Design and Optimization of Energy Systems

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Lecture No. #03

Workable System

So, we will continue with our design of a workable system. So, we, we learnt little bit about design of workable system through an example. The example was the pump and piping, piping system, which you all designed and each of you must have got a different answer, hopefully. There will be several pumps, which could satisfy the same job over, each of which may not be desirable if, if you decide on a criterion of desirability.

What is desirable? For example, if you want minimum total cost, then you will have to do an optimization. That is what we, that is what I mentioned in one of the earlier classes. So, we consider this example, we have now designed the workable system. Now, we had, now we will formally see, what a workable system is. So, what are the features of a workable system?

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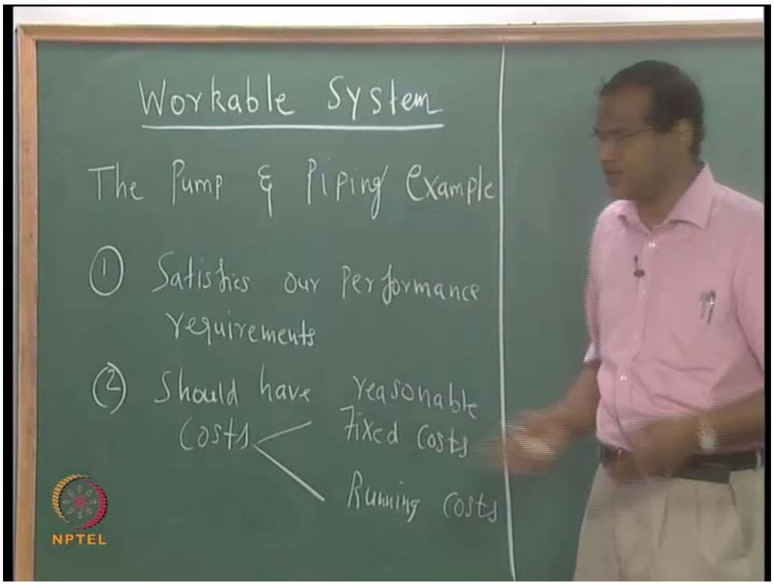

So, workable system is one, workable system is one, which, which…

Student: (( ))

no no, make it more…satisfy the performance, satisfies the performace requirement. In this case, it should be able to pump the water, correct, satisfies our…

Is that all? If satisfies the performance requirements, it is ok? It is…

Student: Cost

Cost what? Right now I do not know whether it is the cheapest or whatever, but you can still say something about the cost. So, you should have reasonable cost. For example, in this, in the problem, which we worked out, had you taken a 6 millimeters, so 6 millimeter diameter pipe, it is a quarter inch pipe, you could have, you would have, you could have come out with an answer where the horse power reading of the pump was 15 or 20. Immediately you would have realised, that even though this pump will also technically do the job, there is something fundamentally incorrect about your value of the diameter, which you assumed in the first place. You will turn around, and try to correct it. Are you getting the point?

Therefore, even though several designs may work, all these may not be, all these may not be workable systems, workable systems, not because they do not satisfy performance requirements, they do not satisfy our criterion of a reasonable cost. Reasonable cost is basically, it is, it cannot be taught, you cannot have course on what is the… So, I think all of us will know for this case, if something is, if you have a cost, pump and piping system, which cost between 5000 and 10000 rupees, 15000 rupees, it is alright. Suppose if something costs 75000 rupees, 100000 or whatever, you know that something is going wrong. So, some of the fundamental dimensions, which you have assumed are not correct. Therefore, you should have reasonable cost and this cost can, the, the cost basically consists of two components. What are the two components in a something like a pump, which is running?

Student: Fixed cost.

Fixed cost, this is running cost and maintanence also included. Running cost is the cost of the power, and both of these should be reasonable. Is that all? If a system satisfies these two criteria, does it become a workable system? We are almost there, but not yet.

Are there some more conditions, which a workable system has to saitsfy, which the system has to satisfy? It should satisfy all our constraints. The constraint could be in the form of pressure, temperature, pollution guidelines, material, properties, correct. The constraint could, could be in the form of (( )).

For example, now asbestos is banned, right. We cannot use asbestos. So, you may come out with the system, which is fine, which satisfies our performance requirement, which satisfies. For example, you are trying to come out with the design of an insulation system with asbestos, it will, it will satisfy these two, but it will, it will cup when it comes to, it will cup when it comes to satisfying some guideline regulation, some regulation, which is in place when it violates. Therefore, it should the, it should satisfy…

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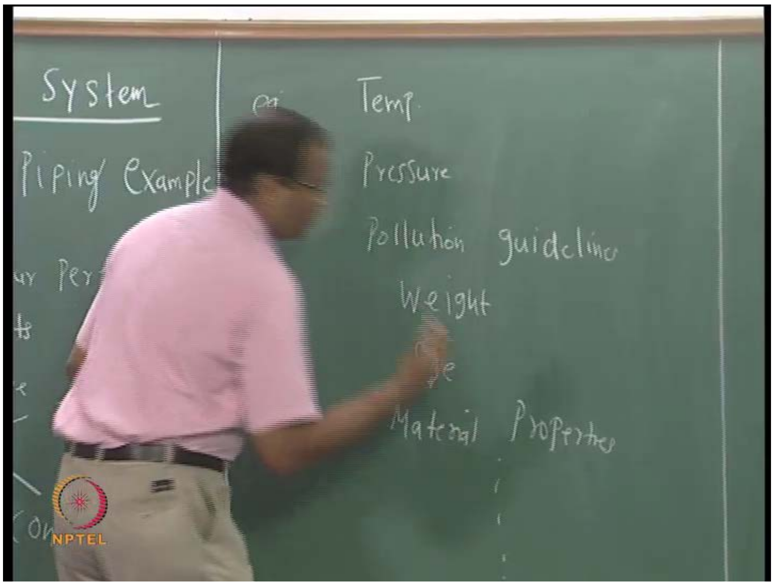

What are these constraints? Example, temperature... and so on. So, in, in trying to define the workable system, I deviated from the normal procedure. So, first we design the workable system, and then I, then I formally defined it, (( )), little more interesting.

Conventional, the conventional way of teaching is, first I will tell you a workable system is one in which all this, and then I will say, now let us do an example. Let us draw, let us design a pump and piping system. Let us have some fun, little, little bit of change. We first did the example, and then I do not know whether this works better than that. There is no way of proving it. Of course, after the class you can tell me whether it is ok or not.

Now, how did you design this workable system? How did, now that we are, now that you have designed one, now that you also know what are the attributes, what are the characteristics of a workable system, when you did this, when, when you carried out this design of a workable system, how did you go about doing this?

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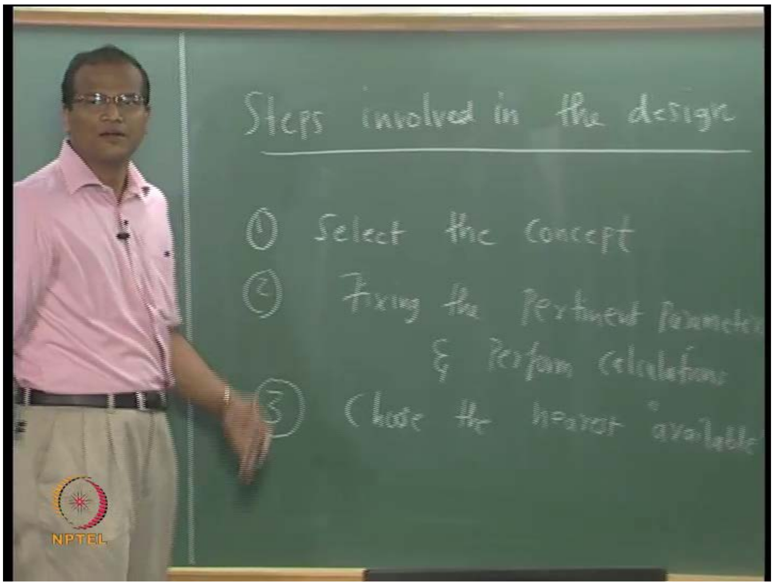

What are the steps involved? First, first is for, first you requirement is given. Can you be, can you be more specific what did you first choose? No, no, you are not getting. You are getting too specific, more conceptual.

Student: (( ))

Even before that.

Student: (( ))

Not, I have all these, more primordial, more fundamental than all these. First, you selected the concept, right. It may, it may sound silly, but everyday you can hire somebody, pay in money and give them two or three buckets and ask them to fill up. (( )) That is also solution. (( )) go and fill up, they climb the stairs and pour the water, take bucket full of, buckets full of water, and that is also…

So, you decided, that there should be a centrifugal pump or a jet pump, whatever. There will be a piping and pump, there will be a piping and pump arrangement, which will do this job. Select the (( )) concept, and then, and then you went about fixing the pertinent parameter, right. You fix certain parameters. For example, in this case, you fix the diameter and perform the calculations. And then, not chose, choose, choose the nearest available, what of, what is it? Product is it, product, solution.

So, if you get something like 3.264 kilowatts or something, you will choose something like if three and a half kilowatt is available, otherwise you go to 4, you go for 4 kilowatts. Normally, outside still they follow the HP system. Even in cars you still talk about HP, you do not talk about kilowatts. So, there will be available into, in multiples of watt, in horse power, it will be 1 horse power, one and half, 2, 3, 4, 5. So, we round it off to the nearest horse power motor and then decide this is the solution, right.

Now, this, this basically, essentially, gives you an overview of how you go about designing a simple system. Of course, you have to design a complex system, you will have to do complex calculations, you may write the program yourself, you may take recourse using commercially available software, whether it is CFX, Fluent, (( )) or what have you, right.

But now, the actual story starts. Each of you has come out with the particular design, but all of these, all of these are not equally desirable. When I say all of these are not equally desirable, I am getting more specific. So, I am introducing what is called an objective function? What is my objective? So, the objective function is mathematically denoted by y. Now, I have to say what y is. So, for example, in a, in a project like this or in a, in a problem like this, the y is very, very straight forward, y is basically the cost.

However, I told you, in social projects, that this y is very, is very nebulous, is very nebulous and cloudy. You do not know what y is. For example, you build a flyover, what is your objective function? How, whether the flyover has eased the traffic problem? It could be at several levels. The user subjectively will say yes or no or you go through a survey and find out whether they are happy or the traffic engineering department, traffic engineering division of the civil engineering department of IIT or Anna University may actually commission a study at the end of one year. They, they find out what is the average time taken by vehicles to cross Raj Bhavan to Madhya Kailash, how much time they have taken before the bridge was constructed and after the, after the flyover is constructed and you can give and you can give some numbers, right. Therefore, please do not assume, that the, please do not assume, that the agreement on what y is the objective function is trivial and straight forward.

Many, often times, often times the definition of this objective function is not so straightforward. So, it requires lot of time, and effort. For example, in a, if you want to design a heat exchanger, it is not that it is always, that you want a minimum cost because you can have a minimum cost heat exchanger, which has terrific pumping power. So, shall, shall we say, that you want to have, you want to have a maximum thermal performance divided by the pumping power. The ratio of the, ratio of the heat transfer rate divided by pump, pumping power pressure drop q by delta p, is it a performance criterion or you can, you can really go to the bottom of it, and say, that I want to design a heat exchanger, which is, which generates these total entropy.

But what is the use of generating? Who cares about in to be, let me generate little more entropy? So, when I speak I am generating entropy who cares about that? There is, then some guy is there, pure thermodynamics, he will say no, no, no, we can link up this minimum entropy generation with actually the rate of heat transfer divided by pressure drop, and all that. You know Professor (( )), he is very (( )) North Carolina, he has done lot of work. So, you are encouraged to read his books and articles on entropy generation. How the entropy generation method can be used for designing thermal equipment that is the separate story.

So, there need not be a consensus on what the objective function is. So, it is left, left to the analyst. You decide what is your objective function, go about, go about minimizing or maximizing maximizing the y. Now, what could be the objective function in this case?

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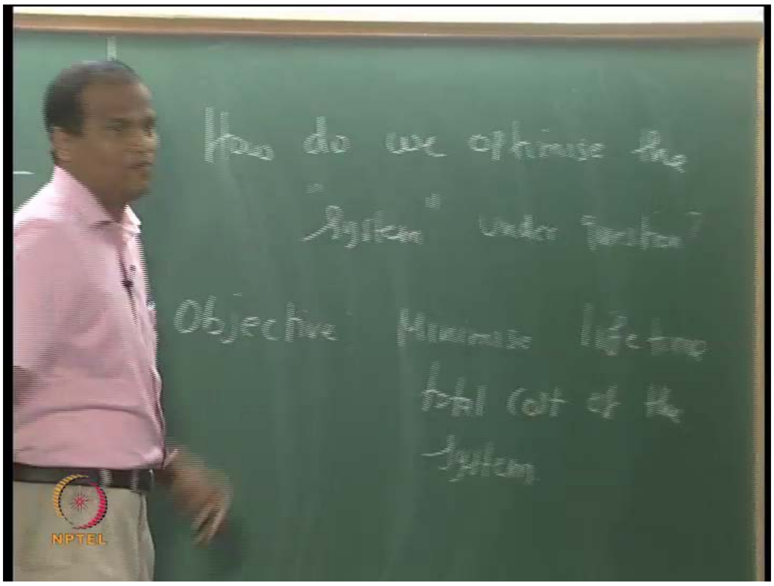

Now, let me, let me ask you very direct and pointed question instead of beating around the bush. How do you optimize the system under question? First, first and foremost, we agree on what is it, what is it to be optimized? In this pump and piping system, what is to be optimized? Cost of insulation, running, that is enough, cost of insulation is, be more specific, you are getting there. So, there is the cost of the pump one, then there is the cost of the piping, then there is the cost of installing all this. Then, there is the cost of labour all that, it is fine. Then, there is cost after you, after you switch on maintenance and running cost. So, the objective function now or you say objective, minimize the lifetime total cost of this system, right. There is a fair objective right.

Now, we will have to enumerate, enumerate the various components, which constitute this lifetime total cost, and try to see whether we can write down all these cost in terms of some numbers, in terms of some equations. Then, you have to get, you have to assign value to the various, assign values to the various constants available in your equations. And then, use an optimization technique of your choice and find out what is the, what are the optimum operating conditions for the system under question. So, that is the story. So, we will just…

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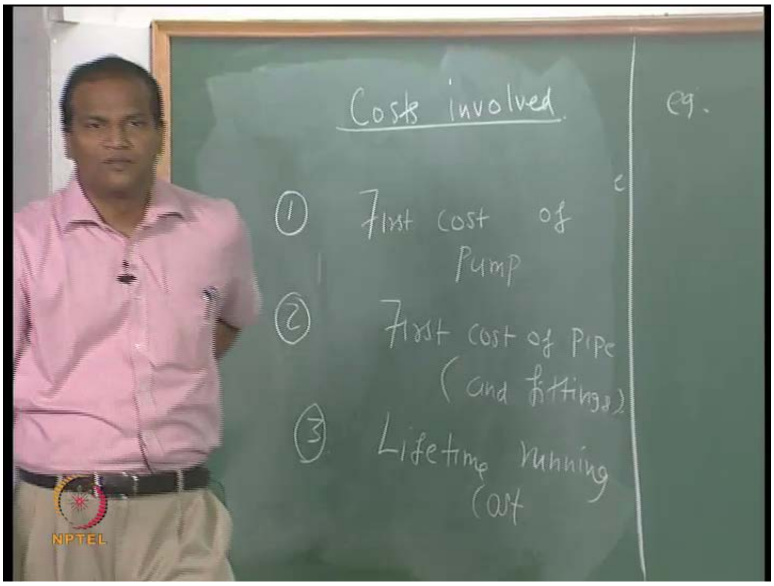

So, cost involved, I will, I will say first cost of pump, first cost of pipe, I am including and fitting. This is not central to this, but lifetime, that means, pressure drop and all that. I can put into some 1.2x and 1.3x to take care of the maintenance and all that, so that the problem is tractable and handlable.

You can keep on complicating the problem, but for a classroom environment, you have to stop it at a certain stage. Now, is it possible for us to write all these costs in terms of the fundamental quantities, which are involved in this problem? The fundamental dependant variable in this problem is the delta p, (( )) pressurize. Now we turn around, and try to write down mathematical equations for all of this, each of these costs in terms of delta p, do that.

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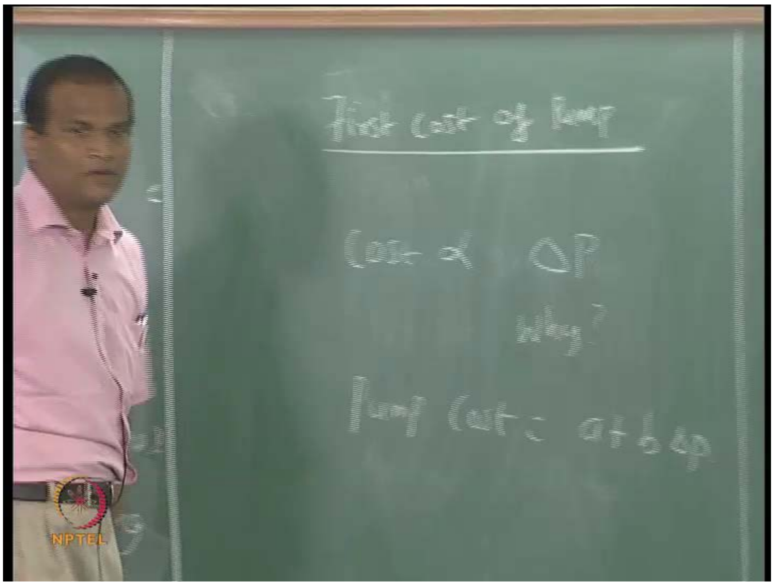

Let us start the first cost of pump. The cost is proportional to, cost is proportional to, because delta p, why? Yeah, it is proportional to delta p, it is also proportional to the volumetric flow rate q, but the volumetric flow rate is is fixed in this problem. So, that your, that does not enter the problem. Therefore, I can say pump cost.

How do you get a and b? It cannot be given in text book. a and b depends on local conditions. a and b may change in Ahmedabad, it may be different in Madras, it may be different in New York or whatever. Local conditions will apply to decide a and b. a and b can be easily obtained. You just go to hardware shop, they give me 1 horse power to 10 horse power, give me the cost, come down put it on Excel and get a and b, which you are going to do in assignment number two, it is there already. So, you will go to Velachery or Taramani or Google, whatever, you will get a and b done. Now, let us see the other cost. I am going from the simplest to the more difficult to the difficult. So, I will defer this, I will defer this to the end. Let us go to lifetime running cost.

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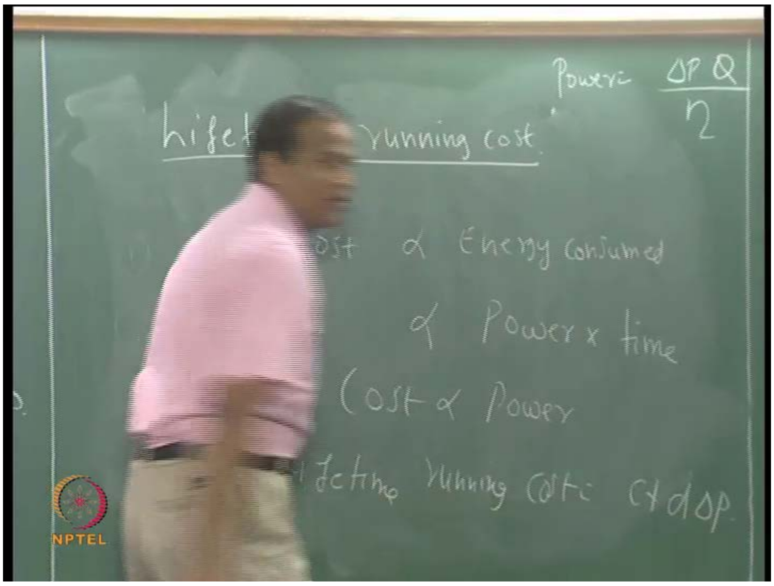

So, the cost is proportional to the energy consumed, right. So, the energy consumed is proportional to the power into…

Student: (( ))

Correct. Assuming, that the performance, assuming that the performance to the machine does not deteriorate with time to the extent, that the time required for operating the pump changes. It is a fair assumption, that the time is need not be (( )) as a variable is the problem. Therefore, the cost is proportional to the power. Again, the power is proportional to delta because power equal to… So, if we assumed the efficiency is constant over this period, it is assumed, that the discharge is constant. It is proportional to delta p. Therefore, the cost, lifetime cost…

You can get c and d, right. Can you get c and d? What all you need to know for c and d? Cost of electricity, it is not so. Sometimes what happens, suppose you are working on a project and the project is supposed to work for 15 or 20 years. Then, you have to consider inflation into account. The, the cost of electricity is never constant, it changes. So, fair assumption will be, last 5 years you look at the trend, then assume the average inflation rate and then factor in the inflation. It will be, they say will be 1, next year it will be 1 plus x into 1 plus x into 1 plus x. So, it will go as a, it will go as a g p, it will go as a g p. So, things get complicated.

Now, you are trying to design an, optimize a power plant. Just like these costs are going up, the revenue will also keep changing with inflation and that is one thing. And you got money from somebody, and you are paying interest for that, and this will be basically diminishing balance at the end of every year, you would have paid a certain part of the principle. So, slowly it will become, becomes very, very difficult. So, you require a large program to run this, but for the classroom environment we will stick, we will stick to this story. But I just want to appreciate, that it could be really messy. So, you have got two costs. Now, how to get the cost of the pipe? Cost of the pipe is directly proportional to the? Length, no.

Student: (( ))

Weight, yeah, that is good, so mass. Assuming, that it is operating under 1 g, assuming that it is operating at 1 g, you can say, that the cost is proportional to the weight. The length is pretty much fixed, right, because you know what is the length, how many bends are there and all that. So, the weight is equal to phi d t l correct, phi d t l, where t is the thickness, d is the diameter, and l is the length.

Assuming, that we are not going to have designs varying from 1 HP to 200 HP, if t is considered more or less constant, which is a questionable assumption, but I am allowed to do all these assumptions. So, t, if t is maintained constant and l is maintained constant, the cost is directly proportional to the diameter. It does not help me, how is the diameter related to pressure drop. Take 5 minutes and get a relationship between the diameter and the pressure drop for turbulent flow.

Cost is proportional to diameter, what is the relationship between diameter and pressure drop? Why, because I wrote the other two costs already in terms of delta p, if I write the third cost in terms of delta p, now I have formulated the optimization problem where the whole thing is the function only of delta p. I, I, go, attack this problem, and get the optimum delta p, so that the cost is minimized.

Student: (( ))

Inversely proportional. I am asking d to the power of what, it is not such a straight forward problem. You have to use flv square by 2gd, all that. You have to use all your knowledge of fluid mechanics to get this, there is a friction factor. Friction factor has a diameter because 0.18 to Reynolds to the power of minus 0.2, then there is a 4 flv square by 2gd. v is the velocity, m is equal to rho a v, a is phi d square by 4. So, d comes, so do not be lazy, get going. That phi d t, how you got that I do not have to explain, right? There is an assumption involved in the phi d t, is not it?

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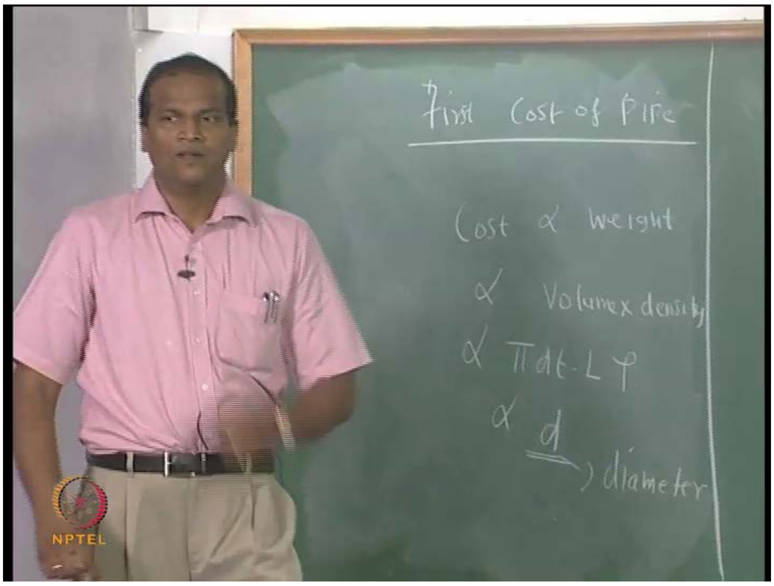

So, phi by 4 d out whole square minus d in whole square, d out... Do a Taylor series expansion and all that. What is this d enough? There are hazards in that, there is a d I, there is d o.

Student: (( ))

Yeah, some average So, I think these guys, normally it is called as a nominal diameter, right; it is called the nominal diameter.

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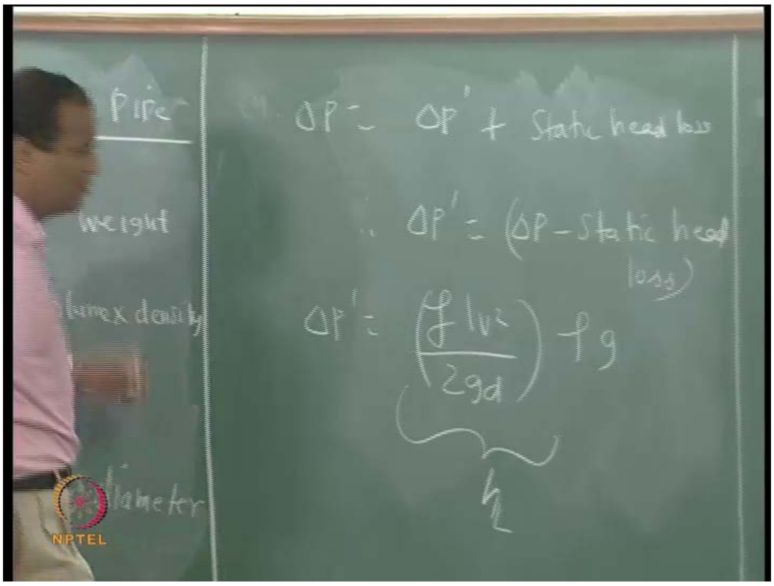

But the nominal diameter will not be the average. Has anybody worried about this or thought about this? It will, it will not be exactly equal to this mathematical average of the inner, and outer of mean, some, it is based on something. Suffice, it would suffice to say, that d is the nominal, is the average diameter when we proceed. Now, delta p dash, delta p will be equal to delta p dash plus static head loss. Delta p dash itself… Now, we do not know the v directly because you have specifed only the mass flow rate.

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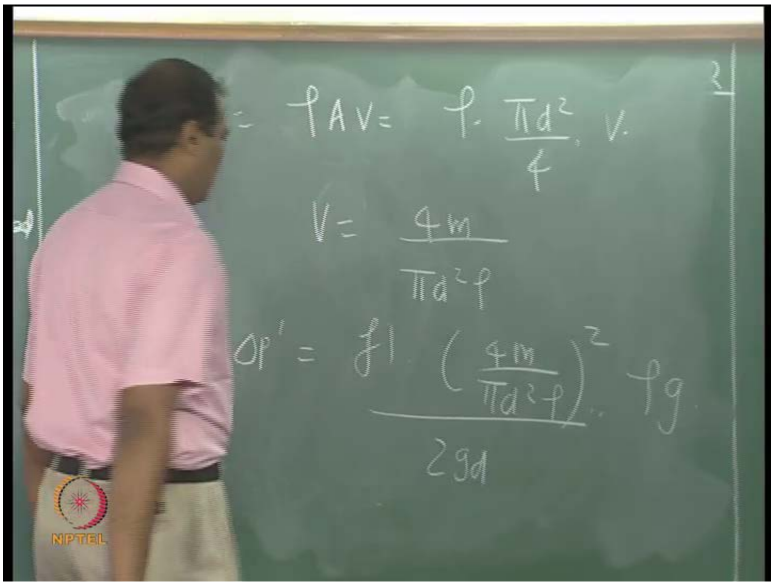

No… Is it ok? Is it ok?

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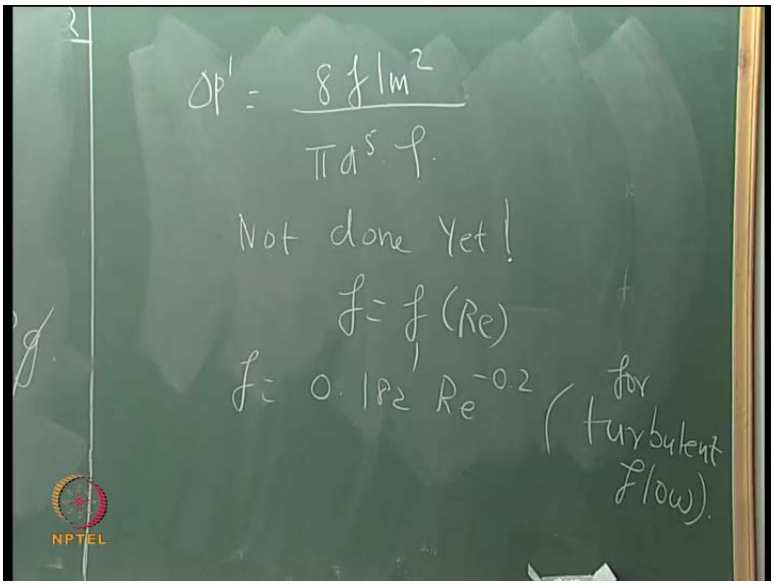

Correct? We have not done yet because f is also function of Reynolds number. Of course, if you are practicing engineering, may be neglect it done. But we want to get to the bottom of the problem, so we will, might as well do it, right, one more step. Assuming, that the flow is stable and… You guys you are able to see this? So, that is the problem, you are able to see upto this. So, next class onwards I will, alright. So, f…

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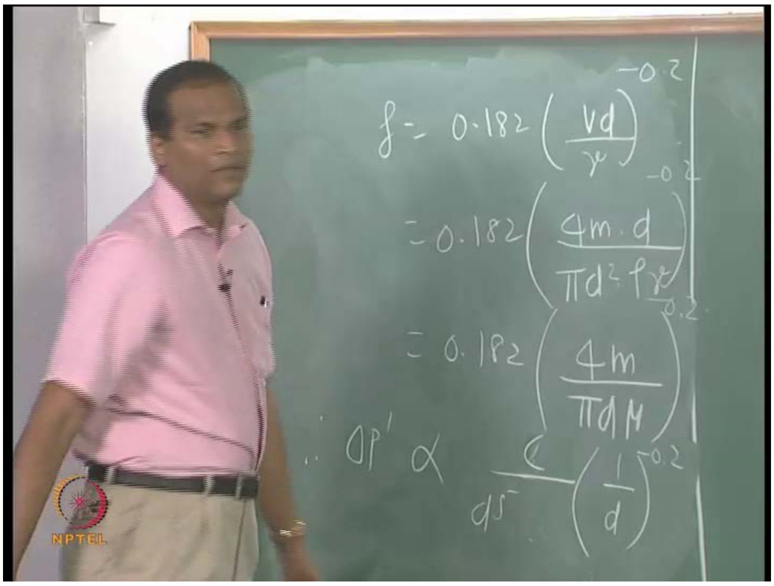

So, now we have, we have to do the, so f is…

Therefore,…

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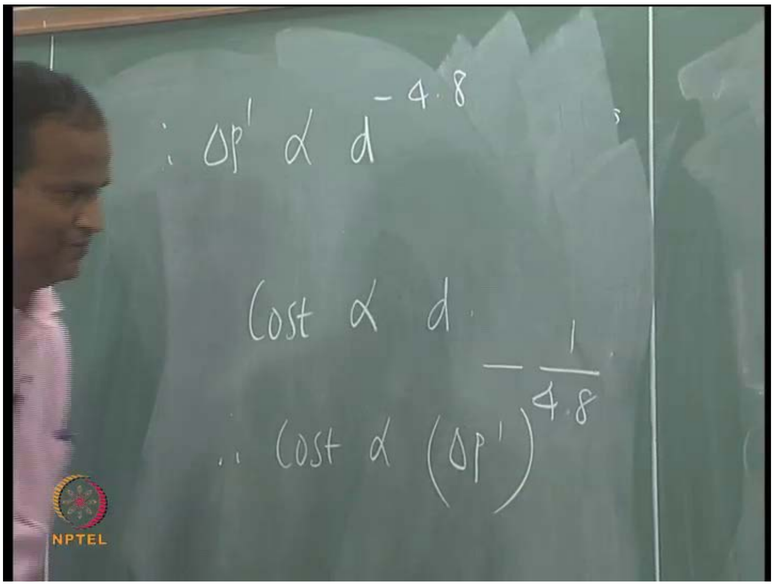

d to the power of minus 4.8. Is it minus, is it plus? Not minus 4.8?

Student: It is correct.

Now, so we have, we have now... See, when you look at, so when you do design and optimization, when you do a design followed by an optimization, the problems will be like this. Nobody will tell you from a textbook, take 4 metres per second or 4 kgs of water flowing in a tube, in a tube, 1 inch in diameter and this thing, calculate. That is text book learning.

So, now, what you do, so we do not have anything, everything is in the air. Now, slowly we will start write everything, and whatever you learnt from fluid mechanics and heat transfer and all this and we incorporate. And then, coming out to the design and then trying to optimize, real life problems will be like this. Analysis will be only one part of a story. Unfortunately, in all the courses we will teach you only analysis because we believe, that if you are strong in analysis, eventually you will be good at design. Design is basically synthesis, synthesis of several concepts, several ideas.

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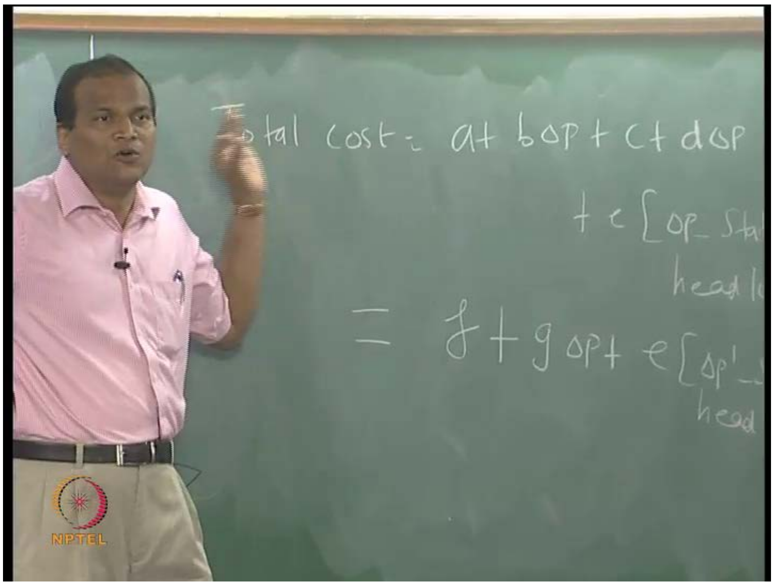

Now, total cost f plus … So, now, now we have the written total, total cost in terms of delta p. Delta p is the pressure rise, which is taking place in the system. Pressure rise is the variable, which is under your control. So, if for different values of delta p, the total cost goes up with delta p, if you look at term number 2 on the right hand side. The term number 3 goes down with delta p because there is one term, which increases with delta p and that is immediately followed by another term, where, which decreases with delta p.

There is hope for us to optimize, there should be particular value of delta p at which the total cost will be at, actually the total cost will be extremized, that is, that is it will be stationary. But you really do not know whether this will be the maximum or minimum cost, but we have been doing all this intuitively. Intuitively, you can guess, that it will be the minimum cost. However, as a purist, as a mathematician we are not able to appreciate this. Go ahead and take the second derivative and evaluate it. For engineers, I do not have, if you, if you try to optimize the total cost of the (( )). We put all these factors into account and then, get all these numbers have a complicated optimization program running and find, you get your final answers. Why would it be some maximum curves of the (( )), but the mathematician, no, no, no second derivative.

So, if it is more than this thing, we will evaluate, the Hessian will prove it is positive definite, semi-definite or whatever you want, we will do it. But as an engineer, I am convinced that already I have got the answer.

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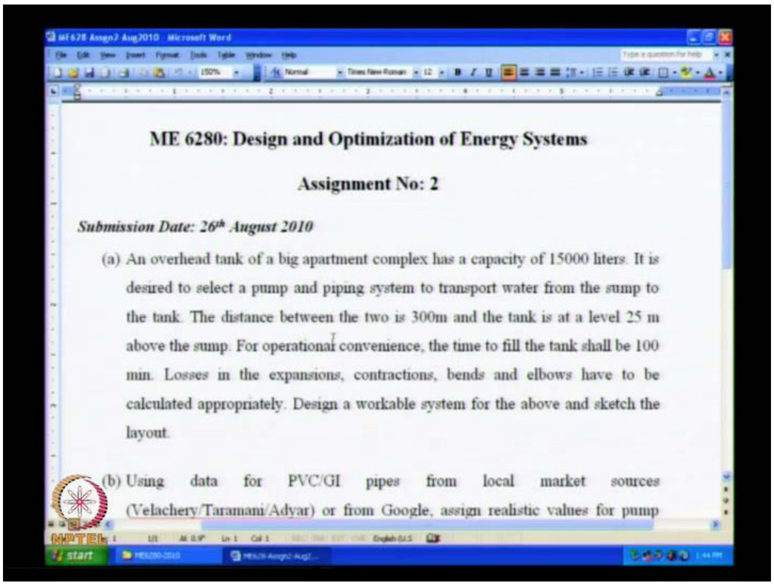

It is written on the board, now we will formally solve this optimization problem. So, this will be the assignment number two. So, submission date is 26th August. So, the problem reads like this. So, there is an overhead tank of big apartment, I have given a capacity of 15000 liters, it is desired to select the pump and pipe, piping system to transport water from the sump to the tank. Distance is 300 meters; tank is at level 25 meters above the sump. So, 25 meters equals to 3, 3 stories or whatever. For operational convenience, the time to fill the tank shall be 100 minutes. Losses in expansions, contraction, bends and elbows have to be calculated appropriately.

You have to get all these kv square by 2 g; k you can get from basic fluid mechanics text books. And then, design a workable system for the above, and sketch the layout. That is the part one of the story, you design a workable system on a A4 sheet, you do.

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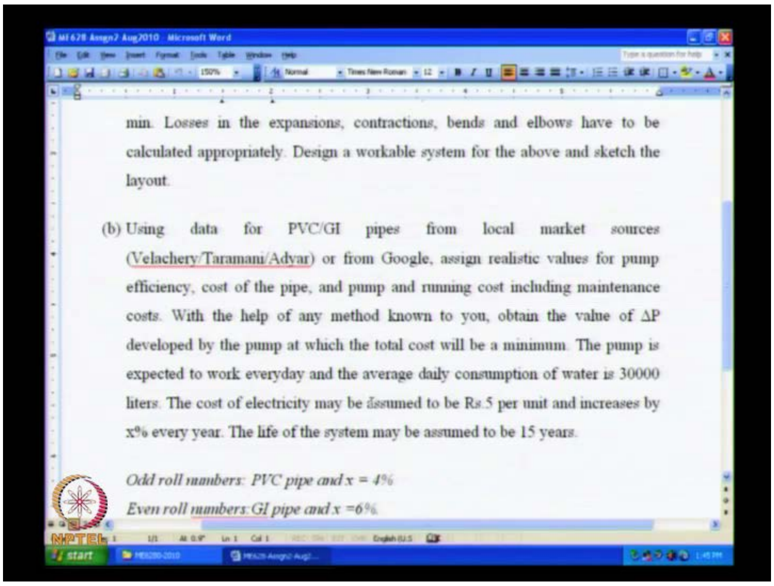

Now, using data for PVC, GI pipes from local market sources, it could be anywhere or from Google, assign realistic values for the pump efficiency, cost of the pipe and pump and running cost including maintenance costs. With the help of the any method known to you, obtain the value of delta p developed by the pump at which the total cost will be a minimum. The pump is expected to work every day and the daily consumption is 300000, 30000 liters, capacity is 15000 liters, and you take 100 minutes to fill. The cost of electricity may be assumed to be 5 per unit, and increases by x percent per every year. The life of the system may be assumed to be 15 years.

Odd roll numbers, we will work it for PVC, and x is 4 percent. Even roll numbers, we will work, we will work it out for GI pipe and x is equal to 6 percent, so that at least I have two copies. So, it cannot be only one, so we need two original designs.

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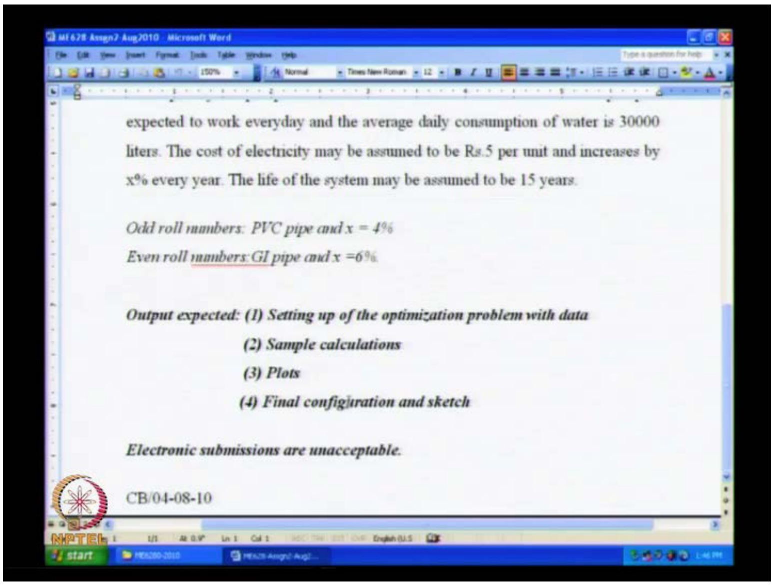

So, the, what is the, see you can talk to each other and group work and all that, but you should not submit the same thing. Suppose you are submitting a script, you will submit your script, Matlab script and this thing, at least change a few variables and… Otherwise, I need to have oral exam, which will involve time and… This is what is done in Germany.

For example, the (( )) examination is oral exam, you know that? In Germany, the (( )), fluid mechanics, the professor will have four (( )). So, in order to ensure that it is fair, he will call his three PAG students who will be sitting. The exam, he will, he will take boundary layer, three by boundary layer theory by (( )), boundary layer 400 p explain this. Then he will directly say, no, you are failing come next time. That is it; we cannot argue this thing, retotalling, revaluation, nothing. The professor is supreme, he says no, you will fail, please go back, come after six months. We, we are some more obsessed with this written exams and all that.

Output expected, setting up the optimization problem with data, sample calculations, you have to show plots, final configuration and sketch. Electronic submissions are unacceptable. But if you want me to take a look at that after submitting a hardcopy, you can meet me in my office. If, if you have got something interesting or something or you come, you, you have solved using a different technique instead of just plotting and looking at a graphical variation, if you have picked up on some other idea and you want to discuss with me, this thing, it is fine, is it ok.