Principles and Practices of Process Equipment and Plant Design
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Lecture – 02
Introduction (Contd.)

Good day to you all. We resume our lecture from where we had left; that means, this is going to be the lecture 2 with the Introduction topic being continued.

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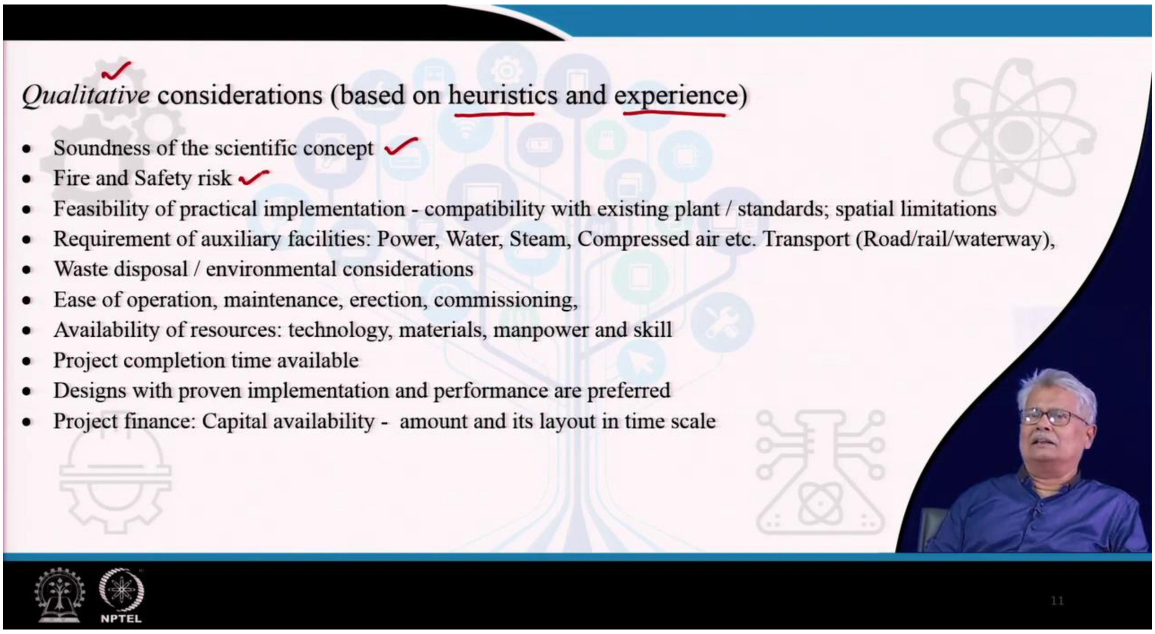

We have been talking in the last class about the basics of process, we have talked about the classification of processes as a simple process as a complex process, and we have compared batch and the continuous mode of operation of different plants and equipment as well.

We also have noted that even though we talk about a major step in a particular process it also involves several others. For example, distillation involves pumps or pumping, piping, heat exchangers, possibly furnaces as well. We also have talked about in general what exactly is an optimum process. We definitely would like to have a very quick design and approach as close as possible to the optimum.

See, in practice also we have several guidelines which help us in achieving things in a much quicker way. These guidelines are not always perfect, but they basically show us a way which is better. These are primarily the qualitative considerations which are based on heuristics and it is based on experience a lot.

So, in design, yes, particularly in engineering design to a great extent experience counts. It is obvious and it is extra to say this as well that someone who has resigned a distillation plant earlier, possibly knows where he had faltered in his last design and will try to eliminate his errors in the last design in the next venture.

Now, when we are talking about qualitative consideration; the first thing is the soundness of scientific concepts. Obviously, if anything has to be designed that has to work it has to be scientifically true. We often forget, but the most important thing is particularly about the design of chemical and process plants which are normally considered by the common persons to be pretty hazardous.

Most of the chemical plants are defined, they run a risk of fire and safety. That means, there is a chance of fire if we are handling inflammable material and the safety is also at stake because many of the chemicals which are used in such processes are poisonous.

We definitely, while designing, have to look at the feasibility of practical implementation. For example, if you are adding something to an existing plant what we are going to design and add has to be compatible. There are standards for each of such plant equipment and design procedures as well as material standards. This helps us a lot in ensuring that our designs are practical and they remain compatible with other sections which are also designed according to the same standards.

Very common practical limitation while designing a physical plant is the spatial limitation. Really, if we think of having an exchanger with 6 meter long tubes, if we really do have that space or we do not have that space is a question that needs to be known to the designer first. That means, the feasibility and the practical implementation is the first and foremost thing that has to be ensured if a design has to work.

Now, when we design very often we focus too much on what exactly is the major equipment. This is often leading us to certain other problems. We have also appreciated so far that the major step or the major equipment is not the end. It also requires plenty of auxiliary facilities.

For example, if you are talking about a plant, what is the power requirement, what where will it be sourced from, what is a water steam and compressed air requirement for its running system, what exactly is a transport arrangement for the material that has to reach. Not only that you have to think about the transport of the equipment to be erected at site.

There is a very beautiful example. One of the refineries while being put up got delayed by about a year because the major equipment which was being transported by waterway, got stuck. It could be refloated and brought to the refinery only when the next monsoon came and the river water level went up.

This is a classic example which definitely will help us to know and which will help us to focus on all the requirements of the auxiliary facilities. It is not just powered water steam or compressed gas. It is related to the transportation of the material, transportation of the equipment, availability of manpower for construction and everything together. This is definitely more important while we are talking about the plant design.

Wherever a plant is being put up the operation is going to generate certain waste. So, the effluent has to be disposed of properly. So, what facility we have, what arrangement we have, and we have to think of the waste disposal and the environmental considerations of the plant.

There are other things like ease of operation, maintenance, erection and commissioning. For example, I will give you a very common example. I worked in two plants which were very similar, one had all the valves which had to be operated manually very close to the waist height of the operating personnel, the others were rather haphazard.

You can understand the ease of operation in the other case was how difficult and definitely while designing you have to give your considerations of the ease of operation, ease of maintenance, ease of erection, and commissioning as well. These make a lot of difference though require a small time or small amount of attention from the designer.

It also translates into another very important factor in the case of process plants. It is closely related to safety of operation, maintenance, and erection. When we are talking about any such project where we are to design a particular plant, we definitely have to go for a technology which is available. And it is available at hand, so that the project can be completed in time. So, the project completion time available to the designer should be definitely known to the best possible way.

The designer with experience will always try to implement systems which are proven. It is obvious because he has weight on those. Thus, it is always better to definitely go for systems which have proven track records. Well, that does not mean that the new technology should be discarded or it should not be encouraged. Yes, it has to be, but it has to be done with definite considerations.

There has to be proven benefits or estimated benefits that can accrue out of such ventures. In case of large projects particularly which involve a substantial amount of capital outlay. The capital availability, its plan of availability, the amount and the layout and time scale is rather important.

That means, if I really have a lot of money available with me while I am designing my refining scheme, I will prefer to put 2 or 3 plants together in one shot, else what I will just go for the first unit which is possibly the crude distillation unit and if it is breaking unit and add other equipment later; after the first portion of the refinery becomes on stream.

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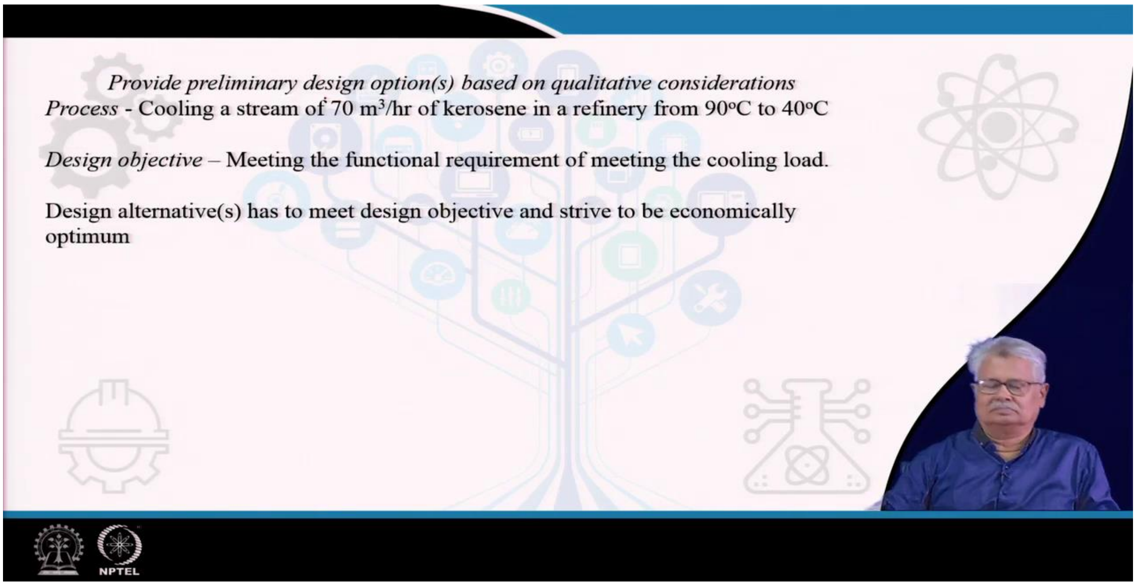

We have a very simple case. We have here a preliminary design problem with us where the processes of cooling a stream of 70 m^3/h of kerosene, which is available in a refinery from its initial temperature of 90°C to a final temperature of 40 °C. Typically, most of the processes before their storage, if it is a light material is standard to cool it up to 40 °C before sending it to the storage.

Here if you look at the design problem which is the way it is posted to us, normally most of the design problems are imposed, they are usually incomplete. But if we look here we have a design objective of meeting the functional requirement, of meeting the cooling load; that means, I know here 70 m^3/h is to be cooled from 90 to 40 °C. Now, we look at the different options of how this can be achieved.

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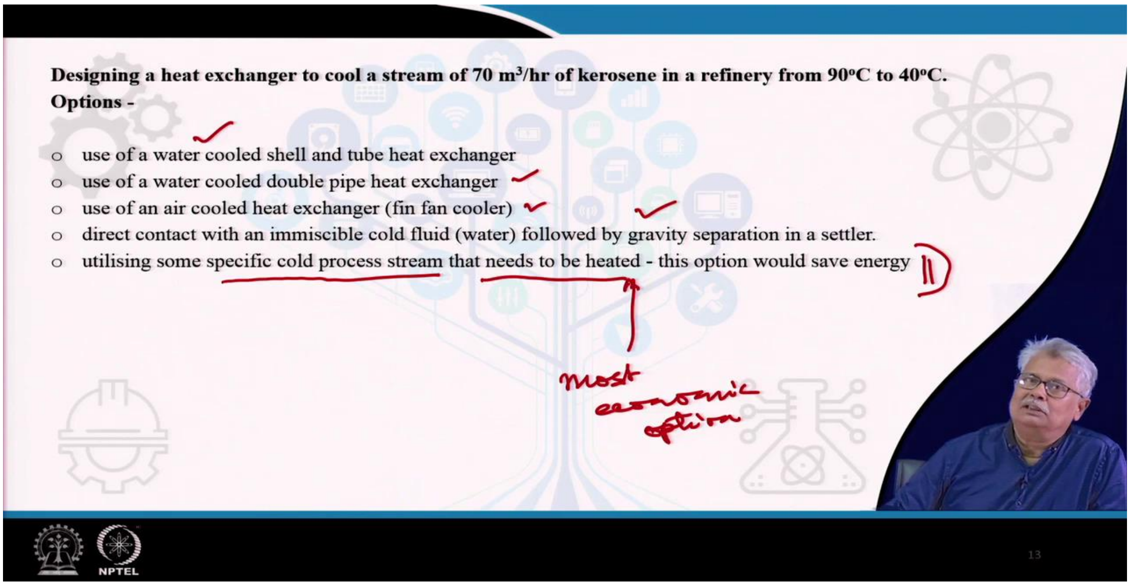

Well, we require the heat to be removed, so possibly the best thing for us is going for a heat exchanger. Now, there are different options just by saying a heat exchanger does not give us a solution. It is possible that we use a water cooled shell and tube exchanger. Well, it is not essential that we go for a shell and tube exchanger, the double pipe heat exchanger could be a cheaper option.

Yes, it is usually cheaper to construct a double pipe heat exchanger as long as the heat duty remains small. Typically, if the heat transfer area is below 35 m^2, it is usually economic to go for a double pipe heat exchanger. We could also go for an air cooled heat exchanger which are called fin fan coolers. Well, this could be an attractive option if we have the plant in a place where water is a scarce commodity.

It is also possible that we have direct contact cooling with an immiscible cold fluid, kerosene does not mix with water. So, we can even consider mixing cold water with kerosene, but remember in this case how feasible it is going to be because the kerosene is available at 90 °C. If you really have to mix it in an open arrangement, there is going to be a lot of hydrocarbon fog or hydrocarbon fume which is going to be generated and that may not be very convenient for you.

But still that remains as a process where we can have a direct mixing of cold water, then send the material in a settler and separate it out. It is also possible that my industry has got some cold process stream that needs to be heated. This heat is picked up by cooling of the 70 m^3/h from 90 to 40 °C.

It serves two purposes, it serves the functionality of the design that we have been entrusted with, at the same time we also solve another problem of removal of heat not only from the kerosene stream, but adding this heat to a stream which was required to be heated. So, it is a dual purpose which gets served this way, and quite naturally if we can really achieve, this is going to be the most economical.

Well, it depends on a detailed analysis, technical, and the economic analysis to see if we really should go for this or not finally. But this is just an example that when a design problem has been posed and there will possibly be several alternatives, and we now appreciate that while solving the design problem based on the heuristics we have generated several solution options and we have to decide what to do finally.

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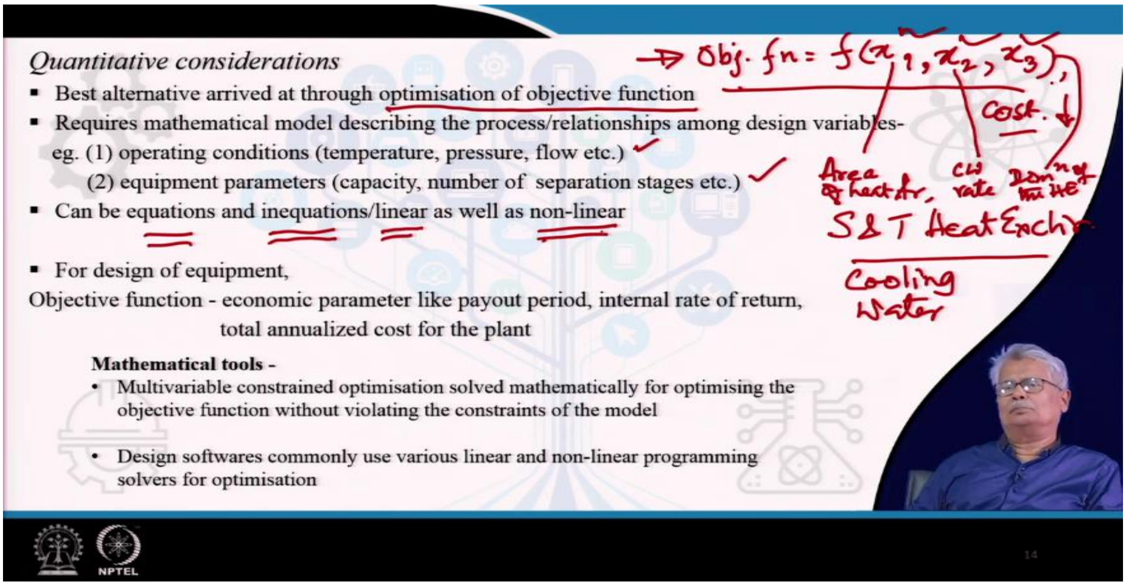

Well, for us let us say that we decide that we are going to use a shell and tube heat exchanger. It is a shell and tube heat exchanger that we are going to use and we are going to use cooling water.

Now, the question is, how do we decide which is the best shell and tube exchanger design for this particular purpose. The selection of the shell and tube exchanger came basically from heuristics, but now in order to establish the basic optimum design of this specific type of heat exchanger, we need to have the optimization.

Whenever we are talking of an optimization problem there has to be an objective, there has to be an objective function when we are solving a mathematical optimization problem. I will just say mathematically, I will just to give you an idea. I will just say the objective function is a function of several parameters of design x1 , x 2 and x 3. Let's say, this could be the cost value.

So, My objective will be to minimize the cost. So, we have to define the objective function which is my cost in terms of different parameters of my design x 1, x 2 and x 3. What are x 1 and x 2 and x 3? These are my parameters of design. What are the examples? The example could be x 1 could be the area of heat transfer. X 2 could be cooling water rate. The x 3 parameter could be some dimension of the heat exchanger.

So, we need to draw an objective function frame in terms of the parameters of design. This is the first step in quantitative consideration. The mathematical optimization we do for this objective function will be giving us the values of x 1, x 2, and x 3. These are the optimum values. If these correspond to the cost value, the objective function will be the minimum cost of my exchanger.

Now, you will also appreciate there will be several constraints. What will be your constraints? The first constraint is the heat load, where a 70 m^3/h flow rate of kerosene being cooled from 90 to 40 °C, there a certain amount of heat has to be removed. So, that is a constraint. If we are designing something where the maximum length of heat exchanger could be 3 m that is another constraint.

That means, what I would like to say here is whenever you have to go for some sort of quantitative considerations and you will have to evaluate alternative tips based on optimization. You will be requiring an objective function, and you will be having this objective function defined in terms of the process design parameters and there will be several constraints which have to obey during your optimization problem.

So, you could see here that the operating conditions are certain variables, the equipment parameters are other variables, and the constraints could be equations or inequalities. The equations could be linear, or it could be non-linear also.

So, one thing is very clear now that if you are talking about optimization of a problem, a mathematical problem which is being optimized, there is possibly a class of mathematical problem which is going to arise. It is a multi-variable optimization problem.

Quite naturally we have talked about x 1, x 2, x 3, multiple numbers of variables. Some of these variables will be the operating conditions, some of these variables will be the equipment parameters. There will be several constraints which could be equalities inequalities and all these mathematical relationships could be linear, non-linear anything.

So, the class of problems normally that you find in these particular design cases are of multivariable nonlinear optimization problems and there are techniques to solve it, but that is a part of mathematics. We appreciate this, at this stage up to this point only.

We need to talk a little bit more about the objective function. One example, we have said that could be the cost of the plant or the cost of the equipment as an objective function which needs to be minimized. If it is a profit, it has to be maximized.

Now, all these, so far what I have said are economic terms. My question now is while we are talking of the objective function; that means, this could be the economic terms, but is it essential that it always has to be a term that has to be optimized? No. Instead of minimizing the cost or maximizing the profit I could also have alternative technical targets. For example, when I am designing my furnace I could also say I would like to maximize the process efficiency of my furnace.

So, instead of talking and saying that it's mostly economic, I could also have a target like efficiency or the number of stages in a plant or some other technical issues or some other technical parameters. By maximizing or minimizing them, we achieve the same economic objective.

So, the objective function need not necessarily always be an economic parameter but usually for large plants it is an economic parameter like profitability. But for most small equipment designs, for example, distillation column or heat exchangers, it normally will be some other technical parameter like efficiency etc.

We look at the other part now, the mathematical tool. The mathematical tool that we require should be capable of solving the multivariable constrained optimization problem. There are several techniques for this. We will not go into the details of this. But we know that that is a part of mathematics pretty well developed and there are plenty of mathematical packages which will offer this type of solving in case we are able to formulate the problem and submit it to it.

Nowadays, there are plenty of design software and simulation software which incorporate these. These quite naturally it could be integer programming, it could be linear programming, it could be non-linear programming and solvers which are these days in many cases are integral part of the simulated and simulation software.

So far we talk about the qualitative considerations, now we talk of the quantitative considerations. In quantitative consideration when we go for the detailed optimization, we have to resort to mathematical techniques that involve primarily, optimization of multiple, multivariable solutions, multivariable problems formulated and these techniques could be linear, non-linear or anything for that matter.

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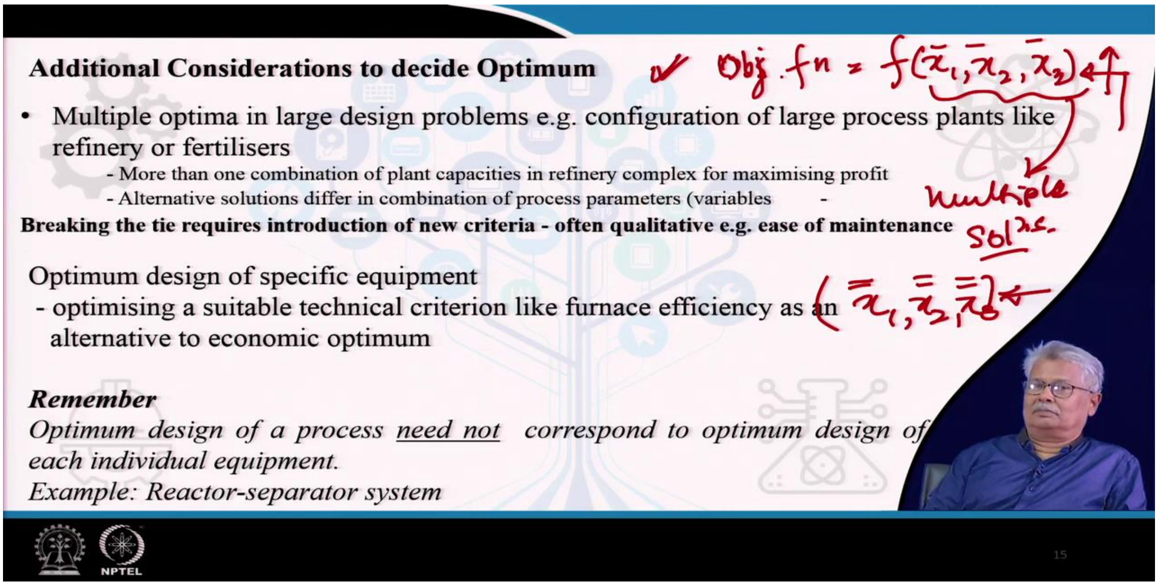

We have talked about solving a particular mathematical problem. We have also said that we have multiple variables and a single objective function to either maximize or minimize depending on if it is a cost or profit or if its efficiency or loss of heat or whatever it could be.

Now, there are certain very interesting mathematical things which happen. I have written the objective function as earlier in terms of 3 functions, 3 variables x 1, x 2, and x 3. Using mathematical techniques is supposed to give us the optimum objective function. Basically what we will be getting here is an objective function which is a function of x 1, x 2, and x 3. The bar now denotes the set of values which maximizes my objective function.

$$obj.fn = f\left(\underline{x}_{1,}\underline{x}_{2,}\underline{x}_{3}\right)$$

Now, my question is or rather we need to appreciate one more thing: when we have a large number of variables and a large number of constraining equations and inequations, you will always have multiple solutions. Now, what does this multiple solution means?

It simply means x 1 bar, x 2 bar, and x 3 bar which I have shown here on the board is not the only set which gives you the minimum value of the objective function. I could also have a combination of x 1 double bar, x 2 double bar, and x 3 double bar which is going to give you the same objective function as well. Mathematically, it may be as follows: $\left(\underline{x}_1, \underline{x}_2, \underline{x}_3\right); (\bar{\bar{x}}_1, \bar{\bar{x}}_2, \bar{\bar{x}}_3)$…..etc.

So, possibly the user or the designer when he finds there exists multiple solutions he has to choose between the two. The question that I have here right now is how does it do it? How will you do it? So, the most common thing which is done is something like this.

For example, it is like this, I have decided that I am going to design a refinery with these, these, these plants and for the moment the plants are only 3 in number and their capacities are going to be x 1, x 2, and x 3. And I find there could be several combinations of these 3 plant capacities which is going to give me multiple solutions of my objective function. Now, which one should I opt for?

One option will be, if I have noted these and these solutions and if I bring in a new criteria. What could be the new criteria in case of a refinery? It could be the pollution level, the pollution it is going to create. It is going to give us the same profitability whether we have the combination of bar or the double bar.

But the level of pollution that is going to create will be different. It is obvious that we will opt for either the bar option or the double bar option of the combination of the capacities depending on in which case my position is lower. So, here I would like to say is an example where more than one combination of the plant capacities in the refinery is going to give us the same optimum value, alternative solutions do exist, and we break the tie by introducing a new criteria which could be qualitative even.

In this specific case, I have said it is possible for me to evaluate the pollution for example, the tons per hour, emission of sulphur dioxide from the refinery. But it could also be some other, it could also be some other criteria. For example, I could go for a vendor which is more reputed.

I could go for another option or another technology which requires less maintenance which are qualitative criteria that I am going to bring in. But one thing is true in both the cases we usually will be bringing in for breaking of the tie in new criteria which could be quantitative, it could be qualitative as well.

This is more common in case of designing large plants or complexes or even plants where there are certain small sub processes. We definitely have to look at the other case of optimum designer specific equipment. I have already said that the efficiency of the furnace could be a parameter which could be an alternative to the economic optimal.

And the lesson of what we have said so far in the last few minutes is we have to remember that optimum design of a process did not correspond to the optimum design of each individual equipment. I will give you an example of this as well. You may feel at this stage that if I optimize every subunit of my entire complex to the best possible optimum option, we will definitely be achieving the global optimum. No, I give you an example and with that possibly I will be stopping here today.