Design and Optimization of Energy Systems

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Lecture No. # 02
System Design and Analysis

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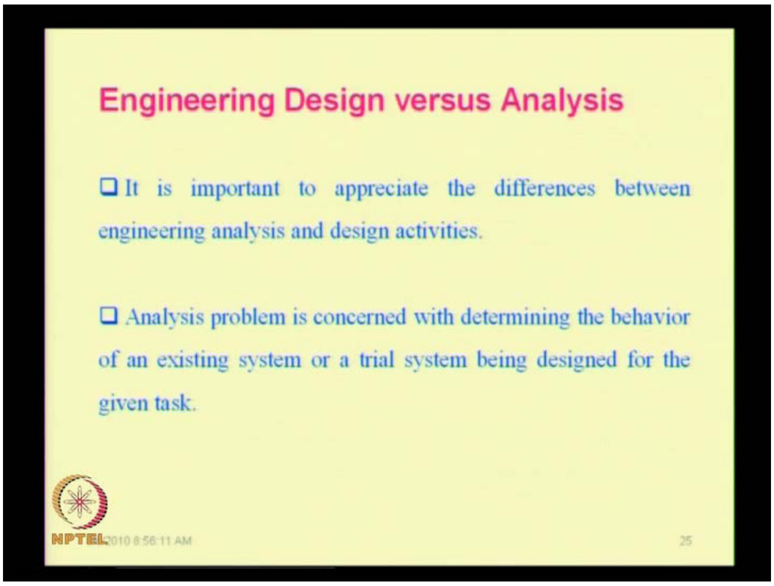

Good morning. So, continue with the lectures on introduction to optimization. So, in yesterday's class we looked at the morphology, anatomy and stuff like that of design, what are the various activities involved in a typical engineering process of undertaking and so on. Now, we will get little more specific and slowly we will begin to insert math into the course. After sometime, it will be, it will be just Applied Maths. So, we will, we will solve lot of problems, but all this problem should be concerned with energy systems or thermal systems.

What is the difference between engineering design and analysis? I think, at this stage it is important to recognize the differences between design and analysis. Analysis problem is basically concerned with determining the behavior of an existing system or a trial system that is being designed for the given task. Let us, let us look at an example.

So, what is this? I will draw on the board, I think people can take down, people who came late, as I keep talking, you take this down. It is basically, essentially, a steam condenser. On the shell side, you have steam entering, then it condenses and hot water comes out.

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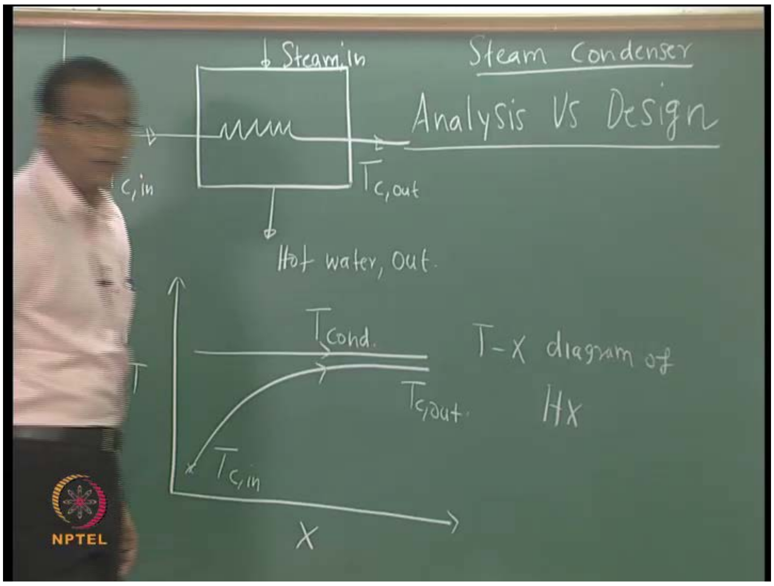

As you know, this will be an isothermal process. As far as this, as far as the steam on the shell side is concerned, so this condensation is accomplished by sending cooling water. The cooling water will, will enter at a temperature of T c, in and will go at a temperature of T c, out, which temperature will increase. This basically is called the T-X diagram of heat exchanger.

So, it does not matter whether it is a parallel flow or counter flow because one of the fluids exchanging phase. This problem, there are several ways of, there are several ways of working this problems out. One possibility is, one possibility is I want to condense, I want to condense m kg of steam, which is at particular temperature and pressure into m kilogram of water. Now, I have cooling water at 30 degrees or 40 degrees centigrade, now I want to come up with design of a steam condenser.

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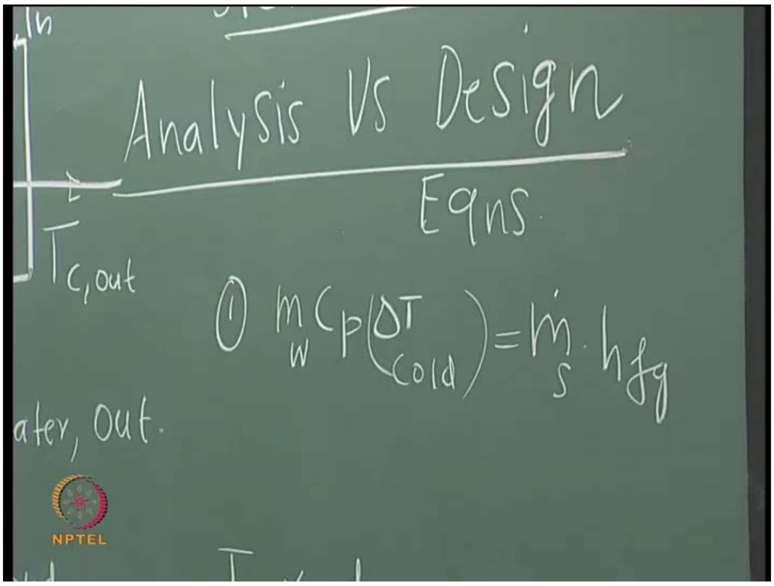

So, how we go about designing this?

Student: (( ))

Energy balance alone is enough? Is energy balance alone enough? What are the equations? What are the equations? m C p delta T of cold will be equal to…

Student: (( ))

m s, m water, correct, this is just energy balance. It is energy balance, you cannot design the, you cannot design a heat exchanger, are you getting the point? So, that is a limitation of thermodynamics.

Thermodynamics, will tell you what are the temperatures, what are the resulting resultant temperatures and how much of heat will be transferred eventually between the hot fluid and cold fluid, but thermodynamics does not tell you, what is the area of the heat exchangers. Heat exchanger, which is required for accomplishing this task, that is the, that is why you study thermodynamics first, then you study fluid mechanics and then you study heat transfer and then you study optimization. You choose to study optimization now.

Is this enough to… is it enough to design the heat exchanger, for example? What do you want to find out? I want to tell the design solution will be, how many tubes are required in a shell (( )), what should be the size of the shell, what should be the diameter of the shell, whether you will have a, whether will, whether you will have a U tube kind of situation where it has several passes for example, will everything go like this or will it go like this, accordingly the, accordingly the diameter will get reduced and so on. So, there is an issue of surface area, how much surface area is required for accomplishing this, what is the equation for this.

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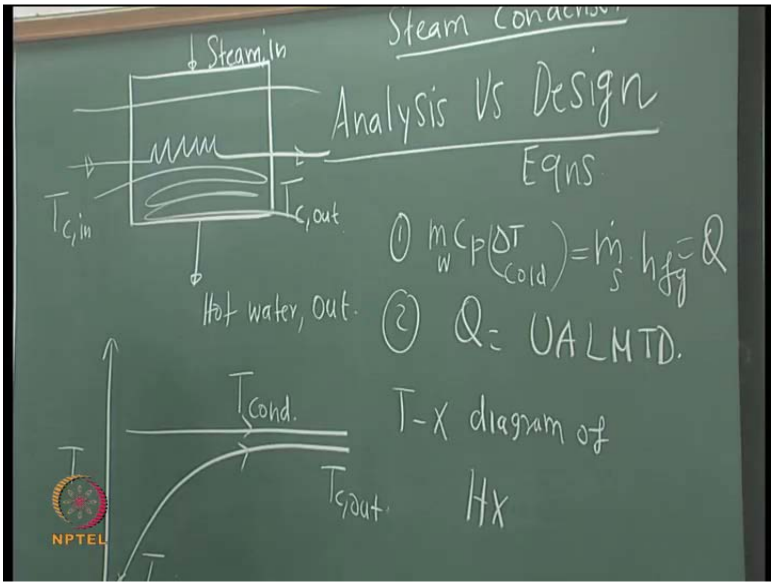

What is this? Basically, the Q of the heat exchanger, it is called the heat duty of the heat exchanger. This Q will also be equal to, this Q will also be equal to UALMTD, where LMTD is logarithmic mean temperature difference, U is the overall heat transfer coefficient, A is the area available for the heat exchanger, area of the heat exchanger, which is directly related to its cost.

So, the analysis problem is, watch very carefully, the analysis problem is like this. I already have a priory some heat exchanger available, some condenser available with me. I want to study its thermal performance, so for the analysis problem, I, I either have a new heat exchanger or either have a second hand heat exchanger or I am getting it from web (( )) the details of the heat exchanger.

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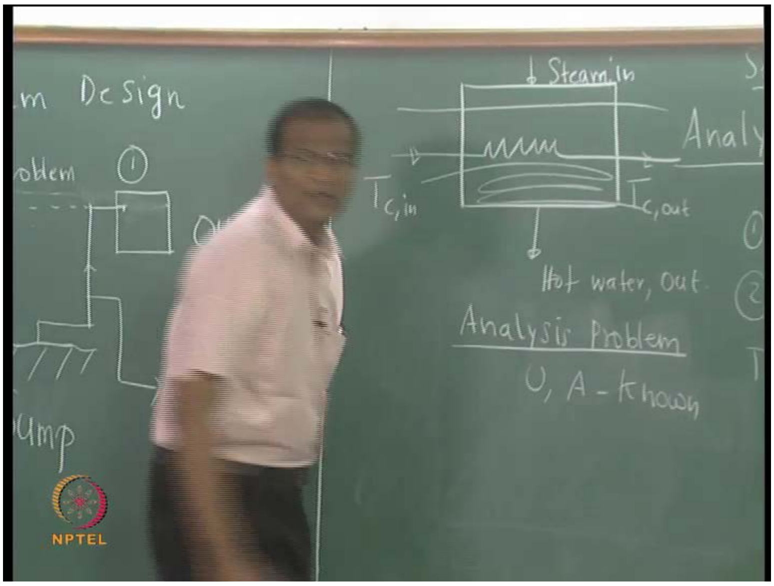

Now, I am going to see if this heat exchanger is used as a steam condenser for the following pressure and temperature what will be the thermal performance. What you mean by the thermal performance? What will be the temperature rise of the cold water for example? That is one thing, which have, that is basically analysis, there is nothing like design, I am not trying to come up with the design of equipment. So, this is the analysis problem.

U A is known, if U A is known there is nothing to design. You do not design that outlet temperature, you analyze and find out what the outlet temperature is, but you design the area, how that area, how you will get, how you want that area to be, whether it is a plate heat exchanger or you desired cylinder tube heat exchanger. How many numbers of tubes, what type of tube, what with thermal coefficient, heat transfer coefficient, how this heat transfer coefficient will vary with time. Why will, why will the heat transfer coefficient will vary with time?

Scaling, scaling and which is called fouling, because of that there will be buildup of this biological matter and all these things, because of which the resistance of the heat transfer increases. The resistance of the heat transfer increases, the heat transfer coefficient will exponentially decay with time.

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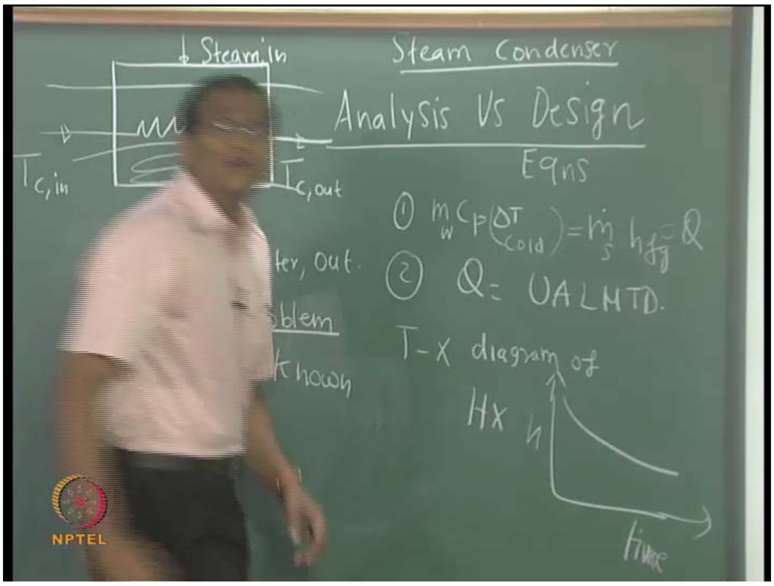

Therefore, you may have a situation where you will have H, which is going like this. So, design of heat, heat exchangers or design of heat transfer equipment for life is not such a straight forward task. Suppose, you want to design it for 15 years, you have to consider all this. There may be something like, there may be something like, what is known as, asymptotic fouling factor Eventually, it will settle down to a fouling factor, that can be obtained by doing calculation and so on. Are you getting this point? So, design will involve all this.

The straight forward problem, which you have learnt probably in ME 317, that is the heat transfer course or the (( )) for M.Tech and PG students will learn heat transfer course, heat transfer elsewhere. Basically, they will give you all the dimensions and you will have to work out. So, sometimes it is very tricky because LMTD is the logarithmic mean temperature difference. So, you will have to go round, round, round, round, round in order to get that thing. So, you have to use tedious iterations to get this temperature. You do not realize importance of what I am saying till you encounter quiz one.

So, it involves tedious iterations, but of course, all the equations are there. You can get, you do not have to put that much of a fight, you have to put little bit of a fight, you will get, you will get the result. So, this is the analysis problem.

What is the design problem? You want to design a steam condenser for the 500 mega watt fast breeder reactor plan coming up in Kalpakam. It is a practical problem, they are doing it now in India. We will have the plant in the next 2, 3 years. We will have the 500 megawatt plan or a 1000 megawatt plan, whatever. Now, you know the conditions, the pressure and temperature of the steel.

So, you know, basically you know the temperature of the cooling water, you go and get the cooling water from the sea, so how do you go about designing this? Can you take water at 30 degree and sent it out at 80 degree? What is the problem? Thermal pollution. So, there is a limit, there is a cap on the maximum delta t, which is allowed. What is that value? 5 degrees, it is about 5 degrees otherwise it is green, the green activists will cry. Even otherwise, severely disturbs the aquatic life if the delta t is more than 5 degree. So, the constraint is already coming up in your design, there is 5 degrees you are allowed, only 5 degrees.

Of course, the sky is the limit. You can have an infinite flow rate, what will be the size of the pump? You can have a beautiful wonderfully green design, delta t is only 1 degree centigrade, but what will be the size of the equipment? Heat transfer, heat transfer equipments work best when there is a temperature difference. So, I want more temperature difference, but some fellows are saying only 5 degrees is allowed. So, there is a constraint, which is coming on and there is a constraint coming in the form of, there is a constraint coming in the form of losses. The power required for the pump should not be more than the output of the 500 megawatt plan. It would not happen, coming, if you come up with some silly design, you come with the most fantastic fluid mechanic solutions and then come out with that, what is the, you go home with negative power.

Now, are there more constraints? Of course, yes, the salt water will corrode; salt water will corrode normal steel. So, you have to go for stainless steel or in fact, even titanium. Titanium, the cost is 2500, 2500 rupees a kilogram, stainless steel about 80 to 100 rupees. So, what, what innocuously started was very harmless m c p delta t hot equal to m c p delta T cold, Q is equal to UALMT. Now, you are stuck with so many things. Now, there will be an engineering manager, there will be engineers and then they will do analysis, then they workout cost. So, the design is going to be extremely, extremely cumbersome affair because of the various constraints, which are built in.

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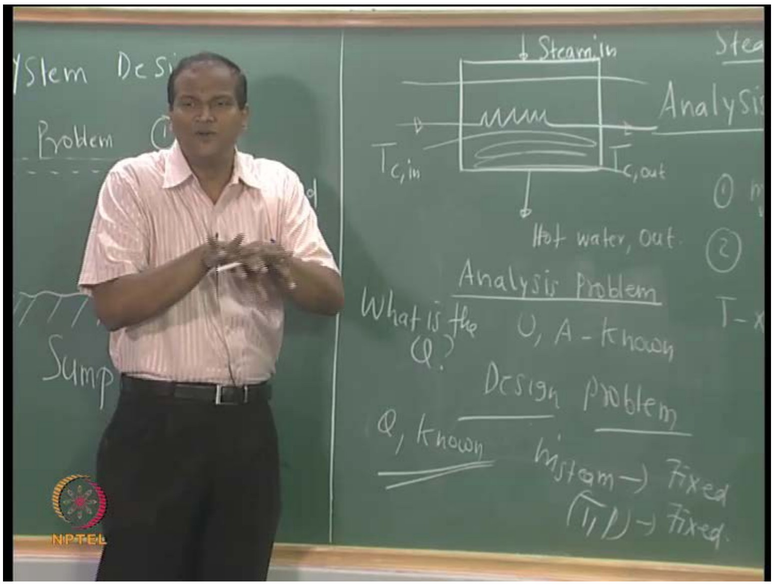

So, the design problem is m dot steam fixed. T, P is fixed, that is, enthalpy is fixed. So, you know, what is, you know, what is the h f g you know. So, Q known, for the given Q what will be the size of the equipment, that is the design problem for a given U and A. What is Q is the analysis problem. The Q is not known a priori in the analysis problem, the Q is known to begin with, in the design problem.

So, a simple problem like this, we can branch out into design and analysis, but originally when people try to design, leave this heat exchanger, other equipment, they will usually form an, they usually follow the monogram or a data book, there will be some data book. So, for this much load, this should be the thickness, this should be the diameter of the shape and they will have a factor safety and do all this. So, analysis was divorce from design, but, but now you have lot of finite element analysis tools and all this. Therefore, analysis is becoming integral part of design.

The idea begin, that is, alternative designs can be analyzed and you can find out whether the stresses are ok and without having to build new prototypes on the computer itself using simulation, you can study the performance and choose the best. So, this is essentially the difference between analysis and design.

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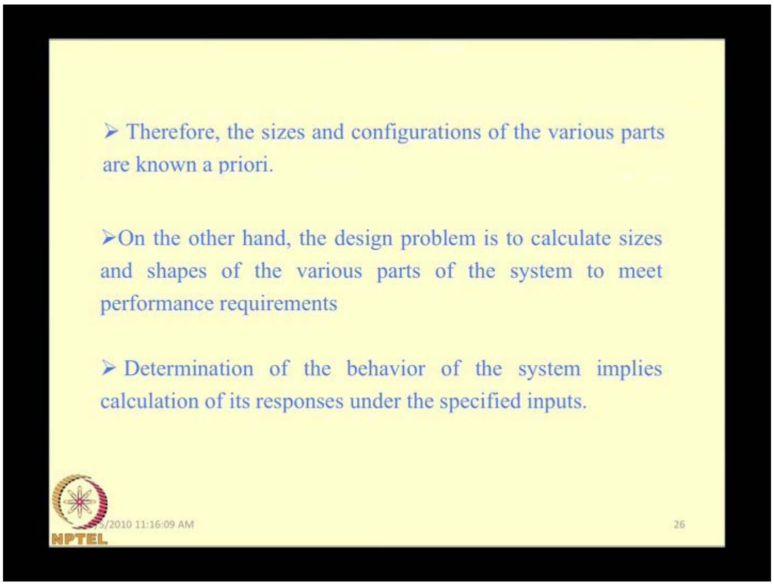

The sizes and configurations of the various parts are known a priori, for which problem, for the analysis problem. On the other hand, the design problem, you should calculate the sizes and shapes of the various parts of the system to meet performance requirements.

So, whatever I have written in Power Point there, it is much better explained when you do it on the black board through the example. So, the determination of the behavior of the system implies the calculation of its response under the specified inputs. For example, this system, suppose I change the U, suppose I change the A in the system, I just change m dot, what happens? From the design, from the design flow rate of steam minus 10 percent, minus 15 percent, plus 10 percent, plus 15 percent, what happens? So, we will have to do what is called a sensitivity study also.

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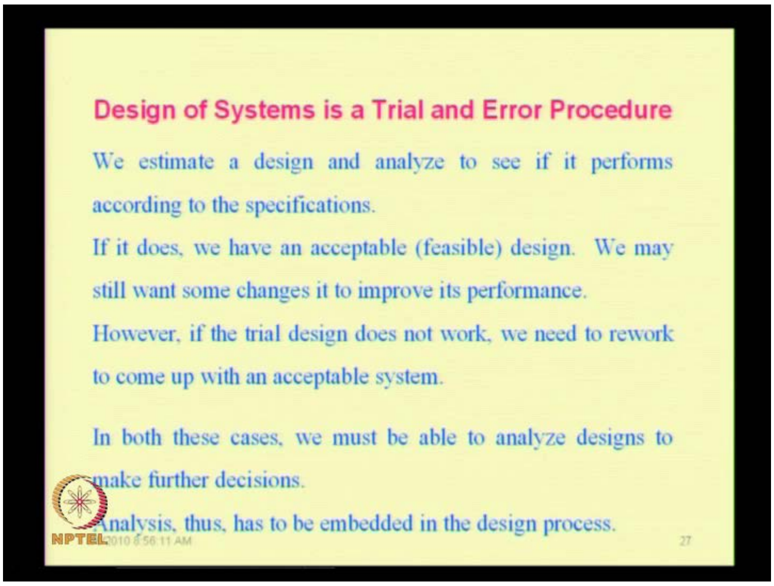

So, design of systems is essentially a trial and error procedure. You will start with some; you will start with some sizes. You are going to do in today's class. We start with simple problem, you will start, you will select a bunch of component and then you will assemble them together, that becomes a system, then you will use, you will use all the equations known to you and see whether this system is working.

If the system is working, it is a feasible or an acceptable design. If it is not working, you will go, you will turn around and then try to change some of these components or some of these parameters and will keep on doing it till you have an acceptable or a feasible design. This is how the design procedure is done. If the trial design does not work, we need to rework to come up with an acceptable system. In both these cases, you must have the capacity or the ability to analyze designs to make further decisions.

Therefore, I make a submission, that analysis, thus, has to be embedded in the design process. It has to be, it has to be integral with the design process. Design and analysis are two sides of the same coin. So, we should not simply do a design based on some data book and based on some thumb rules or formula and so on. Of course, for a silly problem, like what is the size of the pump required for your apartment or something, you do not have to do complicated finite element analysis and all that. You go to a plumber, he will say sir, 5 HP pump will work. But there is no talking about optimum, but there we are, we are trying to choose something, which works, that is ok, because it is not such a costly equipment, that it will, that it really matter. But my assignment number two will make your realize, that all these things also matter even for a, for a pump and piping system for an apartment. It pays; it pays to check your numbers properly, so that you come with an optimum design.

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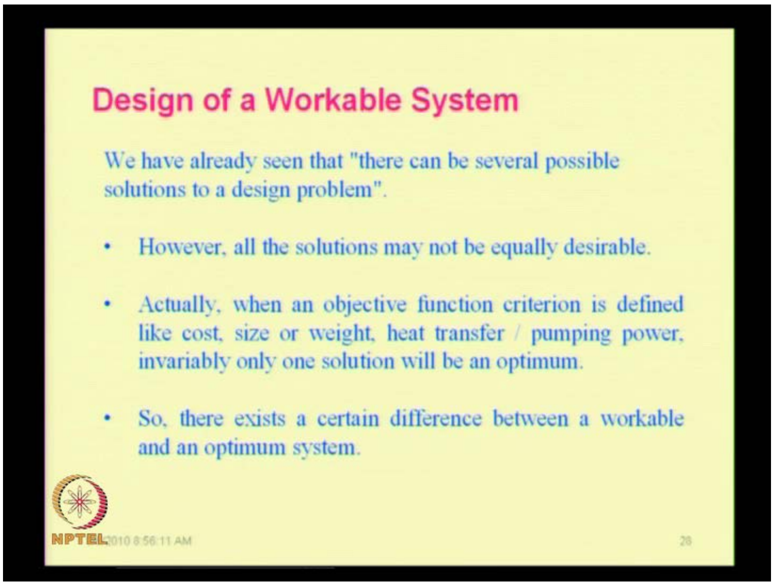

Now, we will go to design of a workable system. So, in yesterday's class we already saw, that there are several possible solutions to a design problem, but all solutions are not equally desirable. Some solutions are better than others, whether it is better or not. How, how, how some solutions are better than others depends upon the objective function and depends on the analyst, depends on the user what he wants to call as desirable or not.

Actually, in an objective function criterion is defined, it could be cost, weight, heat transfer to pumping power, specific fuel consumption, whatever, invariably there will be only one solution, with, which will be an optimum.

So, the goal of this course is to help, help you identify the optimum in certain situation, but because it is a class room environment I will restrict the number of variables, two and three. If you are, if you encounter an optimization problem, whether two or three variables, how do you go about searching for the global optimum, that is a goal, that is intent of the goal. Once you know how it knows for two or three variables, it is possible for you to write a program or give some package and then extend it to any number of variables. Sometimes the optimum may not exist, that is fine, because sometimes optimum is infeasible, sometimes the constraints themselves will fix the solution and so on. All these things we will, we will look into as we progress along.

Therefore, just like there exist a, there exist a difference between design, design and analysis there is a certain difference between workable system and an optimum system. An optimum, an optimum system is necessarily a workable system, but a workable system needs not be, need not necessarily be an optimum system.

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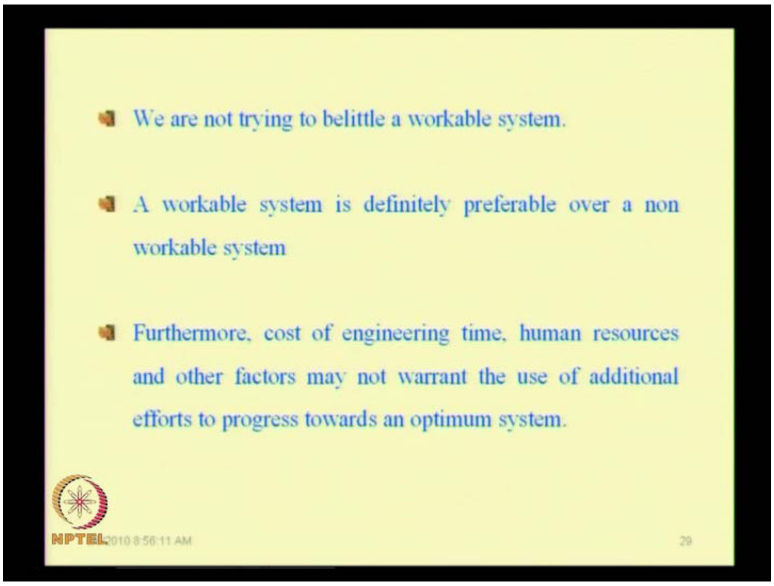

We are not making fun of the workable system, we, I am not making fun of the plumber, after all he gives you a pump, which works for many of us do not even know what the ratings are. How many of you know, what is the rating of the compressor in your refrigerator? What will be the approximate power consumption of the refrigerator? 100 watts, 150 watts, we do not mind it all. So, if some, that is why the Samsung or LG will not advertise, have come up with, we have come up with a new refrigerator, will reduces consumption by 10 percent, we do not really care.

But if somebody says, I have come out with air conditioner, which, which has got 10 percent reduction, we will go and buy because air conditioner, the power consumption is more and then over a 5 year period it will amount a lot of money, lot of savings. However, however, nowadays we have the star ratings in India, right, something called the Bureau of Energy Efficiency, they put for 1 star, 2 star, 3 star, 4 star. So, 5 star is very efficient. So, only some, first you have to get accredited and then they will give a star rating that gives you the economy, economy in terms of power consumption.

So, workable system is definitely preferable over a non-workable system. So, workable system is infinitely superior to something, which is beautifully designed, but does not work. So, first, first is we have to make something work and then we go, go to the optimization. Furthermore, the cost of engineering time, human resources effort, computer systems and the software associated, which are required to optimize large systems, may not warrant use of additional efforts to progress towards an optimum system.

So, there may be cases where, you know, it is under performing, but you prepared (( )) [FL], fine, it is not such a serious problem, but you cannot do this when you are having a 500 megawatt plant and you are trying to design an Airbus 380 or 0.777. Now, the Boeing 787 Dreamliner is having lot of plastic. You know, they are trying to reduce; they are trying to reduce the amount of met aluminum. Now, the long distance flight Boeing 747 had 4 engines, it was a great guzzler, it used to consume so much of fuel. Now the 777 has got only, has got only 2 engines. So, the continuously people are, it has got only 2 engines, but it has got an auxiliary backup invariably the engines fail. Engines fail if basically the starting the starting circuits, which failed. So, they have a redundancy on that and there is something called, I am totally diverting from the topic (( )), cut it later.

So, but still all these things are, have to follow what is called ETOPS, I am now deviating from optimization, I am live on air. So, all these things have to satisfy what is called the ETOPS. ETOPS, extended, extended Twin Engine Operating Performance Standards, ETOPS. So, if a twin engine has to fly between two cities with it, should be within 180 minutes of the nearest airport on which it can land. So, if it is the two engine they will not allow you to fly completely over the ocean for 8 hours or 9 hours. So, even the 777, which is the latest, is subjected to the ETOPS standards, but a four engine jet, Boeing 747, the jumbo is not subjected to that because it has got four engines. But now, the twin engine itself is infinitely superior because it has got terrific fuel, fuel efficiency and so on.

So, it is subjected to the ETOPS, but it has, it has, it has gone on 21000 kilometer, it has flown the, 0.777 has flown 21000 kilometer with 53 pilots and so many crew members.

This was the test fly, but now the maximum they are operating is about 14000 or 15000 kilometer. So, we will cut that, right, now the system simulation is going to come in the next class.

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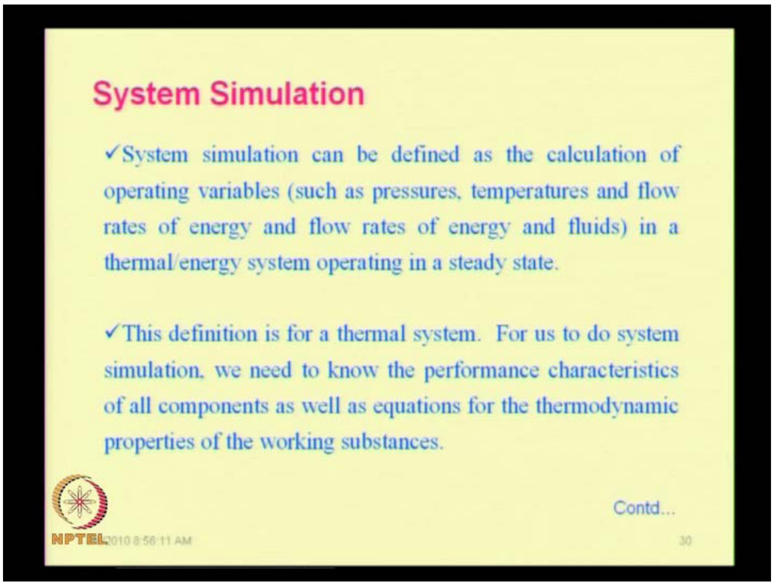

Now, we are going to design, you guys are going to design workable system. Problem number one, we can put the title as design of a workable system, problem number one.

Select the pump and piping, select the pump and piping for a system to convey, select the pipe, select the, did I say pump and piping, no, ok, select the pump and piping for a system to convey 4 kilograms per second of water, first data. Select the pump and piping for a system to convey 4 kgs of water from one location to another, from one location to another, 250 meters away.

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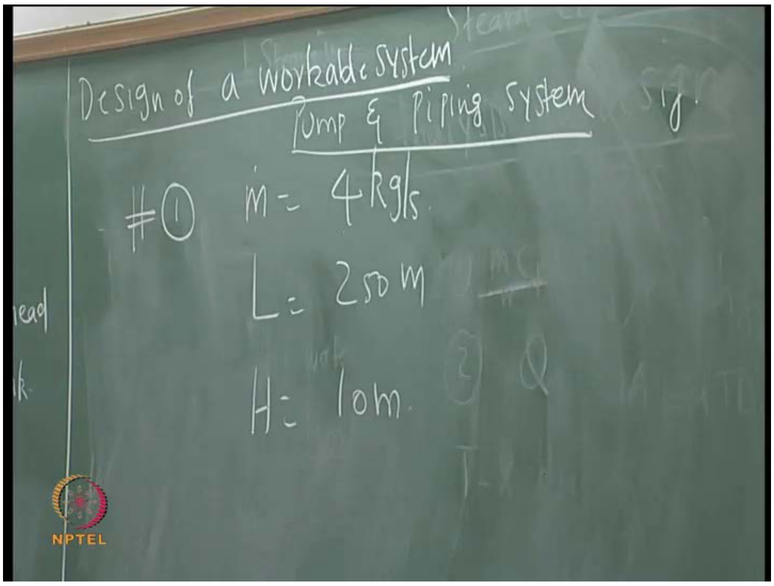

So, length is 250 meters comma 10 meters higher than the original position. So, depiction is given here. There is a sump, there is an overhead tank, you are taking water from here to here, so this is the pipe.

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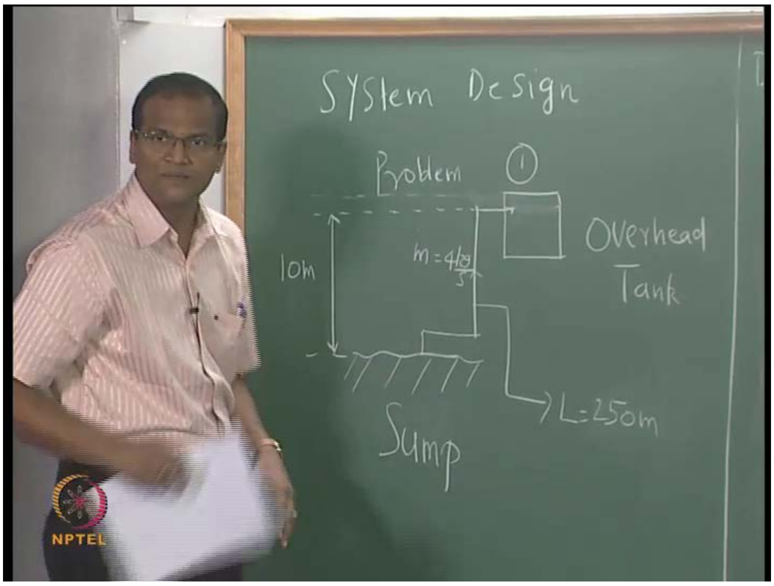

So, your m is 4 kilograms per second, the height difference is 10 meter and this L is 250 meter, may be an apartment complex, whatever, 4 bends exist along, 4 bends exist along the pipe line.

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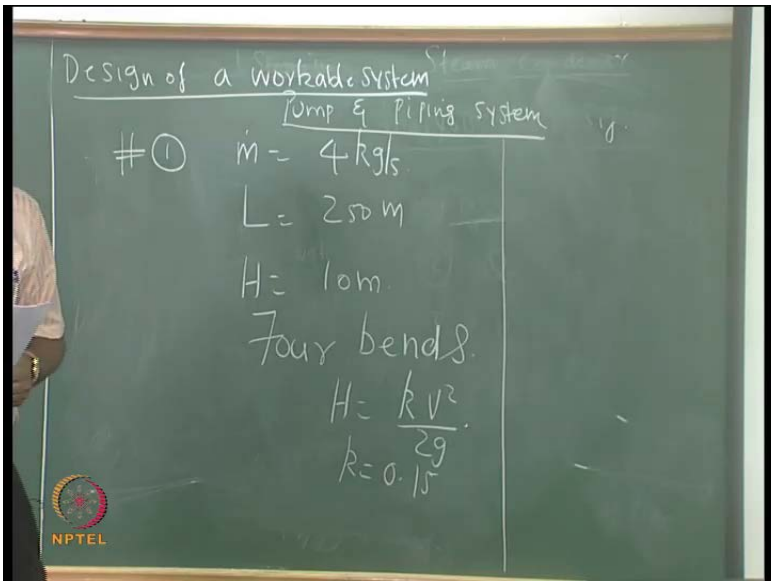

The head loss in a bend is given by, the head loss in a bend is given by H equal to k v square by 2 g, where k equal to 0.15.

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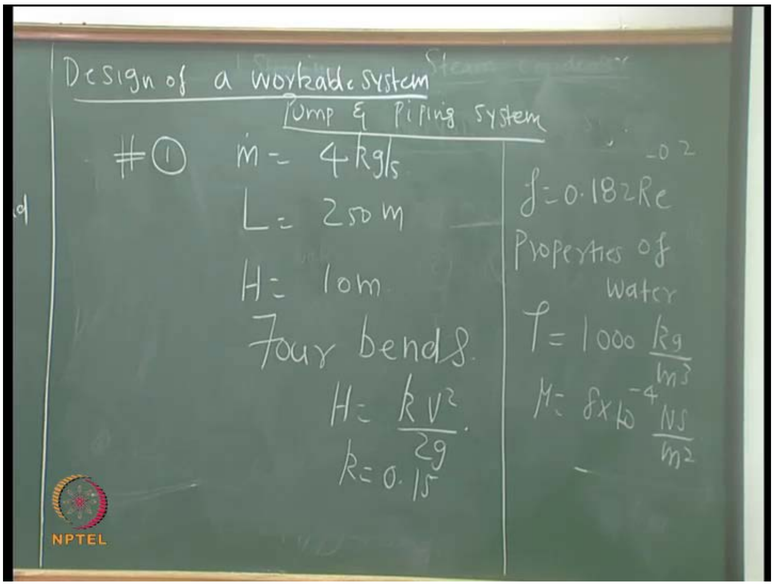

The friction factor for turbulent flow is given by 0.182 Reynolds the minus 0.2, 0.182 Reynolds the minus 0.2. Properties of water are rho equal…

Student: (( ))

Yeah, feel confident, 1000 kilogram, 1000 kilogram per meter cube, mu… Go ahead and give me a proposal, there are two things you have to get, the pump rating, the diameter of the pipe, length of the pipe is given by p.

So, it is a design problem, it is open ended, people are not giving everything and asking you to find, what is the total head loss, that will be fluid mechanics, this is design. Please go ahead.

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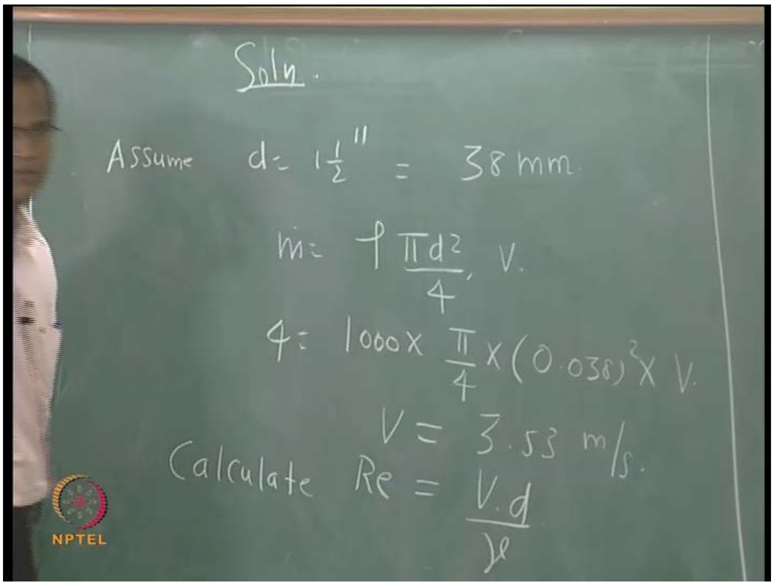

So, how much is it in millimeter? 25.4 into 1.5, 38.

Student: 38.

38, you can take it as 38 millimeter. So, tell me the velocity. What is the velocity Anand?

Student: 1 point…

1.97 meters per second, is it? Is it correct? 2 inches, no, 3.53. First calculate the Reynolds number.

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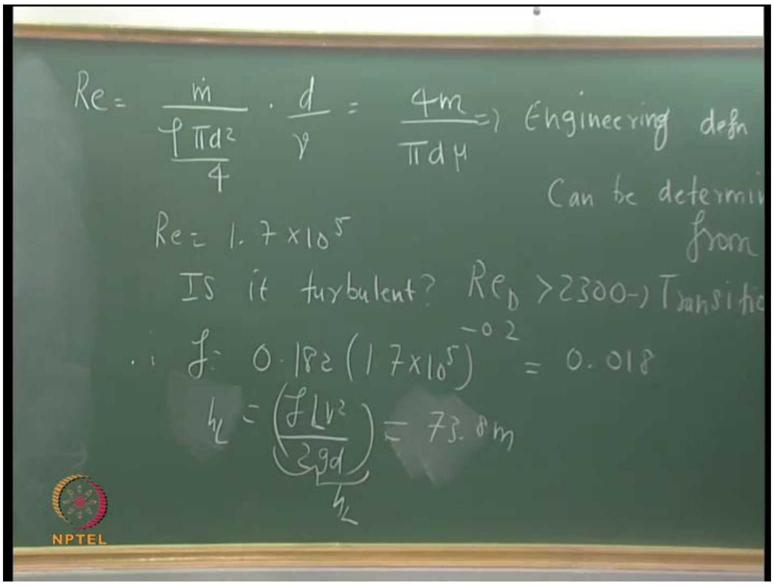

Reynolds number is equal to, Reynolds number… So, why am I writing the same thing in different ways? This is the, this is the engineering definition of Reynolds number. No need to go through the intermediate step of the determining the velocity. However, you will get origin, because unless you calculate the velocity you would not know whether it is laminar or turbulent anyway. You are anyway calculating the Reynolds number. So, this 4 m divided by pi d mu is basically used by practicing engineer, fine.

What is the Reynolds number? 1.7 into 10 to the power of 5. Is it turbulent? Is it turbulent or not? Yes, what is the limit? 2300, do not get confused, 5 into 10 to the power of 5 is for flat plate. So, the use of the correlation is safe, we are allowed to use a correlation. Therefore the friction factor is… Whatever you do, it will be 0.01, 0.02, 0.03, it will be like that. If you get 1, 2, 3, then go back and check, it will be point naught something, how much is it here? Point naught, 0.018, good.

Delta p, delta p is head loss, h l rho g. So, this basically, f l v square by 2gd rho into g. f is known, l is 250 meters, velocity is known, d is known, whether assume, go ahead and calculate this. We got naught 18, does not matter or you can keep it as head loss itself. You can keep it as head loss and add the other heads, does not matter how much is it, 73.8, what. It cannot be meters, this is meters, this is 73.8, head loss is 73.8, is it fine? Now, I will erase this portion to (( )).

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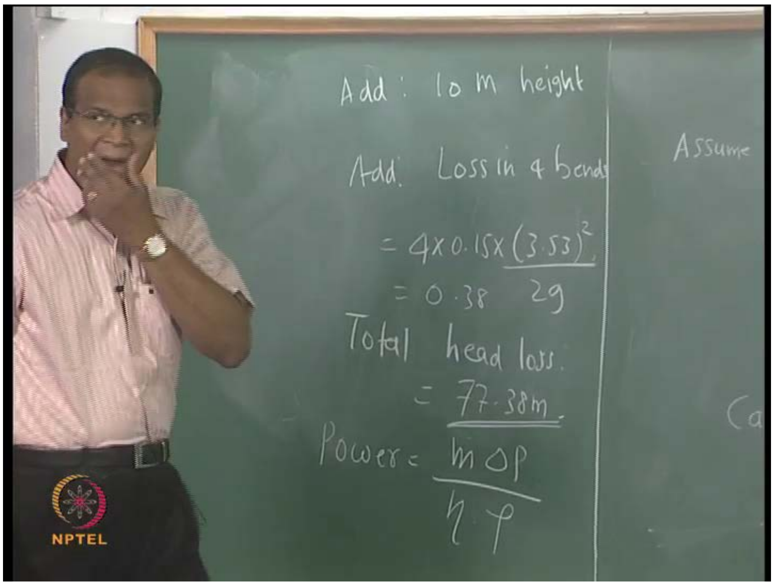

Now, add total head loss is 73.8 plus 10 plus, how much is this? 4 bends, 4 k v square by 2 g. How much is that? 0.38 meters? Total head loss is, 73.8 is correct. I got 67, what happened? I got sixty, what is the correct answer? 67, this one, this one, 60, 67, ok. 77… Now, go ahead and calculate the power. How do you calculate the power?

Student: Head into…

Head into?

Student: Flow rate.

Yeah, so, what is a, is it ok? It will be q delta p, right, it will be q delta p meter cube per second into Newton per meter square, Newton meter per second, joule per second will be 1 eta. No pump will work at 100 percent efficiency; therefore eta has to come in the denominator.

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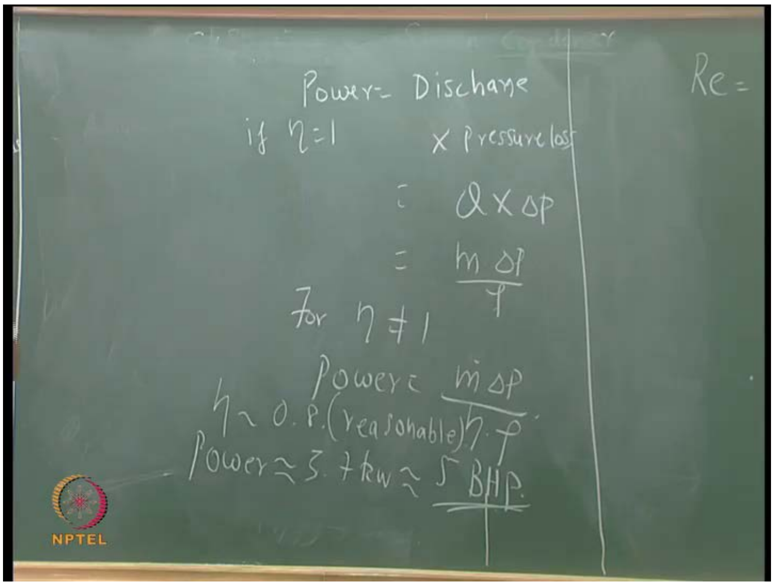

To do that… The reasonable efficiency for, for turbo-machinery, reasonable, therefore, power equal to how much was it? (( )) kilowatts, how much was it? 3.7 kilowatts. So, you go to market, buy a 5 HP pump, go to the market and buy a one and half inch pipe, call your plumber and fix it up and switch it on, it will work.

So, at the end of today's class you have learnt how to design a simple pump and piping system for a domestic application and so on. As somebody said already, as he rightly said, this is not the optimum design. May be the 1 inch pipe, may be the 1 inch pipe will have less; 1 inch pipe will have less cost, but as the diameter decreases what happens? The pressure drops because the velocity, velocity increases and so on. So, there will be a complex interplay between all these three parameters as I told you earlier.

We look at it on in the next class. Next class will be, I look at some, let us develop on this, developed, let us develop on this idea of a simple system consisting of two components of a pump and piping and let us see how we can proceed to an, proceed to an optimum solution of this system.