Plant Design and Economics

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Lecture - 01
Introduction

Welcome to the course on Plant Design and Economics. I am Debasis Sarkar from Department of Chemical Engineering at IIT Kharagpur. Plant Design and Economics is a core course for undergraduate chemical engineering students. This course is also useful for students from allied disciplines such as Chemical Technology, Environmental Engineering, Biotechnology, etc.

Students who are writing GATES will also be benefited from the course. Practicing engineers will also be benefited. Now, as a chemical engineer, you have to design, develop, construct operate a chemical engineering process in a most economic and safe manner. Also, it has to be profitable. For that, you have to choose the best pieces of equipment, the best interconnections among these equipment.

You have to arrive at best operating conditions and overall the operation has to be safe, reliable and profitable. Now, how you do this will be the subject for this course. As the name suggests, this course will cover two major aspects of chemical engineering, design of a chemical engineering plant and economic analysis of a chemical engineering process. So let us start.

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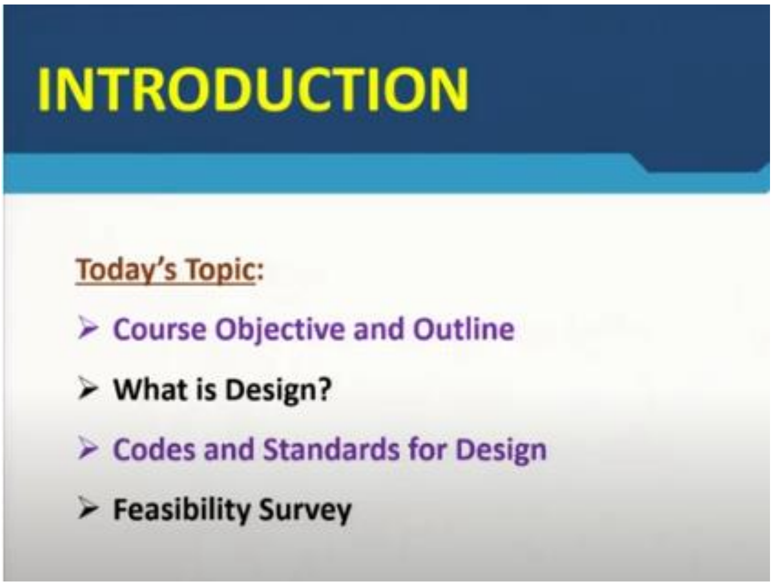

So today, we will first outline the course objectives. Then we will briefly introduce what exactly chemical engineering design is. We will talk about codes and standards for design. And then we will briefly touch upon feasibility survey.

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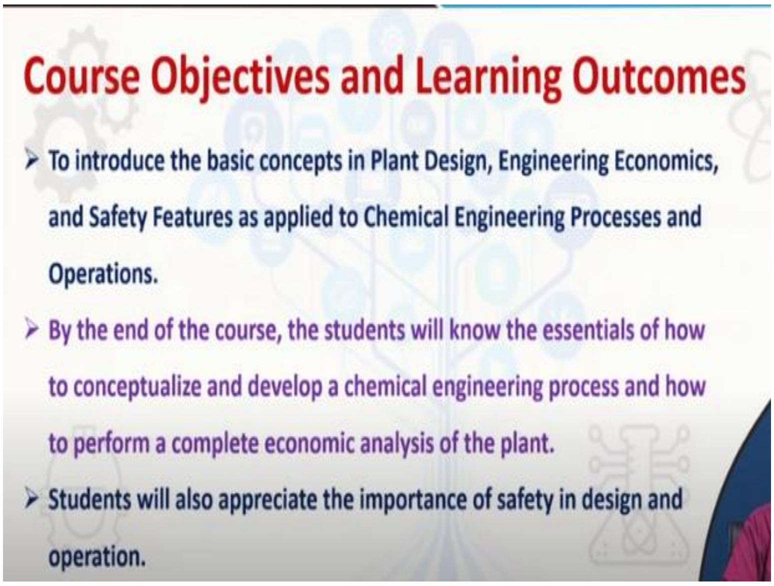

The course objective and learning outcomes are as follows. We used to introduce the basic concepts in plant design, engineering economics, and safety features as applied to chemical engineering processes and operations. By the end of the course, the students or the participants will know the essentials of how to conceptualize and develop a chemical engineering process and how to perform a complete economic analysis of the chemical engineering plant. Students will also appreciate the importance of safety in design and operation.

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So this is the course outline. What you see now is plan for first six weeks. In the first week, we will talk about basic aspects of process design. In the next week, we will concentrate on selection of process equipment, utilities, how to select plant location, and plant layout. The next three weeks, week 3, 4, and 5 we will talk about engineering economics.

So during these three weeks, we will talk about in detail economic analysis of chemical engineering plants. In the sixth week, we will talk about conceptual process synthesis. We will see shortly what we mean by process synthesis.

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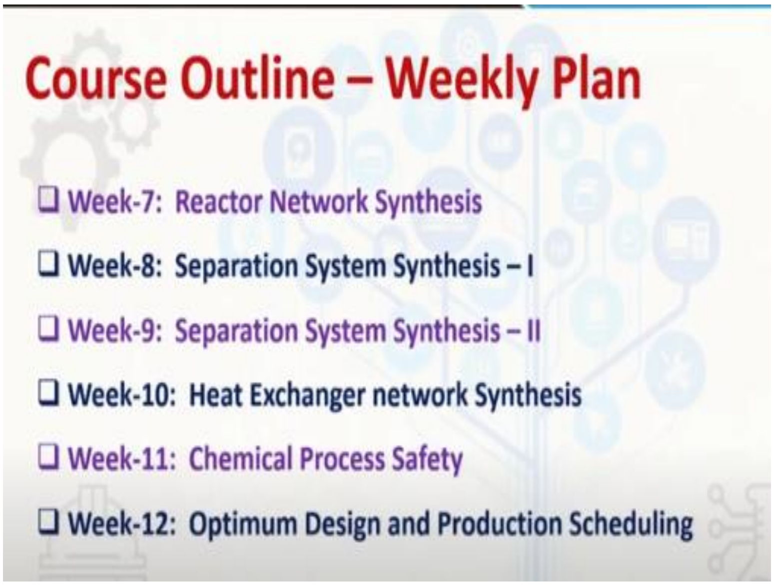

Next week seventh to week twelfth we will see reactor network synthesis in week 7. So we will learn how to synthesize reactor networks, chemical reactor networks. Then week 8 and week 9, we will talk about synthesis of separation systems. Chemical reactor is often the heart of the chemical engineering process. Immediately after that, oftentimes separation system will follow.

The separation systems is very important for chemical engineering plants. And we will devote two weeks for synthesis of separation systems in week 8 and week 9. In week 10 we will talk about synthesis of heat exchanger network. Chemical process safety is a very important issue and week 11 will be devoted for chemical process safety. Finally, on week 12 we will talk about optimum design and how to do production scheduling.

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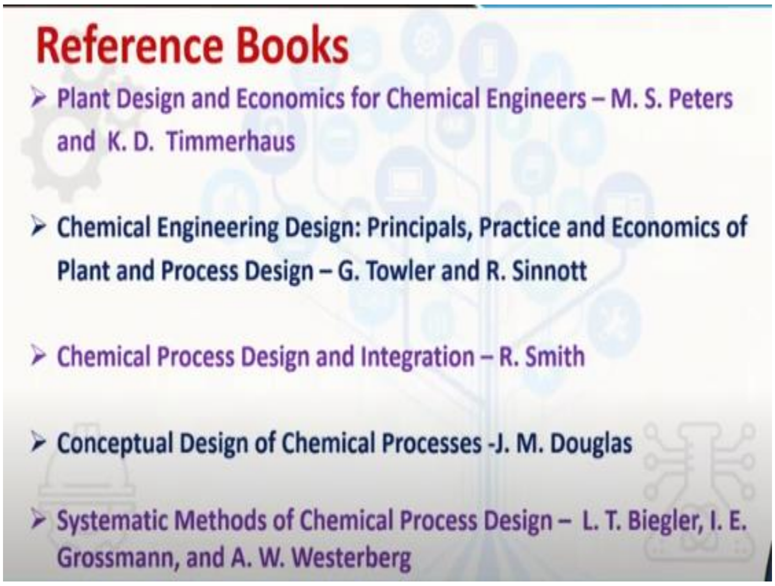

These are the references book, Plant Design and Economics for Chemical Engineers by M. S. Peters and K.D. Timmerhaus. Chemical Engineering Design: Principles Practice and Economics of Plant and Process Design by G. Towler and R. Sinnot. Chemical Process Design and Integration by R. Smith. Conceptual Design of Chemical Processes by J. M. Douglas. Systematic Methods of Chemical Process Design by L. T. Biegler, I. E. Grossman and A. W. Westerberg.

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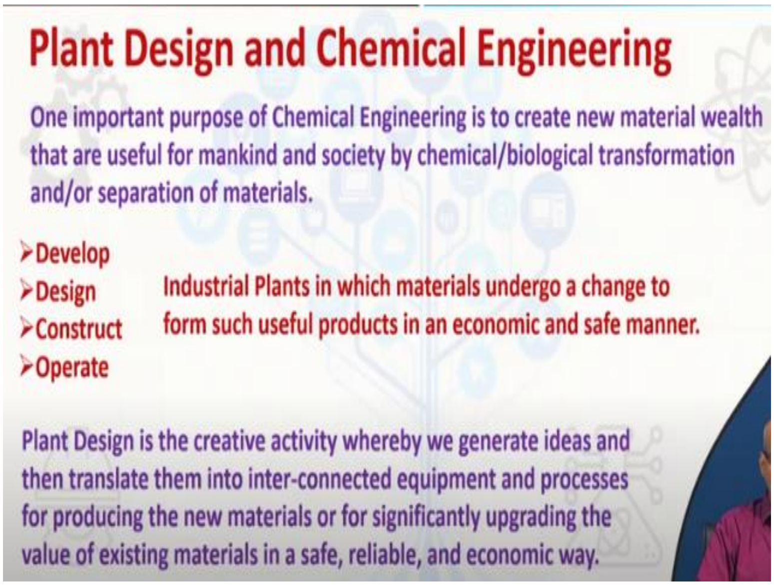

Now, one important purpose of chemical engineering is to create new material wealth that are useful for mankind and society, by chemical transformation or biological transformation or physical separation of materials. As chemical engineers, you have to develop, design, construct, operate industrial plants in which materials will undergo a change to form such useful products that are useful for society and mankind in an economic and safe manner.

So plant design we will define as the creative activity where we generate ideas, and then translate them into interconnected equipment and processes for producing the new materials or for significantly upgrading the value of existing materials in a safe, reliable, and economic way. So that is how we will define the plant design activity.

So it is a creative activity, whereby we generate ideas and then translate them into interconnected equipment and processes for producing new materials or for significantly upgrading the value of existing materials in a safe, reliable and economic way.

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Now, chemical engineering plants produce a broad range of products. An approximate classification of these products can be the commodity of bulk chemicals, fine chemicals or specialty chemicals. Now commodity or bulk chemicals are produced in large volumes. The important considerations here is chemical composition, purity and price. Examples of some commodity or bulk chemicals are ethylene, acetone, sulfuric acid, nitrogen, oxygen etc.

Here the value addition is generally low. We can define the value addition as difference of selling price and cost price of products and raw materials respectively. So selling price of products minus cost price of raw materials is the value addition. So, the value addition for commodity or bulk chemicals is generally low. Now, fine chemicals are produced in smaller volumes compared to commodity or bulk chemicals.

Important considerations here also are chemical composition, purity and price. Some examples are chloropropylene oxide, dimethyl formamide, n-butyric acid etc. The value addition that is selling price of products minus cost price of raw materials are relatively higher compared to bulk chemicals.

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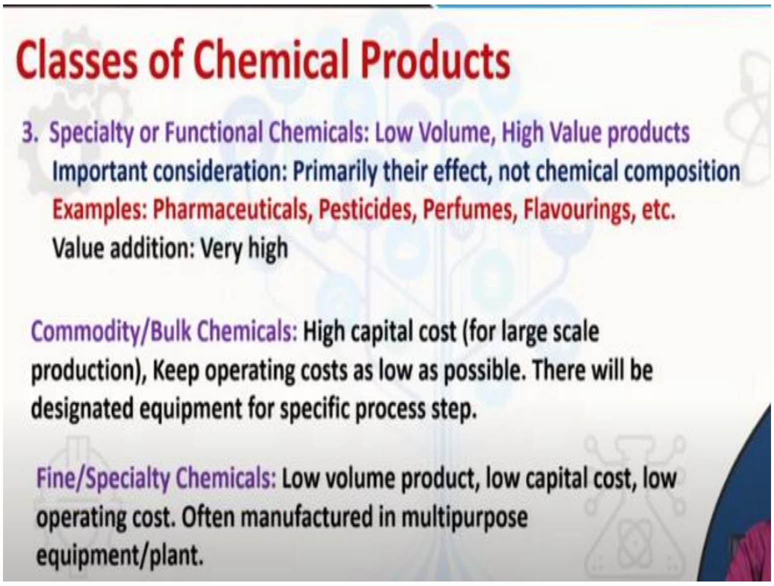

Finally, specialty chemicals are also known as functional chemicals. These we produce in low volumes, but they are very high value products. Here important consideration is primarily their effect, not chemical composition. We buy these products for their effect. For example, pharmaceuticals, pesticides, perfumes, flavorings. We all buy such products because of their effect.

So the value addition is very high compared to other two category products. For commodity or bulk chemicals, high capital cost is required because we produce them at large scale. So we keep the operating cost as low as possible. There will be designated equipment for specific process steps. Generally, these are produced as continuous operations. Fine chemicals or specialty chemicals, they are low volume products.

They require low capital cost, low operating cost and often they are manufactured in multipurpose equipment or plant. So the same plant or equipment can be used to produce various types of fine or specialty chemicals. They are generally produced in batch plants.

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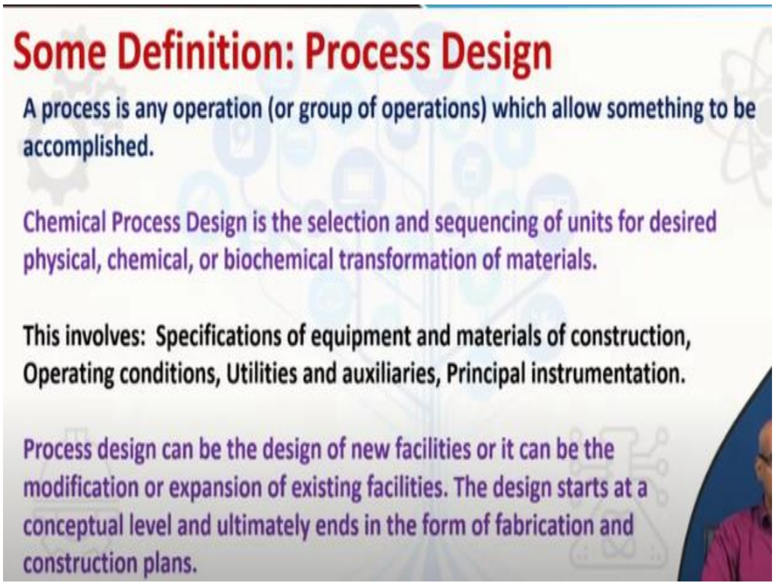

Let us now introduce some definitions. Process design. A process is any operation or group of operations which allows something to be accomplished. Chemical process design is the selection and sequencing of units for desired physical, chemical or biochemical transformation of materials.

This involves specification of equipment and materials of construction, specification of operating conditions, utilities and auxiliaries as well as principle instrumentation. Process design can be the design of new facilities or it can be the modification of expansion of existing facilities. The design starts at a conceptual level and ultimately ends in the form of fabrication and construction plans.

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Next, we introduce the definition for process synthesis. Process synthesis is the step in design where the chemical engineer selects the unit operations, the component parts, their interconnections and operational conditions to create an optimized process flow sheet or flow diagram that meets given objectives and constraints. By flow sheet or flow diagram, we mean a diagrammatic representation of the chemical engineering process.

So process synthesis is the step in design where the chemical engineer selects the unit operations, the component parts, their interconnections and operational conditions to create an optimized process flow sheet that meets given objectives and constraints. So these objectives and constraints are mostly related to economics of the process. But we must also consider the environmental impact and safety issues.

Recently the use of mathematical programming techniques such as nonlinear programming, mixed integer nonlinear programming for generating optimal flow sheets has received considerable attention. So the optimal flow sheets are not only arrived at by using your experience, you can also take help of mathematical techniques to arrive at most optimum process flow sheet.

This has been possible with advent of computer softwares that are very powerful in solving nonlinear programming problem or mixed integer nonlinear programming problems.

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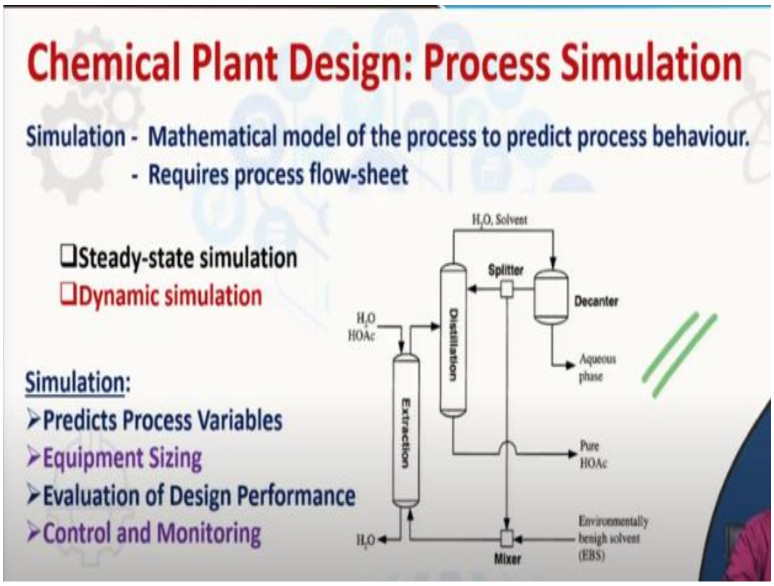

Next, we define process simulation. Simulation is the mathematical model of the process to predict process behavior. To perform a simulation, you need the process flow sheet for the process. Simulations are of two types steady state simulation and dynamic simulation. A broad classification of simulation will be steady state simulation and dynamic simulation. So, steady state simulation means you are simulating a process which is at steady state.

So mass balance informations, energy balance informations are the target for performing steady state simulation. Whereas, in dynamic simulations we are interested in knowing how the process variables vary with time. So, dynamic simulation will give you more detailed information. The time varying informations of the process variables can be obtained by performing a dynamic simulations.

Look at the flow sheet simple flow sheet that is shown here which involves an extraction, a distillation column, a splitter, a decanter. Now once I have this flow sheet and I give the process inputs and operating conditions then this can be posed as a mathematical formulation, as a mathematical problem and can be simulated to obtain the steady state information as well as the dynamic informations.

So simulations will give me information about process variables, equipment sizing, evaluation of design performance, control and monitoring. For control and monitoring, dynamic simulation will be very useful.

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We will use plant design to include all engineering aspects involved in the development of either a new, modified or expanded industrial plant. So the chemical engineer will make economic evaluation of new processes, design or specify individual pieces of equipment and their interconnections. Select plant location, develop a plant layout for coordination of overall operations and also perform safety analysis.

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So why should chemical engineers design a plant? Why should he produce a new product or expand or modernize the existing manufacturing facilities for a product? Generally, the reply will all come from economic considerations. The return on investment must be favorable.

But of course, sometimes strict regulations on safety and environmental issues can compel a manufacturing plant to update their design. The design engineer must do the following preliminary plant design analysis. Process design, selection of process equipment and materials preliminary plant layout and location considerations to estimate labor, building and land cost. Manufacturing cost analysis.

So based on these above analysis, if a decision is taken to design a plant, then only a detailed commercial plant design is taken up. So before we undertake a detailed commercial plant design a preliminary design has to be done to understand that commercial plant design may be a success.

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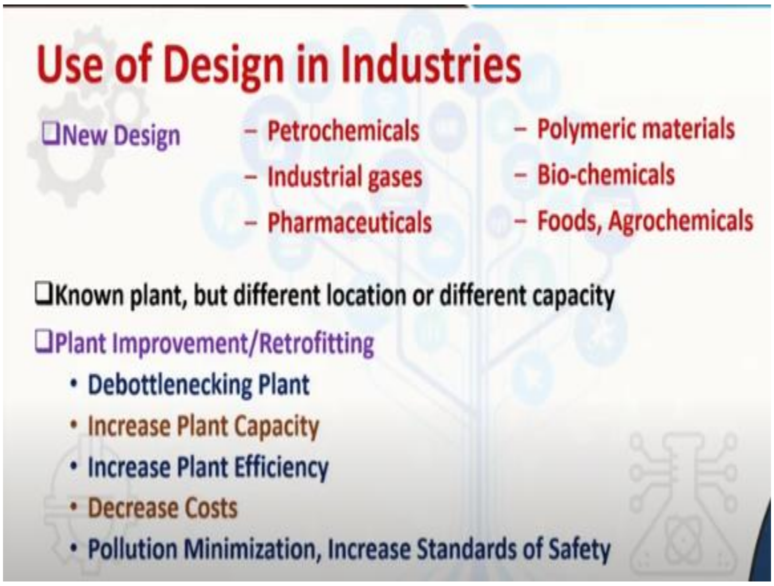

So the design is used for new design of producing materials such as petrochemicals, industrial gases, pharmaceuticals, polymeric materials, biochemical, foods, agrochemicals etc. So whenever you are going for new design. Known plant but different locations or different capacity. Suppose, there is a manufacturing plant in one particular city. Now, the management wants to set up another plant in a different city.

It may be required to redesign the process, particularly if that plant is of different capacity. So we are going to set up the same plant, but it is a different capacity. So again take up the design activity. Design activities also undertaken for improvement or retrofitting of processes. Debottlenecking of plant, increase plant capacity, increase plant efficiency, decrease cost, pollution minimization, increase standards of safety.

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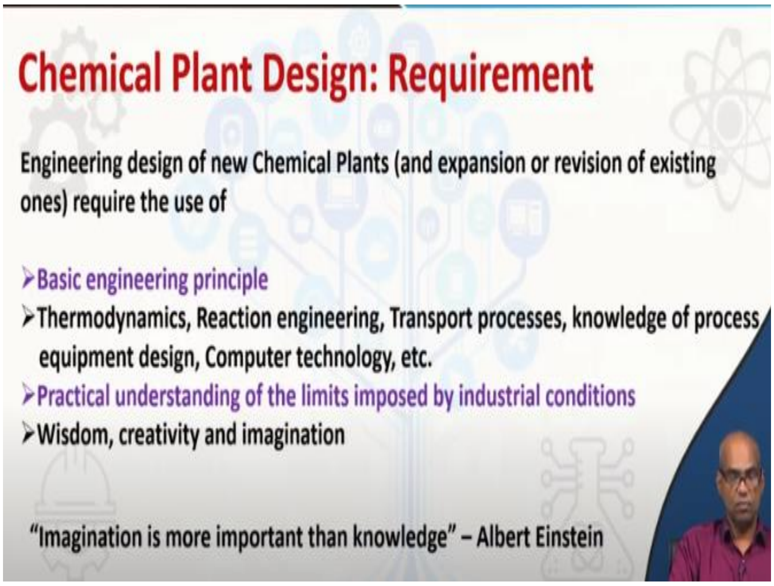

So what does it require to design a chemical plant? It requires basic engineering principles, thermodynamics, reaction engineering, transport processes, knowledge of process equipment design, computer technology etc. Practical understanding of the limits imposed by industrial conditions. So you must clearly understand the limits that are imposed by industrial conditions.

So these are constants on my design. We also need wisdom, creativity and lot of imagination.

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The major goals of engineering design are as follows. Eliminate non-optimal solution with as little effort as possible. Since design activity is often iterative, because the design problems are mostly under defined and there is no true solution or there is no true optimal solution. There are always more than one solutions. But there may be better solution when you have many alternatives.

So you have to eliminate non-optimal solutions with as little effort as possible. Produce a financial estimate. Understand the risk that the process poses to society and the environment and produce the documentation required to build the process. So these are four major goals of engineering design. So you must complete these activities.

So this usually leads to an iterative design methodology that begins with a low level of detail in the solutions and progressively creates more and more detail of fewer possible solutions until an optimal one is found. The key decision making tools at each stage will be economic viability, safety and environmental concerns.

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Now while you are designing a process, you consider various ways of achieving the design objectives. While doing so, the designer will be constrained by many factors. And these constraints will narrow down the number of possible designs. Some constraints are very rigid constraints, they are fixed in variable and the designers have no control over these constraints.

These that external constraints. For example, physical laws, government regulations, codes and standards etc. So you cannot relax these constraints. Now these constraints are shown by these outer sides of this polygon. There are some constraints which less rigid. They are flexible to some extent. The designer has some control over these constraints. For example, choice of process, choice of operating conditions, selection of materials and equipment.

These are known as internal constraints. So, these are shown inside. Now these constraints narrows down the domain of plausible designs, which is shown here. Ultimately my design must satisfy these hard external constraints and it also has to satisfy internal constraints, but there is some flexibility.

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We should aim for sustainable design. Design new chemical processes as part of sustainable industrial activity that retains the capacity of ecosystems to support both life and industrial activity into the future. The needs of the present must be made without compromising the needs of future generations. It is important that we meet the needs for present, but at the same time, it is also equally important that we must not compromise the needs for future generations.

So you must make most economic use of raw materials so that waste is minimized. We can preserve the raw materials for future use. We must make most economic use of energy to preserve the reserve of fossil fuels, to prevent the buildup of carbon dioxide and also you must preserve water for future.

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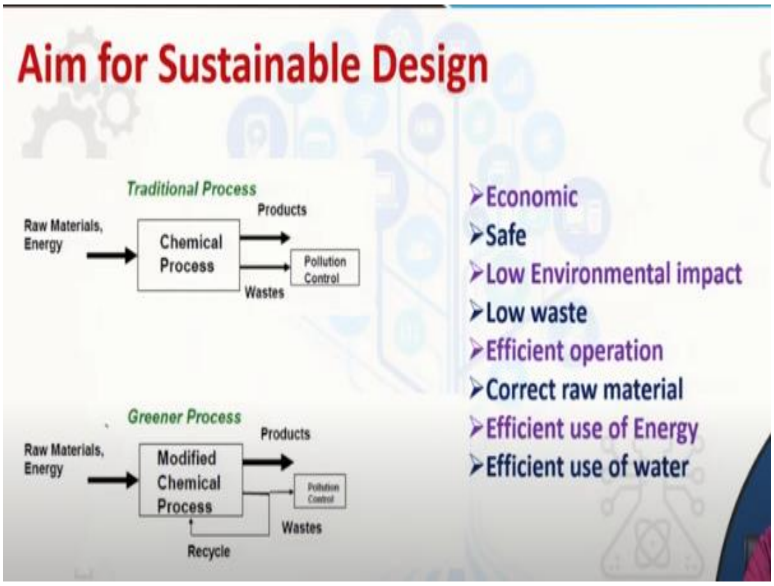

Look at this block diagram for traditional process. The raw materials enters chemical process and what we get is products and waste. So it undergoes pollution control. A greener process will be you recycle the source stream and minimize those production, ideally zero waste. So we should target for such greener sustainable designs. Such designs will be economic, safe, low environmental impact.

It will have low waste efficient operation. Such operations use correct raw materials. They make efficient use of energy and water.

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Now let us talk about codes and standards for design. Plant design should take account of the relevant codes and standards. Conformity between projects can be achieved if standard designs are used whenever practicable. Modern engineering codes and standards cover a wide range of areas including materials, properties and compositions. Testing procedures for example for performance, compositions and quality.

Preferred sizes, for example, for tubes, plates, and standard sections. Design methods, inspection and fabrication. Codes for practice for plant operation and safety. So you must take into account the relevant codes and standards. Then conformity between projects can be achieved.

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Many countries have their own national standards organizations, which are responsible for the issue and maintenance of standards. In India we have Bureau of Indian Standards. So you use IS codes for design of various equipment. For example, for design of unfired pressure vessels, the IS code IS 2825, IS 803 etc., can be used.

USA has National Bureau of Standards and the codes that are useful for chemical engineers are obtained from American National Standards Institute ANSI, American Petroleum Institute API, American Society for Testing Materials ASTM, American Society for Mechanical Engineers ASME codes, which are particularly useful for pressure vessels and pipes.

UK has British Standards Institutes. For example, for design of unfired pressure vessels, they can use BS EN 13445.

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Now when you design a process, uncertainties in design arise from uncertainties in the design data that you use and also from the approximations that you make during design calculations. So to account for this, we have to include a degree of over design which you call design factor or design margin or safety factor. This is required so that the design meets product specifications and operate safely as initially conceived.

For example, a factor of around 4 on the tensile strength is normally used in general structural design to allow uncertainty in material properties, fabrications etc. Similarly, when you calculate process stream average flows from material balances these numbers are typically increased by a design factor of 10% and it gives some flexibility in process operations.

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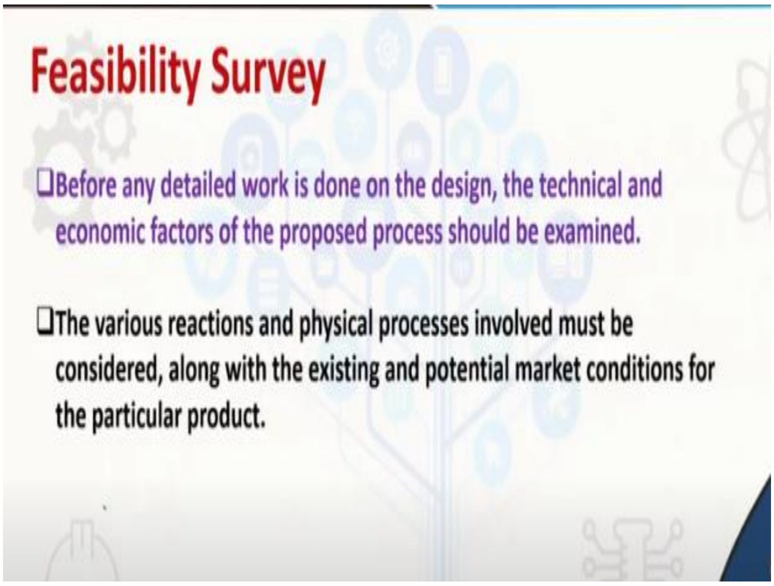

Next, we will quickly go over feasibility survey. Before any detail work is done on the design the technical and economic factors of the proposed process should be examined. The various reactions and physical processes involved must be considered along with the existing and potential market conditions for the particular product. So a feasibility survey must be carried out before any detail work is done on the design.

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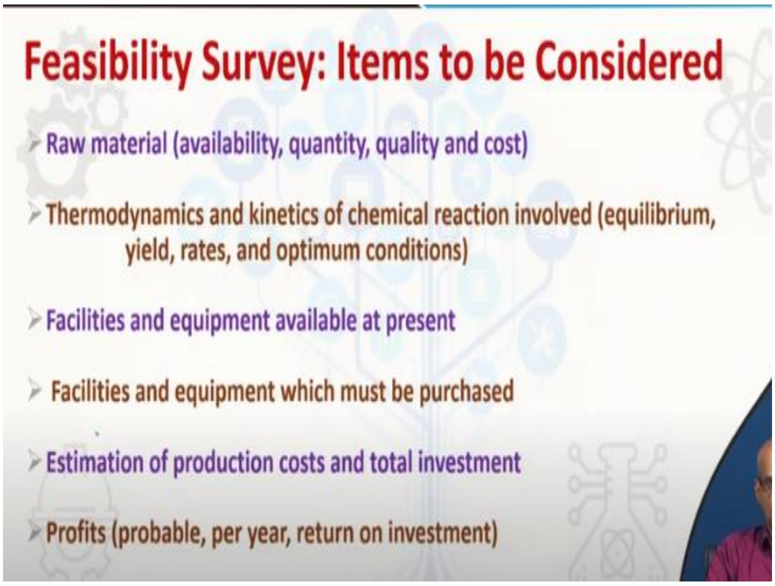

So what are the items that you must consider for the feasibility survey? Raw materials, we must consider about availability, quantity, quality and cost. Thermodynamics and kinetics of chemical reaction involved. Equilibrium, yield, rates and optimum conditions. Facilities and equipment available at present. Facilities and equipment which must be purchased. Estimation of production cost and total investment. Profits, probable profits, per year profits, return on investment etc.

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Materials of construction, safety consideration, markets. Present and future supply and demand. Present uses, new uses, present buying habits, price range for products and byproducts, character locations and number of possible consumers. Competition. Overall production statistics, comparison of various manufacturing processes, product specification of competitors. Properties of products, chemical and physical properties, specifications, impurities, effect of storage.

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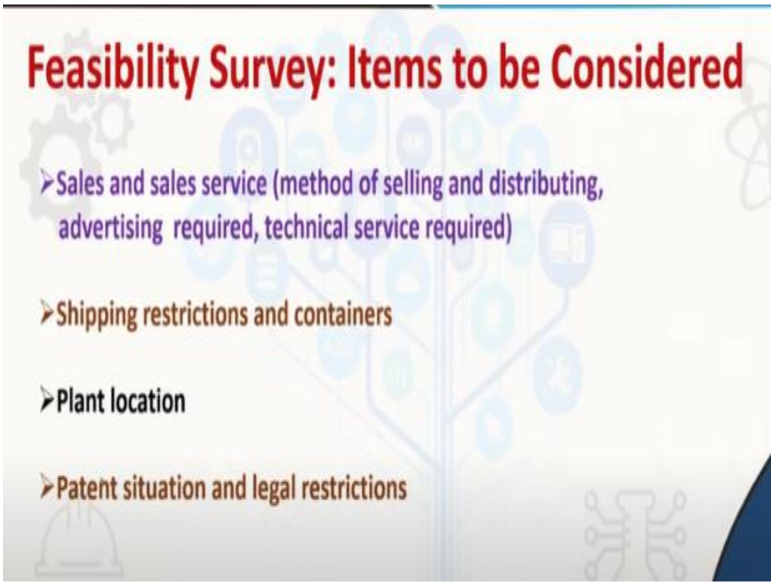

Sales and sales service, method of selling and distributing, advertising required, technical service required. Shipping restrictions and containers. Plant location. Patent situation and legal restrictions. So after you do a feasibility survey and if then it seems to be favorable to go for detailed technical design, we go for that. So with this we stop today's lecture here.