Design and Optimization of Energy Systems

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Lecture No # 04
System Simulation

So, now we will start up with a new chapter, the System Simulation. So, now on it will get, it will get mathematical, everything will get mathematical. So, we will be solving lots of problems in the class, as I told you before, please come to the class with your calculators. Now, first half an hour, we will just go through some basics and I will teach you about information flow diagrams, which will be helpful to you in solving of system simulation problems. Even without that you can solve, but things will be more organized, particularly if a system is made of several components, it is always a good idea to represent each of this as blocks and find out what is the information, which is going into the system, what is the information, which is coming out, so that you get an overall idea.

But I have seen, I have been teaching this for 10 years, IIT students do not like to draw all this and so, straightaway you want to solve. That is ok if there are only two or three components are involved. But if you have large system, which consists of several components, it is always a good idea to do, to do, what is called an information flow diagram, which I will discuss in today's class. So, the mathematics will start from the next class onwards. So, I will teach you the method of successive substitution and Newton-Rapson method for single unknown, as well as, multiple unknowns.

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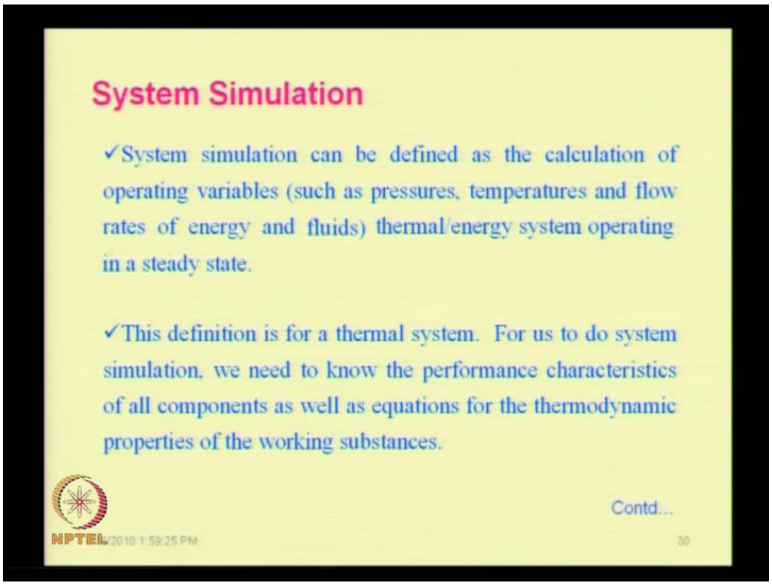

So, what is system simulation? System simulation is basically a, is basically a mimicry or you mimic the system, you mimic a system. It can be defined as a calculation of operating variables, such as pressure, temperature and flow rates of energy in a thermal or energy system operating in a steady state, I am sorry, this, it can also include system operating in the steady state and also operating in the transcendent condition.

For example, a power plant, most of the times we are interested in the steady state performance of the power plant. But there are also issues, like starting up and shutting down of a power plant. These are very critical for the nuclear reactor. Suddenly, there is an accident and there is an emergency shutdown, you can shutdown all the things, you will shut down your reactor, but this nuclear fission is not going to stop immediately. It will continue to, the fission reaction will continue to proceed and if all the, all the systems breakdown, you would not have pumps, which will take the heat from the fission, fission reaction. And therefore, you will not be able to dissipate all the heat ultimately to the ambient. So, in this case natural convection will take over because pump is not working.

So, you should design a nuclear system such that in the case of an accident, in the case of an accident, even under natural convection, even under natural convection you do not have catastrophic consequences. So, these are the essential part of, is an essential safety divisions are very, very important in nuclear, nuclear power plants. Lots of engineers working on safety, there is a separate body in India called the Atomic Energy Regulatory Board (AERB), which is actually separate from the, which is actually separate from the atomic energy, I mean, atomic power plants. So, this is the regulatory body, which comes and checks periodic periodic intervals of time, whether the safe safety systems are in place.

So, as thermal engineers or mechanical engineers, while most of the time we are interested in the steady state, we are also sometimes interested in transient. The chemical engineer, on the other hand, is often times interested, often times interested in the transient operation. So, process control, process control is big time, process control is a big deal in chemical engineering, process control is not a big deal in your…

You are just learning one course in controls, instrumentation and controls. How much of control did you study in that course? It is mostly on instrumentation. Is it? So, control will also involve in stability analysis and all that. So, suppose you give a disturbance to a system, whether it non-linearly grows or decays with time. So, this is essentially, what is called as a stability analysis and so on. So, chemical engineers are often interested in this, but mechanical engineers, somehow we do not concentrate much. Of course, needless to say, in this course we will concentrate only on steady state, but I want you to remember, that transients are also important.

The definition, which I have given above, basically we want to calculate. So, just like in the previous example, you actually calculate the, actually figured out the diameter, the diameter of the pipe, as well as, the ratings for the pump. We should be able to calculate all the operating variables. So, it could be possible, that you actually have a heat exchanger and you want to work out the outlet temperatures of the fluids and so on. That is, basically, I am talking about an analysis problem. So, design problem is given in all this flow rates and all that, what will be the heat exchanger size, how many numbers of tubes and so on.

So, I already explained to you the difference between the analysis problem and the design problem. So, simulation is more concerned with the design, concerned with the analysis rather than the design. So, this, this definition is basically for a thermal system. So therefore, for us to do system simulation, we need to know the, perform, performance characteristics of all components and we need to know the equations for the thermodynamic properties of the working substances, thermodynamic.

So, we are not going to work with air always, it is very (( )), it is very easy to work with air and water, that is why old thermodynamics, there are only two fluids, in your M.E 110, we taught you only two fluids. Now, it is M.E 1100, air, p is equal to rho r d and all that, simply keep on doing this, no problem, otherwise we use the steam tables, anything beyond that we are not taught in thermodynamics. But however, new fluids are constantly coming up deficiencies or because of monitorial protocol people are changing, moving away from CSC and so on.

Who will give us the properties of all these? So, there should be groups of scientists or engineers, who are constantly (( )), who are using equipment, who are developing equipment to measure all these properties and give us in the form of handbooks, charts or in the form of CDs or post it on internet or whatever.

Now, in order to do system simulation, it is not possible to use tables. I ask you to do simulation, you take 100 bar 400 degree centigrade, when will you complete the work. So, what you need, properties must be in the form of, in the form of equations. You need to have equations. Therefore, regression is required for this. So, you need to be good in statistics. If the proper, if, if, for example, the enthalpy is given as a function of pressure and temperature, can you construct, can you construct equations of Y as a function of x 1 and x 2, where x 1 is… Y is enthalpy, x 1 is pressure, x 2 is temperature, so Y as a function of x 1, x 2, enthalpy, entropy and all this, then change of phase, h f g, that is, latent heat. All these things, you should be, you should be comfortable in converting all the, whatever information you have, put them in the form of mathematical equations.

Similarly, if I know, if I know the, if I, if I know the operating variables of a compressor or a blower, whatever, I should be able to calculate the efficiency in terms of these operating variable. Therefore, knowledge of regression and knowledge of how to represent the properties or a system performance in terms of equations is inherent. This information has got to be embedded otherwise you will not be able to do simulation.

Therefore, after, after you go through the simulation for few classes, we will get back to regression and I will teach you, if you have got Y as a function of x 1, x 2, how do you get this equation? So, some two weeks, two weeks, some intensive crash course on regression, essentially with the view, essentially with the view to get equations for either the system properties or for getting the performance characteristics of components is, is very much important. I will teach you certain things, which you have not studied elsewhere, but for my M. Tech student there will be some overlap with your measurements course. There will be some repetitions, but that is unavoidable, but it is very, very important. It is imperative that you learn this.

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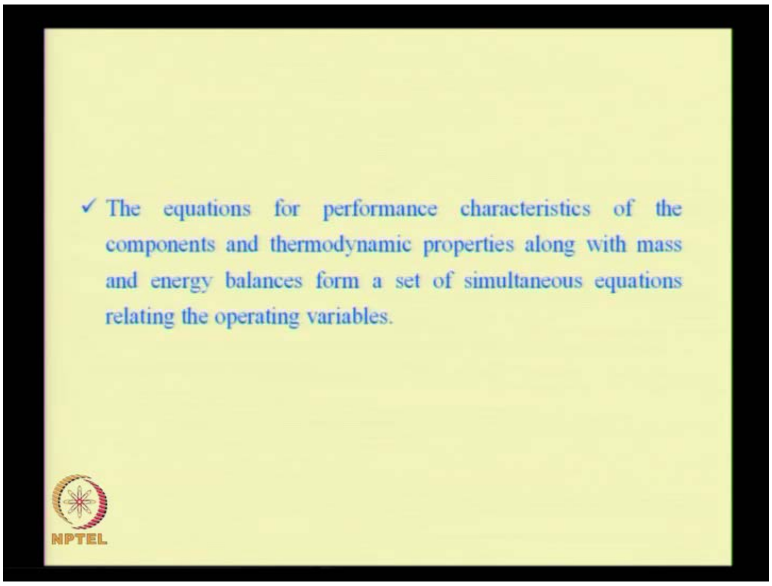

Now, what is a story? The equations for the performance characteristics of the components and thermodynamic properties along with mass and energy balance will constitute a set of simultaneous equations, which relate the operating variables. If you solve the system of simultaneous equations, you will be able to fix all the operating parameters of the system under question. This is basically system simulation.

There will be a large, there will be a large number of variables, so you will have to do matrix operations for large system. However, for the classroom environment, we will restrict our attention only to two and three variables problems.

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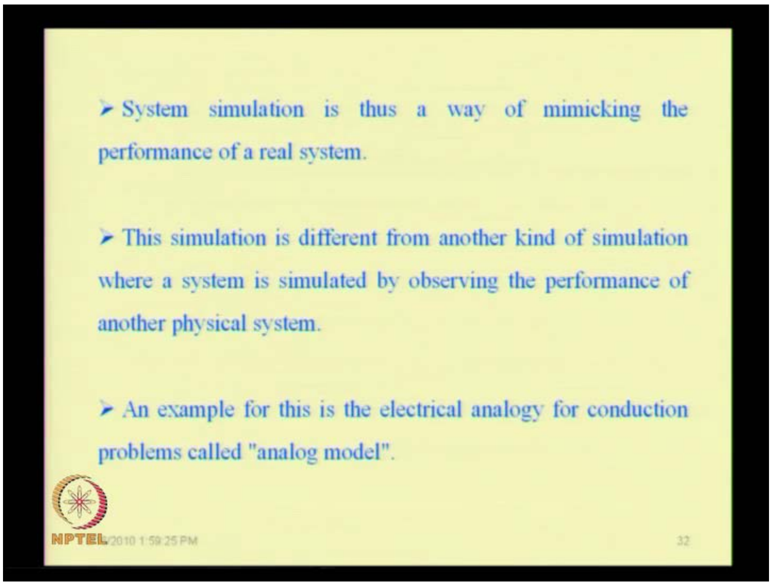

So, system simulation is thus a way, is thus a way of mimicking the performance of a real system. Instead of trying to do an experiment, I am trying to find out, how the output will change in each of these inputs (( )). You write all this in terms of mathematical equations.

So, you have a computer model or a mathematical model of a simulation and you go ahead and do numerical experiments or you do experiments on the computer and upfront, even before you design, you get an idea how the system is, performance is changing if the design, if the operating variables are changed, so that is the goal of, that is the goal of system simulation.

So, this simulation is different from another kind of simulation where a system is simulated by observing, by observing the performance of another physical system. That is basically called the analog model, which you have learnt, which you have studied in heat transfer. So, that is what system simulation. I am not talking about that for example.

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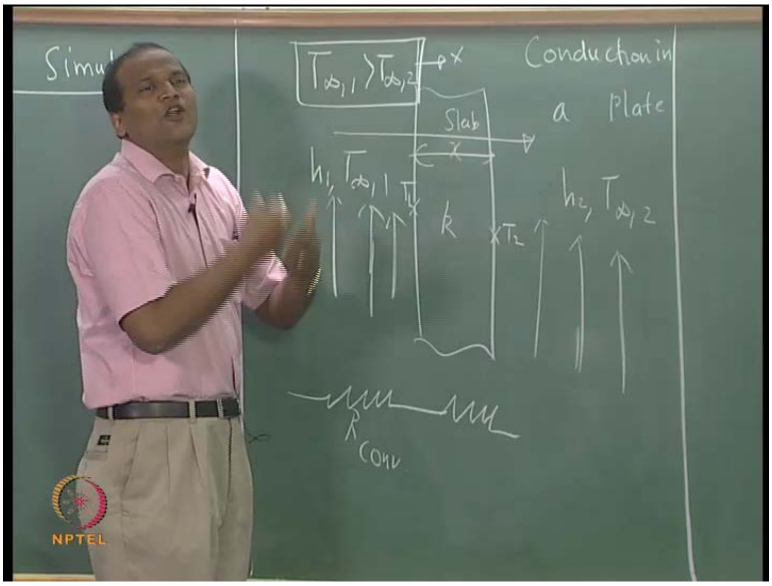

So, there is a slab, it has thickness x, thermal conductivity k, having steady state. So, here there is a heat transfer coefficient of h 1 and (( )) temperature of T infinity 1, here we have a heat transfer coefficient of h 2, it is T infinity 2. So, this situation is typically encountered in heat exchange replication where there is a plate, which separates the two fluids. So, there is a heat transfer from one fluid to another fluid, let us say that.

So, this plate is baked, this plate is baked by hot fluid on one side and it is baked by cold fluid on the other side. So, this plate acts as a mediator for the transfer of heat between, from one, from one fluid to another fluid, but convection is encountered at the interface between this solid and this fluid and convection is also encountered at the interface between this solid and this and therefore, there is a flow of heat from left to right. This is the physical problem.

Now, it is possible for us, because h 1 and h 2 are not equal to infinity. T infinity 1 will not be equal to T 1 and T 2 will not be equal to T infinity. If h were to be infinity, if h 1 were to be infinity, it requires an infinitively, infinitesimally small temperature difference to accomplish the heat transfer from the fluid on to the solid. However, since the maximum heat transfer coefficients, even under boiling or condensation is only 20000 watts per meter square or 15000 watts per meter square Kelvin, watts per meter square Kelvin, technically it is impossible to have a situation where T 1 will be exactly equal to T infinity 1.Therefore, whenever, whenever there is convection, there is always a resistance, therefore denote it as R convection.

Now, because this fellow also does not have an infinite thermal conductivity, it requires the temperature different heat transfer. Heat will not be transferred unless there is a temperature difference. Technically, we will say, in boiling or condensation, heat will flow with no temperature different, but that is only theory, then you do not require heat exchanger at all. q is equal to h a, delta h a is infinity, you can go home by having a heat exchange with 0 area.

It is not possible, if, if you have to make the, if you, are you getting the point? If you were to decrease the delta T, then the A will increase, exponentially the cost will go up. So, you have a R conduction, again have a R convection, we call it R convection inside, outside, whatever it is, outside, so on. This is also a model of the system, this is called the electrical analog model, it is an electrical model, that is, the flow of heat is analogous to the flow of electricity, I am not talking… What you are tried to say is, I am not talking about this that you have, we have talked about in ME 3170 or whatever.

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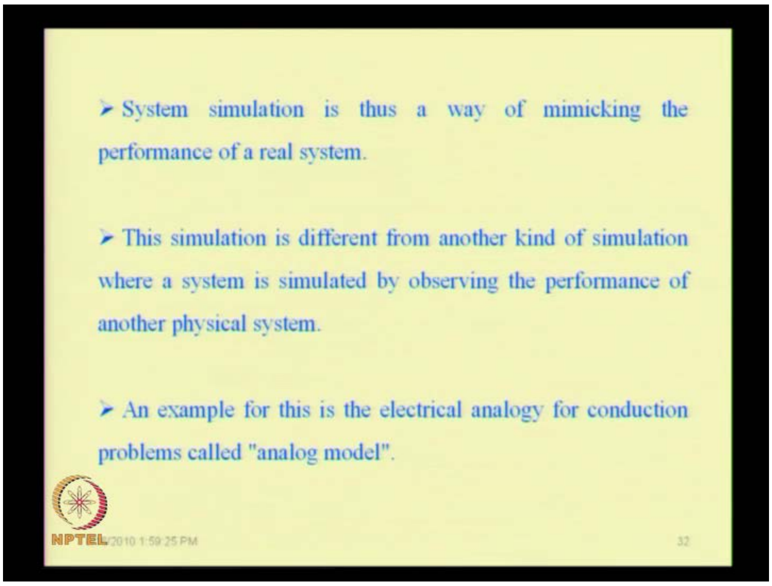

So, an example for this is the electrical analogy for conduction, which is called analog model. An example for, what an example for what we are not talking.

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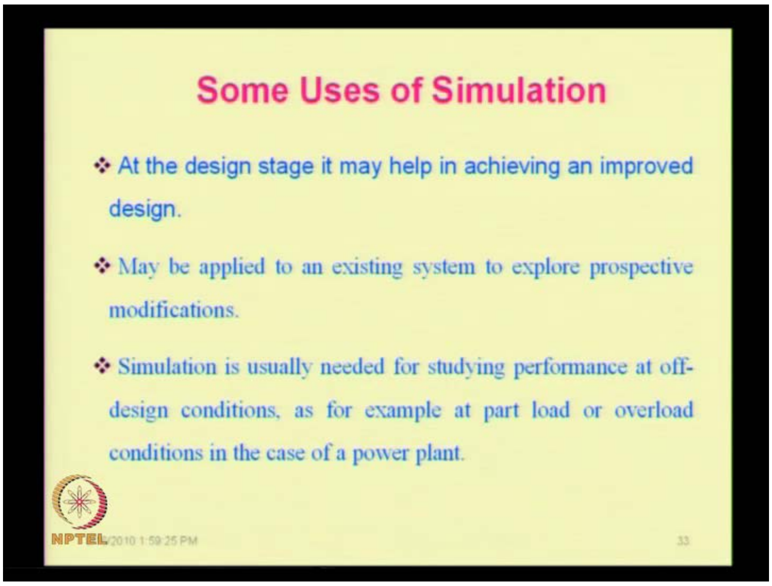

Some uses of simulation, at the design stage simulation, extremely useful achieving an improved design. You can evaluate alternate design and find out, which is better; point number one. Point number two, it may be applied to an existing system to explore prospective modifications. Existing system, you want to improve, you want to meddle with it, then improve, then it is possible for you to use simulation.

Simulation is usually needed for studying performance, this is very critical. Simulation is usually, is usually needed for studying performance at off-design conditions. Why this very critical is, most of the times, most of the times the system is working at off-design, there is a change in some variable or the other. For example, it is working at part load or power plant, during the evening time, afternoon and all that there will be heavy demand. Early morning, there would not be demand and so on. There will be a design load, but most of the time it is off-design load, not consistently above or consistently below. Are you getting the point?

So, how does the system perform under off-design condition is an important question, which can be answered if you are, if you are able to develop a model and simulate the system.

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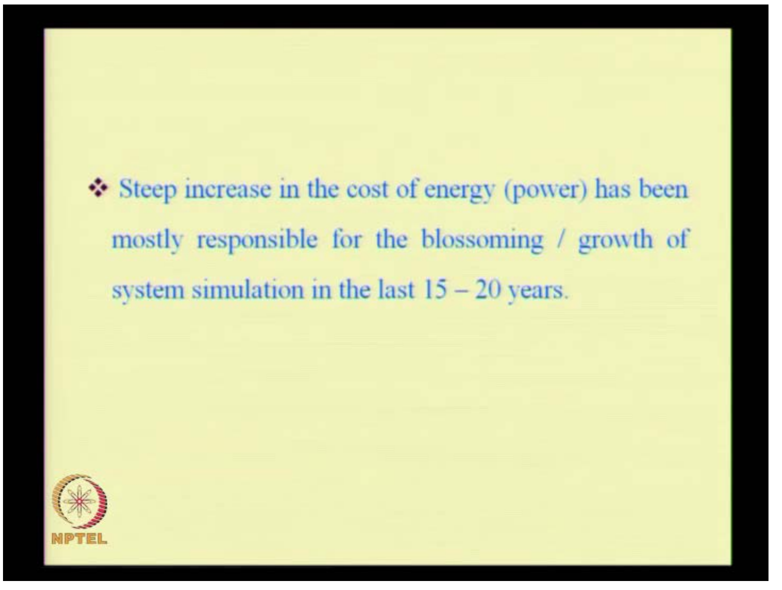

Why are you so much interested in all this? Because generally, for a power plant, for example, if you have to design a heat exchanger or if you are designing air conditioning system for an auditorium, air conditioning system for a mall, city center and other thing, where lot of costs are involved, so you are trying to simulate. And then, you are trying to not only simulate, you are trying to optimize because these costs are going up.

Now, people are taking simulation optimization little more seriously. Accompanied by this is the fact, that you have got powerful computers, as well as, software programs, which can do all these analysis very quickly. Combine these analyses with an optimization technique and try to arrive at an optimum that is the story.

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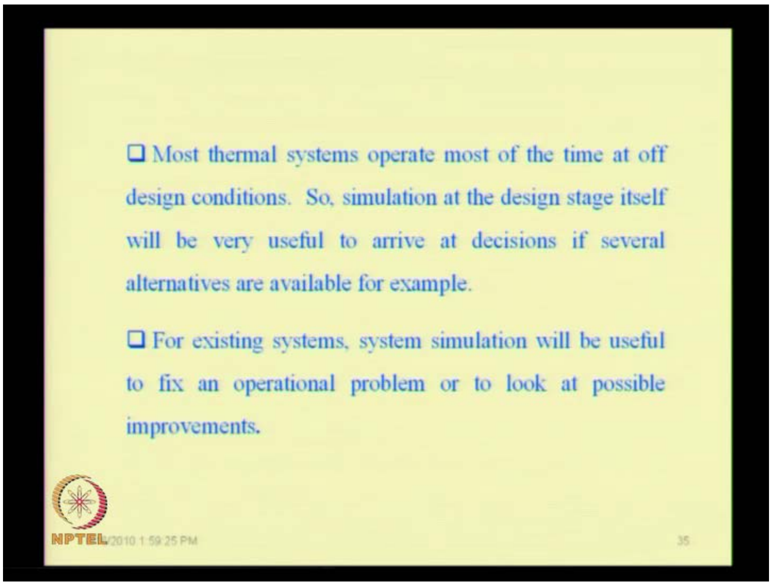

Most thermal systems operated off-design conditions. So, simulation at the design stage itself will be useful to arrive at decisions if several alternatives are available. For example, it helps you to explore several alternatives. For existing systems, simulation, system simulation will be useful to fix at, to fix an operational problem or to look at improvements. I have already discussed about this.

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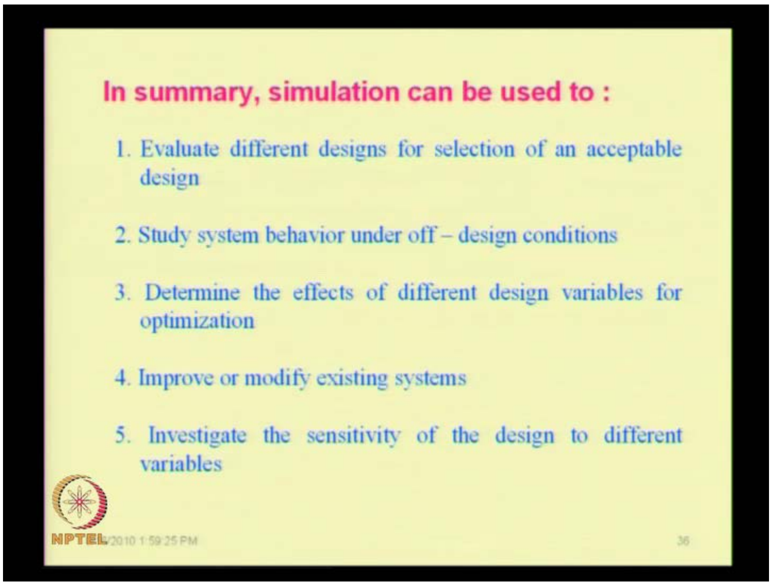

In summary, to cut a long story short, simulation can be used to evaluate different designs. Study behavior under off-design conditions, study the sensitivity of the performance, performance of the system to various operating conditions. If x 1 to x n, if x 1 to x n are, you design variables and y is the variable under question, y is the system efficiency or the power output of the plant d y by d x 1 d y by d x 2. Mathematics, we call it as Jacobean matrix, if you are able to write in terms of matrix, if there are several ys, d y 1 d y 1 by d x 1 to d y n by d x 1, d y n d x 1 to d y n d x n, that Jacobin matrix if you are able to evaluate all the components of that, then you can play around, you get an overall idea how things work out for this complicated system.

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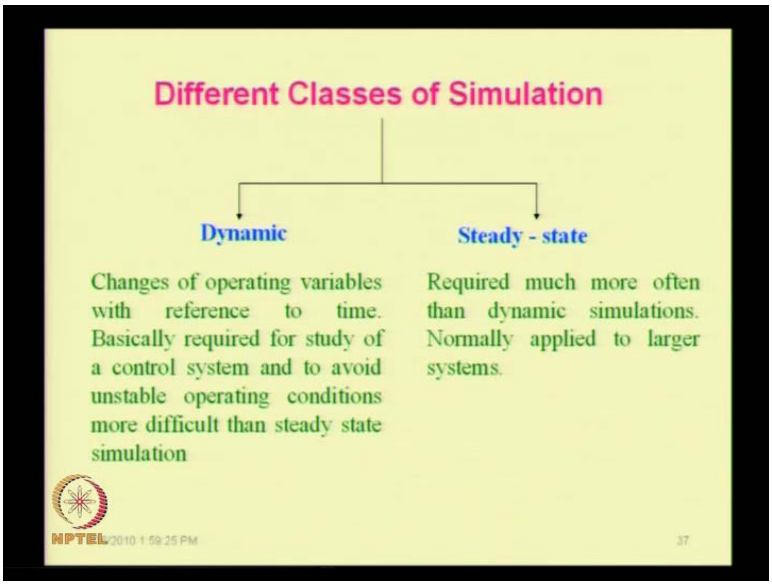

Different classes of simulation, this is only story, do not worry, I am not going to ask, I have already put this up on the net. Did you see it? I have already put it up on my this thing, assignment two also I will put it up, I think all of you have copies, just in case you want to look at it leisurely, you can do that.

Different, so quickly we go through this, these are all necessary evils. Whenever you study something you should also learn the background theory, but (( )) is our (( )). We will start working on problems from the next class.

Different classes of simulation, it can be dynamic or steady-state, that is transient in steady-state. In transient, the change of operating variables with reference to time, you are worried about the transient basically required for a control system to avoid unstable operating conditions. I already explained the background to you, steady-state, most often we are interested only in the steady state and it is usually applied to large systems.

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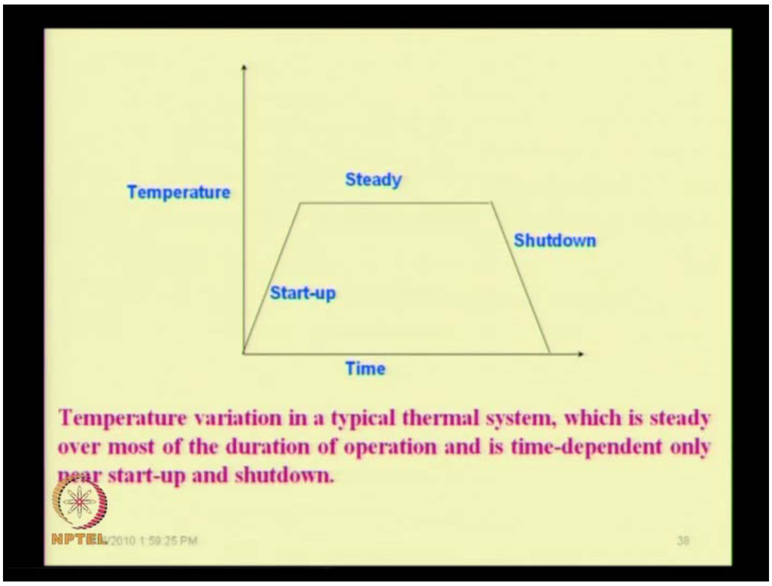

The typical temperature versus time response for a steady state system, so a power plant, even when you, even when you start your motor car, when you start your bike, you start an air plane. So, there will be start up phase involved, the pilot just cannot…

First you will close the door, unless he closes the doors you cannot start the engine. First, you have to close, close the doors and then you will start the engine one by one. He will start the engine, right engine, left engine, then you will raise the throttle, full throttle, he will go, he will reduce the throttle, he will see whether the sounds, everything are ok. He will flap his wings up and down. All these are mandatory just before take-off. If something happen in between he cannot do, but at least before, at least before taking off, he has to, he will check all, he will check all. There will be, there will be humongous number of this thing on his display, he will get the latest radar, radar, this thing.

Now, they all have internet, all these modern planes have internet. He can look at all weather maps, while in, while the plane is in motion. Of course, he has a very powerful radar where he can, he can actually do this, plus or minus 20 degrees he can go. And then, here, this radar has up to 120 kilometers, he can see up to 120 kilometers he can see and then up to here, I think here 60 degrees or 70 degrees left side, 70 degrees right side. So, you can, you can do a lot of things, the only danger is sometimes micro burst. Suddenly, there is an up draft and the down draft, which cannot be detected by radar, that is called clean air turbulence, then he is in trouble.

So, otherwise he has to go through this. First he will start the engine, look at this thing and then, once he gets on to the main runway he has to do it systematically. Then, he will have two or three levels and then at full throttle, at full throttle do the take off. After that the wheels have to go in again. If they are not going in, he is in trouble because what happens, the drag, you know, increases enormously.

So, that is the beauty, look at the wheels, so they are hydraulically operated. You should be able to deploy them whenever you want, he should be able to retract them whenever he wants. So, the transient, all this thing, there is a protocol. So, again approach, that when he lands, again 20 minute before he has to and then there is a particular sequence. There is a particular sequence he has to follow because the other planes are also flying and there is a particular descent rate because he is already flying at the MAC number 0.8 or 0.9.

If it touches MAC number 1, then the centrifugal (( )) m v square by r, then little bit enormously increase, the gas turbine will cup, that is, that is what may happen to (( ))7. If you increase MAC number beyond 1, the engine will go up, but the plane may get blown up because the stresses will be too much, so transients are very important.

In the power plant we just start our nuclear power plant. So, there will be stage where you start with is the start-up, then it reaches a steady state and then there is a shut down. We will shut down for the maintenance or break down, whatever. Now, in this course mostly we are focusing on the steady state. If you want transient, then it cannot be done in a first level course, you would have to learn it separately or you take process control chemical engineering.

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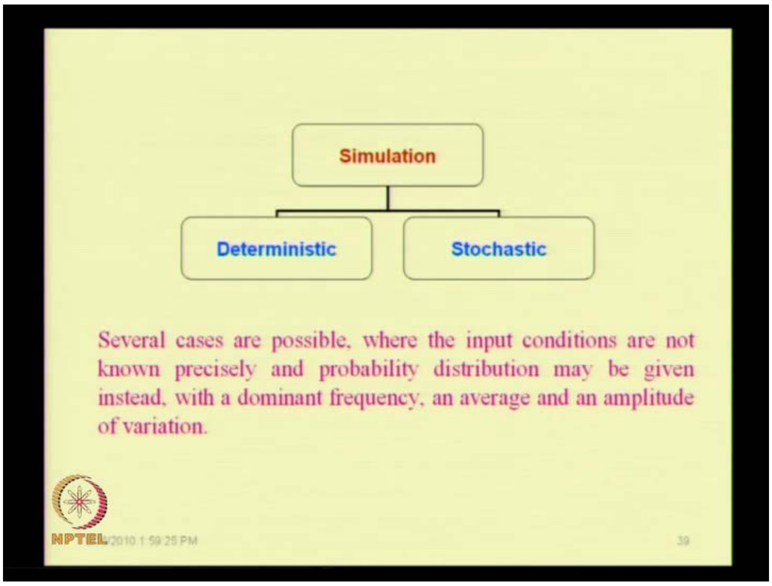

Simulation can be deterministic or stochastic. Several cases are, there are several cases possible where input conditions are not known precisely and the probability distribution may be given instead, with the dominant frequency, an average and an amplitude of variation. Then, you cannot use a deterministic simulation. So, then you have to do a stochastic simulation. Suppose you are, for example, you are going to do your MBA or going to do PhD in management, for example, they are, these guys also do simulation. They do what is called a Monte Carlo simulation.

Let us say, there is a big gastroenterology department of the big corporate hospital. It is hiring a consultant to do simulation to find out the optimum deployment of its OTs; OT is Operation Theater. So, If you test three or four OTs, so it wants to optimally deploy. For example, the bypass surgery and the kidney transplant may take long time, whereas the gall bladder removal may take 2 or 3 hours only. So, it wants to study. Then, what are the various steps involved. For example, a bypass surgery patient is first wheeled in, then anesthetist moves in, then they make measurements.

Mostly surgery is engineering you know, mechanical engineering, mostly it is cutting and they are heavy engineering. Orthopedic surgery is too much engineering actually; surgery is mostly engineering. Then, they make measurements, they, hopefully they remember heart is in the left hand side, then the junior doctor will make the measurement, they will take his X-ray, they will take X-ray, echo cardio, echo cardiogram report and then they will identify what is the size and all that and then he will make primary this thing for where to cut and all that.

And then, the main surgeon will come and then they will, anesthetist will monitor, how the this thing, patient is responding, then you will start the surgery, then they will cut and then they put it on to the heart lung machine or nowadays, it is called, what is it, beating heart surgery? The heart keeps beating, heart keeps beating and they do the surgery, online surgery, whatever. And then, so it is, the heart is not stopped, the heart is technically not stop, stopped and no artificial heart lung machine. Then, he closes and then he is put in a recovery room to see whether it is stabilized and then he is taken to the ICU and so on.

Now, each of this, for example, you can have a Gaussian distribution. The normal time taken by anesthetist will be 30 minutes with a sigma of 5 or 5 or 8 minutes. The normal time taken for a, for a bypass operation, which fellow has got three blocks it is called TVD, Triple Vessel Disease. So, triple will be 3 hours for the surgeon plus sigma of 18 minutes, then for the anesthetist to, anesthesia to ware of all this.

Now, suppose we want to do a Monte Carlo simulation. You generate a random number, random number 44, random number 44 means, you will say, that if it is between 0 to 50, then the anesthetist will do exactly at mean plus gamma. If it is between 50 to 70, he will take mean minus gamma; if it is the number between 70 to 90, you preassign like that, you come with the model and using sequential random numbers you add up all these and find out what is the total number, total time, which is taken.

So, let us say the total time is 218 minutes, you can run this Monte Carlo simulation several times. If you take an average and then take the variance, then that will give you an idea of what is the overall Monte Carlo simulation of a bypass surgery in Apollo hospital, that treatment information you can have. Like that if you do for everything, Monte Carlo simulation, then what is the optimal, what is the total time taken in a day, how many operations can you schedule and all this or the average time. Corporate hotels are interested in the average time taken by a guest when he enters the hotel, between the time enters the hotel, the time actually enters the hotel room, how much time is taken, can we optimize on this, how much time is taken for check out.

These are also related to QN theory and all the ORN. So, in all these cases it is not known, we cannot say that all surgeons will exactly finish it in two and half an hour, they may have some unexpected thing, they will find something new. So, this, it happens, we may find somebody heartless, that can, that can be only in MRI scan, whatever, heartless means, different, something different. So, these are deter…

So, this is basically not deterministic, this is Stochastic, because we do not know. The variables can be, the variables can change with time. In a deterministic simulation, all the things are known a priory with certainty.

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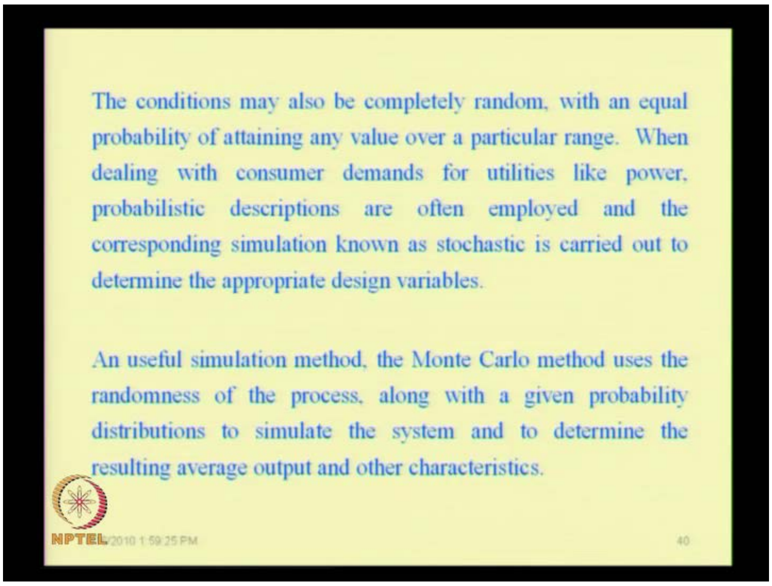

The condition may also be completely random with an equal probability that is what I will explain now in this so called example. When, for example, another example could be when dealing with consumer demands for power, stochastic descriptions is better than deterministic descriptions. So, I already gave you a one on one course on Monte Carlo simulation. Now, useful simulation method is the Monte Carlo simulation method, we use it in heat transfer. In all group we use the Monte Carlo method to solve the inverse heat transfer problem.

The Monte Carlo method uses the randomness of the process, along with the randomness of the process, along with the given probability distribution to simulate the system and to get the average output and other characteristics. I explained in the last five minutes also how to get the average time for the surgery and all that, you can use the Monte Carlo method.

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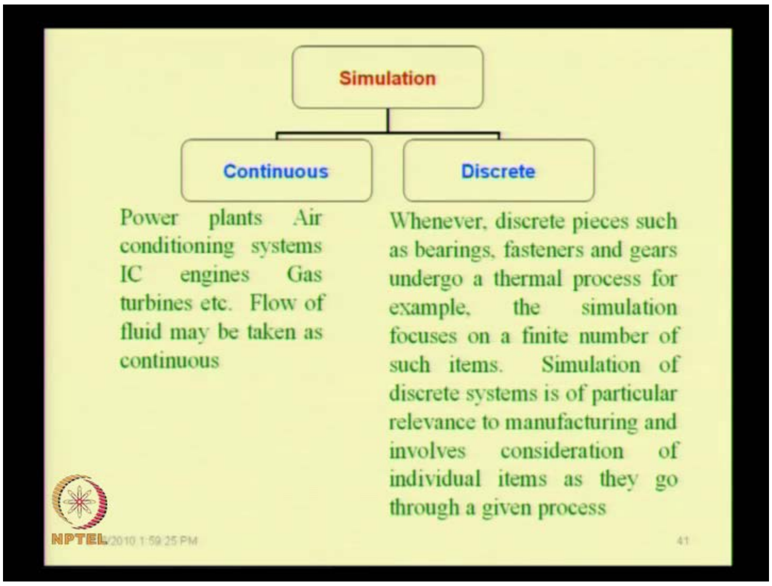

You can have a continuous and discrete simulation. Most, often times in thermal systems you have, we are interested in the continual operations, continues operations of power plant, AC systems, IC engine and so on. The flow of fluid is assumed to be continuous. We do not encounter this discrete kind of system, these discrete kind of systems are encountered in manufacturing, some there is a batch mode and so on.

So, whenever discrete pieces such as bearings, fasteners and gears undergo a thermal process, simulation focuses on a finite number of such items. Simulation of discrete, discrete system is of particular relevance to manufacturing and involves consideration of individual items as they go through a given process.

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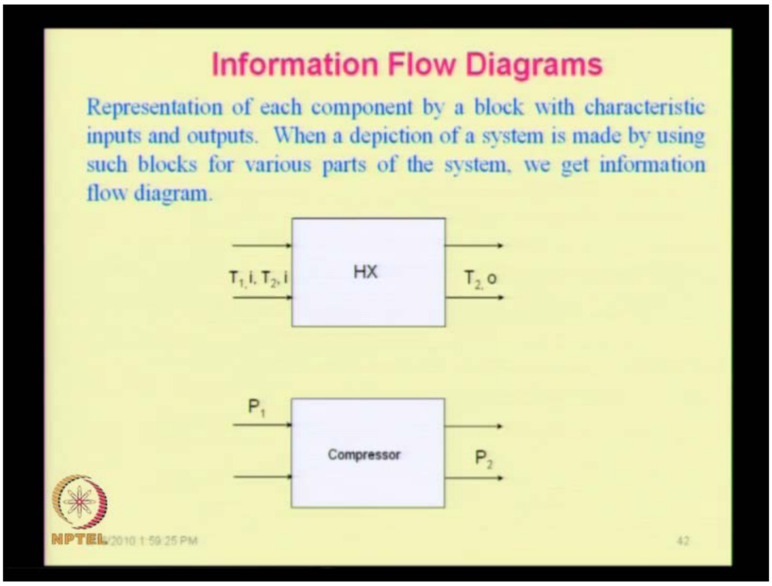

Information flow diagrams, the information flow diagram is a pictorial way of representing the, representing the performance, representing all the information, which is required for simulating the overall system by looking at the, by looking at the information pertinent to a particular component.

Now, this is best, I want to close this represented by a block. The information flow diagram is supposed to tell you what are the inputs to this block, what are the outputs from this block, what is a equation governing this component, that is information flow diagram.

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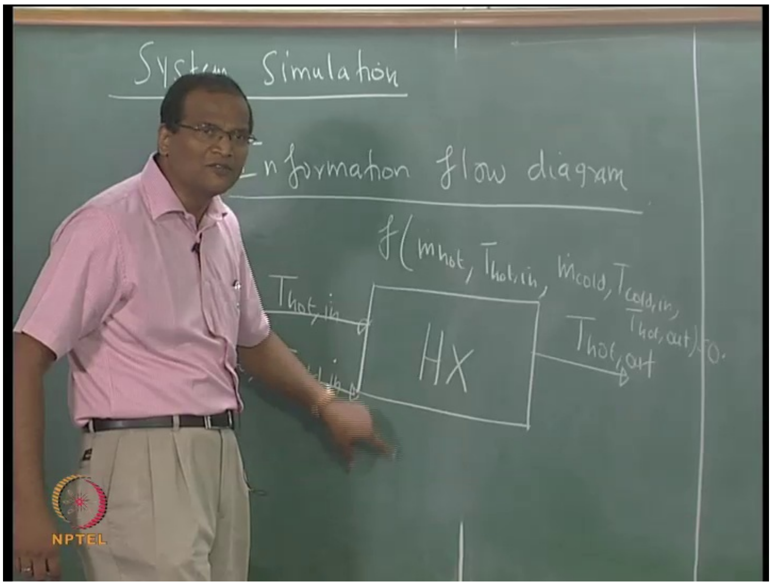

For a typical heat exchanger can you take a guess on what are the inputs and what the inputs are, what the outputs are? You already saw it there, but hopefully, you did not read it carefully. HX, heat exchanger, two fluids are involved, now tell me mathematically.

Student: (( ))

Flow rate, be more specific. The inputs to the… So, now we are looking at the information flow diagram of a heat exchanger. m dot hot, then?

Student: (( ))

What will be the output? T hot in, T, I do not have to put T cold out, because we have already fixed. How? T is already fixed by AC balance. So, the information flow diagram is (( )) in concise and precise. We do not say more than what is required.

What is the equation for equipment, we are saying this now, f of m hot, T hot in, m cold, T cold in, T hot out equal to 0. This is the general, generic depiction or description of the equation for the equipment. Can I get more specific for these equipments? Since you all studied heat transfer, what will be the f for this? What is the equation that is connecting all these variables?

Student: (( ))

Energy balance alone will not help man. These are designing heat transfer equipments.

Hit the, please hit the bull’s eye. What is the equation? UA…

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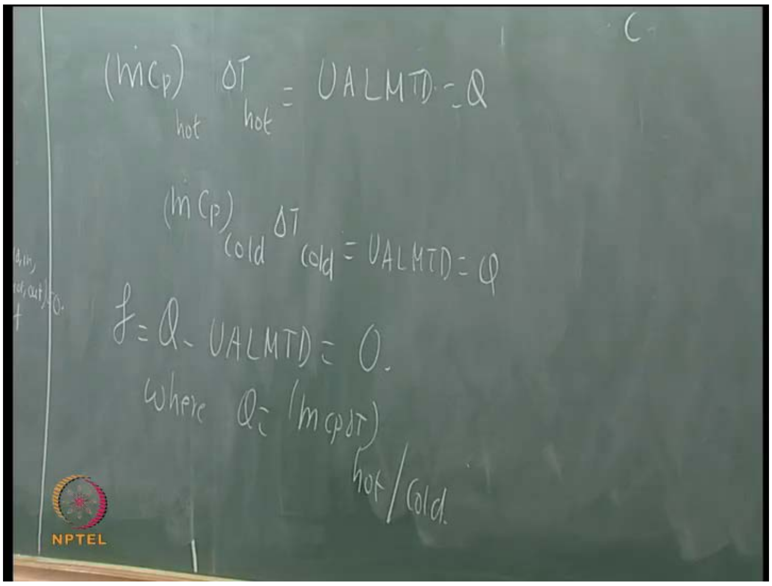

Student: LMTD (( ))

This is one equation, then from energy balance… So…

So, f equal to, so you can write the equation as f equal to Q minus UALMTD f equal to 0. So, actually do the system simulation. The goal of your system simulation is to make f 0 numerically or as close as 0 to possible. You will stop iterations when f reaches 10 to the, 10 to the minus 3 or minus 4 or minus 5. Are you getting this point?

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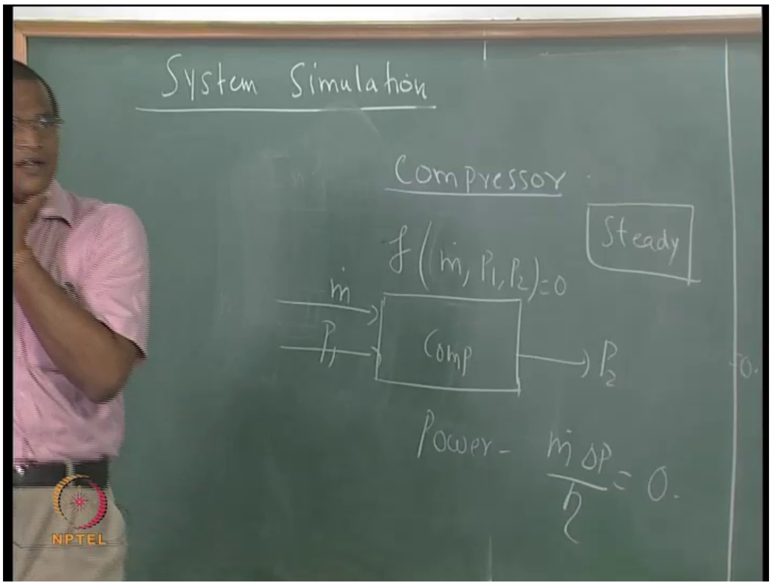

Now, compressor, please think for two minutes and tell me incoming arrows, outgoing arrows, the equation we will write f of and leave it. Compressor, only one fluid is involved, air compressor.

Student: (( ))

Mass and?

Student: (( ))

Correct, good, mass and pressure, so m dot, P 1. I need not put two arrows, m dot, because the same arrow is coming out. Why unnecessarily waste more arrows? Are you getting the point? What will come out? P2.

That is it, good, got the point. So, power equal to m dot.

Student: (( ))

Oh, sorry, sorry. Compressor, in the last portion the board is not visible to them, m dot. Are you doing steady state or unsteady?

So, f of, so I can just say, f of m dot, P 1, P 2 equal to 0. What is that f of?

Student: (( ))

Correct. And make a mistake, it is fine. You have a doubt, something is bothering you, Vinay what is bothering, please feel free, ask me?

Student: P 2 fix...

Yeah, you want to fix P 2, you want to know to, you want to, P 2 is fixed, right?

Student: (( ))

No, I, suppose I give different power what is the maximum P 2 I can get? Suppose I am looking at something like that, so and efficiency is also there. No, this is basically one component system, there is no fun in this, all this you have studied either in turbo machinery and thermodynamics and all that.

Please, draw the information flow diagram for a vapor compression refrigeration system. Question, please draw the information flow diagram for a vapor compression refrigeration system. So, we will close with this example. Please, the question is, draw an information flow diagram for a vapor compression refrigeration system. So, the first part of the story is, represent the vapor compression refrigeration system on PS diagram. Identify the various processes and the components associated with each of these processes, represent each of these components in a box and find out what is the link between the box; that is, what is coming in and what is going out.

The output of one component will become the input of some other component and this is called a sequential simulation because everything is going in one cycle. Are you getting the point? Turbine compressor is evaporator and so, it forms a... So, this is called a sequential, this is called a sequential arrangement.

Please go ahead, I will give you five minutes, please draw the PS diagram, you do not have to very too much of the, about the equation, you can just put f 1, f 2, f 3, f 4.

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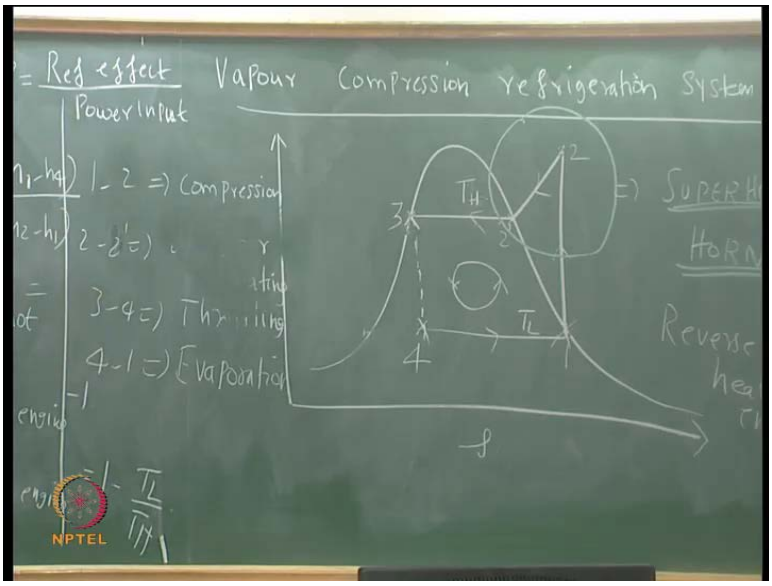

What is this called? Super heat horn. So, I will quickly explain the cycle, I told you modeling, in the syllabus when I gave you the course content I said modeling. So, to the extent required for this course, I will teach you modeling in between. So, I already told you little bit about pump compressor and so on. So, I will explain, I will give you three minutes course on vapor compression refrigeration system.

So, you start from point 1, point 1 is the fully saturated vapor, 100 percent vapor, no liquid. So, let us assume (( )) compression, its pressure and temperature has increased. Its temperature is such that the temperature is, the temperature is raised to a level at which it is possible for you to condense, that is, it is at a temperature greater than the surrounding. Now, there is a (( )) super heating, which takes place, then it becomes fully saturated, then it becomes fully saturated vapor, then it is condensed. Please remember the 2, 2 dash, 3 are taking place at the same pressure. Now it becomes a, it becomes a fully saturated liquid refrigerant. Then, it is throttled, throttled is an (( )), so 1-2, 2-2 dash de-super heating, 4-1 is evaporation.

Student: (( ))

So, it is an isenthalpic process. The basic job of this throttling is to ensure, that the pressure is decreased. When the pressure decreases automatically, the temperature also decreases here, the temperature decreases. Now, it is a, it is a mixture of liquid and vapor, which is at 4. Since, throttling is an irreversible process, you cannot take it from 4 to 3. 4 to 3 is so difficult because it is, it is impossible to design a pump, which will accomplish this objective, because it is impossible to do in a rankine cycle. We take it all the way here and then do this. You remember the rankine cycle? So, 4.

Now, you have got a cold refrigerant, it first enters the, it enters the, in the, for example, if it is, this can be used for both refrigeration, air conditioning. If it is a refrigerator, first it will enter the deep freezer, it will enter the deep freezer, then it will go to the chiller and milk chilling and places and all that. Then, it will come to the place where you keep vegetable and fruits and all that. It picks up the heat, it collects the heat from the food stuff, takes all the heat and vaporizes and comes to state 1 and cycle is repeated. So, the whole thing, we have an anticlockwise operation. Whenever there is an anticlockwise operation, there is an, it is a network absorbing cycle, it is a reverse heat engine.

And this performance is, can be stated in terms of the coefficient of performance. The coefficient of performance is refrigerating effect. So for 1 kg, can you tell me, in terms of enthalpy?

Student: h1 minus h4 by h2 minus h1

Invariably the COP is greater than 1. So, the COP carnot will be… Correct. Will be COP, the heat engine operating between, so let us say this is, I do not know, you have to call it as T i and T H and T L, 1 minus...

Now, we have to draw the information flow diagram for this. Is this clear, if we reverse the arrows, we reverse the direction of arrows you get a, you get a rankine cycle power plant. Correct. If you, so the rankine cycle power plant will be like this. So, if you do this, if you do this, it, it will be an extremely wet, it will be an extremely wet mixture. At the end of the, at the end of the expansion, more than, if it is less than 88 percent, it will cost, it will cost (( )) of the blades, therefore we super heat it and bring it. Now, it is possible for you, it is also possible for you and also possible for you to do this. So, this is basically reheat. So, you can have reheat, so you can have reheat, you can have reheat, regenerative cycle and so on. These are all complicated versions of the more complex, more complex version of the rankine cycle power plant.

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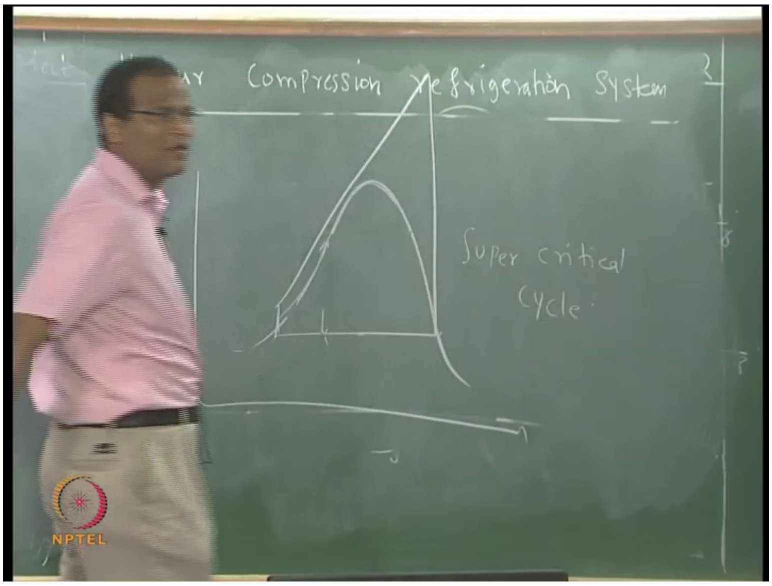

So, basically the idea is, you have got to do this because nobody invented a pump to do this and some, some people may be having an idea, why can we do like this, what will be the pressure here. Then, if this produces x, this will (( )). So, sometime you have this, what is this? Super Critical…So, in the in the tube itself, the water directly becomes steam.

The funda here is the efficiency. The efficiency is a strong function of two temperatures, one temperature is the heat at which the temperature, at which the heat is rejected and the temperature at which the heat is added, the temperature at which the heat is rejected is not under control, because it is basically ambient. But the temperature at which the heat can be added is under your control subject to whatever is allowed to be material scientist. Therefore, all this cycle, basically the funda is, they exploit this and they try to increase the mean temperature of heat addition, the mean temperature at which the heat is added. If it is increased, the efficiency will increase.

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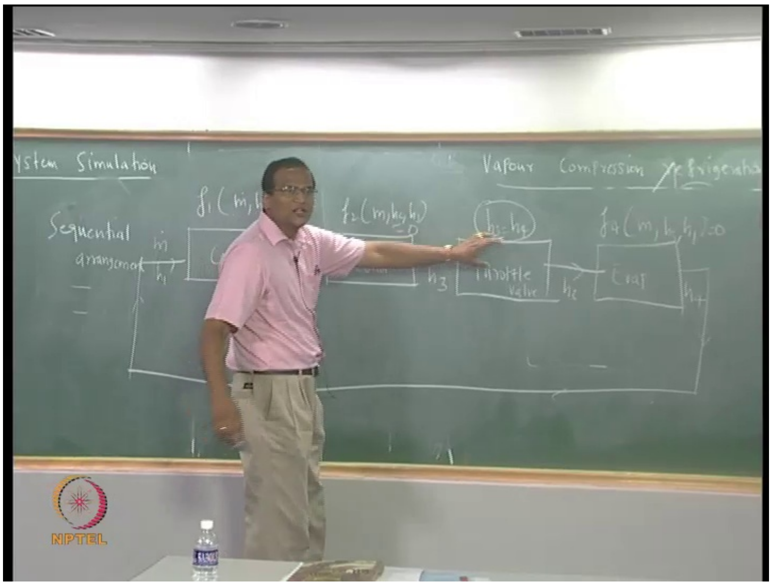

So, so, compressor, condenser, throttle valve, evaporator and it comes back right. m dot no, T 1 will not work here, h 1, h 2, h 3, h 3, good, h, that is it. So, here the equation will be f 1 of m dot h 1.

There is no big design of this equipment, right, so. Sorry. So, this is called a sequential arrangement. The output of one becomes input to the other. Any problem? Some people do not like h 4, if you want to be threateningly formal you can still use h 3. So, this is sequential arrangement, where the output from one component becomes input to the other component, everything is linked.

Now if you know all this equations, these equations will come from the manufacturer or if you got the data for various values of what is the performance and all that if you know, f 1, f2, f 3, f 4, you can write, you can put all this together, write your script and simulate these vapor compression cycle on your Matlab provided if you, provided you know the properties, enthalpies at all temperatures and pressures and then you can start, start playing with the variables and try to find out when your system is working well and all this. And then, you can define a objective function, cost and optimize and so on.

So, you can use (( )) tool of Matlab, which can be used to simulate more than one component. So, if you are doing the B. Tech project, M. Tech project, MS or PhD in system, system design and system design analysis and optimization, I encourage you to learn the (( )). There is also something called (( )). (( )) software also does all this. I stop here.