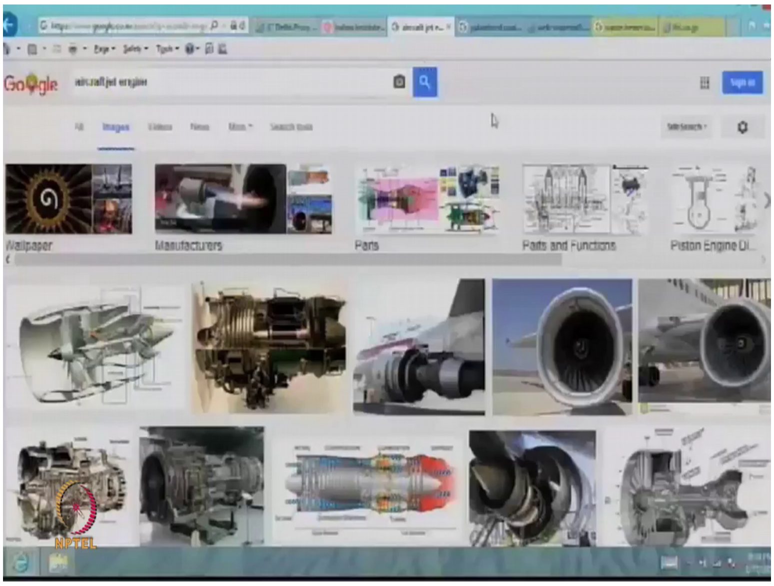
Engineering Thermodynamics
Prof. S. R. Kale
Department of Mechanical Engineering
Indian Institute Technology, Delhi

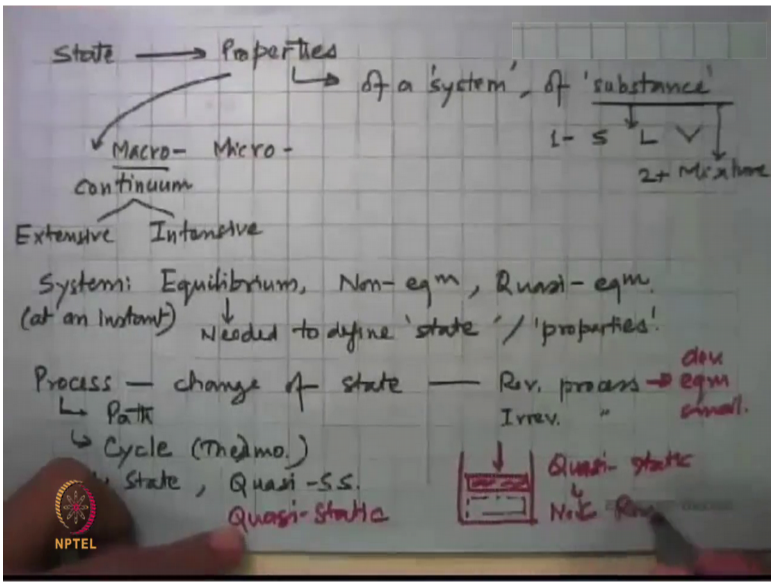
Lecture - 07
Thermodynamic Concepts: Causes of irreversibility

(Refer Slide Time: 00:22)



Let us start the third session of this module and this is the concluding session.

(Refer Slide Time: 00:23)



What I will do today is first quickly revise what we have done yesterday there have been several questions that have come. So, I will take those up, but there are some items that we had still not looked at I will go over those and then we will have plenty of time for taking your questions. So, let us start with a revision of what happened yesterday. We started off by defining what is state? We said that we need properties which give numbers and the set of numbers define the state, so this state of the system. And properties are for that particular material which is there in the system.

And we said that this substance could be a single type of a molecule in any of the phases; solid, liquid, or vapour or it could be a mixture of two different types of molecules in any of the phases. Then we said how can I put properties and then we said to put properties we need to define whether we take a microscopic approach where we look at the property of every molecule or the macroscopic approach where we consider a certain volume that it uses a lot of molecules and say that this is the average of all these. That also leads us to the concept of a continuum and we follow macroscopic approach in this course and defined properties either as extensive or intensive properties.

Extensive ones are that both that depend on the size of the system. Intensive are independent of the size of the system. Having defined properties we were then in a position to come to an important concept which is equilibrium. And we said that a system is in equilibrium and by default at any instant of time if the properties everywhere in the system are the same. If that is not the case it is not a equilibrium non equilibrium thermodynamic. And if it is strictly away from equilibrium and we want to still make an analysis. We said that look non equilibrium is too complicated let us forget about it for a short duration of time I will assume this to be in quasi equilibrium.

So, it is not strictly equilibrium, but we model it as being in equilibrium and then assign properties and then do all the preparations. I mean define that now that we have a system whose properties are known he said well what happens when the system undergoes a change of state and that is what is called a process. So, this is every process is of course, associated with the system there is an initial state and final state and all the intermediate states if in between they are known that would comprise what is the path of the process.

And a system that goes through a series of processes and comes back to it is initial state that is classified as a thermodynamic cycle. We then went back and said well what type of processes can we have and there are two types a reversible process or a irreversible process and then we went on to define what is the reversible process. And this is one where the process can be reversed; that means, the final state can be brought to the initial state without leaving any permanent change in either the system or the surroundings.

And irreversible process is one that to bring it back to the initial state we need to do something more that we did not do when the process went from initial originally went from initial to final states. And the causes we looked at the causes of irreversibility and these were unrestrained expansion heat transfer across of finite temperature difference friction and mixing so, all of these lead to irreversibilities which means; that if that process had any of those attributes to reverse it, we would have to do something more either put more work or put more heat.

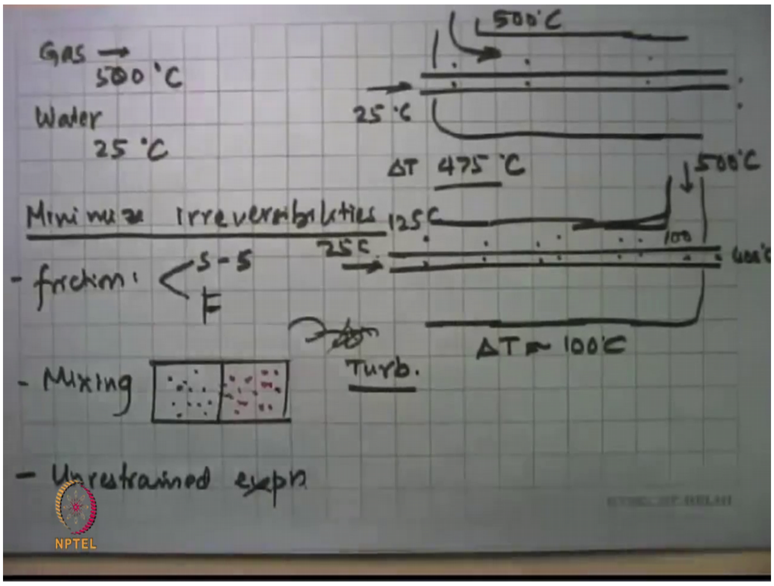
And then only the initial process could have been restored and that work or heat associated with the reversal of the process is what causes the process to become irreversible because that is the permanent change of the system. We then on went on say what is a steady state and we said that a system that any point in the system the property does not change with time that we classify as being steady state the real systems would actually be changing with time and to make a first cut simple analysis using the thermodynamic that we will learn here we say that look if I assume it to be in steady state I can at least make an analysis.

So, let me do that it is not exact thing, but at least good enough to know what is happening. And that approximation we call as quasi steady state. So that is where we left yesterday and now we pick up from here. One of the questions that came was well what is a static system or a quasi static system and in some sense it is same as being in steady state. Although the meaning of a static system was beyond thermodynamics even to learn mechanics. And so a system where there is a very small change over a period of time that we call as a quasi static system.

That means it went from initial state to final state in a very small step very small change. It will deviation from equilibrium is very small so one can even say that reversible process is one where deviation from equilibrium is very small infinitesimally. So, every reversible process is a quasi static process, but every quasi static process is not necessarily a reversible process. And the example is that if there is a gas contained in a cylinder piston arrangement. If this is pushed very small amount and it comes here.

So, this system underwent a quasi static process. But because if there was friction here then this process becomes irreversible. So, the force into distance like this piston experience or part of it went in friction part of it went here this system underwent a quasi static process, but the overall this was not a reversible process. So, this is an example of a quasi static process which is not reversible or irreversible. We spent quite some time looking at one type of irreversibility that will associate with temperature difference a finite temperature difference. And there were some questions that why is it what is the implication of it what is the use of knowing that such a thing happens.

(Refer Slide Time: 08:29)



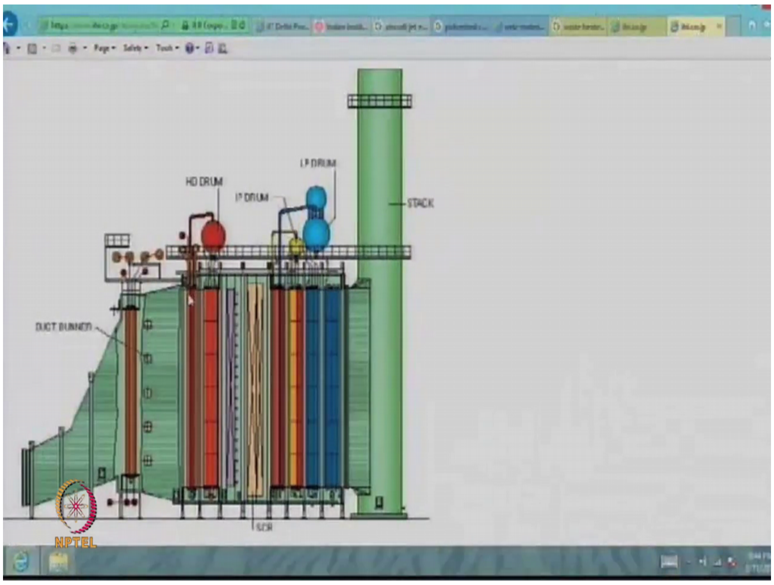
And I will illustrate that with an example, where we say that we have a gas flowing coming out of say a gas turbine power plant and this gas is at say about 500 degrees Celsius. And I want to heat water which is at ambient conditions about 25 degrees Celsius so how do we do it? We have many options and we say that look I will put the water through a pipe it flows this way. And over it I will put another pipe into which the gas flows this way.

So, this is entering at 25 degrees Celsius this enters at 500 degrees Celsius. So, what is happening is at this point 500 degree Celsius gas is giving heat to 25 degree Celsius water. As it goes further this 550 becomes say 400 this becomes some other temperature and like that it goes. And finally, if you make it infinitely long the 2 will exit at the same temperature. So, here temperature difference was very large. In this case 475 degree Celsius, but the maximum temperature difference across which heat transfer was taking place.

Now we look at another situation where this pipe is there, but gas is now entering from the other side. So, water enters here at 25 degrees Celsius, gas enters at the opposite end at 500 degree Celsius. And let us say that the gap water got heated to 400 degrees Celsius as it leaves here. What it means is that at this point here the hottest of the water is being heated by the hottest gas. And it keeps going down and the other end we said the coldest of the water is being heated by the coldest of the gas.

So, it could have a certain temperature difference in each one of these. And what we have done is we have tried to match the hottest gas to give energy to the hottest water. So, overall what we have accomplished is that heat transfer is taking place not anywhere does it does it take place at 475 degrees Celsius at 30 here it is 100 and we can design that at here also it will be hundred here also it will be 100 and so the gas leaves at 125 degrees Celsius. So, everywhere heat transfer was taking place across an average temperature difference now of delta t equal to above 100 degree Celsius. And what this is telling us is that here we have had less irreversibilities than what we had over here. And that is what people put into practice in designing almost everything like a boiler and I will show you a couple of pictures of that.

(Refer Slide Time: 12:05)



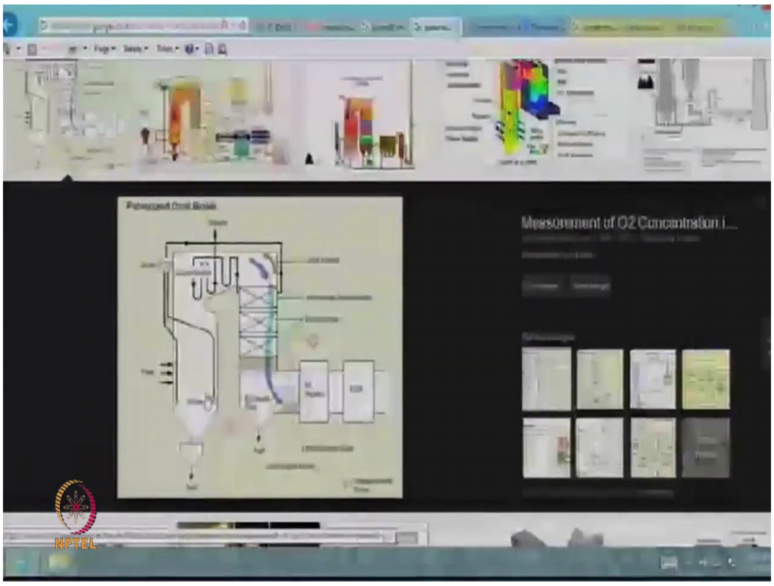
So,e so here is the actual rendering of a heat recovery boiler of a combined cycle power of one. This is a duct at which the exhaust of the engine comes in at 550 degree Celsius. Beyond that there is the gas turbine cover to a generator and then we do not want to waste this heat. So, we want to bring it down to the lowest possible temperature before we exhaust it to the atmosphere which is the job of this duct. And in between all we have done is put lots and lots of tubes, we will do the same thing what I just explained to you.

Then cold water comes in and this end gets heated up a little bit then comes out. Then we put it through another set of tubes will evaporated. Then we have to check out the vapour and put it through this and heat it further and all of this is done with a lower pressure. Because then lower temperatures are possible at other point we put water at a higher temperature then mixed up make it a vapour then again evaporate it and take the vapour and heat a time outfits comes at this end. So, if you have done the same thing what I mentioned there, but because of the engineering the way it is done these are a bunch of tubes whose design is different from each other.

But each one of them has been pick up of the same thing like the coldest water is being heated by the coldest gas. And if we are trying to minimize the delta t as much as possible. Why cannot we go to 5 degrees or 4 degrees or 3 degrees (Refer Time: 13:37) several other pistons gets cooled practical thing tells you that you do that much heat transfer you need a very large size. So, you need more space the amount of material required is very large and that adds cost of the plant so we do not do it.

And so what you see in practice is for our compromise between what thermodynamics that you should do and what the practical world of engineering and costing tells you what is possible and not possible. So, every design is specific in that particular context. The same thing is done in much larger boilers also ok.

(Refer Slide Time: 14:18)



You can see this picture here (Refer Time: 14:19) what we have done here. This is how a power plant boiler works where you burn coal and generate 800 1000 megawatts of electricity from each. The fuel is burnt here and here we have tubes on the sides which takes some heat and the hot gases begin to flow from here and they go out like this finally, in to the chimney.

Like they go out we put different types of surfaces in this through which tube tubes in which water is flowing or where steam is flowing or in some case even air is flowing. And everywhere you try to recover some of that heat and keep it in the system. So, at the coldest end what we have is the air heater; then we take ambient air, heat it up with the coldest gas and then send it into the furnace of combustion.

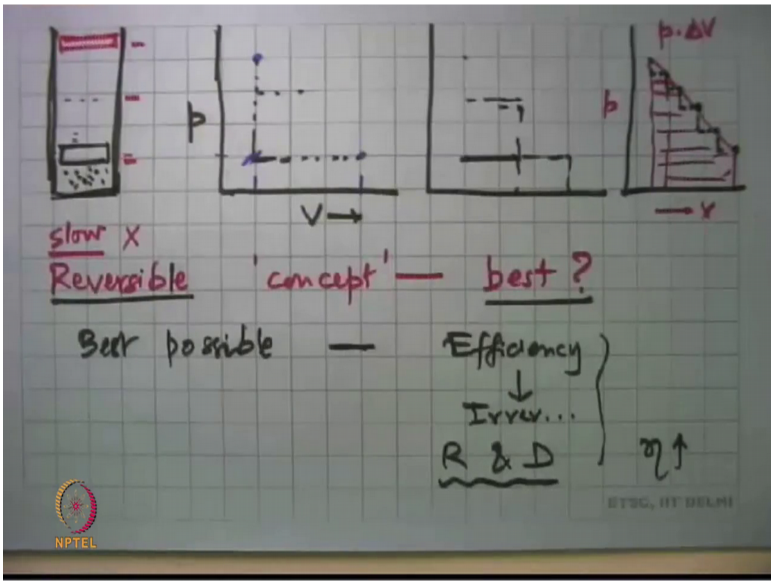
So, we will cover some more of that energy that much air does not need to be heated by the burning of more fuel we get a more efficiency. And then you have water being heated there is low pressure steam high pressure steam. And finally, here we get the highest temperature steam coming out of the boiler which then goes into the turbines. So, that is the practical rendering of the idea of this and that whole design that you saw there is done simply because we are trying to minimize irreversibilities in the system so that is the objective.

And that is not just about heat transfer through a finite temperature difference it is same thing is friction, friction between a solid between two solids. Something moving over it we try to put oil and minimize that or with the liquid itself or a fluid. When air flows over a substance and if it is going around in a random way that is turbulence. And that is doing nothing, but dissipating energy the kinetic energy of the fluid particles, they are rubbing on each other dissipating because of friction and it generates heat.

So, we try to minimize that and so we make the surfaces as much as nicely aerodynamic as possible. In that what you see whether you are looking at the ship these days or an aircraft engine or a pump. Then we have said that mixing of different substances will cause irreversibilities and the example of this we can give is we have two chamber separated by diaphragm with one type of a molecule here and on the other side we have another type of the molecule. Say one side is oxygen the other side is butane and if we ruptured this thing in between gradually they these molecules will move into this moves into this.

And after a long time there will be no concentration gradient in this and that will become an equilibrium system. So, in that case, if you want to reverse and get that two molecules back separate by themselves or without doing anything this cannot happen you will have to put in more work and put it some more processes before the mixing can be reversed. Same thing with unrestrained expansion; and let us see how we can explain that.

(Refer Slide Time: 17:54)



And we will consider the same thing, a cylinder and a piston arrangement. The piston is held here in place and there is the say a gas here let us assume for the time being that between the piston and the cylinder there is no friction and no leakage. In reality, yes there will be leakage and there will be friction and we allow this thing this is held in place and then we do different things with it we just let it go completely.

So, the piston goes off does a few things and say finally it settles down at this point. Here this is it is final state this was the initial state and now we will get introduced to first of the things that we will do quite often now in this course is to show it on a property diagram. And this diagram we will show volume of the system on this side and on this side. We assume that at any point there is a quasi static system and the pressure that is there. So, initial volume is here the final volume is here.

And you can say that the initial pressure is here. So, this is the initial state sorry this is the initial state is the higher pressure and somewhere there will be the final state. So, when we let it go like this suddenly, the piston it has worth pushing the atmosphere out and that is only work it does. And so the work at any instant if you were to take it we cannot do that because it is not a reversible process. We show that change of state by a dotted line and the work that is available here is the area under this curve we have got only that much here.

We know do a second operation here and we said that you know I won't let it go all the way up. But what do I will do is I let it come up and expand up to say the middle part once and I will stop it let it come to an equilibrium and then again I will let it go. So, what happens is in the first case it will come from there and the midpoint is say here. So, this is the work it does and the second process after equilibrium has come it has now come to this process.

And now it will do a little more work there. So, that is what happens that here you got only this much work. But in the next case we get more work coming out of this system and so if you take very small small steps from here we do a little bit of work come to this state, then a little bit of unrestrained expansion then here a little bit of unrestrained expansion then here little bit of un ex unrestrained expansion and here and like that we come to a series of states.

And then we have a path, where we can approximate that this side being V and this is p this at every step the work done is pressure multiplied by the change in volume. And we add it up and that tells you what are the total work that the system did in this process. So, that is the difference one sees and this is also an example that as long as you are able to restrain as you avoid unrestrained expansion. We come to close and closer to a reversible process it would also mean that the pressure should change in very very small steps the piston should move very slowly.

So, that and by a very small amount. So, that the system immediately comes back into equilibrium or never really deviates from equilibrium too much. Such a thing would be very very slow and nobody is going to with that long for an engine to produce power and so we all deal with some degree of what one may call fastness or speed. And so there is always some degree of irreversibility or unrestrained expansion associated with real processes. But what this concept tells us about a reversible process this as a good concept in the sense that it tells you what is the best that you can achieve.

So, it tells us an upper limit what I can do as well as this and not much more than that ok. So, in that sense this idea of what is reversible or irreversible this is very crucial. It will come back later on in the later modules also when we look at cycles and look at actual practical devices in practical processes. And we will see that the whole idea was to make things as reversible as possible.

So, that was a part answered to another question which was there last time what is the use of defining and a concept like a reversible process. So, one is it tells you what is the best you can get and second as I had given you that example of the boiler. It also tells you what should be the basis in designing that engineered system. And the whole idea is that we know what is the best we can get what is the best possible.

And historically what has happened is when innovations were done say aircraft engine or the coal burning power plant to produce electricity or say the even the diesel engine or the refrigerator or anything that you look at they were done with only a minimal understanding of thermodynamics I said let us make something and see whether it works or not and then when you began to understand the thermodynamics better we started looking at it and started defining things like efficiency.

And then we said you know what do I need to do to improve this and that tells us that we went to thermodynamics and look at all these types of things that were happening it has do something with mechanical design, but also you will have to do with these aspects of thermodynamics and so, we said let us tackle the irreversibilities in this design ok. So, if we do everything to do that and with time last 50 years 80 years 100 years what we have seen is various things have been done as research and development.

And in every case, efficiency has increased not to mention the fact that reliability as in three where cost has come down along that also. In that sense, thermodynamics was the driving force and it still is the driving force for what happens in research and development. So, with that I think we will we had enough on the concept of reversible irreversible processes. When there are more questions we shall take more. Yes, you have a question? No.

Student: (Refer Time: 25:40) what are the examples of.

What are the examples of a quasi static process ok. So, the question is what is the example of a quasi static process. And the example that I just gave will tell us more about that. As this piston moves up through small steps at each point we assume this process to be quasi static. So, that is an example of this quasi static process.