about only those aspects of thermodynamics which are required for explaining Turbo machines.

(Refer Slide Time: 1:37)

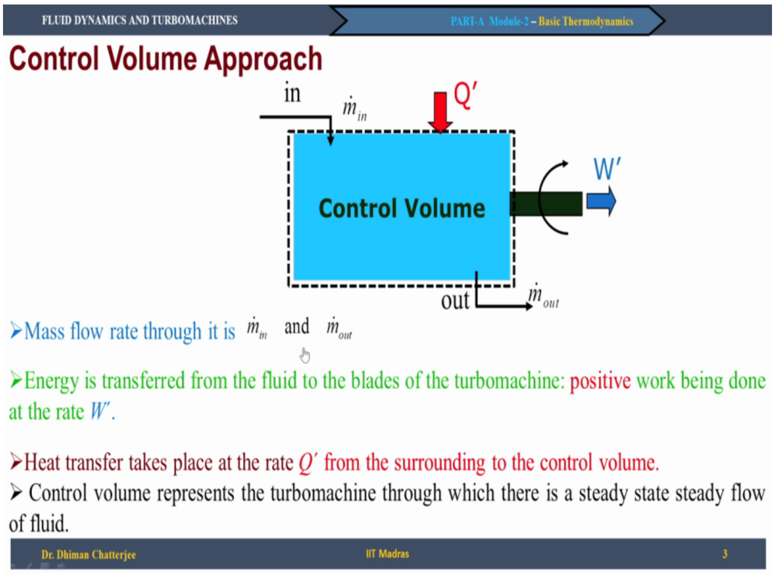


So we will start with first law of thermodynamics. First law of thermodynamics is essentially the conservation of energy. When we talk about first law, we talk about the interaction of heat and work and the changes in different forms of energy. Let us say we have a system and some heat is added to the system and some work is done by the system. So first law tells me that there is a property called energy of the system which will change as a result of the interaction of heat and work with the system, and we get the first law of thermodynamics.

Dell Q - Dell W equal to dE. Q as you have understood is a heat transfer and W is the work done. There is a sign convention, it is not necessary that you have to follow the sign convention but this is mostly followed by all textbooks and I will also follow it here that heat transfer is considered to be positive when heat is added to the system. Similarly we can talk about work done, work done is considered to be positive when work is done by a system. Also another thing you may be wondering that why we have Dell Q to talk about an incremental addition of heat and Dell W for incremental work done whereas we have dE to show the corresponding change in energy.

This is because as you know that property like energy is a point function whereas the heat transfer and the work are path functions. So to make the distinction we are going to use Dell Q and Dell W, whereas for a property like energy we will talk about dE. This energy E comprises of internal energy which is given by capital U, the kinetic energy is a microscopic property which is given by half mV square and also potential energy which is given as mgz while z is the elevation from some datum. We may also express this energy in terms of specific energy E which comprises of then the internal, specific internal energy small u half V square and gz respectively.

(Refer Slide Time: 3:53)

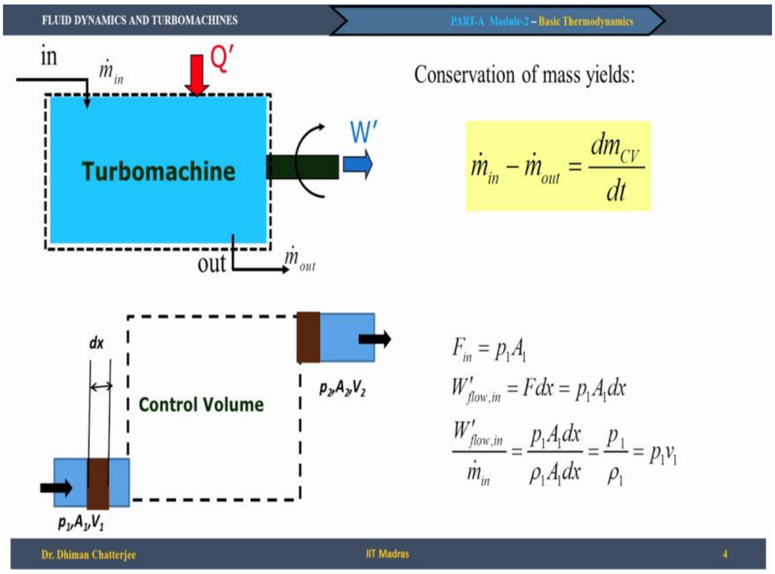



Next thing we have to talk about is the control volume approach. Say in case of Turbo machine the fluid flow enters a Turbo machine and then leaves, in the process there can be heat and work transfers. We have to understand that this is a flowing process, this is not a non-flow system like you can see in some other example. And this is solved using a control volume approach. Also another point I need to mention here is I am not considering the internal details of Turbo machines.

I am considering Turbo machine essentially as a black box. I just want to know what crosses the surface given by these dashed line which is the control surface and what is the net change. So with this description we can say that the mass in any control volume can be M dot in and M dot out, we can have the energy transfers which is, we have given by the Convention the work is done by the machine which is W Prime. Please note that we are talking about W prime which is the rate of work done. And we have taken it as positive but Turbo machines need not always produce positive work, I will come to that shortly.

Similarly we can talk about the heat transfer rate at Q prime from the surrounding to the control volume again following the sign convention that we have adopted. In case of Turbo machines, that is a steady state steady flow which means there is no accumulation of mass inside the control volume. So whatever mass comes in also leave and we will follow these steady-state steady flow energy analysis.

(Refer Slide Time: 5:41)




So let us look at Turbo machines. So we have M dot in and M dot out, very soon we will show that M dot in equal to M dot out but for the time being let us keep M dot in an M not out as notations different, and in and out shows the areas. So conservation of mass yield M dot in - M dot out a d M CV dt. In order to understand it better, let us think about the tank. We have a tank in which we fill water. So what happens, there is a pipe or there may be multiple pipes will bring water into the tank and there is an outlet or there could be multiple outlets through which water leave the tank.

Now let us take a simple case, when there is only one inlet and one outlet, so if water enters the tank with some flowrate M dot in and leaves with a flow rate M dot out such that M dot out is less than M dot in, then what do we expect? You will find that the level of water in the tank increases. That means more and more mass of water gets accumulated in the tank. This change of mass in this the control volume in the tank in our case is given as d M CV dt. Another thing we need to understand, background information to appreciate this steady-state steady flow energy equation, with the flow process we have something what is so-called the work, flow work or the pressure energy.

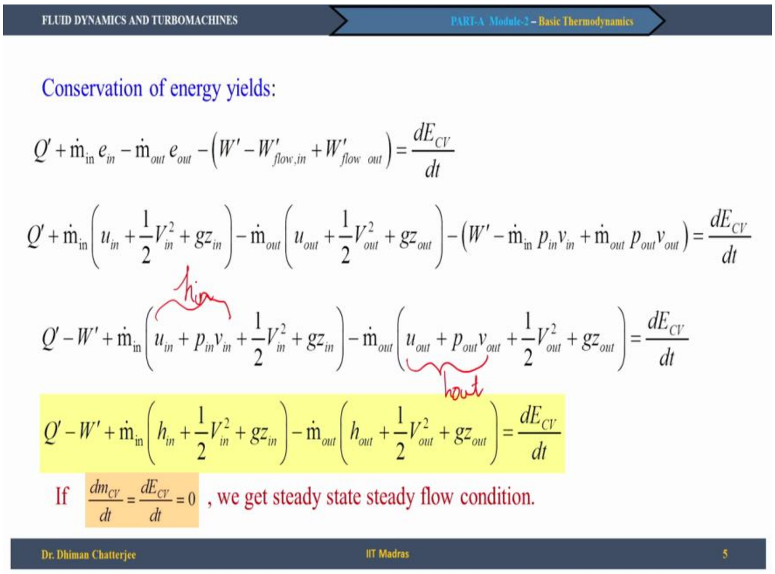
Let us say I have a control volume given by this dashed line and this blue on the left bottom shows the pipe brings the fluid in and the top right shows the fluid that leaves the control volume and we can say that the pressure, the area of the interface and the velocity are given as P1, A1, V1 at the inlet and P2, A2, V2 at the outlet. So we can say that if we have a fluid element which gets displaced by a distance Delta X and then the force that is required to be pushed, to push against the pressure P1 is given as P1 A1, I am talking only about the inlet.

The corresponding analysis can be done for the outlet. So the work done to push the fluid element by a distance Delta x or dx as I have used is nothing but F dx which is P1 A1 dx. So the flow work per unit mass or flow rate or flow work divided by the mass flow rate is going to be given by P1 A1 dx divided by rho 1 A1 dx. Of course you can relate dx with V1 multiplied by the time that you have talked about Delta T but it is one and the same. So you will get that work done flow work per unit mass flowing in is equal to P1 by rho 1.

Which means, we can also write in terms of specific volume as P1 V1. Where v1, the small v1 is specific volume, the capital V please note is not volume, it is the velocity. Okay, and similarly you can talk in terms for the flow work going out as P2 V2. To get the better appreciation of flow work we can say that we can take an example. Let us say that you are standing in a queue trying to enter a cricket stadium to watch a match. So what happens, you are trying to push your neighbour so that you can go fast and that, which means you are doing some work on your neighbour and the neighbour is in turn pushing his neighbour.

So now if we think about the fluid element waiting in queue to enter the control volume, it is actually pushing the neighbouring fluid element, it is doing work on the neighbouring element against the pressure of P1. So we can think about flow work either in terms of flow or the work done or in terms of the energy that is being stored on the neighbouring element. Both ways you can talk about it and hence sometimes it is called the flow work, sometimes it is called the pressure energy. So we will talk about the conservation of energy.

(Refer Slide Time: 10:11)



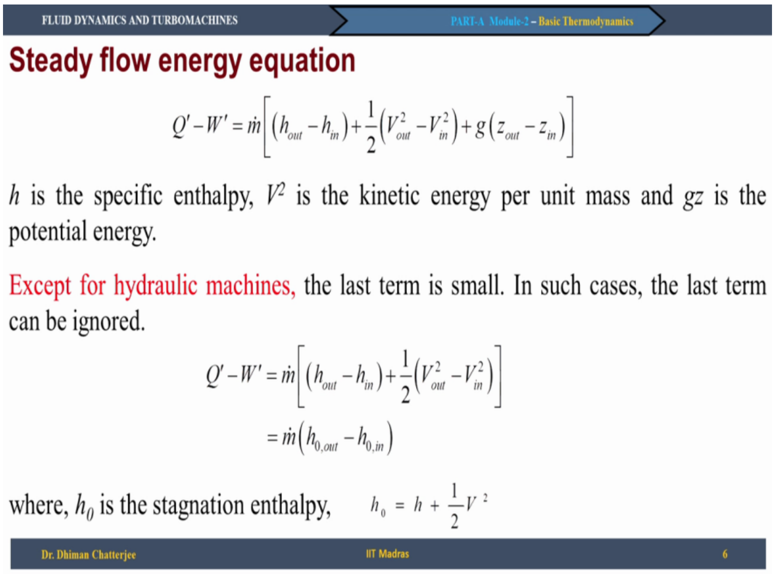

So we already have learned the first law of thermodynamics says that Dell Q - Dell W equal to dE. Essentially this is the same thing we are going to use but in a slightly different form. So we can say Q prime which is the rate of heat transfer + M dot in E in - M dot out E out - W prime - W prime flow in + W prime flow out is equal to d E CV dt. I will talk about E in and E out now. See E in is the specific energy which comprises of the terms like internal energy u which is due to the molecular motions + the macroscopic kinetic energy like half V square + the potential energy gz.

So if we put this in along with the expressions for flow work we have done so far and we rearrange it, we can get that Q prime + M dot in u in + half v in square + gz in - M dot out u out + half V out square + gz out - W prime - M dot in P in v in that is the flow work for the inflow + M dot out P out v out is equal to the net change in the energy in the control volume d E CV dt. We can now arrange all the terms that are with M dot in like the terms in this bracket with the term P in v in and similarly for the terms M dot out in this bracket the terms with the flow work term and put it in discussion.

We can get that Q prime - W prime + M dot in within bracket we will get u in + B in v + half V in square + gz in - the corresponding terms for the flowing out M dot out u out + P out v out + half V out square + gz out equal to d E CV dt. Let us look at this term, u in + it is P in v in, this is nothing but the enthalpy we talked about h in. Similarly we can talk about u out + P out v out is nothing but h out, h being the static enthalpy.

So now if I rewrite it in terms of enthalpies in place of the internal energy and the flow work, we get the final form which we need is Q prime - W prime + M dot in h in + half V in square + gz in - M dot out h out + half V out square + gz out is equal to d E CV dt. But I have already told you that in Turbo machine we talk about steady-state steady flow, which means there is no accumulation of mass, there is no accumulation of energy.

(Refer Slide Time: 13:47)

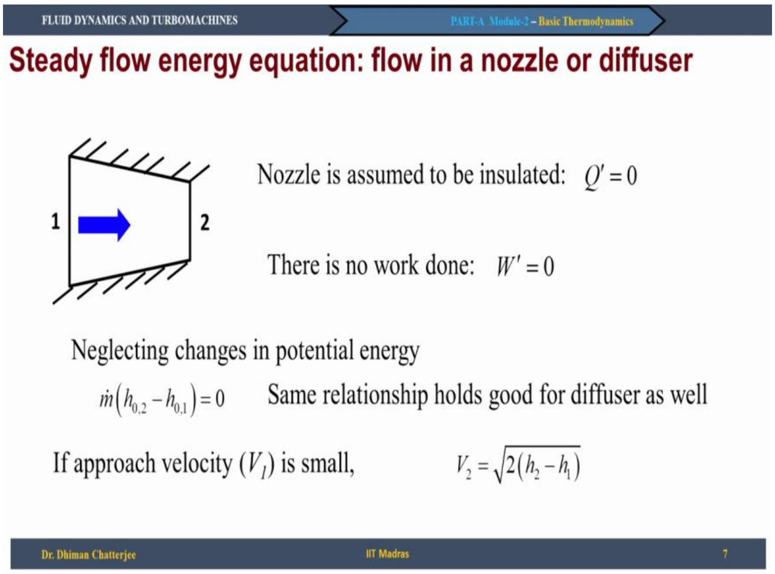



And hence we can say that d M CV dt is equal to d E CV dt is equal to 0 and we get steady-state steady flow condition which means we can simplify the expression that we have got. We will say that M dot in equal to M dot out equal to M dot and the energy equation reduces to Q prime - W prime is M dot h out - h in + half V out square - V in square + g z out - z in. Alright. Let us look at the terms again, h is a specific enthalpy, V square is the kinetic energy per unit mass and gz is the potential energy again per unit mass.

Except for hydraulic machines which we will talk little later, the last term, that is the change in the potential energy is insignificant compared to the other changes. In such cases we can draw the last term. That means for any Turbo machine handling air or steam or any other gas the change in potential energy can often be neglected and we get that Q prime - W prime is M dot h out - h in + half V out square - V in square. And this gives me equal to M dot H0 out - H0 in.

I am introducing a new term here which is H0 out and you can easily understand H0 is nothing but h + half V square which means H0 out is nothing but Hout + half V out square, H0 in is nothing but h in + half V in square. This H0 is called the stagnation enthalpy. So let us take an example of the steady flow energy equation. The flow in a nozzle or a diffuser.

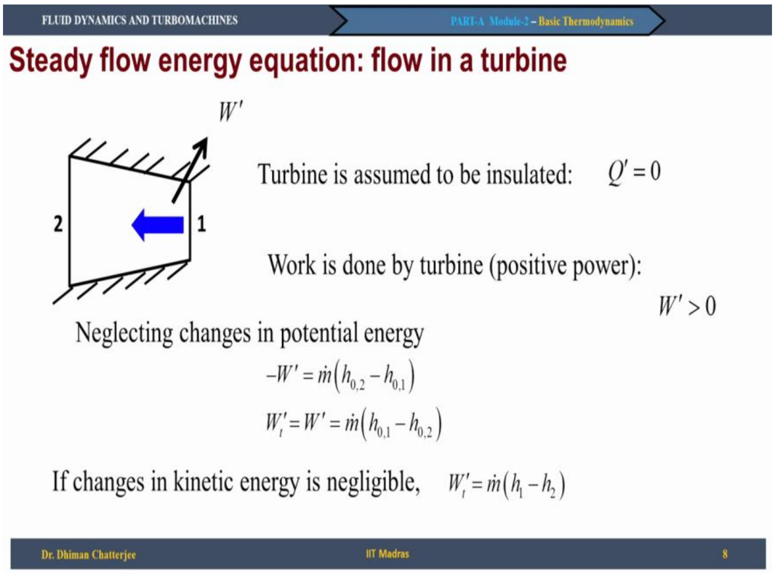
(Refer Slide Time: 15:34)




So this is a nozzle in a conventional sense we have drawn, this is a schematic. So 1 is the inlet, 2 is the outlet and the flow direction is from the inlet to the outlet. This line, Hatched lines is my attempt to show that the flow is adiabatic means that we say that the nozzle is insulated which means that Q prime equal to 0. The nozzle does no work because it is a stationary component and hence we can say W prime equal to 0 and hence the first law of thermodynamics reduces to in the absence of potential energy change as M dot H02 - H01 equal to 0 or H02 equal to H01.

I have shown it for nozzle but the same can be talked about for diffuser as well. And if we say that the approach velocity V1 is small as is often the case, then we can write the changes in the static enthalpy and the velocity or the kinetic energy changes and we can get that V2 is root 2 H2 - H1. When we will discuss Turbo machines, particularly we will talk about steam or gas turbines, we will talk about the role of nozzles and diffusers in much more detail at that time. And at that time you should recollect that we have talked about the change of static enthalpy giving rise to a velocity increase.

(Refer Slide Time: 17:05)

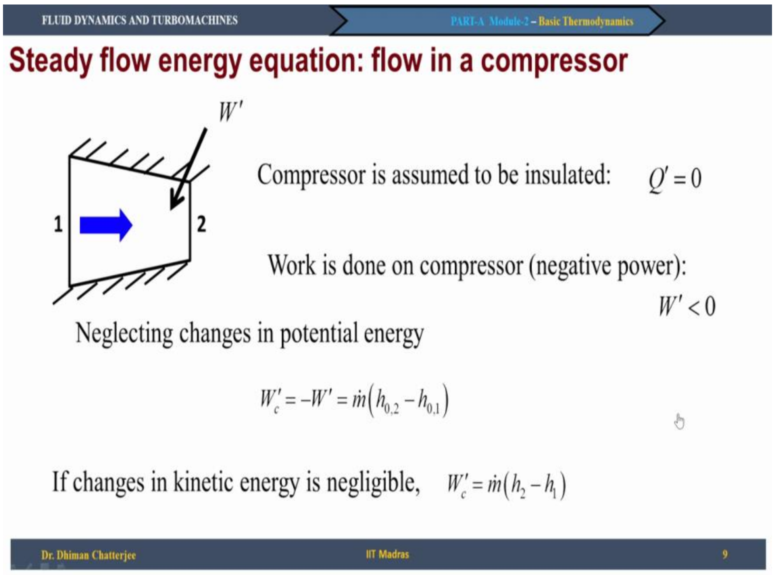



The next example you can talk about is steady flow energy equation as applicable for flow in a turbine. Here again we are talking about the turbine is insulated which means that Q prime equal to 0. Please note that the heat transferred in turbines may be present but it is not significant, so I am taking it to be zero and in most of the applications this is a fair assumption. If in any particular case you come across there is a significant heat transfer from the turbine or from the compressor to the surrounding, you have to account for it.

So we assume that the turbine is insulated here and Q prime is zero, the flow is from the 1 to 2 and there is a work transfer, this is a big difference. So work is done by the turbine, a positive power and we say that W prime is greater than zero. So similarly neglecting changes in the potential energy as we have done in the case of flow nozzles or the diffusers, we now we can say that - W prime equal to M dot H02 - H01 or we can say the WT prime which is the work done, greater work done or the power produced either turbine, T for turbine is equal to W prime M dot H01 - H0 2.

Let us pause here for a minute. We say that the work done by the turbine is positive because it is a positive power and be located at we find that H01 is must be greater than H0 2 in order to WT prime or W prime to be greater than zero. So what happens, it shows that there is a fluid which is coming into the turbine and it gives a part of its energy which makes the blades to move and we get electricity as an output. So there is a transfer of energy from the fluid to the machine and hence we get that the fluid that is coming out of the turbine is having less energy. Of course if the kinetic energy changes are negligible as is often the case, then we can say that WT prime is M dot H1 - H2. That is instead of using stagnation enthalpy difference we will talk about the static enthalpy change.

(Refer Slide Time: 19:22)

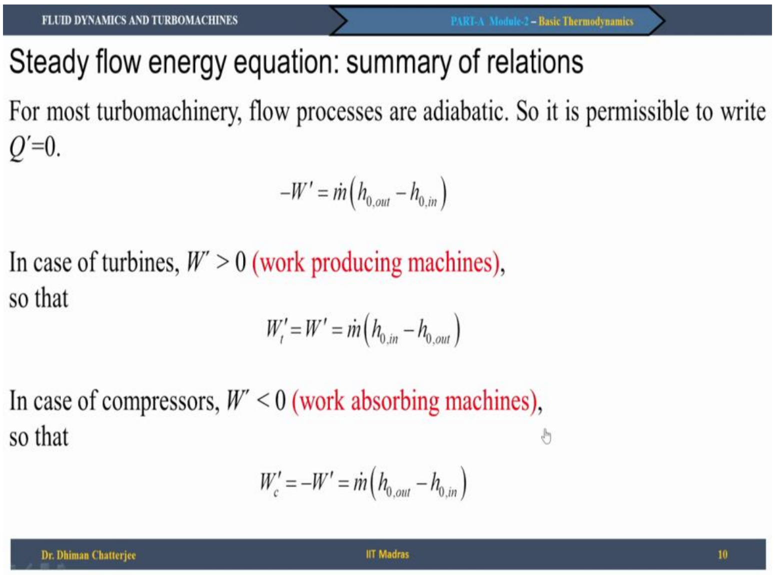



If we take a compressor, the main difference between the turbine and the compressor is in the fact that in case of a compressor, the work is done on the system, so there is a negative power. Let us take a simple example, you might have seen a compressor but we can talk about the household electric fan. The fan produces the air which we are all feeling comfortable about, but how does it work? It does not work on its own, you have to turn on the electricity. So electrical energy gets converted into mechanical energy and then we are talking about the blades move and it produces the air motion.

So now we are talking about a compressor which is a similar instrument, sorry, similar equipment which talks about a negative power that is W prime is less than zero. Following the same analysis as we have done for turbine, that is neglecting changes in potential energy we can say that WC prime is equal to - W prime equal to M dot H02 - H01. So let us again look at it, in thermodynamics you might have come across that we talk about the work done by the compressor as - let us say 5 kilowatt.

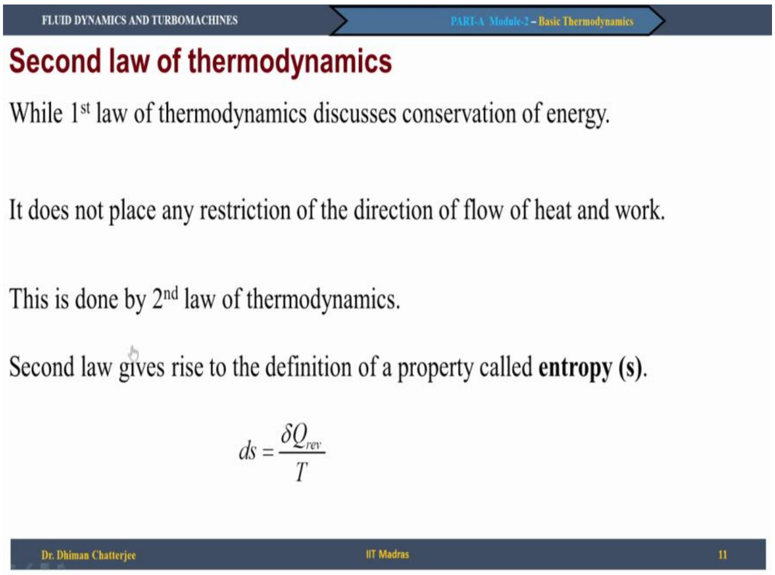
But in reality when we want to a machine and let us say we are going to buy a pump, we do not want to buy a motor which is -5 kilowatt, we want to buy a motor which will be around pump which is having a capacity let us say 5 kilowatt. So to get it positive we are now talking about WC prime as - of W prime which makes it positive and we get dot H02 - H01. What it means, that the fluid leaving the compressor, fluid leaving this Turbo machine actually has more energy because the energy is being added by the blades. And if the kinetic energy changes are negligible, then again we can talk about M dot H2 - H1.

(Refer Slide Time: 21:19)




So let us summarise the steady flow energy relation equation whatever we have learnt so far. For most turbomachinery applications, the flow processors are adiabatic, that is there is no heat transfer and it is permissible to write Q prime equal to 0. And we can write that - W prime equal to M dot H0 out - H0 in and in case of turbines producing work, we can write that WT prime equal to W prime which is M dot H0 in - H0 out. And in case of compressor, W prime is less than zero, which is the work absorbed in machine and we can say WC prime is M dot H0 out - H0 in.

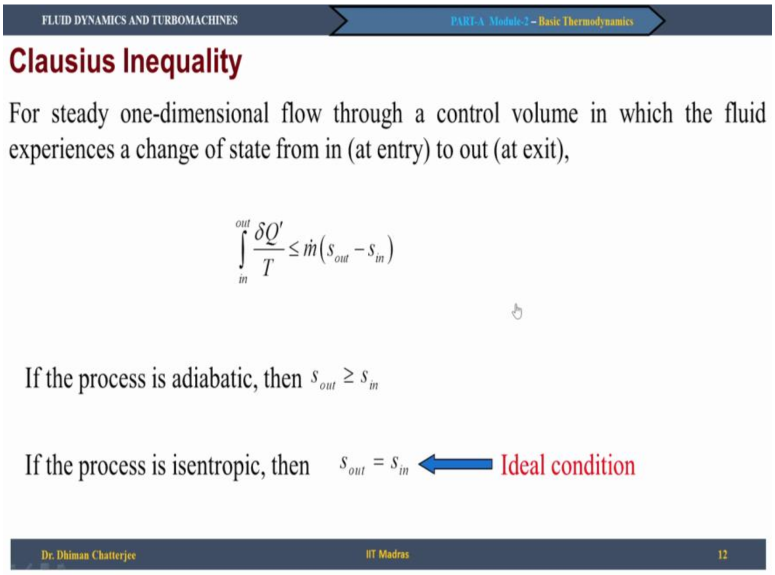
(Refer Slide Time: 22:01)




Now we come to the 2nd law, 2nd law of thermodynamics is a very fundamental law because it gives an additional qualification on the energy transfers. So while first law talks about the conservation of energy and 2nd law will add a restriction, first law does not tell you whether 100 percent of the work can be converted into heat on vice versa. 2nd law puts a restriction on the direction of flow of heat and work. For example, we know from our common experience that water flows falls from a higher level to a lower level spontaneously. Heat flows from a higher temperature to a lower temperature naturally.

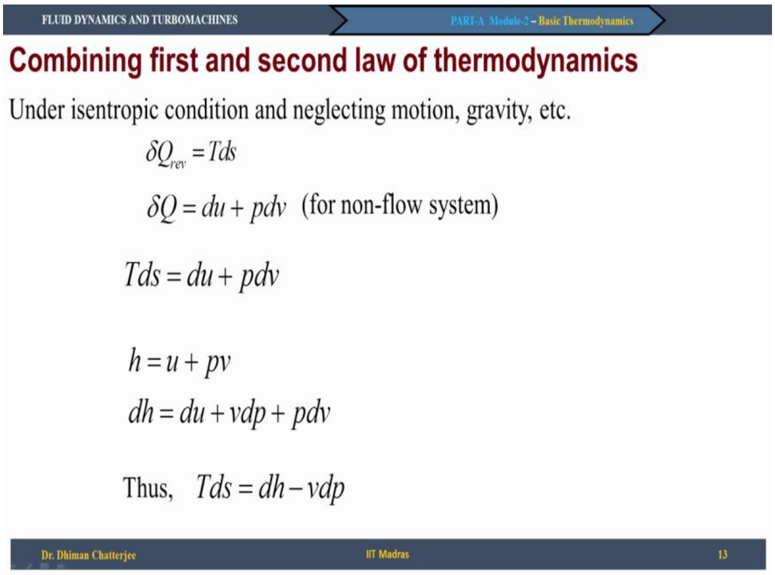
So then it never happens in the other way. First law does not really say that such a process is not possible, the 2nd law brings in the directional aspect. You can actually take water from the ground floor to a multistoried building, top of the multistoried building by using a pump. So that means you have to put in an external agency to supply the work. So these concepts, the directional constraints are added by the 2nd law. 2nd law also gives rise to a property called entropy and it is defined as ds is equal to Dell Q reversible, we are talking about a reversible process by T.

(Refer Slide Time: 23:28)




Next important thing we need is Clausius inequality. For a steady one-dimensional flow to a control volume in which the fluid experiences a change of state from in at entry to out at exit we can write that Dell Q prime by T in to out is less than equal to M dot s out - s in. If the process is adiabatic, that is there is no heat transfer then what happens is s out is going to be greater than equal to s in. This inequality that comes for a **reverse** reversible process. For irreversible process, that is if we talk about a reversible adiabatic or isentropic, then we get s out equal to s in. We will see how these processes take place on and depict it on an HS or a TS plot very soon.

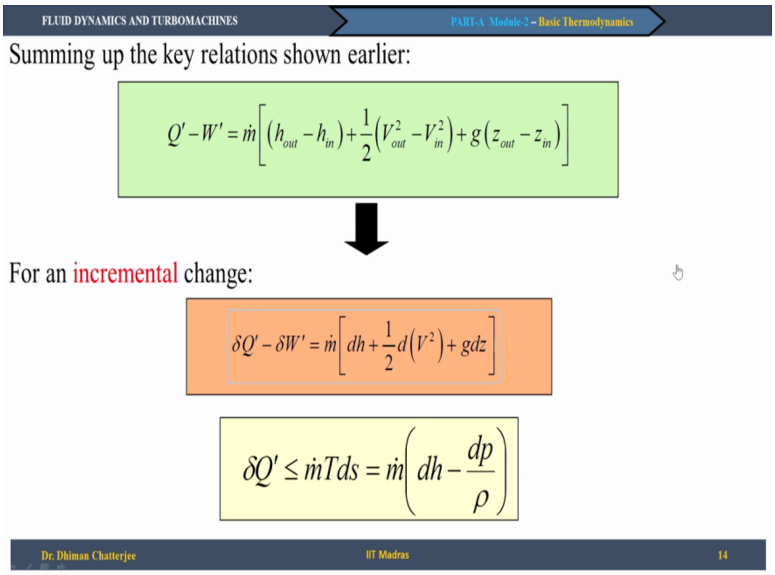
(Refer Slide Time: 24:24)



So now combining the information that we have gathered from first and 2nd law of thermodynamics and using isentropic conditions and neglecting motion, gravity, etc., that is kinetic energy, we can say that Dell Q reversible is T ds, that is we get from the 2nd law and from the first law we get that Dell Q is equal to du + B dv, this is for a non-flow system and where only P dv of the displacement work is the only form of work is possible. And then combining these 2 we can write T ds equal to du + P dv. But please note that though we have got the T ds equal to du + P dv, as a condition, as a relationship under different assumptions but this relationship is valid for all processes.

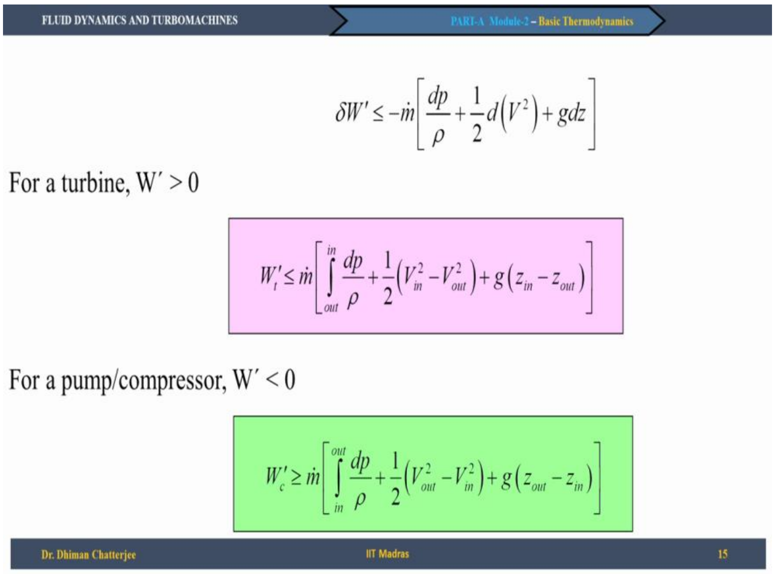
Why because all the, this is actually a relationship connecting different properties. And properties are point functions, so it does not depend on what process, what path the change has taken place. So this is valid for all processes. And now if we bring in enthalpy which is h equal to u + P v and talk about the changes in enthalpy, dH as du + V dp + P dv and then substituted back, we get that T ds equal to dH - V dp. We will make use of this relationship in the next slide.

(Refer Slide Time: 25:50)




So summing up the key relationships shown earlier we can say that from the first law we get Q prime - W prime equal to M dot h out - h in + half V out square - V in square + g z out - z in. Which for incremental change we can write that Dell Q prime - Dell W Prime equal to M dot dh that is the incremental change in enthalpy + half dv square, here again I am talking about the change in the v square quantity, dv square is the notation I am using to talk about the change in the kinetic energy per unit mass + g dz and this when combining with 2nd law we get that Dell Q prime is less than equal to M dot T ds M dot dh - V dp or dp by rho as I have written here. So now let us club the first and the last relationship in the next slide.

(Refer Slide Time: 26:46)

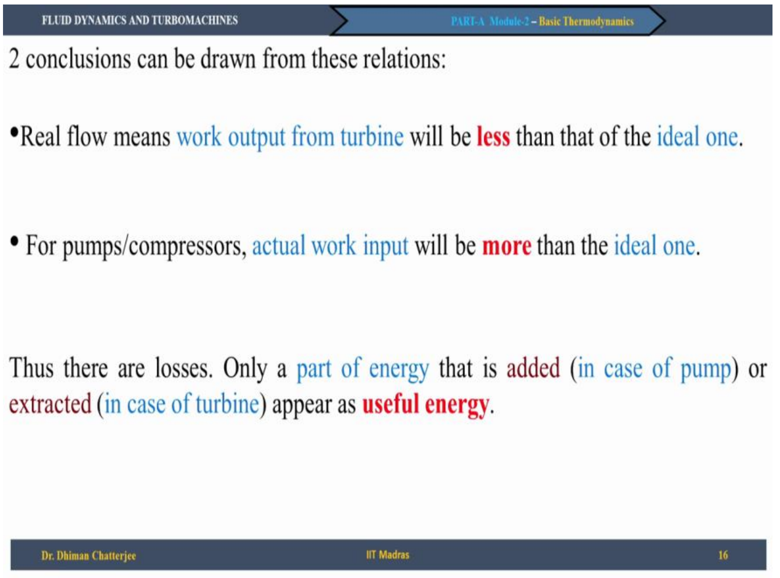



So we get that Dell W prime is less than equal to - M dot dp by rho + half d of V square + g dz. For a turbine W prime is greater than zero and this brings us to a very important conclusion that the work that can be obtained from a turbine, the power that can be produced by a turbine has a maximum, which is achievable only under an ideal condition of isentropic. So we get that WT prime is less than M dot out to in dp by rho + half V in square - V out square + gz g of z in - z out.

You please note and take care of this inequality sign, that means under no circumstance the turbine can actually have any power output greater than these values, that violates the 2nd law of thermodynamics. In fact for all real applications this equal to sign also is not valid. And we will have the upper limit only as an ideal case for isentropic flow. For a compressor however W prime is less than zero, so if you swap the directions of these inequalities, we just bring it to the other side and rewrite it, then we can say that WC prime, because I have now made it into the positive expressing the power as we have done is M dot in to out integration dt by rho + half V out square - V in square + g z out - z in.

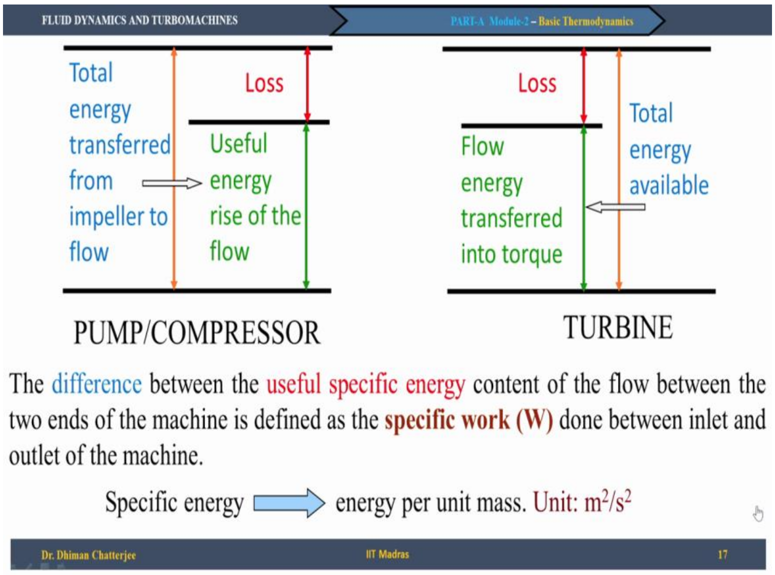
So here you see that this dp by rho is actually for both turbine and compressor is actually indicative of the fact that we need to rely on what is the thermodynamic process, is it reversible or irreversible. If it is a reversible, because of many reasons we will come across in thermodynamics textbooks, I will talk about the losses that take place in the Turbo machines later on, we will get that this inequality sign comes in. That means in order to get a definite work output from a compressor, the valve that you have to add to the compressor, the power that you have to supply to the compressor should be greater than certain minimum quantity.

(Refer Slide Time: 29:22)




This is just the converse of what we see in turbine, in turbine I repeat we get work output from the turbine, the power produced by the turbine less than a maximum achievable quantity. And so these 2 conclusions are written here that real flow means the work output from turbine will be less than that of the ideal one. This real flow means the fluid has viscosity, there are mechanical friction losses and hence the output will be less. And for pumps and compressors, actual work input will be more than the ideal one.

(Refer Slide Time: 30:09)



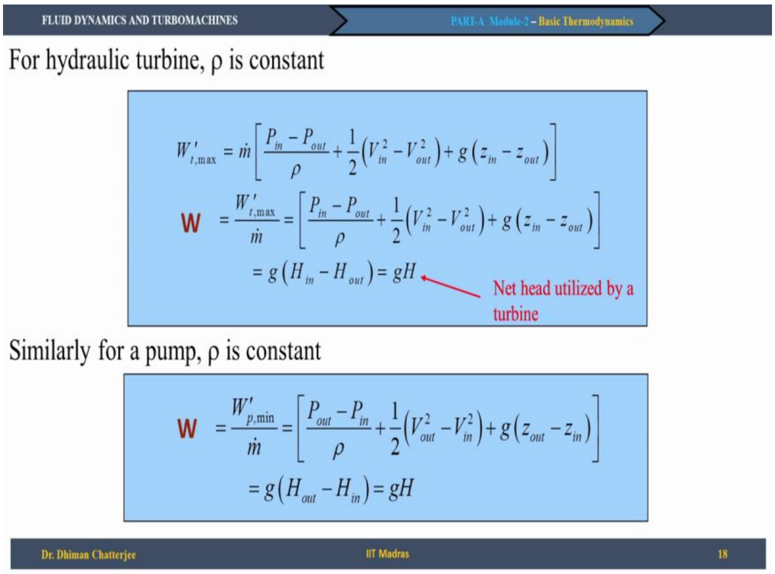

These are because of the losses and hence we can say only a part of the energy that is added in case of pump or extracted in case of turbine appear as useful energy. This term useful energy is very important in the Turbo machine literature, we will talk about it now. So let us look at the schematic. This is my idea of putting in a cartoon form what happens in a pump or compressor. The total energy that is transferred, transferred from the impeller, that is the rotating blades to the flow, only a part of it, maybe a major part of it, but only a part of it is given to the, transferred to the fluid in an useful fashion and there is an energy rise across the Turbo machine in the fluid, whereas loss accounts for the remaining portion.

In case of turbine the total energy available with the fluid, we cannot extract, the energy that goes into the blade, in the form of torque and the power produced is only a fraction, maybe a large fraction, maybe 80, 90, 95 percent but not 100 percent, there is a component called loss. So engineer working in Turbo machine companies, what you would like to do is try to minimise the loss. So in this lecture series whatever we are going to talk about, we will try to understand how this Turbo machine performance, what are the causes of these different classes and how we can improve it.

And now we come to a very important definition of specific work. The difference between the useful specific energy content of the flow between the 2 ends of the Turbo machine is defined as the specific work done between the inlet and the outlet. Please note the all the terms which are marked in different colors. The difference, when we are talking about Turbo machine, there is one inlet, one outlet and we are talking about the difference in the energy that is available with the fluid, you are making the measurement, let us say you are doing an experiment, you find out by some means, we will talk about it later when we talk about the experimental procedures, we find out the energy content of the flow that comes into the Turbo machine and the energy content of the flow that leaves the Turbo machine.

Now find out the difference between the useful energy and divide it by the mass flow rate, we get the useful specific energy. This is known as specific work in case of Turbo machines and this is one of the desirable features of the when you talk about the performance of a Turbo machine. And to remind you that since it is specific energy, there is energy per unit mass flow rate, so it is joules per kg or metre square per second square.

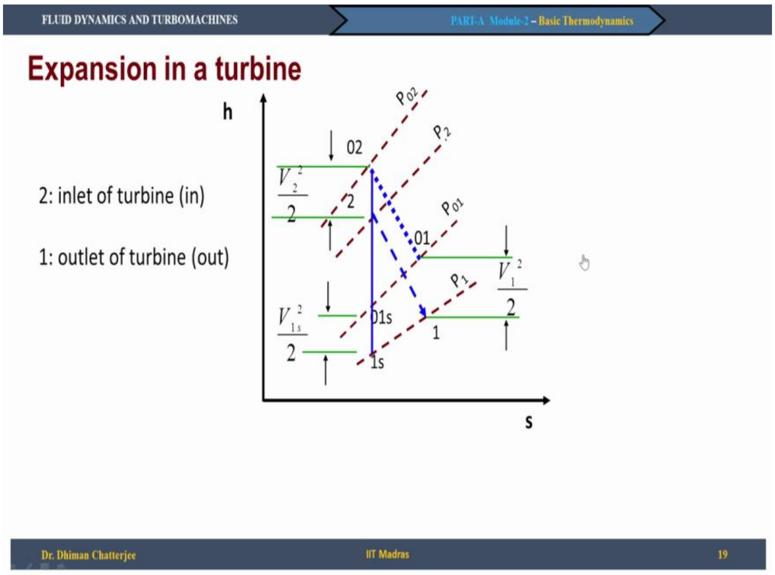
(Refer Slide Time: 32:37)




For hydraulic turbine, density is constant and the first law gets reduced to, the combination gets reduced, the WT prime max, we are now using the equal to sign, so we can write max is M dot into P in - P out by rho + half V in square - V out square + g z in - z out. And specific work W is nothing but the work produced, maximum work produced because that is the useful work, we are talking about the energy available across the Turbo machine in the fluid by per unit mass flow rate is given as P in - P out by rho + V in square - V out square by 2+ g z in - z out which is equal to many times given in form of g multiplied by capital H.

This capital H is nothing but the net head utilised by a turbine. So when we design a turbine we have to know what is the head that is expected across the turbine. So this is the net head H. Similarly for a pump, rho is constant and we can get the specific work to be again established in terms of g into H but in this case, relationship is P out - P in by rho + V out square - V in square the whole divided by 2+ g z out - z in. In this case please note that this H is the head developed by the pump. So we will come across these terms, the head, the net head utilised by the turbine and the head developed by the pump when we talk about the pumps and turbines in the next week.

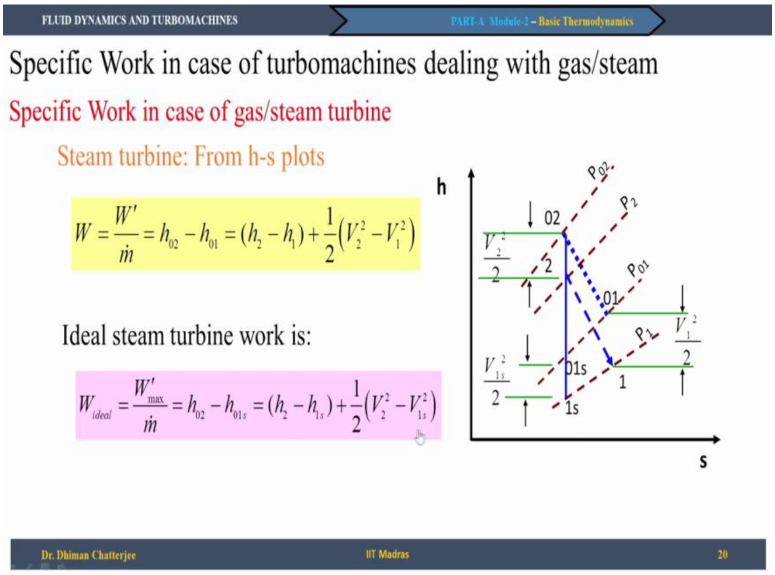
(Refer Slide Time: 34:25)




Now I will quickly talk about the representation of these processes for a gas or steam handling machines on a hs plot or a ts plot. So here we see, the duration show that it has come from 2 to 1. So what type of process is this, is it compression or expansion? Is it a compressor or a turbine, of course this is an expansion in a turbine. We are talking about the turbine, the inlet is at 2 and outlet is at 1 and we see that there is an expansion, this is a reduction in pressure, there is a reduction in enthalpy from 2 to 1 which is the actual process. Whereas in ideal case, in isentropic process if you see there is no change in entropy, we see that from 2 it would have come to 1s.

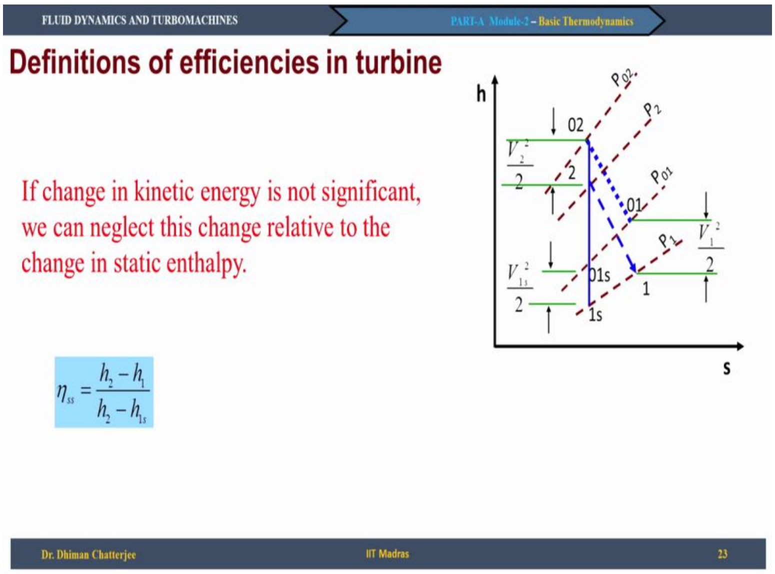
This letter s here denotes the s is constant isentropic process. We can also talk in terms of the stagnation properties which is nothing but H02 for example is nothing but h 2+ V2 square by 2. And or h 01 is nothing but h1s + V1s square by 2. So you see one thing very clearly that if I am talking about an idealized condition, isentropic condition, then the total enthalpy drop that I can talk about is h0 to –h01s. Whereas in real life we because of this irreversibility, because of the losses, what we get it is h02 - h01, that means the actual amount of power produced is related with h02 - h01. If you want to talk in terms of static enthalpy, we can talk about h2 - h1 or h2 - h1s as the corresponding cases, that will give rise to efficiency as I will show you.

(Refer Slide Time: 36:25)



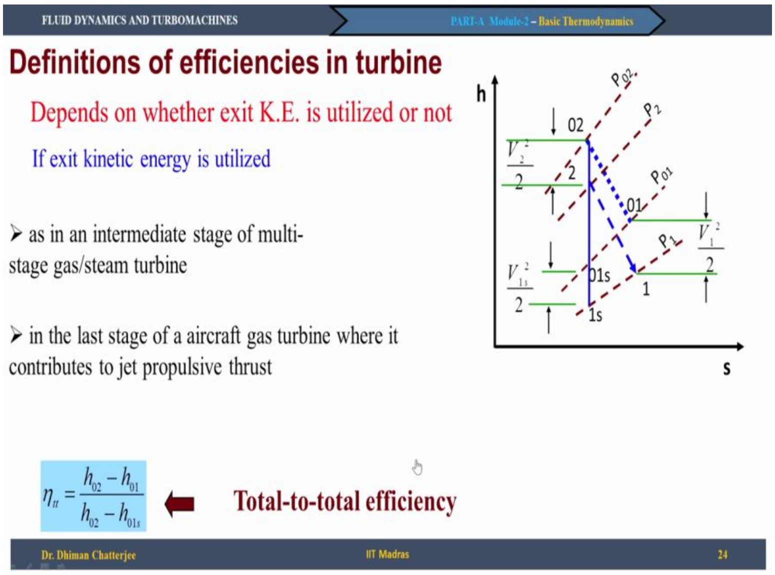

So this is with gas or steam and specific work in this case as we obtain from the hs lot in case of steam turbine, we can say that W, the specific work is W Prime by M dot is nothing but h02 - h01, this is actual one. And you will see that this can be written as h2 - h1 + half V 2 square - V1 square. This is what we get and the maximum or ideal steam turbine work we could have got it as h02 - h01s and that is again given by h2 - h1s + half V2 square - V1s square.

(Refer Slide Time: 37:10)



Now we talk about the definitions of efficiencies in turbine. We can talk about the efficiency is in terms of the static enthalpy or the stagnation enthalpy. So if we say that the change in kinetic energy is not significant, we can neglect change relative to a change in static enthalpy and we can say that Eta s is nothing but h2 - h1 divided by h2 - h1s. That is we are talking about only the change in the static enthalpy in the real situation to the maximum or the ideal situation of h2 - h1s. However many times, or most of the times we would like to express in terms of the stagnation quantity because the kinetic energy change is also going to be accounted for. And this one is known as eta ss, ss stands for static to static efficiency.

(Refer Slide Time: 38:09)

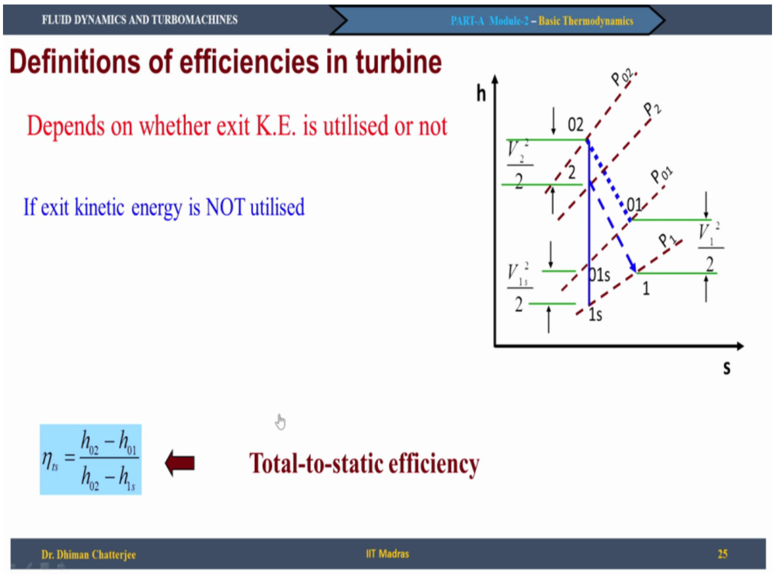



And if we talk about that exit kinetic energy is important as it is not same as the inlet kinetic energy, the kinetic energy change is significant, then we can talk about whether exit kinetic energy is utilised or not. Let us take 2 examples. Let us say that we have an aircraft and we are talking about the last stage of the turbines. Because many times these turbines as I will show you will have multiple stages. That is it goes from one row of blades to the next row of blades and so on and so forth.

Ultimately we are talking about the last stage of the turbine. So if it is in the last stage of the turbine, then in an aircraft, then what happens, the gas that comes out also helps in the propulsion. So that means the kinetic energy of the gas that comes out is utilised, it is desirable to have some kinetic energy. Or else if we talk about an intermediate stage in a turbine, then that kinetic energy that is left out from the one stage will go to the next stage and is also utilised, it is not wasted. And hence in this case we can say that exit kinetic energy can be utilised for 2 cases, as an intermediate stage of a multistage gas or steam turbine or in the last stage of an aircraft gas turbine where it contributes to jet propulsive thrust.

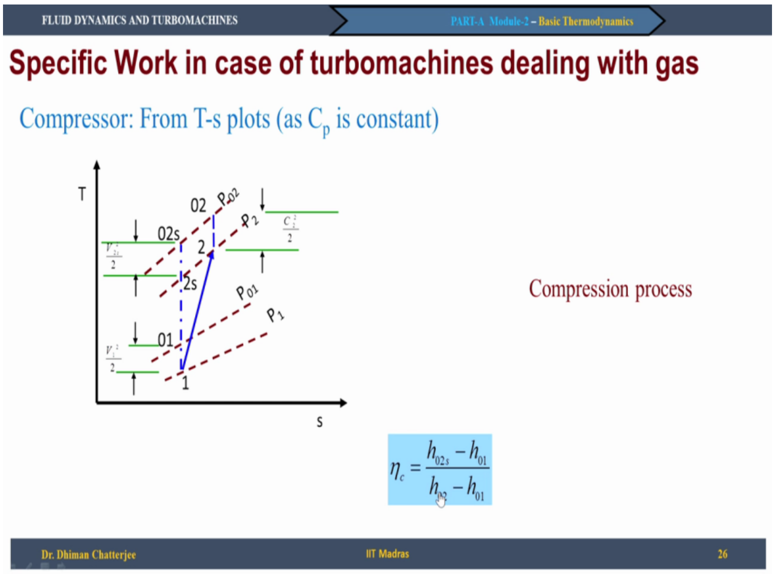
And in these cases we define efficiency in terms of eta tt, tt stands for total to total efficiency and we say it is h02 - h01 divided by h02 - h01s. That is because the kinetic energy is useful. But let us say we are talking about a land-based gas turbine and we are talking about the last stage. Ideally if it is possible for us, then we would not like to have any kinetic energy of the flow leaving with the flow, we would like to utilise all the kinetic energy and if we fail, that means some part of the energy is Wastage.

(Refer Slide Time: 40:18)




So it brings us to the next stage, next question is that it is not utilised, if the kinetic energy is not utilised, like in a land-based gas turbine where the last stage, ideally I would have liked the fluid to leave without any kinetic energy but that is not possible. That means some energy has not been extracted from the fluid and that means the our efficiency should be differently noted and this is given as eta ts which is h02 - h01, because that is the actual energy available for the turbine, whereas the ideal world will say that ideally there is no energy coming out of the fluid and hence ideally the fluid should have come out at h1s and hence the energy that will be available ideally should have been h02 - h1s, because the fluid should not have left with any kinetic energy.

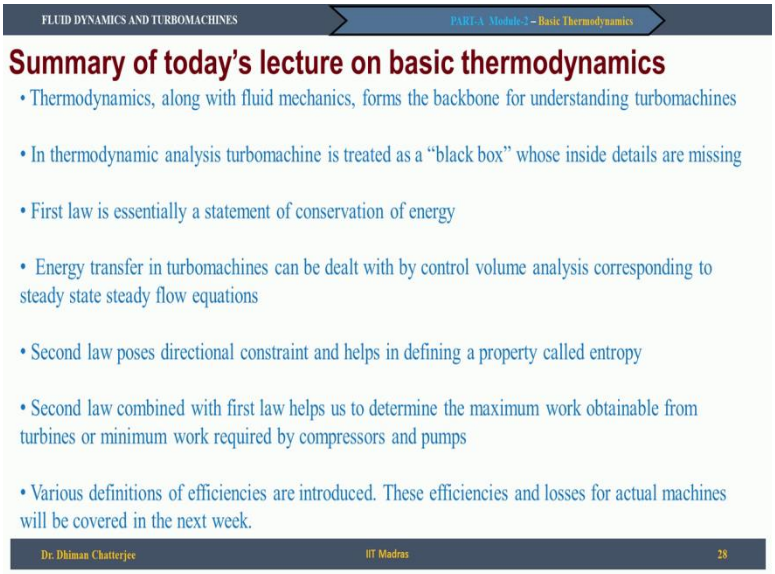
(Refer Slide Time: 41:37)




Whenever the fluid leaves any kinetic, with any kinetic energy, that is a loss from the turbine perspective. And in this case if it is not utilised, we say that we should use eta ts or total to static efficiency. Thus we know that there are different ways of expressing the efficiency of a turbine. And last thing about the compressor and we can talk about the specific work and the efficiency. You see in the case of a compression, it starts at a lower pressure lower temperature and goes to a higher pressure higher temperature because the gas is compressed and 1 is a state in which fluid enters the compressor, 2 is the state in which the fluid leaves the compressor, 01 and 02s are stagnation states in case of the inlet and 02s for the idealised case with constant entropy or either entropic compression idealised world and real is 02.

So in case of compressor we say that h02s - h01 divided, that is h02s - h01 is actually the amount of energy that should have been used because that is what goes into the fluid. But what actually we need is h02 - h01 because we have to overcome the losses. So in this case we get for the compressor h02s - h01 divided by h02 - h01 and this is the end of today.

(Refer Slide Time: 42:56)




So let me summarise what we have learned in basic thermodynamics. We talked about thermodynamics and we found that thermodynamics along with fluid mechanics forms the backbone for understanding Turbo machines. In thermodynamic analysis, Turbo machine is treated as a black box whose inside details are missing, we talk only about the energy interactions. First law is essentially a statement of the conservation of energy, we applied it for the control volume approach and energy transfer in Turbo machines can be dealt with control volume analysis corresponding to steady-state steady flow equations.

2$^{nd}$ law poses directional constraints and helps in defining a property called entropy, actually it gives the property of entropy. The 2$^{nd}$ law combined with the first law helps us to determine the maximum work obtainable from the turbines or the minimum work that is required by compressors and pumps. Various definitions of efficiencies are introduced, these efficiencies and losses for actual machines will be covered in the next week. So as I was saying that in thermodynamics we have dealt with Turbo machine as a black box in which some fluid enters with some energy and leave at the exit with some other energy, that is the steady-state steady flow so there is no mass being accumulated and we have found out the energy conservation equations based on first law, we have also talked about the 2$^{nd}$ law.

What we now need to do is understand what happens inside a Turbo machine. To get to that we need to know what is the construction of a Turbo machine. So in the next class we will talk about the different aspects of Turbo machines, the classifications and of course we will continue with that our discussion on the principles. Thank you.