Engineering Thermodynamics
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Lecture - 06
Thermodynamic Concepts: Steady state. Reversible & Irreversible processes

So that was equilibrium we now look at one more type of a definition which is Steady state.

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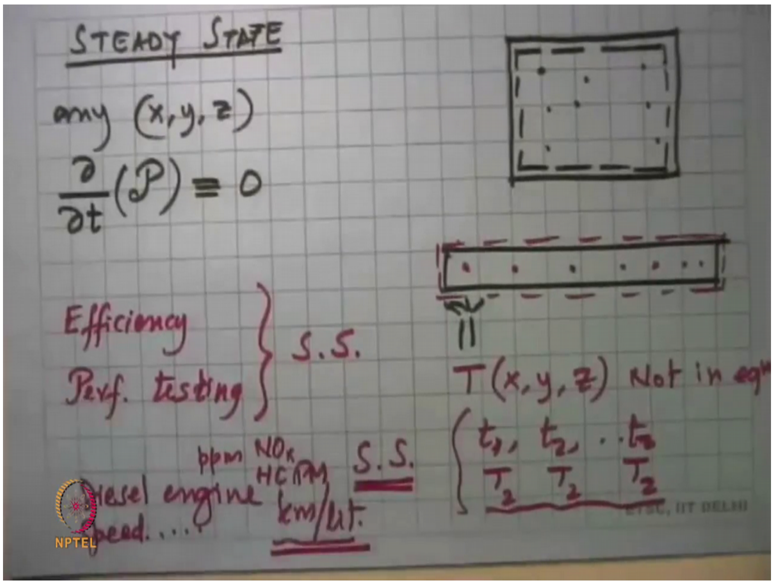

What we mean by steady state is that in the system so say whatever is in the system and could be a open system or closed system does not matter. They have the system boundary. Then at if at any point means any physical location, at any point in the system there is no change of any property with time any property then the system is in steady state ok.

So, what we are saying is that, if I have a rod and I will heating at this end and allow me to cool at the other end. And let the system be operating for a very long time and what we know is that the temperature at the core here is high and it keeps decreasing as we go on.

So, that temperature is of function of space and so this rod is if this rod is taken as in system this rod is not in equilibrium. But, if I stand here and I keep measuring this temperature now and after 5 minutes and after 10 minutes and like that. And if at any instant of time t 1, t 2 like that; the temperature is still the same say whatever cost T 2, T 2, T 2 at any instant of time; then the system is in steady state.

This simple definition help very far (Refer Time: 02:40) implications. So, most obvious and zinc we talk yesterday lot about solar; solar energy falling on any collector photovoltaics or any type of a thing is always changing with time and from sunrise to sunset with undergoes a value after that it becomes 0. So, that is the biggest problem in solar energy; it is not steady.

In a nuclear reactor we can manage it so that heat generations nuclear reactor is steady with time and then you can get continuously a (Refer Time: 03:12) generation from the system. So, that is an example, but this is got lot more things to do with it; later we will talk later on and we talk about efficiency or performance testing. All these analysis whether it is for standardization or certification or problem solving, these concepts make sense if and only if the system is in steady state and most real systems are not in steady state.

So, for example, if you want to test a diesel engine and say what is the kilometres per litre or car powered by diesel engine or say bus. And you say what is that kilometres per litre that we get; then the right thing to do would be (Refer Time: 04:18) which gear me like drive, what speed will I will drive all of that is specified, what is the condition of the road, what is the ambient temperature and pressure, which fuel we are using, what is the health of the engine?

All these things have to be first well controlled and then we operate at a constant load for a certain period of time and then say this is the surely (Refer Time: 04:43) or how many how much PPM of (Refer Time: 04:49) does it throw out or how much hydrocarbon does it throw out or how much particulate matter does it.

That is what one would do with a diesel engine; look at the real life anybody who has been in traffic say it is like what we have all the mess that we saw in Gurgaon or in Bangalore and recently in Delhi the range.

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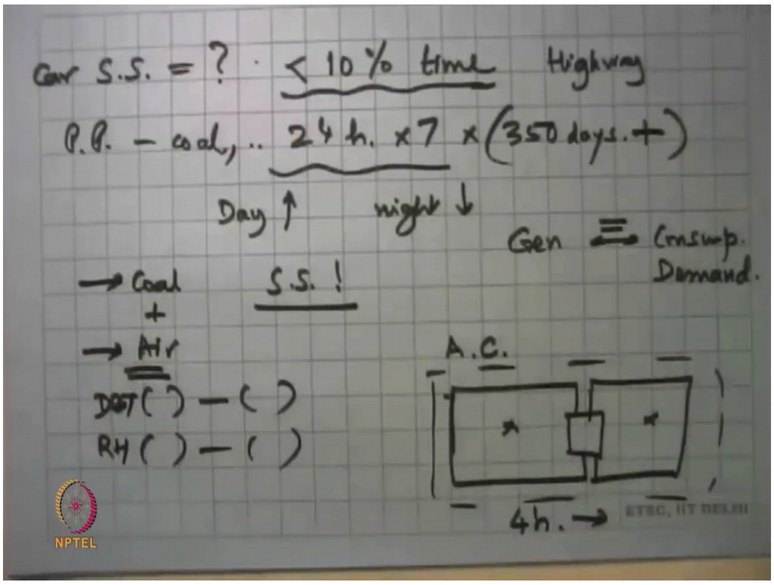

Even if those were not there; in normal times do we have steady state driving in a path? We make a measurement; we find that steady state operation is restricted to less than 10 percent of time that a vehicle moves on a road. In many cases even less on the highway it will is going to be more it is slightly more than this, but not very large.

If the highway is clear; no other traffic road is flat everything is nice and clean no winds; then ok. So, in city conditions you never have steady state; so say what is kilometres per litre of a car is basically admitting the 2 why cannot we bother that there was steady state or not; how much will I get that is the only thing that we will talk about that is fine.

Then you should look at any of the power plants, whether it was nuclear or coal or any one; the plant is operating over 24 hours, 7 days a week and typically it will run atleast 350 days a year without stopping; may be even more these days. But what happens? During the day time the demand for electricity is more; at night almost all activity goes down the demand is less. And electrical great system is such that the generation has to always match consumption; so generation has to be exactly equal to consumption.

This is I call Demand and when that happens; this power plant will never ever operate in steady state. As the thing that will change the operation in that many of burning say coal or oil with air; the coal has to be in steady state, all its property must be same over 24 hour or more. And there also all the properties must be same, but as you know air undergoes a maximum temperature and a minimum temperature and some humidity also.

So, dry (Refer Time: 07:42) temperature goes up and down the relative humidity goes up and down. So, the air content to the boiler is also not in steady state.

The demand is not in steady state. So, if I have to do an efficiency test for emission test on a power plant; it is extremely difficult. And so we have codes and standards which will give the best possible way to measure, but if a system can be well controlled. For example, if you are doing the efficiency test of an air conditioner; then there is a well designed set up where you have marked the AC say window AC setting there; one chamber here which is the upside, one chamber here where we cool it. We maintain the temperature of these two constant and make sure that the system is in steady state or atleast 4 hours and then we take the relay and this is completely isolated sensor.

Then you have a very very larger measuring it is called (Refer Time: 08:34) and their efficiency makes sense; with reality this may not be happening.

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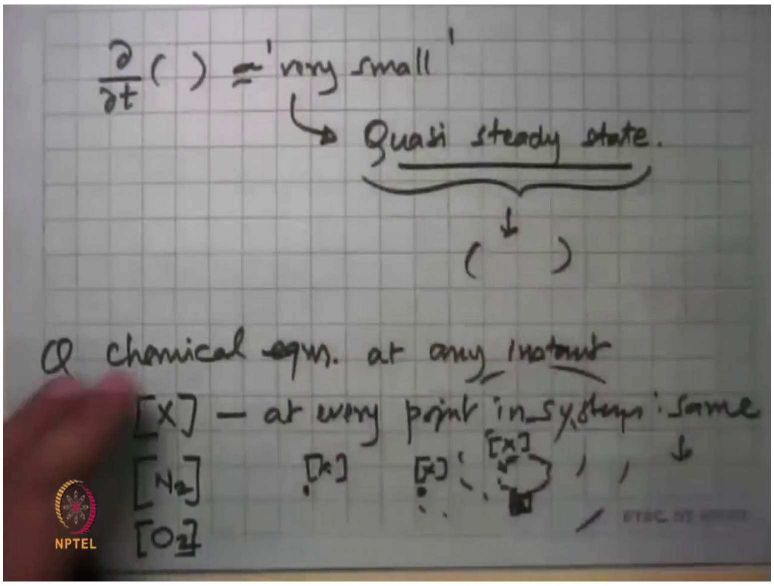

So, steady state is a very important phenomenon, but since many of these systems do not follow any steady state we can say well; is the time dependence of the property very small and how small that our description and if is a it is small it is ok, it is not in steady state, but quasi steady state.

I am having made this assumption of quasi steady state, then we can convince ourselves nice now I can I got all quasi steady state, I can start talking about what are the properties and what are the process that is there. So, this is an assumption that we make in many cases; in some case justify, some cases not justified. There are there are couple of more questions.

So we have still got the reversible question is there; we take that up before that please elaborate on chemical equilibrium ok. What we are saying is that what is chemical equilibrium; what we are saying is that if the concentration of different species at every place is the same; then the system is in chemical equilibrium; which means that we say that there is some chemical which was there; let us call chemical X and in case we have N and we have O. If at every point in the room all these 3 concentrations are the same everywhere and every point at any instance; then the system is in chemical equilibrium else it is not in chemical equilibrium ok.

So, take for example, that example has the (Refer Time: 11:09) and thing very close to the big of that chain the concentration of that repellent is high; if you go out the repellent each one decreasing, this is what happens in the room? So, here the concentration of X which is the repellent is more, here the concentration of X is less and faraway it is being less. So, in the same room if this was different then the system is not in chemical equilibrium, if it is same then the system in (Refer Time: 11:44).

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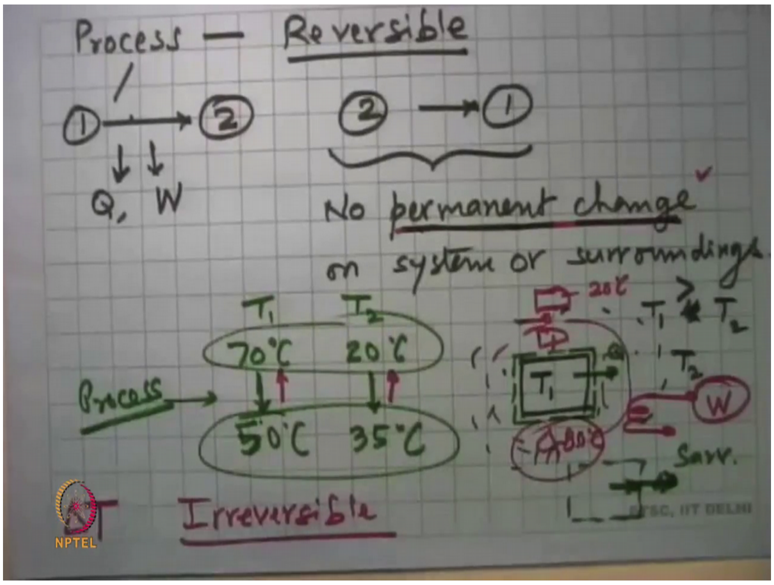

So we now come go back to our process and look at the next most important definition and this is the definition of a reversible process. So, first we have looking at the reversible process; that means, there is a change of state. Going from state 1; the system going to state 2, during this time both the system and the surroundings had some work; system had Q the system the surroundings had minus Q system had minus W; surroundings had plus W.

So whatever was heat on the system; the opposite happens on the surrounding. So, that means, that in every process there is something happening to the system and something happening in the surroundings. And we say that, a process is reversible if at every instant we can reverse this process; that means, get back from state 2 to state 1, but in the process there is no permanent change on either the system or on the surroundings ok. These are important thing no permanent change on or surroundings; that means, both system becomes what it was before the change and the surroundings also become the same before the change.

Then that is permanent change which not an instantaneous one shot beam, but something that always going to be there. So, let us take an simple example; here is the say block of material which is at temperature T 1; sitting in surroundings say T 2 where T 1; where T 1 is less than T 2. So, the body is cold or let us take the another one T 1 is greater that T 2; easy to understand.

So, the first thing to do to see what is the system and what is the process. System we say is this; thing and there were no work transfer taking place, no mass transfer taking place in this the only thing that happened was the system there was tube out and for the surroundings which is now excluding this everything else on the surrounding there is Q coming in. So, this is minus Q this is; so this is entering the system surroundings.

And say this was air; this air got hot and then we reach the state where say we started off with 70 degree C T 1 and T 2 was say 20 degree C; after some time this became say 50 degrees C and this became say 35 degree C; I am just (Refer Time: 15:25).

So, the process was here; this was the initial state, this was the final state and this was our process. And now we say is this reversible and then you say how can I; I did not expect any work, we did not burn anything nothing has happened this thing meant by itself from here to there; is it possible for this energy to go back this way we are heat there so that this comes back to 20 and this goes back to 70. So, we are saying can I by can it by itself this 50 becomes 70 and this 35 becomes 20.

And you almost some experience that you cannot have heat transfer by itself going from a low temperature to high temperature; say what is the next best thing that I can do? Well (Refer Time: 16:33); if I want to bring system back to its original state, I need to have something in the surroundings which is high at temperature. And say in around this; I will burn some fuel and produce gases whichever I want to get it back to 70 degree Celsius. So, I produce a temperature of atleast say about 80 degree Celsius or 90 or 100 degree Celsius, this will cause heat transfer back and T 1 will come back to 70.

So, what is happened? The system got restored its original state it got reversed, but what about on the surroundings? We got some permanent insight there in the form of say burning of a fuel or (Refer Time: 17:25) electric heater, which consume electricity or we could a heat pump say like a refrigerator type of a thing; where this took electricity and took a energy from a low temperature which was 20 degree Celsius and sent it out.

All of these brought the system back to its initial state, but surroundings underwent what we call a permanent change. We expended electricity to do write the (Refer Time: 18:00) or we expended electricity to heated up or we burnt a fuel to heat it up that got depleted permanently in the surroundings. And so that classified as a permanent change and it you could reverse the process with permanent change in the surroundings and so this is not reversible or irreversible that is one way the things happen that heat transfer through a finite temperature difference is always irreversible.

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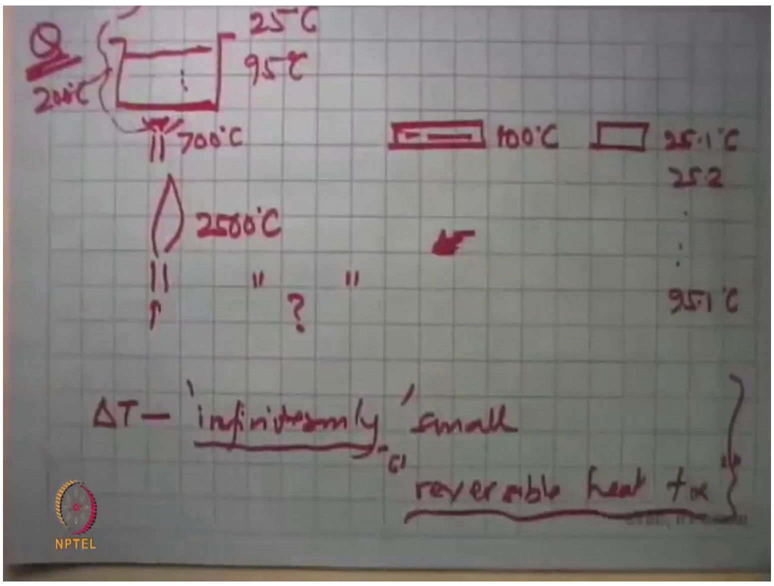

And you can argue yourself that I want to make a cup of tea; I got a so much of water which I want to heat to 95 degree Celsius; it is 25 degree Celsius. I have option number 1 I can heat it on my stove where the temperature of the gases that are going showing around like this. And the flame itself is a 700 degree Celsius and the gases going here as a 200 degree Celsius. How many; well you know it take some time I wanted to do it more quickly in a (Refer Time: 19:15) why do not you put up an oxyacetylene flame over there?

This is 2500 degree Celsius; just put it below I mean at heat it by 25; somebody says no that is not good enough I will just take a heater and maintain a temperature of say 100 degree Celsius on this and the third person says look when it is 25; I will put a heater of 25.1 degree Celsius. When the water becomes 25.1; I will take this temperature to 25 to 2 degree Celsius. And like that finally, I will get 95.1 degree Celsius and so water will be the 93 degree Celsius.

So, I will leave this question for you to think out what is the thermodynamic implication of these things in terms of what we talk as irreversible heat transfer; we know that were these are irreversible. What can be quantify as the gain or the loss because of irreversibility (Refer Time: 20:23) ok. So, this we will leave off and we will argue then that if the temperature difference between the heat transfer happens across the delta T which is the infinitively small; we are not saying what this means. Then theoretically only we can argue this would become a reversible heat transfer; I am mentioning this because this is hugely counter heat relative.

We know that heat transfer just cannot be reverse without any permanent change in surroundings, but here is the concept and we throughout the concept that we develop; that if by some means this temperature difference is exceptionally small, then there is exceptionally small amount or change in the surroundings; we can reverse that process. That is an approximation which will come out later on as a very important approximation for us. So, you have think about it; it is not very easy to appreciate this, but the concept of reversible heat transfer in some way some counter iterative, but it is useful concept reality practically impossible to get.

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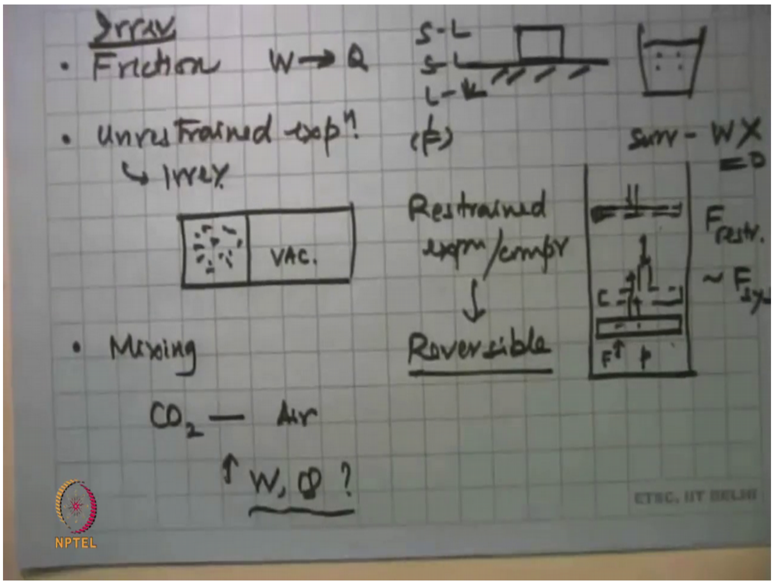

What are the other things that cause irreversibility? Friction and this is not only friction of say a block sets sliding on a table, but also we take say water stir it and leave it the water had energy because it is a motion kinetic energy gradually it stops and everywhere it becomes 0. So, what happen? Thing was that all of them got dissipated because there was friction between the element of the water inside. So, friction is between solid solid, solid liquid, liquid liquid and when I put a liquid I liquid I also can do a gas or fluid.

So, there is friction everywhere including the air; the friction causes. This is because when friction happens work is dissipated and it converted into heat and just cannot let the opposite (Refer Time: 22:36). Then there is unrestrained expansion; so we say unrestrained expansion is irreversible. So, let us talk about work becomes restrained expansion; so that is the piston sitting there and we have there is a pressure here, this is produce a new certain force and this is a force we just about matching this force.

So, this thing is pushing against this force and the piston moves a small distance and comes over there. The pressure inside goes down and then it pushes that force and goes back. So, there is a very very small steps in which the force that is acting on the piston is practically the same as the force that has slowly exerting on it. So, this force if there is straining force is very much equal to the force; that is exerted by the system on the piston. And if the two are pretty much the same whether it is a expansion or compression then this becomes an example of restrained expansion or compression.

And this we say is reversible ok. So, this is reversible work; what is unrestrained expansion? What if the holding it down with certain force at this point of time and then certainly if we just let it go. So, we know that (Refer Time: 24:23) bicycle pump compressor; we let go it has just go up and down ups a few times. So, it goes up and down finally, it will settle down somewhere there which would have been at this equilibrium position anyway.

But during this process the only work it did was to move the piston; the piston at no mass is did not do any work. The surroundings there was no work on the surroundings work was 0, but if you want to get it back from here to there; we would have to do work on it to get it back the initial state. There you would have to expand work and so while unrestrained expansion we got no work to store the system back to its initial state, we have to do work and that is what next unrestrained expansion irreversible ok.

So, this was friction word also called irreversible; another is example of unrestrained expansion with that we take a chamber in which this side there is a gas and this side there is vacuum. And we (Refer Time: 25:33); this gas expands it does not do any work we have to put it back we need to do work to the back to the same thing and that work is the permanent change on the surroundings.

Then there is mixing; mixing means mixing of two different species; if we say that I am going to put say any gas into the air the two will mix and say now I want to remove the separate the two out, but naturally they will not open; we would need to put in some work maybe some heat. And heat will be permanent effect on the surrounding then only you can restore the system back (Refer Time: 26:14) ok. So, these are some of the things that (Refer Time: 26:21) irreversibility ok. There are questions, so there are few minutes left I take some questions and the rest I will then respond it on the web.

Student: Good morning Sir, my name is Manjith Singh; I am a fourth year mechanical student at Dronacharya College of Engineering. And my question is Sir, can we use biogas as fuel in internal combustion engine made from cow dung? And what will be its efficiency and how much distance of vehicle will cover in 1 kg of gas?

So the question is can biogas be used as a fuel in IC engines?

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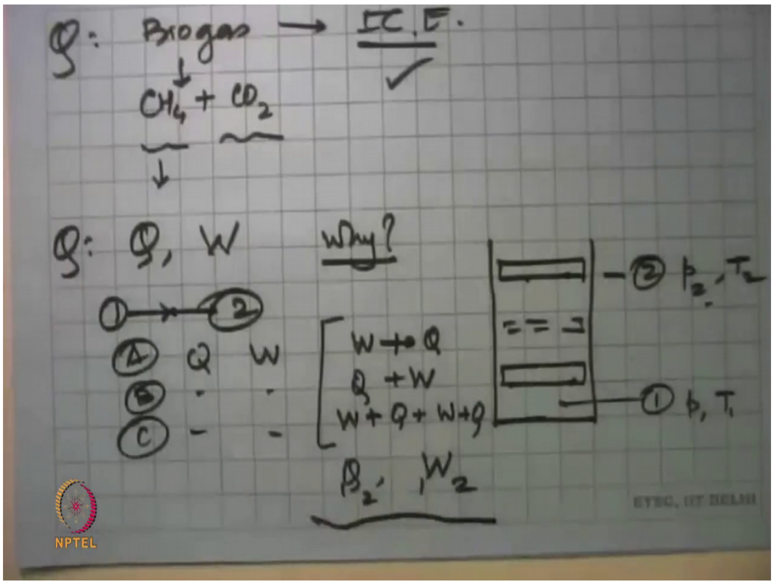

Well biogas is strictly methane 50 percent plus CO 2 50 percent. And of course, there is; so either this way or you can remove the CO 2 and get the methane and use it; in any way it is done which has been done at steely standard technology it is already available commercially. So, there is nothing new to be done on that gas engines are meant available from most manufacturers. As far as the mileage and emissions go; you can read upon the literature on the web; I will not go into the detail (Refer Time: 27:35) there.

Student: We always studied that heat and work depend on the path why is it so?

You done say that again that heat and (Refer Time: 27:47) again heat and.

Student: Heat and work depend on the path near path functions.

So, question is I have mentioned that heat and work will be associated with the change of state. So, we have gone from state 1 to state 2 and I have also mentioned that when this change of state takes place, depending on the paths that one follows; it will decide that Q and W in each case going to be different. So, question is why is this so? So (Refer Time: 28:24) give an example and then we will see that.

Suppose I have a gas which I have to expand from here and this much of the volume change. And my in the initial state 1, there is certain pressure and say certain temperature T 1. And then it reaches this state and here your p 2 and T 2; so that is from here to here one could do is expand this and then if the temperature does not match with the T 2 that you have; you can either had heat or you can cool it or ultimately you can first heat it and then allow it to expand so that it becomes heated.

So, you can at least two things are possible that we first do some work and then gives plus on heat or first heat it and do some work or any combinations of the; some work that brings it upto here then you heat it then some work then some more heat and it brings it upto here. So, what is happening in each one of these cases with the final state is the same whatever we are asked for, but in each one of these; when we do the calculation the Q and W for the process Q 1 2 and W 1 2; these will be different the exact numbers that will fall on this.

We will come to that when we look at the laws and (Refer Time: 29:56) properties when you look at it; when you do a numerical and you will see that Q 1 2 at part A, let me first heat it and then expand it or second when you expand it then heated it because heat and the work with those processes will be different ok. So, now, I read this example here, but we will come back to it again and again in the next 2 modules and also in the final module when we solve the problem. We will welcome back to this many types.

Student: Hello good afternoon Sir. My question is every reversible process is a quasi static process then, but every quasi static process is not reversible process why is it so Sir?

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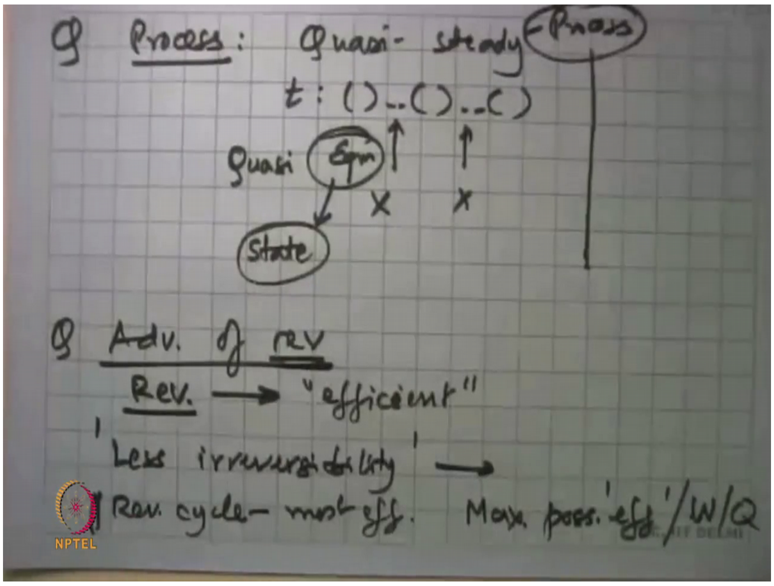

This is that we are talking about process and we are saying; I will not use the word quasi static, (Refer Time: 30:51) for the steady process. In the quasi steady process what we are saying is at any instant of time; we are assuming that the system is in equilibrium, in between the times the system may not be in equilibrium.

The second thing is in reality the system may not be in equilibrium and this could be in quasi equilibrium. So, that difference is there that equilibrium is defined only for a state whereas, the process being quasi steady is for a process which is a change of state. So, it was a very very different things they are not the same. One last question then the remaining I will put up on the web.

Student: Sir, what is the advantage of reversible process?

So the question is; what is advantage of reversible process. So, it is good question; probably some definition, the reversible process is something which we will see later on as being the most what you call efficient process possible. And what it does is; if you get reversible say at reversible work or reversible heat transfer; the less the quantitative amount of irreversibility, the more is what you can gain as the output. I will go back to the schematic of that nuclear (Refer Time: 32:56).

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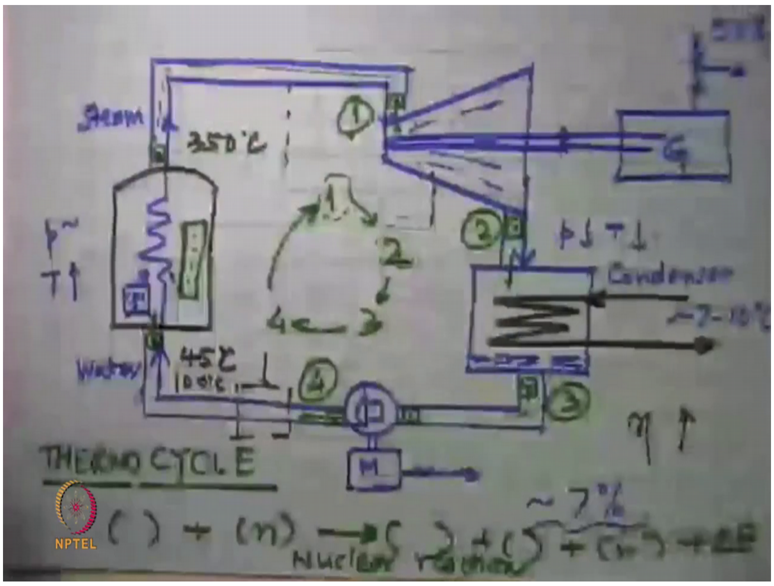

Clear, when we cool water and bring it down to say 45 degree Celsius, when we heat it in a boiler or a nuclear reactor and bring it to say 350 degree Celsius; that means, we are using a high temperature source to heat water from forty 5 to 350 degree.

But it is somehow we can heat the water here by using somehow this steam or not this steam somehow the steam from here and raise its temperature to say 100 degree Celsius. Then the heat transfer in the boiler or in the reactor will now occur over a smaller as a difference. What that did? It reduce the irreversibility in the heat transfer process and because of that the efficiency of this cycle went up. And that is what we try to do in many of the devices is that; if there are heat transfer taking place we try to reduce the temperature as much as possible that way system may get more complicated; the system may get bigger, but that becomes the most efficient thermodynamic system.

In later on when we look at cycles we will find that the reversible cycle is the most efficient cycle. Say from converting heat to work and we have seen that to get it reversible everything has to be very slow differences have to be very small (Refer Time: 34:40) always be there; it is extremely slow and very very difficult to make and practically impossible in reality you want everything fast and quick.

But this gives us a benchmark of what is the sort of the maximum possible efficiency. So, I want to call it efficiency or the work or the heat that I can get from the process that is why reversible process is a concept; which tells about the best possible thing you can achieve and in reality we do everything to get to that process. So, that that is only advantage that we have in this concept.

We will come back to this again when all the modules that we do subsequently.