Indian Institute of Technology Kanpur

National Programme on Technology Enhanced Learning (NPTEL)

Course Title
Engineering Thermodynamics

Lecture – 21

By
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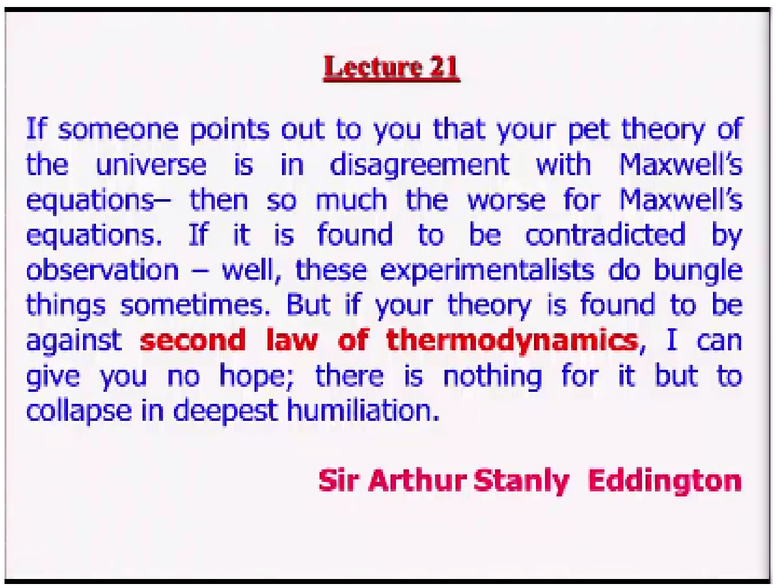

So let us start this lecture with a thought process from Sir Arthur Stanley Eddington who says that, if someone points out to you that your pet theory of the universe is in disagreement with the Maxwell equations, then so much the worse for the Maxwell's equations. If it is found to be contradicted by observation well these experiments do bungle things sometimes. But if your theory is found to be against the second law of thermodynamics, I can give you no hope; there is nothing for it but to collapse in deepest humiliation.

So that is the sacrosanct of the second law of thermodynamics that means he has having so much of faith on the second law of thermodynamics which we discussed in the last lecture. And if you look at we are having two statements we have made for the second law of thermodynamics one is Kelvin Planck statement which says that it is impossible to have a cycle operating device to observe certain amount of heat from the thermal reservoir and does equivalent amount of work that means what it has to reject certain amount of heat without that it is not possible to have a cycle operating heat engine.

And just opposite of that, you know being made by the Clausius that is Clausius statement which says that it is impossible to have a cycle operating device to absorb the heat from the low-temperature sink or a thermal reservoir, and just transfer the same amount to the high temperature thermal reservoir without any external wall right. It is not really possible, and we have seen also in the last lecture that both the statement are same by of course deduction method right.

We first prove that consider that one is wrong and then you find out that other is also, you know not correct. So by that way we have found out and beside this we have also looked at that certain definitions of what you call efficiencies like what we call first law of efficiency, you know thermal efficiency basically first law of thermodynamic efficiency or first law of efficiency. And then we define also, you know certain performance parameters for refrigeration and heat pump systems right that is coefficient of performance right.

And if you look at this COP of your what you call air condition or the heat pump you know we do use that as a performance parameter instead of the thermal efficiency which is being used only for the heat engine. And if you may consider that you know heat pump we use in the winter season right to maintain the room temperature at a comfortable level by extracting heat from the ambient which is at low or what you call temperature.

So now, you know will it be cheaper for you to operate a heat pump or the resistance heater what we use in our you know country which will be cheaper to have the, what you call to have the in a cheaper absence to have more efficient in other words it will be more efficient you know which will be heater, resistance heater or the heat pump which will be more efficient actually it is the heat pump.

Unfortunately we do not use it, because it is a costly and the resistance heater is very cheap means, you know to purchase right. So therefore, but however it is very inefficient so COP of the resistance heater will be what, will be very low as compared to heat pump. Now a question might be coming to your mind is it possible that we can use this air condition as a heat pump during winter season is it possible, is it possible or not, actually it is possible we have already seen that you know.

But then how to do that without really changing anything so that also people have device I think you can think of how it can be done you just reverse the process like, you know instead of evaporator which is being used for the air conditioner. So you use as a condenser inside the room and then, you know the evaporator will be outside so that is the heat pump. So what will be I mean that we have already discussed right.

Now what will be will be continuing to discuss the second law of thermodynamics, and if you look at we have talked about this perpetual motion machine you know right.

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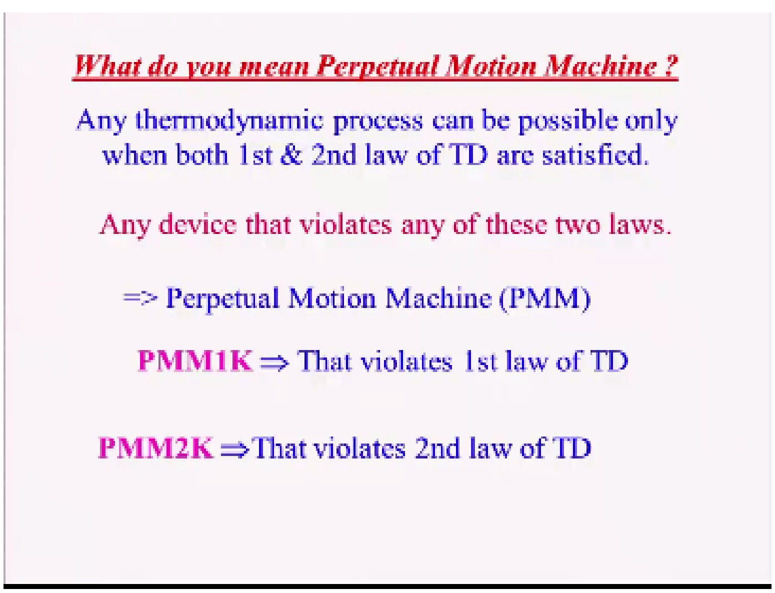

Earlier whenever we are dealing with the first law of thermodynamics right, and that means which will be generating some amount of work without absorbing any heat from anywhere, you know that is the thing we have seen the perpetual motion machine of first kind. So if you look at any thermodynamic process right must satisfy both the first law and second law of thermodynamics that we have already discussed right.

And any device that violates any of these two laws is basically known as perpetual motion machine that means in a perpetual means all the time it will be working without, you know absorbing any heat or any energy from somewhere and doing some work and that we call basically perpetual motion machine of first kind, you know because that wireless the first law of thermodynamics.

If you look at there are several, you know people have approached particular in western country where the patent is, you know very big thing or a mania I call right. And in our country we are not having any patent do you know what is patent, do you know any idea, that means if you find out something you say it is my property and if somebody will use he has to pay money. In our country earlier days it is not that if you have developed something that is for the society and you will have to give so that innovativeness can be propagated very easy people can tinker it and then develop more.

So this is the, you know which we differ, but unfortunately we are following that patent garage I call, you know nowadays we are having several patents and to self-purification a gratification right. So therefore, if you look at lot of patents, you know we are being filed in Western countries for this perpetual motion of machine even some people have gone higher to invest money because they want to make money.

So that if somebody is saying something jazz is this thing that also if you look at also what gullible people are being viewed by this we call, what you call spiritual leaders, you know somebody we say that look I will give everything without you need to not to do anything for example somebody can make bring a rasgulla and give, you know just like that. So that kind of story you might have heard, but those are not really possible so far this first law of thermodynamics.

So there is a perpetual motion of machine of second kind which violates the second law of thermodynamics right, so that you call it a perpetual motion machine of first kind which state that, you know whatever the amount of heat, you know it will be observing from a thermal reservoir the high temperature it will be basically converting to the, you know totally to the work and which is not possible.

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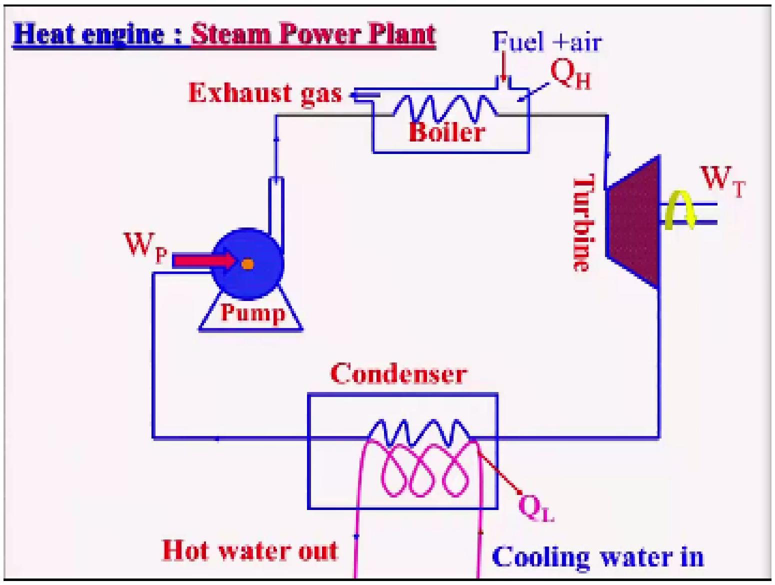

So let us consider few examples, you know just to say that that, you know this is the as usual, you know steam power plant right where it is having a boiler, and a turbine, and the condenser, and the heat pump and if you look at this is a closed kind of a steam power plant which produce some amount of work you know this thing and some work has to be consumed by the pump to elevate the pressure of this liquid which ever coming from the condenser right.

And some amount of heat is going out from the what you call from the condenser to out and of course this we doing. So this satisfy both the, if you look at first law and second law right.

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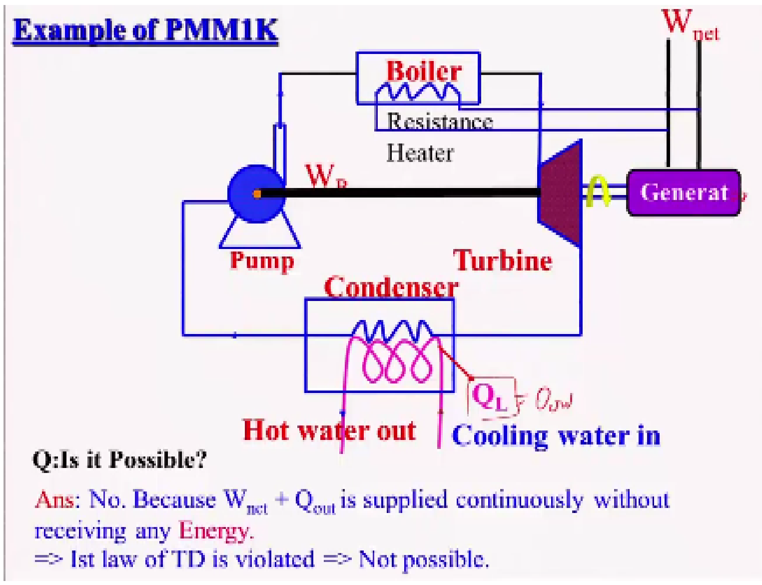

But if we consider, you know somebody has changed this thing what he has done he says that in the instead of boiler where the fuel is being burnt right. Now what will be, I will be putting something like a resistors and this resistors will be heating the fluid, you know and some steam will be produced then it can be expanded in a turbine and then it will go to the condenser and give some amount of heat to the surround, you know coolant and then it will pump.

And this turbine is connected to the pump right that means whatever the power is being developed by this turbine is basically, you know some portion any portion is given to the pump to be get operated right. So therefore there is no problem and then this turbine is connected to a generator right this is basically a generator right. And then you are getting the net work output kind of things right, that means whatever it is giving and then some amount is going to the resistance and then net.

If you look at somebody has proposed look you do this, so that once you start this system then, you know it will go on for because what is happening from the generator you are producing some electricity and that electricity is used to what you call vaporize are the produce the steam vaporize the water for producing steam, and then that is expanded is going on is it really possible what it violates I mean if it is not possibly it will be either violating the first law of thermodynamics or the second law of thermodynamics so what is violating then it is basically violating what first law of thermodynamics let us see how because if you look at the network plus Q out what is Q out in this case this key out is nothing but your Q_l this is equal to Q out.

And that is supplied continuously without any energy coming from somewhere you know how can that possible so therefore the first law of thermodynamics is being violated by the system you know what I have shown here it may be you know somebody might have proposed or something like that you propose that is not try it is not possible you can quickly you know find out look it is violating the first law of thermodynamics so therefore it is not possible so let us take another example like you know so that is the again the steam power plant will say and what will say that you know like as.

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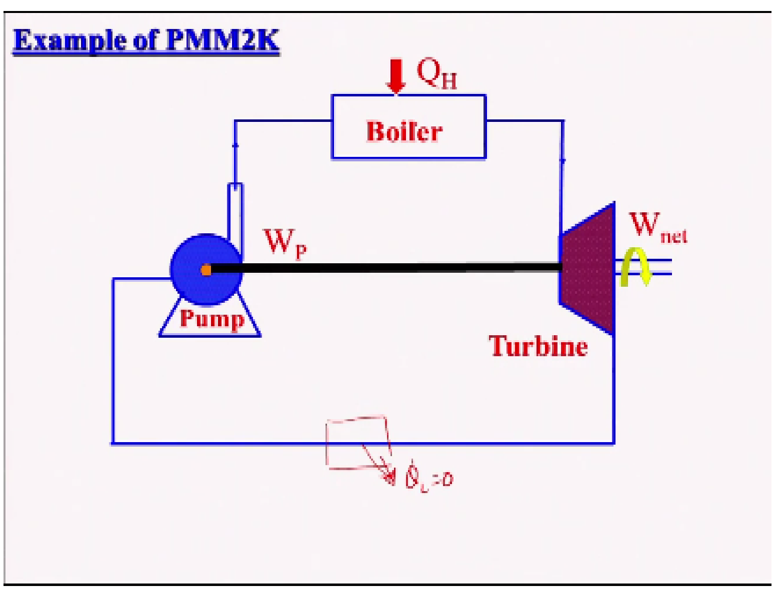

It is you know steam power plant there is a condenser right condenser which will be having you know some amount of heat will be rejected in this case for example some amount of heat being rejected here right in the condenser they say look it is a waste as because what we can do instead of having a condenser what we will do from the turbine I will just directly connect to the pump right I can have let us say some you know stream is they being expanded in a turbine and the same fluid I can put into pump and give right.

So that the heat which is rejected out is a you know kind of a loss then it can be you know like utilize right so that of course it is taking the heat Q_H from the you know like a some heat source may be combustors or this thing by burning fuel or maybe from nuclear from the solar any other place we can take this amount of certain amount of it so therefore and some amount of work is done so it is not violating the first law of thermodynamics am i right okay so is it not a good idea to do that like you just eliminate the condenser and connect directly the turbine to the pump.

So that the fluid after being expanded in a turbine can be pumped back to the boiler because if you know that you know the condenser in the condenser something more than 50% of the heat absorbing reject it right it is a large amount of heat being rejected so is it possible really to do that or not because if some of you could do it will be a wonderful thing because, so that what will happen you know whatever the heat in this case if you look at if the heat is coming out and it is not going out rejected.

So if you look at there is a condenser here and it is 0 right Q_l is 0 so that means whatever heat being what you call being observed by the fluid in the boiler right that is being converted into the work network so that violates the Kelvin plank statement it is impossible to have a cycle operating device to observe certain amount of it and does the equivalent amount of work that means in this case Q_H right is equal to W net right of course if it is.

So then into in 100% efficiency of I mean you can assume that there is some kind of irreversibility or some kind of losses will be there you can say look I can get a instead of forty percent efficient let us say if it is sixty percent it is being rejected in the condenser you know in the condenser then naturally the efficiency will be something around 40% now instead of 40% in this device you can get something around 100% ideally but in reality you can think of getting around 80 90% which is a good profession.

But however it is not possible to have this device because the Kelvin blank statement is being violated so therefore this kind of machine is known as perpetual motion machine of second kind which is impossible to have that kind of, of course if you go back to the history there are several people you know who use some kind of a you know the managerial skill and then convincing power to garner some money by making some very you know sophisticated device to say that they can do this and they have also you know maybe sometimes successful taking the wing the out money.

And other things sometimes they are also you know in the gin so therefore be careful about that and then of course you know one has to look at the thermodynamics second law of thermodynamics also first love them and to say that whether the system is feasible or possible or not you know.

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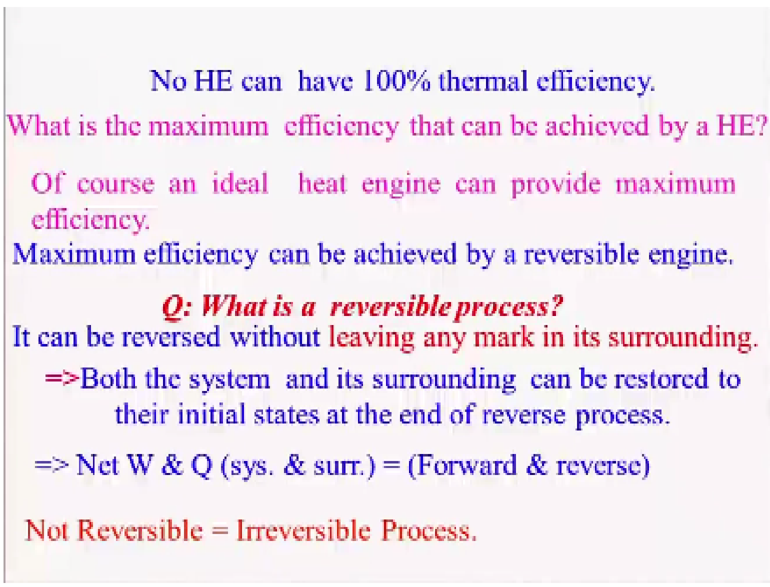

So that we have also seen earlier that no heat engine you know can have 100% thermal efficient that means you know if just now we have seen that if the you know if it is a heat engine is observing certain amount of heat from the thermal reservoir and does the equivalent amount of work then only it will be having 100% thermal efficiency but however it violates the second law of thermodynamics so therefore there would not be any heat engine which can have the 100% efficiency you know 100%.

Thermal efficiency so therefore now question arises what is the maximum efficiency that can be achieved by a of course a heating you right what is that how will come up with that and generally a thought will be coming to your mind that it will be possible only if this ideal engine you know which will we can provide you know maximum thermal efficiency only if the processes are reversible right that means a reversible engine can have a maximum thermal efficient so what is the reversible process.

That we have already discussed let me just again repeat so that it will be engraved in your mind that whenever system and surrounding is interacting you know each other through the walk or the heat there will be some changes and you know like and then this interaction will be half it changes both in the system and the surrounding and if it is reverse back right then there would not be any mark either in the system or the surrounding then only we call it as a basically reversible process.

That means I mean system and surrounding will be coming back to is the original state from where it was started for example if the system is interacting surrounding it was in state 1 it is going to the state two then if it will come through the same path and from the state to the state1 then we call it as a reversible process as a result the net walk and you know and heat interactions will be basically 0 between the system and surrounding whenever it will go forward and reverse the network and heating direction will be 0 then only it will be reversible process so if a process is not reversible then we call it as an irreversible process right so therefore we will be looking at some of the kind of what you call reversible process when it will be occurring.

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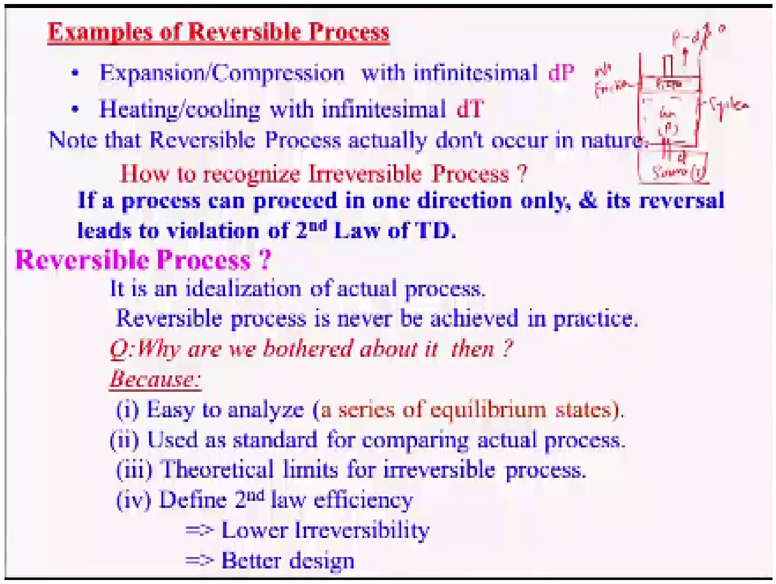

So we have already seen the expansion and compression with the infinitesimally pressure difference right if the when there is a kind of a you know occurring so therefore there will be or to call very, very infinitely and the process is quasi steady state if you look at you there is a piston-cylinder this thing arrangement and if we are assuming that this is my piston and there is no friction here no friction between the piston and cylinder and this is my gas and it is being you know this is being expanded.

If you are hitting giving heat then it will be expanding it will be moving up the piston will be expanding and then you know like the pressure change whatever it will be there p – dp if it is gas pressure is here and this dp is very, very small and there is no friction in between and also if there is some heat transfer and that heat transfer will be you know gradient between this heat source if there is a thermal reservoir you know source at temperature something and that temperature between the gradient between the system and the source.

Or the thermal reservoir is very, very small infinitesimally small then only we call it as a basically reversible process you know possible like either due to the expansion or compression or heating or the cooling you know this is very essential that means the gradient is really should be very small and of course it is not really possible to have that you know because the all the natural processes are irreversible in nature right and but then question arises why do we look at the reversible process and also another question comes to our mind how to recognize a reversible process right, because suppose we say that the reversible processes you know do not occur in nature rather irreversible process occurred neither now we need to know how to do you know identify the irreversible process. If a process can cross it in one direction and only right, it cannot be reversed back to the original thing and that violates you know basically what you call leads to the violation of second law of thermodynamics.

Because it were possible we have taken example of hot tea cup you know like and which will be and he if heat is transferred from the hot tea to the ambient air you cannot get back the energy of the heat energy which is in it sorry heat which is gone into the surrounding to reverse back and come back to the tea you know tea from its surrounding. So therefore that is kind of thing we know and reversible process it is an idealization of actual process basically if it is an ideal one and it is not really a real one.

And revere in other words reversible process is really cannot be achieved in real situation or in the, our day-to-day practices. So now questionnaire why we should bother about it why will be interested look at reversible process if you look at the in thermodynamics we are mostly looking at reversible processes and trying to solve some problems and then you know look at it because it is easy to analyze by considering a series of equilibrium states or what we call it basically quasi equilibrium states.

Because the actual process we can analyze by considering a you know occurring in a several you know equilibrium states so that it is reversible that way we can analyze and it is used as a standard you know for comparing the actual process because it is like a benchmark you know like okay, so one can achieve till that not beyond it so therefore that helps us to use this as an ER stick to say that look it can be done with that so and as a result we know that a is a limit of the irreversible process right.

And that helps in telling like look if somebody is claiming that this process is possible which is beyond the reversible you know like what it could achieve then naturally you know it is not right, so that we also use in our day-to-day kind of things so for that reason we need to you know use this reversible process and then work on it and we will have to also define a second law efficiency.

We have already seen the first law patience the best thermal efficiency is nothing but your first law of efficiency you know like he says that how much heat you are being utilized for producing the work right, we have seen that like how much like you no one can do but the second law efficiency which will be discussing little later on that will tell you what is the maximum one can achieve or what is the scope for the improvement for a particular system you know kind oft hings whether it will be possible or not so that we will define little later on so for that we need to look at reversible processes.

And if we know the second level then we can what we will do we will try our best to reduce the reversibility in a system so that our efficiency can be improved and of course that can be by using your intelligence and also design, methodology you need to develop right and then various ways you can minimize the losses are the irreversibility's rather in the process so that you can improve the performance efficiency faith of a either a thermal, either a heat engine or a refrigeration or any other system as a matter of fact.

So this is a very essential you know like for you to look at in your even life for example you might be working right so you are having some kind of a what you call a time table at the interior this way the life you know kind of things suppose you will do something in the early morning then you know it will mind will be fresh and if you do in the night you are you know energy level will be low so that you know your mind will be sluggish you cannot really do that, so that helps you identify your over to call irreversibilities or the you know losses kind of things to do that.

So what I would suggest you should you know look at your timetable of your daily routine you know and look at how you can you know maximize your efficiency says that you can utilize the time and then you can think of second law of thermodynamics for that.

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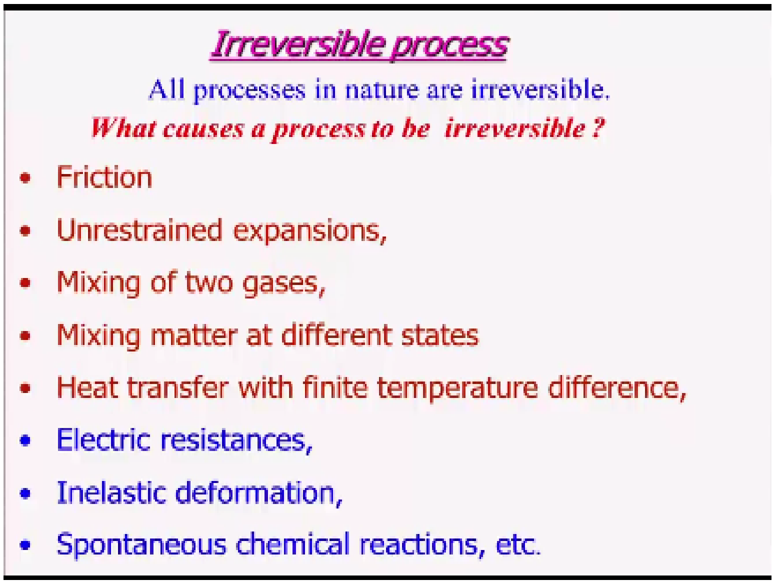

So let us look at irreversible process because it is very important to look at irreversible processes there are various irreversible process one can think of as I told that all processes in nature are irreversible right, because reversible process is basically a myth you know like kind of thing. So what causes a process to be irreversible so what are the processes you know like what are the causes we have already discussed you know like if you look at there will be various one some of them I am just identifying here one is friction right.

Friction and there is an unrestrained expansion and mixing of two gases or more gases right it is not that two gases alone there might be several gases we mixed right and mixing of matter at different states heat transfer with finite temperature difference right, because if the temperature gradient is more than the irreversibility will be more the electrical resistance heating you know register resistance heating.

Because of you are resisting and they know and then you heat it that also is a thing and inelastic deformation you know like elastic deformation basically you can whenever you release the force that elongation due to the applied force can be come back to the original one where it was having like so elastic deformation actually reversible whereas inelastic deformation will be irreversible. And of course the chemical reactions are occurring you know it is not really you know have to bring them back in the same following the same path.

So spontaneous chemical reactions as nuclear reactions and other things you know like is basically irreversible just two I have to give you some of them even like in your day to day life this will be the kind of thing one can connect for example if we are trying to do the something in a just in the sense very fast you want to do then you know you would not really do your things efficiently or you are doing in a hurried manner so that it would not really we you know you will be dissipating lot of your mind power for that.

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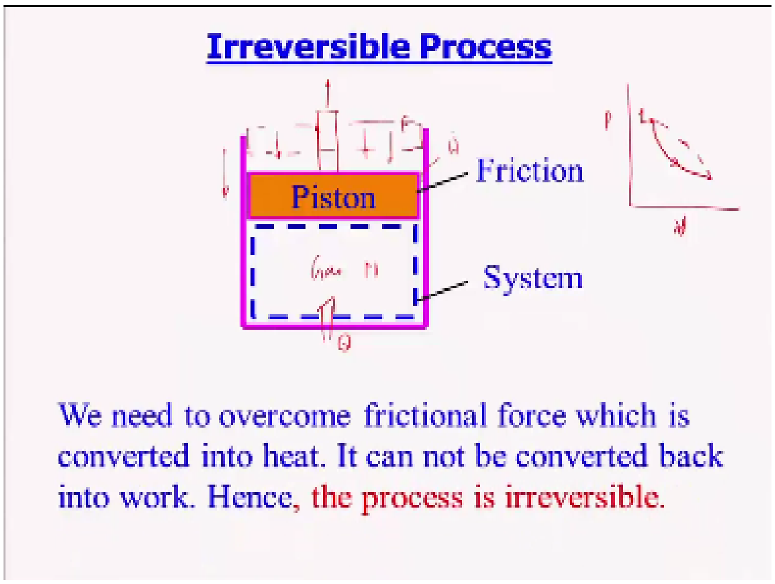

For example, like a friction if you look at all the time whenever we are considering piston and cylinder arrangement and in a let us say this is a gas and it is being heated here right, and then naturally piston will go up right, if it is heated and it is insulated so the pressure will rise and of course you can think of some pressure force is being applied here right and then piston will be moving up.

And we always say that the between the cylinder and the piston there is no friction right, but now we will consider there is a friction if the piston is moving what will happen it will rubbing right if it rubs both the surfaces there will be some kind of work being expanded and converted into some kind of heat you know you might be getting this you know feeling like suppose I rush these two hands what will happen I get some you know little high temperature warm kind of things right.

So in the winter we do I always wrap this thing so that will be getting some you know more blood circulation also way the friction we can get this thing what you call some warm kind of thing and if some heat being released here if the piston is moving you know up let us say and now this heat when this piston is moving down right, what will happen again it will be easy this heat which is generated can be converted into work is it possible certainly no so then what will happen like again more heat will be dissipated, right.

Because it is a rubbing surface and that heat being lost that work which is being you know it lies there it is being lost and you know that is basically irreversibility although the it has gone from one state you know let us say if this is a pressure you know like going for here is the PV and this is the process which is taking place here let us say you are in state 1 to state 2 right, and is it if there is a friction here can I come back in this way I cannot so what will happen I will have to go in a different path because there is some heat which is being expanded than the you know like in the this thing and awhile is the work also it is different.

So therefore what you call it is a irreversibility and that also happens suppose you are having friction between your friends or between your teachers and other thing then what happened you dissipate lot of your energy in that so that these are the irreversible processes right, and one has to avoid like if you look at we always try to avoid the friction in our day-to-day life to be more efficient.

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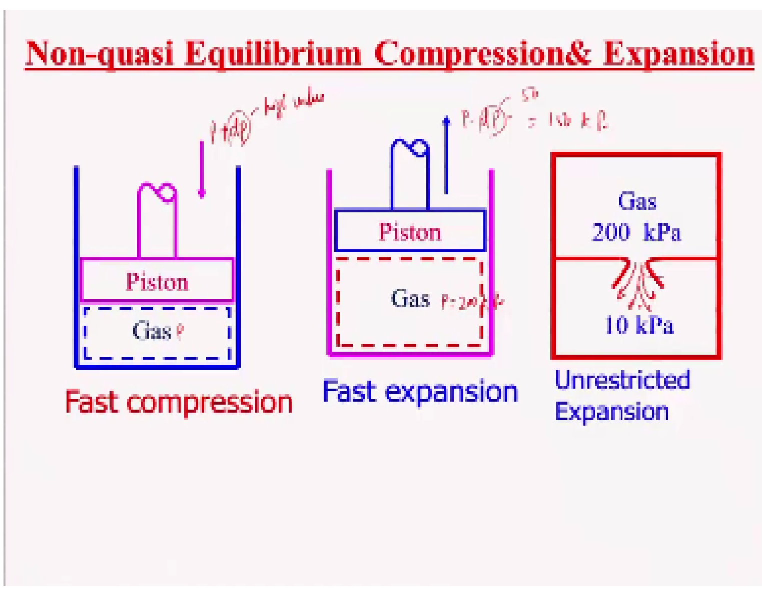

So let us consider some non quasi-equilibrium compression expansion process if you look at the what you call the first expansion is occurring here that means you know this fresh gas which is here it is being pushing in a very fast right, that means the pressure if it is pressure P here right and this is P - DP and this DP is not 0 for example if it is something around 200kilo Pascal here and this pressure is basically what let us say something 150DPI am liking this is something DP is equal to basically 50 that means this pressure is equal to 100 50 kPa.

So that means it is very, very high pressure you know the gradient so that is the first expansion and that we do like we do particularly nowadays in your life also we want to expand we want to expand our business we want to expand our knowledge at a very faster rate and we want to have a very higher growth rate you know that is the what going on and that will be easy right and that will be you know causing because it is a faster anything faster therefore you know lot of stress being generated among the people because of leaving a foster life.

So also in the expansion and so also in the compression so if you look at compression first compression also will be taking place in a very, very high pressure let us say P is here and P plus DP and this DP is very high value very high values right, so therefore this is again you know it will be irreversibility will be occurring although you may assume there is no friction even though there will be irreversibility straight.

And of course friction will be there and therefore the you know in the real situation it will be happy but at the same time if I will say that in actual system I will be using quasi equilibrium the pressure difference are you know during the expansion is very, very small then you know it will be very slow motion and all kind of things which people may not accept so but however the reversibility goes on and if you go or what you call for a either foster expansion or foster compression kind of process.

And there might be another where it is basically the irreversible process that is the expansion you know if there is a what you call partition between these two gas like there is a hole here you know there is a hole right and the gas will be coming out to the from higher pressure to the lower pressure. So that what will happen that there will be a you know certain expansion and is unrestricted expansion so therefore you know there will be also irreversibility that means you cannot take it back in after it reaches the equilibrium pressure you cannot take it back to the original one by following the same path.

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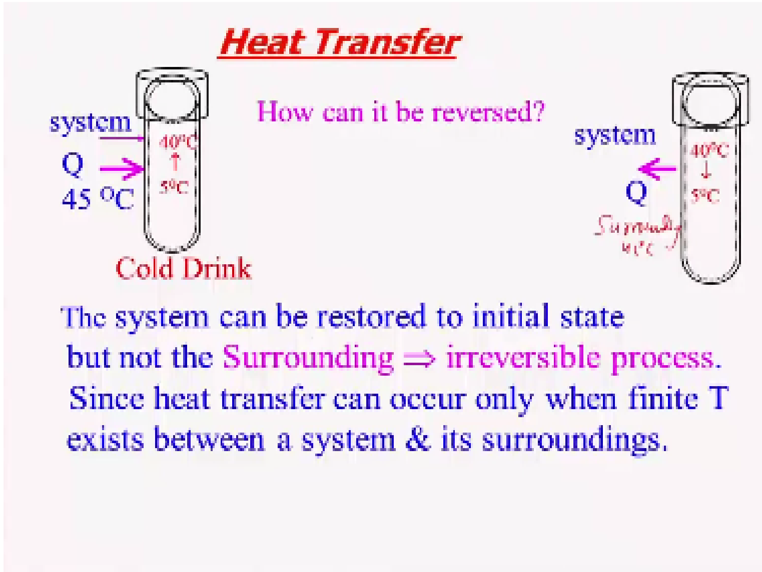

So let us look at some heat transfer problem like let us say there is a cold drink which is at 5^0celsius and the ambient temperature let us say 45 degree and some amount of heat is being transferred says that the you know the cold drink which was at 5^0 Celsius will go to the 45^0 Celsius you know right, that means the what you call some heat bring transfer out and easy it is not really possible as I told that that the heat energy which is being you know gain by this cold drinks will be really transferred to the surrounding.

So if you look at this is your surrounding which is at 45^0 Celsius right because it is ambient temperature. So therefore that is not really possible this is an irreversible process because the system can be restored to the initial state but not the surrounding even if we will do that you know like we can have by putting you know kind of things but the surrounding will be not it will not be coming to the initial state, so therefore this is an irreversible process. So since the heat transfer can occur only with a finite temperature difference you know between the systems and surrounding therefore most of the heat transfer problems will be irreversible in nature in actual states right.

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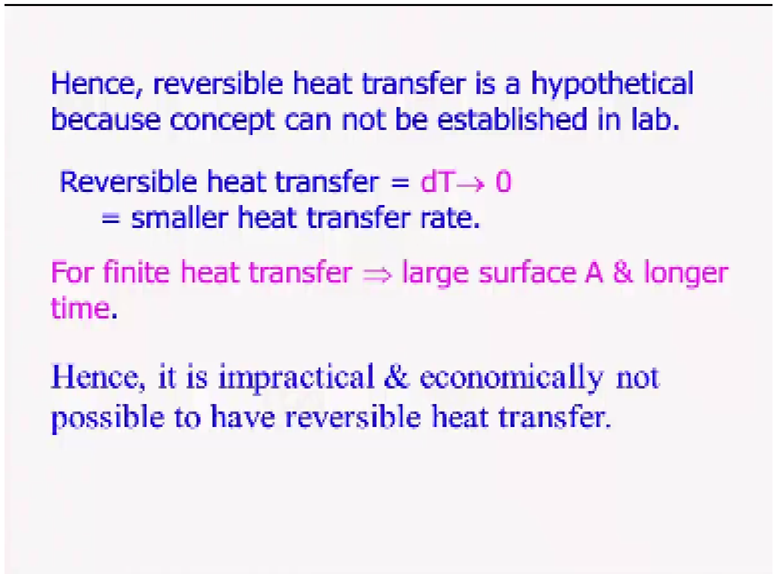

So therefore I am like in a reversible rate transfer is basically hypothetical concept because it cannot be established in the laboratory and if you look at reversible process means δ T is tending towards zero where you very small heat transfer rate and if it is you know heat transfer rate is small then what we will have to do will have to increase the surface area to a very large extent and then it will take a longer time because the temperature gradient is very low I mean if I say let us say there is a something point 5^0 Celsius difference you know like is there dt between the system and surrounding then you know it will take a lot of amount of time and also you need to have a larger surface area to make this.

Hence it is impractical and economically not feasible to have a reversible heat transfer right it is not really possible to have this, so let us now look at you know like when we can call a process to be totally reversible.

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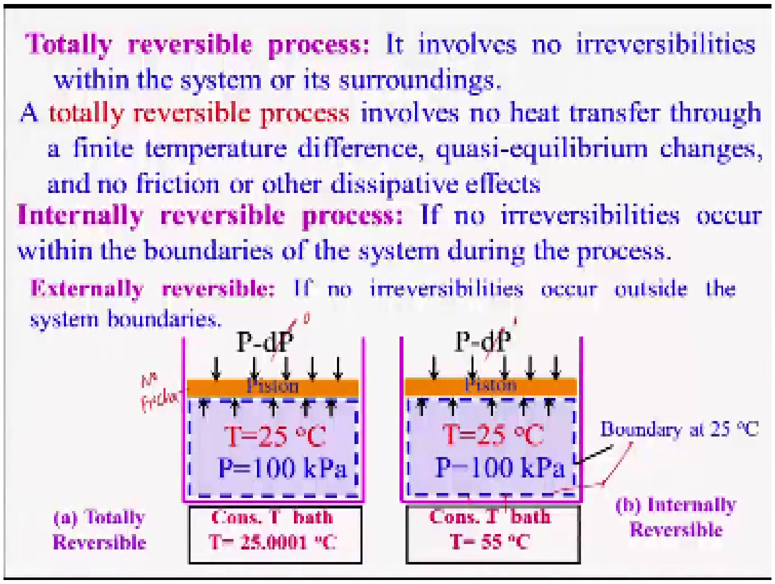

And it is possible only when there is no reverse abilities within the system are thus its surrounding right that means both the system and surrounding should return back to its original state without any you know marks on it. So that is really not possible, so of course one can think hypothetically only when you know like process is change you know process occurring in a quasi-static lee and there is no friction or a dissipative effects and of course the heat transfer you know is occurring with a very, very in finite temperature difference you know gradient kind of things.

So for example like if I take this of course this is the hypothetical node nobody will do that what I am showing here this is the fist in and cylinder I see man there is a something gasps here which is at 25^0 C and this gas in the piston cylinder arrangement will be coming in contact with what you call a temperature bath which is at 25.0001^0 C is a very, very small tiny negligibly small and of course there is no friction here right in this piston and cylinder there is no friction right if you look at no friction here and it is the this is very, very zero the pressure gradient you know like the pressure difference between surrounding is very, very zero so therefore one can say that it is basically reversible process you know totally reversible one can as you because now we are irreversibility there hi positive this is an hypothetical situation not actually right.

And we can call basically the another situation where it will be you know coming with the 55^0 Celsius a bath and the same this is as I told that other cases what we are considering this is 0 there is no friction here however this system boundary in that this is a you know maintaining the almost same temperature right if you look at this is your system boundary here right I mean other these are all insulated but here the heat transfer is taking place here and but this system boundary will be basically at 25^0 C you know if you look at this system bound at 25^0 cell is therefore you know it is you can say internally reversible process where no reverse abilities occur within the boundaries of the system right.

Because whole system is remaining almost same temperature little bit you know like in a same temperature but the you know this surrounding which is for this system the surrounding toned body which is having a very high temperature the gradient is higher therefore it is a reversible process and this is externally what you call what you call like it is not really possible to out that but if no reverse locker outside the system boundary then we callas the external irreversible process that means there is no change in what you call gradient is there.

So generally we will be considering the internal irreversible processes in our systems wherever we are considering and I will you know stop over here and in the next lecture we will be discussing about the reversible heat engine that we call it is a Carnot engine kind of thing thank you.

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