Principles and Practices of Process Equipment and Plant Design
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Lecture – 01
Introduction

Good day to you all, today we are going to start a new course on the Principles and the Practices of Process Equipment and Plant Design. The course will be taken jointly by Professor Gargi Das and myself S Ray and today we have the first lecture which is on the Introduction to the topic.

If you look at a topic, there are few things that we definitely have to appreciate right at the beginning that we are going to talk about the principles as well as a practices. And three more keywords are also there; the first is the process, the second is the equipment, and third is a plant and the plants design, so this is what we start off.

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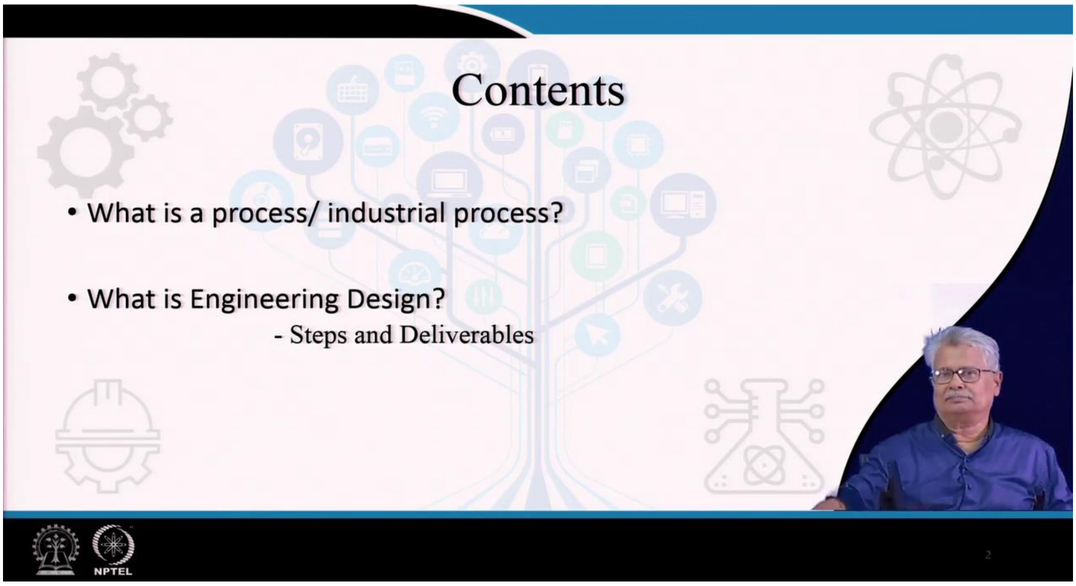

The first question that must be answered in this particular state is what exactly is a process and since we are talking about it process design which definitely is pertinent to industry and industrial processes. We would also like to have a definition of the industrial process.

After all, it is a part of engineering. So, a question should also be cleared in our mind, what we really mean by engineering design. We need to talk about the steps in achieving a final engineering design and look at the deliverables to be provided from this course.

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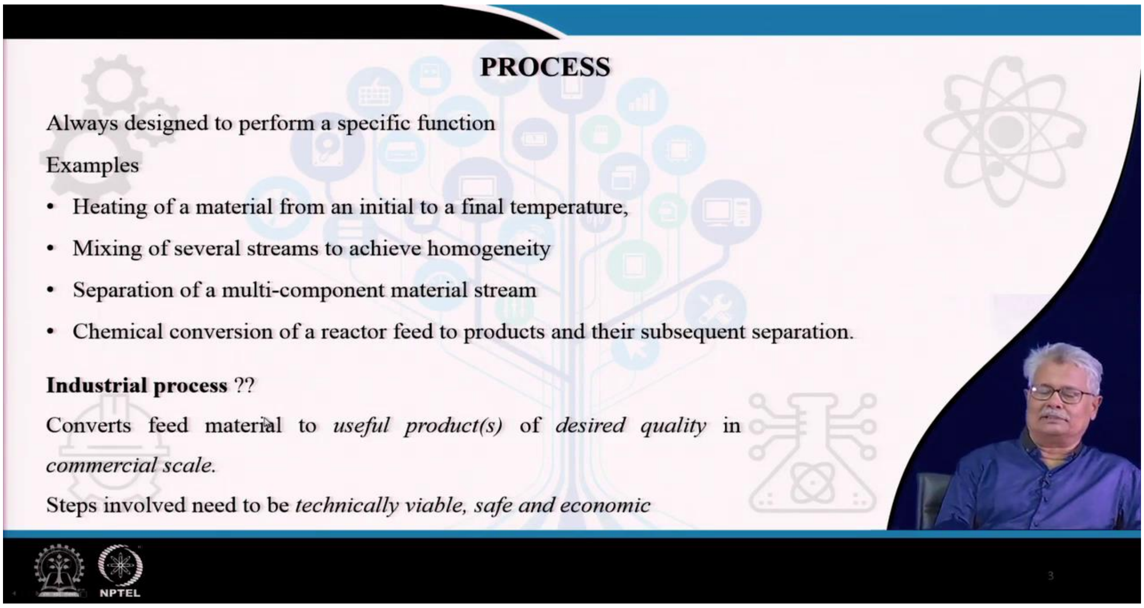

If we talk about a process, a process is always with a function, a very specific function. For example, if you are talking about a material, which has to be heated; it could be a kerosene stream of may be 70 m^3/h, available at a temperature of 30 ˚C to be used as a solvent and is to be used after heating it to a temperature of about 85 ˚C.

So, the process is in this particular case, heating of a particular liquid stream, which is kerosene from an initial to a final temperature. We definitely also have the definition of process in terms of unit operations and unit processes; the conventional definition of unit processes says that it involves a step of reaction, whereas in, it is only the physical processes in case of unit operations.

For example, if we are talking about a physical process of mixing as an unit operation, where we mix several streams to achieve homogeneity; yes, it is a process definitely, which does not involve any chemical reaction, but involves physical process of mixing.

Similarly, if we talk about a separation of a multi component materials stream, for example, the separation could be based on various different things. If it is a solid stream, it could be based on size, it could be based on various other properties like magnetic nature or all or it could even be a homogeneous mixture of different hydrocarbons being separated, either by the chromatographic process in the industrial scale or even by distillation.

We talk about reactions, which is also a process; it basically involves chemical conversion of the reactor feed to products and quite naturally in almost all cases of chemical reaction, you will always have a separation product step for the product. So that you can sell the produce that you have got out of the reaction after separating it to the required purity.

Now, with this in our mind, I believe we have a fair description with us, what exactly is a process. The next point which comes into our mind is basically, what is an industrial process. Yes, we have several processes in our laboratories; we definitely will be calling a process, an industrial process, when it has got some commercial manifestation. For example, it converts feed material to useful products, a single or a multiple number of products of a desired quality in commercial scale.

Normally, that is the conventional idea about an industrial process. The steps involved, obviously it needs to be technically viable, safe and economic. So, one major feature of an industrial process is the steps are feasible or viable and economic and they definitely have to adhere to the safety standards.

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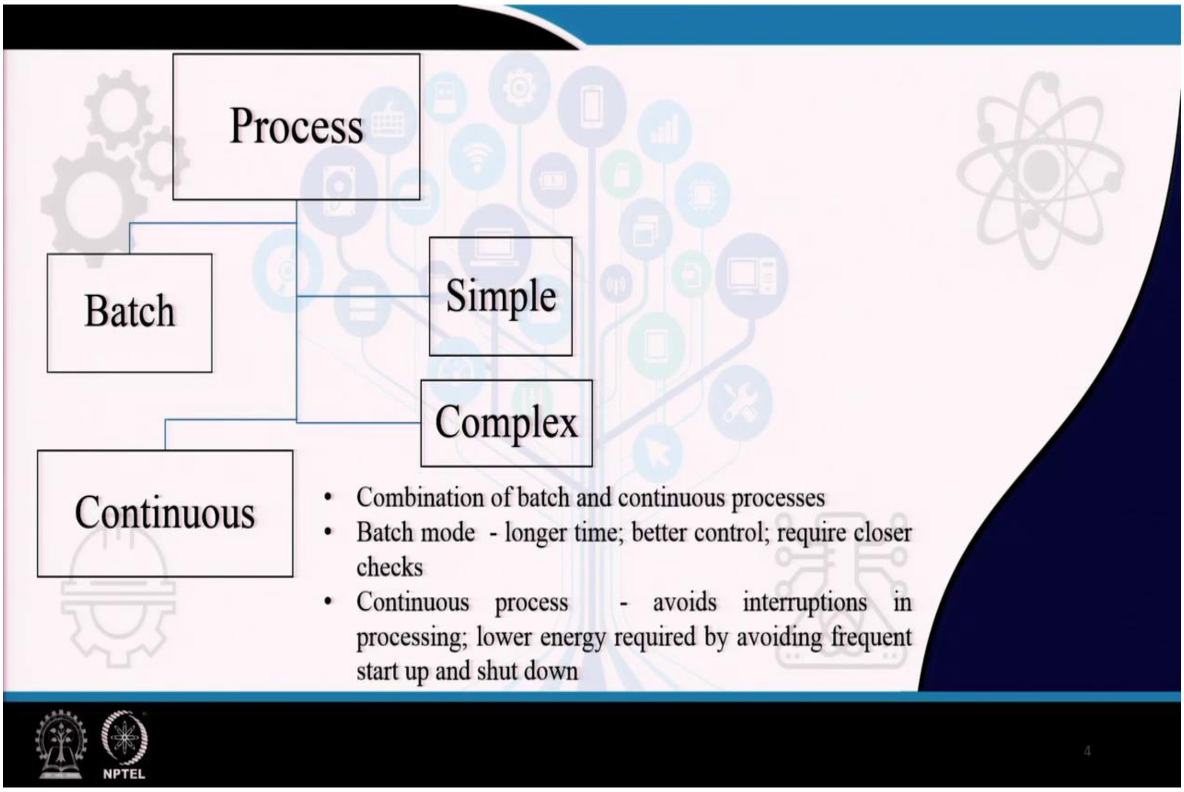

If you look at different types of processes and their classification, obviously the simplest classification would be a simple process and a complex process. The process can also be performed as a batch or it could be a continuous process also. There are several cases of combination of batch and continuous and definitely there are certain advantages and disadvantages of each.

In case of a batch normally what we do is, we have a set of equipment; we feed it first with the set of the feeding material. It could be the reactants in case of a reaction batch or it could be some feed batch in case of some sort of physical processing like distillation, it could be crushing, grinding anything like that and we perform the operation.

At the end of the operation or the end of the batch naturally what we do is, we take out the material and go send it for further processing if required. So, one thing is true that in case of any batch process, there will be startups and shutdowns. And you also have to remember that in any batch operation, the entire feed material of the batch is normally fed to the batch equipment in one shot.

So, if I have a processing system for 10 ton per day and if I decide that I will be doing it in a batch; my batch should be capable of holding all the 10 tons of material together. It is also possible that I have the 10 ton per day capacity broken into maybe three shifts, roughly about 3.3 tons per batch and we have a set of different equipment.

But one thing is true that compared to the continuous processes, the batches will have several startups and shutdown phases, and naturally in between will be the batch operation stage. In comparison to this, in the case of continuous plants, you do not have such startups and shutdowns frequently. What you have instead is, you have a startup, you operate your plant continuously as long as you require it to operate and then shut it down.

So, this gives us a few interesting features of the batch and the continuous. The first thing, since the entire batch feed has to be held in the same equipment as the batch starts; the batch equipment for the same capacity per day will be much larger in size. In the case of, continuous plant, for example, if I am processing 10 tons per day; the capacity will be, the capacity of processing will be 10 divided by 24 hours, roughly around maybe slightly less than 0.5 tons per hour.

So, quite naturally at a time inside I will be having a much smaller quantity of hold up in case of continuous equipment and my process equipment size is going to be much smaller. So, one thing is absolutely clear at this particular point that, the batches will have several startups and shutdowns, continuous plants will have much less number of startups and shutdowns. The batch equipment size is supposed to be much higher as compared to the continuous plant.

There are other features also which makes at times, if the batch processing more advantageous. For example, if you are processing something in a batch and something goes wrong; it is only the material inside the batch which is lost, with respect to quality that is what I am talking about.

That means, in my batch processing, the maximum amount of loss from a batch is a batch size; that means if I lose a particular batch in the previous example which I gave a 10 ton per day. I will lose about three and a half tons of the material which is off quality material, which I can correct later on.

But, at the same time I have more ways of concentrating or processing. I can more precisely look at the temperature and pressure conditions of every batch. In the case of a continuous plant, definitely we would like to monitor the temperature and pressure or other process conditions.

But at the same time I would also like to say that in case of continuous processing, the material that I produce right now goes to the storage and mixes normally with the rest of the material. So, there is a chance that if I am sending it to a particular tank, possibly my entire tank will be going off, If I have something wrong in my continuous processing.

So, these are basically the basic differences or merits and demerits of batch and continuous and there is one more demerit which is written in the slide itself. That means since you do not have many shutdowns and startups in case of continuous processing, your energy requirement which is spent a lot in the startup and shutdowns is going to be much less in case of continuous processes. But it is going to be higher in the case of a batch.

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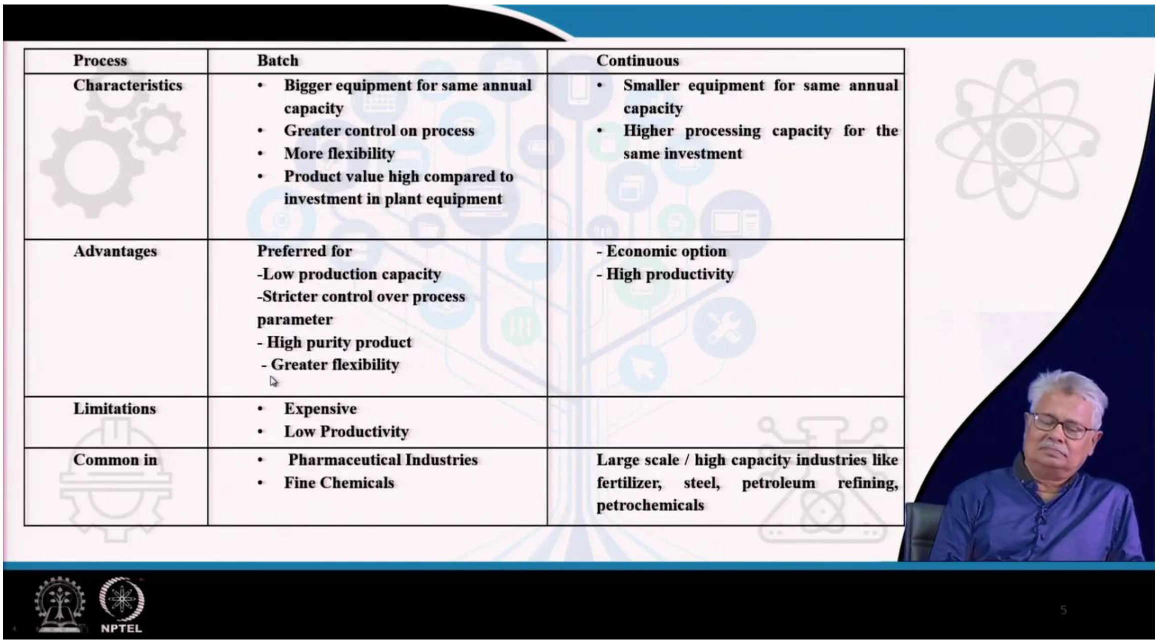

Process	Batch	Continuous
Characteristics	• Bigger equipment for same annual capacity • Greater control on process • More flexibility • Product value high compared to investment in plant equipment	• Smaller equipment for same annual capacity • Higher processing capacity for the same investment
Advantages	Preferred for -Low production capacity -Stricter control over process parameter - High purity product - Greater flexibility	- Economic option - High productivity
Limitations	• Expensive • Low Productivity	
Common in	• Pharmaceutical Industries • Fine Chemicals	Large scale / high capacity industries like fertilizer, steel, petroleum refining, petrochemicals

So, with this what we do is, we look at basically the characteristics, advantages, limitations and what are common in the batch and continuous things. The first thing in case of a batch we find that it is a bigger equipment that is required, you can have a greater control on the process, and you definitely do have more flexibility.

Because you can use the same set of equipment for producing different quality of material by just altering either the processing time or slightly touring the temperature, pressure, flow and level and the processing mode. The product value normally if it is high, in the batch extra spent money on the batch process usually pays off.

In case of continuous processing, you definitely do have a smaller equipment; you have a higher processing capacity for the same equipment size and that is basically a reward of what I have just now said. If you are talking about the advantages of batch, we definitely will prefer it for low production capacity; because if we really want to have a large batch, our equipment size has to be huge.

Wherever we require restricted control, we usually prefer a batch. For example, if we really want to go for a high product purity; for example, in the case of pharmaceutical products, which require a very high standard of quality, you usually go for a batch. You also get greater flexibility in processing of batches.

Continuous usually is an economic option and has high productivity. There are limitations of batch, for example, two things; the first thing is, it is expensive, in a related scale of cost and its productivity per unit volume of the equipment is low, compared to the continuous processes.

Batch processing definitely is usually for more expensive material that is what you find in the fine chemical industry as well as the pharmaceutical industry. Whereas usually you will find the large industries or the large scale production facilities and fertilizers, refineries, petrochemicals they normally will be using continuous processes.

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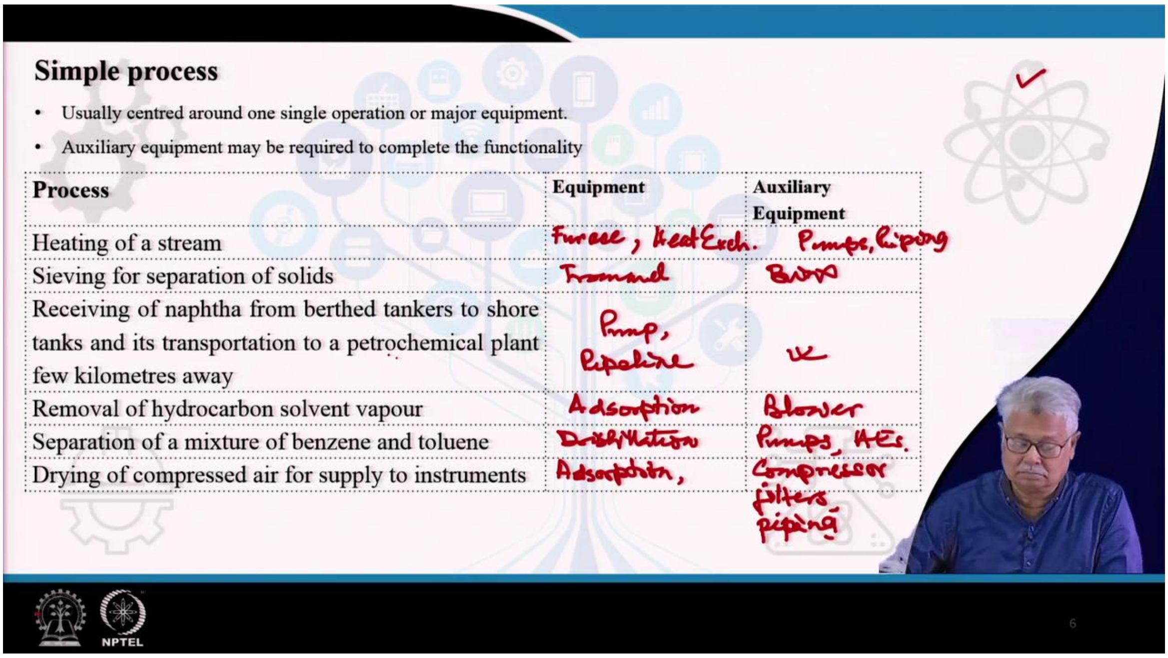

We had another demarcation, the simple process and a more complex process; usually if I have a single step of processing. For example, I am going to distill a mixture of benzene and toluene into some purity of benzene and some purity of toluene, it is a very simple process and it involves a single piece of equipment.

So, in case of a simple process, possibly we will be defining a simple process by it, such processes where we usually have a single unit operation or a unit process; but one thing we must remember, there could be certain auxiliary processes which could be necessary in order to execute this particular step.

One such example is yes, we have a distillation column; but a distillation column is just not a standalone thing, we need to have pumps, we need to have condensers, we need to have storages and similar auxiliary facilities. We need to have a furnace possibly or a heat exchanger to supply heat to the distillation process.

Certain example processes are here; one is heating of a particular stream, the example which I gave of heating of a kerosene stream from 30 to 70 ˚C earlier. We see for separating solids according to the size. If we receive naphtha from the berthed tankers to the shore tanks and for transportation to a petrochemical plant a few kilometers away, yes that is also a process.

Removal of hydrocarbon solvents, vapor separation of a mixture of benzene and toluene, the example which I just gave; drying of compressed air for supply to instruments. Now, since all of these are processes and all of these processes work around specific steps or specific equipment, let us try to identify the difference, let us try to identify the different equipment and auxiliary equipment involved.

The first thing is heating of a stream; the major equipment in this particular case could be a furnace or it could be a heat exchanger also. In order for the stream to flow, we need to have auxiliary equipment; for example, we need to have the pumps and we need to have the piping.

So, you definitely will be appreciating at this particular point that your process will consist of equipment as well as auxiliary equipment. The sieving for the separation of solids perhaps will involve a trammel; but it will also involve certain bins for storage.

For receiving of naphtha we will require a pump, it will involve a pipeline, and it will also have a lot of instrumentation involved. Removal hydrocarbon solvent vapour possibly will be done by the process of adsorption; possibly you will be using a carbon molecular sieve or charcoal whatever is your adsorption material. But at the same time you have to make the material flow, so you need to have blowers in place.

The separation mixture, the separation of a mixture of benzene and toluene could be done by distillation efficiently. But you will definitely be requiring certain other things, which I have mentioned, you require pumps, you require heat exchangers. The drying of compressed air for the supply to the instruments normally involves adsorption; but you will be requiring compressors and you will be requiring filters and you definitely will be involving piping networks also. So, we move forward now.

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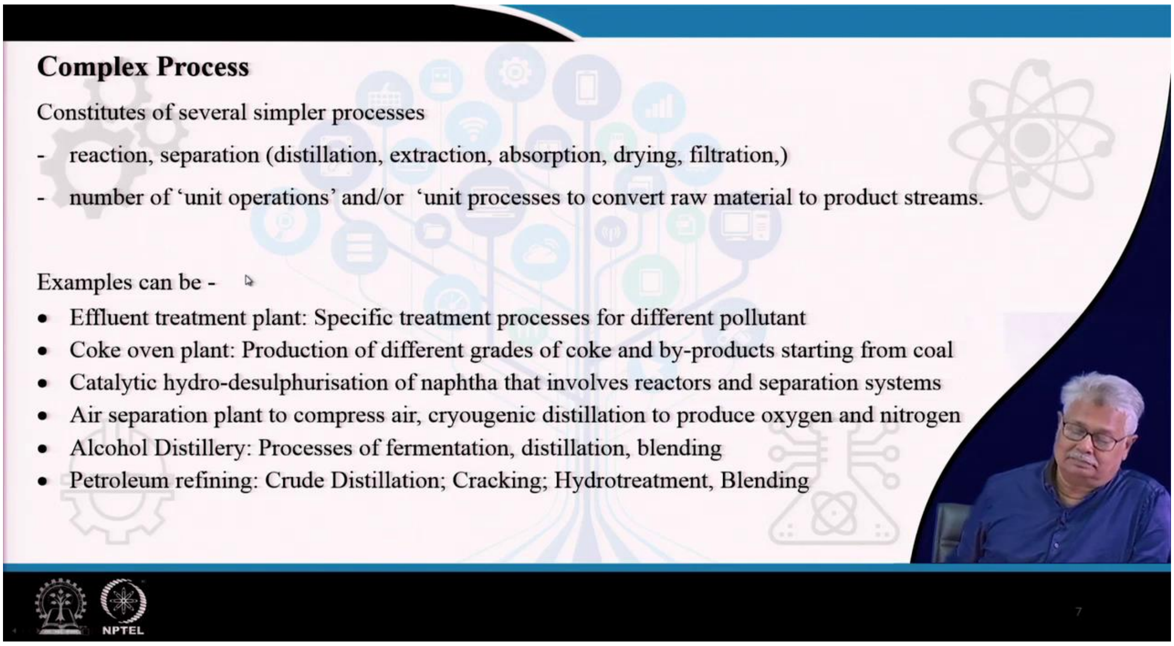

We come to the complex processes, the complex processes will normally be constituting several simpler processes. You will have such simpler processes involving reaction; it could be a separation process also, the separation process could be distillation, extraction, absorption, drying, filtration and many others.

You may definitely get involved in different types of unit operations or unit processes as we have mentioned and there could be combinations of these as well. I will give you certain examples; the first example is that of an effluent treatment plant.

Normally, in any particular process plant, there will be an effluent which will be constituting different pollutants, which require separate treatments, some require adsorption, some require skimming, some require some sort of chemical treatment in order to get rid of those. So, quite expectedly such effluent treatment plants are complex processes, consisting of different types of treatments.

If you look at the coke oven plant, the plant is mainly for production of different grades of coke and it also produces by-products starting from coal. So, it is not just the process where you have the coke oven itself, there is a lot of other equipment and other processes which are associated.

So, all individual such processes may be simple processes, but the overall process naturally is a complex process. Air separation plant is also another example, where you compress air and distill the air after it liquefies. Similarly, the example of alcohol distillery, the example of petroleum refinery all these are different complex processes.

In case of refining, the major process is that of distillation; crude distillation is the third step in any refining process. But apart from this you have other processes, which could be cracking of hydrocarbon, hydro treatment to remove certain impurities, and blending of streams. So, all these together make the complex process.

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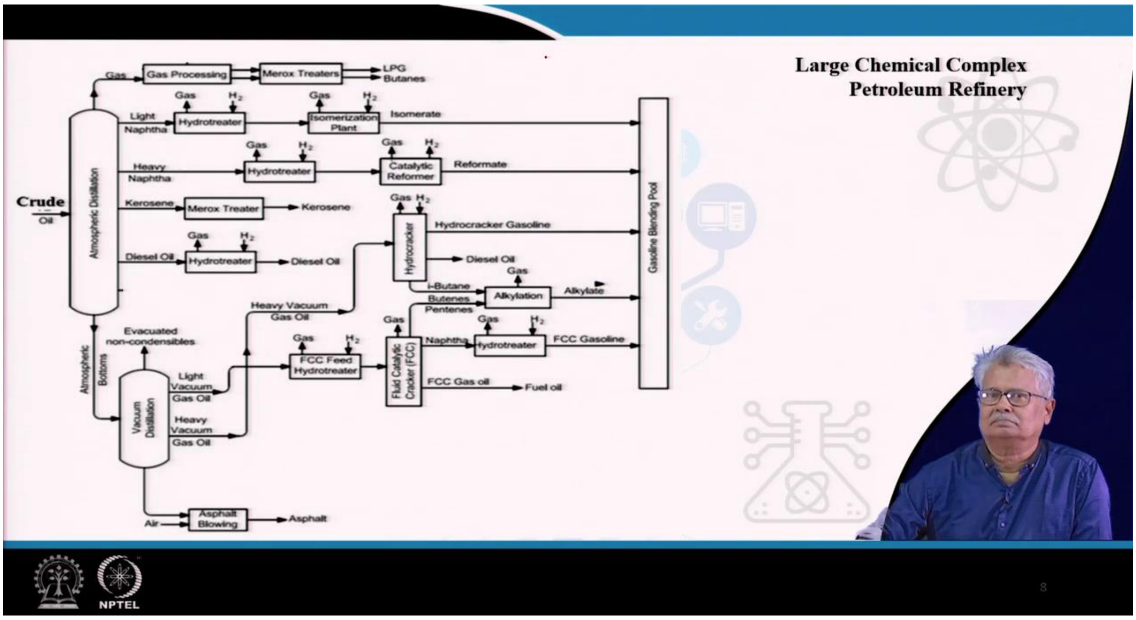

We have an example here. We have an example in the sense what we have here is, the first unit is the atmospheric distillation column which is at the extreme left. It produces gas, it goes into the gas processing section, it goes into treaters, and it produces LPG and butanes. You have a light naphtha stream which goes for hydro treatment, it goes for isomerization and it produces isomerate, which is also a product and goes into gasoline blending.

Similarly what I would like to say is, there are different blocks here; in fact though we have just attempted here to represent the entire processing of the refinery on a single sheet. Actually each of the blocks which have been placed here are rather complex processes. The entire thing leads to the integrated plant for manufacturing petroleum products; this is the petroleum refinery example.

For example, if we look at the atmospheric distillation unit, the vacuum distillation unit, these two are the major distillation units here. Well, there are other subunits within these boxes, which also will be involving the process of distillation and each of these are complex processes and the entire thing is often called a refinery complex.

So, we have an idea at this particular point to say, we have simple very simple processes or simple processes. We have more complex processes and we have large complexes like the refinery complex or the petrochemical complex or the fertilizer complex, which consists of several plants intermingled together.

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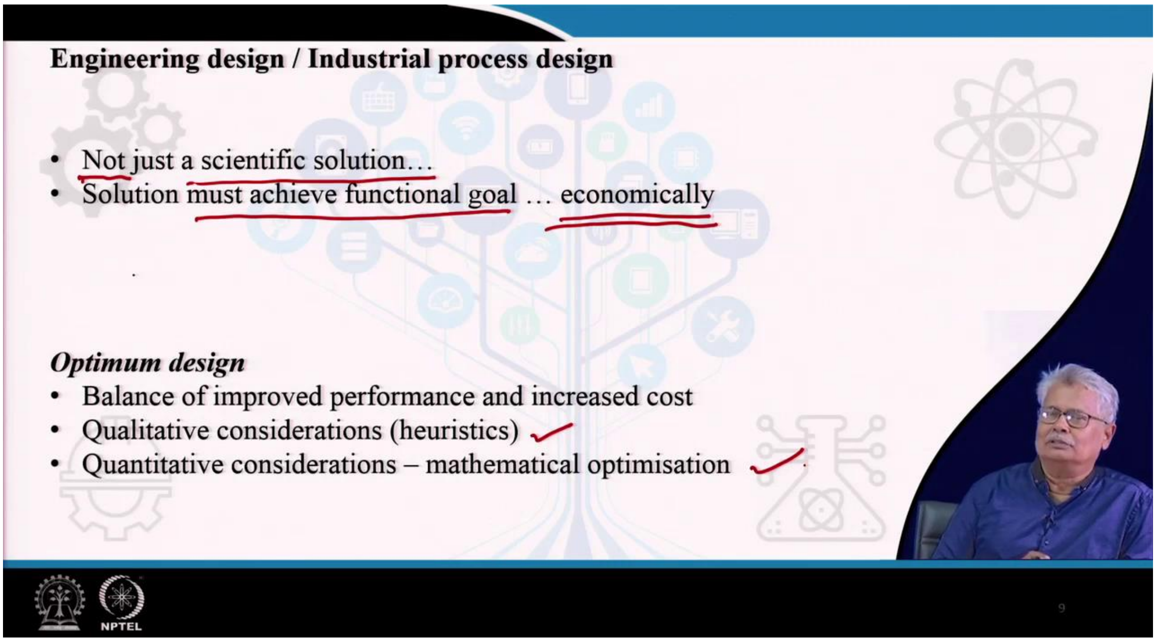

So, we have some idea about the plant. What we do now is, we talk about engineering design or industrial process design. The basic difference in the case of engineering is not just science; it also involves a good amount of economics. So, what we look for in an engineering design solution or an industrial process design; it is not just the scientific solution, it is not just the scientific solution that we are looking for.

The solution definitely must achieve the functional goal; we have talked about the functional goal and different examples earlier, but it must be achieved economically. So, in a sense if you are talking of engineering design, there are two features; the functional goal must be achieved and it has to be achieved economically. It is obvious that in order to achieve anything in reality, it must have a scientific solution.

So, definitely the solution is a solution as long as it is based on the fundamentals; it serves the functionality and it works economically. We definitely have to talk about design; very often we hear the term optimum design. By optimum normally we mean, we gain one way and we lose other ways and there is a balance.

So, basically in case of optimum design what we look for is a balance of improved performance and increased cost. Yes, we can improve the performance even more by investing more; but by increasing the cost, there has to be a balance. Now, in order to obtain the optimum design, it is essential for us that we achieve it quickly. Quite often there are quite a few thumb rules or heuristics. These are basically the qualitative considerations.

The hypothetical or rather the theoretical heuristics can lead to near optimum; but if you really have to achieve the exact optimum or a working optimum about which you are confident, only the qualitative considerations do not help. One got to have quantitative considerations on the mathematical optimization technique also resorted too. So, you definitely will be using heuristics in your design and you will also be using certain mathematical techniques to optimize your design, so both are required.

Thank you, I think from here we start off in the next class.