Plant Design and Economics
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Lecture - 02
Typical Design Steps

Welcome to lecture 2 of plant design and economics. In this lecture, we will talk about typical design steps.

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So today's topic will be typical design steps for a chemical plant. Factors affecting selection of a process and levels of design accuracy.

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Now design problems are generally under-defined and thus many solutions are possible. There is no absolutely correct solution to a design problem. However, there may be a better solution because many alternatives are possible. Since many alternatives are possible, you will be able to find better solutions. But it is hard to get the best solution. Let us think of a design problem. A very simple design problem.

You have to store a cryogenic liquid so that you can minimize seasonal variation in temperature. So one solution can be you design an underground tank and let us bury the storage tank say one meter below the ground. Another design solution maybe you design above-ground tank for easy maintenance and you use extra heavy insulation to minimize the seasonal variation in temperature.

So in one design, you bury the storage tank below the ground, but you compromise with maintenance. The second solution is you design the tank above ground, but use extra heavy insulation for minimization of seasonal variation in temperature.

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Now if appropriate material construction is chosen and executed properly, either design can function satisfactorily. So how will you choose one from possible several alternatives? Obviously, there will never be single factor which will allow to make the choice. Several factors will contribute to your choice. Some important factors are economics, environmental and safety concerns, location, political climate, aesthetics, etc.

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When you design a process, depending on the particular design objective at hand you will have various states. But in general the following steps can be identified for a given design activity. First, the design starts with conception and definition. Next flow sheet development, then design of equipment, economic analysis, optimization, then reporting or documentation.

So these are the major steps that will always be there in a design activity. Now we see these design steps in more detail now.

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So what are the typical design steps of a chemical process? First recognize a societal or engineering need. So make a market analysis for a new product. Create one or more potential solutions to meet this need. Make a literature survey and patent search.

Identify the preliminary data required. Undertake preliminary process synthesis of these solutions. Determine reaction, separations, their operating conditions. Recognize environmental safety and health concerns.

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Assess profitability of preliminary process or processes. If negative, reject process and create new alternatives. So you remember that we said that as soon as possible, you have to eliminate the non-optimal design solutions. Refine required design data. Establish property data with appropriate software. If necessary, verify experimentally the key unknowns in the process.

Prepare detailed engineering design. You have to develop base case if economic comparison is required. Prepare process flow sheet. Integrate and optimize process. So here you do heat integration and do optimization of the process. Check process controllability. So dynamic simulation will be of great help here. Size equipment. So get proper specification of the equipment. Estimate capital cost.

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Reassess the economic viability of process. Again, if negative, either you modify the process or investigate other process alternatives. Review the process again for environmental safety and health effects. Remember your design must satisfy these conditions. Provide a written process design report.

Complete the final engineering design, which involves determination of equipment layout and specification, development of piping and instrumentation diagram, preparing bits for the equipment or the process plant.

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Procure equipment if work is done in-house. Provide assistance if requested in the construction phase. Assist with startup and trial runs. Trial runs are also known as shakedown runs. Finally, initiate production. So these are all typical design steps of a chemical process. But it is not necessary that all the design steps will be there for any design process particularly for a simple design project.

For a simple design project, all the design steps may not be necessary. On the other hand, a commercially unproven technology may require additional design steps. Also the order of design steps may be altered depending on the problem at hand.

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Now we will look at some of the steps in more detail. First, the source of new ideas. Most large chemical companies invest a portion of their total gross sales on some type of research. A product will sell if it is better in quality or low cost than a competitive product. So it is necessary that a research is carried out. Research may be broadly classified into two categories, basic research and applied research.

Basic research consists of exploratory studies driven by scientific curiosity. No obvious commercial value to the discoveries is immediately specified. End use of such research is not specified. For example you can investigate, how did the universe begin? What are the electrons composed of etc. See, no obvious commercial value to the discoveries of these questions is specified or identified.

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On the other hand, applied research has a definite goal and it seeks to solve a practical problem. So companies will spend more on applied research and compared to basic research. For example, improve energy efficiency in the plant, develop a new approach to manufacture a product for example say polystyrene.

So these are typical examples of applied research, which are mostly carried out in large chemical engineering companies. Research is not the only source of new ideas, there are other sources as well. The idea may also come from sales department as the result of customer request or to meet a competing product. There is a new product in the market and the company wants to meet their product.

Anyone in plant operation can come up with some idea. Engineering department may originate new process or they can also initiate retrofitting of existing process. There are also some accidental discoveries. For example, Teflon by Roy J. Plunkett at the DuPont in 1938. Penicillin by Sir Alexander Fleming in 1928, etc. So these are very important accidental discoveries. There are many more.

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Now let us take one or two examples of the need for process design development. In 1960s, nearly all detergents contained sodium tripolyphosphate known as a STPP as builders that assisted cleaning by sequestering calcium ions and magnesium ions. The amount of STPP in these detergents used to be as high as 40% or even higher. During effluent treatment the secondary treatment could only remove 1 to 2 milligram per liter of phosphates.

So these effluents used to be sent to local rivers or water bodies with lots of phosphorus in it. So a rapid increase in the phosphorus content of the local water bodies, rivers, lakes, etc., resulted in rapid growth of algae and plant bodies. This depleted oxygen supply in water, damaged ecology and caused fish to die. The growth of algae and plant bodies was so thick that even sunlight could not enter and the plant bodies also died.

So it led to eutrophication. Some developed countries such as European Union, USA, Japan, banned the use of phosphates in detergents. So it was necessary to come up with a replacement.

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Another example. Branched alkyl benzene sulfonate, which is branched chain anionic surfactant was introduced in 1930s as synthetic detergents. It removes dirt, oil, but it also foams and this is undesirable when discharged into rivers or lakes. Like phosphates it was also not removed by the sewage treatment plants. Linear alkyl benzene sulfonate, which is a straight chain anionic surfactant was introduced in 1960s.

This is a biodegradable product. So secondary treatment facilities can remove them. The linear alkyl benzene sulfonate has now largely replaced branched alkyl benzene sulfonate in detergents throughout the world.

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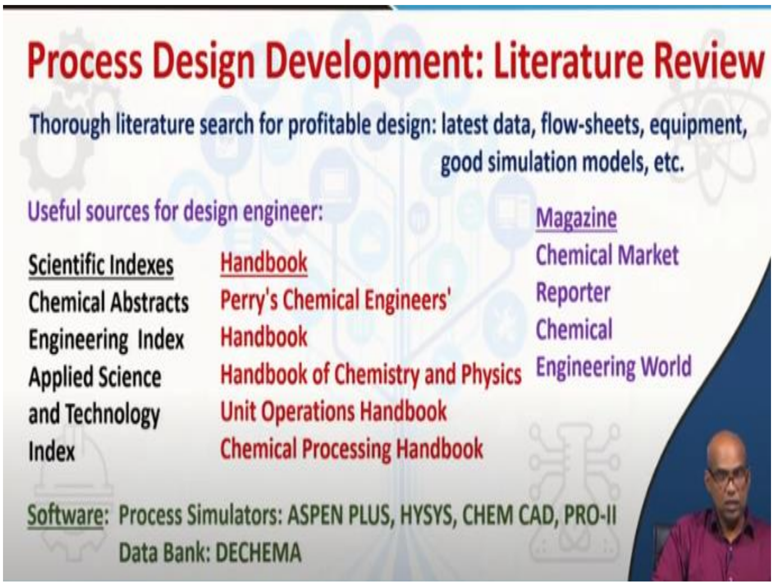

Now let us look at the literature review part. Through literature search, thorough literature search is required for profitable design. You need latest data, flow sheet, equipment, good simulation models etc. There are several useful sources for performing thorough literature review for design engineers. There are several scientific indexes such as chemical abstracts, engineering index, Applied Science and Technology Index.

There are several important handbooks. Perry's Chemical Engineers' Handbook, Handbook of Chemistry and Physics, Unit Operations Handbook, Chemical Processing Handbook. There are several important magazines such as Chemical Market Chemical Market Reporter, Chemical Engineering World, etc. Software are also useful for design engineers.

Process simulators such as Aspen Plus, HySIS, CHEMCAD, PRO/II are very useful. Then DECHEMA is a good source for data, is a good databank.

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Next, patent search. A patent is the right granted to an inventor by the government that permits the inventor to exclude other form, making, selling or using the invention for a specified period of time. So a patent is a right granted to an inventor by the government that permits the inventor to exclude others from making, selling or using the invention for a specified period of time.

After a patent expires, the invention becomes public property and can be used freely by anyone. Design engineers must be aware of patents to avoid duplication of designs protected by these patents. So you must not duplicate designs that are already patented. After the expiry, which may be say typically 16 years, 15 years, for some products 20 years the expired patents can provide helpful information in the design of second generation processes.

So the patents, which are expired can provide helpful information in the design of next generation processes. Patents are available in major libraries. Patents are also available on the internet now.

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Next, let us elaborate on process creation. In this step, to create a new process or to significantly improve an existing process, we find one or more practical solutions to the design problem. So during process creation, we create a new process or to significantly improve an existing process, we find one or more practical solutions to the design problem. This step is most creative.

Involves the synthesis of various configurations of processing operations that will convert raw materials to products in a reliable, safe and economical manner with a high yield and minimum undesirable byproducts or waste. Traditional method. Use past experience, use of heuristics or rule of thumb. Modern methods. Treat synthesis problem as a quantitative problem and use mathematical programming, computer simulations to come up with best solutions or more optimal solutions.

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So when you create a process, we have to decide whether the process will be operating as batch or continuous. Continuous operations are preferred for large scale production, such as production of bulk chemicals or commodity chemicals, petroleum products, plastics, paper, solvents etc. Continuous plants typically run for 90 to 95% of 365 days, which is 8760 hours.

Continuous operations has several advantages, such as improved process control, more uniform product quality, reduced labor cost, more economical for large volumes, less fouling etc. Whereas batch and semi batch operations are preferred, when production rates are small.

For example, manufacture of specialty chemicals, pharmaceuticals, bio-chemicals or when the product demand is intermittent. Batch processes also offers several advantages such as flexibility. You can use multi-product batch plant, improved control in semi-batch operations, easy scale-up from laboratory and maintenance etc. However, a major drawback for batch operations is batch-to-batch variability.

So very strict process control must be in place for batch operations. Otherwise, it will lead to batch-to-batch variability. Whereas, continuous operations has advantage on batch processes on this particular item. You can get more uniform product quality easily for continuous operations. But getting uniform product quality in all batches is still a challenge in chemical engineering operations. So batch-to-batch variability is the major drawback for batch operations.

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So how to select a process from several alternatives? What will be the basis for comparison? So you are creating processes, you have created many alternatives. So how will you select a process from several alternatives? Again there will be several factors. There will be some technical factors, there will be some other factors. Under technical factors, we need to consider process flexibility.

Mode of operation, batch continuous, semi-batch or semi-continuous. Special controls involved, commercially yields, technical difficulties involved, energy requirements, special auxiliaries required, possibility of future developments, health and safety hazards involved, etc.

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You have to consider raw materials, present and future availability. So you must select a process for which raw material's availability is ensured currently as well as in future. Processing required. Processing of raw materials that is required will influence the process selection. Storage requirement for raw materials will influence process selection. Waste products and byproducts.

The selection of process will depend on the amount of waste product and byproducts produced, the value of such byproducts if any, potential markets and uses, how will you discard waste and environmental aspects.

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Equipment will influence process selection, availability of equipment, materials of construction of equipment, initial cost, maintenance and installation cost, replacement requirements, special designs etc. Plant location will have influence. Amount of land required, transportation facilities, proximity to markets and raw material sources, availability of service and power facilities, availability of labor. Climate, legal restriction and taxes.

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Cost will of course have a major influence on selection of process. Raw materials, cost of raw materials, cost of energy, depreciation, other fixed charges, processing and overhead charges, special labor requirements, real estate cost, patent rights, environmental controls etc. Time is very important. So time factor will also have influence on selection of process. Project completion deadline, process development required, market timelines, value of money.

Process considerations. Technology availability, raw materials common with other processes, consistency of product within company and general company objectives. So all these will influence process selections.

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Now we ask the question what should be the level of design accuracy? It is said about one out of 15 proposed new processes is ever actually constructed. We have to avoid loss of money on one hand and we must not lose business opportunity on the other hand. Engineering evaluation is an essential activity at all stages of your promising project from the conception of the new process to final stage of construction.

Depending on the accuracy and detail required design engineers generally classify process designs in the following five levels. Order of magnitude designs, study or factor designs, preliminary designs, detailed estimate designs and final process designs.

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Now order of magnitude designs and study or factored designs for these two cases, no actual process design is involved. These are used only to determine very quickly the level of investment that may be required for a proposed design project. You identify raw materials here, you identify products and utilities and you try to come up very quickly with the level of investment that is required.

Next detail is preliminary designs. This is used as, as a basis for determining whether further work should be done on a proposed process. Approximate process methods and approximate cost estimates are prepared. Design details and the time spent on calculations are kept to a minimum.

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Next, detailed estimate designs. This is done if preliminary design shows good prospect. Here the cost and profit potential of the process is determined. Exact specifications are not given for the equipment. Piping and layout work is minimized. So detailed estimate designs will be undertaken if preliminary design shows good prospect. So it will have some detail but it would not have every details.

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Final process design will be undertaken if detailed estimate design indicates that there is an opportunity for commercial success. Here, complete specifications are presented for all components of the plant. Accurate cost analysis based on quoted prices is done. Profit analysis and plant-wide controllability studies are done. It will include detailed documentation for immediate construction of the project.

So final process design will have all detailed informations for the construction of project. So this is, this contains highest level of design accuracy. With this, we stop today's discussion here. Thank you.