Engineering Thermodynamics
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Lecture - 05
Thermodynamic Concepts: Process. Cycles. Applications

So, what we have done now, you may define the process. And, now we have added one more definition to our vocabulary and that is of thermodynamics cycle.

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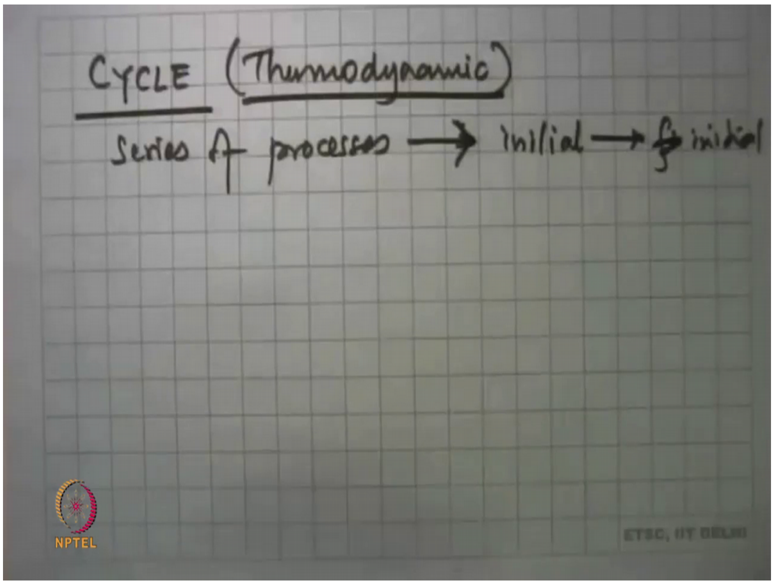

And, this is nothing, but a substance or a system that undergoes a series of processes, but restores it back to the initial state, that these are such that from initial state it comes back to it is initial state. So, this is something we will come back again in detail ok.

There are some more questions let me take that, please explain the reversible process good I am about to come to that in a few minutes. So, just have a little patience. In solar thermal power plants how is heat stored in storages ok?

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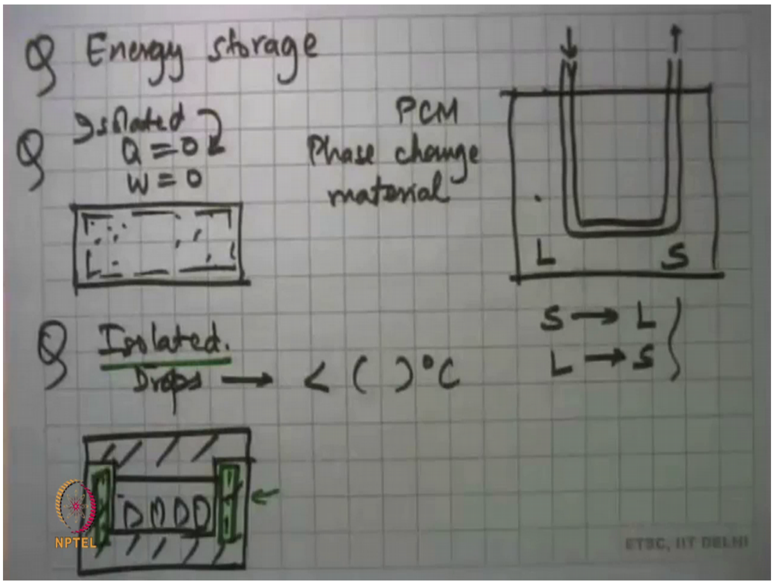

What happens here is very simple, what you do is we take a material. And, we may do not call it heat storage, we will call it strictly we should call it energy storage. And, what we have done is that you basically do a very simple thing that, if I take something and put a pipe through this so, which I put steam generated by the solar system and outfit comes.

And this could have any material in it could be sand, it could be water, then what have we done we transferred energy to this, this material it is temperature went up. And, then when we want this energy we put in cold stuff in and that hot stuff coming out, but what we also use here instead of sand or water is what is called the PCM or phase change material.

It is nothing, but some sort of salt well when you are heating it, it goes into liquid phase and when you take the energy away from it comes back to solid phase. So, during the heating phase it goes from solid to liquid then when we do the temperature change, and when in the opposite thing you are drawing energy out of it, it goes from liquid to solid. So, that is what we do in energy storage? In isolated system due to work then is internal energy will change or not ok. In an isolated system which is not in thermodynamic equilibrium that is one thing.

So, we say that here is the system where say the pressure here was different than the pressure here it is isolated; that means, for this system boundary Q is 0 W is 0. So, what that the question is, what will happen to the internal energy, we will we have not yet defined internal energy, when we do that in the next module we will answer this question at that point of time. But, for now we say that it made the system boundary and said that, because it is isolated during the process that whatever happens inside heat and work are 0 that that is coming from this.

Please explain reversible process I will come back to that in a minute, that is done energy of an isolated system is constant please give some practical examples and it is significance ok. One example I give and tell you how tricky it is and the example is of an isolated system ok. Here is an example; our country had a big problem. Now, you would still realize that every now and then there is advertisement notices on the TV, saying that this Sunday is polio Sunday so, bring your child and get the drops.

Now, that is important because our nation needs to eliminate polio, but to get those drops to each and every little corner and village and house in the nation, it does not easy. Especially, because those drops have to be stored below a certain temperature and say 2 degrees Celsius or minus 2 degree Celsius something like that and, if during the transport of the drop from say the main storage who get in to the smallest town or community, this temperature goes beyond that, then that the active like bacteria or what will call whatever in the vaccine those die and the drop becomes useless. And, that was happening several years back in our country and this is look we are giving drops, but polio is not going away.

Then we have to go back and say look. When I transform this vaccine, I need to make a box, and in this we put this medicine which came from say a refrigerator where the temperature was quite nice and low you are always had electricity over there now remember that that is so, important. And, then we put it in a box and cover it and we would ideally like this inside the system to be isolated. So, that 5 hours 6 hours during the transport of these, but there should be no heat input going in is between problem is much worse in our country especially, but our ambient temperatures are very high.

So, you would like to keep this system isolated put as much information as is possible, but these days people have done one more trick, that if this heat is going in what they have done is, they put some phase change material over there also, which was frozen then the box started. And, as it went out whatever heat brought in it melted this phase change material and kept inside thing at a temperature that it was stored in. And, so, that way by the time we get to the remotest town, the vaccine is still preserved and then the whole program becomes very effective.

So, does that is where like an example; where isolated system is very very important ok. It is electric cooler electrical equilibrium and a necessary condition for system to maintain thermodynamic equilibrium ok. We will come back to this a little later, I would not define electrical equilibrium yet we will come back to that later. One more example and then we will continue and this is a very very different type of a thing, and what I have I am showing you a picture here is a (Refer Time: 07:50) very different type of about this car.

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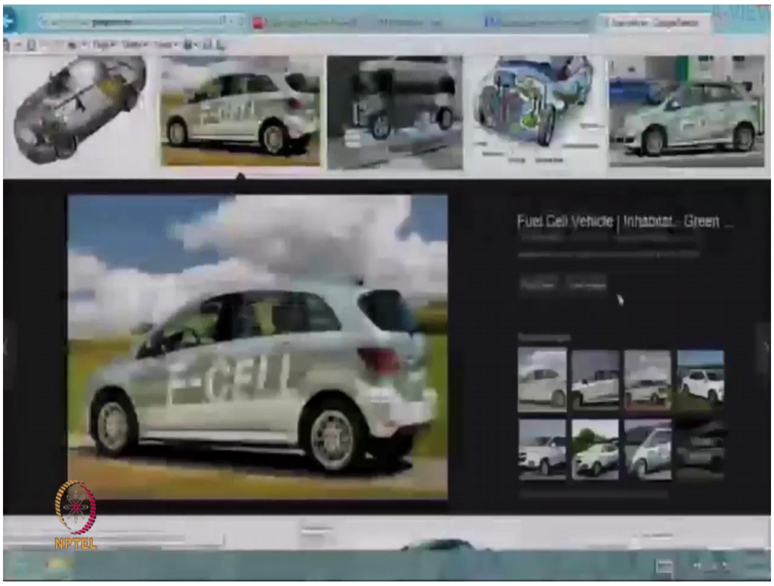

This car does not have an internal combustion engine; no diesel engine, no petrol engine, no CNG, none of that stuff. This is powered by a fuel cell and there are few companies whose advertisements which you might have seen, that you have a car that drives itself and all it produces is pure distilled water which you can even drink. And, it is powered by a fuel cell. So, let us see what is the fuel cell?

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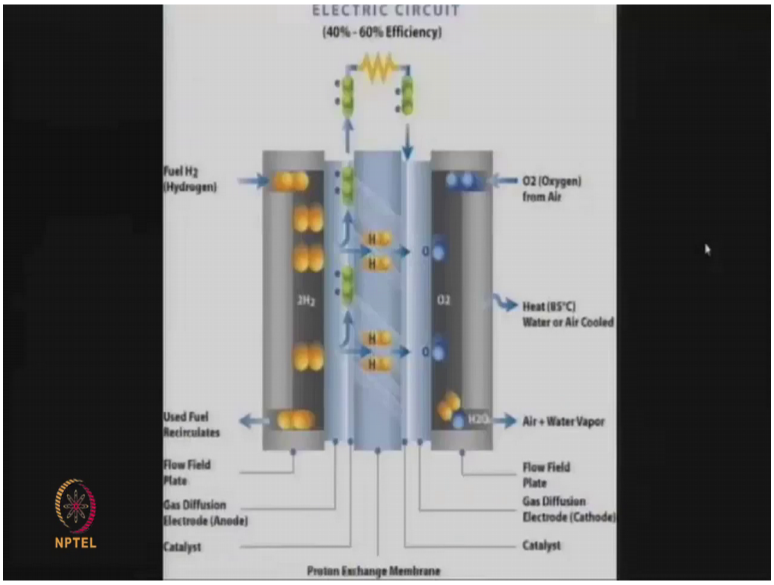

Here is the simple picture that tells us what happens inside a fuel cell?

In the middle we have what is this is one type of a fuel cell called a proton exchange membrane. So, this is the membrane there which is like a sheet of paper 100 microns thick maybe 200 micrometers thick of a particular material on one side of this is the anode, and in the other side is the cathode.

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And, in between this is a thin layer of a cathode 50 microns that type of a thing. And, then around this is this device through which we can connect a supply of hydrogen into this, and unused hydrogen comes out over there, and on the other side we have a similar thing here, where oxygen or air is put in after cleaning it up. And, it goes in and comes out as air plus water vapour, what happens in the cell is that this hydrogen comes into contact with the anode.

The electrons go out through a conductor into a circuit, the proton or the hydrogen nucleus goes through the membrane and comes into the cathode, where it meets the electron coming from there. And, there is oxygen which has been broken up into O 2 has gone into O plus O and so, this H O and electron combine to form H 2 O and that what gives you the electricity?

So, what you need is the cleans and reliable supply of hydrogen, and ability to make this thing and supply of clean air. And all it gives of is H 2 O is water. Efficiency of this cell is much higher this particular picture says it is 40 to 60 percent compared to whatever else you have engines have anything like 15 20 25 percent efficiency that is all, this is much more efficient ok. So, this is the basic construction or the basic physics underlying a fuel cell, and there are many how do we make a fuel cell and here is what we one does?

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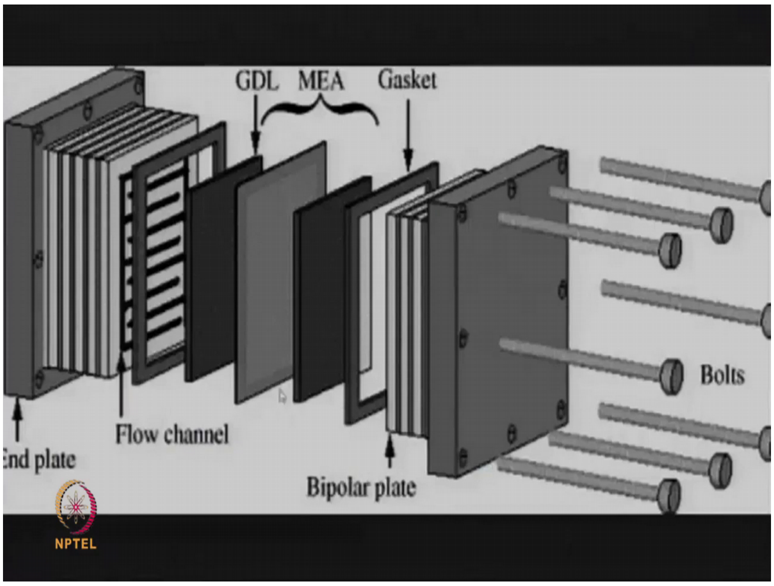

So, from that basic physics we now come to the engineering, where you got to put various thin membranes together, for gaskets to make it leak proof make this device through which the gas can be fed over the entire phase of the cathode and the anode, there are 2 end plates. So, that 1 2 3 4 5 6 7 things all put together.

Sandwiched for bolt through this and make it completely leak proofs, that is how we get a fuel cell. And this can be very very small thing you can hold it in one hand. And, we put many of these things together and that is what we call a fuel cell stack.

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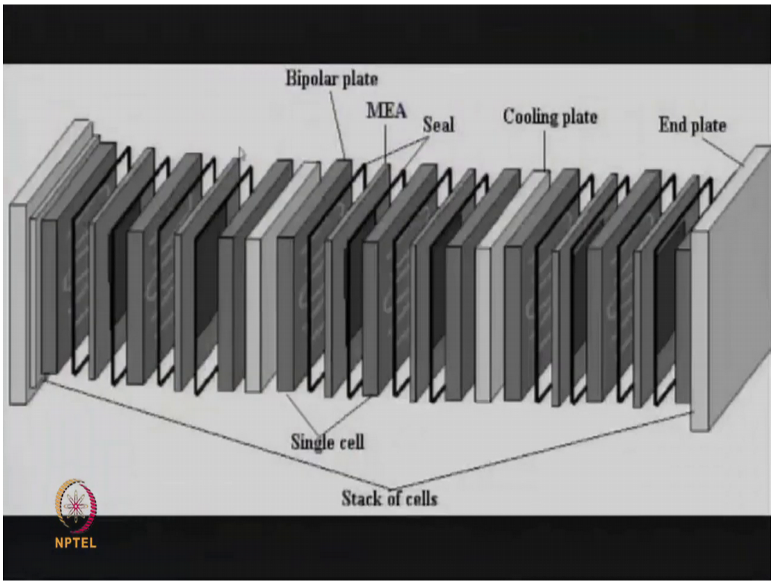

Here is a stack and this is a single cell, it is another cell another cell you may build up more and more of these and you start increasing the power that you can generate. And, once done that and you start making cells, you can start using it in various things the one of the applications here is charging your cell phone.

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This is a little thing which is called a fuel cell in it, you take a little sort of a pen type of a thing which has got hydrogen in it, stick into it. And for many days, many months, you can keep getting electricity from this and keep charging it or do anything else with these fuel cells. When it is over remove that cartridge get on the cartridge of hydrogen, but you need somebody who can do hydrogen?

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On a bigger scale I just showed you a car, but here are people who are used a fuel cell to power a fork lift truck or bigger thing here is the bus.

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So, on the top you have hydrogen supply, the fuel cell, the air conditioning unit, in this a bus, it does not require oil or coal or electricity generates, it is own electricity and produces water. Absolutely a clean way of doing it only catch is how do I get that hydrogen and how do I do the engineering of this and everything else in it?

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Or one can even put together and say look I will take a trailer and put into this, and all you do is pick up this trailer on put it on your truck take it where you want connect it, and you get electricity. You see this happening the nowadays in many places every time you put up a tent or a Shamiyana, there are a whole bunch of the generators they are all powered by diesel engine, you can have a fuel cell power device, no noise, no pollution, and you will have a electricity.

So, people have been working on it and some big systems have come have been commissioned.

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And, that what it shows that starting with that little physics how big and complicated the engineering actually becomes. So, what it is nice to get excited about technology is whether it is the electric car, or a solar cell, or fuel cell, getting it in to this point is a lot of hard work takes many years and lot of dedicated work and good engineering. To make this whole thing work, work reliably where the customer does not want something that works for 2 days and then does not work on the third day, something that can work reliably for years satisfied.

And, if it goes wrong you need to have spare parts you need to have a mechanic who will come and repair, then only you are happy with it many technologies fail towards all of that does not get completely done.

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And, what you saw in that fuel cell is that all the thing that you have learnt in any of your manufacturing process, casting, welding, forming, whatever you did all of that is practically useless. All of the material going in a fuel cell are very very thin films, whose thickness over the whole area has to be maintained very small, which has very thin coatings on it and you have to put these things together with no gap in between them, no air bubbles in them, and then squeeze them together and make them in thousands over many square meters of cross section.

That is a big manufacturing challenge; it is one type of a machine which shows how the type of a membrane is being manufactured for fuel cell. A completely different again, that we are entering and we do that and as this chart shows.

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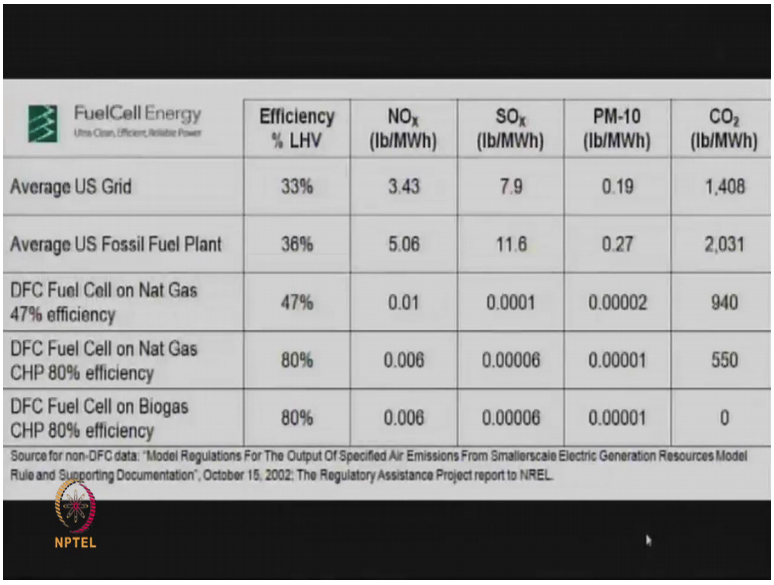

FuelCell Energy	Efficiency % LHV	NO_x (lb/MWh)	SO_x (lb/MWh)	PM-10 (lb/MWh)	CO_2 (lb/MWh)
Average US Grid	33%	3.43	7.9	0.19	1,408
Average US Fossil Fuel Plant	36%	5.06	11.6	0.27	2,031
DFC Fuel Cell on Nat Gas 47% efficiency	47%	0.01	0.0001	0.00002	940
DFC Fuel Cell on Nat Gas CHP 80% efficiency	80%	0.006	0.00006	0.00001	550
DFC Fuel Cell on Biogas CHP 80% efficiency	80%	0.006	0.00006	0.00001	0

Source for non-DFC data: "Model Regulations For The Output Of Specified Air Emissions From Smallerscale Electric Generation Resources Model Rule and Supporting Documentation", October 15, 2002; The Regulatory Assistance Project report to NREL.

It is a probably one of the most efficient technologies that we can get. So, this again I have taken from the web this is not my own creation, it tells you that if you take grid supply where 60 70 percent is coming from coal burning power plants or oil burning power plants, the load heating value efficiency is 33 percent, average US fossil fuel plant average efficiency is 36 percent.

So, do not think that even Indian power plant is 35 percent efficient or 37 percent efficient, we are not really that bad off we are pretty much the best in the world. How much NO x does it give, how much sulphur oxides that are thrown out, PM 10 particulate matter, we can even talk about pm 2.5 how much particulate matter it throws out, how much carbon dioxide do we add to the atmosphere? And, now we compare that with different type of a fuel cell, which is operating on natural gas with 47 percent efficiency NO x is much less SO x is practically un measurable carbon footprint is one half.

If, this cell or natural gas is operated with a combined heat and power cycle, we will come to that in a few lectures. Overall energy utilization efficiency is now 80 percent, carbon footprint 550 per energy, that you use and if we get it from biogas, which is that you treat sewage and get gas and clean it up, and use it with a combined heat and power plant 80 percent efficiency very small amounts of emissions. And, we did not put any permanent carbon dioxide into the atmosphere at all; that is what actually makes sense where we have a country where we do not have toilet us we do not have sewage treatment systems.

But, if we put both those together treat that swage get biogas and generate electricity from it that will be a really great thing to do. That was a small application in between about different type of a technology, but everything that deals with this. The reason for showing that here and bring it up is that what we just talked about mass flow, that material crossing across the system boundary, that is mass flow.

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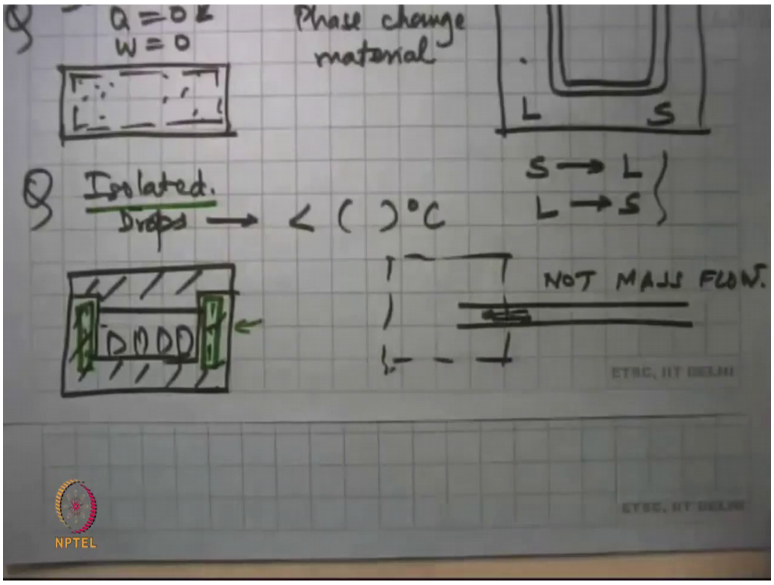

But, if an electrical cable is cutting and coming into a system, then the cable is being cut here. And, it will tell the electron flow through this; this is not mass transfer or mass in.

A flow of electrons in the cable in classical thermodynamics is not a mass flow, but we do not have to worry about it. How will it treat the fuel cell where the hydrogen nucleus enters the membrane, I leave it for you to think about it; how do we analyse the defects? But, why the fuel cell is more efficient than all the cycles that we will learn or the uncertain (Refer Time: 17:35) in what we are learning which is thermo dynamics and we will look at that also. The next thing that comes up have been defined this, in that if at any time if there is a, what is now a change in the system or change of state.

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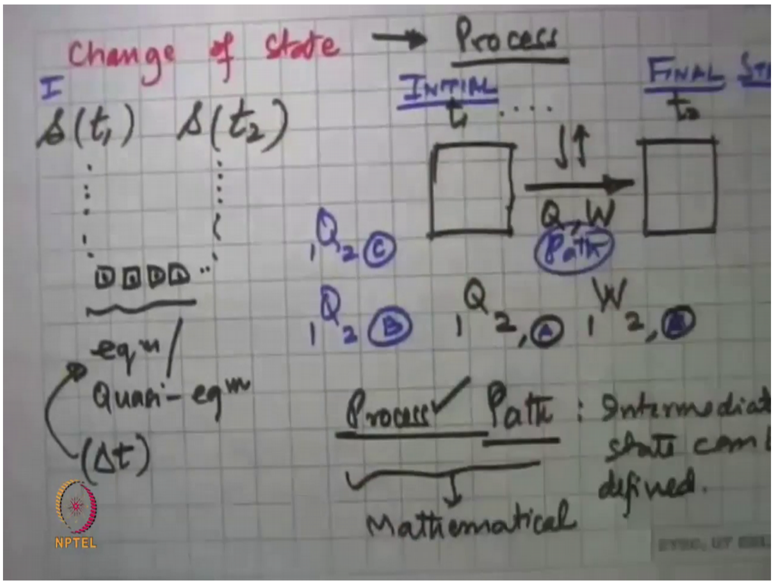

We have defined the system and at some instant of time t 1, it is state is given by s t 1, which is a set of properties, I have to certain other instant of time t 2 it is state is specified by another set of properties. So, if the system has this state and something happens to it and it goes to this state there has been a change of state. And, this process of change of state is what is called a process or a thermodynamic process ok.

So, this is where we start to ask questions, that state t 1 the system was here and system is there, but at some point at t 2 something else is happening. When the system is in equilibrium heat and work are not associated with it same thing here. So, during the process what happened we have interactions with the surroundings as heat and work.

And so, we now associate heat and work with a process, and there is something we left unsaid (Refer Time: 19:28) is that heat and work that happened here are denoted as Q 1 to 2 or W 1 to 2, and also by something else, which is what we call path. A path is a series of states between these states. So, we started from here then it went say incrementally to another state, another state, another state, another state and then it reached this state.

The state at each one of these intermediate times and these 2 all of these together is what we call the path; the path of the path of the process the process path. And, this can be defined only when every intermediate state can be defined, which means that at every point here the system at that instant is in equilibrium or we assumed it as quasi equilibrium, and we said that if I take very very small time steps in (Refer Time: 21:07) problem.

So, even if we take a finite time step at which we look at the system and say whether this is yes or not, then we say this is what is coming. So, process is the change of state of a system from one to the other. There is no restriction whether this was a control mass, control volume or a closed system, or an open system, what he said there is a change of state? And, if we know every intermediate state in between, we can completely define the path, if that is not the case then we cannot say what the path of the system was.

So, if we know the path we could possibly also make a mathematical representation of it. So, we defined what is the process? What the process path? And, we have already defined state and said that there are so, many properties to it with this add one more things in it, before we move on just mention it.

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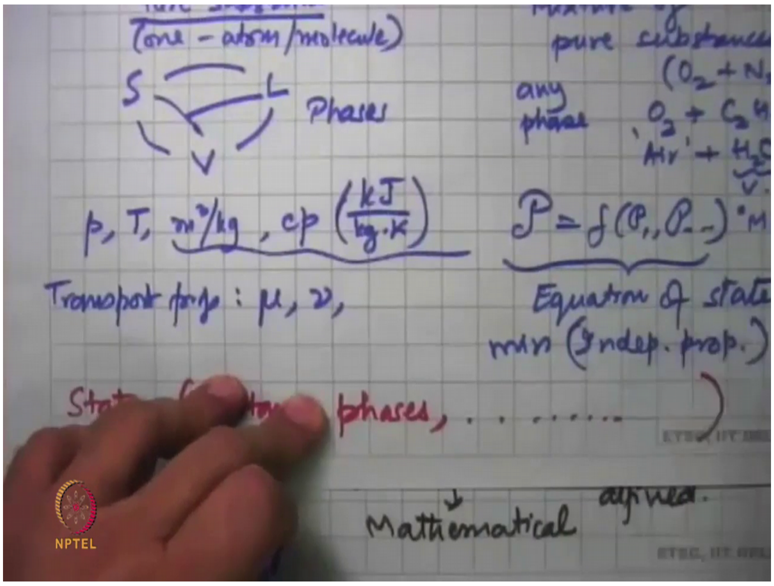

Is that the state without defined by all these properties these properties can be inter related to one another. So, that some property is a function of some other properties and this is what we call equation of state. And, it tells you that there are so, many independent states here and these are dependent state. And, they are not come to that point, but they look if I know. So, many how many minimum number of states do I need to know to fully define the state. The equation of state that if you tell me this many number of properties, then using these equations you can get all the other properties.

So, there is what we call a minimum number of properties or independent properties that need to be defined for we get the state. And, that equation of state is applicable at every instance that helps us when we come to solving problems.

So, what we have done here is that is the initial state is known and the final state is known, then to say what was the heat or the work associated with this process, we also need to specify something more, whether it was path A or whether it was path B; sorry A. If, it met by another path then it will be Q 1 2, but we path B. If, it was to another path it could be path C. What they are saying is that a system can go from one state to the other state through many paths.

And, for each path the heat and work associated with that path would be going to destroyed. And, just by knowing these few states it is not enough to say what was heat and work in the system, yeah for that process not in the system what are the heat and work associated with the process. The process associated with 2 states; one we call this as the initial state t 1 and 1 t 2 at the final state.

So, to top of the process it completeness we need to know what the initial state, what is the final state and what on the path which is a set of immediate states that the system went through to come from here to here yes. Now, take an example to see there is a tube.

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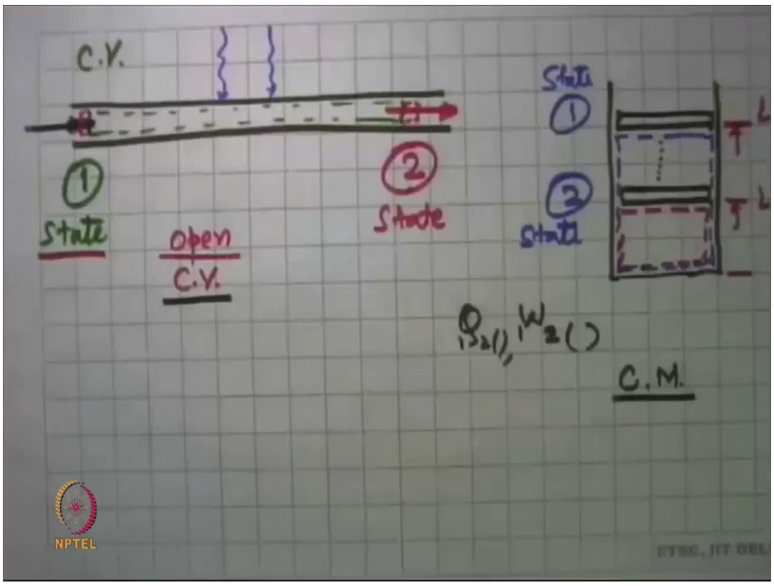

And, this is saving x exposed to sunlight. So, there is solar radiation falling on it and we have water flowing through this the solar reactor that you see in houses. And, you say whether my system boundary is going to be this and they say that this is an open system.

So, I have to use the control volume approach. What one does here, when there is a flow across the system boundary we define that and say that this is state 1. What we are in a way saying is that I have trick a take a very small amount of that material, and I say each state was one at the point where it entered the system. And, this thing went through and say came out over there and this they say is state 2. And, the next elements behind it comes in it does the same thing. The next one undergo the same thing it, goes through it there is heat transfer to it is temperature changes pressure changes something else may change.

So, what we have done in this is that when we have an open system or a control volume with each mask in flow the associated a state at that point and in every mass outflow we associate a state. So, that is how we take care of open systems? And, this is what we will be doing; you look at the control volume approach of analysing system process. Now, this is quite different from that say a cylinder piston arrangement, we say that initially the piston wall over there and then in the second state the piston wall over there.

So, when we say that the position of the piston is here. And, this would be say the characteristic would be that we define the volume or we define this name say this was L 1 from here. And, then it came down here and this length we can do. What happened here was the system that we defined in at time t 1 or it L L 1 at both the at state 1, at state 1 this is the system. It has a certain volume and various other properties which we; is to define. When this piston went down over there, how many yes still not knowing about that, once it got here this is now stable initial state final state. And, now what happened, it came to state 2 it was a closed system and now a system boundary becomes this.

So, it is step 2 where this much is the length. So, you can associate the certain volume with it and then certain other properties also. So, state 2 gets defined. And, that is what we got defined state 1. And, then in the same thing we then try to calculate heat and work and like I said before. In this case W 1 2 will depend on path we took so, would be Q 1 2. And, we will know how what happened in between and different lengths omissions in order to be fully able to calculate this ok.

So, that is how we will treat open systems and close systems in the analysis of control volume and in this case we have the control mass approach ok. So, we will take an example now say especially from this one and then we will come back and revisit the next part of this discussion.

So, we (Refer Time: 29:56).

Student: (Refer Time: 29:57) we can start the questions.

What question? Ok. There is a question here is heat and work has any relation with thermodynamic equilibrium, but look heat and work are associated with change of state which is the process. The only relation we can say is that during that process if we know that the system is in thermodynamic equilibrium, then we can using that data calculate what was the heat and work associated with that process. So, that is the sort of relation that is there the second question is why is it said that heat cannot be stored in a system ok.

We should go back and we yesterday we defined what is heat in thermodynamics as we are discussing. And, we said that it is that form of energy that transfers x a system boundary because of temperature difference between the system and the surroundings.

So, heat in our definition is seen only at the system boundary as a energy flow, it is not something which is stored in the system, because there is nothing crossing the system boundary then it is not unit. We will come back to it in the next module when we say that that is what it will be what we will call in broadly as energy, but right now we say that this is not heat is only at.

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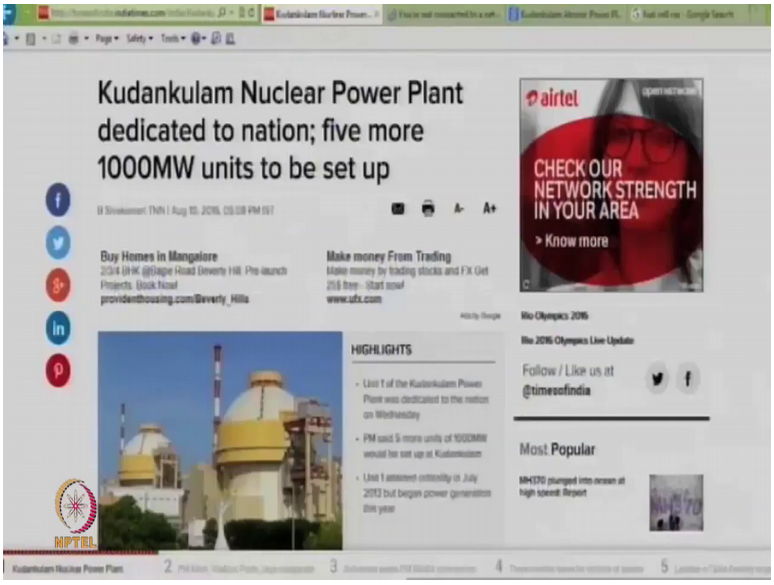

So take an example and see what it how, what we have been talking about what do you this? This is a newspaper has all these all over the place, that yesterday our Prime Minister and the Russian President dedicated Kudankulam Nuclear Power Plant to the Nation. And you are going to set up 5 more 1000 megawatt electric power of units.

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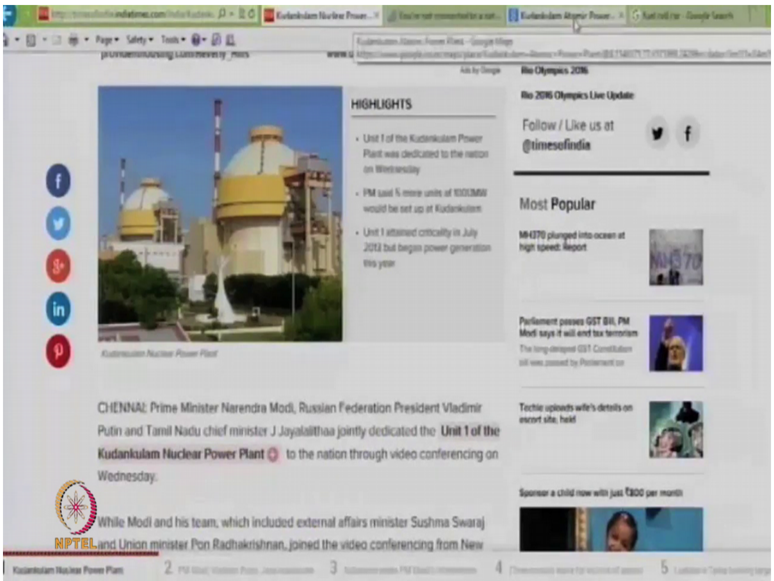

And, there is this is picture over here which shows these 2 big buildings, which are what is called the reactor building in which the nuclear part of it is kept.

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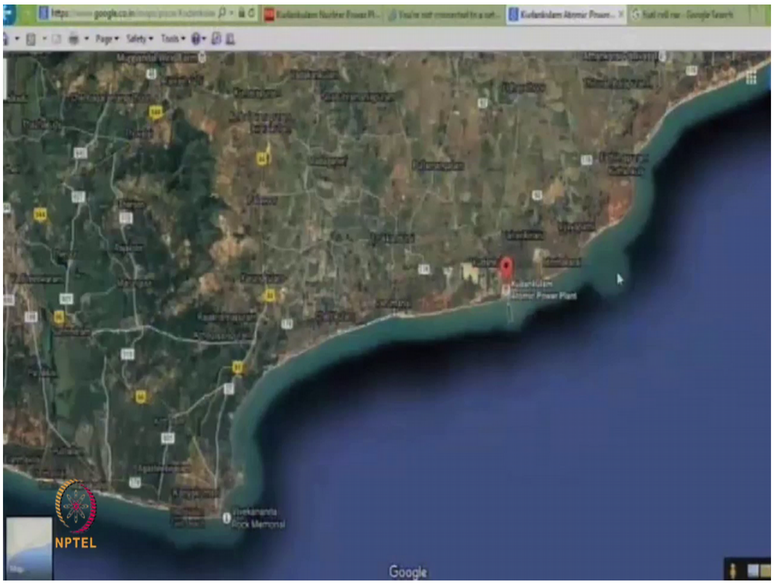

So, but go back to Google maps and see where is this place and what it is doing? So, this is here at the here is Kanyakumari. You are down at the tip of the Indian peninsula and a little bit distance away from it this is Kudankulam, and that is about what about something like 15 20 kilometres. And, let now zoom into it and let us see what do we see there.

So, there here is what we see that is the atomic power plant and we get closer to this, we see a lot of other buildings here, you can see some things over here. These are a bit of water coming in over there and have 2 building. These are 2 building these are the reactor buildings, these 2 these are the turbine hall and the accessories building. So, generators will be there from it will generate electricity and push it out (Refer Time: 32:59).

Yeah. So, how does this thing work? So, what we are seeing is reactor and then you have the turbine hall generating electricity. What else do we see on this we see a big building here, and this is another thing here. And, something else here you can see water coming out or going in into the power station. Here there is some more water being thrown out and it goes out there. And here we have something else you can see there is a sort of a little pond which has been made. And, the question is how does it produce electricity? It was it might subcritical 3 years ago and finally; yesterday it started generating power. So, we look at the schematic of this.

And, we say well how do I show what is there in the nuclear power plant ok.

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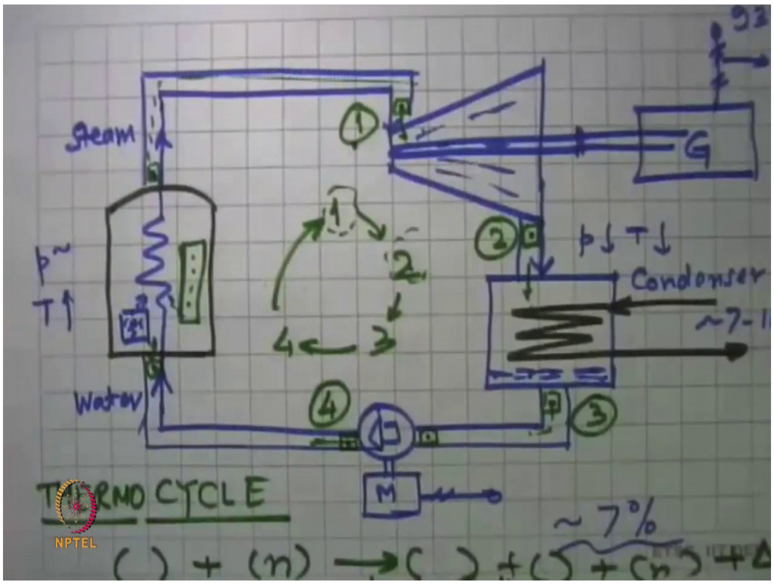

And so, say this is the reactor building and we are now making a just a sketch of this does not matter what it is inside it. And, what it and what it does is we pump in water and out comes steam, we just call it steam. And, the in the process the pressure is about constant the temperature increases and the liquid becomes vapour.

So, all that this has done in fact, this water which went through this got heated and that heat came about from a material in which nuclear reactions are taking place. So, this material got heated up around this waterway it picked up that heat something happened and finally, we got steam out of it.

And, then we take the steam and it is put into a steam turbine the pictures that I shown in you yesterday, the steam expand where it goes through this and exhausts in the process, it drives the shaft which is coupled to a generator, which produces electricity, and this sent into the steam. This steam which comes out here is it at a lower pressure and lower temperature and what one does is to put it in a device or in condenser. And, in this case what would the condenser has is that will pump water sea water into it, it goes through many many tubes and goes out and it discharge back into the ocean at (Refer Time: 35:51).

So, the temperature of this water rises typically by 7 to 10 degree Celsius. And, the process this steam were condensed I you got liquid water there in it which is then on top back into the reactor. So, what we see happening is what I have shown here as lines are actually pipes. And, the entire flow is driven by this pump which is powered by an electric motor. This gets electricity and power station this pump is the biggest consumer of electricity, and one of the biggest consumers of electricity in a grid is a thermal power plant itself.

So, some of this electrical power plant was here came back here and then drove here and the other things that are required to keep a power plant going and that is above the order of 7 percent of what we generate? So, what you generate here some came in and about 93 percent is exported which giving you a revenue.

So, these are pipes and like we just drew a few minutes back say this is the pipe, and in this pipe we got the substance going there. It was here it flows like this and comes over here, then it is pushed in something happens and then it comes out over there, then it pushed it gives this and then it comes up into this and so, it hold on. The thing is let us make all the pie and then we will come back. So, there is a pipe over there and then there is another pipe that brings it back over here.

So, this material the substance move came here got pushed into the pump, the pump pushed it out and got pushed into this. What happens is that if you take any point say this one and say this is a point, where the steam is just (Refer Time: 38:08) going to the turbine and I call this as state 1. Then, it goes into this undergoes the process in the steam turbine, where this work transfer and maybe some heat transfer and it comes out and state 2.

So, this is one process that is happening. And, then this thing go went into this is a very small pipe say nothing has happened it came out at state 3. And, then this went through the pipe except for pretty no pressure drop nothing much happens there it comes here; so, it is state 3 we can assume it and then it comes here and out at the pump high pressure state 4.

And, then processed at the same state at state 4, it enters this comes out and comes here and if we ignore pressure temperature drops in this pipe this is also state 1. And, so, it goes through this go through this and it comes here and it is back at state 1.

So, I started with one change 2 3 4 happened everything came back to state 1. And, so, if this was processed 1 2 process 2 3 process 3 4 and back process 4 1. So, what we are seeing is that we went through a series of processes 1 to 2, 2 to 3, 3 to 4, 4 to 1 and we started with state 1, it came back to state 1 if we consider starting state 2 we will come back to state 2, which means that this material went through a series of change of states and came back to it is original state.

And, this is the thermodynamic cycles. And, that is not important to us because this is a continuous process as long as we keep giving heat and taking heat away and taking the electricity away from there, we can run this 24 7 non-stop power long time. And, that is what we want and not just an intermediate process, they are saying just do it once and then now what would we do how do I get back on (Refer Time: 40:17) that is not required we want something with (Refer Time: 40:20) some depth is finished.

So, this is the basic thing that is happening in that nuclear power plant there is a nuclear reactor over there. In this you have the fuel rods; in which we put some fuel and gradually that fuel underwent nuclear reactions nuclear reactions is not part of classical thermodynamics. And so, we do not go in this and what we learn in this cannot be applied to what happens inside this. For that we have to go to nuclear physics and that goes back to atom and molecular level phenomena. But, just survive to say that we had some particular atom a neutron came and bombed it and this gave something plus something plus some more neutrons.

So, this atom disappeared to new atoms appeared and maybe 1 or 2 or 3 more neutrons were produced this is a nuclear reaction. We cannot study this from what we have learnt, because here the energy that comes out is associated with the loss of mass. And, that is something E couple in classical thermodynamics and say that even when energy is released by the combustion of gases must still conserved.