Design and Optimization of Energy Systems

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Lecture No # 05
Information flow diagrams

So, we will continue with the discussion on information flow diagrams. As I have already told you, drawing an information flow diagram will help you before you start the system simulation. Though it may not be required for simulating systems with just two or three components, either if the number of components is exceedingly large or there is a, this is too much of coupling between all the components of a system, which you will, which you will understand by an example I am going to discuss in a little while. So, in, in these cases, so it always helps to draw, to draw an information flow diagram. So, I just give you a problem on information flow diagram, please takes this down. So, this is the problem number what?

Student: (( ))

Problem number 1, is it?

Student: (( ))

3, ok, let us say problem number 3. A closed plastic container, a closed plastic container used to serve coffee in a seminar hall, a closed plastic container used to serve coffee in a seminar hall is made of two layers, is made of two layers with an air gap between them, with an air gap between them. List all the heat transfer processes, list all the heat transfer processes, list all the heat transfer processes, associate, associated with the cooling, associated with the cooling, list all the heat transfer processes associated with the cooling of the coffee, with the cooling of the coffee in the inner plastic vessel, in the inner plastic vessel. Draw an information flow diagram for the system. What steps will you take, what steps will you take for a better container design, what steps will you take for a better container design, so as to reduce the heat loss, so as to reduce the heat loss, so as to reduce the heat loss? Ok.

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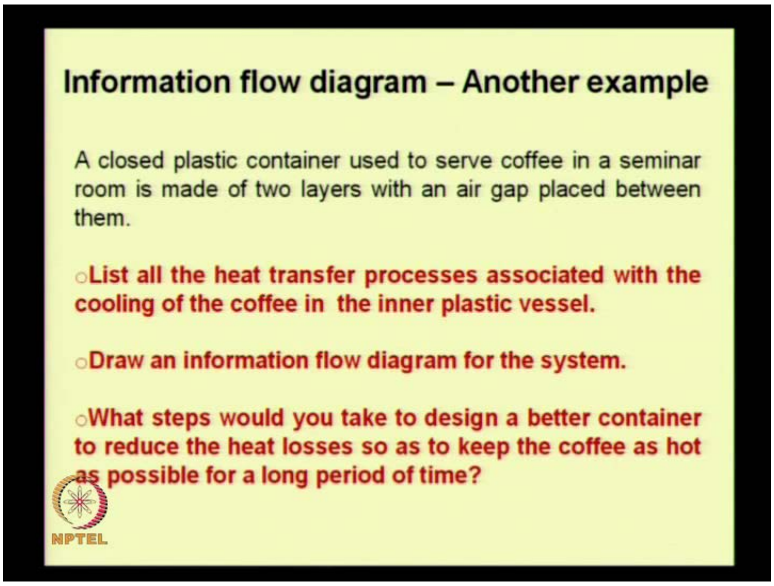

The same problem has been given. So, I have asked three questions basically. The first part is, list all the heat transfer processes; second part is, draw an information flow diagram and the third part is, what steps should be necessary or what steps should be required to ensure, that the copy is the, the coffee is kept as hot as possible for a long period of time.

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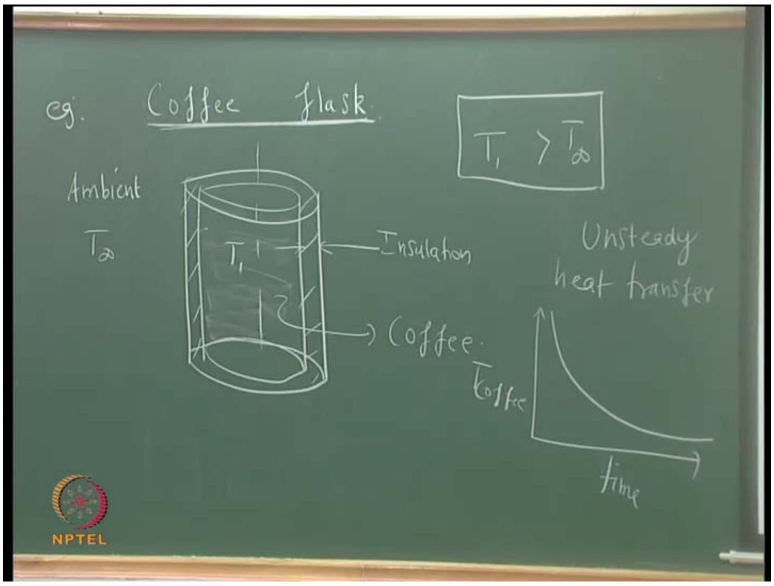

So, do not worry about the free convectional, free surface and all that. Let us assume that it is fully… Is it a steady state problem or unsteady problem? Is it a steady state problem or unsteady problem? Unsteady problem. Assuming, that the coffee is well mixed, there are no temperature gradients within the coffee, so the temperature of the coffee, how is it expected to vary? Decrease, that, that we know, exponentially, ok.

Student: (( ))

They will have a thickness, yeah, make it as complicated as possible and so, so, so let us say in a plastic vessel

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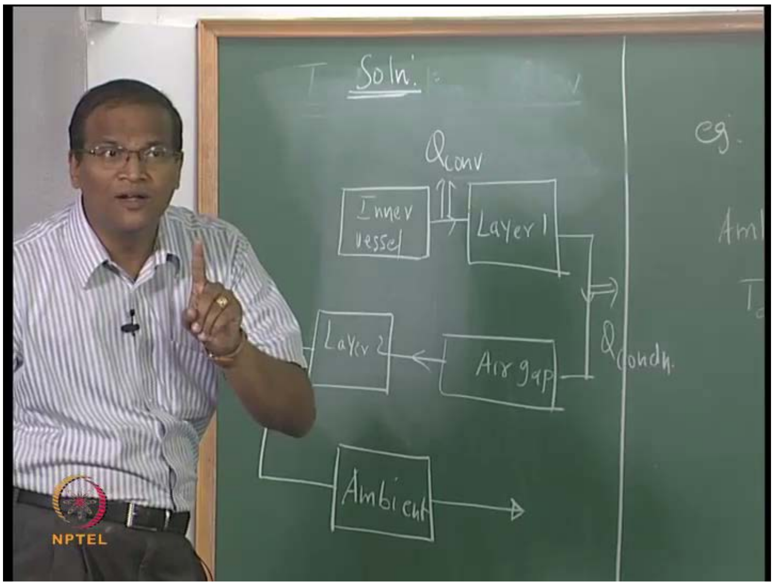

Shall I give some more time or are you through with this?

What did I say apart from this? A closed use is made of two layers. Ok, so, there is an air gap, right.

What is this now? Ambient, ok, it is a one way path or a two way path. Now, I have constraint of space, that is why, I went in for a zigzag. You can just start from left and go to right and start from top and go to the bottom ok.

So, now what are the heat transfer processes associated? Inner vessel to layer 1 let us, ok, Q convection. Radiation, radiation of coffee possible? But I think coffee, if coffee is consisting of 90 percent water, it is highly absorbing and I do not worry about scattering and Raman's spectroscopic effect and all, ok. So, let us forget about that. So, layer 1 to layer 2, layer 1 to air gap, not convention, conduction, correct. Air gap to layer 2, air gap to layer 2? Natural convection, ok, yeah. So, layer 2 to ambient layer, 2 to ambient, no conduction, convection and radiation, correct, ok. So, this is T coffee or T 1, whatever.

Student: (( ))

No, there will be some natural convection, right.

Student: (( ))

Then, you want to consider conduction within the layer. I just, just leave, that is what I, if you want you can consider. So, I am trying to make it simple, you can make it complex if you want. Now, let us answer the more important question, inner vessel to layer 1.

Some people say, that there would not be any convection, what is your opinion? There could be natural convention, but where are the temperature gradient. We assume that.

Student: (( ))

No, no, no, no, see, but that layer, the layer will come to temperature, which is between the coffee temperature and the outside. So, if the temperature difference is sufficient to cause velocity, which is greater than 0, then it is possible for you to have Q convection. So, you can say Q convection store Q conduction without any, without any loss of accuracy or whatever. Is that fine?

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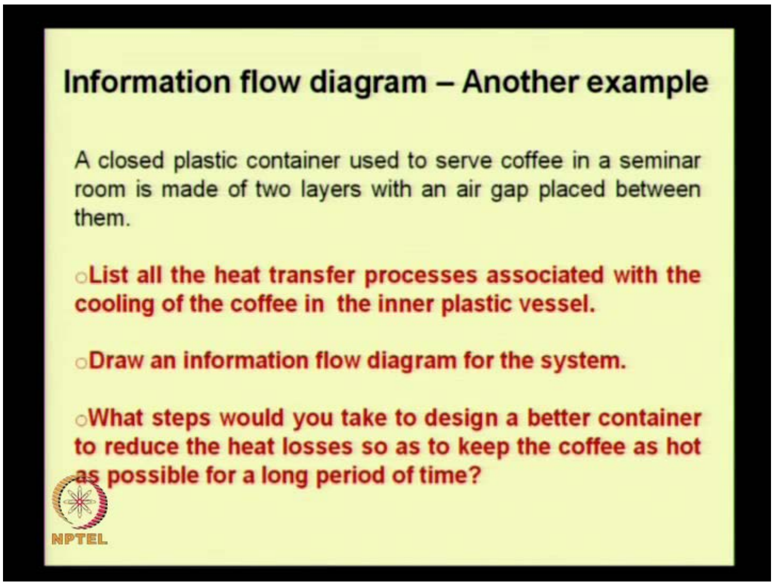

Now, so, list all the heat transfer processes associated with the cooling of the coffee in the inner plastic vessel. So, you can think, you can now imagine very apparently silly and simple problem like this. So, many heat transfer processes associated with this. You can write a differential equation and put it on Matlab and try to solve and whether it is required or not is another matter, but it is possible for us to model.

What you are trying to do is you are trying to model this even before you start the simulation. So, modeling precedes the simulation and the simulation precedes the optimization. This is the story we are going to, this is the, this is the story we are going to look at throughout this course: modeling, simulation, followed by optimization.

Now, the T of the coffee is generally not under our control. We, we do not want to make it too hot and this thing, you cannot overheat the coffee, so that it gets spoiled or ok. Water boils at 100 degree centigrade at 1 atmosphere pressure, correct. So, probably the coffee temperature will be 60 or 70. What is temperature at which you drink the coffee?

Student: (( ))

50, ok, it will be around 45 or 50 degree centigrade. So, probably we keep it at 55 or 60, so that it, so it stays on for some time. Now, the ambient temperature is 30 or 35, both are not under your control, right. Now, we have drawn the information flow diagram. Of course, we have not written the equations, you can put f of thickness, this thing and h n and whatever, let us not worry about that, we are looking at step 3, but before that Raghav has a question.

Student: (( ))

What? That layer I am considering, all this. Heat loss on the top will be there, ok. Yeah, what was he saying? So, what are the steps, which would be, which you would take (( )) better container to reduce the heat losses, so as to keep the coffee as hot as possible? Yeah, what can you do now?

Student: (( ))

Mirror

Student: (( ))

Reflect heat, what is this, (( )). What are you saying? We cannot reflect heat at all.

Radiation we are not considering, the radiation inside, inside, ok, the outside of the container can be highly polished or whatever. So, it is dull, I mean, it is highly polished, so that its emissivity is very low. Ok.

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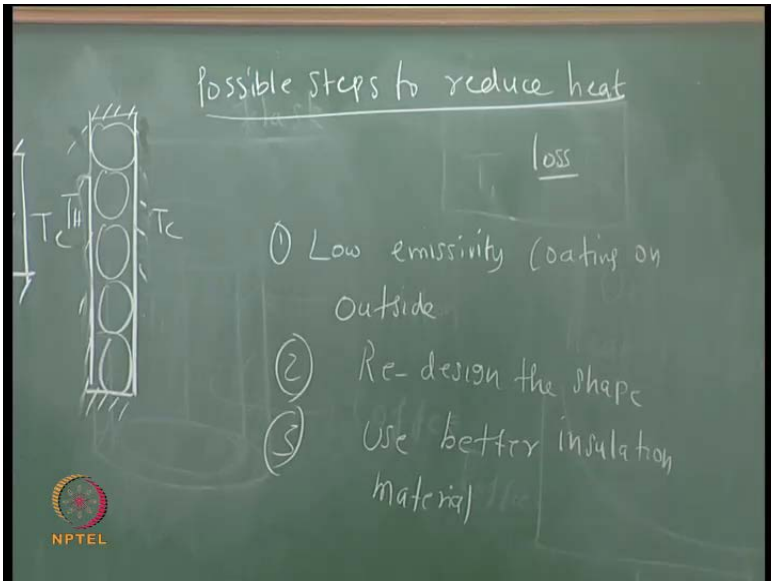

So, possible steps, for the same volume we can make it, we can make it a tall container, one second, we can make it a tall container, so that the, what happen, so that the air layer actually consists of slender and tall, it actually consists of slender and tall layer, so that you reduce the natural convection. Are you getting the point?

So, if you consider, so if you look at the natural convection, if you have a cavity like this, so there is a close cavity, there is heated wall on the left side, there is a cold wall on the right hand side, top and bottom are (( )). So, if this gives some amount of heat, the same thing, suppose if you have do like this, no, sorry. Now, what happens? This, this results in, what is called, multi-cellular pattern.

In your multi-cellular pattern, there is a resistance with flow of heat and therefore, the convective heat transfer reduces. So, redesign the shape, use better insulation material and so on. Are there any other point, any other points?

Student: (( ))

Yeah, if you can do that, that is a vacuum glass or whatever. So, try to maintain vacuum. By the way, the air gap to layer 2, you can also have radiation, right, correct. Actually, we start probing deeper and deeper, then this problem itself gets messier and messier. What we will have to leave it at some stage, there is a question you thought about the radiation, vacuum. So, these are some of the, so these are some of the steps, which can be taken. I have already told you whatever is critical, whatever is required in order, that you, you will be able to write a computer program, that are known, is required.

Student: (( ))

Temperature, no, no heat, the rate of change of temperature with time, that is what, you want to model. The temperature is an input, the initial temperature of the coffee is known, but the temperature of the coffee at various instance of time t is you are unknown in the problem, ok, that you want to model. Are you getting the point?

Student: Sir, the temperature of the coffee is a function of time. It depends on all the boxes, so how is it, as in, how can you say information is flowing in one diagram? (( )) is being affected by the things, which are there…

It is ok, everything, but I am saying, it is not a, it is not a, there is no feedback loop because inside is hot, outside is cool. All the heat is going from inside to outside, there is no question of something coming back. Are you getting the point? No, this is different from the vapour compression system where we again, from the pump, the loop is completed. Here, there is no refrigerant or something, which flows continuously. So, that is the difference between that, between a sequential arrangement and, and an arrangement like this.

Let us consider one more problem and then we will close the discussion on information flow diagram and we will proceed to system simulation.

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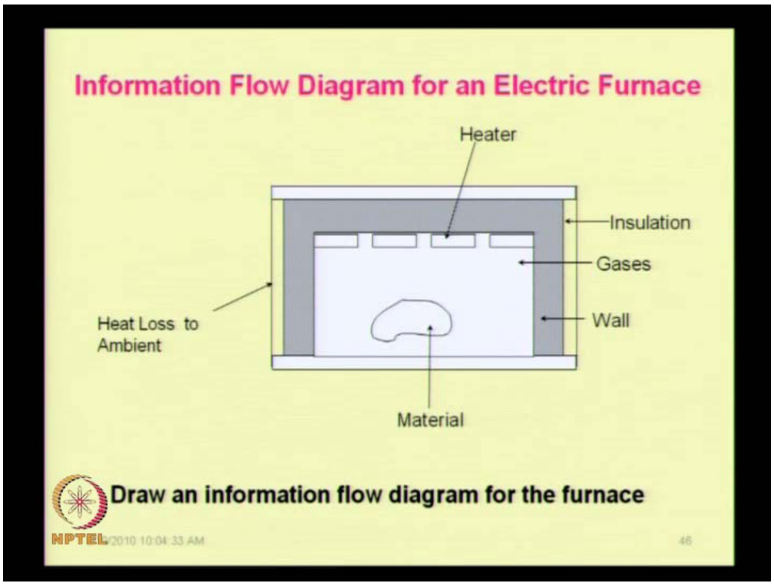

Yes, please take down this diagram. So, problem number 4; consider an electric furnace as shown in the figure. Problem number four, consider an electric furnace as shown in the figure, draw an information flow diagram for the furnace. Consider an electric furnace as shown in the figure. Draw an information flow diagram for the furnace.

So, I quickly explain the situation to you. So, this is the furnace, there is a material, which is kept inside, which is got to be heated. The heaters are placed, strip heaters, radioactive, which will radioactively heat the material and it may also convectively heat. I am not going to give you all the clues. So, these are all pasted on the, these are all pasted on the top wall of the furnace. So, there are gases inside, which separate the material from the walls and also from the heater you have got insulation, you have got a wall and then there is insulation. So, material heater, wall, insulation and finally, there is heat loss to be ambient. Now, please draw an information flow diagram for this. Please take 5 minutes, I hope you have got the solution.

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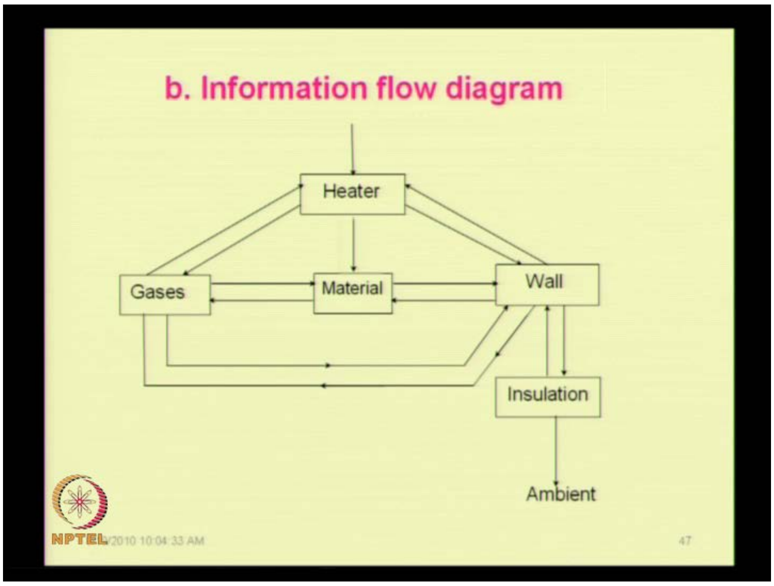

This is the solution to the problem. So, please, so, we will have to write, you have to put everything in the form of blocks. So, you have got the material, you have got the heater, you have got the gases, you have got the wall, you have got the insulation, you have got the ambient. Since radiation, see radiation does not necessarily flow off from the body at high temperature to the body at low temperature. Any body, any body, which is at the temperature greater than 0 Kelvin, there will be a radioactive transfer, so there always being dynamic equilibrium. So, whenever radiation is there you have to have a two way arrow.

So, if you look at the material, so material, material to the gases or from the gases, material to the wall or from the wall, from the heater to the gases or from the gases heater to the wall, but heater to material can also be there, right. I am, so one arrow is missing, probably you should have an arrow here. From the wall, again you can have to the gases, correct, and then from the wall to the insulation, but there, there is no need for a two way arrow, right, so because from the wall, wall will be hotter and from wall to insulation and from insulation to the ambient.

Then, you have to write down the governing, you have to write down the governing equation for each of these components and we can model and then you can find out the temperature response, response of the material with respect to time if you solve this equation given the initial condition. If it is a lump capacitance model, then if the temperature of the material is only a function of time and not a functional spatial coordinate, you can solve for the temperature as a function of time and with the given initial condition you can march in time and find out the temperature as the function of time. Is that ok?

So, this is, this is the first step once problem is given. But you would draw an information flow diagram and identify all the processes, then give the mathematical equation for the various processes, model them and then you can go in for the simulation, alright.

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Now, we will start with the system simulation. So, basically, one component, so you can have one component system which is pretty straight forward. Then, you can have a two component system, then n component system. For the purposes of this course we will handle, we will deal with only one component and two component systems. It will be very difficult for you to solve a system consist consisting of more than two components.

Now, system simulation may mean solving a set of equations, which can, which control, which control the phenomenon, which is, which is taking place. If the system consists of more than one component, then you have to assemble the equations, which govern the performance of or which govern the performance for each of these components. Now, this can be at various levels. You can have just algebraic equations, which give you the performance of the system or this can be governed by ordinary differential equation or this can be governed by linear partial differential equation or this can be governed by non-linear partial differential equation.

If you have got equations of fluid flow and heat transfer, that is, Navier-Stokes equation, equation of energy, if you consider a participating gas, if you want to model the atmosphere, if you want to model the radiation through the atmosphere, you have to consider the equation of transfer in the atmosphere, which is called RTE, radioactive transfer equation, which becomes an integro-differential equation. So, you can just start our system simulation and hijack the course completely towards in mathematics.

But since differential equations, partial differential equation, how to solve the Laplace equation, Laplace equation, how to solve a Poisson equation, what is (( )) theory, I have taught elsewhere, we look at only algebraic equations where the focus is on assembling of more than one component. That will be the focus, otherwise system simulation itself, whatever I am teaching is, is far from being complete because if I have to teach you really system simulation up to partial differential equations. Now, linear partial differential equation I have to go, but that it is not central to the theme of the course.

This course is a course on optimization, but to do optimization you have to do simulation, in order to do simulation you have to solve the system of equation. So, if you spend lot of time in solving the partial differential equation, then you will get lost. So, we will, we will restrict our attention to generally algebraic equations and to add a little spice will make them non-linear algebraic equations. Because many of the components, for example, if you have a compressor, turbine and all this, this, the performance can be related, the dependant variable can be related to independent variable in terms of simple non-linear algebraic equations. So, with that in mind I will teach it basically two methods.

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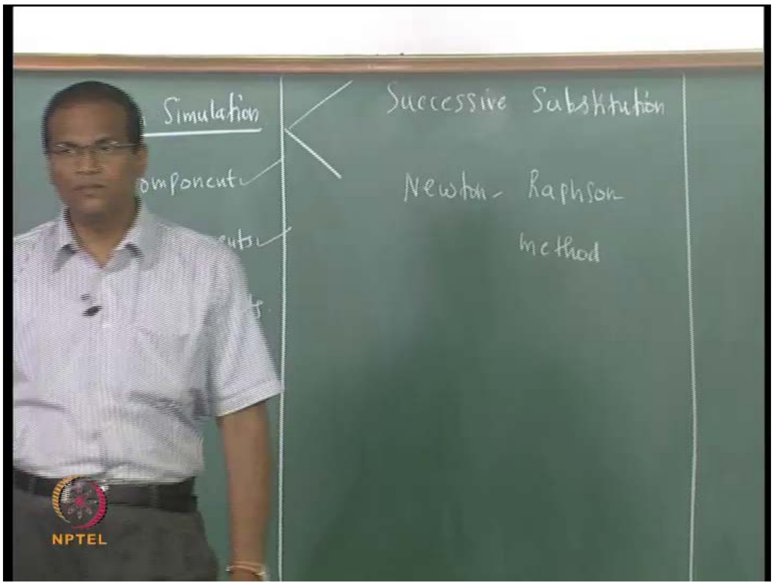

Successive substitution; successive substitution.

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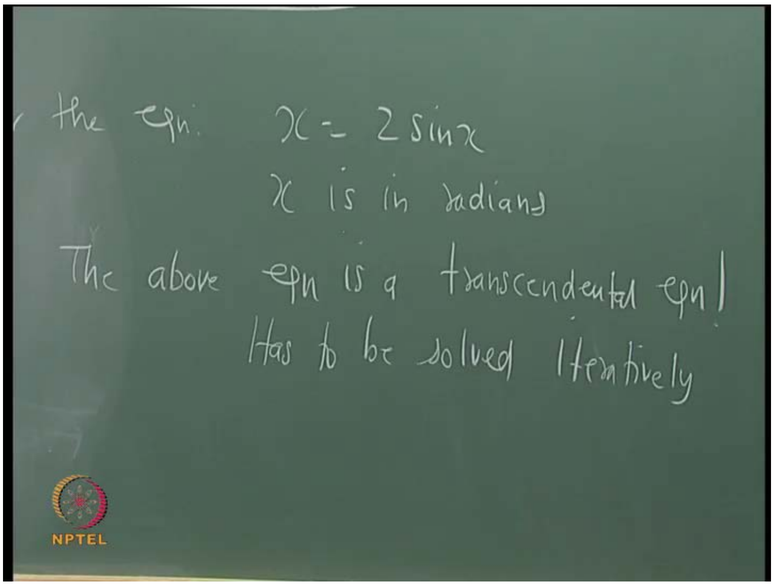

Consider an equation like this. Consider an equation x equal to 2 sine x. Can it be analytically solved? Can it be analytically solved? Is it a linear equation? Is it a quadratic equation? What sort of an equation is this?

Student: transcendental

It is a transcendental equation, has to be solved iteratively.

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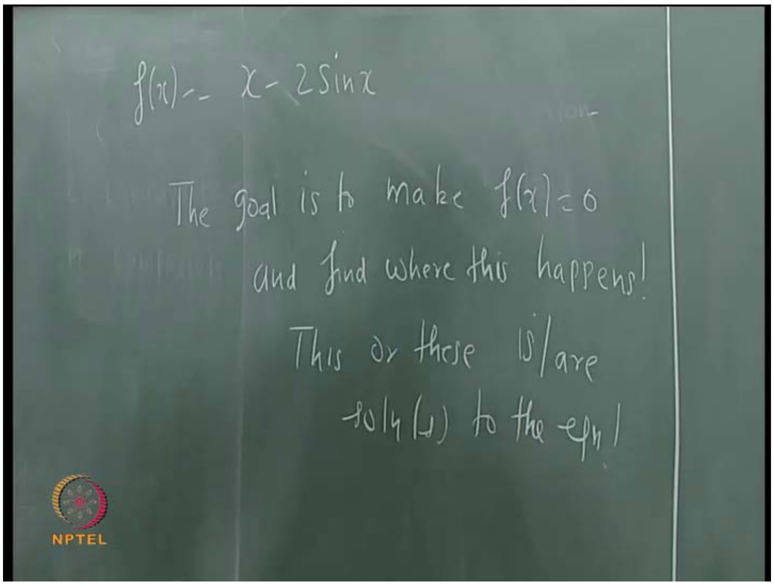

So, you can write, rewrite that equation as f of x, you can write the, rewrite the equation f of x equal to x minus 2 sine x. So, the goal is to make f of x 0 and we have to determine where this happens. This or these is, are the solutions or solutions to this problems.

If you want to do successive substitution, so if you want to do successive substitution, you have to write an algorithm for this, Correct. You have to write an algorithm for this and then, either do hand calculation with your paper pencil and calculator, or go to the computer and do it. What will be the algorithm for this?

Student: (( ))

That is why, they (( )) doing it. Yeah, it may work, but you have to get little more threateningly formal. How do you write the algorithm? Make a guess, write in terms of mathematical, right. Hit the bull's eye, that is Newton-Raphson method, you learn from some other course, I am asking about successive substitution.

How do you write the algorithm? Chose an arbitrary (( )) everything, write the algorithm, this is the algorithm.

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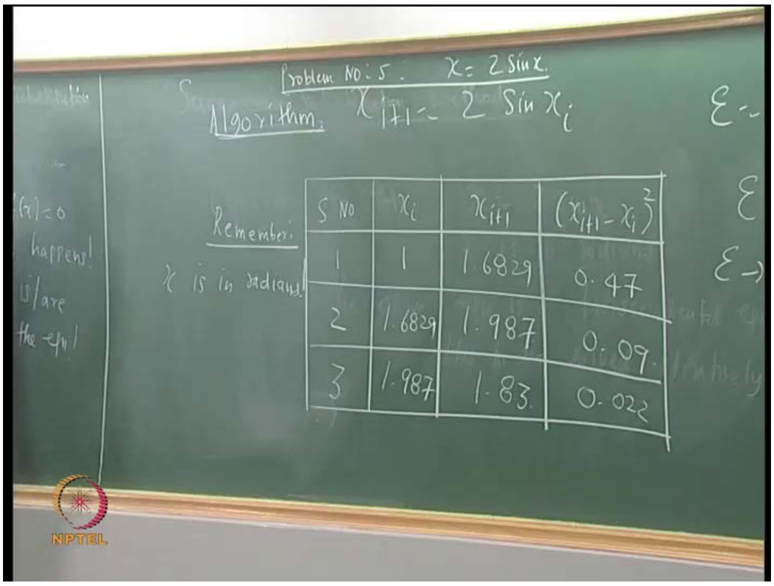

So, start with x 1, get x 2, start with x 2, get x 3, start, where do you stop. So, so this is the algorithm. So, I can put serial number, this is the iteration number x of i, x of i plus 1, then this is some kind of a norm. So, whenever the 4th column goes on to a reasonably small value, I can stop my iterations and I can be happy, that I got the solution and then I can go home. Solve this now.

When x is in radiance, please solve this, take an initial guess x i. I will give u 5 minutes. So, we start doing the iterations. So, we start with the value of 1, please remember.

So, x is in radiance, so let us go to the 7th or 8th iteration is, there somebody already got the answer, tell me the iteration number.

Student: 8

Good 8.

Student: 1.902

90

Student: 2

1.902.

Student: (( ))

No, no, this 1.

Student: No, that is…

Yeah, with 1 point you do again, Abhinandan do it again.

Yeah, norm is, so this is called the norm.

1 into

Student: (( ))

So, as you can see, as you can see, after a few iterations the method of successive substitution works, but the problem is if there is a function, which changes very rapidly, then there is a possibility, there is a possibility that the method of successive substitution may miserably fail. So, when the gradients are very sharp and so on. So, if you start with the wrong guess, then you may end up with the wrong, you may end up with the, with the solutions, which diverges, I mean, we are not able to proceed further.

So, the method of successive substitution is not a universal cure, it is not a universal panacea where you can solve all problems of this, but simple problems can be solved with the help of the successive substitution. So, I would like to demonstrate this with, can I get with MS-Excel. Somebody said we will use that (( )) technique. We will, we will list x, we will draw two curves, that is what I am doing now graphical, you can do for only two variables. I mean, if there are, if gets…

Successive substitution can be used for any number of variables. Are you getting the point? I will teach you, from one equation you calculate x 1; the other equation, you calculate x 2; from this equation you calculate x 1, you go back.

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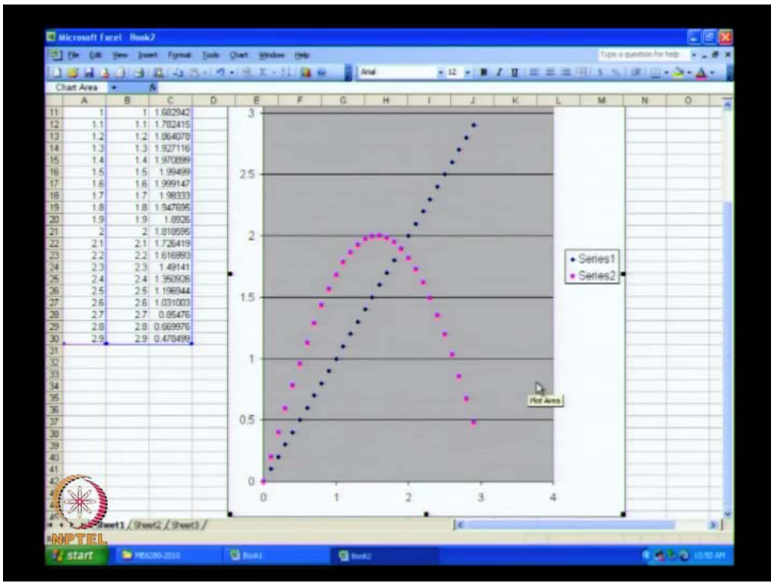

So, there is a way to automatically get point one, point two, point three and all that right, ok, good. So, what is the first equation is equal to?

Student: (( ))

Correct, it is all radiance only, there we are. So, this is the solution to the problem, this is what he said. So, it is possible too. I should not compare. So, so it is possible to solve graphically. So, this is what we ask lot of, this, this, ask, this is what we ask the students in the viva voce and interviews and all, that they are not able to. Suppose I say, x equal to 2 sine x, how will you solve it graphically? I mean, they do not know, we, we usually say x equal to 2 sine x, solve by any method known to you. Successive substitution is one, you can plot and also, but this fellow will go up and down like this, right. This fellow will go straight. So, they are probably, how many solutions are there?

Student: 3 (( ))

Yeah, ok, if x is positive there are two solutions. Of course, the trivial solution is x, x equal to 0, if you put tan x and all that, it will become more dicey. So, this is a good, this gives an idea how the method of successive substitution works. The same problem can also be solved using a Newton-Raphson method, which we will see in, in the next class.

Now, I will stop here. In the next class we will take a heat transfer problem and use the method of successive substitution and then we will go to a problem where we use successive substitution for a system consisting of two components, which is directly related. For example, piping and duck system, ok, piping and fan.